UNCLASSIFIED

AD NUMBER

AD878778

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; Dec 1970. Other requests shall be referred to Air Force Aero Propulsion Lab, Wright-Patterson AFB, OH 45433.

AUTHORITY

AFAPL ltr dtd 25 May 1973

THIS PAGE IS UNCLASSIFIED

AFAPL-TR-70-71
Part I

20

AD878778

AD No. ____
DDC FILE COPY

Hydrocarbon Fuels for Advanced Systems

**G.H. Ackerman, L.E. Faith, C.K. Heck,
H.T. Henderson, A.W. Ritchie, L.B. Rylund**

Shell Development Company
A Division of Shell Oil Company
Emeryville, California

Technical Report AFAPL-70-71, Part I
December 1970

DDC
RECEIVED
JAN 20 1971

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Air Force Aero Propulsion Laboratory
Attn: APFF-1

Air Force Aero Propulsion Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

8/5

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not be be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This document is subject to special export controls and each transmittal to foreign Governments or foreign nationals may be made only with prior approval of the Air Force Aero Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio 45433

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

HYDROCARBON FUELS FOR ADVANCED SYSTEMS

G. H. Ackerman, L. E. Faith, C. K. Heck, H. T. Henderson,
A. W. Ritchie, and L. B. Ryland

AFAPL-TR-70-71

FOREWORD

The work described in this technical report was authorized under U.S. Air Force Contract No. F33615-70-C-1038, Project 3048. The program was administered by Mr. H. R. Lander and Lt. J. C. Ford, Project Engineers, Air Force Aero Propulsion Laboratory/APFF-1, Wright-Patterson Air Force Base, Ohio 45433.

This program is being conducted at Shell Development Company, Emeryville, California 94608 under the general supervision of K. D. Detling, Manager, Government Research Department. This report is the first annual technical report under Contract No. F33615-70-C-1038. It was submitted on September 17, 1970. The report describes the results of work performed during the period 1 September 1969 to 31 August 1970. This investigation represents a continuation of a previous study, "Vaporizing and Endothermic Fuels for Advanced Engine Application" under Contract No. AF 33(615)-3789, the results of which were published in Technical Report AFAPL-TR-67-114, Part I, October 1967, Part II, September 1968; Part III, February 1970.

Acknowledgment is made to A. C. Nixon for many valuable contributions to the program as principal investigator and project supervisor until his retirement on 1 June 1970.

This technical report has been reviewed and approved.

Arthur V. Churchill

ARTHUR V. CHURCHILL, Chief
Fuel Branch
Fuel, Lubrication and Hazards
Division

ABSTRACT

The general objective of this investigation is the development of new fuels and new fuel systems which will provide the cooling and propulsion [illegible]ts of advanced air-breathing engines. In previous studies on the utiliza[illegible] endothermic reactions of hydrocarbon fuels, the catalytic dehydrogenation [illegible]thenes showed the most promise for practical applications. In continuing these studies, a large number of catalysts were prepared and tested for activity and stability for the dehydrogenation of methylcyclohexane and decalin. The stability of supported platinum catalysts for these reactions was affected by the physical properties and chemical composition of the support and by the metal content and metal composition of the catalyst. Bicyclo(2,2,2)octane was dehydrogenated to bicyclooctene in low yield with a supported platinum catalyst. Additives were found which enhanced the rate of thermal cracking of paraffins. Improved wall catalysts were formulated for the dehydrogenation of naphthenes and a mathematical model was developed for a catalytic wall reactor. Various fuels were evaluated for thermal stability in both our standard ASTM Coker and a special Alcor JFTOT unit designed for operation up to 1000°F and 1000 psi. The high temperature thermal stability of fuels was improved by means of additives. The deposit profiles on coker tubes were reproducibly determined with a recently developed beta-ray backscatter instrument which is capable of measuring deposit thicknesses up to 2500 Å. The physical properties of JP-7 jet fuel were recalculated using improved methods. The new values compare favorably with data obtained from heat transfer experiments. The supersonic combustion of decalin, tetralin and naphthalene was investigated using the shock tube. A literature survey was made of articles and patents of interest to this and related programs.

CONTENTS

CONTENTS (Contd)

CONTENTS (Contd)

<u>CONTENTS (Contd)</u>

ILLUSTRATIONS

Figure

ILLUSTRATIONS (Contd)

ILLUSTRATIONS (Contd)

ILLUSTRATIONS (Cont'd)

TABLES

TABLES (Contd)

TABLES (Contd)

TABLES (Contd)

HYDROCARBON FUELS FOR ADVANCED SYSTEMS

INTRODUCTION

As vehicles propelled by airbreathing engines are being designed to fly at greater speeds, thermal problems multiply and cooling needs increase. The most critical regions which require cooling are leading edges and engines. Although thermal effects can be somewhat accommodated by improved materials and passive cooling, sustained hypersonic flight in the atmosphere requires a substantial heat sink. Mechanical refrigeration or a noncombustible coolant can be used for cooling, but the fuel remains as the most efficient source of heat sink.

The speed limit on vehicles in the range above Mach 4 will depend on the cooling capacity of the fuel. Fuels such as hydrogen, methane, and ammonia can furnish a heat sink only through sensible heating and vaporization, whereas hydrocarbon fuels can provide additional cooling through endothermic reactions. Hydrocarbons can undergo both thermal (noncatalytic) and catalytic endothermic reactions. Theoretically the total heat sink of hydrocarbon fuels range from 50 to 112% of the cooling capacity of hydrogen, based on heat sinks normalized by the heat of combustion. Laboratory proven capability has achieved 85% for catalytic reaction accompanied by sensible heating and vaporization, whereas thermal reaction, such as cracking, with heating and vaporization has been limited to 55%.

Catalytic reactions of interest include dehydrogenation, dehydrocyclization, and depolymerization. The most promising type that has been studied is the catalytic dehydrogenation of naphthenes. A typical example of this reaction is the dehydrogenation of methylcyclohexane over a platinum on alumina catalyst. Other promising reactions are the catalytic dehydrogenation of dicyclohexyl and decahydronaphthalene.

Until a few years ago the use of hydrocarbon fuels in advanced engines at speeds greater than Mach 3 was no more than a concept. Studies under contracts AF33(657)-11096 and AF33(615)-3789 investigated the possibility of using hydrocarbon fuels under the severe conditions of hypersonic flight. These programs were directed toward evaluating the capability of these fuels in advanced engines and developing the information necessary for the design of systems for the promising fuels.

The current contract is a continuation of these past programs with emphasis on extending the knowledge and improving the capability and performance of known hydrocarbon fuels. In addition, investigations of new candidate fuels and new techniques for utilizing hydrocarbon fuels are continuing.

Areas of investigation in the current program are the study of endothermic reactions and the determination of properties and characteristics of hydrocarbon fuels. The catalytic and thermal reactions of different fuels are being investigated and the kinetics of reactions with significant heat sinks are being measured and analyzed. Catalysts are being studied with the objective of optimizing the composition and geometry so as to improve catalyst activity, stability, and performance. Properties and characteristics of fuels are being determined experimentally and theoretically. Gas properties can be predicted reliably, whereas liquid properties must be measured. Thermal stability and combustion characteristics of fuels are being determined by experimental work.

SUMMARY

As hypersonic aircraft and missiles are developed with increasing speed, the need for engine cooling multiplies. The fuel used in an engine is a convenient coolant for this purpose, absorbing heat as sensible heat and latent heat of vaporization. Certain hydrocarbon fuels can furnish additional heat sink in the form of endothermic reactions. Possible endothermic reactions include thermal reactions such as cracking, and catalytic reactions such as dehydrogenation, dehydrocyclization, and depolymerization. Of these, the catalytic dehydrogenation of naphthenes to aromatics is currently the most promising type of reaction. Reactions of this type are very selective and proceed rapidly to achieve high conversion. The total heat sinks for these reactions compare favorably with heat sinks for other fuels.

Over forty-five catalysts were evaluated in bench-scale studies for stability in the dehydrogenation of naphthenes without added hydrogen. Almost all of the catalysts contained platinum either alone or with other metals as bimetallic or trimetallic mixtures; these were mounted on eighteen different supports. In short tests with decalin (30 minutes) at 10 atm pressure, six catalysts showed moderate stability at 1200°F and good stability at lower temperatures. Four of these catalysts contained platinum on four different supports; the other two were bimetallic and trimetallic mixtures. In less severe tests with MCH nine of the catalysts showed moderate stability at high space velocity (LHSV = 100). Based on the tests with decalin it appeared that catalyst stability was affected by catalyst support composition, physical properties of the support, and the catalyst metal content and composition.

Exploratory studies with bicyclo(2,2,2)octane in a pulse reactor showed that this naphthene could be catalytically dehydrogenated to bicyclooctene. Yields were low (ca 26%) and the reaction was quite sensitive to catalyst properties and reaction conditions. With one catalyst bicyclooctene was formed using He carrier gas but not with H_2 carrier; with two other catalysts containing platinum, bicyclooctene was formed with one catalyst but not with the other.

Twenty different additives were tested in the pulse reactor as free radical initiators for enhancing the rate of the thermal cracking reaction. Of the additives tested six gave substantial increases in the rate of cracking of n-dodecane at 1100°F. The most effective additive caused an increase in conversion of about 75%.

Addition of 30% propane to methylcyclohexane enhanced the reactivity of MCH at and below 932°F but reduced reactivity at higher temperatures.

Development of granular and coating catalysts and screening of catalysts for dehydrogenation activity have continued. Many additional granular catalysts have been prepared which consist of one or more metals on various supports or mixtures of several unsupported metals. Development of catalytic coatings for metal surfaces have continued in order to improve ease of application, mechanical properties, adherence to metal surfaces, and catalytic activity. Candidate coatings in platinized granular form have been evaluated in tests in the micro catalyst test reactor.

The need for obtaining intrinsic reaction kinetic data in the absence of heat and mass transfer effects has been discussed. Packed bed reactors have a number of drawbacks and some kind of recycle reactor must be used. A catalytic continuous stirred tank reactor is appropriate and one has been designed to measure the kinetics of the dehydrogenation of methylcyclohexane and decalin.

A mathematical model of the catalytic wall reactor configuration has been developed. The model is one-dimensional in fluid flow, but accounts for radial heat fluxes. Differential equations describing temperature, pressure and conversion are integrated numerically along the reactor. The experimental data on methylcyclohexane dehydrogenation obtained in the Fuel System Simulation Test Rig (FSSTR) are discussed and compared with the model. After slight modification of the kinetic parameters, the model agreed well with the experiments. Approximations and possible modifications of the model are also considered.

Test runs were made on the dehydrogenation of decalin with three different catalysts in the FSSTR. Shell 10860-146 catalyst was far superior in activity and stability to Shell 10280-113 and UOP-R8 catalysts at conversions up to 80% and outlet fuel temperatures up to 1050°F. The two latter catalysts were comparable in initial activity, but Shell 113 catalyst was much less stable than UOP-R8 catalyst at higher temperatures.

A problem in the determination of fuel thermal stability by a heat transfer device such as the ASTM Coker is the uncertainty in evaluating both the amount and the distribution of the deposits on the tube at the conclusion of the test. While it is usually possible to rate deposits by appearance on highly polished aluminum tubes, many other metals such as stainless steels and nickel change color when heated, even in inert environments, and this complicates the visual rating. To solve this problem we have built a beta-ray backscatter instrument which is capable of evaluating deposit thicknesses up to 2500 Å. We have demonstrated that the deposit profiles on coker tubes can be reproducibly determined. The calibration of this instrument on aluminum tubes has been accomplished, and similar calibrations on stainless steels and other metals are in progress. We have measured deposits from several sources, and in many cases the geographical distribution of deposits measured by this instrument is the same as determined by the optical methods of evaluation. However, the relative values vary greatly, and in some cases even the geographical distributions are different. In fact, it appears at this time that the beta-ray backscatter instrument is capable of giving a truer picture of deposit distribution than the optical method.

One recent addition to the battery of equipment being used for evaluation of fuel thermal stability is a special Alcor JFTOT unit, designed for operation up to 1000°F and 1000 psi. Although the equipment has not been operated as yet up to its maximum capability, considerable data have been obtained with it under less severe conditions with excellent results. Good agreement has been found between data obtained with this equipment and those obtained with our standard ASTM Coker. However, some difficulty has been encountered at high temperatures due to a tendency of the thin aluminum tubes to buckle. Attempts to correct this by the use of TEFLON® O-rings and a conducting grease at the bus-bar clamps were not successful.

About 50 compounds have been screened on the SD/M-7 Coker for their possible use as fuel additives in improving high temperature thermal stability. Six of these have been found effective in the liquid temperature range of 675 to 700°F, and the best of them increases the thermal stability breakpoint by 125°F liquid or 160°F metal temperature.

A storage stability experiment on high purity MCH, which was initiated about 4-1/2 years ago, has been terminated with the removal of the samples from the hot room and their examination. The samples were stored in one-gallon epoxy-lined pails with a 2:1 gas/liquid ratio at 130°F, the gas compositions ranging from pure oxygen to pure nitrogen. The remarkable result was that all the samples appeared equivalent to their original condition; no deterioration had occurred that could be ascertained by color change, gum determinations, or thermal stability testing with the SD/M-7 Coker. Some tests have been made for the selection of the most favorable antioxidant for SHELLDYNE-H® hydrocarbon fuel. Samples were tested with various commercial inhibitors under accelerated conditions, 200°F in the presence of excess oxygen for 18 and 30 hours. Although the results were not clear because of difficulties with gum determinations, the most effective antioxidant for SHELLDYNE-H® fuel appears to be the amine inhibitor, di-sec-butyl p-phenylene diamine.

A new batch of MCH, synthesized by toluene hydrogenation, has been tested in the SD/M-7 Coker, and is now being filtered to meet thermal stability specifications.

Revised physical properties for JP-7 jet fuel were calculated by improved predictive methods. Properties were estimated for saturated gas and liquid at subcritical temperatures and for the gas at supercritical temperatures and different pressures. These revised values are considered to be better than previous properties, especially for the liquid heat capacity and thermal conductivity. The revised properties agree quite well with properties of similar mixtures, and compare favorably with data from heat transfer experiments.

Physical properties were estimated for binary mixtures of methylcyclohexane (MCH) and a low molecular weight hydrocarbon (ethane, propane and n-butane). These were prepared for use in future studies on fuel cooling of advanced engines. Mixture properties were determined from known properties of the individual constituents. Melting and freezing points of MCH-propane mixtures were measured and used to calculate melting point depressions for the desired mixtures.

The surface tension of SHELLDYNE-H® hydrocarbon fuel was measured at three temperatures. These results were correlated, and the correlating equation was used to estimate surface tension at higher temperatures.

The supersonic combustion of decalin, tetralin and naphthalene were investigated using the shock tube. Methods of accounting for attenuation were compared, and the best one was found to be the use of a constant value (0.001) for the attenuation coefficient. The ignition delay time correlation was modified by adding the effect of fuel concentration. The data obtained on decalin and tetralin and much of the data on ignition delay times obtained earlier were correlated using the new equation. A statistical analysis showed that the correlations could not be analyzed by standard techniques. The method of fitting the parameters in the equation to the experimental data was also discussed. In general, it is seen that oxygen has the effect of reducing the ignition delay times, while increases in fuel concentration tend to increase it. The rate of combustion of tetralin was also measured. From limited data it seems that temperature, oxygen, and fuel all tend to increase the rate of combustion. As has been observed before, the activation energy is fairly low.

Pertinent articles and patents that appeared in the literature during the past year were compiled into a bibliography. This survey covered the following subjects: Advanced Fuels, Physical and Chemical Properties of Fuels, Thermal Stability of Fuels, Fuel Contaminants and Additives, Catalysts and Catalytic Reactions, Heat Transfer and Fluid Mechanics, Combustion, and Advanced Engine Development.

LABORATORY STUDIES OF CATALYTIC AND THERMAL REACTIONS

The bench-scale studies of candidate endothermic fuels and their catalyst systems that were initiated under the previous contract are being continued. Tests were conducted in apparatus developed under the previous contract.1)2)3)

Extending the work on the stability of catalysts for the dehydrogenation of naphthenes, over forty-five catalysts were evaluated using the dehydrogenation of decalin and of methylcyclohexane as the test reactions in our bench-scale system. The dehydrogenation of bicyclooctane was studied in a pulse reactor as part of our exploratory search for additional endothermic fuels. A number of additional additives were tested as free radical initiators for the thermal cracking of n-dodecane.

Bench-Scale Catalyst Stability Studies

Work under the previous contract showed that there were considerable differences in the stabilities of supported platinum catalysts for the dehydrogenation of naphthene reactions.2)3) Further, preliminary studies with a few commercial and laboratory catalysts showed that stability was strongly affected by the catalyst pore structure.3) As the most efficient catalyst for naphthene dehydrogenation appears to be platinum, it was of interest to expand the study of the stability of this catalyst system. The purpose of the work was to study the variables that influenced stability, with the subsequent aim of optimizing the catalyst composition.

Under the present contract about forty-five catalysts have been evaluated for stability using the dehydrogenations of decalin (DHN) and methylcyclohexane (MCH) as test reactions. Three of these catalysts contained no platinum. The remainder consisted of fourteen different elements combined with platinum as bimetallic or trimetallic mixtures or compounds and mounted on twelve different supports. The variables under study were composition of catalyst support, physical properties of the support, metal composition, metal content, and metal dispersion. A detailed description of the preparation of these catalysts is given in a later section.

The tests were done in our bench-scale laboratory reactor system which was a tubular flow reactor equipped with conventional devices for measuring feed flow rates and for collecting liquid and gas products. The reactor was a stainless steel tube (No. 347, 1/2-in. IPS) 32-in. long and 5/8-in. ID., which was heated by an electric furnace. The catalyst was contained in the annular space between the thermowell and the reactor wall. In order to supply heat rapidly to the catalyst bed, the annular distance between the thermowell and the reactor wall was about 1/16 in., which was about one-pellet diameter. The catalyst bed was about 4-1/2-in. long and had a volume of 7 ml. Prior to carrying out the experiments, the catalysts were reduced in situ with hydrogen for 30 minutes at 572°F (300°C) and then for one hour at the reaction temperature. The complete apparatus was described in detail in a previous report.3)

The reactor wall temperature was measured by a thermocouple pressed against the outside reactor wall by the furnace block and located about 1 in. below the top of the catalyst bed. The catalyst bed temperatures were measured by thermocouples contained in the thermowell. The thermocouples were 1 in. apart and the top thermocouple was about 1/2 in. below the top of the catalyst bed (the flow was downward through the catalyst bed). The "effective" catalyst temperature was between the reactor wall temperature and the catalyst bed temperature.

During reaction the catalyst bed temperature (thermocouple measurements) was considerably lower than the furnace block temperature due to the endothermic heat of reaction. As the catalyst deactivated the catalyst bed temperature increased and the magnitude of the temperature increase was taken as a measure of catalyst deactivation. Another quantitative indication of catalyst deactivation was the movement of the "cold spot" down the catalyst bed.

Product analyses were done by GLC from which conversions and selectivities were calculated.

Dehydrogenation of Decalin

The catalysts were tested at 10 atm pressure and a liquid hourly space velocity (LHSV, volume of feed per volume of catalyst per hour) of 100. Each catalyst was tested initially at 842°F, and then at successively higher temperature (in 90°F increments) through 1202°F or until the catalyst became inactive. The test period was 30 minutes at each temperature. The feed (F-113 DHN) had the following composition:

25.0% trans-DHN
74.6% cis-DHN
0.4% tetralin (THN)

The catalysts were tested in two groups, one of which contained catalysts prepared under the previous contract for another purpose, and the other which contained catalysts prepared under this contract. (The preparative methods are described in a later section.)

The principal reaction products were tetralin (THN) and naphthalene (N). With fresh catalyst high selectivities (90-100%) to THN and N were observed. When the catalysts became highly deactivated side reactions occurred that gave products which emerged from the GLC before and after trans-DHN, after cis-DHN, and after N. These products were not identified further, although those emerging before trans-DHN were assumed to be cracked material (i.e., lighter than DHN). Some cis to trans-DHN isomerization was observed at the lower temperatures (842° and 932°F) with all of the catalysts. The complete data, including product analyses, are shown in Table 55 in the Appendix.

In the first series of runs, fifteen catalysts were tested that had been prepared under the previous contract. These consisted of pure platinum, platinum combined with twelve other metals as bimetallic or trimetallic mixtures, and three different non-platinum bimetallic mixtures. The metals were mounted on four different supports. The pertinent data are summarized in Table 1, which also includes data for a few catalysts tested previously. Figures 1 and 2 show activity (i.e., conversion) and deactivation (i.e., increase in catalyst temperature, ΔT_{max} °F) as functions of block temperature.

The most stable catalyst in this series was Shell 157B (10280-157B). This catalyst was a bimetallic platinum mounted on a granular Type 1 support. The stability (Figure 2) was about that of Shell 46 (granular Type 1 support) and 114C granular Type 6 support) but the activity was lower than that of the latter two catalysts (Figure 1). Another catalyst with good to moderate stability was Shell 15A (10280-15A), a trimetallic platinum mounted on a spherical Type 1 support. In fact this catalyst was the most stable of all of the catalysts containing this support that have been tested thus far. UOP-R16E, which is the UOP "high stability" platforming catalyst, did not deactivate at 1112°F, but did show a catalyst temperature increase of 104°F compared to only 36°F for Shell 15A. However, the activity of this latter catalyst was lower than that of UOP-R16E (Figure 1). Thus Shell 15A was more stable but less active than UOP-R16E.

The remainder of the catalysts in this series showed poor stability at the higher temperatures (Table 1, Figure 2).

In a second series of runs eighteen different catalysts prepared under the present contract were tested. These catalysts were pure platinum or platinum plus another element that were mounted on ten different supports. The preparation of these catalysts is described in a later section. The pertinent test data are shown in Table 2.

Of the catalysts tested in this series, Shell 135B and 142B were the most stable. Thus moderate stabilities with increases in catalyst bed temperatures of 47° and 56°F, respectively, were observed at 1202°F (block) and good stabilities at lower temperatures. The other catalysts showed poor stabilities at 1202°F ranging from complete deactivation to temperature increases of 131 to 227°F (Table 2). Figure 3 shows stability as a function of block temperature for a number of these catalysts. The performance of Shell 135B and 142B was comparable to that of Shell 46 and Shell 114C (Table 2) and these four catalysts together with 157B are the most stable of those tested thus far. Actually Shell 135B and Shell 46 are nearly identical catalysts. They contained the same support and same Pt content, but the method of mounting the platinum on the support was different. One of the catalysts contained chloride and the other was chloride-free. Within the limits of our tests the performance of these catalysts was the same.

Shell 146 (10860-145) was a large batch of catalyst (500g) prepared in same manner as was Shell 46 and is intended for use in the FSSTR. In our tests the performance of this catalyst was similar to that observed with Shell 46, possibly a little more active and a little more stable than the latter, based on the test data at 1112°F (Table 2). Unfortunately it was not possible to complete the test at 1202°F with Shell 146 due to plugging of the liquid receiver with naphthalene. This suggests that Shell 146 was a little more active (i.e., gave higher conversion to naphthalene) than Shell 46 as the receiver did not plug in tests with this latter catalyst.

Activities (as measured by conversions) were different for the various catalysts but in general the more active catalysts were the more stable.

Tables 1 and 2 and
Figures 1 through 3 follow

Table 1. DEHYDROGENATION OF DECALIN OVER VARIOUS CATALYSTS: FIRST SERIES.

Catalyst Stability Tests

Pressure: 10 atm
LHSV: 100
Reaction Time: 30 minutes

Feed: F-113 DHN
Feed Composition: 25.0% trans DHN
74.6% cis DHN
0.4% THN
Catalyst Volume: 7 ml

Catalyst	DHN Conversion, %w at					Increase in Catalyst Temperature, ΔT_{max}, °F at				
Number	842°F	932°F	1022°F	1112°F	1202°F	842°F	932°F	1022°F	1112°F	1202°F
10280-46[a)]	41.9	50.0	59.2	67.9	81.2	13	14	16	24	65
10280-157B	29.8	37.9	47.2	56.3	67.9	16	22	27	31	58
10280-119C	37.6	47.0	56.3	67.0	77.1	13	14	16	23	171
10280-124C	25.3	34.0	43.2	53.4	46.5	20	29	27	40	234
10280-15A	30.6	38.3	48.2	59.3	66.9	16	23	25	36	107
9874-193A	29.3	36.4	42.9	43.2	-	17	45	154	272[b)]	-
10280-13	30.3	37.9	41.3	24.0	-	14	38	238	281[b)]	-
10280-50A	9.6	5.7	10.2	-	-	126	-	-	-	-
9874-194A	29.8	37.9	40.5	-	-	18	43	256[b)]	-	-
9874-192A	29.0	35.2	30.4	-	-	22	157	252[b)]	-	-
9874-186A	29.7	36.3	37.0	-	-	20	74	261[b)]	-	-
9874-189A	27.3	33.4	23.2	-	-	16	92	248[b)]	-	-
9874-187A	27.8	32.0	26.6	-	-	20	101	257[b)]	-	-
9874-194B	21.5	25.8	25.6	-	-	128	315[b)]	-	-	-
9874-139B	19.2	22.8	20.7	-	-	140	191	194[b)]	-	-
UOP-R16E[a)]	31.1	42.1	52.9	61.7	-	5	11	22	104	-
UOP-R8[a)]	36.2	43.9	47.7	-	-	14	43	160	-	-
10860-114C[a)]	41.8	50.5	62.0	71.7	83.0	5	2	4	16	67
10280-77A	33.1	47.2	57.0	64.3	72.8	13	14	22	70	229
9874-119B	39.3	47.1	55.8	62.6	57.4	14	22	45	133	339[b)]

a) Previously tested.
b) Catalyst completely deactivated.

Table 2. DEHYDROGENATION OF DECALIN OVER VARIOUS CATALYSTS: SECOND SERIES

Catalyst Stability Tests

Pressure: 10 atm
LHSV: 100
Reaction Time: 30 minutes
Temperatures: Block

Feed: F-113
Feed Composition: 25.0% trans DHN
74.6% cis DHN
0.4% Tetralin

Catalyst Number	Support Pore Diameter, A	% DHN Conversion at, °F					ΔT, °F of Catalyst Bed at, °F				
		842	932	1022	1112	1202	842	932	1022	1112	1202
10280-44[d]	106	33.5	42.7	51.4	-	-	7	20	43	-	-
10860-132A	176	33.2	39.5	33.7	-	-	7	58	248	-	-
-134A	176	26.2	31.1	19.4	-	-	27	94	182[a]	-	-
-134B	176	27.2	34.5	33.4	-	-	11	56	241	-	-
10860-135A	40	34.8	42.6	52.2	64.9	72.0	16	9	27	31	131
-132C	40	35.5	43.7	53.5	61.7	68.8	14	20	25	40	-[a]
10280-114B	-	33.1	44.9	53.2	60.6	64.1	14	16	43	108	-
10860-132B	176	33.5	44.0	55.5	66.6	69.2	5	9	32	95	227[b]
10860-138B	106	37.2	45.0	55.2	65.9	32.2	23	20	31	97	-[a]
-135D	50	37.2	48.0	55.2	63.7	73.2	11	16	7	23	142
-134D	65	36.1	46.7	51.1	62.6	71.2	7	4	11	23	146
-142B	28	41.4	50.7	56.3	71.2	77.6	5	4	7	36	56
-137B	70	29.7	39.6	48.5	56.0	-	13	23	41	67	-
10280-46	40	41.9	50.0	59.2	67.9	81.2	13	14	16	24	65
10820-139B	-	30.3	40.0	44.7	59.5	52.2	18	23	56	139	-[a]
-143B	-	28.9	33.6	20.4	-	-	47	160	-[a]	-	-
10860-146	40	43.7	53.8	62.2	71.2	84.1[c]	3	5	13	18	-[c]
-147	-	30.0	36.7	43.2	44.2	-	13	22	40	135	-
-135B	40	42.4	53.7	62.6	70.0	77.9	6	5	9	12	47
-163A	-	39.3	44.7	54.3	63.7	45.5	7	11	37	48	290

a) Catalyst completely deactivated after 10-15 minutes at this temperature.
b) Catalyst completely deactivated at end of run.
c) Reaction time 10 minutes.
d) Standard Catalyst

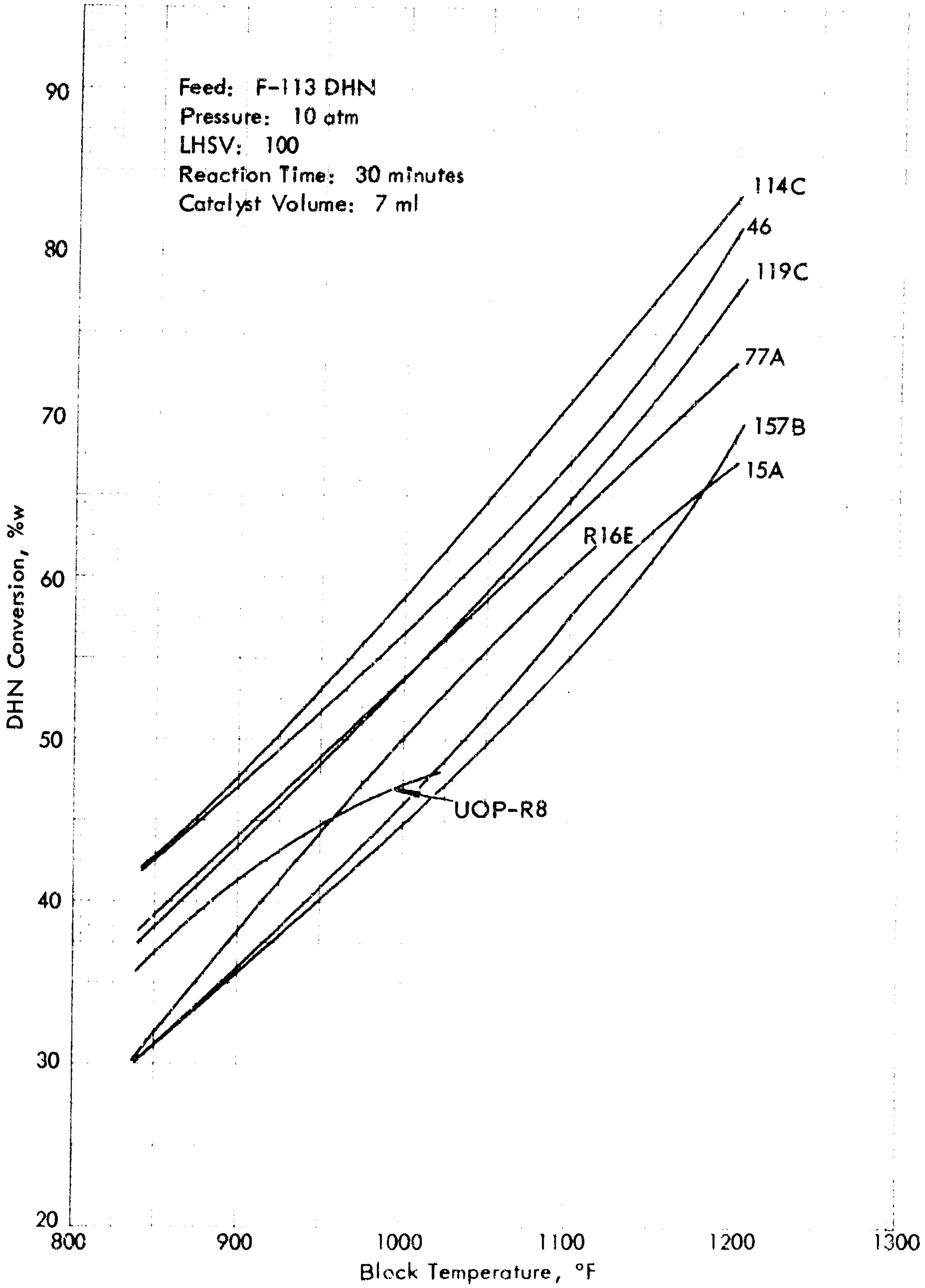


Figure 1. DEHYDROGENATION OF DECALIN: EFFECT OF TEMPERATURE ON CONVERSION

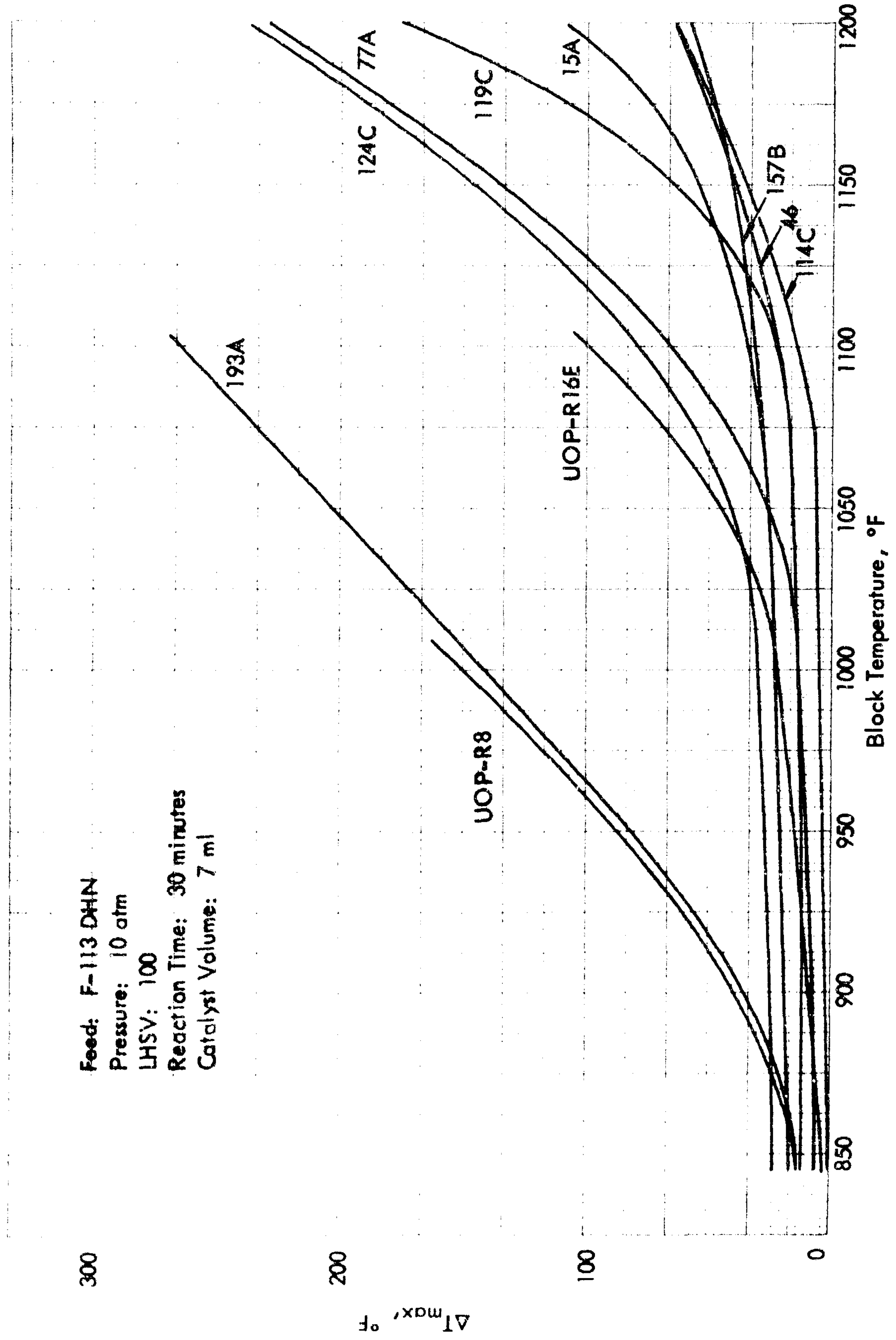


Figure 2. DEHYDROGENATION OF DECALIN: EFFECT OF TEMPERATURE ON CATALYST STABILITY

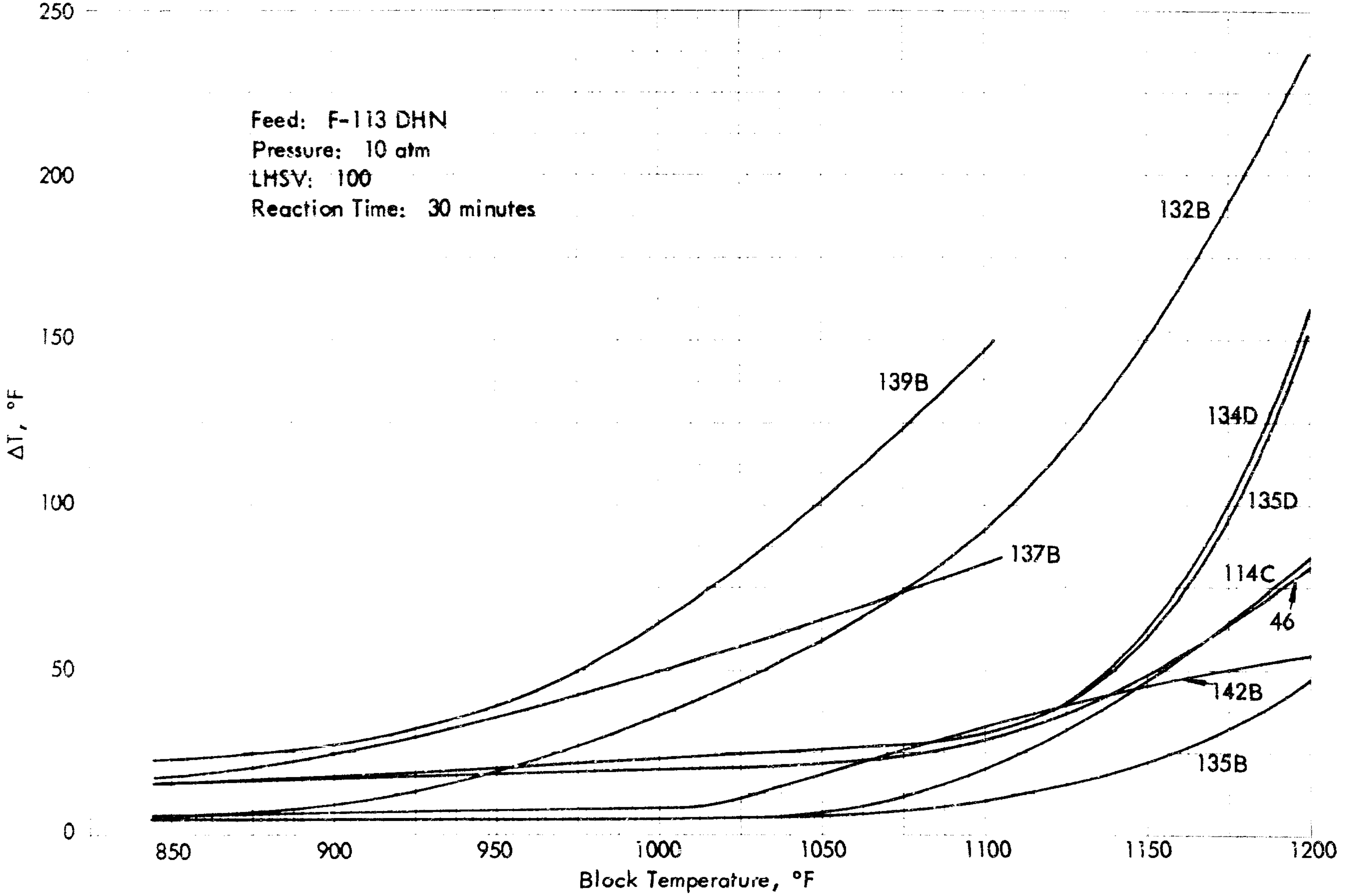


Figure 3. DEHYDROGENATION OF DECALIN: EFFECT OF TEMPERATURE ON CATALYST STABILITY

In earlier work it was shown that stability varied greatly with the catalyst supports.[3] Further it appeared that the best supports were those with smaller pore diameters. Figure 4 shows the increase in catalyst bed temperature (ΔT_{max}) as a function of average pore diameter of the support for catalysts with similar Pt contents and supports at block temperatures of 1022° and 1202°F. Indeed those catalysts with smaller pores appear to be more stable.

Dehydrogenation of Methylcyclohexane

The MCH-catalyst system was considerably more stable than the decalin system. Thus with our standard 1% Pt on Al_2O_3 catalyst good stability was observed with MCH at 10 atm pressure but not at 1 atm[4], while with DHN good stability was observed at 30 atm but not at 10 atm pressure.[1] Consequently in these studies with MCH, stability tests were made at 1 atm pressure. Each catalyst was tested at a single temperature, 852°F, in a series of successive runs with increasing space velocities of 5, 15, 30, 50, 80 and 100 LHSV. The reaction time at each LHSV was 30 minutes. The test was terminated if the catalyst became inactive before reaching LHSV of 100. Fourteen catalysts were evaluated in these tests, four of which had shown good stability with DHN. The complete data are presented in Table 56 in the Appendix, while the pertinent data are summarized in Table 3.

Catalyst deactivation was measured by the magnitude of the increase in catalyst bed temperature during the 30 minute test period. Conversions and catalyst bed temperatures increases at the highest LHSV are shown in Table 3, which also includes two catalysts for comparison that were tested previously (UOP-R8 and UOP-R16E). Conversion as a function of space velocity are shown in Figure 5 for 1% Pt and in Figure 6 for 4% Pt catalysts.

Of the catalysts tested during this period all but five showed little or no catalyst deactivation at the highest space velocity (catalyst bed temperature change was 0 ± 2, Table 3). This group included platinum mounted on both commercial and Shell prepared supports. Our test was not severe enough or of sufficient duration to differentiate between these ten catalysts; thus, all of them must be considered to have comparable good stability for MCH dehydrogenation. Commercial UOP-R8 appeared to be the least stable, but stability was improved greatly by UOP by adding a "metal activator" (i.e., UOP-R16E).

Activities varied greatly between catalysts, and at LHSV of 100 the most active catalysts were commercial Girdler T-309C and 10860-171E. Six of these catalysts have been tested with decalin. Further testing of the others with this naphthene are planned, as decalin gives a more severe test of catalyst stability.

In summary, we have evaluated many catalysts for stability for the dehydrogenation of naphthenes without added hydrogen. Almost all of the catalysts contained platinum, either alone or with other metals as bimetallic or trimetallic mixtures, mounted on various supports. In the tests with decalin six of the laboratory prepared catalysts showed moderate stability at 1202°F and good stability at lower temperatures. All of these catalysts contained platinum; one was a bimetallic and one was a trimetallic mixture mounted on four different supports. With the less severe tests with MCH nine of the catalysts showed moderate stability at high space velocity. These catalysts will be evaluated further with decalin.

Table 3. DEHYDROGENATION OF METHYLCYCLOHEXANE: SUMMARY OF CATALYST STABILITY TEST DATA AT TERMINATION OF TESTS

Pressure: 1 atm   Block Temperature: 842°F

Catalyst Number	LHSV	MCH Conversion, %w	Catalyst Bed Temperature Increase, °F
10280-44a)d)	80	19.8	76
10280-108	100	31.6	+2
10860-132Cd)	100	30.9	0
10860-135Ad)	100	32.5	-2
10860-137Bd)	100	16.1	27
10860-142Bd)	100	37.3	-2
10860-170A	100	33.3	+2
10860-170B	80	10.7	180
10860-171A	50	10.8	-b)
10860-171B	100	34.9	+2
10860-171C	100	33.2	0
10860-171D	100	34.8	0
10860-171E	100	41.4	+2
10860-196	80	2.9	29b)
UOP-R8c)d)	30	15.3	168b)
UOP-R16c)d)	100	18.5	31e)
Girdler T-309Cc)	100	44.4	0

a) Standard Catalyst 1% Pt on Al_2O_3.
b) Catalyst almost completely deactivated at the end of the test.
c) Commercial catalyst.
d) Also tested with decalin.
e) Cold spot moved down the catalyst bed.

Figures 4, 5 and 6 follow

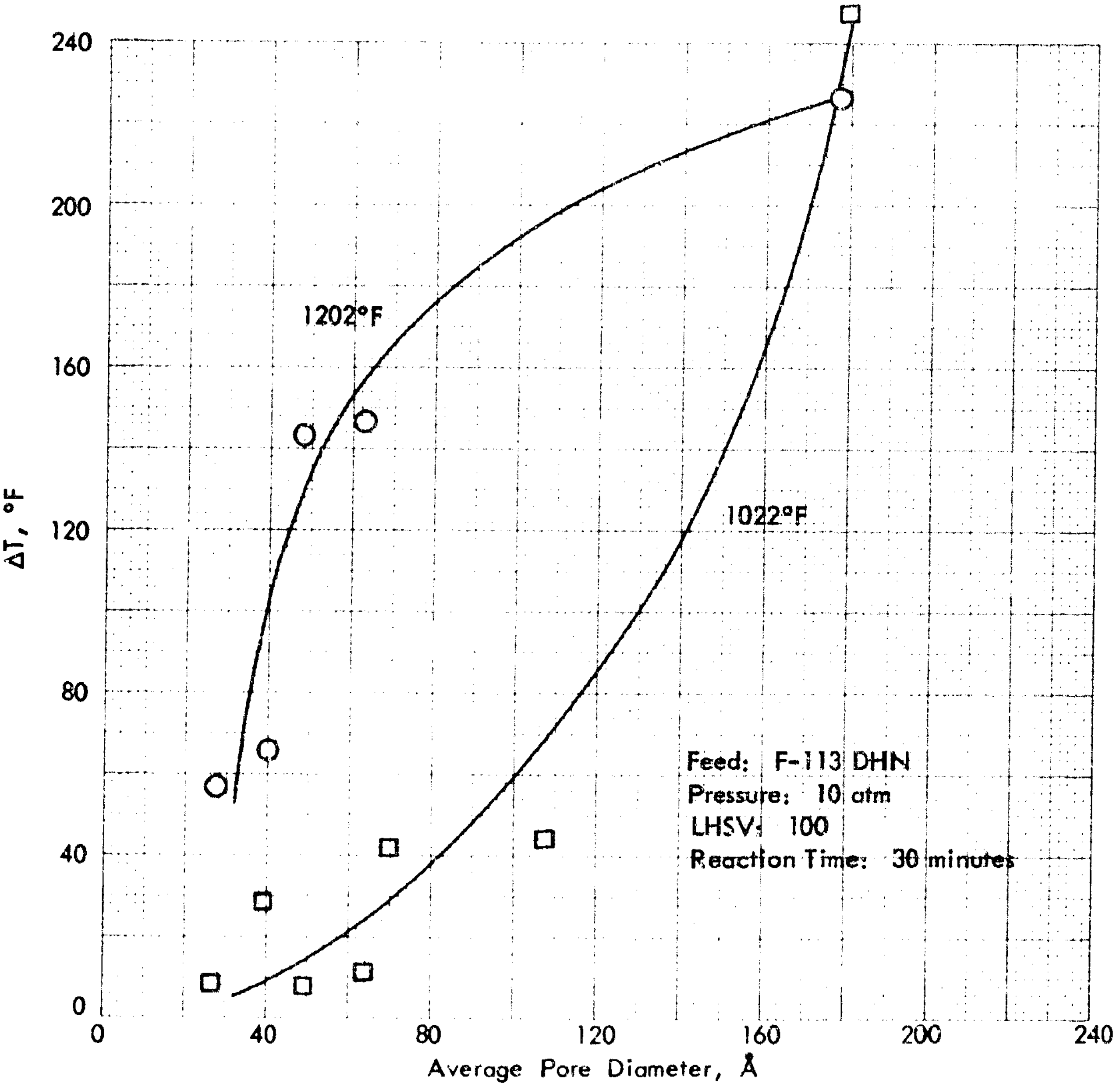


Figure 4. DEHYDROGENATION OF DECALIN: EFFECT OF CATALYST PORE DIAMETER ON STABILITY

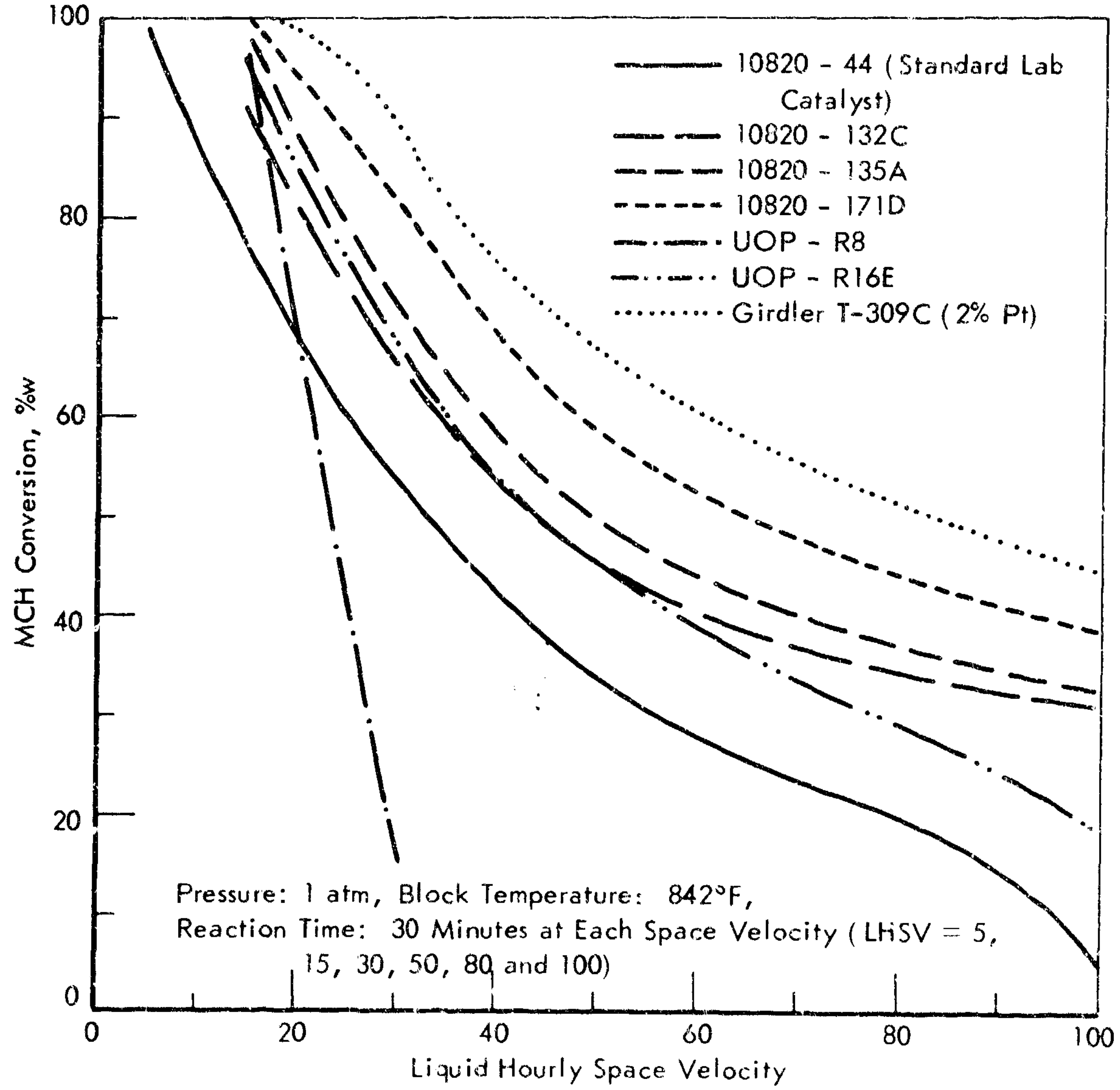


Figure 5. DEHYDROGENATION OF METHYLCYCLOHEXANE OVER ONE PERCENT PLATINUM CATALYSTS

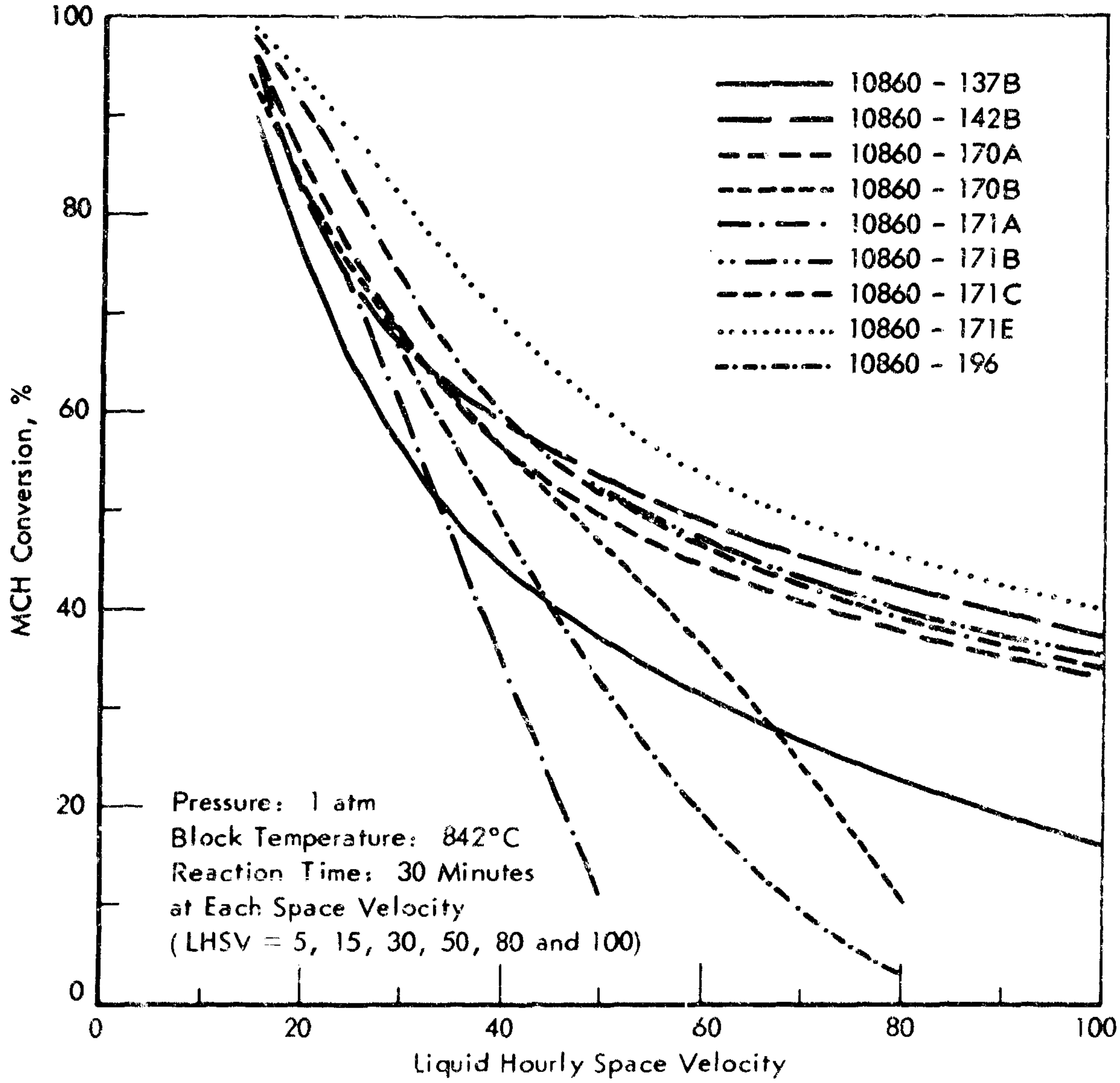


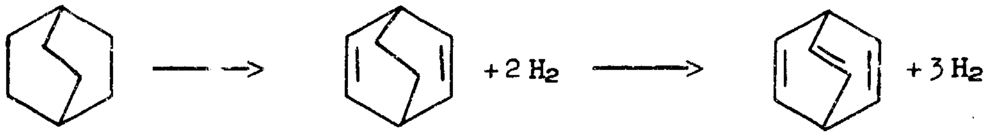
Figure 6. DEHYDROGENATION OF METHYLCYCLOHEXANE OVER FOUR PERCENT PLATINUM CATALYSTS

Based on the tests with decalin it appeared that stability was affected by catalyst support composition, physical properties of the catalyst, the catalyst metal content, and composition.

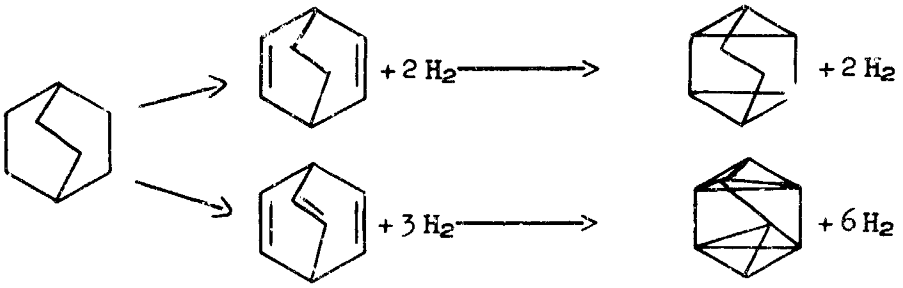
This study is continuing with other supports and metal compositions. Longer tests are being considered in which the catalyst will be run for 50-100 hours at constant reaction conditions.

Dehydrogenation of Bicyclo(2,2,2)octane

Bicyclo(2,2,2)octane (BCO) is a monocyclic naphthene with a C-C bridge across the 1,4-position. In principle it can be dehydrogenated to yield three molecules of hydrogen according to the reaction:



The endothermic heat of this reaction is about 1200 Btu/lb for the first step and possibly 1800 Btu/lb for both steps. Another possible reaction of BCO involves small ring formation, thus:



The total endothermic heat for reaction I is estimated at about 2300 Btu/lb and for II over 4000 Btu/lb. Thus BCO is potentially a very attractive fuel, even though it may be difficult to carry out the reaction beyond the first steps.

An exploratory study of the dehydrogenation of BCO was initiated using our pulse reactor. In this system a carrier gas such as helium or hydrogen flowed through the reactor. A small amount of liquid feed (i.e., 1 μl) was injected into the gas stream and was carried through the reactor as a "pulse". The exit gas was led directly into a GLC for analysis. The reactor was a 1/4" O.D. stainless steel tube (type 304) five inches long and was heated by an electric furnace. This reactor system is described in detail in the Appendix. GLC analyses were made with an F and M Model 5754 chromatograph using a hydrogen flame detector with a 160' capillary column 0.010" I.D. coated with SF96.

BCO was tested under conditions of both thermal and catalytic reaction at 10 atm pressure. One microliter of liquid feed was injected per pulse. BCO melts at 334°F. Hence, it was dissolved in a solvent in order to inject it into the reactor. Mesitylene (1,3,5-trimethylbenzene, TMB) and n-hexane were used as solvents. Neither one was particularly satisfactory; both were catalytically reactive and gave reaction products similar to those obtained with BCO. The solubility of BCO in the above solvents was limited to about 30% in TMB and 40% in n-hexane.

Product identification was based on GLC emergence times obtained with pure compounds. With BCO numerous side reactions are possible such as cracking and dealkylation leading to the formation of benzene, toluene, ethyl benzene, p-xylene, and their corresponding naphthenes.

Thermal Reaction

The thermal reaction was studied over the temperature range of 572° to 1202°F with both helium and hydrogen carrier gas. Apparent contact times (ACT) were 4.2 to 0.2 seconds. (Apparent contact times were calculated from the carrier gas flow rates and the void volume in the reactor tube. The void volume was assumed to be one-half of the bulk volume of the quartz chips.) The reactor tube was filled with quartz chips having a bulk volume of 2.1 ml. Feed was 25% BCO in mesitylene (TMB). Pure TMB was tested separately. The complete data for TMB are shown in Table 4.

With He carrier gas TMB was reasonably stable, and at contact times of 4.0 and 3.7 seconds, conversions of only 8.0% and 2.2% were observed at 1202°F and 1112°F, respectively (Table 4). Lower conversions were observed at shorter ACT. Based on first order kinetics (see Appendix) the apparent activation energy was 37.1 k. cal/mole (1202° to 1112°F; ACT = 3.7 sec). Figure 7 is an Arrhenius plot of the data.

With H_2 carrier TMB was considerably more reactive than with He at 1202°F but not at 1112°F. Also the apparent activation energy was higher with H_2 carrier. For example with H_2 and an ACT of 3.7 seconds, 24.5% conversion was observed at 1202°F and only 2.4 at 1112°F, which corresponded to an apparent activation energy of 79.2 kcal/mole (Figure 7).

Products and product distributions appeared to be similar with both carrier gases, based on GLC emergence times. With this hydrocarbon the principal reaction product appeared to be ethyl benzene (peak no. 4, Table 4).

BCO was more reactive thermally than TMB by about a factor of 3 to 4, based on first order rate constants. Further, as was observed with TMB, BCO was more reactive with H_2 than He at 1202°F but not at 1112°F. The complete data are given in Table 5, which shows the values for the product analyses in parentheses and the calculated values on a TMB-free basis. These calculated values were also corrected for any contribution to the various components by thermal reaction of TMB, using the data of Table 4. A typical correction calculation is shown in the Appendix. With BCO the lower molecular weight hydrocarbons were the principal reaction products (possibly benzene or toluene).

Activation energies with BCO were 38.3 kcal/mole and 74.2 kcal/mole with He and H_2, respectively. The data are shown in Figure 7.

Table 4. THERMAL REACTION OF MESITYLENE: PULSE REACTOR

Pressure: 10 atm
Pulse Volume: 1 µl
Reactor Filled With Quartz Chips.

Run 11023-	106-3	107-1	107-5	108-1	105-3	106-1	106-2	107-2	107-3	107-4	105-2	105-1	104-3
Block Temperature, °F	1022		1112		1202			1022	1112		1202		
Carrier Gas	He							H_2					
Carrier Gas Flow Rate, cc/min	50	200	50	200	50	600	1000	50	50	900	50	200	1000
ACT, seconds	4.2	0.99	4.0	0.99	3.7	0.33	0.19	4.2	4.0	0.99	3.7	0.31	0.19
Product Analysis, %w													
Peak No. 1	0.0	0.0	0.1	0.0	0.3	0.0	0.0	2.9	0.5	0.1	3.8	1.4	0.6
2	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0
3	0.0	0.0	0.1	0.0	0.5	0.0	0.0	0.4	1.9	0.0	1.4	0.3	0.1
4	0.1	0.0	1.6	0.4	6.7	0.6	0.2	5.2	0.0	0.6	18.7	7.5	2.1
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0
6	0.0	0.2	0.0	0.2	0.0	0.3	0.0	0.0	0.0	0.3	0.1	0.3	0.3
(TMB) 7	99.1	99.0	97.5	98.7	91.7	98.9	99.6	91.5	97.3	98.2	75.3	89.7	96.8
8	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.2	0.2	0.3	0.2	0.0
9	0.5	0.5	0.4	0.4	0.4	0.0	0.0	0.0	0.0	0.5	0.2	0.3	0.1
10	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.0	0.0	0.1	0.0	0.1	0.6
TMB Conversion, %w	0.6	0.7	2.2	1.0	8.0	0.8	0.1	8.2	2.4	1.5	24.5	10.0	2.9
First Order Rate Constant, $sec^{-1} (x 10^3)$	-	-	0.67	-	2.13	-	-	-	0.74	-	-	8.67	-

Table 5 and Figure 7 follow

Table 5. THERMAL REACTION OF BICYCLO(2,2,2)OCTANE: PULSE REACTOR

Pressure: 10 atm　　Reactor Filled with Quartz Chips
Pulse Volume: 1 µl　　Feed: 23% BCO in Mesitylene

Run No. 11623-	99-1	99-2	100-2	100-3	100-4	102-1	102-2	102-3	102-4	99-4	98-2	104-1	100-5	101-1	101-2	102-5	103-2	104-2
Block Temperature, °F	1022		1112			1202				1022			1112			1202		
Carrier Gas	He									H_2								
Carrier Gas Flow Rate, cc/min	50	150	50	200	600	50	200	600	1000	50	300	200	50	200	600	50	200	1000
ACT, seconds	4.2	1.4	4.0	0.99	0.33	3.7	0.94	0.31	0.19	4.2	0.71	0.99	4.0	0.99	0.33	3.7	0.94	0.19
Product Analysis, %w Peak No. 1	0.4 (0.1)	0.0 (0.0)	1.2 (0.4)	0.0 (0.0)	0.0 (0.0)	9.3 (2.4)	2.2 (0.9)	0.4 (0.1)	0.0 (0.0)	1.3 (0.3)	0.6 (0.3)	0.4 (0.1)	0.0 (0.4)	0.4 (0.3)	0.4 (0.1)	20.7 (7.2)	2.8 (1.7)	0.9 (0.7)
2	1.2 (0.3)	0.4 (0.1)	3.3 (0.8)	0.4 (0.1)	0.0 (0.0)	12.3 (3.0)	2.7 (0.7)	0.9 (0.2)	0.0 (0.0)	2.6 (0.6)	0.4 (0.1)	0.4 (0.1)	3.0 (0.7)	1.7 (0.4)	0.4 (0.1)	25.0 (5.3)	6.1 (1.5)	1.3 (0.3)
3	0.4 (0.1)	0.0 (0.0)	0.0 (0.1)	0.0 (0.0)	0.0 (0.0)	0.9 (0.6)	0.0 (0.1)	0.4 (0.1)	0.0 (0.0)	0.4 (0.1)	0.4 (0.1)	0.0 (0.0)	0.0 (0.1)	0.4 (0.1)	0.0 (0.0)	0.0 (0.9)	0.0 (0.2)	0.4 (0.2)
3A	0.4 (0.1)	0.4 (0.1)	0.4 (0.1)	0.0 (0.0)	0.0 (0.0)	0.9 (0.6)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.1)	0.8 (0.2)	0.4 (0.1)	0.4 (0.4)	0.4 (0.1)	0.4 (0.1)	1.0 (0.2)	0.9 (0.2)	0.0 (0.0)
3B	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.4 (0.8)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
4	3.1 (0.9)	0.8 (0.3)	3.3 (2.0)	0.0 (0.0)	0.4 (0.1)	0.4 (5.3)	0.0 (1.0)	0.0 (0.3)	0.9 (0.2)	0.0 (0.4)	0.8 (0.2)	0.4 (0.1)	3.0 (0.7)	0.0 (0.5)	1.4 (0.3)	0.0 (8.0)	0.0 (3.4)	0.9 (1.8)
BCO	94.5 (24.2)	98.4 (23.9)	91.7 (22.2)	99.6 (23.0)	99.6 (23.2)	76.2 (17.9)	94.2 (21.3)	98.3 (22.6)	99.1 (22.8)	95.8 (22.7)	95.9 (23.3)	98.4 (23.1)	93.6 (21.8)	97.0 (22.6)	97.4 (22.7)	52.9 (11.0)	90.0 (19.8)	96.4 (21.6)
5	(0.1)	(0.3)	(0.1)	(0.2)	(0.2)	(0.1)	(0.2)	(0.2)	(0.0)	(0.1)	(0.1)	(0.0)	(0.0)	(0.0)	(0.2)	(0.2)	(0.2)	(0.4)
6	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.2)	(0.2)	(0.2)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
TMB 7	(74.3)	(75.1)	(73.8)	(75.7)	(76.2)	(70.0)	(75.3)	(76.4)	(77.0)	(75.0)	(75.8)	(75.7)	(75.4)	(75.5)	(76.4)	(66.7)	(72.6)	(75.0)
8	(0.2)	(0.0)	(0.1)	(0.2)	(0.0)	(0.1)	(0.2)	(0.0)	(0.0)	(0.1)	(0.2)	(0.1)	(0.2)	(0.1)	(0.0)	(0.2)	(0.1)	(0.0)
9	(0.4)	(0.2)	(0.3)	(0.4)	(0.2)	(0.3)	(0.4)	(0.1)	(0.0)	(0.3)	(0.0)	(0.4)	(0.4)	(0.3)	(0.1)	(0.2)	(0.2)	(0.0)
10	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.0)	(0.0)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.0)	(0.1)	(0.1)	(0.0)
BCO Conversion, %w	5.5	1.6	8.3	0.4	0.4	23.8	5.8	1.7	0.9	4.2	4.1	1.6	6.4	3.0	2.6	47.1	10.0	3.6
First Order Rate Constant, sec^{-1} ($x 10^3$)	-	-	2.79	-	-	9.15	-	-	-	-	-	-	2.13	-	-	21.40	-	-

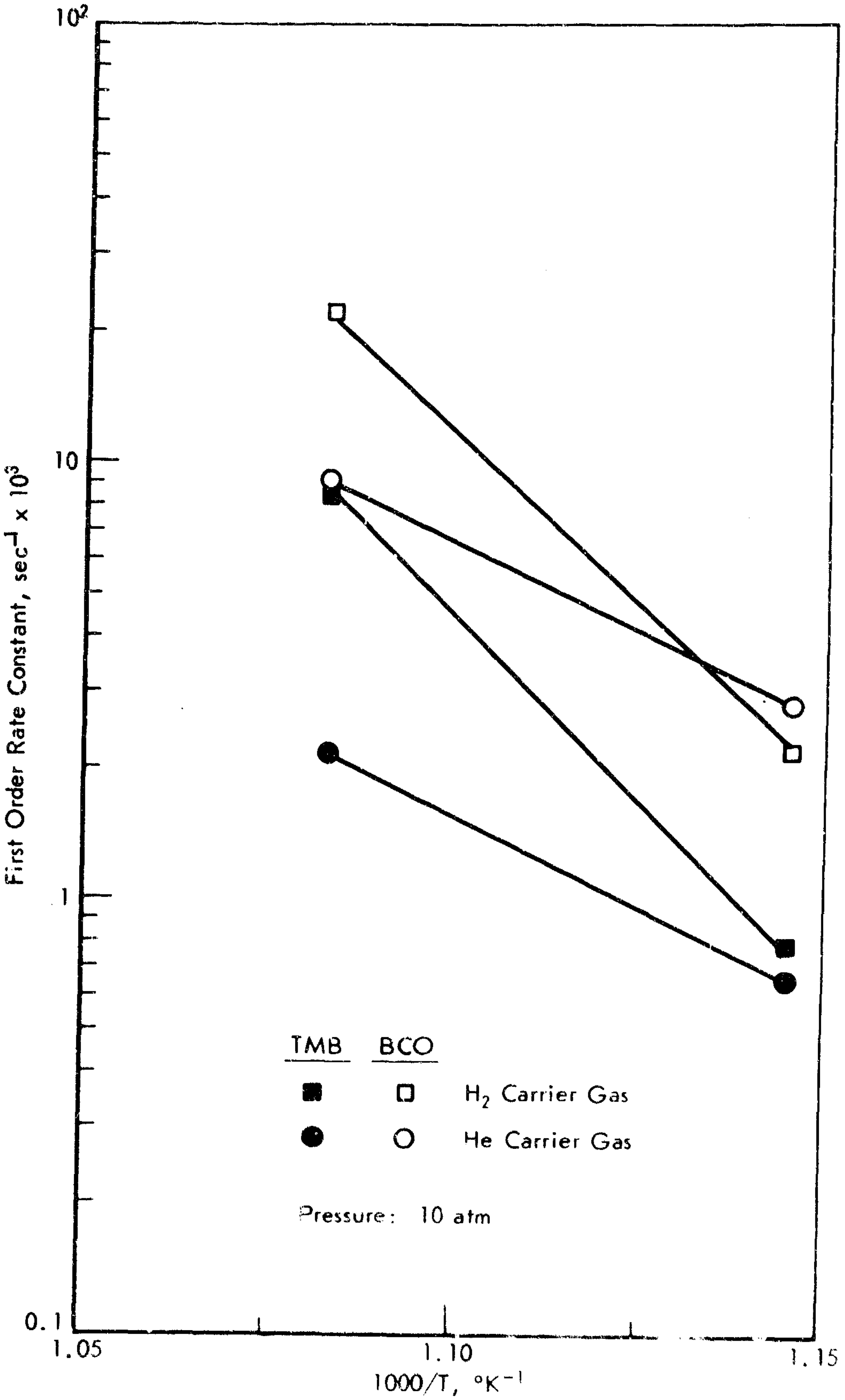


Figure 7. EFFECT OF TEMPERATURE ON THERMAL REACTION OF MESITYLENE AND BICYCLO(2,2,2) OCTANE

The enhanced reactivities of TMB and BCO with H_2 carrier gas could have been due to a hydrocracking-type reaction that occurred at a significant rate at 1202°F but not at lower temperatures. This would explain the higher activation energies with H_2 carrier, as the rate of disappearance of starting material at the higher temperature with H_2 would be due to two (main) reactions, while with He only one reaction occurred (i.e., thermal cracking). This effect of H_2 carrier on naphthene reactivity was observed earlier in work with dimethanodecalin and bicycloheptane.[3)] Based on first order rate constants the reactivity of BCO was less than that of bicycloheptane (BCH) by about a factor of 1.7 to 2.4 (Table 6).

Table 6. COMPARISON OF THERMAL REACTION RATES OF BICYCLO(2,2,1)HEPTANE AND BICYCLO(2,2,2)OCTANE: PULSE REACTOR

ACT = 4.0 to 3.7 seconds Pressure: 10 atm.

Temperature °F	Carrier Gas	First Order Rate Constant, $sec^{-1} \times 10^3$ BCO	BCH[a)]
1112	He	2.8	4.8
	H_2	2.1	5.0
1202	He	9.2	22.0
	H_2	21.4	37.0

---

a) Table 48, pg. 107, reference 3.

Catalytic Dehydrogenation

Dehydrogenation of BCO was studied over the temperature range of 572° to 1022°F with both He and H_2 carrier gas. Two feedstocks were used, namely, BCO dissolved in TMB and in n-hexane. Four laboratory catalysts were tested which were 1% Pt on Al_2O_3 (standard catalyst), 10860-132C, 10860-141A, and 11637-190. In these studies 0.25 ml of catalyst was diluted with 1.0 ml quartz chips. One ul of liquid feed was injected per pulse.

Two of the catalysts were tested with the BCO in TMB feed (about 30% BCO) at 572-752°F using He carrier gas. These were our standard catalyst and 10860-132C; 132C was a bimetallic platinum catalyst. Liquid hourly space velocities varied from 172 to 686 based on total liquid fed or from 52 to 206 based on BCO fed.

With the standard catalyst (1% Pt), [illegible]% BCO conversion was observed at the highest temperature and lowest space velocity (Table 7). Lower conversions were observed at higher space velocities and lower temperatures. This is shown in Figure 8 which shows conversion as a function of space velocity for each test

Table 7 and Figure 8 follow

AFAPL-TR-70-71
66758

Table 7. DEHYDROGENATION OF BICYCLO(2,2,2)OCTANE OVER 1% Pt ON Al_2O_3: PULSE REACTOR

Pressure: 10 atm
Carrier Gas: He
Catalyst Volume: 0.25 ml
Catalyst Wt: 0.2349g
Catalyst No: 10280-44
Feed: 27-30% BCO in Mesitylene
Pulse Volume: 1 µl
Catalyst Diluted With 1.0 ml Quartz Chips.

Run 11623-	95-1	91-5	92-1	92-4	92-5	93-1	93-2	93-3	93-4	94-2	94-3	95-2	95-3	96-1
Carrier Flow Rate, cc/min	150	300	600	150	300	600	150	300	600	300	600	150	300	600
Total LHSV	172	343	686	172	343	686	172	343	686	343	686	172	343	686
BCO LHSV	43	86	172	45	86	172	43	86	172	86	172	43	86	172
Block Temperature, °F	← 572 →			← 617 →			← 662 →			← 707 →		← 752 →		
Product Analysis, %w (TMB-free)[a]														
U_1[b]	3.7 (1.0)	3.2 (0.9)	1.9 (0.5)	4.7 (1.4)	3.6 (1.0)	2.6 (0.7)	7.7 (2.4)	5.8 (1.7)	3.8 (1.2)	5.9 (1.7)	4.0 (1.1)	16.6 (6.3)	10.5 (3.2)	9.9 (3.0)
Benzene	2.6 (0.7)	6.1 (1.7)	4.1 (1.1)	7.7 (2.3)	6.0 (1.7)	6.3 (1.7)	12.5 (3.9)	12.7 (3.7)	8.6 (2.7)	13.5 (3.9)	10.3 (2.8)	27.7 (10.5)	22.2 (6.8)	23.6 (7.2)
Toluene	1.9 (0.5)	1.4 (0.4)	0.7 (0.2)	3.3 (0.5)	1.1 (0.3)	1.1 (0.3)	3.5 (1.1)	1.7 (0.5)	1.9 (0.6)	2.1 (0.6)	1.5 (0.4)	8.4 (3.2)	3.6 (1.1)	3.6 (1.1)
Ethyl Benzene plus Bicyclooctene	4.1 (1.1)	3.2 (0.8)	1.9 (0.5)	8.0 (2.4)	4.3 (1.2)	3.3 (0.9)	11.2 (3.5)	7.9 (2.3)	4.8 (1.5)	5.6 (1.6)	5.5 (1.5)	9.5 (3.6)	7.2 (2.2)	6.0 (1.8)
m-p-Xylene	14.8 (4.0)	2.2 (0.6)	3.3 (0.9)	11.0 (3.3)	6.0 (1.7)	4.0 (1.1)	16.0 (5.0)	8.2 (2.4)	5.7 (1.8)	8.5 (2.4)	5.5 (1.5)	26.4 (10.0)	13.4 (4.1)	11.3 (3.4)
U_2[c]	[illegible] (1.1)	3.2 (0.9)	1.5 (0.4)	6.3 (1.9)	4.3 (1.2)	2.6 (0.7)	6.1 (1.9)	4.8 (1.4)	2.9 (0.9)	4.5 (1.3)	2.2 (0.6)	2.4 (0.9)	4.2 (1.3)	2.3 (0.7)
BCO	60.6 (18.5)	80.6 (22.4)	86.7 (23.4)	60.7 (18.2)	74.7 (21.0)	80.1 (21.8)	42.9 (13.4)	58.8 (17.1)	72.4 (22.8)	60.1 (17.3)	71.0 (19.3)	9.0 (3.4)	38.9 (11.9)	43.0 (13.0)
Mesitylene	(72.7)	(70.2)	(73.0)	(70.0)	(71.8)	(72.8)	(68.0)	(70.9)	(68.3)	(71.2)	(72.6)	(62.0)	(69.1)	(69.8)
BCO Conversion, %w	31.1	19.4	13.3	39.3	25.3	19.9	57.1	41.2	27.6	39.9	29.0	91.0	61.1	57.0
First Order Rate Constant, sec⁻¹	0.168	0.195	0.257	0.234	0.274	0.415	0.413	0.520	0.630	0.517	0.697	1.271	0.997	1.779

[a] Numbers in parenthesis give total product analysis.
[b] U_1 = unidentified; emerged before n-hexane.
[c] U_2 = unidentified; emerged after m-p-Xylene.

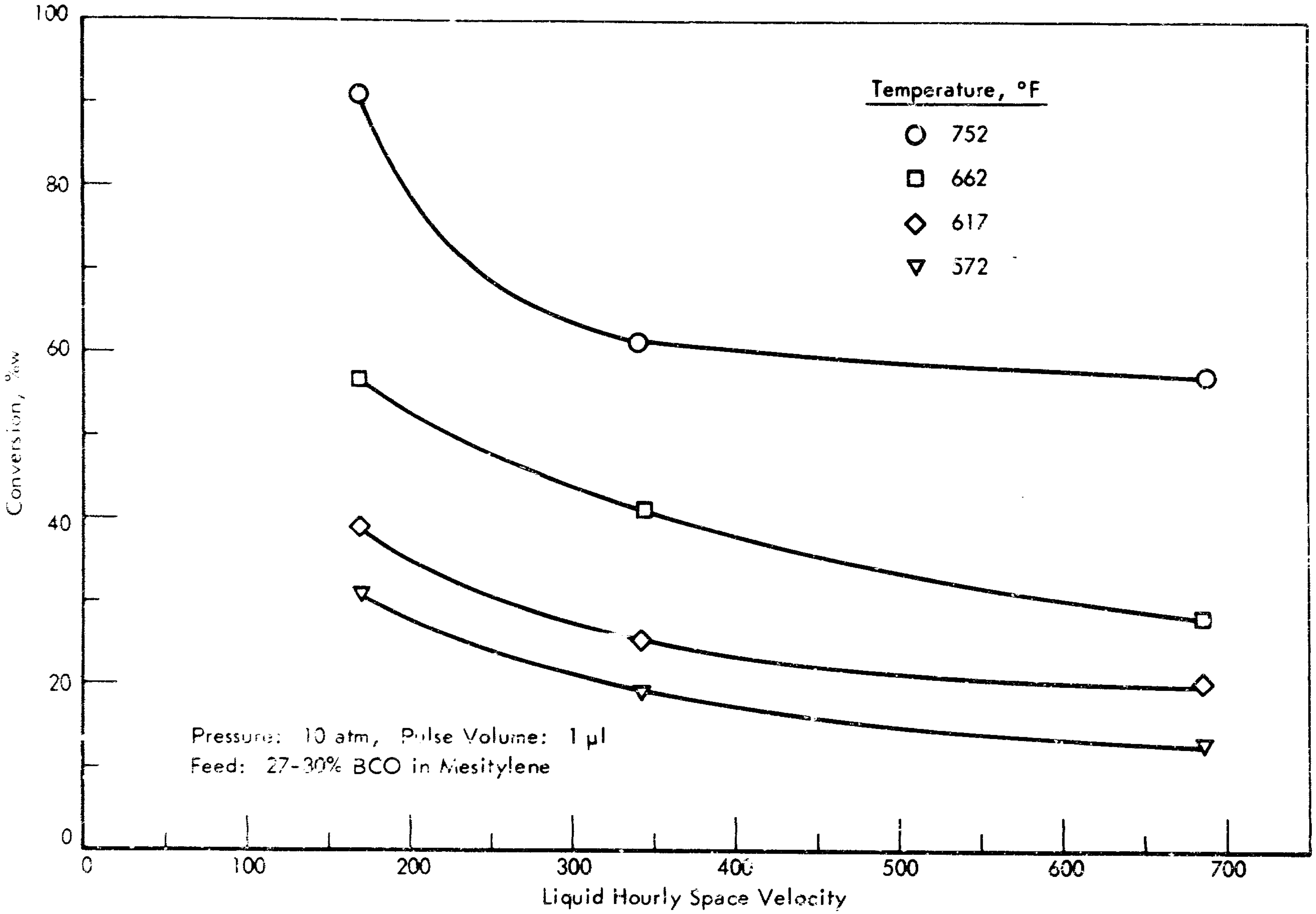


Figure 8. DEHYDROGENATION OF BICYCLO(2,2,2)OCTANE WITH ONE PERCENT PLATINUM ON ALUMINA IN PULSE REACTOR

temperature. There was no measurement of catalyst deactivation during these tests; hence, the conversion values are minimal. The complete data are presented in Table 7 in the order in which the tests were performed. Product analyses, calculated on a TMB-free basis, are shown in the Table 7, and the complete product analyses are shown in parentheses. The calculated values were obtained assuming no TMB reaction. This will introduce a slight error at the higher temperatures, as, in a separate experiment with pure TMB at 752°F (LHSV = 172, He), it was determined that 1.6% TMB was converted to m-xylene (0.8%), toluene (0.4%), and unidentified products. Thus 1.6% should be the maximum error due to TMB reaction, unless there are synergestic effects when TMB is mixed with BCO.

First order rate constants, calculated from conversion of BCO, increased with increasing space velocity. Presumably this effect was due to changes in pulse shape with varying flow rate of carrier gas. Apparent activation energies were calculated from the rate constants at the same space velocity and were 15 to 18 kcal/mole.

Product material was principally benzene and other alkyl aromatics. No dehydrogenation products with bicyclo structures were observed. This suggests that with this catalyst ring opening at one of the secondary carbon atoms is faster than dehydrogenation of the ring, or that the two reactions occur simultaneously.

Based on the first order rate constants the BCO was more reactive than BCH. A comparison of the reactivities of the two naphthenes is shown below:

Table 8. COMPARISON OF REACTIVITIES OF BICYCLO(2,2,2)OCTANE AND BICYCLO(2,2,1)HEPTANE: PULSE REACTOR

Temperature, °F	LHSV	First Order Rate Constant, sec^{-1}	
		BCO	BCH[a]
1112	43-57	0.413	0.022
	172-238	0.630	0.070

a) Table 51, pg 113, Reference 3.

Preliminary results indicated that considerably more catalyst poisoning occurred with BCH, probably due to formation of cyclopentadiene structures.

Catalyst 132C was more active initially than our standard catalyst, but deactivated appreciably with use. For example, initially 47.6% BCO conversion was observed compared to only 31.1% with our standard catalyst (572°F, LHSV = 172). However, at 752°F (after successive tests at lower temperatures) only 58.4% conversion was observed compared to 91% with the standard catalyst. Finally, on returning to the original test conditions (572°F, LHSV = 172) only 10.1% conversion with 132C was observed. Thus, this latter catalyst had very poor stability for BCO dehydrogenation. The complete data are shown in Table 9.

Table 9 follows

Product distributions were similar to those observed with the standard catalyst, namely benzene and higher aromatic homologues. No component with a bicyclo structure could be definitely identified in the dehydrogenation product.

A series of short tests were made with catalysts 10680-141A (141A) and 11637-190 (190) over the temperature range of 662 1022°F. Both catalysts contained the same type of support; 141A was platinum only and 190 was a binary platinum mixture. The feed was 38% BCO in n-hexane. Tests were made at a single LHSV with He (LHSV = 65) and H_2 (LHSV = 130) carrier gas.

With catalyst 141A BCO was dehydrogenated to bicyclooctene in low yield. Best results were obtained at 932°F with H_2 carrier, where 22% BCO was converted to bicyclooctene. Total BCO conversion was 83.5% which gave a yield of bicyclooctene of 26.4% (Table 10). Lower yields were obtained at lower and higher temperatures and with He carrier gas. The complete data are presented in Table 10.

Besides bicyclooctene the principal reaction products were two unidentified components that emerged after bicyclooctene and before BCO (U_2 and U_3, Table 10), plus a considerable amount of material that emerged in the C_6 region of the GLC chromatograph. This latter group could not be successfully resolved by our analysis system but appeared to be hexanes, hexenes, and benzene.

The emergence times of component U_2 was about that of p-xylene, but the emergence time for U_3 did not correspond to any of the benzene homologues. Thus, identification of these components is pending.

BCO conversions were about the same with He and H_2 at 752°F and lower, but at higher temperatures (932°-1022°F) higher conversions and yields of bicyclooctene were observed with H_2.

Catalyst 190 was less active, less selective for bicyclooctene, and for some reason appeared to be completely poisoned by hydrogen at 842°F and lower temperatures. For example, at 932°F BCO conversion was 77.5% with He compared to only 5% with H_2. Further, at 842°F there was absolutely no reaction with H_2 carrier, although with the He 30.1% conversion was observed. This is interesting as this catalyst was designed primarily for dehydrocyclization of paraffins (i.e., ring closure), in which H_2 is part of the system. The complete data are presented in Table 11.

In summary, bicyclo(2,2,2)octane was catalytically dehydrogenated to bicyclooctene in low yield in pulse reactor tests. The reaction was quite sensitive to catalyst properties and to reaction conditions. With one catalyst bicyclooctene was formed with helium present but not with hydrogen, and with two catalysts containing platinum bicyclooctene was formed with one but not with the other. Present tests indicate that bridged-ring naphthenes can be dehydrogenated but that it may take a highly sophisticated naphthene-catalyst system to effect dehydrogenation to the corresponding dienes or trienes with good selectivity. The work is continuing and other catalysts and BCO solvents are being considered.

Table 9. DEHYDROGENATION OF BICYCLO(2,2,2)OCTANE OVER CATALYST 10860-132C: PULSE REACTOR

Pressure: 10 atm	Carrier Gas: He
Feed: 20-25% BCO in Mesitylene	Pulse Volume: 1 µl
Catalyst Volume: 0.25 ml	Catalyst Diluted With
Catalyst Weight: 0.2403 g	1.0 ml Quartz Chips

Run No. 11623-	109-1	109-2	110-1	110-3	110-4	111-3	112-3	112-4	113-1	113-3	113-4	114-1	114-2	115-2	115-3	115-4	116-1	116-2	117-1
Carrier Flow Rate, cc/min	150	300	600	150	300	600	150	300	600	150	150	300	600	150	300	600	150	300	600
LHSV																			
Total BCO	172 43	343 86	686 172	172 43	343 86	686 172	172 43	343 86	682 172	172 43	172 43	343 86	686 172	172 43	343 86	686 172	172 43	343 86	686 172
Block Temperature, °F	572			617			662				707			752			572		
Product Analysis, %w (TMB-free)a)																			
U₁b)	4.8 (1.2)	2.6 (0.6)	1.4 (0.3)	2.7 (0.6)	2.3 (0.5)	1.0 (0.2)	4.7 (1.1)	2.0 (0.4)	1.0 (0.2)	2.2 (0.5)	5.5 (1.3)	1.9 (0.4)	0.5 (0.1)	5.0 (1.0)	2.5 (0.5)	0.4 (0.1)	0.5 (0.1)	0.0 (0.0)	0.0 (0.0)
Benzene	3.2 (0.8)	3.1 (0.7)	2.8 (0.6)	4.0 (1.1)	5.1 (1.1)	3.4 (0.7)	14.5 (3.4)	6.0 (1.2)	2.5 (0.5)	7.1 (1.6)	15.5 (3.7)	5.3 (1.1)	2.6 (0.5)	12.6 (2.9)	8.6 (1.7)	3.5 (0.9)	1.5 (0.3)	0.0 (0.0)	0.0 (0.0)
Toluene	3.2 (0.8)	0.9 (0.2)	0.5 (0.1)	0.4 (0.[illegible])	0.5 (0.1)	0.0 (0.0)	0.9 (0.2)	0.5 (0.1)	0.5 (0.1)	0.4 (0.1)	0.8 (0.2)	0.5 (0.1)	0.0 (0.0)	0.9 (0.2)	1.0 (0.2)	0.4 (0.1)	0.5 (0.1)	0.0 (0.0)	0.0 (0.0)
Ethyl Benzene plus Bicyclooctene	6.1 (1.5)	3.5 (0.8)	2.4 (0.5)	3.5 (0.8)	3.2 (0.7)	5.4 (1.1)	4.2 (1.0)	6.0 (1.2)	6.6 (1.3)	5.4 (1.2)	5.0 (1.2)	7.7 (1.6)	6.7 (1.3)	5.7 (1.3)	8.1 (1.6)	5.4 (1.4)	4.0 (0.8)	2.7 (0.5)	0.0 (0.0)
m+p-Xylene	21.8 (5.2)	6.2 (1.4)	2.8 (0.6)	4.9 (1.1)	3.7 (0.8)	2.0 (0.4)	6.0 (1.4)	4.0 (0.8)	3.0 (0.6)	4.9 (1.1)	7.6 (1.8)	7.7 (1.6)	4.6 (0.9)	10.4 (2.4)	11.1 (2.2)	5.4 (1.4)	2.5 (0.5)	1.1 (0.2)	1.1 (0.2)
U₂c)	9.1 (2.3)	6.6 (1.5)	3.3 (0.7)	7.8 (1.8)	5.1 (1.1)	0.5 (0.1)	6.8 (1.6)	2.0 (0.4)	0.5 (0.1)	4.5 (1.0)	8.4 (2.0)	2.9 (0.6)	0.5 (0.1)	8.3 (1.9)	3.5 (0.7)	0.0 (0.0)	1.0 (0.2)	0.0 (0.0)	0.0 (0.0)
BCO	52.4 (13.2)	77.1 (17.5)	86.7 (18.3)	75.2 (17.0)	80.2 (17.4)	87.3 (17.8)	62.9 (14.7)	79.6 (16.0)	85.9 (17.0)	75.9 (17.0)	51.7 (12.3)	74.0 (15.4)	85.1 (16.6)	45.2 (10.4)	64.6 (12.8)	60.8 (15.8)	89.9 (17.9)	96.3 (19.3)	98.9 (18.8)
Mesitylene	(74.8)	(77.3)	(78.9)	(77.4)	(78.3)	(79.6)	(76.6)	(79.9)	(80.2)	(77.5)	(77.5)	(79.[illegible])	(80.5)	(79.9)	(80.2)	(80.1)	(79.4)	(80.7)	(81.0)
BCO Conversion, %w	47.6	22.9	13.3	24.8	19.8	12.7	37.1	20.4	14.1	24.1	48.3	26.0	14.9	58.4	35.4	39.2	10.9	3.7	1.1

a) Values for total analysis shown in parentheses.
b) Unidentified; emerged before n-hexane.
c) Unidentified; emerged after p-xylene.

Table 10. DEHYDROGENATION OF BICYCLO(2,2,2)OCTANE OVER CATALYST 10860-141A

Pressure: 10 atm
Feed: 38% BCO in n-Hexane
Catalyst Volume: 0.25 ml
Catalyst Wt: 0.0966g
Pulse Volume: 1 µl
Catalyst Diluted With 1.0 ml Quartz Chips

Run No. 11767-	71-1	71-3	72-1	72-2	72-3	73-1	73-2	74-1	74-2
Carrier Gas	He	He	H_2	He	H_2	He	H_2	He	H_2
Carrier Gas Flow Rate cc/min	150	150	300	150	300	150	300	150	300
LHSV									
Total	172	172	343	172	343	172	343	172	343
BCO	65	65	130	65	130	65	130	65	130
Furnace Temp., °F	662	← 752 →		← 842 →		← 932 →		← 1022 →	
Product Analysis, %w									
C_6 and lighter[a]	71.0	71.3	71.2	80.4	71.6	86.9	75.7	87.0	85.4
U_1[b]	0.0	0.6	0.0	0.5	0.8	0.6	1.5	0.4	1.7
Bicyclooctene	0.8	1.9	0.8	3.0	4.0	2.4[e]	8.4	2.4[e]	6.5
U_2[c]	1.0	1.2	2.8	1.1	7.5	0.7	6.2	0.8	3.4
U_3[d]	0.7	1.4	1.7	1.7	2.5	1.0	1.9	0.9	0.8
BCO	26.5	23.6	23.5	13.3	13.6	8.4	6.3	8.5	2.2
BCO Conversion, %w	31.0	38.7	38.8	65.4	64.6	77.9	83.5	77.6	94.2
BCO Converted to $BCO^{=}$	2.0	4.9	2.0	7.8[f]	10.4	6.3[f]	22.0	6.3[f]	17.0
Yield $BCO^{=}$	6.4	12.8	5.1	12.0	16.0	8.0	26.4	8.1	18.0

a) Hexane, hexene, benzene, cyclohexane, and lighter than C_6.
b) Emerged before bicyclooctene - unidentified.
c) Unidentified; emerged after bicyclooctene.
d) Unidentified; emerged after U_2.
e) Two unresolved peaks; one was bicyclooctene, the other may have been bicyclooctadiene.
f) Assume this component is all bicyclooctene.

Table 11 follows

In this respect it is of interest to test BCO-MCH and BCO-DHN feed systems. Presumably interpretation of product analyses should be simplified as the two pure naphthenes dehydrogenate to toluene and to tetralin and naphthalene over these catalysts. These feeds would have a practical application also as successful dehydrogenation of BCO in DHN in effect would be extending the heat sink range of this latter naphthene.

Thermal Cracking of n-Dodecane Using Additives

There is considerable interest as to the maximum amount of heat sink that can be obtained with a paraffinic type jet fuel (JP-7). The latent and sensible heat obtainable from this material is about 1000 Btu/lb when heated to 1300°F. An additional 300 Btu/lb could be obtained by thermally cracking the fuel to about 50% conversion. However, under conventional cracking reaction conditions some coke is produced, which is undesirable. Also, the rate at moderate temperatures is too low. Under the previous contract an investigation was initiated as to the possibility of enhancing the rate of thermal reaction with concurrent reduction in coke make, using free radical initiating fuel additives. This work is being continued under the present contract.

The experiments were done in the pulse reactor, which is described in detail in the Appendix. In this system a stream of carrier gas flowed through the reactor continuously. At the desired time a small amount of feed (ca 1 microliter) was injected into the carrier gas stream and subsequently passed over the catalyst as a pulse. Reaction products, or a slip-stream sample thereof, were led directly into a GLC for analysis.

In these experiments the reactor tube was filled with quartz chips (10-20 mesh). Liquid hourly space velocities were calculated based on the bulk volume of the quartz (i.e., volume of the empty tube), and the apparent contact time (ACT) was calculated based on the void volume in the tube (i.e., one-half the volume of the empty tube). This is close to the actual contact time and is different from our calculation of ACT for catalytic beds, which ignores catalyst volume.

The tests were done at 10 atm pressure and LHSV of 60 using n-dodecane as the test fluid. Helium was used as carrier gas and 1 ml of feed (n-dodecane + additive) was injected per pulse.

In the first series of experiments fourteen additives were tested at 1112°F. The feed was 2%w or less additive in n-dodecane. (Some of the additives were not soluble at this concentration.) The results are tabulated in Table 12.

Some of the additives were effective in increasing the cracking rate and increases in conversions of 40% to 75% were observed (cf 165-7,8,5). Other additives were ineffective or acted as rate inhibitors (cf 165-2,3,13). The additives used were organic compounds containing various functional groups, and it was evident that some of these groups were more effective than others.

The reaction products were lighter than n-dodecane and presumably were cracked material (Table 12). From GLC emergence times the principal component appeared to be a C_8 hydrocarbon (peak No. 1, Table 11) and was not identified

Table 12 follows

Table 11. DEHYDROGENATION OF BICYCLO(2,2,2)OCTANE OVER CATALYST 11639-100: PULSE REACTOR

Pressure: 10 atm
Feed: 38% BCO in n-Hexane
Catalyst Volume: 0.25 ml
Catalyst Wt: 0.0986 g
Pulse Vol: 1 µl
Catalyst Diluted With 1.0 ml Quartz Chips

Run No. 11767-	64-1	65-1	65-2	65-3	65-4	66-1	66-3	67-1	68-1	68-2	68-3
Carrier Gas	He	H_2	He	H_2	He	H_2	H_2	He	He	H_2	He
Carrier Gas Flow Rate, cc/min	150	300	150	300	150	300	300	150	150	300	150
LHSV											
Total	172	343	172	343	172	343	343	172	172	343	172
BCO	65	130	65	130	65	130	130	65	65	130	65
Block Temperature, °F	← 662 →		← 752 →		842	752	← 842 →		← 932 →		1022
Product Analysis, %w											
C_8 and lighter	66.2	62.8	66.0	63.9	66.2	-a)	-a)	71.9	71.9	63.2	87.2
Bicyclooctene	1.0	0.0	0.6	0.0	1.2	-	-	1.4	1.1	0.3	0.4
U_1 b)	0.2	0.0	0.0	0.0	0.3	-	-	0.0	0.5	0.0	0.7
U_2 c)	0.1	0.0	0.3	0.0	2.2	-	-	0.7	1.0	0.1	0.7
BCO	32.7	37.2	33.1	36.1	30.1	-	-	26.7	8.6	36.4	2.0
BCO Conversion, %w	14.6	0.0	13.6	0.0	21.4	-a)	-a)	30.1	77.5	5.0	94.7
BCO Converted to Bicyclooctene	2.6	-	1.5	-	3.1	-	-	3.7	2.9	0.9	1.0
Yield Bicyclooctene	18.0	-	11.0	-	14.6	-		12.3	3.7	17.6	1.1

a) No reaction; only n-hexane and BCO present in chromatogram.
b) Unidentified; emerged after bicyclooctene.
c) Unidentified; emerged after U_1.

Table 12. THERMAL CRACKING OF N-DODECANE USING ADDITIVES: PULSE REACTOR

Pressure: 10 atm
Pulse Volume: 1 ml
Reactor Filled With Quartz Chips
Temperature: 1112°F
Carrier Gas: He

Carrier Gas Flow Rate: 200 cc/min
LHSV: 60
Contact Time: 1 sec

Run No. 11525-	Feed	116-2	116-1	116-3	167-1	167-2	167-3	168-1	168-4	169-2	169-3	170-1	174-2	174-3	174-4	183-1
Additive 11325-		NONE	165-7	165-10	165-6	165-1	165-8	165-14	165-11	165-4	165-13	165-5	165-9	165-2	165-3	165-2
Additive Concentration, %w		-	2	Sat (<2%)	Sat (<2%)	Sat (<2%)	2	2	2	Sat (<2%)	Sat (<2%)	2	Sat (<2%)	Sat (<2%)	Sat (<2%)	Sat (<2%)
Reactor Wall Temperature, °F		1092-1100	1094-1103	1094-1100	1094-1101	1090-1100	1092-1100	1094-1101	1094-1101	1098-1105	1094-1101	1094-1101	1094-1101	1092-1100	1092-1100	1100-1108
Product Analysis, %w																
Component No.																
1	0.0	10.7	15.5	11.4	10.2	11.4	20.1	9.7	9.9	11.0	8.1	16.0	10.8	9.0	9.0	10.0
2	0.0	2.3	2.8	2.5	2.3	2.5	3.4	2.1	2.2	2.2	1.7	3.0	2.1	2.1	1.6	2.3
3	0.0	1.7	2.4	1.7	1.6	1.8	3.7	1.8	1.5	1.7	1.4	3.4	1.7	1.6	1.4	1.3
4	0.0	1.4	1.9	1.6	1.4	1.5	2.0	4	2.0	1.4	1.2	2.0	1.4	1.3	1.2	1.5
5	0.0	1.2	1.5	1.3	1.1	1.3	2.0	.2	1.2	1.2	1.0	1.7	1.3	1.1	1.0	1.2
After 5	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	1.0	1.4	0.8	0.9	1.1	1.7	1.0	1.3	1.2	0.9	1.6	1.1	1.0	0.9	1.1
7	0.0	0.3	0.4	0.3	0.3	0.5	0.6	0.3	0.3	0.4	0.4	0.6	0.3	0.3	0.2	0.5
8	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.1	0.3	0.1	0.0	0.3	0.3	0.3
9	99.4	80.6	73.2	79.6	81.4	79.0	65.8	82.3	80.5	79.9	83.9	71.6	80.3	83.3	84.4	81.3
10	0.6	0.6	0.3	0.6	0.6	0.6	0.4	0.0	0.9	0.9	1.1	0.0	0.0	0.0	0.0	0.0
Dodecane Conversion, %w	--	19.4	26.8	20.4	18.6	21.0	34.2	17.7	19.5	20.0	16.1	28.4	19.7	16.7	15.6	18.7
Increase in Conversions Due to Additives, %	--	--	38.1	5.2	-4.1	8.2	76.3	-8.8	0.5	3.1	-17.0	46.4	1.5	-13.9	-19.6	-3.6

further. In calculating conversion it was assumed that each molecule of dodecane reacted gave one molecule of product; hence, the conversions are maximum values. Product distributions did not appear to be affected by additives, and analyses for several runs with different additives are presented in Table 12. No estimate of coke make could be made from the pulse reactor data.

These results were similar to those observed previously and the maximum rate enhancement was about that observed in the previous work. The best results obtained thus far for all additives tested showed that at 1112°F the rate can be enhanced by about a factor of 1.8 with about 2% additive.

In a second set of experiments a few additives were tested at 1202°F using 3% additive or less in n-dodecane as feed. These additives had been tested previously at 1112°F.3) The complete data are tabulated in Table 13, in which the values in parentheses are those for 1112°F.

At 1202°F considerably less enhancement of reaction rate was observed than with the corresponding additives at 1112°F. For example, with 200-1 and 119-13 the overall conversions were increased by 105% and 62%, respectively, compared to increases of 41% and 9% at 1202°F. No essential difference was observed in product material or product distributions at the two temperatures, nor was the product distribution affected by the additives.

Presumably the overall rate of the cracking reaction was due to free radicals generated by (a) thermal means and (b) the additives. As the rate enhancement by the additives declined with increased temperature, this suggests that the activation energies for the production of free radicals by purely thermal means was greater than that for the generation of free radicals by initiators. This work is continuing.

Effect of Propane on the Catalytic Dehydrogenation of Methylcyclohexane

The sensible heat sink of the methylcyclohexane (MCH) system could be extended by mixing MCH with a light hydrocarbon such as propane, which would lower the melting point of the system. For additional heat sink MCH would undergo endothermic reaction. Consequently it was of interest to determine if propane affected the reactivity of MCH for dehydrogenation.

A mixture of 30% propane in MCH was tested for MCH dehydrogenation in our bench-scale reactor at 10 atm pressure, 842-1112°F, and an LHSV of 50 (basis MCH fed) over our standard 1% Pt on Al_2O_3 catalyst. Reaction time was 30 minutes at each temperature. Liquid product material was analysed by GLC and the gaseous products by mass spectrometer. The data are shown in Table 14, which includes data for pure MCH obtained under the same reaction conditions.

Addition of propane enhanced the reactivity of MCH at the lower temperatures but not at 1022°F. This is shown more clearly by Figure 9, which shows conversion as a function of block temperature. This suggests that propane acted as a diluent, and as such improved the heat transfer to the catalyst resulting in higher conversions. At the higher temperatures it appeared that the catalyst was deactivating, possibly due to propane decomposition, although no propylene or lighter hydrocarbons were observed in the gas products. In earlier work with this catalyst and no propane present in the MCH feed, 95% MCH conversion was observed at LHSV of 100, 10 atm pressure, and 1112°F.5)

Table 13 and Figure 9 follows

Table 13. THERMAL CRACKING OF N-DODECANE USING ADDITIVES

Pulse Reactor: 1202°F

Pressure: 10 atm
Pulse Volume: 1 µl
Reactor Filled With Quartz Chips

Carrier Gas: He
Carrier Gas Flow Rate: 200 cc/min
Contact Time: 1 sec.

Run No. 11325-	161-1	162-1	162-2	162-4	163-2	163-3	164-1	164-3
Additive: 11325-	NONE	199-7	199-12	199-13 Sat	NONE	119-21	119-26	200-1
Additive Concentration, %w	--	2.7	2.1	(<3.4%)	--	1.7	1.8	2.6
Reactor Wall Temperature, °F	1175-91	1175-91	1175-89	1175-89	1175-91	1177-93	1175-91	1175-91
Product Analysis, %w Component No.								
1	41.1	46.2	47.4	45.5	41.9	42.9	44.9	49.8
2	5.7	5.0	6.6	6.4	4.9	4.6	5.9	6.7
3	3.7	6.1	3.9	4.0	3.9	3.9	4.1	4.2
4	2.9	3.1	3.8	3.1	3.0	2.9	3.9	3.0
5	2.2	2.3	1.8	2.1	2.2	2.2	2.5	2.1
After 5	-	-	0.3	-	-	-	0.2	-
6	1.8	1.8	1.1	1.9	2.0	2.0	1.9	1.8
7	0.7	0.6	0.4	0.7	0.8	0.6	0.7	0.7
8	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.1
9	41.6	34.6	33.4	36.1	41.2	40.7	35.6	31.6
Others	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0
Dodecane Conversion, %w	58.4 (20.1)[a]	65.4 (27.6)[a]	66.6 (29.1)[a]	63.9 (32.6)[a]	58.8 (20.1)[a]	59.3 (27.3)[a]	54.6 (35.8)[a]	68.4 (41.2)[a]
Increase in Conversion due to Additive, %	-- (37.3)[a]	12.0 (44.8)[a]	14.0 (62.2)[a]	9.4 --	0.7 (35.8)[a]	1.5 (78.1)[a]	-6.5 (105.0)[a]	17.1

a) Values obtained previously at 1112°F.

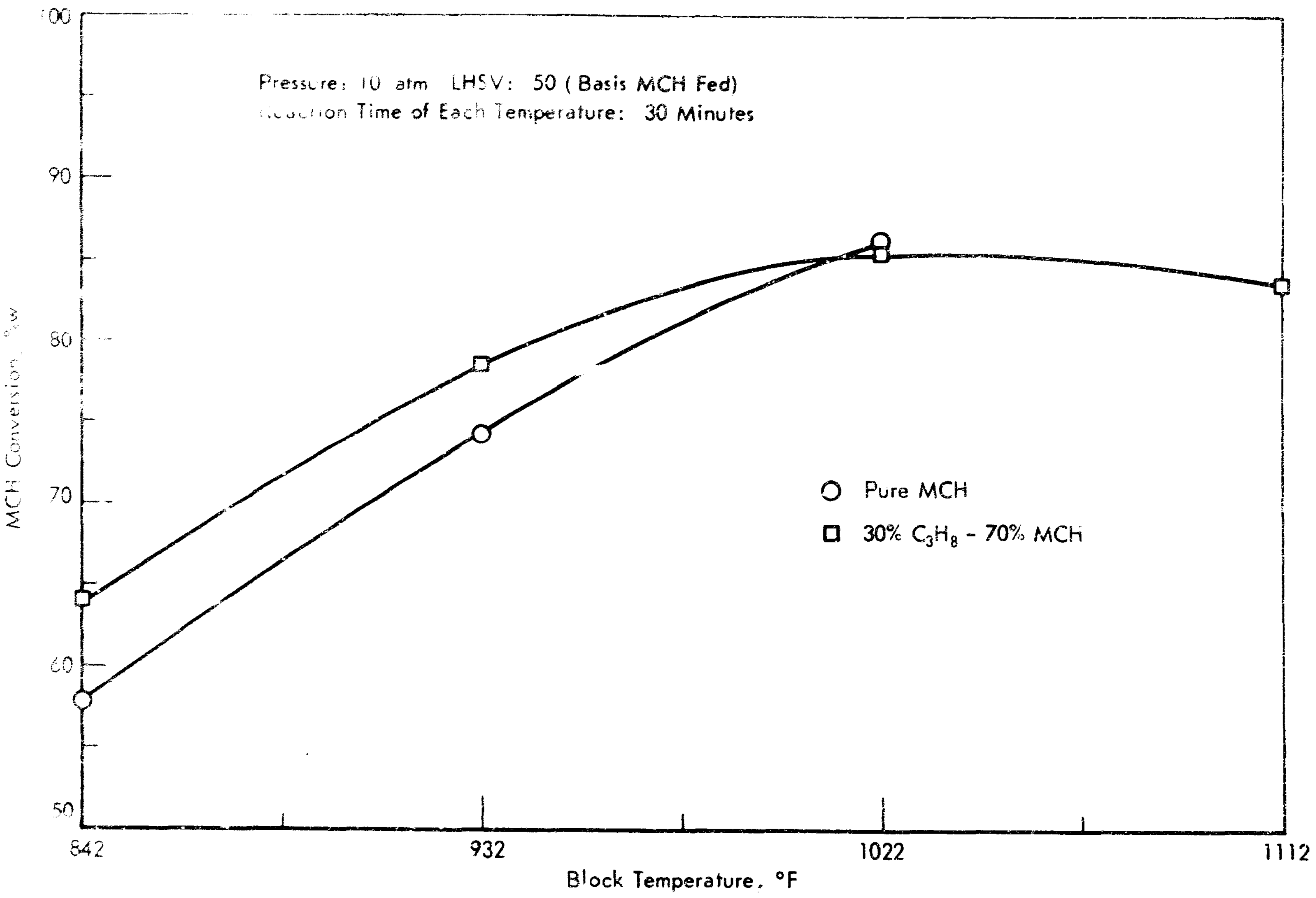


Figure 9. DEHYDROGENATION OF METHYLCYCLOHEXANE: EFFECT OF PROPANE DILUTION

Table 14. DEHYDROGENATION OF PROPANE-METHYLCYCLOHEXANE MIXTURE

Catalyst: 1% Pt on Al_2O_3 Pressure: 10 atm
Catalyst Volume: 7 ml LHSV: 50 (basis MCH bed)

	11623-			11767-			
Run	189	190	191	11-1	12-1	12-2	13
Feed	← Pure MCH →			← 30% C_3H_8-70% MCH →			
Temperature, °F							
Block	842	932	1022	842	932	1022	1112
Wall	765	837	921	734	806	891	1013
Catalyst Bed	650	694	752	662	671	752	855
Liquid Product Analysis, %w							
MCH	42.2	26.1	13.9	36.2	21.6	14.7	16.8
Toluene	57.8	73.9	86.1	63.8	78.4	85.3	83.2
MCH Conversion, %w	57.8	73.9	86.1	63.8	78.4	85.3	83.2
Gas Product Analysis, %m							
Propane	-	-	-	29.3	26.5	25.5	26.5
H_2	100	100	100	70.7	73.5	74.5	73.5

CATALYST STUDIES

We have continued the study and development of conventional granular and coating catalysts and the small scale screening of catalysts for dehydrogenation activity in the micro-test reactor (MICTR), which began under a previous contract.1)2)3) Many additional granular catalysts have been prepared that consist of one or more metals on various supports or mixtures of several unsupported metals from in-house programs. Improvement in dehydrogenation activity at high selectivity still is being sought.

A number of catalysts consisting of 1 and 4% Pt on types 1 or 6 supports with various physical properties have been prepared in furtherance of the concurrent MICTR and bench-scale reactor studies on the activity-stability of dehydrogenation of endothermic fuels, namely MCH and decalin. Included in this study are many additional type 1 supports from both commercial and in-house sources prepared in quantity for bench-scale evaluation. In addition, a study has been started on stabilization of the activity of one of the best type 1 supports, at 1% Pt concentration, by adding single metals at different concentrations. On this support 4% Pt has given better activity-stability than 1% Pt in the bench-scale tests. These metals are expected to suppress the coke forming side reaction that is believed to limit catalyst life during dehydrogenation reactions at low hydrogen partial pressures. Bench-scale testing has shown that greater stability results from using a support with small pore sizes and a high platinum concentration3). Favorable information obtained from this present study probably can be utilized in creating coating formulations with extended catalyst life.

Study has also been initiated in improving the activity-stability of granular platinized type 6 support catalysts, a problem encountered in scale-up preparations, by using two nonalkaline sources of platinum to avoid attack on the surface of the support.

Study has continued of the improvement of catalytic coatings for metal surfaces, such as ease of application, mechanical properties, adherence to metal surfaces, and catalytic activity. New formulations have been studied by metal strip test evaluation and by MICTR tests of candidate coatings in platinized granular form. A possible substitute for the fibrous type 1 component in the best older formulation and which is no longer manufactured has been sought in a widely available natural fibrous material (type 16). Efforts have been made to reformulate coating materials with components shown separately to be activity-stable when platinized. Also, the effect of finer grinding of the wet component mixtures has been studied to obtain better metal adhesion on drying, and to simplify the formulation. Further, formulation with one or more preplatinized components rather than platinization of in situ coatings has been studied as a means of obtaining more exact control of the amount of impregnated platinum.

Through July, 1970, a total of 958 catalysts have been prepared or obtained from proprietary or commercial sources; all of these have been screened in the MICTR during the present and past contracts. Most of the catalysts have been tested in 10-20 mesh particle sizes, including many candidate coating formulations, and some 1/4" OD stainless tubes catalytically coated internally have also been tested. Screening has been for dehydrogenation activity of MCH to toluene without added hydrogen at 10 atm pressure, 100 LHSV, and 662, 752, and 842°F. The same pump rate (90 ml/hr) was maintained for the coated tubes as for the usual granular catalyst charge (0.9 ml catalyst diluted to 2.0 ml with granular quartz). The coated tubes have been filled with quartz to create better mixing and heat transfer. All catalysts have been compared with reference catalysts 9874-139 or its equivalent 10860-70 (1% Pt/UOP R-8 type Al_2O_3). The purpose of the screening tests was to obtain a quick comparison with the reference catalyst so as to determine the more promising catalyst compositions, and to eliminate catalysts with activities too low or selectivities too poor to be of practical importance.

A sketch and photographs of the MICTR are shown in Figures 87, 88 and 89 in the Appendix of a previous report[1] along with a description of the operational details. Subsequent modifications appear in a later report[2]; more recently the original GLC trace recorder has been replaced with a Westronics recorder. Detailed test data appear in the Appendix, Tables 57 and 58, of this report.

Preparation and Evaluation of Granular Catalysts

Most of the particulate catalysts have been prepared by impregnation of various supports (10-20 mesh) with one or more metal salts, followed by drying at 126°C and reduction of the metal (or metals) in situ with hydrogen at 795°F prior to evaluation. Some of the catalysts were unsupported oxide mixtures of various types from several in-house catalytic programs.

Typically, quantities prepared were a few grams for MICTR evaluation with MCH, 30-40 grams for bench-scale studies with endothermic fuels, and 300-400 grams for FSSTR studies (10860-146 and 147). Metal limits were usually between 1 and 4% for the supported catalysts.

Catalysts of the 132, 134, 135, 137, 138, 139, 141, 142, 158, 165,167, and 161 series were prepared at the 1 and 4% Pt levels on two types of supports with various physical properties. The approximate physical properties of the supports are given in Table 15. These catalysts were prepared primarily for activity-stability studies with decalin in the bench-scale reactor, although they were first screened in the MICTR for activity with MCH (Appendix, Tables 57 and 58). Study of factor affecting activity-stability has been carried out primarily with granular materials, but the factors are considered to be likewise important in catalytic coatings on metals, also.

Catalysts of the 188, 189, 190, 191, and 192 series were prepared from a type 1 support previously shown to be activity-stable in the bench-scale reactor at 4% Pt concentration but much less so at 1% Pt concentration. Various metals (AA-AE) at different concentrations were incorporated into this support in an effort to improve the activity-stability at the lower Pt concentration (1%) and to further investigate stability factors. This treatment has been directed toward the suppression of coke-forming side reactions.

Table 16 summarizes MICTR evaluations of a group of catalysts containing 1 or 4% Pt on type 1, 6, or 10 supports with various physical properties (also Table 57 of the Appendix). Table 17 summarizes MICTR evaluation of additional catalysts prepared from type 1 supports from never sources. The first group of

Table 15 follows

Table 15. APPROXIMATE PHYSICAL PROPERTIES OF VARIOUS CATALYST SUPPORTS

(muffled at ~1112°F)

Type	Support Original Configuration	Bulk Density (gm/ml)	Surface Area (m² / gm)	Pore Vol. (ml / gm)	Av. Pore Dia. (Å)
1c)	Granular	0.50	164	0.719a)	176
"	"	0.58	234	0.384a)	65
"	"	0.76	380	0.51	50
"	"	0.80	230	0.23a)	40
"	"	0.88	210	~0.37	70
"	"	0.75	350	~0.25	~28
"	"	0.87	80	0.29a)	145
"c)	"b)	0.63	275	0.62	90
"d)	"	0.65	242	0.494	82
"d)	"	0.61	342	0.367	43
"d)	"	0.87	319	0.323	40
"d)	"	0.60	264	0.526	78
"c)	"	0.49e)	250	0.44	77
"c)	Extrudate	0.68	249	0.55	89
"c)	"	0.63	207	0.66	127
6	Granular	0.72	~800	0.43	~21
"	"	0.38	340	1.15	135
"	Extrudate	0.30	314	1.33	125
10	"	0.62	600	--	~9
16	Granular f)	0.41 f)	125g)	0.60g)	200g)

a) Does not include macro pore volume.
b) Primary particles are fibrous.
c) Commercial source.
d) In-house source.
e) Bulk density of powder.
f) With 20% type 6 binder.
g) Unbonded powder.

Table 16. MICTR SCREENING OF VARIOUS PLATINUM SUPPORTED CATALYSTS OF DIFFERENT PHYSICAL PROPERTIES

Conditions: Feed Stock MCH, LHSV 100, 10 atm pressure, no added hydrogen. Temperature variable. GLC samples taken at 5, 8 and 13 minutes, respectively, at each temperature

Cat. No. 10860-	% Pt	Support		MICTR Run No.	wt Charged	Conversion of MCH to Toluene, %w		
						662	752	842°F
9874-139	1	UOP R-8 type Al_2O_3 (Ref.)		1122	0.43	24, 22, 24	50, 46, 47	70, 70, 70
132 A	1	Type 1 Support		1127	0.41	24, 24, 24	52, 49, 49	76, 75, 75
132 B	4	" " "		1118	0.45	24, 22, 24	47, 47, 47	76, 78, 78
134 C	1	" " "	a)	1123	0.54	24, 23, 24	58, 54, 55	85, 84, 82
"	"	" " "		1134	0.53	33, 29, 23	53, 53, 53	82, 81, 81
134 D	4	" " "		1124	0.53	20, 24, 21	59, 48, 48	77, 77, 76
"	"	" " "		1135	0.56	(15), 25, 26	54, 53, 49	79, 77, 76
135 C	1	Type 1 Support	a)	1125	0.52	25, 26, 26	59, 56, 54	83, 81, 80
"	"	" " "		1137	0.53	27, 25, 27	54, 52, 52	81, 81, 80
135 D	4	" " "		1126	0.57	27, 23, 24	53, 50, 51	78, 77, 77
"	"	" " "		1138	0.54	25, 24, 24	58, 53, 53	83, 81, 81
135 A	1	Type 1 Support	a)	1120	0.78	24, 21, 20	51, 48, 49	76, 76, 76
135 B	4	" " "		1121	0.81	25, 22, 22	58, 53, 55	83, 82, 83
137 A	1	Type 1 Support	a)	1133	0.73	28, 23, 24	53, 50, 49	79, 78, 77
137 B	4	" " "	a)	1139	0.72	26, 30, 27	57, 54, 52	82, 80, 81
144	4	" " "	c)	1153	0.83	35, 35, 35	62, 56, 58	87, 87, 86
138 A	1	Type 1 Support	a)	1140	0.74	26, 24, 24	51, 49, 49	80, 76, 76
"	"	" " "		1142	0.75	22, 32, 30	55, 53, 53	82, 81, 80
138 B	4	" " "		1141	0.76	28, 25, 31	59, 56, 55	83, 82, 81
"	"	" " "		1145	0.77	33, 33, 28	60, 58, 58	87, 86, 85
139 A	1	Type 1 Support	a)d)	1143	0.31	28, 25, 24	44, 44, 42	66, 63, 63
139 B	4	" " "		1144	0.32	26, 30, 27	55, 50, 50	75, 74, 73
141 A	1	Type 1 Support	a)	1146	0.31	20, 19, 18	40, 35, 34	56, 55, 55
141 B	4	" " "		1147	0.34	27, 22, 22	49, 45, 44	70, 68, 69
142 A	1	Type 1 Support	a)	1149	0.67	23, 23, 22	55, 55, 51	80, 80, 79
142 B	4	" " "		1150	0.72	30, 25, 24	62, 59, 58	89, 88, 88
143 A	1	Type 10 Support	b)	1151	0.61	24, 22, 21	38, 36, 41	60, 57, 56
143 B	4	" " "		1152	0.66	25, 24, 21	44, 46, 46	70, 71, 71
147	4	Type 6 Support		1156	0.33	19, 20, 18	44, 41, 41	64, 61, 58
"	4	" " "		1157	0.33	23, 21, 20	43, 41, 41	65, 64, 65
146	4	Type 1 Support	e)	1176	0.81	37, 38, 33	60, 58, 59	88, 86, 86
"	"	" " "		1177	0.81	30, 31, 35	63, 59, 59	89, 86, 86
9874-139	1	UOP R-8 type Al_2O_3 ref.		1136	0.435	22, 24, 21	50, 46, 47	69, 70, 71
10860-136A	1	Type 6		1131	0.586	11, 12, 14	27, 26, 26	41, 49, 37
10860-136B	4	" "		1132	0.598	16, 15, 15	25, 32, 32	48, 47, 48
10860-154A	1	" "		1186	0.638	14, 17, 14	35, 37, 34	47, 41, 40
10860-154B	4	" "		1191	0.657	26, 21, 19	38, 36, 35	50, 45, 45

a) Muffled before impregnation.
b) Muffled before Pt $(NH_3)_4^{++}$ ion exchange step.
c) On as received basis
d) Surface area 314 m^2/gm.
e) Muffled before impregnation.

Table 17. MICTR EVALUATION OF PLATINIZED CATALYSTS WITH NEWER TYPE I SUPPORTS

Test Conditions: Feed Stock MCH, LHSV 100, 10 atm., no added hydrogen
(0.9 ml 10-20 mesh catalyst diluted to 2.0 ml volume with quartz)
GLC Samples taken at 3, 8, and 13 minutes, respectively

Catalyst 10860-	% Pt	Source of Type 1 Support	MICTR Run No.	wt. charged, g.	Average Conversion of MCH To Toluene, %		
					662	752	842°F
70 (ref)	1	--	1201	0.410	22	46	71
158A[a)]	1	commercial	1206	0.535	25	53	83
158B[a)]	2	"	1207	0.542	24	52	81
158C[a)]	4	"	1208	0.567	24	53	83
165A[a,b)]	1	"	1219	0.534	26	56	81
165[a,b)]	4	"	1218	0.549	29	51	80
157A	1	"in house prepn."	1202	0.562	22	50	78
157E	4	" " "	1203	0.596	25	58	83
170B[b)]	4	" " "	1231	0.597	22	51	80
157B	1	" " "	1204	0.545	22	52	80
157F	4	" " "	1205	0.562	27	58	87
170A[b)]	4	" " "	1236	0.559	24	57	87
157C	1	" " "	1210	0.843	18	36	49
157G	4	" " "	1211	0.828	18	35	47
157D	1	" " "	1212	0.527	21	46	74
157H	4	" " "	1213	0.548	23	50	77
171C[b)]	4	" " "	1237	0.541	27	55	82
171A[b)]	4	commercial	1233	0.606	25	57	84
171B[b)]	4	"	1234	0.498	25	51	77
171D[b)]	1	"	1238	0.712	21	48	69
171F[b)]	2	"	1240	0.762	20	48	76
171E[b)]	4	"	1239	0.747	22	52	82

a) Granules prepared from fibrous type 1 support.
b) Prepared in larger quantities for bench-scale activity-stability tests with endothermic fuels.

catalysts were predominantly larger scale preparations of various types, mostly with high activity, and were prepared primarily to further the study of activity-stability in the bench-scale reactor with endothermic fuels.

Two general problems of scale-up were encountered with type 6 supports:

(1) High density type 6 support particles decrepitated extensively to smaller than 20 mesh on impregnation with platinous tetrammine dihydroxide, notwithstanding the prehumidification of the particles with water (10860-136A and 136B, Table 16). This was avoided in subsequent preparations (10860-134A and 134B) by a modified technique. Catalysts from this support have been shown in the past to be less active in the MICTR test and less stable in the bench-scale test with decalin than those prepared from low density type 6 support which does not decrepitate on contact with liquid water.

(2) Scale-up of type 6 supported preparations requires longer drying time and thus longer contact time, resulting from thicker catalyst layers during evaporative concentration of the highly alkaline platinum solution. This undoubtedly leads to greater attack of the siliceous surface with consequent dissolution of silica at the expense of surface area contributed largely by the walls of small pores. A glass-like film has been observed at the evaporating interface in the porcelain dish during concentration of impregnating solutions. The experimental preparations designed to avoid this problem are described below.

Earlier study with small batches of catalysts consisting of 1 or 4% Pt on low density type 6 support showed good activity for MCH dehydrogenation in the MICTR, notwithstanding the low charging weight (Table 18, catalysts 10860-114B and 114C). Also, catalyst 114C showed excellent activity-stability on bench-scale tests with decalin. Reproduction on a larger scale gave catalysts less active for MCH dehydrogenation (10860-141A and 141B), and catalyst 141B showed poorer activity with decalin in the bench-scale test than catalyst 114C.

Various factors have been studied to elucidate further this difficulty. These results indicate that when platinum solution 30 is used as a source of platinum equally active catalysts are obtained regardless of whether the low density type 6 support is used on a "as received basis", or is muffled in air at 1112°F, (catalysts 10860-149A and 149B). Slightly higher activity is obtained if the platinum solution is first neutralized (catalysts 10860-149C, 149D, and 166A). This modification of the impregnating solution is expected to play a more important role in activity-stability with decalin in the bench-scale test, because surface attack on the type 6 support by the highly alkaline platinum solution probably damages the catalytic surface more than the neutralized platinum solution. Catalysts of equal performance to those prepared by the latter solution have been obtained when an acidic source of platinum is used (No. 31). The data shown in Table 18 indicate that highly active catalysts can be prepared from extruded low density type 6 support with good correlation of activity with platinum content (10860-128A, 128B, and 128C).

Catalyst 10860-113 (4% Pt, 9-16 mesh, spherical type 1 support), made in large quantity for FSSTR studies, was found to be less active in the MICTR with MCH than earlier counterparts (10280-107B and 91A). These latter catalysts had

Table 18. MICTR EVALUATION AND COMPARISON OF VARIOUS PLATINUM PROMOTED TYPE 6 SUPPORTED CATALYSTS

Conditions: MCH, LHSV 100, 10 atm pressure, no added H_2, temperature variable.
(10-20 mesh particle size catalyst)

Catalyst No.	% Pt	Pt Source	Form of Type 6 Support	MICTR Run No.	Average Conversion of MCH to Toluene, % w		
					662	752	842°F
9874-139	1	30	reference (spherical Al_2O_3)	1116	25	48	71
10860-114B	1	30	granular (low density)	1112	17	38	64
" 114C	4	30	" "	1113	23	52	78
" 141A	1	30	" "	1146	19	35	55
" 141B	4	30	" "	1147	22	45	69
" 70	1	30	reference (spherical Al_2O_3)	1166	24	45	71
" 149A	4	30	granular[a] (low density)	1163	24	44	65
" 149B	4	30	" [b] "	1172	28	43	69
" 149C	4	30[c]	" [a] "	1173	24	47	60
" 149D	4	30[c]	" [b] "	1179	20	46	70
" 149E	4	31	" [a] "	1174	25	45	64
" 149F	4	31	" [b] "	1175	24	48	63
9874-139	1	30	reference (spherical Al_2O_3)	1105	25	47	72
10860-128A	1	30	extruded, granular[d] (low density)	1098	20	44	69
" 128B	2	30	" "	1106	21	47	77
" 128C	4	30	" "	1100	26	51	77
" 166A	4	30[c]	granular[b] (low density)	1220	22	43	65
" 166B	4	31	" "	1221	21	43	66

a) Support as received.
b) Support muffled.
c) Neutralized impregnating solution.
d) Support muffled in air.

been prepared on the same support screened to 10-16 mesh, (Table 20, runs 1108 vs 1155 and 401). A 10-16 mesh portion of catalyst 113 had higher activity (run 1114) but less so than earlier counterparts; thus the particle size range was only partly responsible. Heating of the 9-16 mesh particles of catalyst 113 in air at 932°F improved the activity somewhat (run 1130).

A number of type 1 supported catalysts containing different amounts of metal G at a 1:1 weight ratio with platinum have been tested with MCH in the MICTR without added hydrogen. Suitable control catalysts with the same amounts of platinum without metal G on the same supports have also been tested (Table 19). Under present MICTR conditions the addition of metal G produced no appreciable improvement in activity for dehydrogenation of MCH. Platinum-metal G promoted catalysts have been examined for activity-stability with decalin in the bench-scale test apparatus and the results are given earlier in this report.

Table 19. EFFECT OF METAL G ON PERFORMANCE OF PLATINUM/TYPE 1 SUPPORTED CATALYSTS WITH METHYLCYCLOHEXANE IN MICTR

Conditions: LHSV 100, 10 atm. pressure, no added H_2, temperature variable; 9874-139 reference catalyst.

Catalyst No.	Metals		MICTR Run No.	Average Conversion of MCH to Toluene, %w		
	% Pt	% G		662	752	842°F
9874-139	1	0	1105	26	47	72
10860-129F	0.5	1	1110	23	52	82
" 129A	0.5	0.5	1102	26	54	79
" 129G	1	0	1111	24	54	84
" 129B	1	1	1103	27	53	78
" 132C	1	1	1119	21	49	74
" 129C	2	2	1115	23	51	80
" 129E	4	0	1109	25	55	83
" 129D	4	4	1107	25	56	87
9874-139	1	0	1122	23	47	70
10860-134A	0.5	0.5	1128	26	42	65
" 134B	1	1	1129	21	43	65

Table 21 shows the MICTR evaluations with MCH of 1% platinized type 1 supports containing various amounts of several metals intended to improve activity-stability on more rigorous bench scale testing. Metals AA and AB with content increasing from 1 to 4% decreases initial activity only slightly at 752°F (runs 1263-1259). Metal AB produces a much more pronounced decline of initial activity

Table 20. RELATIVE ACTIVITIES OF CATALYSTS PREPARED FROM SPHERICAL TYPE 1 SUPPORT WITH METHYLCYCLOHEXANE IN MICTR

Conditions: Same as for Table 18

Catalyst No.	% Pt	Mesh Size of Spherical Particles	MICTR Run No.	Average Conversion of MCH to Toluene, %w		
				662	752	842°F
10860-70[a)]	1	10	1148	22	46	68
10280-91B	2	10-16	400	25	52	74
" 91A	4	"	401	26	57	79
" 130G	4	"[b)]	543	23	45	70
10280-107B	4	10-16	1155	22	49	73
" 113	4	9-16	1108	20	43	69
" "	4	10-16	1114	20	46	69
10860-137C	4	9-16[c)]	1130	21	47	72

a) Reference catalyst on UOP R-8 type Al_2O_3.
b) Catalyst 10280-91A muffled in air 2 hours.
c) Catalyst 10280-113 muffled in air 1/2 hour.

Table 21. MICTR EVALUATION OF PLATINUM/TYPE 1 SUPPORTS CONTAINING SEVERAL CONCENTRATIONS OF VARIOUS METALS INTENDED TO IMPROVE ACTIVITY-STABILITY WITH ENDOTHERMIC FUELS

Test Conditions: Feed stock MCH, LHSV 100, 10 atm., no added hydrogen (0.9 ml 10-20 mesh catalyst diluted to 2.0 ml volume with quartz)
GLC samples taken at 3, 8, and 13 minutes, resp.

Catalyst 10860-	% Pt	% And Type Of Second Metal	MICTR Run No.	wt. Charged g	Average Conversion of MCH to Toluene, %w		
					662	752	842°F
70 188A	1 1	Ref. Control[a)]	1254 1256	0.419 0.303	20 27	45 52	69 81
190A 190B 190C	1 1 1	1 AA 2.3 AA 4 AA	1263 1265 1266	0.711 0.767 0.764	24 23 20	54 51 47	81 81 76
188B 188C 188D	1 1 1	1 AB 2.3 AB 4 AB	1257 1258 1259	0.738 0.713 0.752	24 23 16	55 51 45	84 79 68
189A 189B 189C	1 1 1	1 AC 2.3 AC 4 AC	1260 1261 1262	0.759 0.731 0.747	29 19 15	51 49 38	81 68 47
191A 191B 191C	1 1 1	1 AD 2.3 AD 4 AD	1267 1268 1269	0.767 0.746 0.742	28 21 22	54 53 53	82 84 73
192A 192B 192C	1 1 1	1 AE 2.3 AE 4 AE	1270 1271 1272	0.736 0.737 0.769	24 25 23	57 53 50	87 83 79

a) For series 10860-188, 189, 190, 191, and 192.

with increasing content (runs 1260-1262). Metal AD at different concentrations has no appreciable effect on initial activity (runs 1267-1269). Metal AE with increasing concentration decreases initial activity only slightly at 752°F, acting in a manner similar to metals AA and AB (runs 1270-1272).

Preparation of Catalyst Coatings on Metal Surfaces

Stainless Steel

A large number of new candidate metal-coating formulations have been studied. Most of these have been made by wet grinding the ingredients with a mortar and pestle. However, in certain cases ball-milling the ingredients together has shown to have certain advantages. Small portions of each candidate formulation were spread as thin coatings, usually 3-7 mils thick, onto the smooth and sandblasted sides of degreased stainless steel strips, 1/2 x 2", or on aluminized stainless strips. These coatings were dried, calcined, and then evaluated for coating thickness, metal adhesion, and physical condition. A few coatings were stored wet in a humid desiccator and then subjected to similar tests to check their storability. A portion of each original formulation was dried and muffled, and the 10-20 mesh particle size platinized and evaluated in the MICTR with MCH. Activity at 752°F is shown in Tables 22 and 23 with coating evaluations. Complete MICTR test data are given in Tables 57 and 58 of the Appendix.

In the past, the more successful thixotropic candidate materials were applied to metal surfaces with freedom from cracks and with good adhesion after drying and muffling, and were platinized to produce active surfaces[3]. It was found that application of the hydrous formulations must be made more swiftly, however, since these formulations dry out rapidly at room temperature while being applied to flat metal surfaces. Coating of tubes internally is less of a problem since the drying proceeds at a slower rate. It has been found that this difficulty can be avoided by the addition of 10 or 20% (based on dry solids) of deliquescent salt No. 22. On drying and thermal decomposition this salt becomes a binder itself, and also within certain limits can supplant part of the No. 6 binder currently used. Examples of catalysts using No. 22 binder alone are the 10860-119A-D series impregnated with 2 or 3% platinum (runs 1084 to 1087) and tube No. 28 (run 1088, Table 57 of the Appendix). While activity of the solid catalysts is high, this type of formulation has poor metal adherence and self strips easily. This apparently accounts for the low activity of 1/4" O.D. coated tube No. 28 (run 1088). Coatings were made with 15% No. 6 binder - 5% No. 22 binder and 10% No. 6 binder - 10% No. 22 binder, which have been used to prepare the active platinized catalysts of series 125 and 126 (runs 1094 and 1101). Metal adhesion of the formulations appears satisfactory. Demonstration of activity of a platinized coated tube was not deemed necessary.

Some experimentation was carried out in which alkaline platinum solutions themselves were used as binders for a powdered support with a spherical particle shape (10860-121 and 123, runs 1091-1092). Although active catalysts resulted on platinization, adhesive properties of this type of formulation were poor.

Tables 22 and 23 follow

Table 22. MICTR EVALUATION AND METAL ADHESIVE PROPERTIES OF VARIOUS WALL COATING CANDIDATES

Test Conditions: Feed stock MCH, LHSV 100, 10 atm, no added hydrogen.
(0.9 ml 10-20 mesh catalyst diluted to 2.0 ml volume with quartz).
GLC samples taken at 3, 8, and 13 minutes, respectively.

Catalyst 10860-	% Pt	Material Composition	Thickness (mils)		Muffled (°F)	Adhesion		MICTR Run No.	Conv. of MCH To Toluene, 752°F
						Rating	% off		
119A	2	40% particulate type 1 support 40% fibrous type 1 support 20% type 22 binder (deliquescent before muffling)	13-14	SM	932	poor	a)	1084	52
119B	3		" "	SB	"	"	a)	1085	59
119C	2	45% particulate type 1 support 45% fibrous type 1 support 10% type 22 binder (deliquescent before muffling)	---	SM	--	poor	a)	1086	53
119D	3		---	SB	1004	"	90	1087	57
125A	2	40% particulate type 1 support 40% fibrous type 1 support 15% type 6 binder 5% type 22 binder (deliquescent before muffling)	3-6	SM	1004	poor	30	1094	51
125B	3		5-15	SB	"	good-excellent	15	1095	49
126A	2	40% particulate type 1 support 40% fibrous type 1 support 10% type 6 binder 10% type 22 binder (deliquescent before muffling)	---		1004	Excellent	10	1101	58
126B	3							1097	57
121 123	2 2 d)	type 1 (spherical particle shape)[c]	2 2	SM SB	824 "	poor[b]	-	1091 1092	55 53

a) Self-stripped on dehydration.
b) Easily rubbed off (continuous film).
c) Platinized.
d) Neutralized impregnating solution.

Table 23. MICTR EVALUATION AND METAL ADHESIVE PROPERTIES OF VARIOUS PREPLATINIZED WALL COATING CANDIDATES

Test Conditions: Feed Stock MCH, LHSV 100, 10 atm., no added hydrogen
(0.9 ml 10-20 mesh catalyst diluted to 2.0 ml volume with quartz)
GLC samples taken at 3, 8, and 13 minutes, respectively.

Catalyst 10860-	% Pt	Support Composition	SS Adhesive Properties of Support		MICTR Run No.	Conv. of MCH To Toluene, Wt %
			Thickness	% Stripped		
70	1	UOP R-8 type Al_2O_3 (ref)	--	--	[illegible]	46
163A	3.2	80% type 1 fibrous Support$^{c)}$-20% type 6 binder	3-4 mils SM 2-3 mils SB	60 20	[illegible]	[illegible]
161A	3.2	80% type 1 particulate support$^{c)}$-20% type 6 binder	4-5 mils SM 2 mils SB	70 35	[illegible]	[illegible]
163C	1.6	40% type 1 support (1)$^{c)}$-40% type 1 support (2)-20% type 6 binder	5 mils SM 5-7 mils SB	90 40	[illegible]	[illegible]
168	1.6	40% type 1 support (1)-40% type 1 support (2)$^{c)}$-20% type 6 binder	2-3 mils SM 4 mils SB	90 50	[illegible]	45
161B	1.6	" " " "	3-4 mils SM 2-3 mils SB	95 5	1200	46
163B	3.2	40% type 1 support (1)$^{c)}$-40% type 1 support (2)$^{c)}$ 20% SiO_2	3-5 mils SM 3-5 mils SB	45 10	1194	50
160A	1	80% type 16 fibrous support - 20% type 6 binder$^{d)}$	3-7 mils SM	50	1196	47
160B	2	" " " $^{d)}$	5-6 mils SB	25	1197	47
160C	4	" " " " $^{d)}$			1198	55
167C	3.2	80% type 16 fibrous support$^{c)}$-20% type 6 binder	6 mils SM 4 mils SB	30 30	1225	43
161A	3.2	80% type 1 particulate support$^{c)}$-20% type 6 binder	4-5 mils SM 2 mils SB	70 35	1199	45
172	1.6	40% type 16 support$^{e)}$-40% type 1 support$^{c)}$-20% type 6 binder	--	--	1230	47
173	1.6	40% type 16 support$^{f)}$-40% type 1 support$^{c)}$-20% type 6 binder	3-4 mils SM 4 mils SB	40 5	1235	51
175	3.2	40% type 16 support$^{c,f)}$-40% type 1 support$^{c)}$-20% type 6 binder	4 mils SM 3-4 mils SB	70 35$^{g)}$	1242	50

SM = Smooth degreased stainless steel.
SB = Sand blasted stainless steel.
SS = Stainless Steel.

a) % stripped off when pressure sensitive tape pressed onto surface, and then gently pulled off.
b) Self stripped during drying.
c) Preplatinized with 4% Pt before formulation.
d) Entire support platinized.
e) Unmuffled.
f) Muffled.
g) On aluminized SS, 2-3 mils thick; 60% stripped.

In past studies various formulations have been used to coat the interior walls of metal tubes. After drying and platinizing, the exact platinum laydown could only be determined by removing part of the coating and analyzing it for platinum content[3]. Another approach has been studied, namely formulation in which one or more components has been preplatinized with an exactly known amount of platinum on powdered type 1 or type 16 support. These were then formulated with the usual type 6 binder and tested as 10-20 mesh granules. The adhesive properties and activities of 10-20 mesh granules are shown in Table 23. Generally, with a single platinized (either fibrous or particulate) type 1 support - type 6 binder adherence to smooth stainless steel is poor but adherence to sandblasted stainless steel (10860-163A and 161A) is fair. About the same results were obtained with a combination of fibrous and particulate type 1 supports (with binder) if either the fibrous support was preplatinized (10860-163C) or the particulate type 1 support was preplatinized (10860-163 and 161B). Somewhat better adhesion was obtained if both fibrous and particulate type 1 supports were preplatinized (10860-163B). Platinum contents varied from 1.6 to 3.2% overall in these catalysts, and the MCH dehydrogenation activity was as great as or greater than that of the reference catalyst. Similar experiments were conducted substituting preplatinized fibrous type 16 support for preplatinized type 1 support. The type 16 support is attractive as a possible substitute for the type 1 fibrous support no longer manufactured, a component in the ternary 40:40:20 type I formulation. For comparison, the results shown in Table 23 are obtained with a type 16 support - type 6 binder (80:20) which is first dried and then metallized with three concentrations of platinum (10860-160A, 160B, and 160C). Adhesion of the coating material is fair on smooth stainless steel and better on sand blasted stainless steel. The activity of the metallized dry granules is a little better than the reference catalyst. If the type 16 support is preplatinized (10860-167C) and then bonded, about the same adhesive properties to metal are obtained. Activity is a little less than for the 160 series of catalysts at the same platinum content. Premuffled fibrous type 16 support-preplatinized particulate type 1 support-type 6 binder (40:40:20, 10860-173) gives fair adherence to smooth stainless steel and good adherence to sand blasted stainless steel. The dehydrogenation activity is fairly high. If both supports are platinized and type 6 bonded, adherence is poorer to both smooth and sand blasted stainless steel (10860-175); activity of the platinized granules is about the same.

A recently available type 1 support with excellent physical properties has been studied as a coating candidate component and has shown excellent results in all respects, except for activity-stability on bench scale tests.

The data in Table 24 show that substitution of this new type 1 support into the usual 40:40:20 formulation (type I), in place of the most commonly used particulate type 1 support, gives good adhesion to aluminized and sand blasted stainless steel but not to smooth stainless steel surfaces (10860-176A). Rod milling improves the adhesion to smooth surfaces considerably (10860-178). Very high MCH dehydrogenation activities are obtained with the platinized granular counterparts (10860-177, 177B, and 184A). Equivalent results are obtained on rod milling the type I formulation containing the usual type 1 support component (10860-78B, 183, 81D, and 184E).

Table 24 follows

Quite divergent results are obtained on rod milling 80% newer type 1 support - 20% type 6 binder together (type II formulation). Adhesion is poor to both smooth and sand blasted stainless steel on mortar mixing but excellent after rod milling (10860-164 and 181). Catalyst activity is high and equivalent in both cases at the same platinum content (10860-164A-C, and 184C). With the previously used counterpart type 1 support included, adhesion is equally poor after either mortar mixing or rod milling with 20% type 6 binder. Again dehydrogenation activity is high at the same platinum content (10280-56A, 10860-182, 58A, and 184D). Thus, the use of the new type 1 support in the type I formulation appears to give a promising and simpler wall coating metal support than the previous corresponding support. However, another important factor, namely activity-stability, is yet to be determined.

Satisfactory adhesion to smooth, sandblasted and aluminized stainless steel surfaces has been obtained with fibrous type 16 instead of type 1 support formulations if mortar mixing is used, but poor adhesion to a smooth surface results with ball milling (176B and 180). A small penalty in activity is taken in both cases (10860-177C, 177D and 184B). The activity-stability of this type of catalyst has not been studied as yet in bench scale studies.

Aluminum Clad Stainless Steel

Sources of internally aluminum clad stainless steel or Hastelloy C tubes are being sought. The oxidized aluminum surface is expected to form an even better bonding surface than the bare stainless steel walls for coating formulations, and may itself be a suitable support for impregnation with very thin coatings of metals catalytically active for dehydrogenation reactions. Coated tubes of these types should have better resistance to thermal strains set up by differences in thermal expansion between metals and catalytic coating materials.

One type of aluminum diffusion alloyed 1/4" OD stainless tubing was obtained from Alon Processing Company. These were unsatisfactory in that about one-half of the tubes were plugged solid, and all tubes had rough, uneven, and very rusty internal surfaces. The exteriors had a very rusty appearance and copiously shed rust flakes. The ends of tubes were magnetic, more so than the centers, apparently because magnetic austenite was formed at high temperatures in the cladding treatment. Emission spectroscopy verified that the material was 304 type stainless steel, and this was later confirmed via telephonic conversation with a representative of Alon Processing Company. The poor condition of the tubes did not warrant catalytic coating studies with them.

Four stainless steel strips which had been aluminized on one side were obtained from the above company. These strips had the usual general grey metallic appearance of stainless steel and were free from rust. The aluminized sides had a dull grey, rough, pebblegrain appearance. On heating in air at 1292°F a slight white surface oxidation was observable. Coating material 10860-124, after drying and muffling, adhered well to the aluminized but unoxidized surface of a small strip. The coating principally filled the indentations between the pebblegrains. In view of the unsatisfactory physical condition of the above tubes, no further experimentation with coating them catalytically is contemplated.

Table 24. MICTR EVALUATION AND METAL ADHESIVE PROPERTIES OF VARIOUS PLATINIZED WALL COATING CANDIDATES

Test Conditions: Feed Stock MCH, LHSV 100, 10 atm, no added hydrogen, (0.9 ml 10-20 mesh catalyst diluted to 2.0 ml volume with quartz).
GLC samples taken at 3, 8, and 13 minutes, respectively.

Support		Metal Adhesive Properties				Catalyst 10860-	% Pt	MICTR Run No.	Conv. of MCH To Toluene, 752°F
		Stainless Steel		Aluminized SS					
10860-	Composition	Thickness	% Stripped[a)]	Thickness	% Stripped[a)]				
--	JOP R-8 type Al_2O_3 (ref)	--	--	--	--	70	1	1232	46
164	80% type 1 support - 20% type 6 binder (not rod milled)	7 mils (SM) 9 mils (SB)	100 100	-- --	-- --	164A 164B 164C	1 2 4	1215 1216 1217	49 55 57
181	80% type 1 support - 20% type 6 binder (rod milled)	7 mils (SM) 6-7 mils (SB)	20 5	3-4	5-10	184C	4	1250	59
176A	40% type 1 support (1) - 40% type 1 support (2)- 20% type 6 binder (not rod milled)	2 mils (SM) 5 mils (SB)	95 5	6-7	5	177A 177B	3 4	1244 1245	54 53
178	40% type 1 support (1) - 40% type 1 support (2) - 20% type 6 binder (rod milled)	2-3 mils (SM) 2-3 mils (SB)	5 0	2-3	0	184A	4	1248	55
10280-56A	80% type 1 support - 20% type 6 binder (not rod milled)	-- (SM) -- (SB)	-- -100	--	--	10280-58A	4	308	~55
182	80% type 1 support - 20% type 6 binder (rod milled)	3-4 mils (SM) -- (SB)	90 90	3-4	70	184D	4	1251	54
78B	40% type 1 support (1) - 40% type 1 support (2) - 20% type 6 binder (not rod milled)	-- (SM) -- (SB)	100[b)] 20	--	--	81D	2	965	57
183	40% type 1 support (1) - 40% type 1 support (2) - 20% type 6 binder (rod milled)	3-4 mils (SM) 1-2 mils (SB)	5 0	3-4	0	184E	4	1252	53
176B	40% type 16 support - 40% type 1 support - 20% type 6 binder (not rod milled)	8 mils (SM) 7 mils (SB)	5 0	5	20	177C 177D	3 4	1246 1247	51 51
180	40% type 16 support - 40% type 1 support - 20% type 6 binder (rod milled)	mils (SM) -4 mils (SB)	65 20	2	10	184B	4	1253	50

SM = Smooth degreased stainless steel.
SB - Sand blasted stainless steel.
SS = Stainless Steel.

a) % Stripped off when pressure sensitive tape pressed onto surface, and then gently pulled off.
b) Self stripped during drying.

Various stainless steel and Hastelloy C tubes of different lengths and diameters and several strips of stainless steel have been obtained that are aluminum clad on all exposed surfaces. These have been clad by a proprietary vacuum diffusion process (PNA-73) by Pratt and Whitney Aircraft Division. Preliminary experiments have been carried out by coating one side of the aluminized strips with the more recent experimental coating formulations. These tests have been carried out at the same time as those with the smooth and sand blasted stainless steel strips, and the data are included in Tables 23 and 24. Generally, coating adherence is about equivalent to that of sand blasted stainless steel and superior to that of smooth stainless steel. Preoxidation of the aluminized surface in air at 1382°F appears to increase slightly the tenacity of the coating adhesion.

MEASUREMENT OF CATALYTIC REACTION KINETICS

Quantitative data on the chemical kinetics of MCH dehydrogenation have been obtained previously in a tubular flow reactor with packed bed catalyst. A single stoichiometric reaction is involved, constituting fairly simple kinetics. Even so, difficulties were encountered with temperature and concentration gradients in the packed bed and in the catalyst pellets. The gradients in the packed bed were accounted for by calculating them with a rather involved computer program, and also by attempting to minimize these gradients by changing the reactor geometry. The gradients in the catalyst pellets were not fully taken into account and have only been fully appreciated recently.3) The result of these interfering nonkinetic effects of heat and mass transfer is that the true chemical kinetics are difficult to extract from the experimental data.

Need For Intrinsic Kinetic Data

A legitimate question that could be raised is: Why is it necessary to determine the true chemical kinetics? Since in the full scale reactor heat transfer and mass transfer effects will be present, why not just run the experiments at the desired conditions and fit a model to the results, regardless of whether the effects are due to mass transfer, heat transfer, or the intrinsic chemical kinetics? The answer stated simply is that is is extremely difficult (often impossible) to exactly simulate the conditions of the final application. Furthermore, if one were to obtain such a model based on this completely empirical approach, extrapolation of the model to conditions other than those of the experiments would be highly questionable. As a straightforward example, consider an experiment performed to measure the rate of chemical reaction using a catalyst pellet 1/4" in diameter. One could certainly measure this quantity and fit a chemical kinetic model to it. The problem would arise if the measured rate of reaction was affected by the rate of diffusion of reactants and products through the pores of the catalyst. An attempt to use the kinetic expression for the same catalyst as a 1/8" diameter pellet would fail, since the diffusion would occur much more rapidly than before, resulting in a higher net rate of reaction. The kinetic model would not predict this since the pellet size and shape is not part of the kinetic expression. A similar problem could occur by changing the velocity of the fluid flowing past the catalyst. This can change the rate of heat and mass transfer to the catalyst pellet and thereby the apparent rate of reaction, whereas a kinetic model would not account for this and would miss the effect entirely. A broad experimental study could be made of the effect of all of the important variables in the reactor such as reactor configuration, pellet shape and size, catalyst composition and structure, and fluid pressure, temperature, and velocity. But one rapidly finds that an enormous amount of experimental work would be required, and the resulting model would simply be a device for representing the data.

A more satisfactory procedure is to separate the different processes which occur, study each independently, and then recombine them to form a model which often has a sound fundamental basis and can be used fairly confidently to calculate results, even in regions where experimental data are not available. In heterogeneous catalysis, there are several processes which can often be separated. Much is known about the rate of heat and mass transfer to and from inert particles (e.g., spheres). This information can be applied to a model of the processes surrounding a spherical catalyst pellet. Models are also available for the rate of diffusion in the pores of the catalyst and the rate of heat transfer within the catalyst pellet. Also, much information is available on the mechanisms of catalytic chemical reactions. Assuming one can obtain kinetic information in the absence of the interfering effects of heat and mass transfer, mechanistic models can be proposed, tested, evaluated, and fitted. Once a good mechanistic model is found which relates the rate of reaction to concentrations, pressures, and temperatures, then the models of heat and mass transfer can be applied to result in a reasonable mathematical model with the desired characteristics.

Design of Experimental Reactors

The problems in designing a laboratory reactor for catalytic chemical kinetics has been widely discussed in the literature.6,7) The problems are exactly those described above. A system is required in which the interfering effects of heat and mass transfer are either absent or mathematically describable. The reactor type used in the traditional approach, and the one used in this investigation in the past, has been a packed tubular reactor. The problems with this reactor are that the flow patterns are complicated, and there are invariably appreciable temperature and concentration gradients between catalyst particles as well as within particles. Also, the reactor produces integral rate data and not the rate at a particular set of conditions. Differential reactors are sometimes used to eliminate the last problem, but errors in the chemical analysis lead to large errors in rates. To remedy these problems two different kinds of reactors have been developed: the recycle reactor and the catalytic continuous stirred tank reactor. In both the conditions of reaction are uniform and well defined, and many of the heat and mass transfer problems can be eliminated. In both reactors the reaction rate is measured directly from the conversion and the flow rates.

A recycle reactor consists of a small amount of catalyst exposed to a flowing stream of reactant, most of which is being recycled past the catalyst. During each cycle only a small amount of conversion is occurring, but the total conversion of feed to product can be as high as desired for easy analysis. Such reactors have been used by Butt et al.8) and Perkins and Rase9). About the only problem with this kind of reactor is the pump used to recycle the fluid. It must meet rigid standards of noncontamination and be able to withstand the operating conditions. Bernard and Teichner10) describe a novel pump.

A catalytic continuous stirred tank reactor (CCSTR) has essentially the same advantages as the recycle reactor. In this type the catalyst is either contained in the impeller or is mounted on the wall, and the reactant enters, becomes well mixed, reacts, and leaves. Again, virtually any conversion is feasible. Reactors of this type have been used by several workers.(11-13) The problem here is one of agitation. Sufficient agitation must be supplied to the fluid phase to ensure complete mixing. In a high temperature, high pressure system special equipment is required. Since this type of reactor has been found to work well at high temperatures and pressures, we have chosen it for our work on the dehydrogenation kinetics of the MCH and decalin systems.

The catalytic continuous stirred tank reactor which we have designed will be a modification of one of our existing standard reactors made by Autoclave Engineers. The agitation will be supplied by a magnetic drive with speeds up to about 2000 rpm. The reactor is designed to operate to 1000 psig at 1000°F. It will be constructed of Inconel and be about 1 liter in size. The impeller will be constructed of parallel screens containing catalyst pellets.

MATHEMATICAL MODEL OF CATALYTIC WALL REACTOR

A mathematical model has been developed for our catalytic wall reactor (CWR). The model should be useful in analyzing our experiments and in estimating the effects of changes in operating conditions, reactor geometry, and catalyst composition. The model assumes that the fuel flows turbulently through a tube which has a thin coating of catalyst on the wall. The fuel is assumed to be well mixed radially so that the bulk flow may be considered to be one-dimensional. The heat is assumed to be applied by generation in the tube wall, since that is how it is done in the experiments with the Fuel System Simulation Test Rig (FSSTR). The heat transfer between the outside of the tube and the environment is given as a boundary condition. The model then accounts for the heat transferred radially between the tube wall and the catalyst layer, and between the catalyst layer and the bulk fluid flow. It also calculates the axial temperature, pressure, and conversion profiles.

Model Development

The equations for the bulk gas and for the tube wall were adapted from those derived previously for the regenerative heat exchanger model.(2) The equations describing the bulk fluid flow result from a one-dimensional momentum balance, an energy balance, and a mass balance (see Appendix):

$$\frac{d}{\rho}\frac{\partial\rho}{\partial P}\left(\frac{dP}{dZ}\right) + \frac{d}{\rho}\frac{\partial\rho}{\partial T}\left(\frac{dT}{dZ}\right) - \frac{\rho d}{G^2}\left(\frac{dP}{dZ}\right) - 2f = 0 \qquad (1)$$

$$\frac{\rho^2 c_p d}{G^2}\left(\frac{dT}{dZ}\right) + \frac{Td}{G^2}\frac{\partial\rho}{\partial T}\left(\frac{dP}{dZ}\right) + \frac{4\rho^2 q_l}{G^3} - 2f = 0 \qquad (2)$$

where

d = inside catalyst diameter
ρ = fluid density
P = total pressure
Z = axial distance
T = temperature of bulk fluid
G = mass flux of fluid
f = Fanning friction factor
c_p = fluid specific heat at constant pressure
q_i' = heat flux from fluid to catalyst layer (based on inside diameter of catalyst)

Equations (1) and (2) may be solved for the derivatives of P and T with respect to Z:

$$\frac{dP}{dZ} = \frac{G^2}{\rho d}\left(\frac{a_{22}b_1 - a_{12}b_2}{a_{11}a_{22} - a_{12}a_{21}}\right) \tag{3}$$

$$\frac{dT}{dZ} = \frac{G^2}{\rho^2 d}\left(\frac{-a_{21}b_1 + a_{11}b_2}{a_{11}a_{22} - a_{12}a_{21}}\right) \tag{4}$$

where

$$a_{11} = -1 + \frac{G^2}{\rho^2}\frac{\partial\rho}{\partial P}$$

$$a_{12} = \frac{G^2}{\rho^3}\frac{\partial\rho}{\partial T}$$

$$a_{21} = \frac{T}{\rho}\frac{\partial\rho}{\partial T}$$

$$a_{22} = c_p$$

$$b_1 = 2f$$

$$b_2 = 2f - \frac{4\rho^2 q_i'}{G^3}$$

Equations (3) and (4) are integrated numerically to give axial temperature and pressure profiles of the bulk fluid flow. The following data are required to solve these equations:

1. The density at each axial position.

2. The partial derivatives of the fluid density with respect to pressure and temperature.

3. The heat capacity at constant pressure.

4. The Fanning friction factor.

5. The rate of heat transfer to and from the catalyst layer.

6. The composition of fluid at each axial position.

The required physical properties are calculated by techniques discussed previously.[3] In addition to density, density derivatives, and heat capacity, the viscosity and thermal conductivity must be calculated. Suitable subroutines were written to do this. The Fanning friction factor is calculated by the equation presented by Koo[17], modified slightly:

$$f = 0.0014 + \frac{0.125}{(Re')^{0.32}} \left(\frac{T}{T_i} \right)^{0.5} \tag{5}$$

where

Re' = modified Reynolds number = $(dG/\mu)\ (T/T_i)$
μ = viscosity at wall
T = bulk absolute temperature
T_i = wall absolute temperature

The rate of heat transfer is based on film theory using the Dittus-Boelter correlation for the heat transfer coefficient:

$$h = 0.023 \frac{k}{d} (Re)^{0.8} (Pr)^{0.4} \tag{6}$$

where

h = heat transfer coefficient
k = thermal conductivity of film
Pr = Prandtl number of film
Re = Reynolds number of film

The differential equation describing the conversion is derived in the Appendix. The equation is

$$\frac{dx}{dZ} = \frac{r}{\dot{m}} \quad v_c \tag{7}$$

where

x = number of moles reactant converted per unit feed
r = rate of reaction per unit volume of catalyst (kinetic expression)
$\dot{m}$ = total mass flow rate
v_c = volume of catalyst per unit length

The temperatures in the catalyst layer and in the tube wall are calculated assuming that the rate of heat generation or absorption is uniform across each section. With this assumption analytical expressions may be derived (see Appendix) for the temperature rise across each section, and the average temperatures can be estimated. The temperature rise across the catalyst layer is found from

$$\Delta T_{cat} = \frac{q_R' y_2}{2k_c}\left[\frac{1-\left(\frac{y_2}{y_1}\right)^2 + 2\ln\left(\frac{y_2}{y_1}\right)}{1-\left(\frac{y_2}{y_1}\right)^2}\right] - \frac{q_1' y_2}{k_c}\ln\left(\frac{y_2}{y_1}\right) \quad (8)$$

And the temperature rise across the tube wall is

$$\Delta T_{wall} = -\frac{q_G' y_2}{2k}\left[\frac{1-\left(\frac{y_2}{y_3}\right)^2 + 2\ln\left(\frac{y_2}{y_3}\right)}{1-\left(\frac{y_2}{y_3}\right)^2}\right] + \frac{q_3' y_2}{k}\ln\left(\frac{y_2}{y_3}\right) \quad (9)$$

where

ΔT_{cat} = temperature increase from inside to outside of catalyst layer

q_R' = heat flux to chemical reaction, based on inside tube area

y_2 = inside radius of tube

k_c = thermal conductivity of catalyst

y_1 = inside radius of catalyst layer

q_1' = heat flux from fluid to catalyst, based on inside tube area

ΔT_{wall} = temperature increase from inside to outside of tube

q_G' = heat flux of heat generated in tube wall, based on inside tube area

k = thermal conductivity of tube wall

y_3 = outside radius of tube

q_3' = heat flux from outside of tube to ambient conditions, based on inside tube area

The average temperatures in the catalyst and the wall are estimated by assuming that the temperature differences can be divided into a generation part (terms involving q_G' and q_R') and a transfer part (terms containing q_1' and q_3'). Heat generation leads to approximately parabolic temperature profiles, while heat transferred leads approximately to linear profiles. The average temperatures then are found by using 1/3 of the difference due to generation and 1/2 of the difference due to transfer.

At the present time, the model assumes that there is no diffusional resistance between the bulk fluid and the interior of the catalyst. In the language of catalysis, this assumes external and internal effectiveness factors of one, and can be approached by high fluid velocities and thin catalyst layers.

The calculation of the radial heat fluxes and temperature profiles involves a trial and error procedure as follows:

1. The average catalyst temperature is assumed.
2. The rate of reaction is then calculated from the kinetic expression.
3. The heat absorbed by the reaction can then be calculated.
4. The heat flux from the tube wall to the catalyst is found as the difference between the heat generated in the tube wall and the heat lost from the outside of the tube.
5. The difference between the heat flux from the tube wall to the catalyst and the heat absorbed by the reaction is the heat flux between the catalyst and the fluid.
6. Knowing the temperature of the fluid and the heat flux to or from the fluid, the temperature of the inside catalyst surface can be found using the Dittus-Boelter equation.
7. Assuming that the heat absorbed by the reaction is constant radially, the radial temperature profile may be calculated by equation (8).
8. Then an improved value of the average reaction temperature can be found by a simple convergence procedure, and the process is repeated.

The key assumptions in this calculation are that the average reaction rate takes place at the average temperature and that the heat uptake by the reaction is uniform radially. Neither assumption is strictly true. The reaction rate is an exponential function of the temperature so that the average temperature will underestimate the average rate. The other assumption, however, tends to counteract the error. Since the reaction is endothermic, the hotter part of the catalyst, where the reaction occurs faster, is cooled more by the reaction, thereby retarding the rate.

Application to Methylcyclohexane Dehydrogenation

Only two experiments have been performed with catalytic wall reactors under realistic flow conditions. The runs were made in the FSSTR and were reported earlier.3) Test series 10018-167 was chosen for comparison with the model. The experiments were conducted at three power input levels: 0, 95,000, and 195,000 Btu/hr-ft^2, all at 860 psig pressure and 930°F fluid inlet temperature. The feed rate was 19.7 lb MCH per hour, which gave a Reynolds number of about 100,000 in the highly turbulent flow regime.

The computer program required the heat losses to ambient conditions, which were obtained from the measured outside wall temperatures during the run and a knowledge of heat losses as a function of temperature, which had been obtained experimentally under no flow conditions. The critical constants of methylcyclohexane and toluene were supplied along with a set of pseudocritical constants for hydrogen:

$$T_c = 43.6°K$$

$$P_c = 20.2 \text{ atm}$$

$$V_c = 51.5 \text{ cm}^3/\text{gmole}$$

These constants for hydrogen yield more accurate results than the true ones for corresponding states correlations. The thermal conductivity of the catalyst was estimated to be 0.15 Btu/hr-ft-°F, based on data of Sehr18) on similar catalysts. The thermal conductivity of the tube wall was calculated by

$$k = 7.33 + 0.00458\, T_w \qquad (10)$$

where

T_w = temperature of the tube wall, °F

The kinetic expression used was that obtained from packed bed experiments:2)

$$r = \frac{k_1 c}{1 + k_2 c} \left(1 - \frac{p_T\, p_H^{\,3}}{p_M\, K_e} \right) \qquad (11)$$

where

r = rate of reaction of MCH per unit volume of catalyst, lb mole/hr-ft^3 catalyst
c = concentration of MCH, lb mole/ft^3
$k_1 = A_1 \exp(B_1/RT)$
$k_2 = A_2 \exp(B_2/RT)$
p_T = partial pressure of toluene, atm
p_H = partial pressure of hydrogen, atm
$K_e = A_3 \exp(B_3/RT)$

R = universal gas constant = 1.987 Btu/lb mole -°R
T = absolute temperature, °R
A_1 = 5.4×10^5 hr^{-1}
B_1 = -5000 Btu/lb mole
A_2 = 4.5×10^{-8} ft^3/lb mole
B_2 = 54,000 Btu/lb mole
A_3 = 4.0×10^{20} atm^2
B_3 = -92,500 Btu/lb mole

It was found that 50 integration steps were sufficient to obtain an accurate solution to the equations.

The results using the packed bed kinetic parameters are summarized in Figure 10. The conversion of MCH at the three different power levels is shown, as is the outlet fluid temperatures. The experimental values are represented by the discrete points, and the calculations by solid lines. As can be seen, the conversions are calculated much lower than those found experimentally. The fluid temperatures are therefore much higher, since the transferred heat not absorbed by reaction must heat the fluid. The fact that the conversions are calculated too low indicates that either the catalyst temperatures are calculated too low or that the kinetic expression predicts a rate which is too low. The first possibility can be eliminated since the wall temperatures are calculated much higher than those observed experimentally, and as a result the catalyst temperatures are actually predicted too high. Therefore the packed bed kinetic parameters predict too low a rate of reaction. This is probably due to pore diffusional limitations, which are calculated to be appreciable in the catalyst pellets used in the packed bed. The thin layer of catalyst used in the catalytic wall experiments (3 mils) would not show the same diffusional limitations.

Several variations in the parameters A_1, B_1, A_2, and B_2 were made to determine their effect on the results. The most reasonable results with the least effort were obtained by increasing the value of A_1 only. A value of $30. \times 10^5$, rather than 5.4×10^5, gave the best agreement with the data. The results are shown in Figure 11. The conversions at the two higher power levels are calculated slightly too high. The outlet fluid temperatures are also too high, indicating a small error in the heat balance. The fluid temperature at zero power level is 40°F high, which is somewhat greater than the others. In general, though the results are encouraging. The lack of heat balance is easily explained by a loss of heat between the points at which the fluid temperatures are measured and the beginning and end of the reactor, which is not included in the calculations. If 910°F is used as the entering temperature, instead of 930°F, the heat balance checks out. Figure 12 shows the result for using 910°F initial fluid temperature. The calculated temperatures and conversions agree quite well with the experiments at the two higher power levels, and are not very far off at zero power.

A comparison between the calculated and experimental outer tube temperatures is shown in Figure 13. The agreement is not excellent, but except for the first few inches the results agree within 40°F. It became apparent during the experimental run that something was wrong with the first 4 inches of catalyst. The outer wall temperatures climbed steadily with time indicating that the catalyst was deactivating. This could be explained in terms of coke formation on the catalyst; however, the phenomenon affected only the first four inches and apparently did not progress downstream. It was not clear why the apparent lack of activity only occurred in the initial region of the reactor. Part of the answer may lie in an indication that the catalyst was thicker in this region. Outer temperature profiles were obtained during the activation of the catalyst with hot nitrogen gas. The profiles for no input power and a low power level are shown in Figure 14. At no power input the initial temperatures appear to be too low. When power was applied, the temperatures appeared to be too high. This seems to indicate that the catalyst was thicker in the first four inches of length, which would cause at least part of the greater temperature differences observed. However, this apparent lack of activity may also be due to lower partial pressure of hydrogen or poisoning of the catalyst at the inlet end of the reactor. Further experiments are clearly in order to resolve this question.

The fluid pressure was measured to be 860 psig at the end of the reactor for all three power levels. This pressure was calculated by the model to be 853, 851, and 848 psig in order of increasing power input.

Accuracy of Predicted Reaction Rates

In an effort to check the effect of the several assumptions concerning the temperature profile and rate of reaction in the catalyst layer, a detailed calculation of the radial variations was carried out. A set of conditions at the 195,000 Btu/hr-ft^2 heat flux during experimental run 10018-167 was used. The CWR model gave an average reaction rate of 10,600 lbmole/hr-ft^3 cat. and an average reaction temperature of 911°F. The inner and outer surfaces of the catalyst were calculated to be 892 and 1006°F, respectively. These conditions were determined for a position 0.037 ft from the entrance of the reactor.

The differential equation for the radial temperature profile of the catalyst is

$$\frac{d^2T}{dy^2} + \frac{1}{y}\frac{dT}{dy} = \frac{r\Delta H_R}{k_c} \qquad (12)$$

where

T = temperature of catalyst, °F
y = radial distance, ft
r = reaction rate, lbmole/hr-ft^3
ΔH_R = heat of reaction, Btu/lbmole
k_c = thermal conductivity of catalyst, Btu/hr-ft-°F

This equation was integrated numerically using the inner catalyst surface temperature of 892°F and the known heat flux at the surface between the catalyst and the tube wall. The temperature, the reaction rate, and the concentration were allowed to vary during the integration. The results for the temperature profiles are

Figures 10 through 14 follow

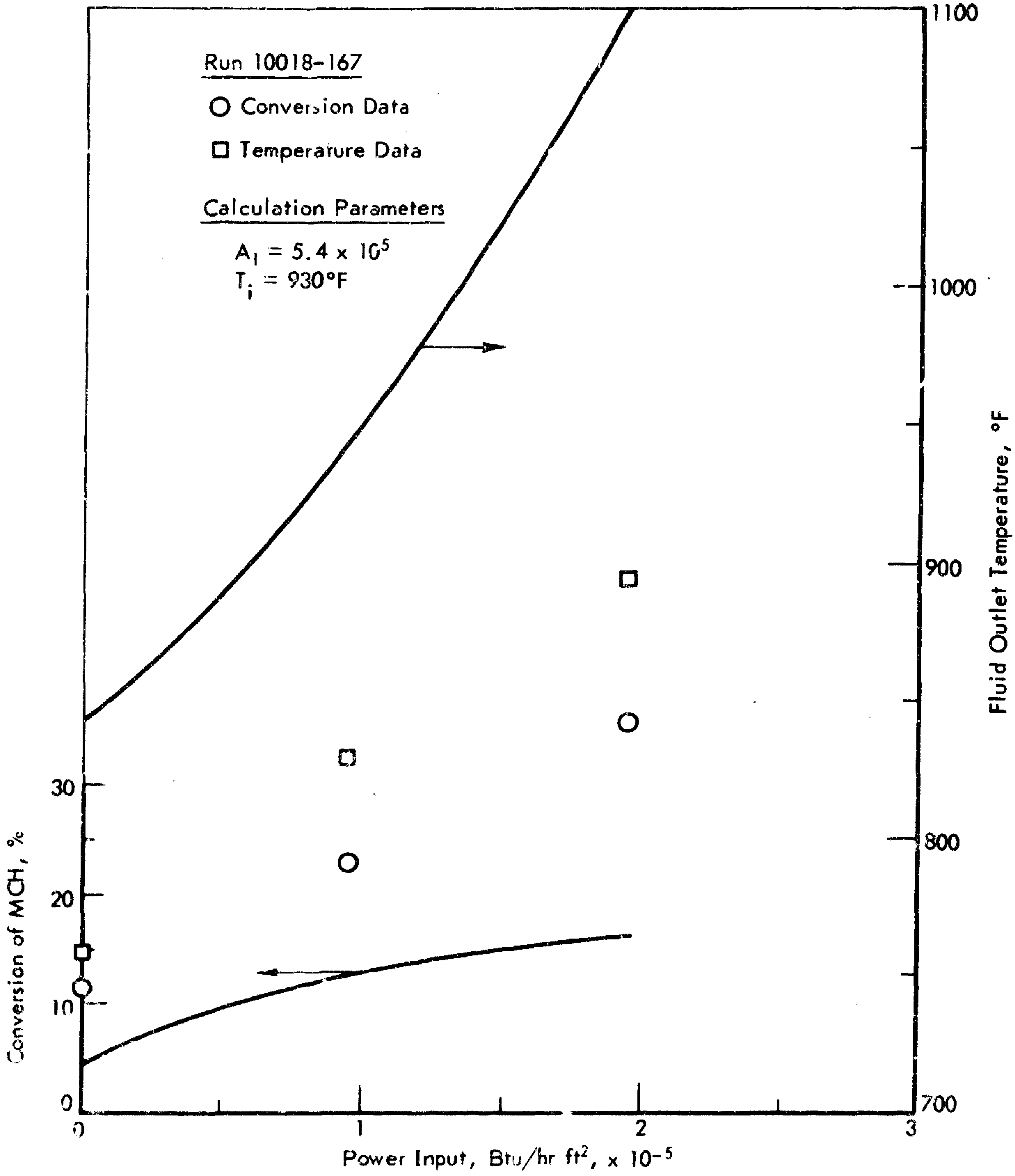


Figure 10. METHYLCYCLOHEXANE DEHYDROGENATION IN A WALL CATALYST

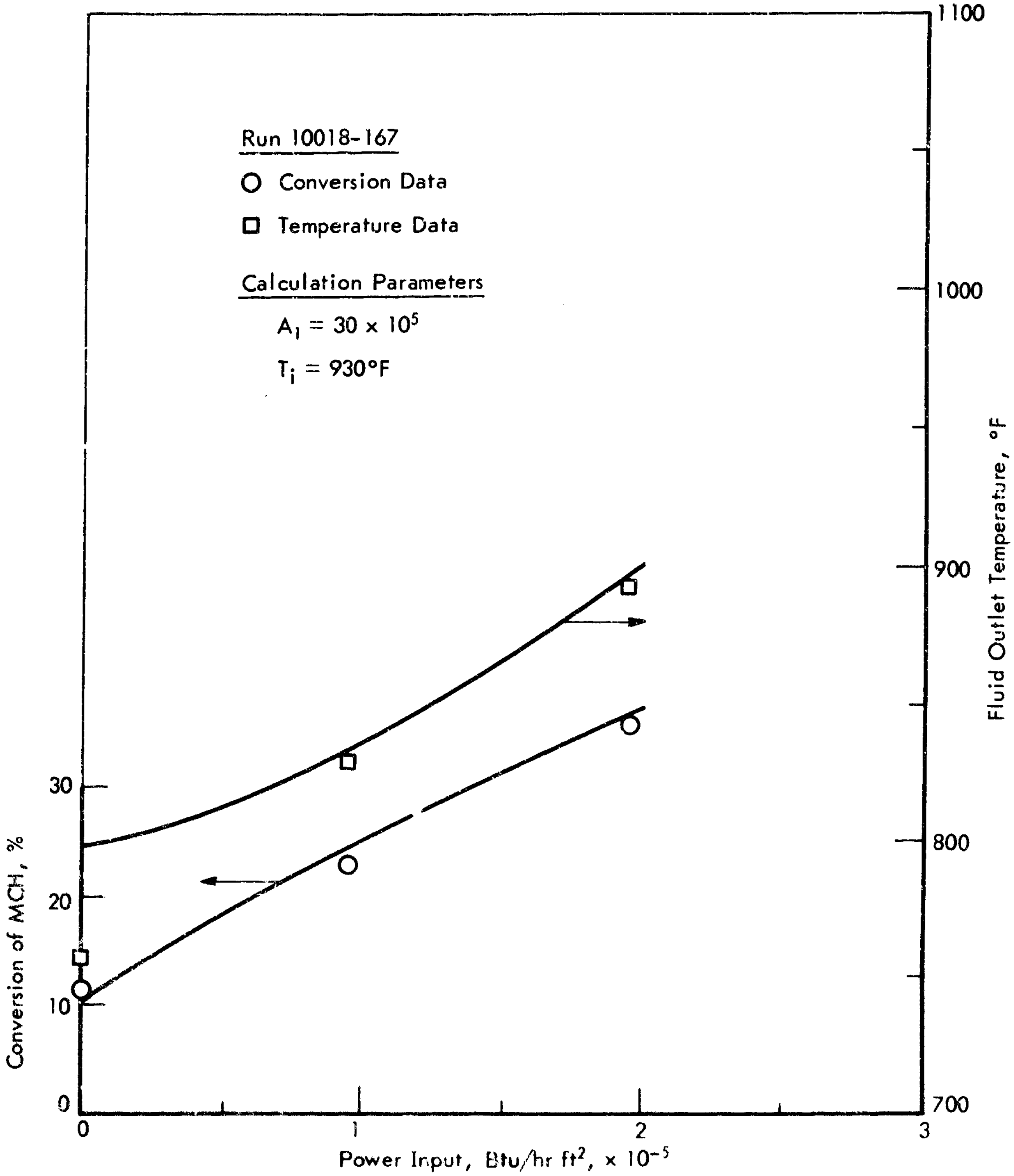


Figure 11. METHYLCYCLOHEXANE DEHYDROGENATION IN A WALL CATALYST

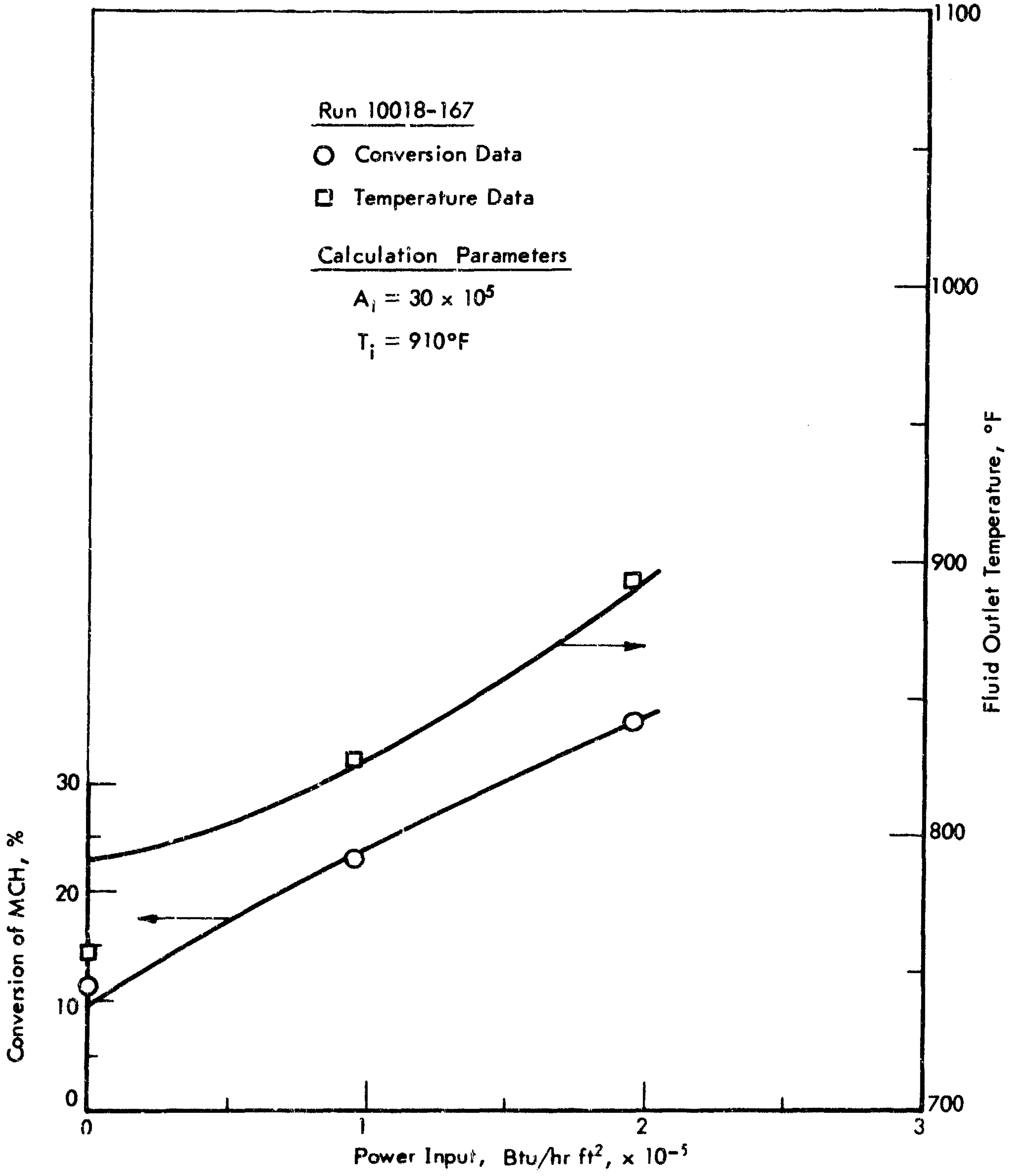


Figure 12. METHYLCYCLOHEXANE DEHYDROGENATION IN A WALL CATALYST

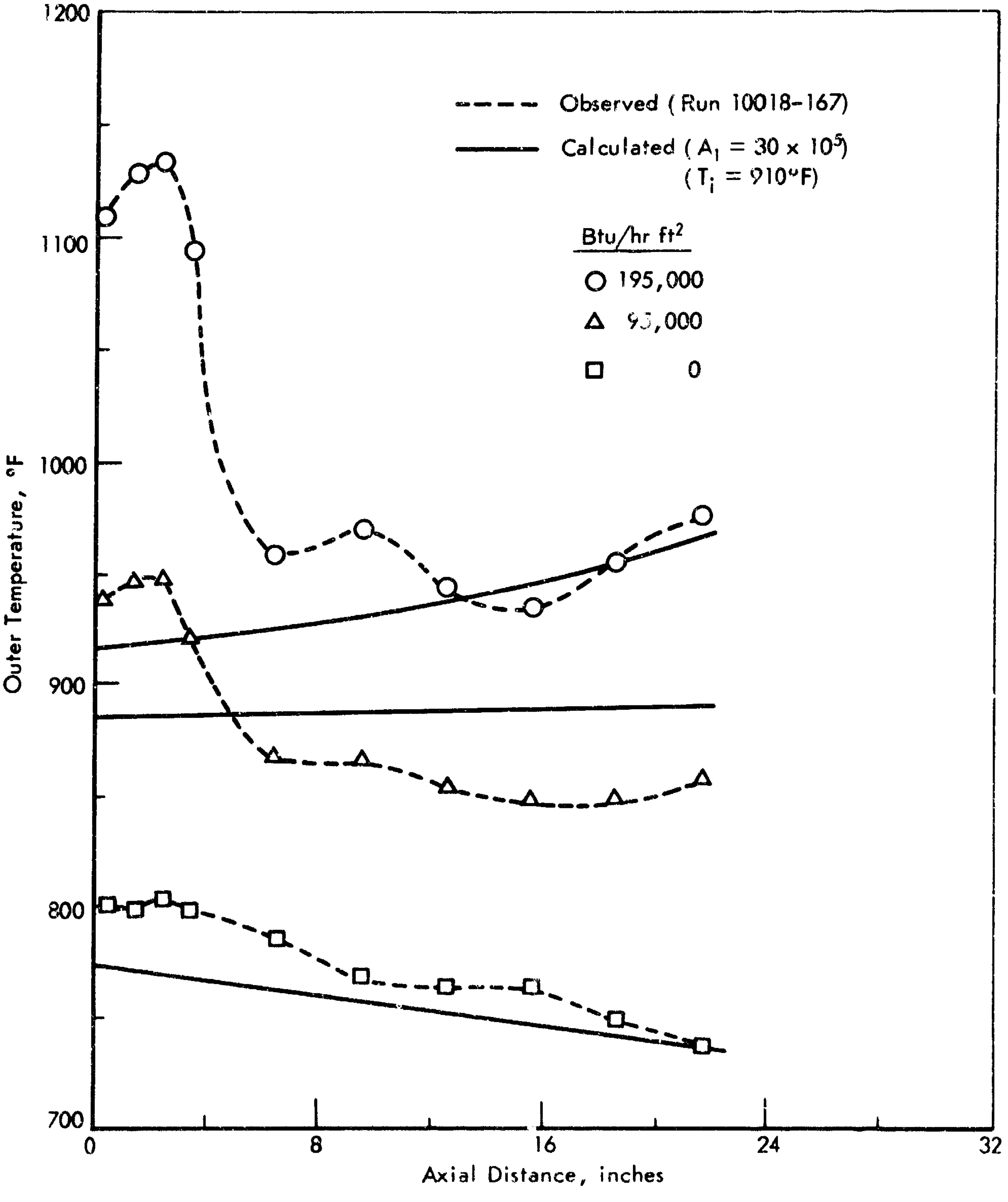


Figure 13. OUTER WALL TEMPERATURES DURING METHYLCYCLOHEXANE DEHYDROGENATION IN A WALL CATALYST

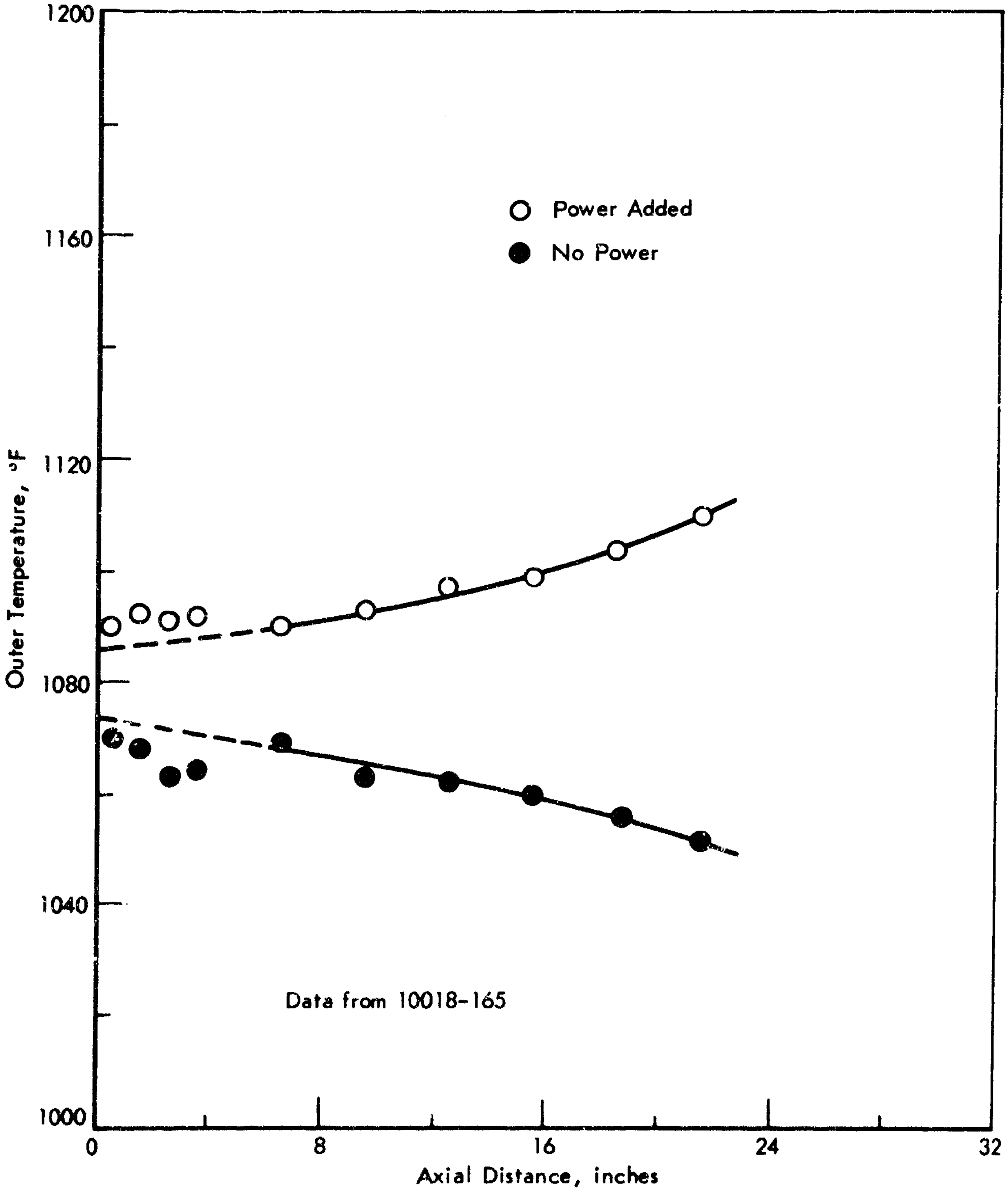


Figure 14. OUTER WALL TEMPERATURES DURING ACTIVATION OF WALL CATALYST

shown in Figure 15. As was expected the temperatures resulting from the radially integrated equation gave a flatter profile (solid curve), reflecting the additional cooling in the region of highest temperature. The profile resulting from the analytical solution in the CWR model, assuming uniform heat sink (dashed line), gave more temperature variation and a higher outer surface temperature.

The average temperature of the catalyst calculated by the radial integration is 900°F, and the reaction rate is 9300 lbmole/hr-ft^3. This corresponds to an error in the CWR model calculation of about 1.2% in the temperature and about 14% in the reaction rate and conversion. The results were obtained by comparison with the experiments at the most extreme conditions we have run. At lower heat fluxes the errors should be less. One solution to this problem would be to integrate radially as well as axially; however, the execution times probably would become excessive. Instead, there may be a way to obtain a better estimate of the average reaction temperature without resorting to this two-dimensional approach.

DEHYDROGENATION OF DECALIN IN THE FUEL SYSTEM SIMULATION TEST RIG

The reactor (3/8" OD x 0.049" wall x 24" long Hastelloy C) used in these tests has been used previously in this program. However, during its last use a leak developed in one of the welds and this had to be repaired. Since several of the attached thermocouples were also damaged, the ceramic coating was completely removed from the tube and all couples were replaced. A sketch of the reactor is given in Figure 16.

The following three test series have been completed using the indicated catalysts charged to the reactor section in the Fuel System Simulation Test Rig (FSSTR).

Series 10018-194	UOP-R8 catalyst (ca 0.8% Pt/ 1/16" Al_2O_3 spheres)
Series 10018-198	Shell 10280-113 catalyst (ca 4% Pt/ 1/16" Al_2O_3 spheres)
Series 11644-6	Shell 10860-146 catalyst (ca 4% Pt/10-20 mesh Al_2O_3)

The normal operating sequence for these tests was as follows:

1) Charge catalyst to reactor and activate by heating in nitrogen for 1 hr at 1100°F.

2) Set feed rate at 25.0 lb/hr (LHSV = 545).

3) Set inlet pressure at 900 psig.

4) Establish inlet temperature at 900°F by preheating feed in two 3/8" OD x 10' long heat exchange sections.

Figures 15 and 16 follow

5) Operate long enough with no power supplied to the reactor to establish steady state conditions. (Outlet fluid temperature was ca 720°F under these conditions.)

6) Supply sufficient power to reactor to raise outlet temperature to 800°F. Maintain power constant for ca 1 hr.

7) Increase power to reach 900°F outlet and run for ca 1 hr at constant power.

8) Increase power to reach 1000°F outlet and run at constant power long enough to establish catalyst activity decline rate.

9) Decrease power to bring outlet temperature down to 800°F again and hold long enough to establish final catalyst activity.

When the outlet temperature is changed to a new value in this operating procedure, the initial power requirement is noted and maintained constant for that particular test period. By following this procedure it is possible to tell when the catalyst activity is decreasing, as a decrease in conversion at constant power input results in an immediate increase in fluid outlet temperature. Of course, product analyses also show the decline in activity, but these are not available until well after a run has been completed.

The three catalysts exhibited quite different characteristics. The UOP-R8 and Shell 113 catalysts had similar initial activity up to 900°F outlet fluid temperature, but the Shell 113 catalyst declined in activity so rapidly at this power input that the outlet temperature had increased to 1000°F at the end of one hour. Hence, no further power increase was made. The Shell 146 catalyst not only had much higher initial activity than either of the other two catalysts but also exhibited superior stability. Figure 17 shows the initial conversion attained by the three catalysts at outlet fluid temperatures up to 900°F before any deactivation had occurred. Table 25 summarizes the conversion and outlet temperature history for the three test runs. Decline in conversion and the accompanying rise in outlet fluid temperature are evident for the three catalysts at power levels sufficient to give 900°F or higher outlet temperatures.

Operating data and product analyses are tabulated and fluid temperatures and decalin conversions are plotted against run time for each of the tests in the following Tables and Figures:

Series 10018-194:	Tables 26 and 27, Figures 18 and 19
Series 10018-198:	Tables 28 and 29, Figures 20 and 21
Series 11644-6:	Tables 30 and 31, Figures 22 and 23

Corresponding data for these three catalysts, or their simulants, are given in Tables 32 and 33 in bench-scale and MICTR equipment. In the bench-scale runs with decalin the Shell 113 prototype catalyst appeared somewhat more active and stable than UOP-R8 catalyst, but the Shell 146 catalyst was considerably

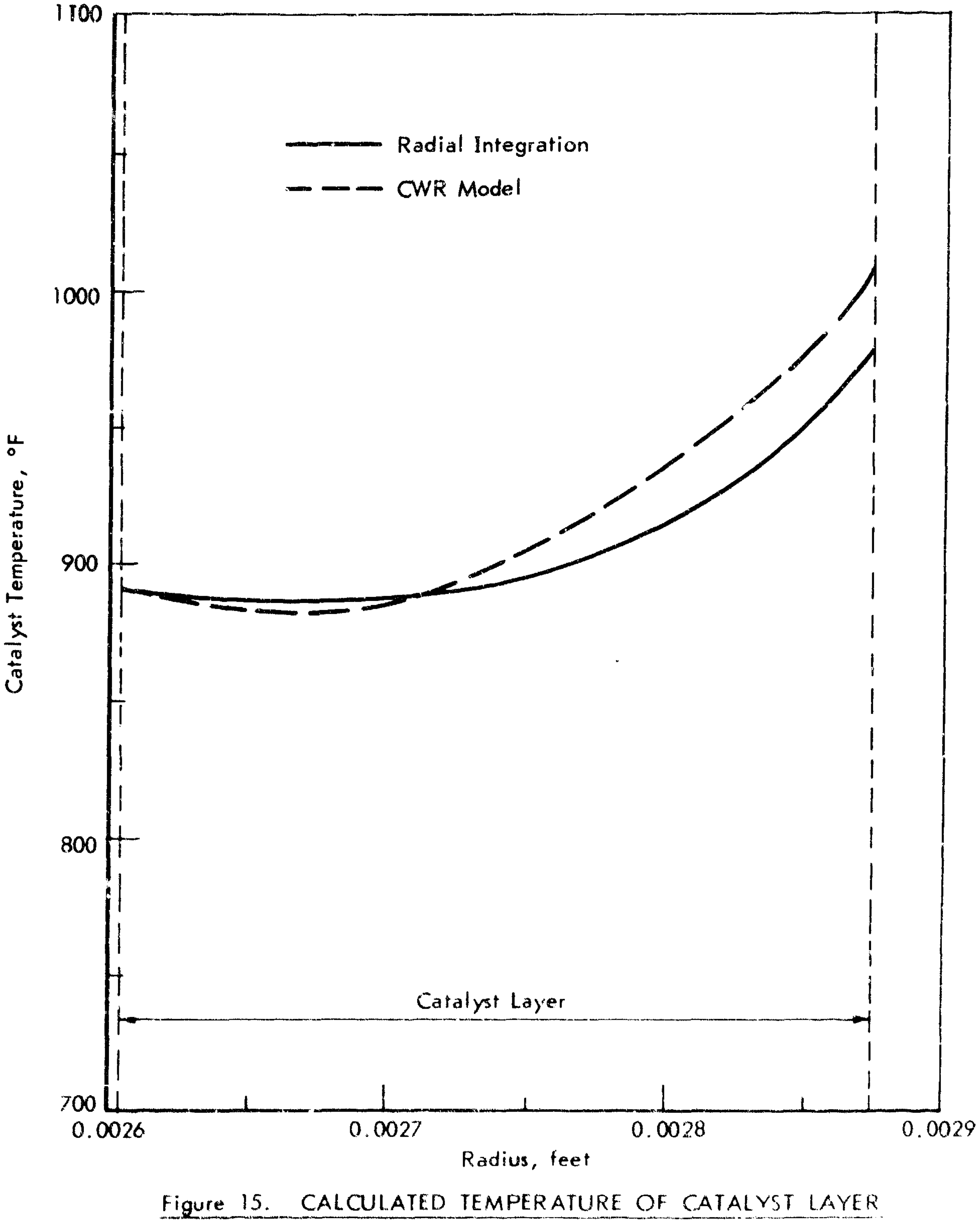
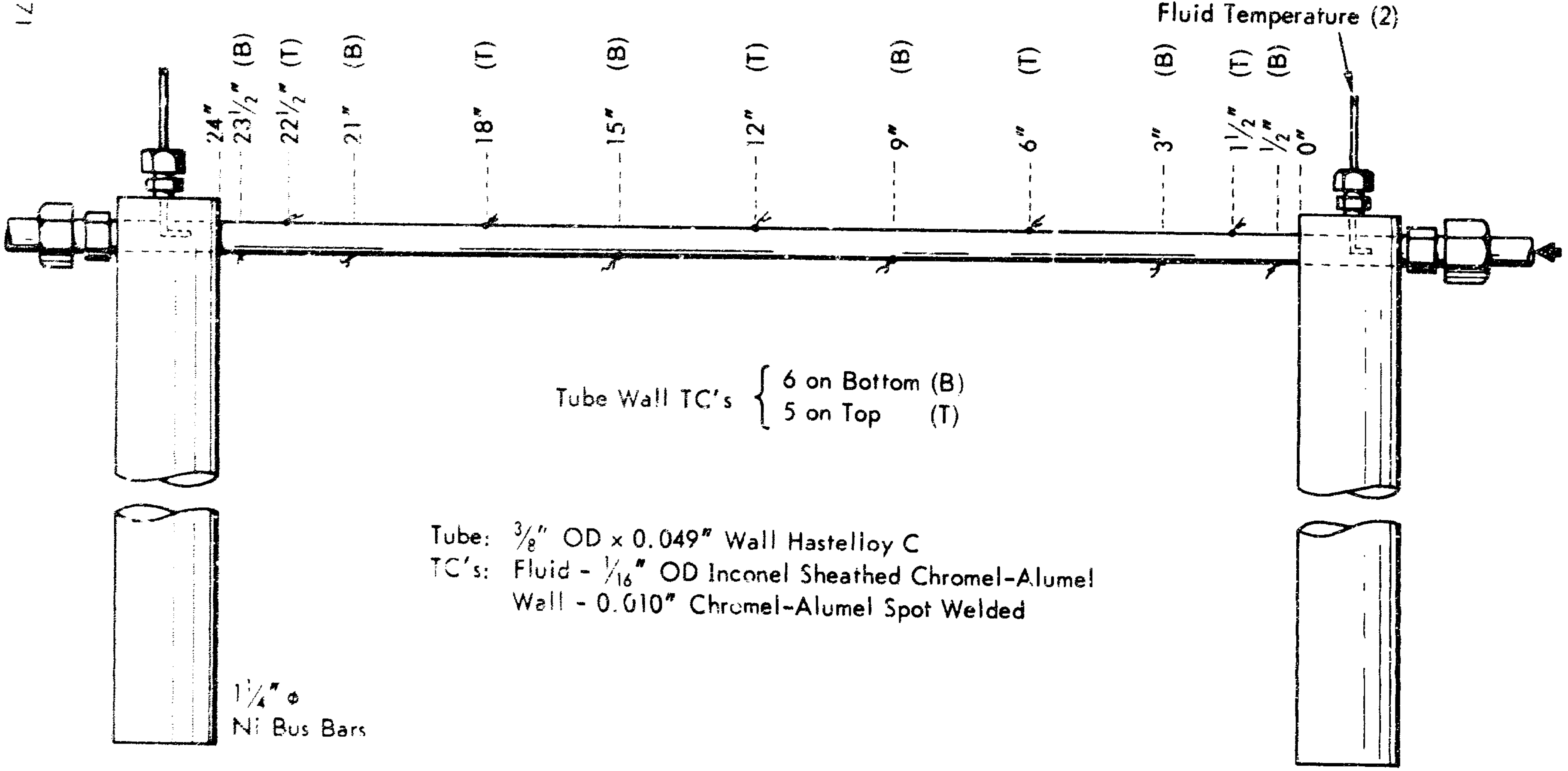


Figure 15. CALCULATED TEMPERATURE OF CATALYST LAYER



Tube Wall TC's { 6 on Bottom (B)
5 on Top (T)

Tube: ⅜" OD × 0.049" Wall Hastelloy C
TC's: Fluid - $\frac{1}{16}$" OD Inconel Sheathed Chromel-Alumel
Wall - 0.010" Chromel-Alumel Spot Welded

Figure 16. FSSTR REACTOR SECTION: 0.277" ID × 2-FT LENGTH

Table 25. FSSTR: DEHYDROGENATION OF DECALIN IN 2-FT REACTOR, SUMMARY OF TESTS WITH THREE CATALYST FORMULATIONS

Reactor: 3/8" O.D. x 0.049" wall x 2 ft long Hastelloy C

Catalysts:		
	UOP-R8	0.8% Pt on 1/16" Al_2O_3 Spheres
	Shell 10280-113	4% Pt on 1/16" Al_2O_3 Spheres
	Shell 10860-146	4% Pt on 10-20 mesh Al_2O_3

Nominal Inlet Conditions

Pressure	900 psig
Temperature	900°F
Feed Rate	25.0 lb/hr (545 LHSV)

Feed:

33.6%	t-DHN
65.8%	C-DHN
0.5%	THN
0.1%	other

Test Series (Catalyst)	Time, Hr:Min	Heat,		Outlet Fluid, °F	DHN Conv'n, %	Selectivity to	
		Btu (hr/ft²)	Btu lb			THN	N
10018-194 (UOP-R8)	11:15 - 11:50	-1,400	-8	723	13.9	85.2	14.8
	12:05 - 12:50	43,200	251	801	32.0	63.1	36.9
	13:10	106,800	620	906	54.5	31.5	68.0
	13:40	"	"	924	52.5	29.2	70.2
	13:50	139,100	807	1001	62.4	17.0	81.4
	14:15	"	"	1038	59.0	16.1	82.2
	14:40	"	"	1051	57.2	16.5	81.8
	15:00 - 15:35	22,600	131	795	20.1	67.9	32.1
10018-198 (Shell 10280-113)	10:35 - 11:05	-1,300	-8	720	14.0	83.8	16.2
	11:25 - 12:05	47,000	273	805	33.6	61.4	38.6
	12:20	104,500	606	927	51.3	28.7	71.3
	13:20	"	"	1000	43.7	21.7	78.3
	14:20	"	"	1054	39.1	19.6	80.4
	14:50 - 15:45	16,300	94	800	14.5	61.4	38.6
11644-6 (Shell 10860-146)	10:35 - 10:45	-1,300	-7	709	16.9	89.8	10.2
	11:10 - 12:15	75,600	439	800	53.0	59.9	40.1
	12:30	150,100	871	916	78.3	22.0	78.0
	13:30	"	"	942	73.3	19.9	80.1
	13:50	176,100	1022	1009	80.7	10.4	89.6
	14:50	"	"	1035	78.3	9.5	90.5
	15:50	"	"	1050	77.3	8.9	91.1
	16:10 - 16:35	38,300	222	794	29.9	66.5	33.5

Table 26 and Figure 17 follow

Table 26. FSSTR: DEHYDROGENATION OF DECALIN OVER UOP-R8 IN 2-FT REACTOR, DATA SUMMARY SERIES 10018-194

Reactor No. 10018-49; 0.277" ID x 0.049" Wall x 2 Ft Long Hastelloy C

Feed: 99.5% Decalin, 0.5% Tetralin;
25.0 lb/hr, 545 LHSV, 59,740 lb/(hr · ft²)

	Experimental Data										Smoothed and Calculated Data					
Run No. 10018-194-	Fluid Temp., °F		Pressure, psig		Decalin Conv'n %	Selectivity, %		Tube Wall T.C.'s			Tube Length, in.	Wall Temp., °F[c]		Heat Flux,[d] Btu/(hr · ft²) x 10⁻³	Cumulative Heat[e]	
	In	Out	In	Out		to Tetralin	to Naphthalene	Location Inches[a]	Location Position[b]	Temp. °F		Outside	Inside		Btu/hr	Btu/lb
1150	901	725	900	884	13.9	85.2	14.8	0.5	B	842	0	(860)	(861)	-1.7	0	0.0
	(Fresh catalyst charge. Activated							1.5	T	830	2	813	814	-1.6	-38	-1.5
	1 hr. in N_2 at 1100°F.)							3	B	798	6	773	774	-1.5	-57	-2.3
								6	T	769	10	753	754	-1.4	-92	-3.7
								9	B	760	14	742	743	-1.4	-126	-5.0
								12	T	745	18	735	736	-1.4	-160	-6.4
								15	B	744	22	730	731	-1.4	-193	-7.7
								18	T	732	24	(728)	(729)	-1.4	-210	-8.4
								21	B	733	(0 - 24)			(-1.45)		
								22.5	T	730						
								23.5	B	731						
1250	905	801	898	866	32.0	63.1	36.9	0.5	B	893	0	(905)	(896)	43.1	0	0
								1.5	T	887	2	868	859	43.1	521	20.8
								3	B	859	6	841	832	43.2	1565	62.6
								6	T	844	10	841	832	43.2	2610	104.4
								9	B	843	14	843	834	43.2	3654	146.2
								12	T	843	18	846	837	43.2	4699	188.0
								15	B	849	22	850	841	43.2	5743	229.7
								18	T	843	24	(852)	(843)	43.2	6265	250.6
								21	B	853	(0-24)			(43.2)		
								22.5	T	849						
								23.5	B	850						
1310	900	906	899	853	54.5	31.5	68.0	0.5	B	953	0	(956)	(934)	106.8	0	0
								1.5	T	950	2	949	927	106.8	1291	51.7
								3	B	946	6	946	924	106.9	3874	155.0
								6	T	944	10	958	936	106.8	6457	258.3
								9	B	956	14	970	948	106.8	9038	361.5
								12	T	969	18	983	961	106.8	11620	464.8
								15	B	980	22	997	975	106.7	14200	568.0
								18	T	980	24	(1003)	(981)	106.7	15490	619.6
								21	B	997	(0 - 24)			(106.8)		
								22.5	T	994						
								23.5	B	999						
1340	903	924	899	853	52.5	29.2	70.2	0.5	B	955	0	(956)	(934)	106.8	0	0
	(Continuation of Run 1310)							1.5	T	950	2	949	927	106.8	1291	51.7
								3	B	946	6	946	924	106.9	3874	155.0
								6	T	743	10	959	937	106.8	6457	258.3
								9	B	956	14	974	952	106.8	9038	361.5
								12	T	968	18	990	968	106.7	11620	464.8
								15	B	982	22	1006	984	106.7	14200	567.9
								18	T	986	24	(1015)	(993)	106.7	15490	619.5
								21	B	1006	(0 - 24)			(106.8)		
								22.5	T	1007						
								23.5	B	1014						
1350	897	1001	899	845	62.4	17.0	81.4	0.5	B	989	0	(987)	(958)	139.2	0	0
								1.5	T	984	2	988	959	139.2	1683	67.3
								3	B	992	6	997	968	139.2	5048	201.9
								6	T	993	10	1016	988	139.2	8413	336.5
								9	B	1012	14	1039	1011	139.1	11780	471.0
								12	T	1031	18	1065	1037	139.0	15140	605.5
								15	B	1050	22	1095	1068	138.9	18500	739.9
								18	T	1061	24	(1111)	(1084)	138.9	20180	807.1
								21	B	1091	(0 - 24)			(139.1)		
								22.5	T	1095						
								23.5	B	1106						
1415	900	1038	900	846	59.0	16.1	82.2	0.5	B	995	0	(989)	(960)	139.2	0	0
	(Continuation of Run 1350)							1.5	T	987	2	990	961	139.2	1683	67.3
								3	B	996	6	999	970	139.2	5048	201.9
								6	T	996	10	1020	992	139.1	8412	336.5
								9	B	1016	14	1050	1022	139.1	11780	471.0
								12	T	1038	18	1082	1055	139.0	15140	605.4
								15	B	1061	22	1121	1094	138.9	18490	739.8
								18	T	1078	24	(1142)	(1116)	138.8	20170	806.9
								21	B	1112	(0 - 24)			(139.1)		
								22.5	T	1124						
								23.5	B	1140						
1440	902	1051	900	848	57.2	16.3	81.8	0.5	B	992	0	(983)	(959)	139.2	0	0
	(Continuation of Run 1350)							1.5	T	984	2	989	960	139.2	1683	67.3
								3	B	995	6	998	969	139.2	5048	201.9
								6	T	994	10	1019	991	139.2	8413	336.5
								9	B	1014	14	1050	1022	139.1	11780	471.0
								12	T	1038	18	1087	1060	139.0	15140	605.4
								15	B	1063	22	1130	1103	138.9	18490	739.7
								18	T	1082	24	(1152)	(1126)	138.8	20170	806.9
								21	B	1120	(0 - 24)			(139.1)		
								22.5	T	1134						
								23.5	B	1150						
1550	910	795	890	854	20.1	67.9	32.1	0.5	B	876	0	(894)	[illegible]	22.4	0	0
								1.5	T	866	2	845	840	22.5	272	10.9
								3	B	832	6	805	800	22.6	818	32.7
								6	T	807	10	796	795	22.7	1366	54.6
								9	B	801	14	800	795	22.7	1914	76.6
								12	T	796	18	807	802	22.6	2461	98.5
								15	B	[illegible]	22	816	813	22.6	[illegible]	120.5
								18	T	805	24	(824)	(819)	22.6	3281	131.3
								21	B	817	(0 - 24)			(22.6)		
								22.5	T	[illegible]						
								23.5	B	822						

[a] T.C.'s spotwelded to outside wall at indicated inches from inlet end bus bar.
[b] Position of T.C. junction on horizontal tube. B = Bottom, T = Top.
[c] Outside wall temperatures by smoothing experimental data. Inside temperatures by calculation.
[d] Corrected for losses. Values in ( ) are average over entire heated length.
[e] Net heat to fluid up to indicated tube length.

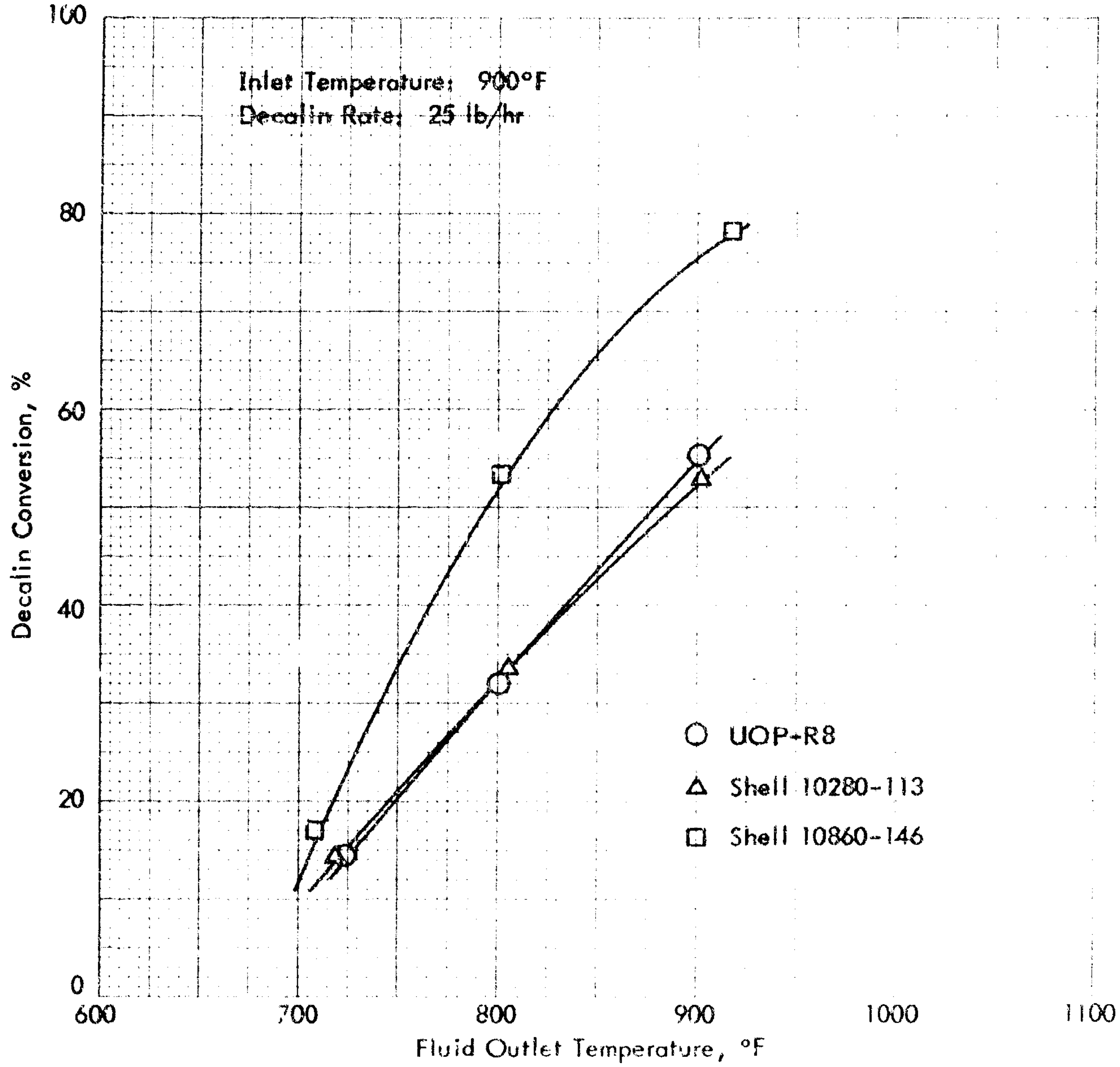


Figure 17. FSSTR: DEHYDROGENATION OF DECALIN IN 2-FT REACTOR, INITIAL ACTIVITY OF THREE CATALYST FORMULATIONS

Table 27. FSSTR: DEHYDROGENATION OF DECALIN OVER SHELL 10860-146 IN 2-FT REACTOR, PRODUCT ANALYSES FOR SERIES 11644-6

Time	Product Composition, %w			
	t-Decalin	c-Decalin	Tetralin	Naphthalene
10:35 - 10:45 1)	51.6	31.6	15.0	1.6
11:10 - 12:15 1)	35.7	12.5	31.6	20.2
12:30 2)	17.7	5.1	17.8	59.4
13:30 2)	20.8	7.1	15.1	57.0
13:50 2)	15.1	5.3	9.0	70.6
14:50 2)	16.3	6.5	8.0	69.2
15:50 2)	16.8	7.1	7.4	68.7
16:10 - 16:35 1)	41.6	29.5	19.5	9.5
Feed	33.6	65.9	0.5	

1) Average values over indicated time period.
2) Smoothed data.

Figures 18 and 19 and Table 28 follow

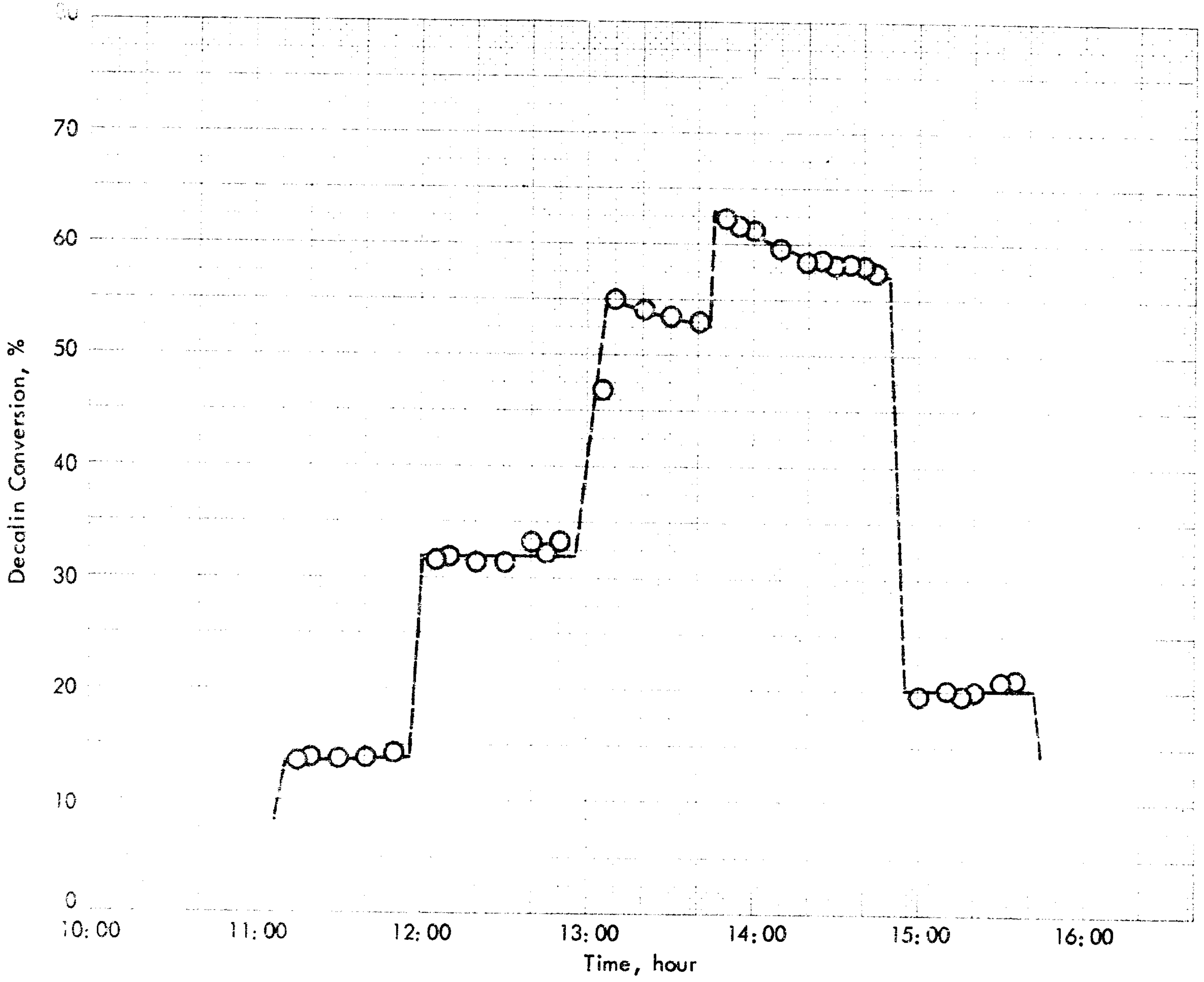


Figure 18. FSSTR: DEHYDROGENATION OF DECALIN OVER UOP-R8 IN 2-FT REACTOR, DECALIN CONVERSION, SERIES 10018-194

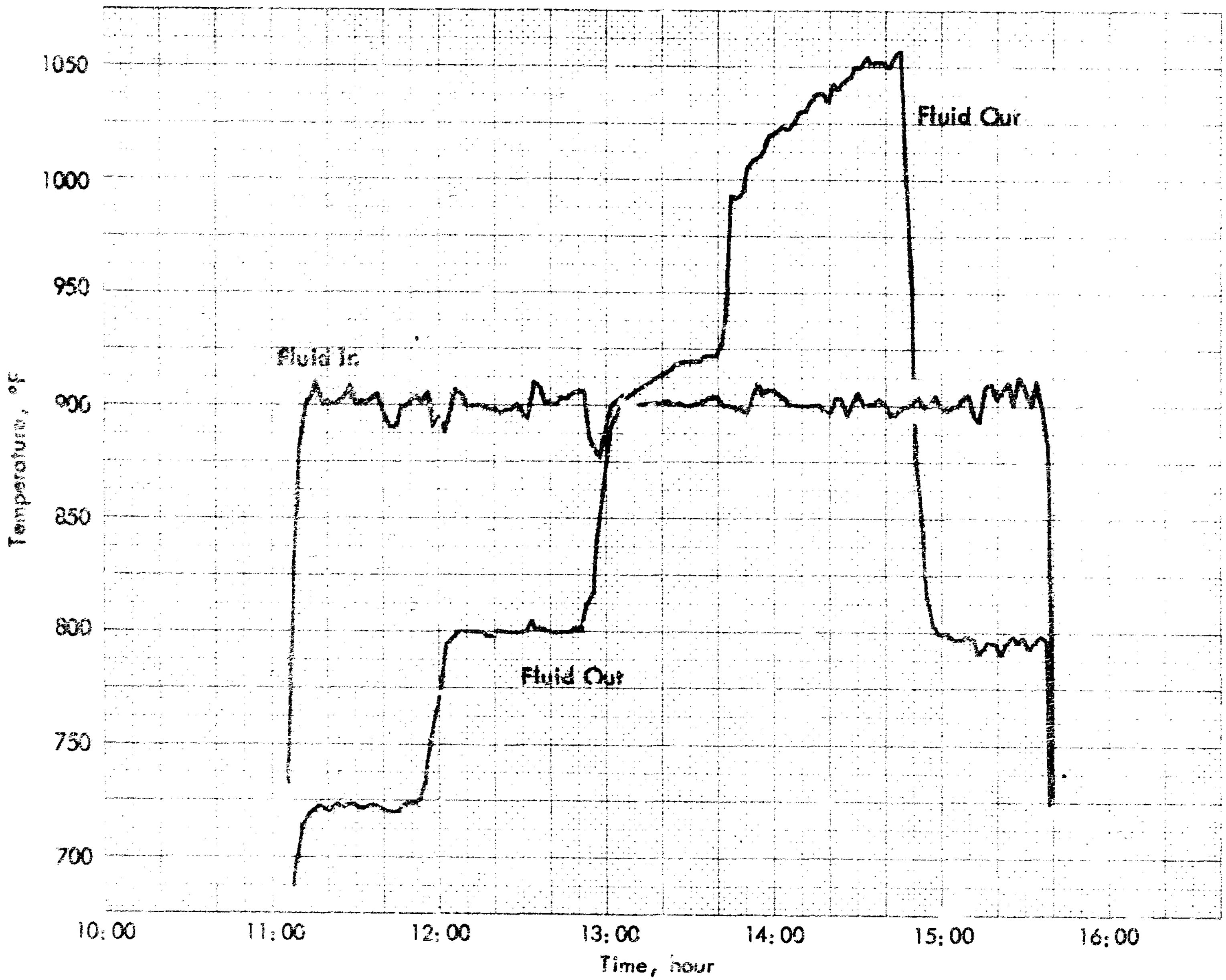


Figure 19. FSSTR: DEHYDROGENATION OF DECALIN OVER UOP-R8 IN 2-FT REACTOR, FLUID TEMPERATURES, SERIES 10018-194

Table 28. FSSTR: DEHYDROGENATION OF DECALIN OVER SHELL 10280-113 IN 2-FT REACTOR, DATA SUMMARY SERIES 10018-198

Reactor No. 10018-49; 0.277" ID x 0.049" Wall x 2 Ft Long Hastelloy C

Feed: 99.5% Decalin, 0.5% Tetralin;
25.0 lb/hr, 545 LHSV, 59,740 lb/(hr · ft²)

Run No. 10018-198-	Experimental Data										Smoothed and Calculated Data					
	Fluid Temp., °F		Pressure, psig		Decalin Conv'n %	Selectivity, %		Tube Wall T.C.'s			Tube Length, In.	Wall Temp., °F[c]		Heat Flux,[d] Btu/(hr · ft²) x 10⁻³	Cumulative Heat[e]	
	In	Out	In	Out		to Tetralin	to Naphthalene	Location Inches[a]	Location Position[b]	Temp. °F		Outside	Inside		Btu/hr	Btu/lb
1100	906	720	900	885	14.0	83.8	16.2	0.5	B	850	0	(895)	(896)	-1.6	0	0
	(Fresh Catalyst Charge. Activated 1 hr in H_2 at 1100°F.)							1.5	T	849	2	821	822	-1.5	-18	-0.7
								3	B	800	6	775	776	-1.3	-52	-2.1
								6	T	771	10	754	755	-1.3	-84	-3.4
								9	B	760	14	741	742	-1.3	-115	-4.6
								12	T	743	18	733	734	-1.3	-145	-5.8
								15	B	742	22	729	730	-1.2	-175	-7.0
								18	T	731	24	(728)	(729)	-1.2	-190	-7.6
								21	B	731	(0 - 24)			(-1.31)		
								22.5	T	728						
								23.5	B	750						
1200	895	805	898	865	33.6	61.4	38.6	0.5	B	900	0	(924)	(914)	46.9	0	0
								1.5	T	898	2	883	873	47.0	568	22.7
								3	B	867	6	856	846	47.1	1704	68.2
								6	T	856	10	849	839	47.1	2842	113.7
								9	B	849	14	848	838	47.1	3980	159.2
								12	T	848	18	850	840	47.1	5117	204.7
								15	B	850	22	854	844	47.1	6255	250.2
								18	T	847	24	(856)	(846)	47.1	6824	272.9
								21	B	854	(0 - 24)			(47.0)		
								22.5	T	855						
								23.5	B	856						
1220	903	927	896	852	51.3	28.7	71.3	0.5	B	974	0	(989)	(968)	104.4	0	0
								1.5	T	967	2	962	940	104.5	1265	50.5
								3	B	956	6	956	934	104.5	3790	151.6
								6	T	956	10	961	939	104.5	6316	252.6
								9	B	962	14	974	952	104.5	8842	353.7
								12	T	968	18	993	972	104.4	11370	454.7
								15	B	980	22	1014	993	104.4	13690	555.7
								18	T	990	24	(1026)	(1005)	104.4	15150	606.1
								21	B	1007	(0 - 24)			(104.5)		
								22.5	T	1020						
								23.5	B	1023						
1320	894	1000	896	852	43.7	21.7	78.3	0.5	B	968	0	(973)	(951)	104.5	0	0
	(Continuation of Run 1220)							1.5	T	965	2	961	939	104.5	1255	50.5
								3	B	958	6	962	940	104.5	3790	151.6
								6	T	962	10	976	954	104.5	6316	252.6
								9	B	973	14	1000	979	104.4	8840	353.6
								12	T	986	18	1032	1011	104.3	11360	454.5
								15	B	1008	22	1072	1051	104.2	13890	555.4
								18	T	1029	24	(1092)	(1072)	104.2	15140	605.8
								21	B	1059	(0 - 24)			(104.4)		
								22.5	T	1078						
								23.5	B	1087						
1420	897	1054	896	852	39.1	19.6	80.4	0.5	B	974	0	(981)	(959)	104.5	0	0
	(Continuation of Run 1220)							1.5	T	969	2	966	944	104.5	1263	50.5
								3	B	965	6	970	948	104.5	3789	151.6
								6	T	970	10	991	970	104.4	6314	252.6
								9	B	987	14	1021	1000	104.4	8838	353.5
								12	T	1009	18	1063	[illegible]	104.3	11360	454.4
								15	B	1039	22	1113	[illegible]	104.1	13880	555.2
								18	T	1062	24	(1140)	[illegible]	104.1	15140	605.5
								21	B	1099	(0 - 24)			(104.4)		
								22.5	T	1125						
								23.5	B	1134						
1540	896	800	895	868	14.5	61.4	38.6	0.5	B	872	0	(920)	(917)	16.0	0	0
								1.5	T	868	2	851	848	16.2	195	7.8
								3	B	855	6	810	807	16.3	587	23.5
								6	T	810	10	798	795	16.3	981	39.2
								9	B	800	14	797	794	16.3	1375	55.0
								12	T	795	18	804	801	16.3	1769	70.8
								15	B	800	22	816	813	16.3	2162	86.5
								18	T	801	24	(824)	(821)	16.2	2359	94.3
								21	B	814	(0 - 24)			(16.3)		
								22.5	T	817						
								23.5	B	821						

a) T.C.'s spotwelded to outside wall at indicated inches from inlet and bus bar.
b) Location of T.C. junction on horizontal tube. B = Bottom, T = Top.
c) Outside wall temperatures by smoothing experimental data. Inside temperatures by calculation.
d) Corrected for losses. Values in ( ) are average over entire heated length.
e) Net heat to fluid up to indicated tube length.

Table 29. FSSTR: DEHYDROGENATION OF DECALIN OVER SHELL 10280-113 IN 2-FT REACTOR, PRODUCT ANALYSES FOR SERIES 10018-198

Time	Product Composition %w			
	t-Decalin	c-Decalin	Tetralin	Naphthalene
10:35 - 11:05[1]	43.0	43.2	11.7	2.1
11:25 - 12:05[1]	35.7	31.6	20.5	12.2
12:20[2]	26.1	24.0	15.0	34.9
13:20[2]	26.8	30.9	9.8	32.5
14:20[2]	27.2	35.0	8.0	29.8
14:50 - 15:45[1]	35.8	50.0	9.0	5.2
Feed	33.6	65.9	0.5	

1) Average values over indicated time period.
2) Smoothed data.

Figures 20 and 21 and Table 30 follow

Table 30. FSSTR: DEHYDROGENATION OF DECALIN OVER SHELL 10860-146 IN 2-FT REACTOR, DATA SUMMARY SERIES 11644-6

Reactor No. 10018-49; 0.277" ID x 0.049" Wall x 2 Ft Long Hastelloy C

Feed: 99.5% Decalin, 0.5% Tetralin;
25.0 lb/hr, 545 LHSV, 59,740 lb/(hr · ft²)

	Experimental Data										Smoothed and Calculated Data					
Run No. 11644-6-	Fluid Temp., °F		Pressure, psig		Decalin Conv'n %	Selectivity, %		Tube Wal			Tube Length, In.	Wall Temp., °F[c]		Heat Flux,[d] $\frac{Btu}{(hr \cdot ft^2)} \times 10^{-3}$	Cumulative Heat[e]	
	In	Out	In	Out		to Tetralin	to Naphthalene	Location Inches[a]	Posit	emp. °F		Outside	Inside		Btu/hr	Btu/lb
1045	906	709	900	825	16.9	89.8	10.2	0.5	B	[illegible]	0	(900)	(901)	-1.6	0	0
	(Fresh Catalyst Charge. Activated 1 hr in N_2 at 1100°F.)							1.5	T		2	782	783	-1.4	-17	-0.7
								3	B		6	745	746	-1.3	-49	-2.0
								6	T	[illegible]	10	730	731	-1.2	-80	-3.2
								9	B	[illegible]	14	722	723	-1.2	-109	-4.4
								12	T	[illegible]	18	718	719	-1.2	-139	-5.6
								15	B	[illegible]	22	716	717	-1.2	-168	-6.7
								18	T	715	24	(716)	(717)	-1.2	-183	-7.3
								21	B	717	(- 24)			(-1.26)		
								22.5	T	[illegible]						
								23.5	B							
1200	900	800	900	795	[illegible]	59.9	[illegible]		B		0	(980)	(965)	75.3	0	0
									-		2	882	866	75.5	912	36.5
								3	B		6	845	828	75.6	2740	109.6
								6	T		10	842	825	75.6	4568	182.7
								9	B	[illegible]		847	830	75.6	6396	255.9
								12	T	[illegible]	18	857	840	75.6	8224	329.0
								15	B	858	22	871	855	75.6	10050	402.1
								18	T	857	24	(878)	(862)	75.6	10970	438.6
								21	B	871	(0 - 24)			(75.6)		
								22.5	T	871						
								23.5	B	872						
1230	904	916	902	741	78.3	22.0	78.0	0.5	B	1019	0	(1050)	(1020)	149.9	0	0
								1.5	T	980	2	973	942	150.1	1813	72.5
								3	B	960	6	942	910	150.2	5443	217.7
								6	T	941	10	943	911	150.2	9073	362.9
								9	B	940	14	959	927	150.1	12700	508.1
								12	T	951	18	985	954	150.1	16330	653.2
								15	B	976	22	1019	988	150.0	19960	798.3
								18	T	984	24	(1053)	(1008)	149.9	21770	870.8
								21	B	1014	(0 - 24)			(150.1)		
								22.5	T	1025						
								23.5	B	1031						
1330	899	942	902	741	73.3	19.9	80.1	0.5	B	1015	0	(1050)	(1020)	149.9	0	0
	(Continuation of Run 1230)							1.5	T	979	2	973	942	150.1	1813	72.5
								3	B	960	6	942	910	150.2	5443	217.7
								6	T	942	10	946	914	150.2	9073	362.9
								9	B	941	14	967	936	150.1	12700	508.1
								12	T	955	18	1000	969	150.0	16330	653.2
								15	B	983	22	1041	1011	149.9	19950	798.2
								18	T	998	24	(1064)	(1034)	149.9	21770	870.7
								21	B	1053	(0 - 24)			(150.1)		
								22.5	T	1048						
								23.5	B	1055						
1350	899	1009	903	718	30.7	10.4	89.6	0.5	B	1046	0	(1070)	(1035)	176.0	0	0
								1.5	T	1003	2	997	961	176.2	2129	85.1
								3	B	991	6	973	936	176.2	6388	255.5
								6	T	973	10	978	941	176.2	10650	426.0
								9	B	973	14	1005	969	176.2	14910	596.3
								12	T	990	18	1049	1014	176.1	19170	766.6
								15	B	1027	22	1107	1073	175.9	23420	936.8
								18	T	1048	24	(1139)	(1105)	175.8	25550	1021.8
								21	B	1092	(0 - 24)			(176.1)		
								22.5	T	1114						
								23.5	B	1127						
1450	900	1035	903	716	78.3	9.5	90.5	0.5	B	1048	0	(1070)	(1035)	176.0	0	0
	(Continuation of Run 1350)							1.5	T	1005	2	1001	965	176.2	2129	85.1
								3	B	992	6	974	937	176.2	6388	255.5
								6	T	975	10	984	947	176.2	10650	425.9
								9	B	977	14	1013	977	176.2	14910	596.3
								12	T	998	18	1062	1027	176.0	19160	766.6
								15	B	1038	22	1124	1090	175.9	23420	936.7
								18	T	1062	24	(1160)	(1127)	175.8	25540	1021.7
								21	B	1110	(0 - 24)			(176.1)		
								22.5	T	1135						
								23.5	B	1148						
1550	901	1050	903	718	77.3	8.9	91.1	0.5	B	1049	0	(1070)	(1035)	176.0	0	0
	(Continuation of Run 1350)							1.5	T	1007	2	1003	967	176.2	2129	85.1
								3	B	997	6	982	945	176.2	6388	255.5
								6	T	982	10	989	952	176.2	10650	425.9
								9	B	982	14	1019	985	176.1	14910	596.3
								12	T	1003	18	1070	1035	176.0	19160	766.5
								15	B	1045	22	1140	1106	175.8	23420	936.6
								18	T	1070	24	(1179)	(1146)	175.7	25540	1021.6
								21	B	1121	(0 - 24)			(176.1)		
								22.5	T	1150						
								23.5	[illegible]	1165						
1530	900	794	901	825	29.9	66.5	33.5	0.5	B	[illegible]	0	(952)	(944)	58.0	0	0
								1.5	T	878	2	843	[illegible]	58.2	461	18.4
								3	B	[illegible]	[illegible]	795	784	58.3	1387	55.5
								6	T	796	[illegible]	787	778	58.4	2314	92.6
								9	B	785	14	795	786	58.5	3241	129.6
								12	T	789	18	810	802	58.5	4167	166.7
								15	B	805	22	[illegible]	821	58.5	5093	203.7
								18	T	809	24	[illegible]	[illegible]	58.2	5555	222.2
								21	B	828	(0 - 24)			[illegible]		
								22.5	T	850						
								23.5	B	854						

a) T.C.'s spotwelded to outside wall at indicated inches from inlet and bus bar.
b) Location of T.C. junction on horizontal tube. B = Bottom, T = Top.
c) Outside wall temperatures by smoothing experimental data. Inside temperatures by calculation.
d) Corrected for losses. Values in ( ) are average over entire heated length.
e) Net heat to fluid up to indicated tube length.

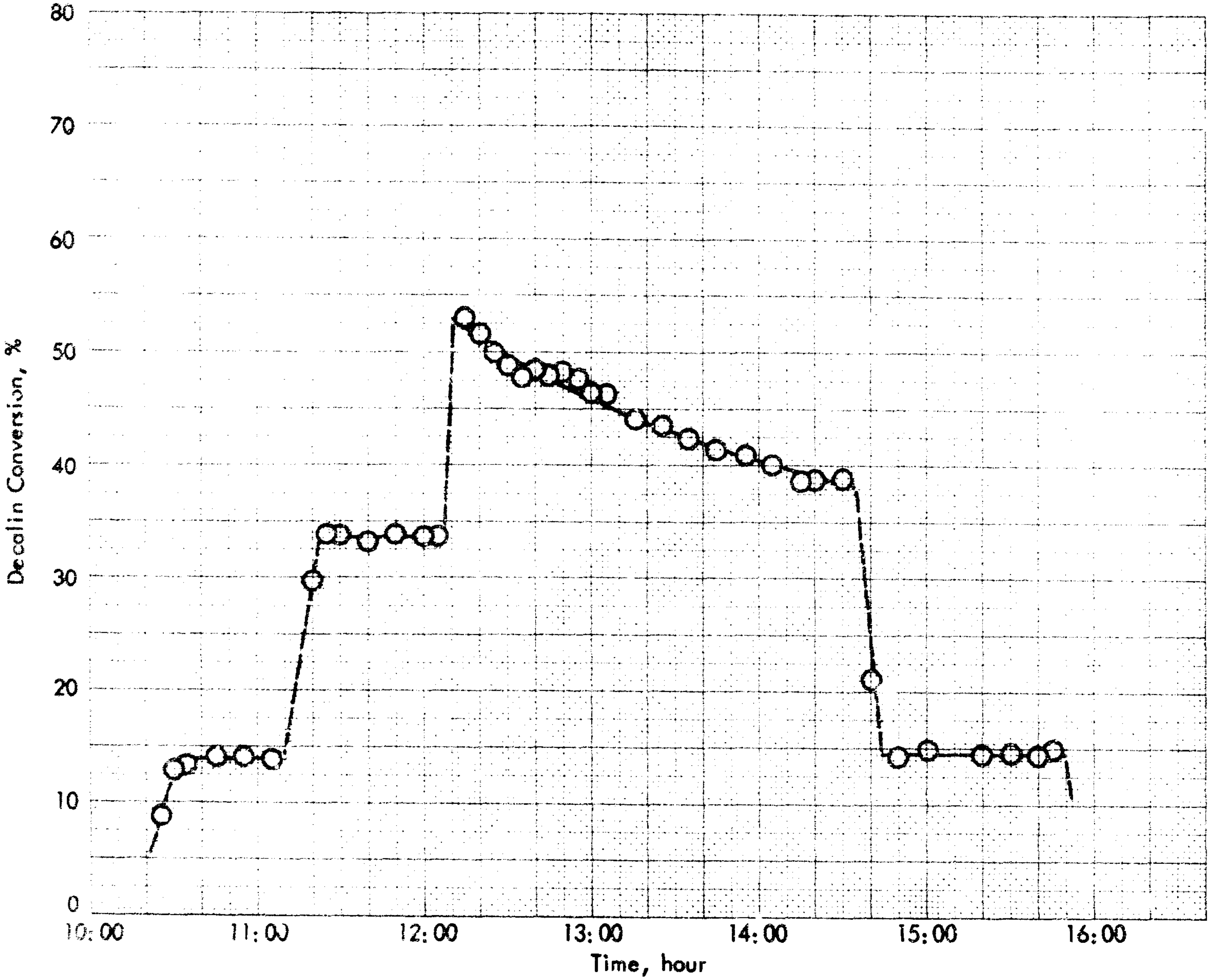


Figure 20. FSSTR: DEHYDROGENATION OF DECALIN OVER SHELL 10280-113 IN 2-FT REACTOR, DECALIN CONVERSION, SERIES 10018-198

66504

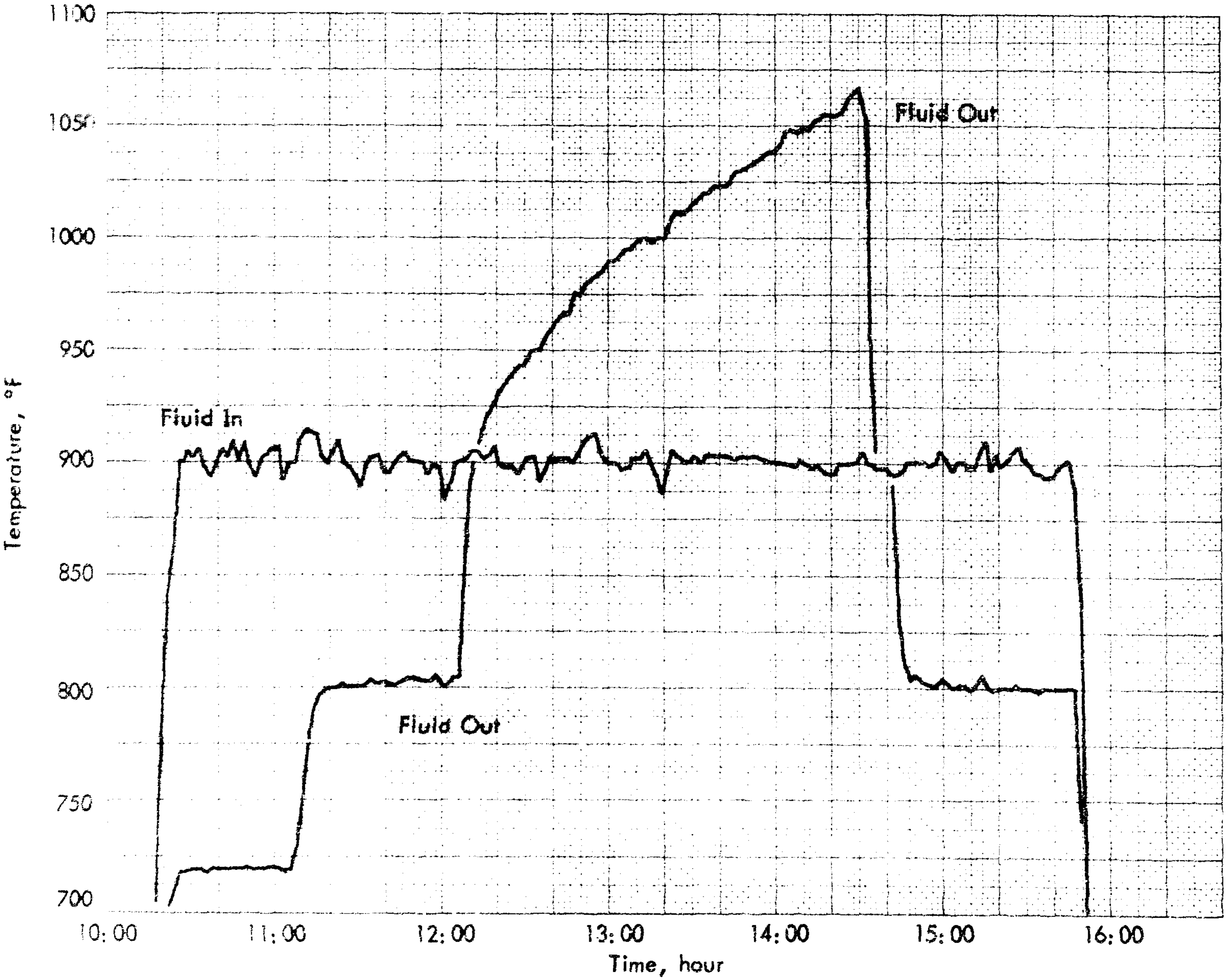


Figure 21. FSSTR: DEHYDROGENATION OF DECALIN OVER SHELL 10280-113 IN 2-FT REACTOR, FLUID TEMPERATURES, SERIES 10018-198

Table 31. FSSTR: DEHYDROGENATION OF DECALIN OVER UOP-R8 IN 2-FT REACTOR, PRODUCT ANALYSES FOR SERIES 10018-194

Time	Product Composition, %w				
	t-Decalin	c-Decalin	Tetralin	Naphthalene	Unknown
11:15 - 11:50 1)	43.4	42.9	11.8	1.9	0
12:05 - 12:50 1)	36.7	32.1	20.1	11.1	0
13:10 2)	26.0	20.9	17.4	35.4	0.3
13:40 2)	26.6	22.3	15.6	35.2	0.3
13:50 2)	21.1	18.0	11.0	48.9	1.0
14:15 2)	22.0	20.5	9.9	46.6	1.0
14:40 2)	22.6	21.7	9.8	44.8	1.0
15:00 - 15:35 1)	38.8	41.5	13.6	6.0	0
Feed	33.6	65.9	0.5		

1) Average values over indicated time period.
2) Smoothed data.

Figures 22 and 23 follow

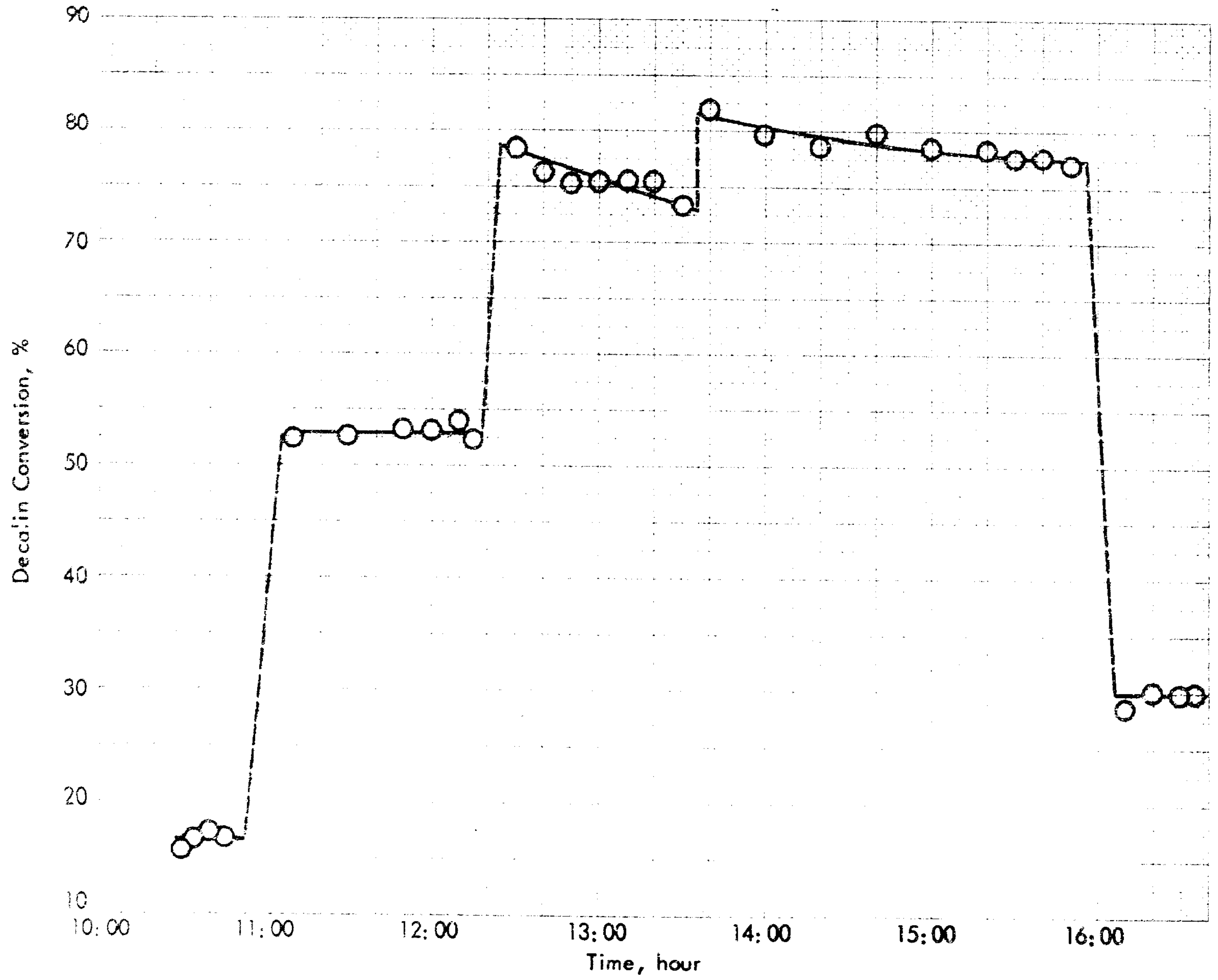


Figure 22. FSSTR: DEHYDROGENATION OF DECALIN OVER SHELL 10860-146 IN 2-FT REACTOR, DECALIN CONVERSION, SERIES 11644-6

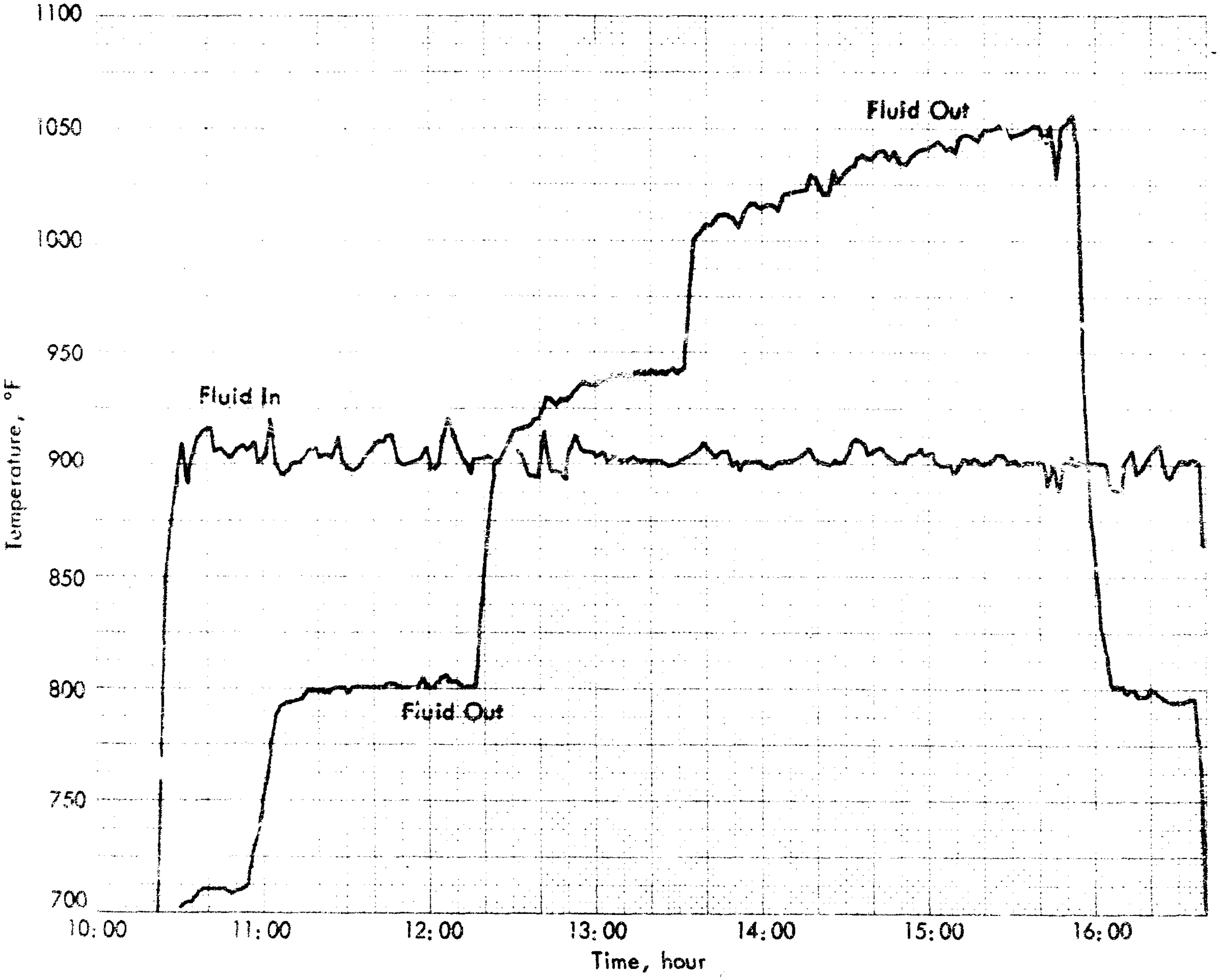


Figure 23. FSSTR: DEHYDROGENATION OF DECALIN OVER SHELL 10860-146 IN 2-FT REACTOR, FLUID TEMPERATURES, SERIES 11644-6

Table 32. DEHYDROGENATION OF DECALIN OVER VARIOUS CATALYSTS

Feed: F-115 DHN
Feed Composition:
25.0% trans DHN
74.5% cis DHN
0.4% THN

Pressure: 10 atm
LHSV: 100
Reaction Period: 30 minutes

Reactor: Bench Scale, 5" bed in 1/2" IPS SS tubing furnace heated.

	% DHN Conversion at, °F					ΔT, °F of Catalyst Bed at, °F				
Catalyst	842	932	1022	1112	1202	842	932	1022	1112	1202
10860-146	43.7	58.3	62.2	71.2	84.1[a]	3	5	13	18	66[a]
UOP-R8	36.2	43.9	47.7[b]	-	-	14	43	160[b]	-	-
10280-107B[c]	39.1	46.7	54.2	61.5	66.5	11	25	34	56	160
10280-91A[c]	39.0	46.1	54.9	61.6	68.8	13	22	36	50	205

a) Reaction time: 10 minutes.
b) Catalyst completely deactivated at the end of this run.
c) 10280-113 prototype.

Table 33. ACTIVITIES OF CATALYSTS 10280-113 AND 10860-146 FOR METHYLCYCLOHEXANE DEHYDROGENATION AT SEVERAL TEMPERATURES

Conditions: MCH, LHSV 100, 10 atm pressure, furnace heated
Reactor: MICTR 4-1/4" bed in 1/4" O.D. S.S. Tubing, catalyst diluted 0.9/1.1 with quartz chips

Catalyst No.	% Pt	Support		Average Conversion of MCH to Toluene, %w			
		Type	Mesh Size	Run No.	662	752	842°F
10860-70	1	UOP-R8 type Al_2O_3	-10	1166	24	45	71
10280-113	4	1	9-16	1108	20	43	69
10860-146	4	1	10-20	1177	53	59	86

better than either the UOP-R8 or Shell 113 catalysts. Thus the FSSTR data confirms these finding in general. The lesser activity/stability of the Shell 113 catalyst compared to UOP-R8 catalyst in the FSSTR compared to the results with the prototypes may be due to some misadventure in the makeup of the large batch prepared for FSSTR evaluation; this will be rechecked. In the MICTR the comparison involves MCH rather than decalin, but the order of activity bears out the results found in the FSSTR with decalin.

THERMAL STABILITY OF FUELS

Thermal stability studies have progressed along several lines during the past year. One of the chief advances has been in the completion of the prototype beta-ray backscatter rig for measuring deposits. This device, although still undergoing evaluation and testing, has been used successfully on standard ASTM, SD/M-7, and JFTOT Coker tubes. It has also been used in measuring the deposit thicknesses on titanium strips from experimental fuel tanks at Boeing Aircraft Company.

The characterization of candidate fuels requires the development of suitable apparatus to characterize routinely the behavior of the fuel at high temperature and pressure in both the absence and presence of endothermic reaction. To provide a method of so characterizing fuels, we developed and put into operation during the last contract period a piece of equipment, the Catalyst and Fuel System Test Rig (CAFSTR), capable of evaluating a fuel/catalyst combination to a maximum temperature of about 1300°F. However, a major difficulty in the utilization of this apparatus was the determination of the amount of deposit on the heating tubes, which, because of the high temperatures involved, could not be fabricated of aluminum and rated visually as is done with tubes from the ASTM Coker. Now that the beta-ray backscatter device is available, we shall be able to start fuel evaluations with the CAFSTR, in which Inconel 600 heater tubes are used. Because of color changes of the metal itself, color rating of the Inconel tubes is impossible and deposits from this equipment could not be evaluated in the past.

Further progress in thermal stability testing has been achieved, in that the JFTOT fuel tester is now complete and operative, and a number of tests have been made. The rig has been found to be delightfully simple and rapid to use, but does seem to have a high temperature limitation. This can probably be solved, however.

No further changes have been made on the SD/M-7 fuel coker, except that a Beckman Oxygen Analyzer has now been installed and is functioning properly.

Various thermal stability investigations have been made including brief studies of hydrocrackate fuels and current commercial Jet-A type fuels. In addition, we have been exploring a new class of potential additives for improving thermal stability of fuels. Several additives have been found to be effective, although tests to date have shown that they are beneficial only in fuels containing dissolved oxygen, the benefits from the additive being substantially the same as those from nitrogen sparging of the fuel. This suggests, of course, that the additives directly interfere with the degradation mechanisms in which oxygen is a participant.

Measurement of Deposits by Beta-Ray Backscatter

After a broad investigation of possible ways to measure fuel coker deposits quantitatively, a prototype beta-ray backscatter test rig was built for this purpose. This equipment[a] has been completed to an operational stage, and its characteristics and capabilities are now being evaluated. A photograph of the apparatus in its present state of development is shown in Figure 24. A description of the equipment appears in the Appendix.

Initially, the test rig was set up partially from ordered commercial and shop produced components, plus some borrowed components, including a vacuum pump and a scanning mechanism drive motor. These borrowed parts have now been replaced with a large capacity vacuum pump to provide rapid pumpdown, and a suitable drive motor, speed control and gear reduction arrangement to permit scanning of different sized tubes. In addition, the original temporary detector, devised by modifying one which had been used for other purposes, has been replaced by one designed specifically for this instrument, and embodying improvements based on experience with the first. A commercial detector which was ordered while the temporary one was used has finally arrived. Although this detector is no longer needed, we plan to test its operation in comparison with the newly designed one. However, we are not optimistic about the commercial unit, since it has a window thickness of approximately 2500 Å. Since it was ordered, we have determined that the maximum window thickness to avoid loss of sensitivity is about 1500 Å.

Our currently installed window has a thickness of approximately 1000 Å and has been in use 24 hours per day for five weeks without leakage. The differential pressure across the window, which is supported by a 280 line-per-inch nickel screen, is essentially one atmosphere, and the vacuum system holds readily at a few millimicrons Hg pressure. This clearly demonstrates that there are no holes in the window. However, the window has been a problem. If the window thickness is too small, the window either breaks or develops holes; if it is too thick, it cuts out the low energy electrons required for measurement of deposit thickness. We originally used a cellulose nitrate material which was on hand in the laboratory, but windows cast from this material, when sufficiently thin, proved too fragile and short-lived. The window material that we had planned to use (Union Carbide PARYLENE® film) was too thick (2600 Å). We have now received a thinner film (1000 Å PARYLENE® film), which we plan to install later. While we were waiting for delivery of the thin film, we successfully cast a 1000 Å film of PARLODION® (also a cellulose nitrate material), which we are now using. Although the PARYLENE® material is believed to be stronger, the present window is performing satisfactorily and will not be replaced until necessary. The present arrangement of window film and wire screen permits about a 70 percent transmission of electrons, which is considered adequate.

A considerable amount of effort has been expended in the evaluation of this equipment and is still continuing. The effects of vacuum level, detector time constant, rotational-translational tube speed, detector head positioning, chart speed, pen response time, and a number of other variables have been under investigation.

---

a) A. Telfer and R. M. Curtis of our Analytical Department were responsible for the design, construction and preliminary testing of this equipment.

Figure 24 follows

As was noted previously[3)], it is possible to reach saturation for any given electron energy level, and hence to reach a maximum deposit thickness beyond which readings will be inaccurate. If thicker deposits are to be measured, a dual set of detectors and sources might be required to be assured that true deposit thicknesses are being measured. In addition, the span of the current 5 mv single channel 5-inch strip recorder is so narrow that it cannot read out the signal from all deposit levels at the same sensitivity setting. This often requires multiple runs at different sensitivities in order to measure the entire deposit profile. This could be corrected by utilizing a 1 mv 10-inch strip recorder with dual channels. This would increase the sensitivity, and the use of the two channels a decade apart would enable us to handle a greater range of thicknesses.

We have found that wobble or surface unevenness of tubes can cause baseline fluctuation, and experimentation has shown that this is observable for steps as little as 0.0001 inch. This is not due to differences in air thickness, but rather to the geometric characteristics of the beta-ray collimator. This problem can be overcome, however, by cleaning deposit from narrow bands spaced along the strip to provide a reference level of backscatter.

Although the beta-ray backscatter equipment has given reproducible results, a satisfactory method of calibration which relates backscatter values to the actual thickness of the deposit is still being pursued. For our purposes, such calibration, while intellectually satisfying, is not actually necessary as long as we compare deposits on tubes of the same composition. The output of the device is assumed to be proportional to the number of atoms of material on the tube under examination, if the average atomic number does not depart too seriously from that of carbon; this requires a low concentration of higher atomic number elements. This will generally be the case.

Calibration of the instrument thus far has been attempted with nitrocellulose films wrapped around an aluminum coker tube. These films have been separately cast and then taped to the tube for rating by the backscatter equipment. The film is then removed and the thickness of it measured independently by a microscopic light diffraction technique. Roughly, we have found by using this method that 1 inch on the strip chart corresponds to a thickness of 550 Å on an aluminum tube. However, the film so applied has always been wrinkled and nonuniform; hence, the search for an accurate method of calibrating the instrument is still underway, and an absolute calibration was not available in the earlier work. For that reason, deposit measurements are reported here in nondimensional units, but are approximately equal to thicknesses in Angstroms.

As a part of the overall calibration problem we needed a calibration method for deposits on different substrate metals. To implement this investigation, a calibration rod of 1/8-inch OD has been constructed which consists of sections of the following materials: brass, silver, aluminum, cadmium, cobalt, zinc, iron, tin, titanium, magnesium, carbon, and TEFLON® rod. By scanning this rod we obtain a series of steps on the recorder due to the different backscattering efficiencies of the materials of the rod. A 1000 Å PARYLENE® film then is wrapped onto the tube under tension, thus avoiding the previous wrinkling problem. The tube is then rescanned to obtain the calibrations for deposit thickness. An additional advantage of the multimaterial tube is that it will be available for restandardizing the tube when it becomes necessary to change windows, or to make regular calibration checks in the event of drift in the electronic equipment.

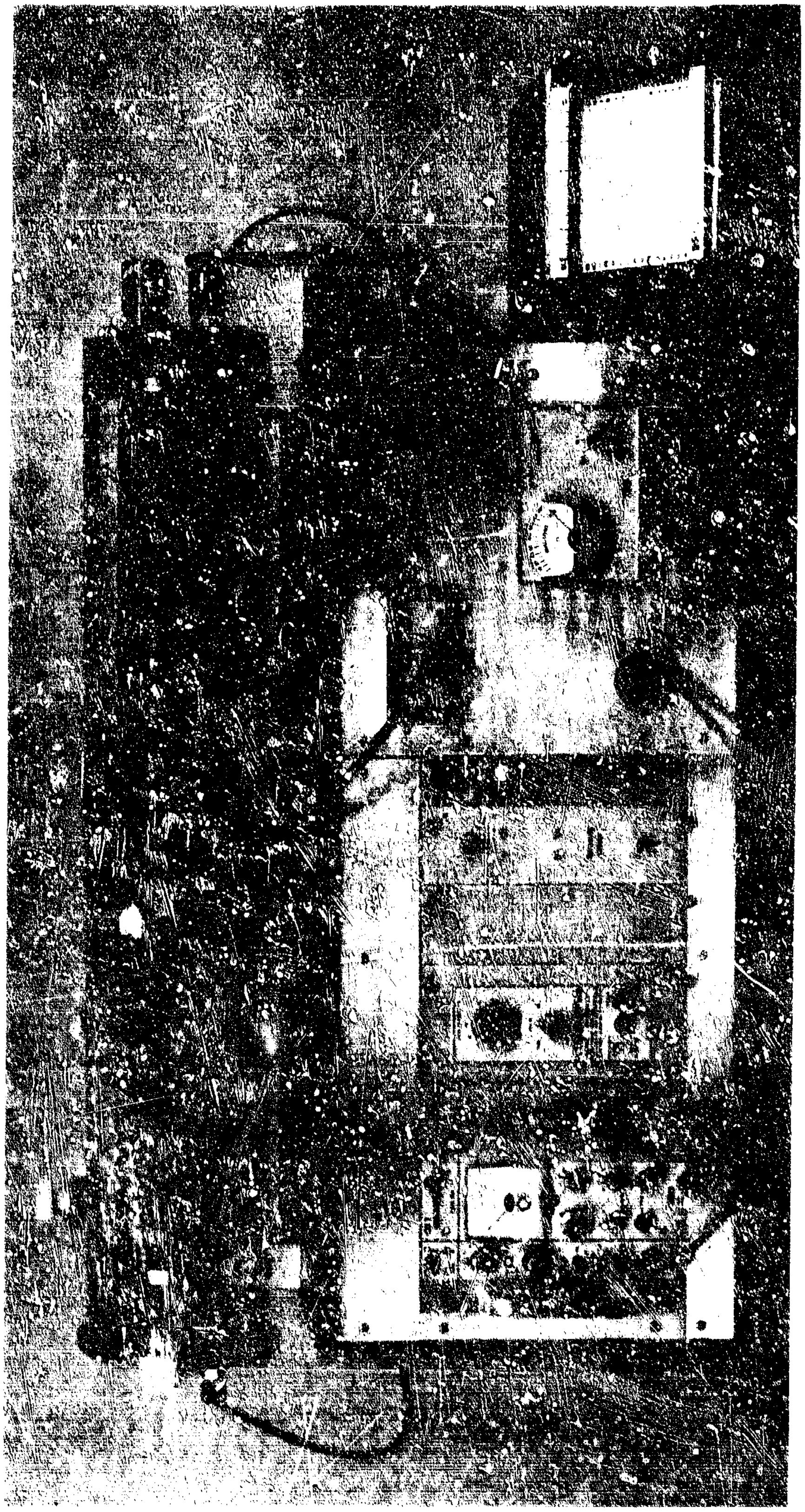


Figure 24. BETA-RAY BACKSCATTER INSTRUMENT FOR MEASURING COKE DEPOSITS

Calibration with other pure hydrocarbon films is planned, although calibration with nitrocellulose is not considered to introduce a serious error, since the difference in the beta-ray backscattering by nitrogen and oxygen and the backscattering by carbon is not expected to introduce a significant error. However, this will be checked.

Boeing Titanium Strips

We have completed an evaluation of the tank deposit strips that were sent to us by Mr. George Hays of Boeing Aircraft Company. Results of these surveys are plotted as deposit profiles in Figures 25-28, where deposit thickness in A°(approximate) are plotted versus distance along the strips. The narrow vertical dips shown are due to the fact that divider strips were welded and cemented to the flat titanium sheets, from which the fuel tanks were constructed, and were then removed. The greatest thickness of deposits was in the region of the divider strips, and this suggests a possible interaction of fuel with the cement or sealant, or an electrostatic attraction of deposit towards the dividers. The thickness of the sealant is indicated by the ends of the dips and ranged from an apparent 150 to 800 A°.

In order to compensate for the departure from flatness of the strips, the deposit was periodically removed by mild abrasive action, although this is not shown on the deposit profiles. By assuming that the minimum deposit thickness midway between divider strips represented the true unhindered depth, approximate dashed curves have been sketched in. It can be seen from the figures that apparent deposit thicknesses ranged from about 500 to 1400 A°. Calibration was made with a 1350 A° nitrocellulose film on cleaned titanium strips.

An effort was made to check these results by cutting two sections 2.5 cm in length with apparently uniform deposits from one of the strips. One of these areas measured 1200 A° and the other 1400 A° by beta-ray backscatter. These were then analyzed by combustion for carbon and hydrogen and a clean, freshly abraded sample was also analyzed for background impurities. Great care was taken to prepare these specimens so as to avoid contamination, and the edges and backs were filed clean with a fine file. The samples were then rinsed with normal heptane and dried in a vacuum oven for two hours at 150°C. The amount of carbon and hydrogen determined for the deposited samples, however, was much higher than would be expected from an oxidized hydrocarbon film of the thicknesses indicated by beta-ray backscatter, calculated densities being about 4.0 and 6.1 gm/cm^3. This could have been the result of the inclusion of substantial amounts of oxides of heavy elements in the coating, since they would scatter more effectively than titanium, and would make the deposit appear thinner to the instrument. However, scanning the strips with the IEES instrument (Varian Corporation) indicated that no large concentration of elements existed in the film other than carbon, hydrogen, and oxygen. At the present time the most reasonable explanation for this phenomenon is either that the original calibration of the instrument was at fault or that the deposit retained substantial amounts of the normal heptane with which it was washed, in spite of being dried in a vacuum oven for two hours at 160°C. This will be checked further.

Figures 25, 26, 27 and 28 follow

Alcor JFTOT and SD/M-7 Coker Tubes

A few aluminum and stainless steel tubes used in our Alcor JFTOT unit have been examined both in the Tuberator and with the beta-ray backscatter device.

A distinct advantage of the beta-ray backscatter method is that it enables one to know when an observed color is not a true deposit, but rather the color of the metal itself. This was demonstrated with a stainless steel Alcor JFTOT tube having a faintly yellow tinted area which one might have rated a code 1-1/2. Nevertheless, the area still looked like bare metal, and indeed the beta-ray backscatter scan showed no difference between the tinted and the original metal colored areas. The beta-ray backscatter readout was constant for this entire tube.

However, a stainless steel Alcor JFTOT tube having an apparent code 2-1/2 rating, and giving the impression of being a true deposit overlay, gave a definite beta-ray backscatter count indicative of a deposit, as shown in Table 34. Here only the maximum visual code rating was taken, and then only on the side with the heaviest deposit. The beta-ray backscatter readout was, of course, on the entire tube, and shown in Table 34 is the range of thicknesses for both the heaviest and lightest deposits on opposite sides of the tube. The deposited area was about 1-1/4 inches long, but no effort was made to reduce the code ratings into shorter lengths, since most of the deposited area was the maximum code color, with lighter color around the fringes. This is rather typical of JFTOT deposit appearances.

Table 34. COMPARISON OF ASTM CODE AND BETA-RAY BACKSCATTER RATINGS FOR ALCOR JFTOT STAINLESS STEEL AND SD/M-7 COKER TUBES

Tube Designation	ASTM Code Tube Ratings												
	1	2	3	4	5	6	7	8	9	10	11	12	13
JFTOT Stainless Steel[a)]	(2-1/2)					0	0	0	0	----	----	----	----
SD/M-7 Coker Run 525[b)]	1	1	1		1/2	1/2	1/2	1/2	0	0	0	0	0
	Thickness Range by Beta-Ray Backscatter, Å												
JFTOT Stainless Steel[a)]		(140-700/480-340)					(no deposits)			----	----	----	----
SD/M-7 Coker Run 525[b)]		160-175	140-160	50-110	35-50	35-50	35-50	[illegible]-35		(no deposits)			

a) per cm.
b) per inch.

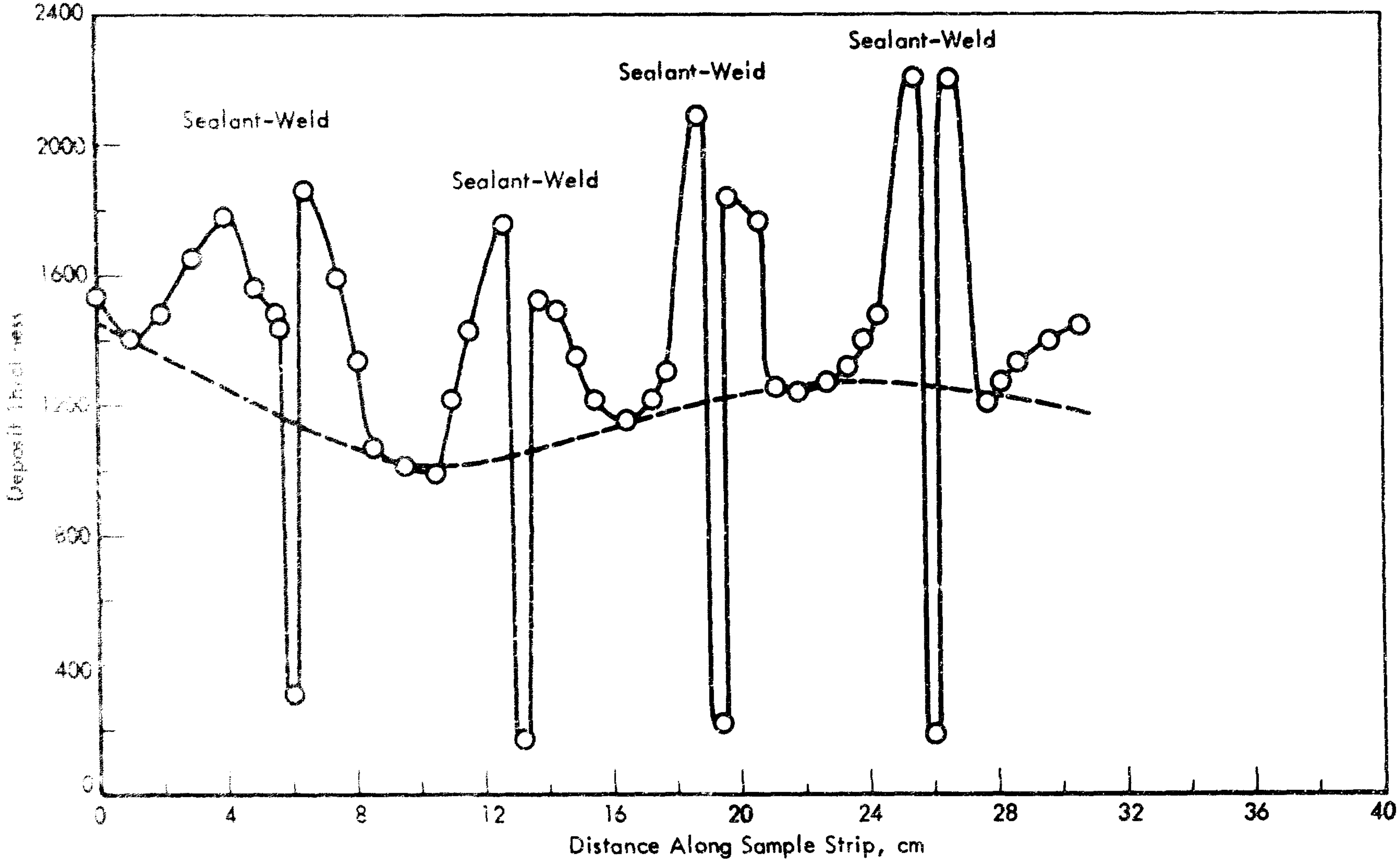


Figure 25. DEPOSIT PROFILE: SAMPLE STRIP NO. 2 FROM BOEING AIRCRAFT COMPANY

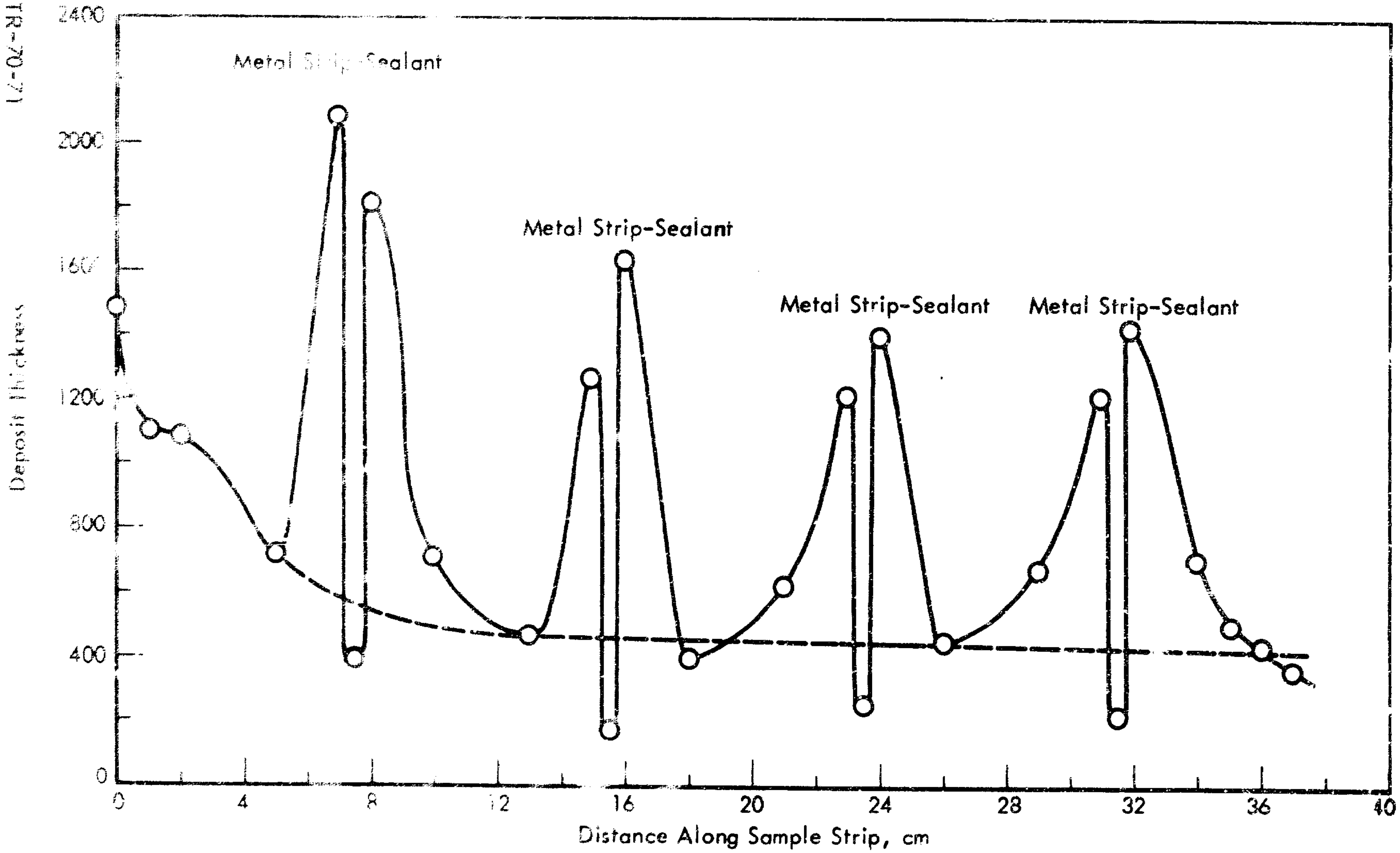


Figure 26. DEPOSIT PROFILE: SAMPLE STRIP NO. 3

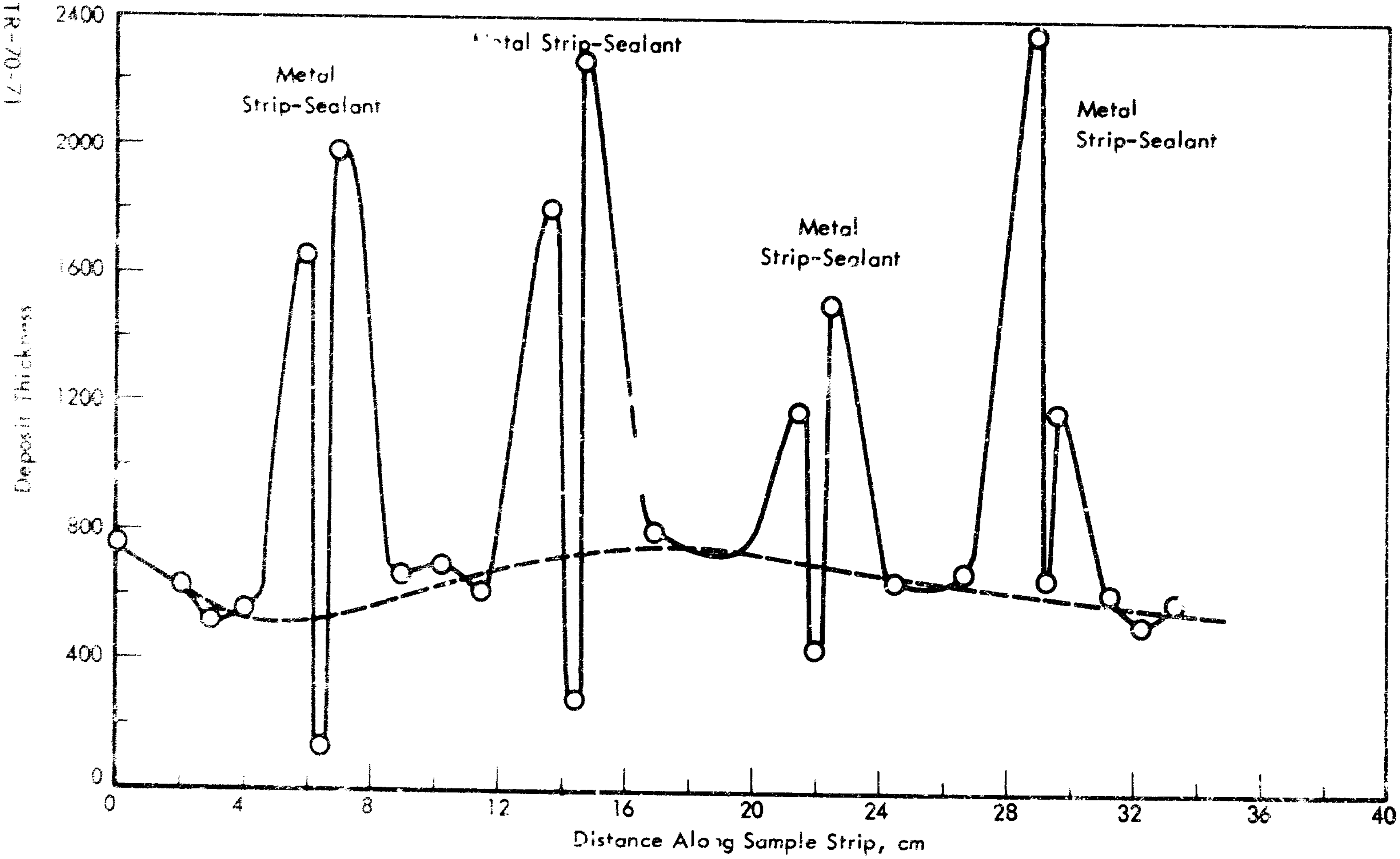


Figure 27. DEPOSIT PROFILE: SAMPLE STRIP NO. 4

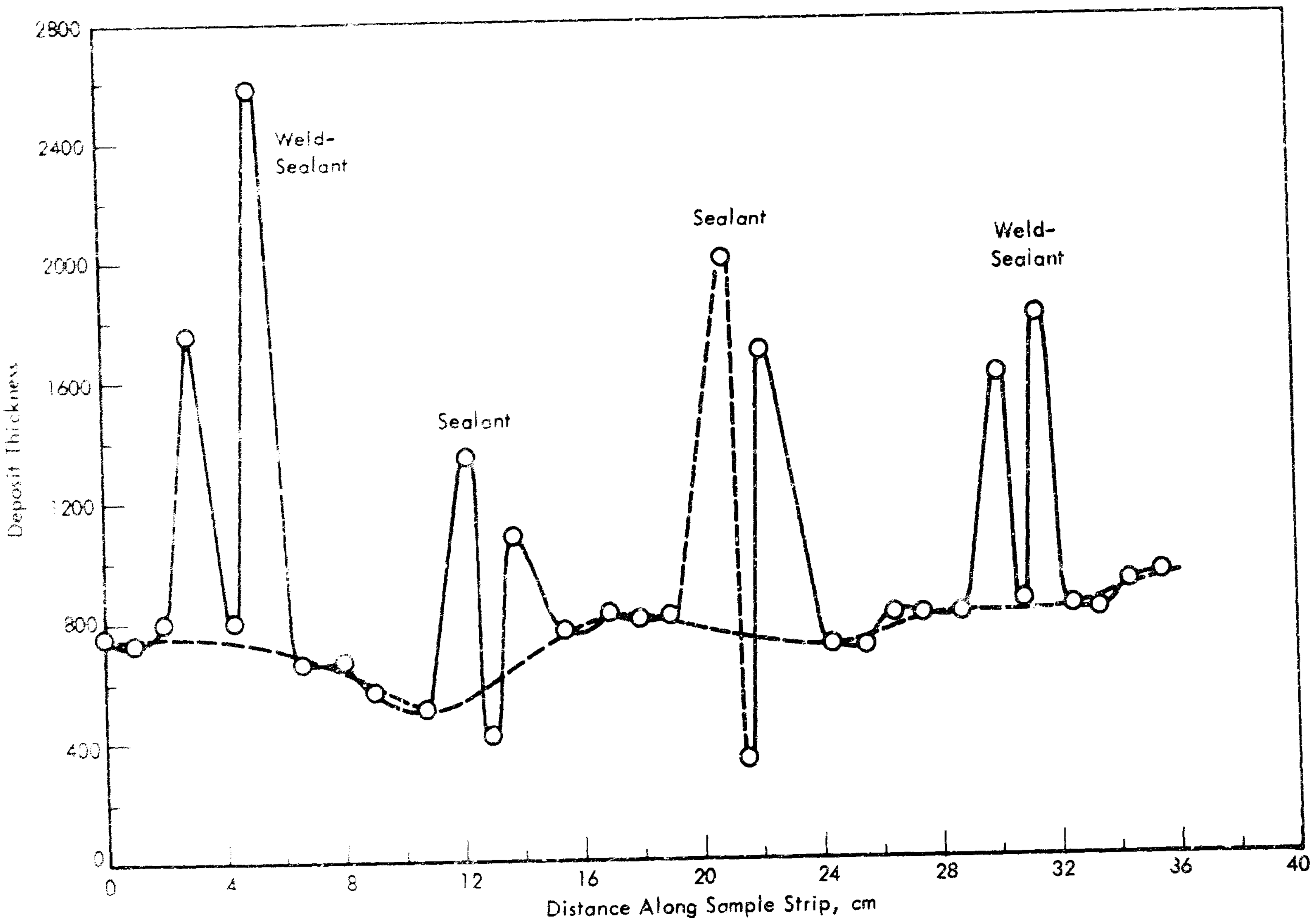


Figure 28. DEPOSIT PROFILE: SAMPLE STRIP NO. 5

One should not take the deposit thicknesses shown as being precise, since calibrations on stainless steel had not been made when this tube was measured. Moreover, since bare metal backscatter is a function of true metal composition, true calibration must be done on the same metal composition as that on which the deposit is measured.

The ASTM code versus the beta-ray backscatter ratings of a lightly deposited SD/M-7 coker tube deposit is also shown in Table 34. Actually, the areas shown do not correspond exactly, the area "1" for the backscatter ratings starting about an inch further away from the fuel outlet point than that of the ASTM code. One has to keep in mind this point in studying the other tube rating comparisons; the starting points are not necessarily the same. However, the regions in which deposits are located are in approximate agreement, the beta-backscatter results being much more discriminating than the visual code ratings.

The scanning width of the beta-ray backscatter instrument is slightly greater than 1/8 inch, since the radiation source slit is 1/8 inch wide and about 1/8 inch from the nearest point of the tube surface. The beta-ray backscatter readout is an average measurement of deposits for an area about 1/8 x 1/8 inch. Actual deposit boundaries can be detected accurately, but the thickness at the boundary cannot be determined precisely because of the slit width. Alcor JFTOT tubes have a diameter of only 1/8 inch; hence, the backscatter measurement is influenced by tube diameter, or surface curvature. Consequently, for careful work calibrations would be necessary not only for every tube material, but for different tube diameters and for flat surfaces.

CRC Erdco JFTOT Preheater Tubes

A series of ten Erdco JFTOT preheater tubes from the CRC JFTOT evaluation program were supplied to us and rated by both the beta-ray backscatter method and our own laboratory ASTM Tuberator. The results of these ratings together with the average values of the ASTM code ratings from the panel evaluations and the results with the Erdco Reflectance Rater are tabulated in Table 35, and represented graphically (except for the values for the two most heavily fouled tubes) in Figures 29 and 30.

These tubes are 5/8" OD and 8-1/2" overall length. All ratings are given as the maximum values within one-inch long sections of the tube, numbering from the fuel outlet end. Actually the beta-ray backscatter readout was in the form of a sine wave, because the deposits were situated mainly on one side of each tube and the tube rotates and translates during the rating procedure. However, for the the present comparison we have simply given the maximum rating or deposit thickness in Å for each inch of the tube length. In the majority of cases, the geographical distribution of the deposits are found to be about the same by all methods of rating. That is, the deposits are heaviest near the exit end, although there are a couple of exceptions to this rule as shown with Tubes 10 and 2. Probably the two most interesting cases are tubes 7 and 15, which by both our own ratings and the CRC average fall in the critical region of code 2 to 3. Here the results with the beta-ray backscatter apparatus suggests that Tube 15 should fail whereas Tube 7 would probably pass, while the measurements with the Erdco Reflectance Rater would lead to the opposite conclusion. Although the Erdco Rater seems

Table 35. COMPARISON OF BETA RAY BACKSCATTER RATINGS OF CRC ERDCO JFTOT TUBES WITH THOSE FROM THE ASTM TUBERATOR AND THE ERDCO REFLECTANCE RATER

Tube Sections, Inches	Tuberator Ratings		ERDCO Rater	Beta Ray Backscatter, Å
	CRC Ave.	Shell		
	Tube No. 2, P. and W. No. 56 8 1/2" x 5/8" Tubes			
0-1	1.5	0.5	0.04	30
1-2	1	0	0.02	0
2-3	0.5	0	0.01	30
3-4	0.5	0	0.01	80
4-5	0.5	0	0.01	110
5-6	1.5	0.5	0.05	360
	Tube No. 3, P. and W. No. 34 (8 1/2" x 5/8")			
1	2	3	0.08	820
2	3	5	0.17	1130
3	3	4.5	0.08	580
4	1	0.5	0.03	none
5	1	0.5	0.02	none
6	0.5	0.5	0.02	none
	Tube No. 4, P. and W. No. 138			
1	2.5	3	0.15	1290
2	3	6.5	0.21	1790
3	3	6.5	0.21	1210
4	2.5	0	0.04	220
5	1	0	0.03	0
6	0.5	0	0.02	0
	Tube No. 7, P. and W. No. 38			
1	2.5	1.5	0.16	680
2	2.5	1	0.11	440
3	1.5	0.5	0.08	220
4	1	0.5	0.04	110
5	1	0	0.02	30
6	0.5	0	0.02	0
	Tube No. 10, P. and W. No. 80			
1	1	1.5	0.06	30
2	1.5	1.5	0.07	0
3	1	1.5	0.07	60
4	1	0.5	0.06	140
5	1	0	0.04	140
6	1	0	0.02	80

(Contd)

Table 35. (Contd). COMPARISON OF BETA RAY BACKSCATTER RATINGS OF CRC ERDCO JFTOT TUBES WITH THOSE FROM THE ASTM TUBERATOR AND THE ERDCO REFLECTANCE RATER

Tube Sections, Inches	Tuberator Ratings		ERDCO Rater	Beta Ray Backscatter, Å
	CRC Ave.	Shell		
	Tube No. 12, P. and W. No. 90			
1	2	0.5	0.08	580
2	1.5	0.5	0.07	190
3	1	0	0.03	0
4	1	0	0.03	0
5	0.5	0	0.02	0
6	0.5	0	0.02	0
	Tube No. 14, P. and W. No. 118			
1	2.5	5	0.13	1400
2	2.5	4	0.14	1140
3	2	2	0.06	470
4	1	0.5	0.03	30
5	1	0	0.02	0
6	0.5	0	0.01	0
	Tube No. 15, P. and W. No. 137			
1	3	2	0.11	1620
2	2.5	1.5	0.09	1260
3	2	1.5	0.06	910
4	1	1	0.04	600
5	1	0.5	0.03	360
6	0.5	0	0.02	220
	Tube No. 17, P. and W. No. 102			
1	1	0	0.05	0
2	1	0	0.05	140
3	1	0	0.05	140
4	1	0.5	0.05	310
5	1	0.5	0.04	240
6	1	0.5	0.02	200
	Tube No. 18, P. and W. No. 9			
1	1.5	1	0.08	880
2	3	3	0.16	1320
3	3	5.5	0.12	1700
4	1.5	0.5	0.02	630
5	1	0	0.01	80
6	1	0	0.01	0

to give quite consistent values within itself, the disagreement with the beta-ray backscatter apparatus is quite marked as shown in Figure 31. Although these data have not been analyzed statistically, the lack of concordance between the two methods of rating is evident. Of course, some of the scatter must be due to the beta-ray backscatter instrument, but we cannot assign this precisely since complete data on reproducibility will not be obtained until development work is complete. However, repeat runs on the same tube do not show deviations greater than about ± 10 A. The relation between ASTM Tuberator ratings and the beta-ray backscatter rating is shown in Figure 32 for both the CRC average ratings and the Shell ratings. Again a great scattering of results is noted. The CRC average ratings increase with a reduced slope for higher values because of the maximum 4 code rating imposed on those values.

A summary comparison of ratings by the other methods with the maximum deposit found with the beta-ray backscatter method is given in Table 36.

CRC Alcor JFTOT Preheater Tubes

We have also examined a group of ten tubes from the test program of CRC New Test Equipment Panel for the selection of a new thermal stability tester. Information received from the panel included ratings by an Alcor Mark 5 Tube Rater and Erdco Reflective Rater and values obtained by different panel members using the standard ASTM Tuberator. The latter values were averaged. The tubes were also rated on our own ASTM Tuberator equipment using our expanded scale (up to code 8), values being obtained every 1/2" along the 2-1/2" active length of the tube.

Values obtained by the various methods are given in Table 37 and are shown graphically in Figures 33 and 34, except for the two tubes with the heaviest deposits. Except for the Alcor Mark 5 Rater, which was obviously not sensitive enough, values obtained by the various methods showed general geographic agreement. The CRC Average ratings, of course, were always low in tubes having heavy deposits since the ASTM scale stops at 4. In general, the best agreement with the beta-ray backscatter method was exhibited by the Erdco rater (Figures 33A and 34A and D). However, in a number of cases (Figures 33B, C and D and 34 B and C) rather marked differences were observed. This is particularly true of tubes 2, 6, and 8 (Figures 33C and D, and Figure 34C), which would have presumably been failed by the Erdco rater but passed by the beta-ray backscatter instrument.

The relation between the various ratings and the beta-ray backscatter measurements are shown in Table 38 and Figures 35 and 36. The considerable scatter of the points is evident. However, in view of the favorable characteristics of the Erdco rater, it will be worthwhile to evaluate this instrument further using the beta-ray backscatter instrument as a standard.

With both the Erdco Reflective Rater and the beta-ray backscatter equipment, the absolute level of the values observed could very well be related to tube geometry. Certainly in the case of the backscattering principle, the calibration of the equipment with respect to actual film thicknesses was preliminary and subject to error in absolute accuracy.

Figures 29 through 32 follow

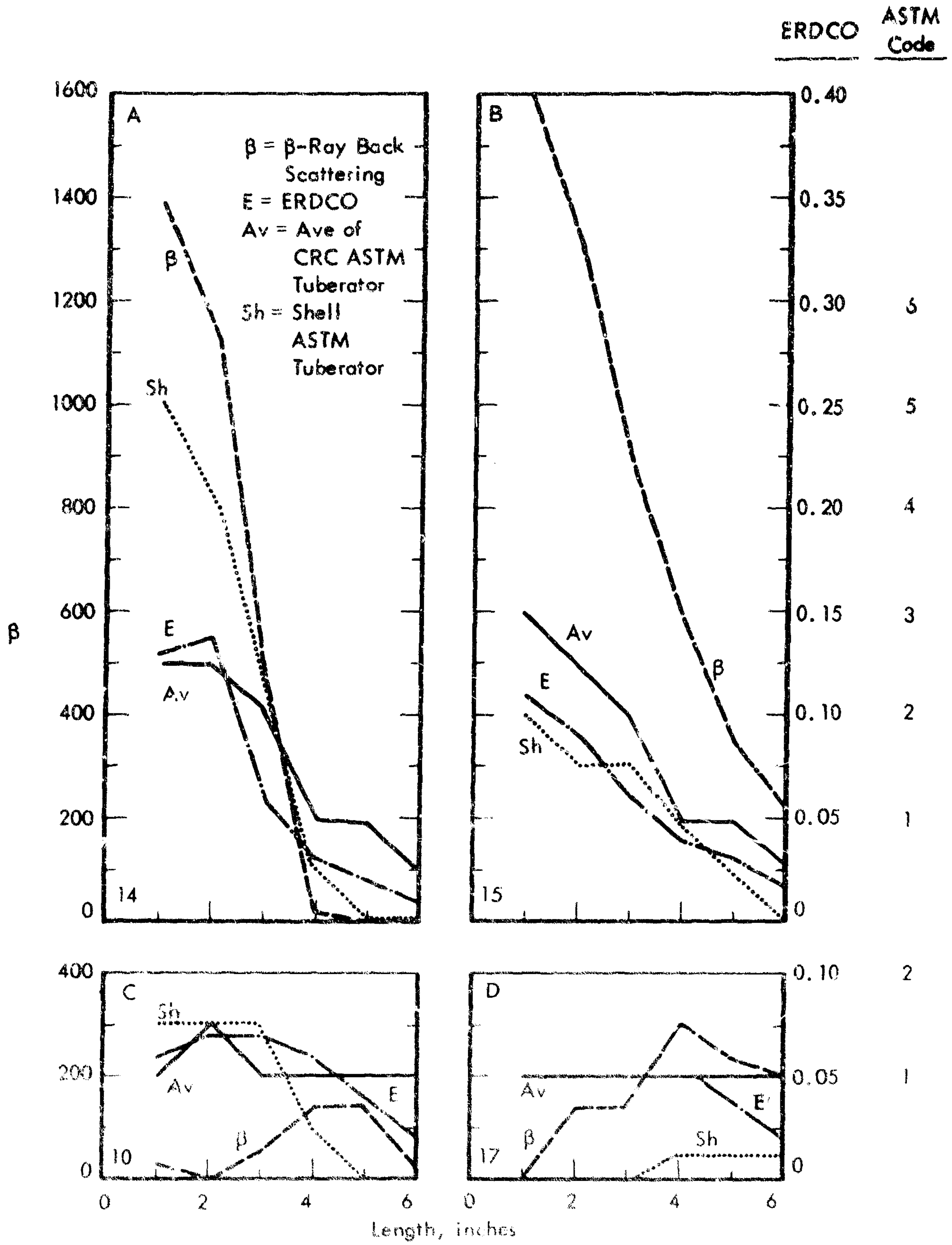


Figure 29. COMPARISON OF METHODS OF RATING ERDCO JFTOT TUBES

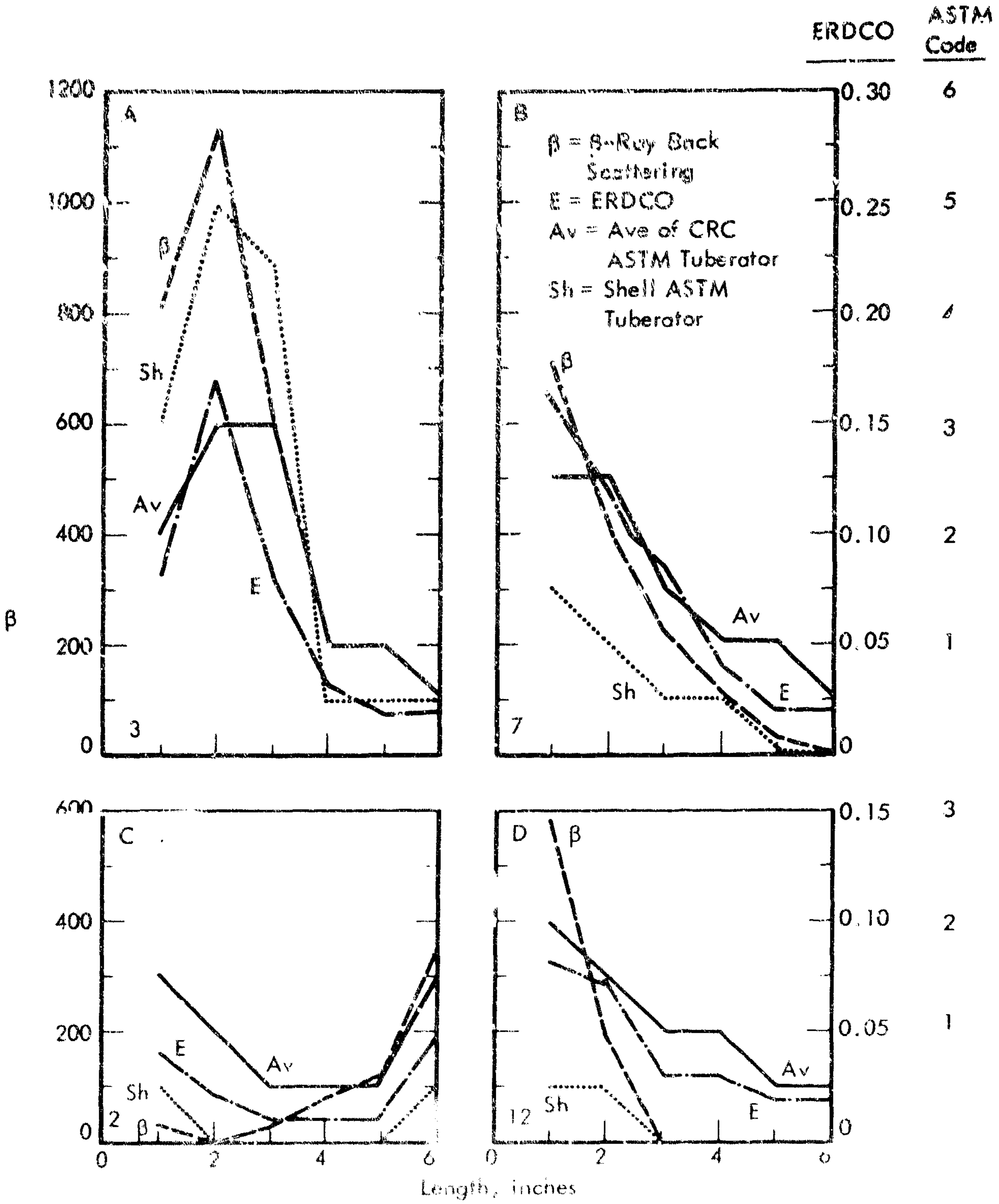


Figure 30. COMPARISON OF METHODS OF RATING ERDCO JFTOT TUBES

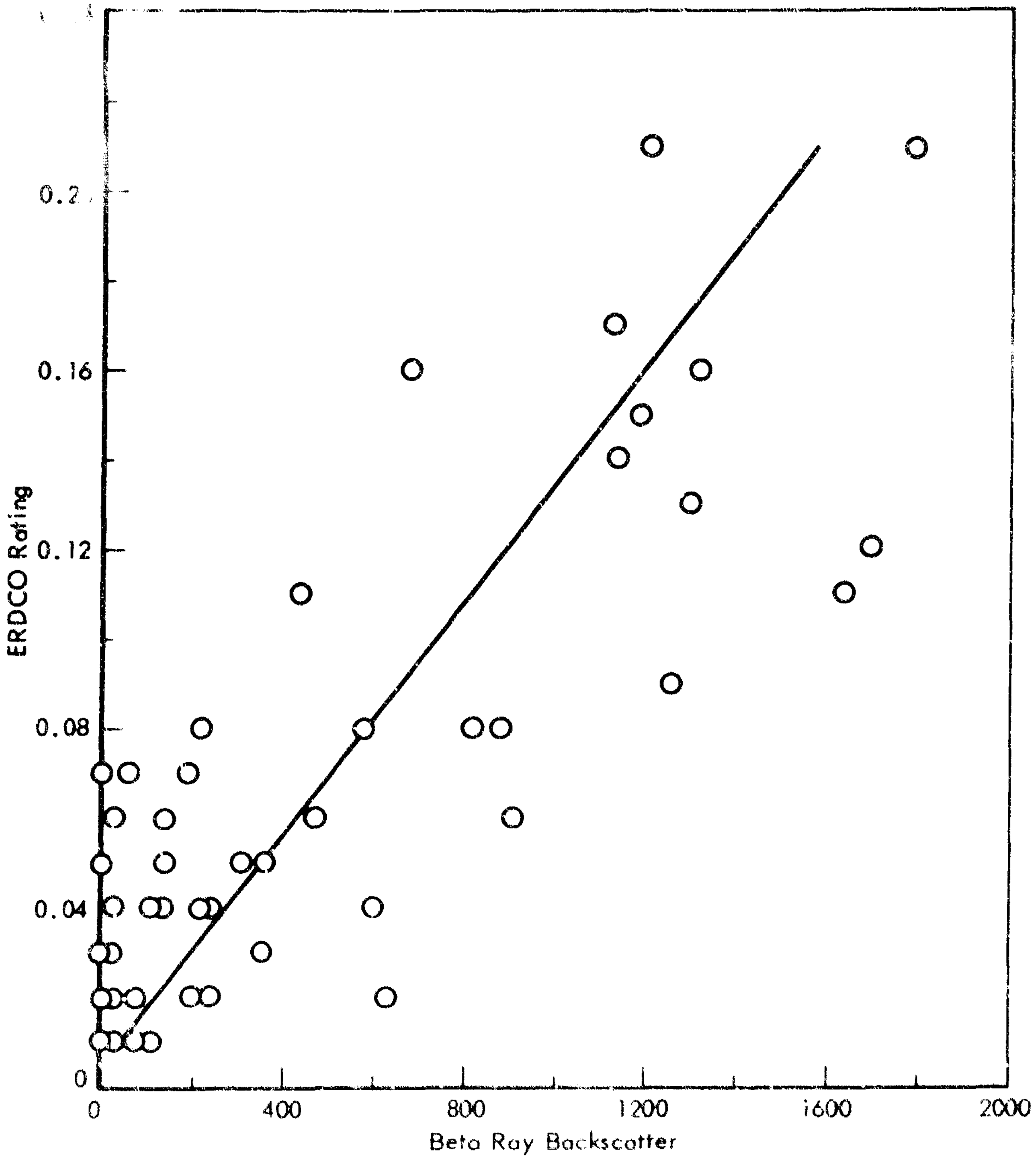


Figure 31. BETA-RAY BACKSCATTER RATINGS vs ERDCO REFLECTANCE RATINGS
CRC Exchange Program ERDCO JFTOT Tubes

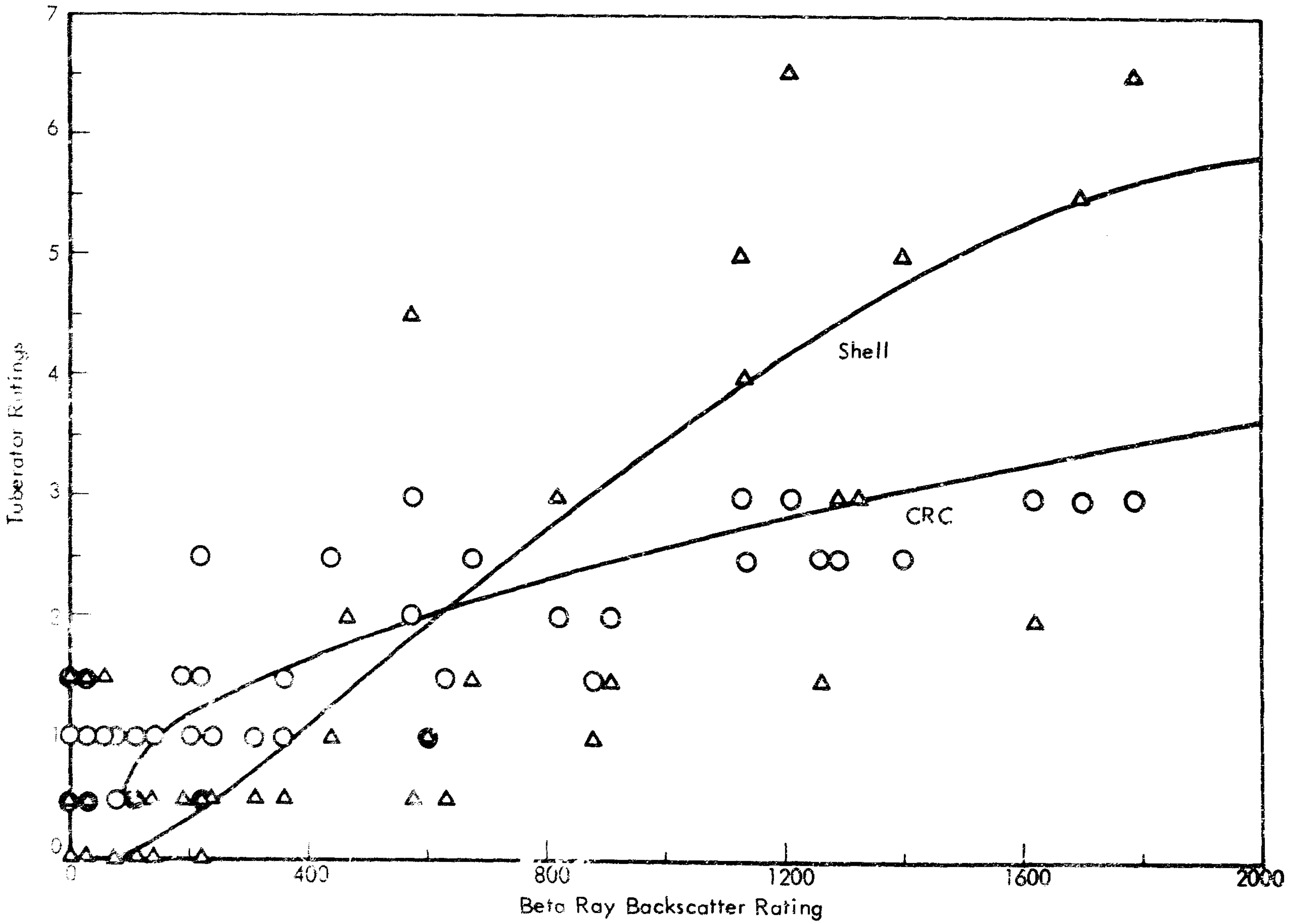


Figure 32. TUBERATOR RATINGS vs BETA-RAY BACKSCATTER RATINGS OF ERDCO JFTOT TUBES $8\frac{1}{2}'' \times \frac{5}{8}''$ OD

Table 36. SUMMARY COMPARISON OF OTHER RATING METHODS WITH BETA-RAY BACKSCATTERING METHOD FOR CRC ERDCO JFTOT TUBES

Tube No.	Max Beta-Ray	Rating of Beta-Ray Max by[a]		
		ERDCO	Shell ASTM	CRC Ave.
4	1790	0.21	6.5	3
18	1700	0.12 (.16)	5.5	3
15	1620	0.11	2	3
14	1400	0.13 (.14)	5	[illegible].5
3	1130	0.17	5	3
7	680	0.16	1.5	2.5
12	580	0.08	0.5	2
2	360	0.05	0.5	1.5
17	310	0.05	0.5	1
10	140	0.06 (.07)	0.5	1 (1.5)

[a] Values in parentheses are maximum values according to specified method.

Table 37. COMPARISON OF BETA RAY BACKSCATTER RATINGS OF CRC ALCOR JFTOT TUBES WITH THOSE FROM THE ASTM TUBERATOR AND THE ERDCO AND ALCOR MARK V RATERS

Tube Section, Inches	Tuberator Ratings		ALCOR MARK V	ERDCO Reflectance Rater	Beta Ray Backscatter, Å
	CRC Ave.	Shell			
			Tube No. IIA1		
0-1/2	1.5	1	9.5	0.19	580
1/2-1	1.5	1/2	9.5	0.18	480
1-1 1/2	1.5	1/2	9.5	0.12	320
1 1/2-2	1.5	1	9.5	0.05	40
2-2 1/4	1	0	9.5	0.07	0
			Tube No. IIA2		
1/2	1	1	9.5	0.15	200
1	1	[illegible]	9.5	0.15	120
1 1/2	1	[illegible]	9.5	0.10	40
2	1/2	[illegible]	9.5	0.08	[illegible]
2 1/4	1/2	[illegible]	9.5	0.06	[illegible]
			Tube No. IIA4		
1/2	3	5.5	9.0	0.24	560
1	3	5.5	9.0	0.23	740
1 1/2	[illegible]	5.5	9.0	0.19	540
2	2	1	9.5	0.08	120
2 1/4	[illegible]	0	9.5	0.03	20
			Tube No. IIA6		
1/2	3	2.5	9.0	0.15	95
1	[illegible]	3	9.0	0.18	140
1 1/2	2	1 1/2	9.0	0.12	40
2	1	1/2	[illegible]	0.04	50
2 1/4	1	0	[illegible]	0.03	[illegible]
			Tube No. IIA8		
1/2	3	3.5	9.0	0.16	200
1	3.5	6	9.0	0.24	260
1 1/2	1.5	1	9.0	0.10	80
2	1	1	[illegible]	0.10	120
2 1/4	1	0	[illegible]	0.04	[illegible]

(Contd)

Table 37. (Contd). COMPARISON OF BETA RAY BACKSCATTER RATINGS OF CRC ALCOR JFTOT TUBES WITH THOSE FROM THE ASTM TUBERATOR AND THE ERDCO AND ALCOR MARK V RATERS

Tube Section, Inches	Tuberator Ratings		ALCOR MARK V	ERDCO Reflectance Rater	Beta Ray Backscatter, Å
	CRC Ave.	Shell			
Tube No. IIA14-13					
0-1/2	1	1/2	9.5	0.14	560
1	1.5	1/2	9.0	0.18	420
1 1/2	1.5	1	9.0	0.16	220
2	1.5	1/2	9.0	0.07	60
2 1/4	1	0	9.0	0.03	0
Tube No. IIA9					
1/2	4+	6.5	6.0	0.46	2480
1	3.5	7	5.5	0.60+	2480
1 1/2	1	1/2	9.5	0.06	0
2	1	1/2	9.5	0.03	0
2 1/4	1	0	9.5	0.01	0
Tube No. IIA10					
0-1/2	3	5.5	9.0	0.22	800
1	3	2.5	9.0	0.25	900
1 1/2	3	3	9.0	0.20	660
2	2	1/2	9.0	0.09	240
2 1/4	1	0	9.5	0.03	0
Tube No. IIA20-18					
0-1/2	3.5	3.5	9.0	0.21	680
1	3.5	3.5	9.0	0.22	800
1 1/2	3.5	3.5	9.0	0.15	480
2	2	2	9.5	0.06	80
2 1/4	1	0	9.5	0.02	0
Tube No. IIA22					
1/2	4.5	6.5	6.0	0.44	1860
1	4.5	7	5.5	0.60+	2460
1 1/2	1	1/2	[illegible]	0.12	80
2	[illegible]	1/2	9.5	0.10	0
2 1/4	[illegible]	[illegible]	[illegible]	0.07	0

Table 38. SUMMARY COMPARISON OF OTHER RATING METHODS WITH BETA-RAY BACKSCATTER METHOD FOR CRC ALCOR JFTOT TUBES

Tube No.	Max β-ray	Rating at β-Ray Max[a]		
		Erdco	Shell ASTM	CRC ASTM Ave.
9	2480	0.60+	7 1/2	3
22	2460	0.60+	7	4
11A10	900	0.25	2 1/2 (5 1/2)	3
20-18	800	0.22	3 1/2	3 1/2
4	700	0.23 (0.24)	5 1/2	3
1	600	0.19	1	1 1/2
14-13	550	0.14 (0.18)	1/2 (1)	1 (1.6)
8	200	0.24	6	3.5
2	200	0.13 (0.15)	1	1
6	140	0.18	3	3

a) Values in parentheses are maximum values according to specified method.

Figures 55 through 56 follow

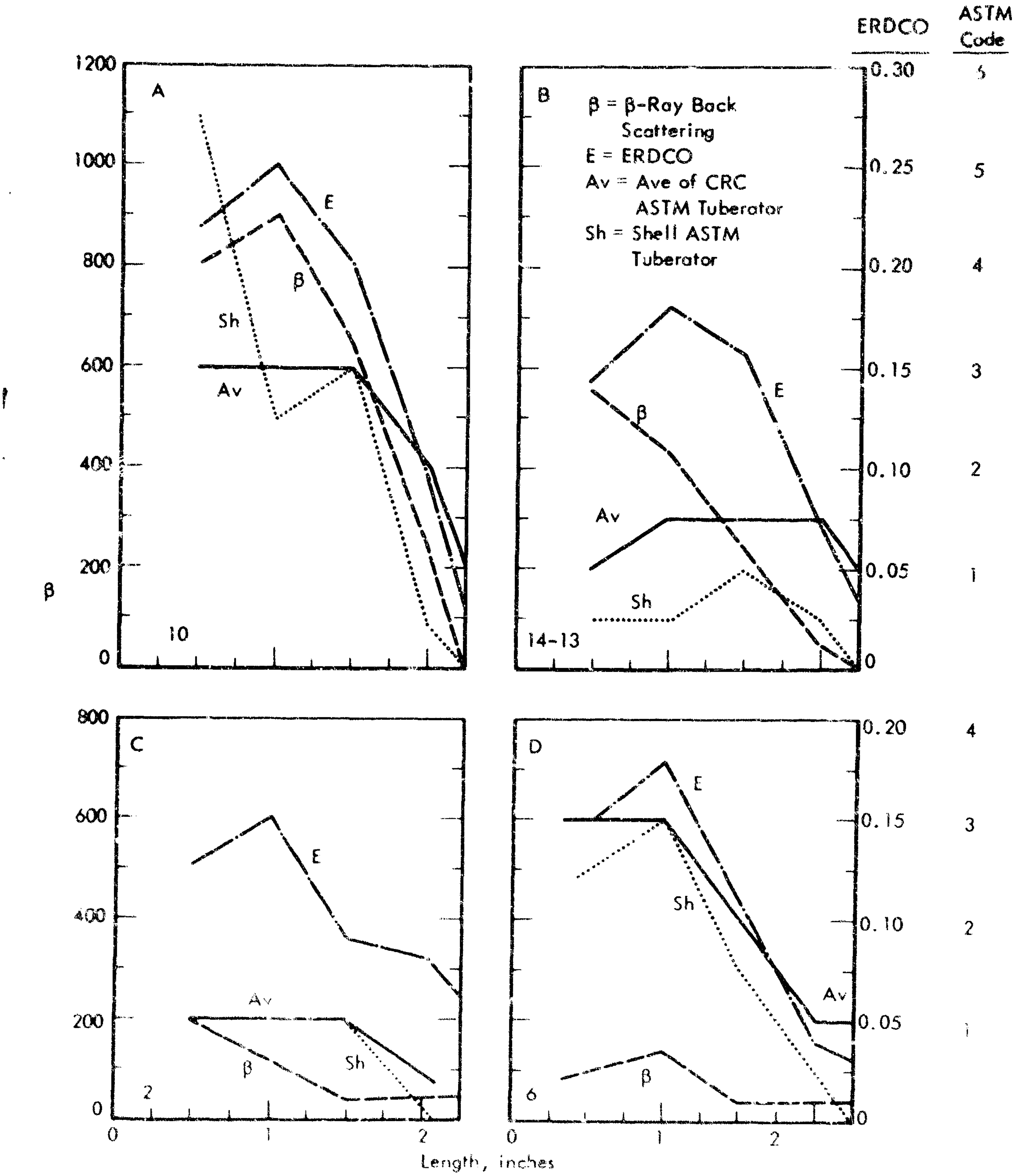


Figure 33. COMPARISON OF METHODS OF RATING ALCOR JFTOT TUBES

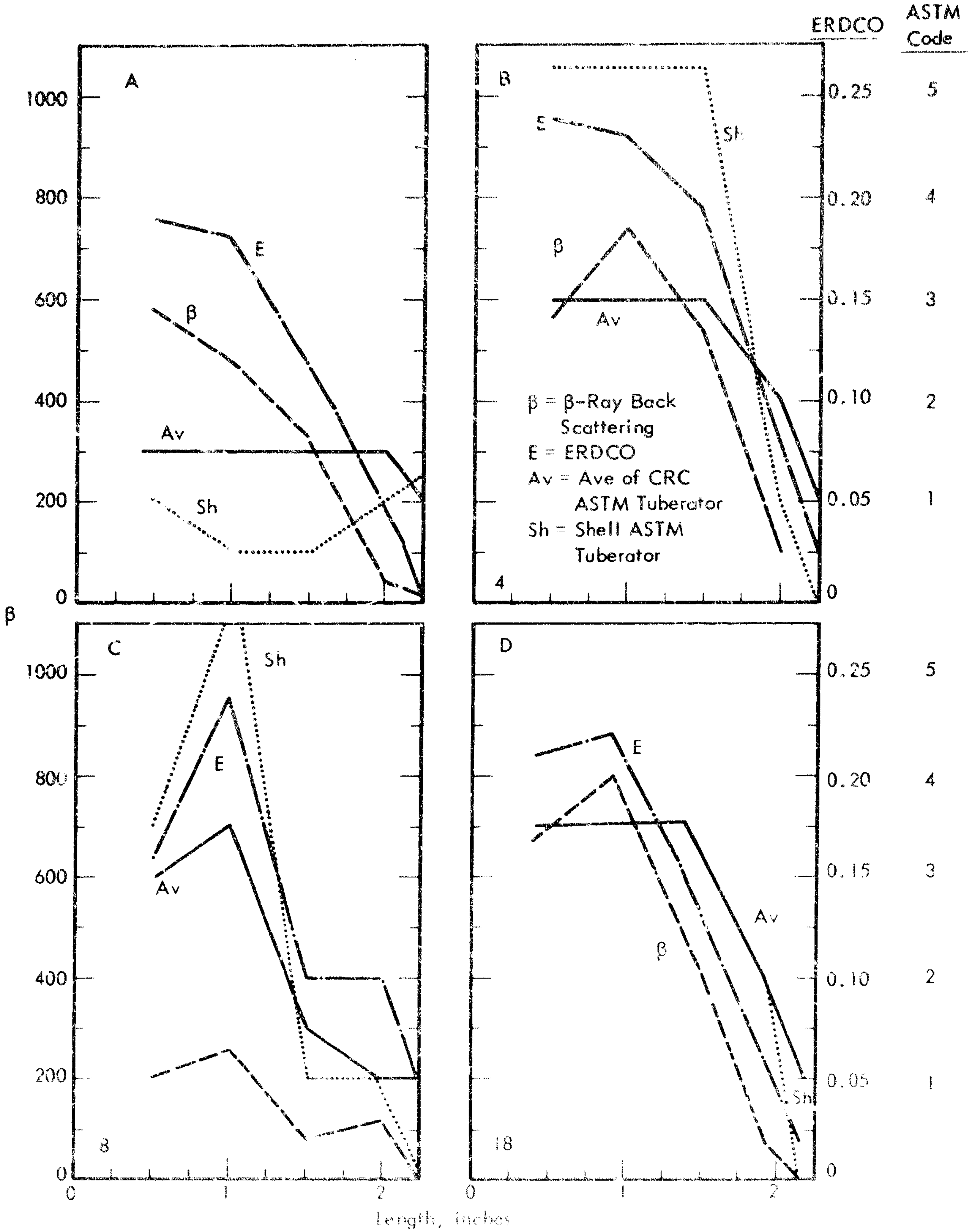


Figure 34. COMPARISON OF METHODS OF RATING ALCOR JFTOT TUBES

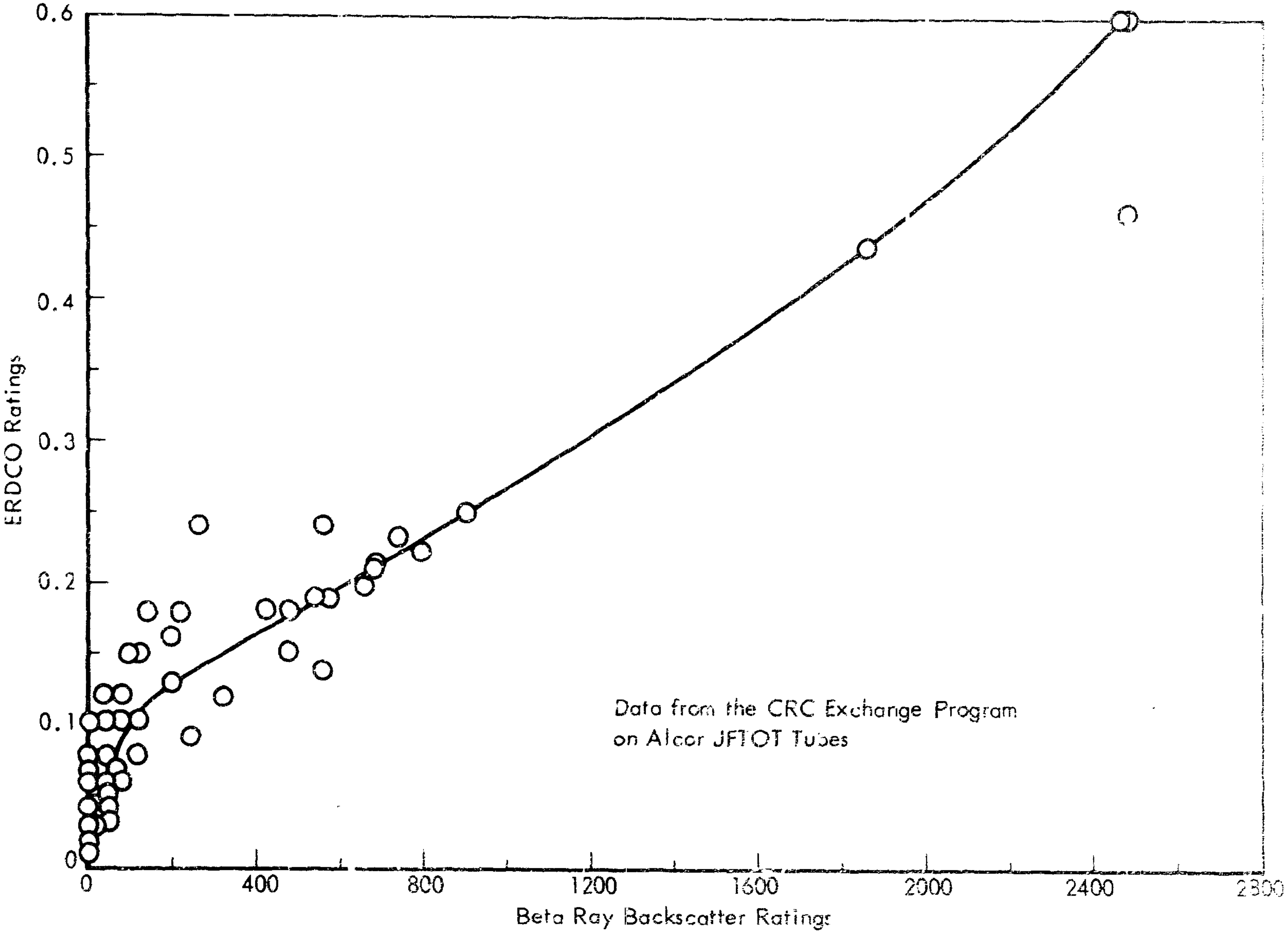


Figure 35 CORRELATION OF BETA-RAY BACKSCATTER RATINGS WITH THOSE FROM THE ERDCO REFLECTANCE RATER

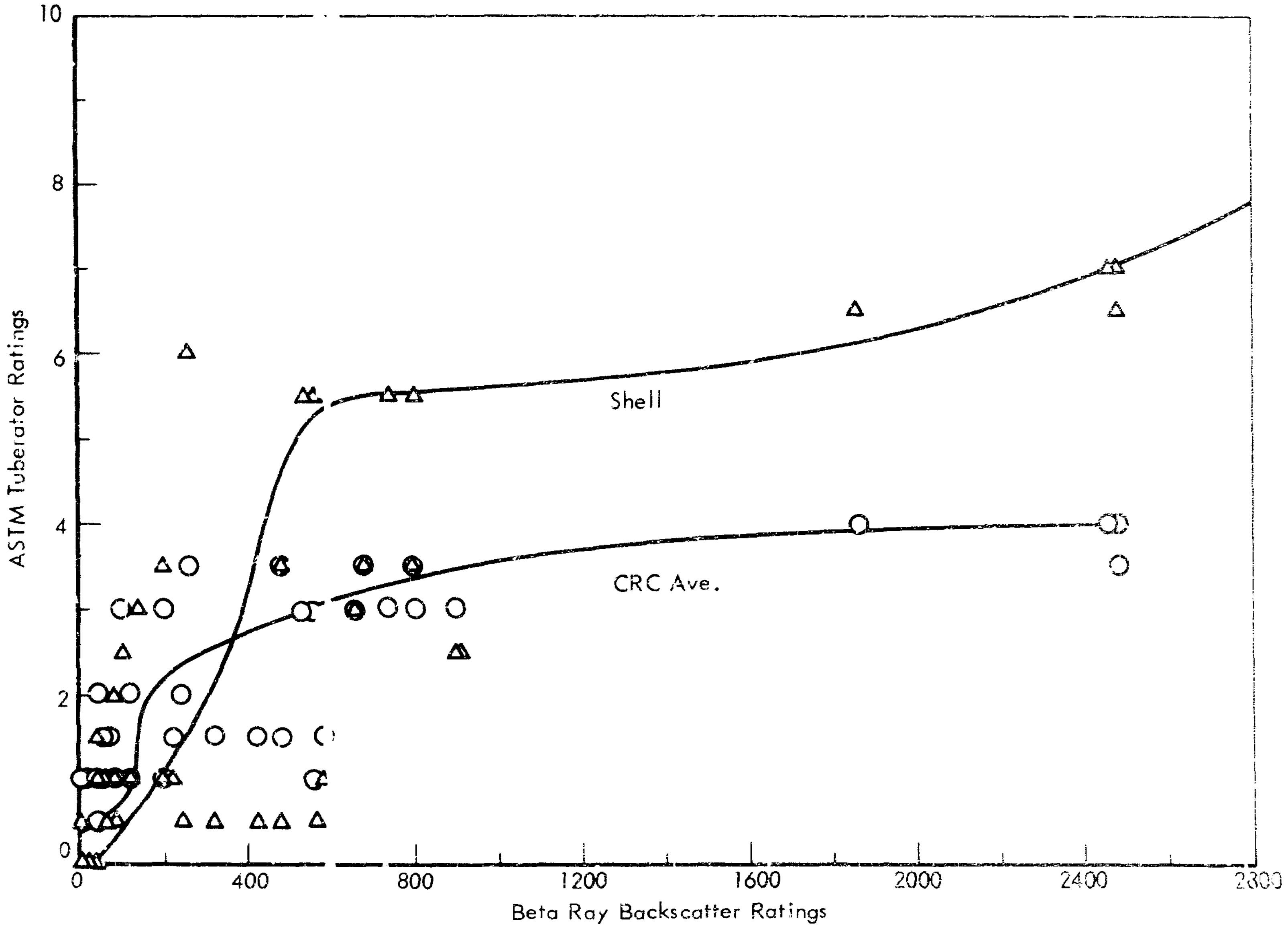


Figure 36. CORRELATION OF BETA-RAY BACKSCATTER RATINGS WITH ASTM TUBERATOR RATINGS OF ALCOR JFTOT TUBES BY SHELL AND CRC EXCHANGE GROUP RATERS

Problems in the Use of The Beta-ray Backscatter Instrument

Although it is evident from the above that the beta-ray backscattering principle can be applied to the evaluation of the amount of deposit formed on a metallic surface, there are a number of problems which could complicate the application of the principle. One is the composition of the tube metal substrate. Since the intensity of the scattered electrons is roughly proportional to the atomic number of the element, it is obvious that a calibration must be established for each type of metal used on which deposits are measured. In addition, the composition of the deposit will have an effect on the apparent thickness. This is shown in the Table 39. However, it is evident that the amount of error introduced by the presence of the usual percentages of oxygen, sulfur, and nitrogen will not be large, and it is unlikely that any significant error will be introduced if an average composition of the deposit is assumed. The presence of large amounts of heavy metals or metal oxides in the deposit, however, would seriously hamper interpretation of the measurements. Another problem is the need for a standardized calibration procedure, which requires the production of standardized films with known thicknesses. So far we have been using nitrocellulose films, the thickness of which can be measured by optical refraction. Another factor which can influence accuracy is distortion of the surface or a serious wobble in a rotating tube. However, this has been tolerable at the level usually encountered with JFTOT tubes and warped plane surfaces by providing occasional clean surfaces on the specimen for measurement references. Another definite limitation is the thickness of the deposit measured. For each source there is a limit of thickness which can be measured as a result of saturation, i.e., capture of essentially all the electrons entering the deposit. Thus, the intensity of the source was chosen so that the instrument could measure the 2,500 Å thickness that we expected to encounter. Measurements of thicker deposits would require a more intense source.

Table 39. ESTIMATED ERRORS IN BETA-RAY BACKSCATTER MEASUREMENTS OF DEPOSIT THICKNESSES DUE TO NONCARBON ELEMENTS

Assumed Composition of Deposit	%w non CH	Error In Deposit Thickness, %
CH	---a)	---a)
CH_2	7, H	+2.0
$CHO_{.25}$	23.5, O	-1.5
$CHS_{.05}$	11.0, S	-3.5
$CHFe_{.01}$	4.1, Fe	-2.5
$CHPb_{.001}$	1.4, Pb	-3.1

a) CH was taken as the reference composition.

The present instrument is still under development, and it is anticipated that the above problems will be sufficiently resolved to allow the instrument to be used for evaluating the thickness of deposits on heat-exchange surfaces, as well as for other uses in which it is desired to measure the thickness of coatings.

Fuel Additives for Improvement of Thermal Stability

One important consideration in the development of fuels for high temperature operations is the decision as to what additives, if any, will be used with the fuels. Although the selection of the additives is best left until the conditions under which a fuel will be used are known, some preliminary investigation has to be done in order to ascertain the interaction between the fuel and different additives. One of the additives which is suspect is the metal deactivator, since it has a decomposition temperature of about 540°F in bulk.

Accordingly, a program has been initiated to screen potential additives for improving thermal stability, particularly of a variety which will function at higher temperatures. As a part of this investigation, we have taken a look at iodine, partly because of the lubricity improving characteristics of this material. It was reasoned that if iodine decreases the coefficient of friction, as has been reported under certain circumstances, then it might reduce the deposition tendency of fuels in a coker, where metal from pump wear might be a contributing factor. However, the addition of 0.1 percent iodine to PWA-535 jet fuel caused very severe deposit formation in the SD/M-7 coker at 600°F (code 5.5/56.5 compared to 2.5/16 for the iodine-free fuel). Consequently, no further testing is planned with this additive.

Following a lead from earlier work on the influence of metal environments on thermal stability, in which metallic zinc was thought to have a beneficial effect, zinc 2,4-pentanedione was tested in decalin at 600°F. The metal was added at a concentration of 200 ppm without effect (code 2.5/16.5 versus 2.5/15 for the nonadditive fuel) in the SD/M-7 Fuel Coker. Further observations with metallic zinc in decalin indicate that the benefit originally found was characteristic of the effect of metal deactivator (MDA; N,N'-disalicylidene-1,2-propanediamine) also present. MDA was found to provide improvements in thermal stability of decalin up to 600°F, but became ineffective at higher temperatures. This suggested the need for a chelating agent with a higher thermal stability, since MDA is not stable above about 540°F.

It had been concluded in the earlier tests that Zn did not interfere with the effect of MDA on the deposition tendency of decalin as did certain other metals such as Ni, Fe, Pb, and Cr. The results with zinc 2,4-pentanedione were therefore in harmony with this conclusion.

The beneficial action of MDA was assumed to be directly related to its action in passivating dissolved, and possibly surface metals, and not necessarily to the action of a zinc chelate which had been formed. Conceivably, even where concentrations of soluble metals are extremely low (ppb level), these metals may nevertheless play a key role in oxidative thermal degradation of fuels. Since virtually all fuel handling and storage equipment is metallic, metal is always present, and even in glassware tests of thermal stability the fuel has been previously in contact with metals.

It was concluded that perhaps a more stable chelating agent would extend the resistance of fuels to thermal oxidative degradation to higher temperatures than does MDA, even at air saturation conditions. Starting from this premise, some fifty compounds have been screened using the SD/M-7 fuel coker, of which six definitely have been found to be effective at 675-700°F. Probably several of the others would also prove effective at lower temperatures. A highly saturated jet fuel of a JP-7 type with high thermal stability (RAF-159-60, designated F-68) was used for the screening tests. This fuel has a thermal stability breakpoint by the SD/M-7 coker method of about 675°F. Other properties for this fuel are shown in Table 40.

The simplest member and first discovered of the new class of thermal stability additives (additive A) was found to improve the coker ratings of F-68 over the temperature range of 600 to 700°F. At the latter temperature the improvement in thermal stability is equivalent to ca 125°F. That is, the coker deposit rating at 700°F is equivalent to that obtained at 575°F without the additive.

Most of the other compounds tested have involved structural variations of the basic form of additive A by substitutions of groups and atomic species on and about the functional parts of the molecule. However, in the work done to date, no one simple mechanism appears to account for the activity of all the additives. Indeed, not all of the effective compounds are believed to be chelating agents. Some of the materials tested, although having some of the structural features of additive A, are entirely different in their chemical properties. Moreover, we have no simple explanation for the maximum temperatures at which these additives are effective. Structural modifications which increase the thermal stability of the additive do not necessarily improve its effectiveness. Most of these changes have resulted in less favorable activity, some decreasing the thermal stability of the blended fuel.

In four cases with the six effective additives, group substitutions at the functional group of additive A apparently did not harm the ability of additive A to enhance thermal stability, and in addition are expected to improve the resistance of the additive to water leaching. The fifth effective compound (additive A') is a different chemical type, but the structure was suggested by that of additive A. The sixth additive is a fluorinated form of additive A (A_F). The effectiveness of these six compounds and MDA is shown in Table 41. Although the effectiveness of the additives increases with temperature, the results shown in Table 41 demonstrate how an additive may first be beneficial and then become harmful above some critical temperature. None of the additives has been found effective at 725°F, when tested at that level, and one additive (A') that was beneficial at 675° was very harmful at 700°F. The cause for this sudden change in activity with temperature rise is due either to a thermal stability limit of the additive itself, or to a change in the thermal degradation mechanisms with which the additives interfere. The fact that MDA was not effective above 600°F in either decalin or F-68 jet fuel suggests limitations in the thermal stability of this additive. The more thermally stable additive A_F was found to be no better and even worse than additive A.

Table 40. DESCRIPTION OF JET FUEL RAF-159-60

Properties			
Grav ASTM D287, °API	50.7	Water Tol, F-791, 3251, Interface Rating	1
Distillation, ASTM D86, °F		Sulfur, D1266, %w	0.0007
I. B. P.	399	Mercaptan Sulfur, D1323, %w	nil
5%	403	Corrosion, Cu Strip, D130, 2 hr at 212°F	1B
10%	407	Aromatic Content, D1319, %v	0.8
20%	410	Bromine No. D1159	0.7
30%	413	Naphthalenes, F791, 3704T, %v	nil
40%	418	Smoke Point, D1322, mm	35
50%	423	Luminometer No., D1740	100
60%	428	Existent Gum, D381, mg/dl	1
70%	436	16-hr Potential Gum, D873, mg/dl	2
80%	450	Net Heat of Combustion, Btu/lb	
90%	471	ASTM D240 (Paar 2600 Modified)	18,905
95%	496	NBS 5917	18,886
E. P.	533	Hydrogen, D1018, %w	14.9
Residue, %	1.5	Copper, mg/liter	< 0.02
Loss, %	0.5	Nitrogen, ppm	< 5
Flash Point, TCC, D55, °F	164	Basic Nitrogen, ppm	< 0.3
Freezing Point, D1477, °F	-32	Peroxide No., D1563	< 0.04
Color Saybolt, D15	30+	Water Separometer Index, Severity 15	99
Viscosity, D445:		Light Transmission, % at 425 mμ	100
at 100°F	1.81	Sediment, mg/gal, 0.45 micron	
at 0°F	6.75	Average	4.6
at -30°F	12.9	Range, Eight Determinations	1.8-9.8
Aniline Pt, °F	182	Other	
Aniline-Gravity Constant	9227	Paraffins, %v Mass Spec	80
		Naphthenes, %v Mass Spec	19

Table 41. EFFECTIVENESS OF ADDITIVES IN IMPROVING THE COKER RATINGS OF F-68 JET FUEL

Based on SD/M-7 Coker ratings at 250 psig, air saturated fuel.

Additive	Volume Percent	Increase in Temperature (°F) at Equal Tube Code Rating							
		Liquid Temp. (°F):	600	625	650	675	700	715	725
MDA	0.67		0	-	-	-	-40	-	-
A	0.2		25	50	75	100	125	-	-50
A_1	0.25		-	-	-	-	125	-	-
A_1	0.20		-	-	-	-	-	130	-
A_2	0.20		-	-	-	-	125	-	-50
A_3	0.20		-	-	-	90	-	-	-
A_4	0.20		-	-	-	90	-	-	-
A'	0.20		-	-	-	100	-125	-	-
A_F	0.20		-	-	-	-	-	-	-140

Table 42. EFFECT OF ADDITIVE A ON SD/M-7 COKER RATINGS OF METHYLCYCLOHEXANE

(Air saturated, 250 psig)

Additive -	Percent	Temp., °F	ASTM Code, max/total
	-	450	1.0/7.5
-	-	475	1.5/9, 1/8.5, 1/5
-	-	500	8/32.5
A	0.2 + 65ppm Ionol	475	5/39.5
A	0.2 (Ionol-free)	475	6/26
A	0.2 (Silica gel treated)[a]	475	0/0
A	475 (Silica gel treated, then H_2O equilibrated)	475	3/10.5
Copper[b]	3130 ppm	425	1.0/9.5
Copper[b]	2920 ppm	475	1.5/6.0

a) Silica gel treatment to remove dissolved water.
b) Copper added as copper undecylenate.

Of course, we are most interested in thermal stability additives for endothermic fuels, and have therefore extended our investigations with additive A to MCH. The breakpoint of air-saturated MCH is about 480°F on the SD/M-7 fuel coker and rather sharp. Some of the experimental runs with MCH are shown in Table 42. The first run with MCH containing 65 ppm Ionol oxidation inhibitor was disappointing, in that it increased deposit formation. To test whether this was due to the large concentration of Ionol, we next ran a test with Ionol-free MCH, but with essentially identical results (Table 42). We then passed MCH through a silica gel column and repeated the test. As shown, additive A gave a deposit-free test at 475°F, compared to a code 1 rating without the additive. Presumably, this improvement was due to dissolved water having been removed. To test this hypothesis we put equal amounts of MCH and water together in a bottle on a laboratory shaker for 10 minutes, then carefully decanted off the MCH and added 0.2 percent of additive A to it. This sample gave a 3/10.5 SD coker rating. Although this was not as bad as the untreated MCH, it certainly demonstrated the deleterious effect of water on the additive. However, other reasons may exist for the improved response of MCH treated with silica gel to additive A such as the removal of other polar dissolved substances, or resinous or metallic particles with the gel acting merely as a depth filter.

To test the hypothesis that additive A acts by effectively removing suspended metal from the fuel, copper in the form of copper undecylenate was added to MCH. However, even the rather large amount of about 3000 ppm had no harmful effects on the rating of MCH (Table 42). Similar additions of 300 and 3000 ppm copper undecylenate to decalin had no effect whatever on coker ratings at 600 and 650°F, and the effect of additive A was not significant at 600 and 650°F (Table 43).

Table 43. EFFECTS OF ADDITIVE A AND COPPER UNDECYLENATE ON THE THERMAL STABILITY OF DECALIN

Additive	Concentration	Temp., °F	SD Coker Tube Rating, Max/Total
--	--	650	1.5/6.5
A	0.2	600	1.5/6.5
A	0.2	650	1.0/10.5
A	0.2	700	5/11.5
Copper[a)]	300 ppm	650	1.5/8.5
Copper[a]	300 ppm	650	1.5/9.5
Copper[a]	3000 ppm	650	1.5/6.5

a) Copper Undecylenate.

This strongly suggests that the action of additive A has nothing to do with the presence of dissolved copper, since copper appears to have no harmful effect on the thermal stability of decalin or MCH. It also suggests that the action of additive A may not be related to the catalytic activity of dissolved metals at all, but rather to the activity of metal surfaces or to some other dissolved species. There is yet the possibility that iron or nickel, perhaps present from the MCH synthesis catalyst, may be involved. Further work is needed in this area, since the A-type additives seem to provide a tool for studying thermal stability mechanisms in addition to their possible practical applications.

Since copper addition had no effect on the thermal stability of either decalin or MCH, actual tests of additive A with added copper were not tried. Instead, it is planned to try this approach in a fuel such as F-68 in which there is a marked benefit of additive A for the thermal stability.

Since these tests had been made on the SD/M-7 Coker, which operated on the recycle mode, a question arose as to whether the result we obtained with additive A was merely an artifact of the test method or perhaps of the fuels, since both fuels tested in the SD Coker were virtually 100 percent saturated. We therefore used a commercial production turbine fuel (F-187) in the Alcor JFTOT Fuel Test. Here we found the same kind and magnitude of benefits, however, without any treatment of the fuel in advance. Results of these preliminary tests are shown in Table 44.

Both the maximum tube temperature and the fluid effluent temperature are shown. In fact, as would be expected, the maximum code ratings for the nonadditive runs correlate with the tube temperatures rather than with the liquid temperatures. With reference to liquid temperatures, 0.1 percent of additive A increases the thermal stability of F-187 by about 117°F, but the metal temperature, which is more significant, is extended by 160°F. As before, additive A_F failed to give any improvement. We do not intend to screen any more compounds of the A-type at this time. Instead, the effectiveness and concentration effects of the six superior additives are being tested on the heat sink fuels from the current program and on a few pure hydrocarbon types. The improvement in the thermal stability of MCH by additive A after silica gel treatment suggests that we should look further at the effects of pre-purification treatments, and also together with antioxidants, anti-icants, corrosion inhibitors, and lubricity additives in selected cases. This will be combined with storage stability studies of the most promising combinations of additives and fuels. As soon as supplies of SHELLDYNE-H® fuel are available, work will be started to select the most desirable additives for this material.

Most of the future work will be done using the Alcor JFTOT Fuel Tester, so that realistic concentration requirements can be determined. The fuel makes over a hundred passes per test in the SD/M-7 coker but only a single pass through the hot test zone in the JFTOT. Hence, testing in the JFTOT may indicate a greater effectiveness for the additive and a higher temperature or lower concentration requirement for its use, especially if the additive is limited by its own thermal stability.

Table 44. EFFECT OF ADDITIVE A ON ALCOR JFTOT FUEL TEST RATINGS OF F-187 TURBINE FUEL

Additive - Percent		Temperature, °F		ASTM Ratings, maximum code
		Max. Tube	Liquid Effluent	
A	- 0.16	579	411	0
A	- 0.1	605	437	0
A	- 0.1	680	485	1
A	- 0.1	728	505	1.5
A	- 0.1	724	528	2
A_F	- 0.1	724	528	8
--	--	568	411	2
--	--	580	408	3
--	--	575	409	2.5

Research on additives for improving the thermal stability of fuels is continuing in several directions:

1. The relationship of additive concentration to temperature level will be investigated.
2. Suitability of additives of this type to various other endothermic fuels will be explored, together with some study of the effect of fuel hydrocarbon type composition.
3. Possible interaction problems with other jet fuel additives and common impurities will be examined.
4. Interaction effects with catalyst systems now under study will be investigated.
5. Possible deleterious side effects may be uncovered, particularly with respect to other fuel properties and storage stability.
6. Studies of the theory and mechanism of deposit formation as related to the action of A-type additives will be pursued.

Hydrocrackate Jet Fuels

Modern refinery processing has progressed to the point that certain processed hydrocarbon mixtures may be sufficiently high in naphthene content to be good endothermic fuel candidates. Accordingly, we have measured the thermal stability of hydrocrackate jet fuels.

Hydrocracking is generally a two-stage process which is designed to reduce the molecular weight of gas oil components under hydrogenating conditions to produce fractions which can be incorporated into gasoline and jet fuels. This process is coming into increasing use, and will be relied upon more and more to supply the increasing demand for jet fuels in the future. Since hydrogen requirements and operating conditions are directly related to the amount of aromatics left in the hydrocrackate, economics demands the highest permissible aromatic content in the jet fuel boiling range. This could have an adverse effect on thermal stability. On the other hand, deep hydrocracking might produce a very stable fuel. Since there are no published data available on this subject, we have obtained two samples from the Shell Emeryville pilot plant operation, one from each stage, having 30 and 10 percent aromatics contents (designated F-155 and F-156, respectively). The former could be used for blending purposes with a predominantly paraffinic straightrun material, and the second might be used as fuel directly.

A series of SD/M-7 Coker runs on these two samples are shown in Table 45, from which code 2.5 tube rating breakpoints of 405 and 355°F were estimated; the high aromatics sample from the first stage (F-155) was the more stable fuel, which was a surprising result. Both ratings are better than specifications for jet fuels; the 405°F breakpoint is characteristic of a good jet fuel. Filter plugging tendencies were actually more limiting than tube deposits, reaching values of 13 inches of mercury for pressure drops at 350°F for both samples. No fuel additives were included, and since these are samples from a rather small pilot plant they are merely suggestive of what would be produced from commercial scale plants. No further work in this area is planned at this time.

Table 45. SD/M-7 COKER RATINGS OF HYDROCRACKATE JET FUELS

Fuel	Temperature, °F	Filter Pressure Drop,[1] psi	ASTM Code Ratings[1] max./total
F-155	500	40	8/35
F-155	425	12.4	5.5/18.5
F-155	425	74.4	5/20
F-155	425	100	4/18
F-155	400	--	(2.5/8)
F-155	375	24.1	0.5/9.5
F-155	350	7.7	0/10
F-155	325	0.5	1/6
F-155	405	--	(2.5/10.5)
F-156	425	35.4	8/35
F-156	400	53.7	4/14
F-156	350	5.5	1/4
F-156	325	1.6	2/8
F-156	355	(6.4)	(2.5/10)

1) Bracketed values are interpolations to obtain breakpoint temperatures.

Modifications and Assembly of Thermal Stability Apparatus

The ancillary equipment for the special high severity "barebones" JFTOT received from the Alcor Corporation has now been installed, including a constant speed pump, watt meter, and pressure transducer. The constant speed pump consists of a Zenith No. 1/2 pump driven by a 1/50 h.p. Bodine motor. However, this motor is slightly underpowered and we have now installed a Minarik Electric speed and torque controller, which has overcome this problem. The pump normally turns at 10 rpm, but is capable of flows four times that rate.

Temperature is controlled at the maximum tube temperature point, which is 0.85 inch from the discharge end for aluminum tubes and 0.6 inch for stainless and ordinary steel. A Guardsman West Controller is being used satisfactorily in this application. We have also installed a liquid effluent thermocouple in the discharge hole of the preheater with readout on a Honeywell strip recorder.

Nitrogen pressure on the system is read on a Heise Gage (0-1,000 psig), while the filter pressure drop is measured by a 0-5 psi Stratham Pressure Transducer and read out on another Honeywell strip recorder. Nitrogen pressure is controlled by a simple two-stage Victor regulator.

Voltage to the pump motor and preheater Variac is supplied by a Stabiline Automatic Voltage Regulator capable of controlling to ± 1/20 volt. All other equipment is the same as supplied by Alcor Inc.

Besides the standard aluminum tubes, tubes made of stainless steel and No. 1015 steel already have been obtained and tested. The steel tubes all appear to give more severe ratings than does aluminum, but several factors complicate this comparison, such as temperature profile and metal color change, so that true comparison awaits the proper application of the beta-ray backscatter deposit analyzer. Other metals such as Inconel, nickel, and Incoloy are also being obtained for comparison studies in JFTOT tubes. A complete list of tube metals now on hand as JFTOT tubes is shown in Table 46. Except for Haynes 25, these and aluminum have been run on a Jet-A type fuel for evaluation of catalytic effects of metals on fuel deposition tendency. The tubes are currently being rated by the beta-ray backscatter technique, and will be rated afterwards by combustion for confirmation. Calibrations on the various metals are still being made using 1000 Å nitrocellulose film. Following satisfactory completion of this work, the effect of these different tube metals will be determined on MCH.

Assistance was obtained from Alcor Inc. and from Pratt and Whitney, East Hartford, Connecticut, on obtaining some of these special materials. In general, tubing with a 3/16" OD and approximately 0.68" ID for fabricating these tubes is difficult to locate. Alcor Inc. has manufactured coker tubes by attaching 3/16" end pieces of gold-plated brass to the desired 1/8" test section, and we have obtained two of these tubes for testing. We are not sure whether the brass, although gold-plated, is entirely innocuous in the deposition mechanism.

The high temperature version of the JFTOT which we obtained was designed for operation up to 1000°F and 1000 psig. So far we have only operated the rig at 300 psig, and the highest tube temperature we have tested has been 724°F (528°F liquid effluent temperature). At this temperature and even lower, the tube becomes

Table 46. COMPOSITION OF TUBE METALS FOR JFTOT

Tube Metal	Typical Composition, %										
Metals in Stock	Ni	Co	Cr	Mo	Fe	C	Al	Cu	Mn	W	Si	Other
Hastelloy Alloy C1)	54.6	2.5	15.5	16	5	0.08	--	--	1.0	4	1.0	0.35 V
Seamless Monel 4002)	65.173)		--	--	1.2	0.13	--	32.33	1.05	--	0.09	0.008 S
Inconel Alloy 600	72.03)		15.5	--	10	0.15	--	0.5	1.0	--	0.5	0.015 S
316 Stainless	13.28	--	16.75	2.50	65.14	0.05	--	--	1.73	--	0.51	0.035 P + S
304 Stainless1)	9	--	19	--	72	0.08	--	--	--	--	--	--
446 Stainless	--	--	25	--	75	0.35	--	--	--	--	--	--
Nickel 2002)	99.563)		--	--	0.04	0.06	--	0.01	0.26	--	0.04	0.005 S
Cartridge Brass	30	--	--	--	--	--	--	70	--	--	--	--
1015 Steel	--	--	--	--	99.85	0.15	--	--	--	--	--	--
TD Nickel 1)	2 percent by volume Thorium Oxide dispersed in Ni											
L-605 (Haynes 25)	9.90	51.75	19.85	--	1.60	0.12	--	--	1.65	15	0.60	0.015 P + S

1) These tubes are also on hand in aluminized form.
2) Compositions for these alloys are measured values.
3) These values are the combined nickel-cobalt compositions.

bent during the run so that it is no longer concentric with the outer shell. Of course, this is due to the thermal expansion of the tube, which is restricted by the clamping restraints of the end seals. This event seems to cause an actual change in the temperature difference between the tube control point and the liquid effluent during the course of the run.

We have attempted to overcome this problem by substituting the rubber O-ring seals with TEFLON® seals, which are more slippery, and applying a high electrically conductive lubricant to the electrical end clamps, in the hopes that the inner tube might slip during expansion. However, to provide good electrical connection with the aluminum tubes the clamping must still be too tight to allow for slippage during thermal expansion, and the tubes still bend. Perhaps with steel tubes this approach may work, but some redesign might be required. The bending can be particularly bothersome with the beta-ray backscatter device since it alters the distance from the source to the tube. This causes a sinusoidal fluctuation in the recorder output even on bare metal and if extreme would preclude the use of this method.

Several comparisons have been made between the JFTOT and ASTM methods on the same commercial turbine fuels, as shown in Table 47. These are all production fuels of recent date. The two methods are within 1/2 code number of each other generally, and at least as close as the probable repeatability of either method.

Two runs on the same F-187 fuel using stainless steel JFTOT tubes are also included for comparison. However, until these tubes can be rated by the beta-ray backscatter method, the true relative effects of aluminum and stainless steel will not be known, since the steels themselves change color on elevated heating. We do know from preliminary tests that a code 2 1/2 rating on a stainless steel tube was found by beta-ray backscatter measurement to have a thickness of less than 50 Å, while a code 1/2 deposit on aluminum with a whitish appearance (normally thought to be thinner) could be readily observed.

Recent experience with the Alcor JFTOT Fuel Tester showed that we were experiencing errors in control temperatures due to worn insulation on the control thermocouple. This emphasizes the need to inspect carefully and regularly the condition of the insulation after each run and to replace the thermocouple as needed.

To improve the accuracy of our tube metal temperatures, we have installed a double thermocouple, one which actuates the West temperature controller and one which reads out on a millivolt strip chart recorder. The latter is much more accurate and readable than the West controller dial and is not sensitive to thermocouple resistance. Liquid temperatures are also read out on a strip chart recorder as before. We believe the millivolt strip chart recorder is a more accurate instrument for the measurement of temperatures than the digital Honeywell recorder used as standard equipment with the Alcor Fuel Tester.

SD/M-7 Fuel Coker

A Beckman Oxygen Analyzer (Model 778) has been installed on the SD/M-7 Fuel Coker. However, this instrument is limited to operation at or below 50 psi maximum pressure, and hence cannot be used continuously throughout the test period.

Table 47. COMPARISON OF RATINGS BY THE JFTOT AND ASTM METHODS

Fuel	Fluid Temperature, °F	Test Method	Max. Visual Code Ratings
F-185	418	JFTOT	4
F-185	417	ASTM	4
F-185	420	ASTM	4
F-187	420	JFTOT	3
F-187	411	JFTOT	2
F-187	411	JFTOT	3
F-187	409	JFTOT	2.5
F-187	408	JFTOT	3
F-187	420	ASTM	3.5
F-187	415	ASTM	3.5
F-187	415	ASTM	1.5
F-187	410	ASTM	1.5
F-187	410	ASTM	0
F-187	410	JFTOT (stainless)	6
F-187	411	JFTOT (stainless)	4

Since the test method depends upon diffusion of oxygen through a semipermeable membrane, the flow velocity of the test fuel past the detector head must be maintained at a minimum of 1.8 ft/sec. To accomplish this a special fitting with a restricted passage was designed and built. The analyzer actually meas[illegible] the oxygen partial pressure, and therefore the pressure at the pickup mus[illegible] known to permit calculation of O_2 in ppmw. Static pressure at the pi[illegible]eing measured with a Statham pressure transducer readout system. Pressure drop across the restricted passage has been determined to be about 0.4 psi, and so the pressure at the pickup is simply taken to be 0.2 psi less than the upstream pressure reading. This is a trivial correction.

Currently the oxygen can only be measured at the beginning and end of the test, that is, before and after operating at high pressure. After measurement of O_2 concentration, the detector, which is located on a by-pass leg at the discharge end of the pump, is isolated from the rest of the system for the remainder of the coker run. This is an undesirable condition, but it will suffice until a detector is designed and built which will withstand greater pressures.

STORAGE STABILITY OF MCH AND SHELLDYNE-H® FUELS

Storage stability tests which were started over four years ago have been completed and the results evaluated. At that time samples of pure MCH were stored in the 130°F hot room. Samples were packaged in one gallon epoxy lined pails with a 2:1 ullage ratio with oxygen concentrations from pure O_2 to pure N_2. Several phenolic and diamine type oxidation inhibitors were included, as well as MDA, in some of the samples, while control samples contained no additives at all.

Examination of the samples for soluble and insoluble gum gave no indication of deterioration in any of the samples during this period of storage. No insolubles were observed in any case and steam jet gums were less than 1 milligram per deciliter. No indication of discoloration was observed. Finally, coker tests showed no loss whatever of thermal stability. In fact, the actual ratings were better than those obtained on the fresh material prior to this severe exposure.

The storage stability of SHELLDYNE-H® fuel over a shorter period has also been investigated in accelerated tests. Three different batches of SHELLDYNE-H® fuel with minor differences in bromine number have been exposed to 200°F constant temperature for 18 and 30 hours. Three different oxidation inhibitors were tested in comparison with the nonadditive material, and all samples were blanketed with pure oxygen. Exposed samples were examined for both soluble and insoluble gums.

Unfortunately, results of these tests showed no consistency, either with respect to exposure time or to the presence of inhibitors (Table 48). Apparently an unknown factor was influencing the results; the 450°F temperature of the standard steam jet was probably too low to drive off all the SHELLDYNE-H® fuel. Accordingly, the steam jet temperature was raised to 500°F and the results were more consistent. However, even on this basis the results are quite erratic and it is possible that some other factor is affecting the results.

On the basis of our present results, it appears that the phenolic inhibitor 24M6B (duPont 22) is the most efficacious antioxidant for this fuel.

Table 48 follows

Table 48. STORAGE STABILITY OF SHELLDYNE-H® FUEL

Oven Tests at 200°F Under O_2 Blanket

Shelldyne-H® Sample Designation	0 - Hours			18 - Hours					30 - Hours			
	Insolubles ex Solvent mg/dl	Solubles ex Filtered Fuel-450°F mg/dl	Total Gum, mg/dl	Insolubles ex Solvent mg/dl	Solubles ex Filtered Fuel, mg/dl		Total Gum, mg/dl		Insolubles ex Solvent mg/dl	Solubles ex Filtered Fuel, mg/dl		Total Gum, mg/dl
					450°F	500°F	450°F	500°F		450°F	500°F	
F-151												(500°F)
Ionol®	0.4	14.6$^{a)}$	15.0$^{a)}$	0.0	3.2	5.4		5.4	0.0	16.2$^{a)}$	6.4	6.4
duPont 22	0.8	5.8	6.6	1.3	5.8	4.2		5.5	0.0	5.6	3.0	3.0
duPont 30	0.6	6.0	6.6	0.0	16.6$^{a)}$	3.8		3.8	0.4	9.2	5.6	6.0
—	0.2	20.8$^{a)}$	21.0$^{a)}$	0.6	15.2$^{a)}$	6.0		6.6	0.8	10.6	11.4	12.2
F-158												
Ionol	0.4	13.2$^{a)}$	13.6$^{a)}$	5.8	12.2$^{a)}$	—	18.0		0.6	—	—	—
duPont 22	0.4	10.4	10.8	2.4	2.2	—	4.6		0.0	5.0	0.0	0.0
duPont 30	0.0	9.4	9.4	13.3$^{a)}$	8.2	—	21.5		0.0	0.8	0.2	0.2
—	5.2	0.2	5.4	0.0	7.8	—	7.8		0.2	7.0	7.0	7.2
F-157												
Ionol	0.4	1.0	1.4	0.0	6.4	—	6.4		1.2	5.2	3.0	4.2
duPont 22	0.6	2.4	3.0	5.6	10.4	1.0		6.6	0.4	1.0	2.4	2.8
duPont 30	0.2	2.6	2.8	9.3	4.8	—	14.1		0.4	5.4	—	5.8
—	0.2	1.6	1.8	6.7	7.0	—	13.7		0.8	3.4	5.0	5.8

a) Highly suspect data: values unrealistically high.

Elastomer Interactions With SHELLDYNE-H® Fuel

Three SHELLDYNE-H® fuel samples, which were exposed to different elastomers by Atlantic Research Corporation (contract F33615-69-C-1849), have now been tested further to determine any possible solution of elastomer or leaching of plasticizer during this exposure. In Figure 37 it is shown that the U.S. 941 Viton/Nomex nylon had the maximum effect on the light transmission properties of SHELLDYNE-H® fuel in the 335-375 millimicron wavelength range, although curiously the U.S. 3094 Viton gave the only significant change in refractive index as compared to the original stock (see Table 49). Results of microgum analyses, which indicate the amount of high boiling materials present, are shown in Table 49. These were run at 260°C under vacuum, at which conditions about 0.8 mg. carbon/100 g sample was obtained with the unexposed fuel. Fuel exposed to either U.S. 941 Viton/Nomex nylon or U.S. 3094 Viton gave about double this amount, but only the sample in contact with U.S. 566 Nitrile Nylon gave markedly higher results (20 times as much).

Table 49. MICROGUM AND REFRACTIVE INDEX ANALYSES OF SHELLDYNE-H® FUEL SAMPLES SOAKED WITH ELASTOMERS FOR A PERIOD OF SIX MONTHS

Elastomer	Microgum (expressed as carbon) mg/100g SHELLDYNE-H® Fuel	n_D^{20}
none	0.8, 0.9	1.5396
U.S. 941 Viton/Nomex Nylon	1.6, 1.8	1.5394
U.S. 3094 Viton	1.6, 1.9	1.5385
U.S. 566 Nitrile Nylon	15.6, 16.6	1.5394

Thus, three different methods have each selected a different elastomer as the one having the most interaction with SHELLDYNE-H® fuel. Nitrile nylon apparently contributes the most heavy material to SHELLDYNE-H® fuel, although this material apparently has a smaller effect upon light transmission and refractive index than do the impurities from the other two elastomers. This suggests the possibility of micelle or suspended solids formation in the Nitrile nylon sample, which visual inspection in room light confirmed. Both a yellow tint and a slight turbidity were observed. The other three samples were all water white and free of apparent solids content. Since neither micelles nor solids affect transmission of light of short wavelength appreciably, the more minor effect of the Nitrile nylon on refractive index and light absorption is at least partially explained.

In a final series of tests, the four samples of SHELLDYNE-H® fuel of Table 49 were run by GLC analysis. The three samples which had been soaked with elastomers all showed a small unidentified peak representing about a 0.1 percent impurity, which was not present in the original stock. Other than that, the elastomer soaked SHELLDYNE-H® fuel samples all gave similar GLC analyses. The impurity could either have been introduced to the original material in handling prior to soaking, or might have come from the polymer film (which appeared to be polyethylene or polypropylene) which had been placed over the shipping bottles prior to capping.

Figure 37 follows

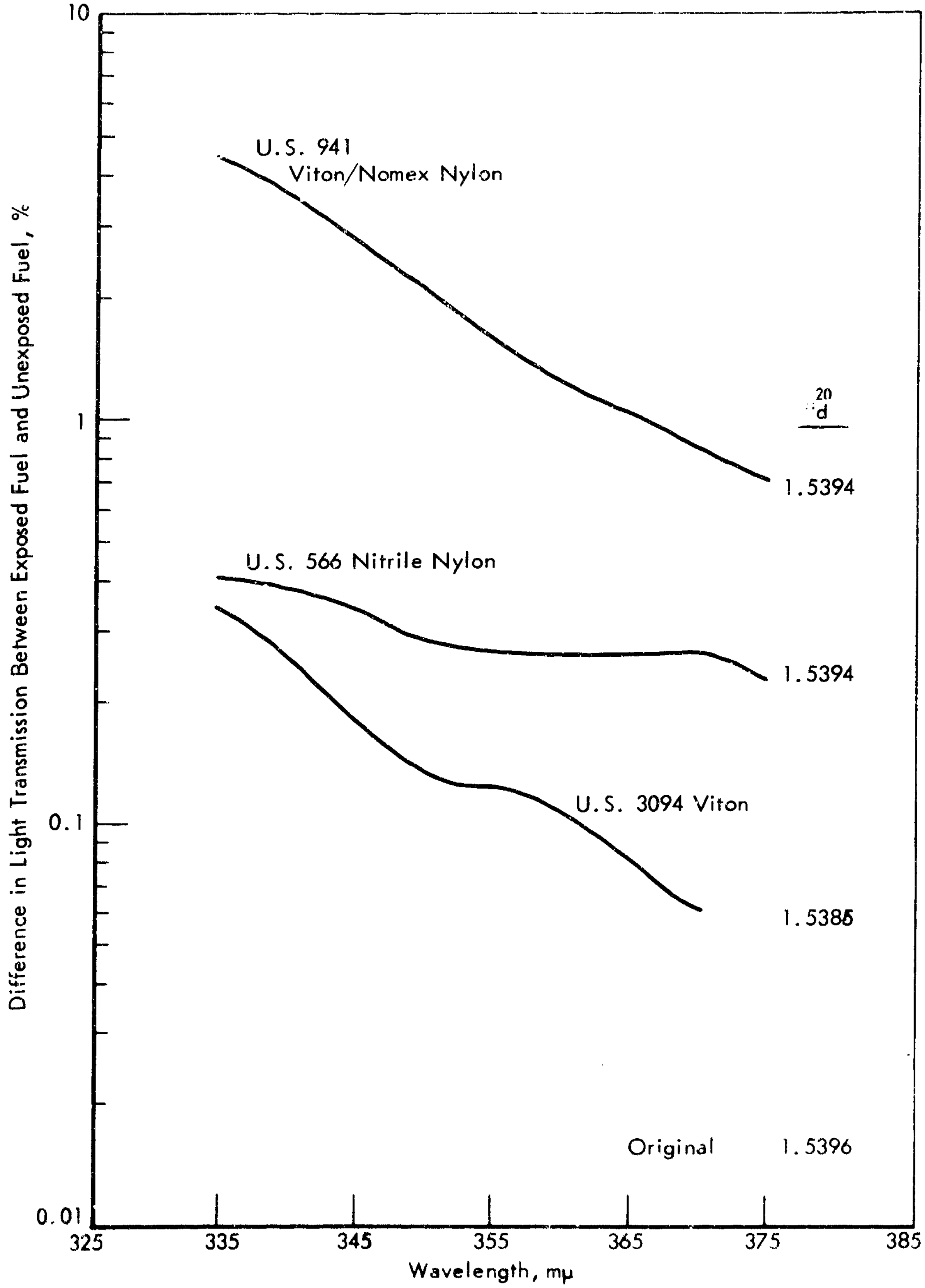


Figure 37. EFFECT OF EXPOSURE OF SHELLDYNE-H® FUEL (F-157) TO DIFFERENT ELASTOMERS

Whatever effect this film might have had, it probably would have been the same for all three elastomer soaked samples. The fresh SHELLDYNE-H® fuel came from our own retainer stock and was not exposed to the film. For the GLC procedure used, in which the sample size was 1 microliter, the detection limit is about 0.01 percent, unless the small impurity peaks are close to one of the larger peaks, in which case sensitivity would be much less.

In summary, we feel that the microgum test gives the more significant results with regard to compatibility of these elastomers with SHELLDYNE-H® fuel. From previous experience with SHELLDYNE-H® fuel it has been shown that light transmission properties do not necessarily correlate with coker test results. The reduction in light transmission indicates the presence of trace contamination, but thermal stability tests would be required to demonstrate any adverse effect on the fuel.

THERMAL STABILITY OF NEW BATCH OF METHYLCYCLOHEXANE

A new batch of 1200 gallons of MCH has been made by hydrogenation of toluene, and on checking this material for thermal stability it was found to be defective when compared to the MCH remaining from the last production run. It appeared that the cause of the poor thermal stability ratings was due to presence of suspended nickel catalyst particles, although this is surprising since the MCH had been distilled. Refractive index determinations of the twelve drums of product showed no variations whatever. SD/M-7 coker tests at 475°F demonstrated that silica gel treatment brought the fuel up to standard and that filtration through a 0.45-micron membrane filter gave even greater improvement. Thus, two methods for upgrading were available. We are now, therefore, filtering the MCH through a 0.2-micron membrane filter, and will blend the new material with the MCH now in the storage tank as soon as coker tests confirm a high thermal stability. This method of upgrading is comparatively simpler and cheaper than that of silica gel treatment.

ESTIMATION OF PHYSICAL PROPERTIES OF FUELS

JP-7 Jet Fuel

Revised physical properties for JP-7 jet fuel (F-71) have been obtained using improved predictive methods and are given in the Appendix. These techniques were used in estimating physical properties for decalin and JP-5 jet fuel.[3] The PVT behavior of the gas was represented by the Redlich-Kwong-Ackerman reduced equation of state:[19]

$$Z = Z_{RK} + Z_1 + \omega Z_2 \tag{13}$$

where Z = compressibility factor

Z_{RK} = compressibility factor calculated by the Redlich-Kwong equation of state[20]

ω = acentric factor

Z_1, Z_2 = generalized functions of reduced pressure and temperature

The ideal gas heat capacity was represented by the group contribution method of Rihani-Doraiswamy:21)

$$c_p^\circ = a + bT + cT^2 + dT^3 \qquad (14)$$

where c_p° = ideal gas heat capacity
a,b,c,d = parameters determined by group contributions

Most of the other gas properties were obtained from these two properties using thermodynamic relationships.

Chemical analyses indicated that JP-7 is composed primarily of paraffins in the C_{11} to C_{16} range. Hence, the critical properties of the normal paraffins in this molecular weight range were used to obtain pseudocritical properties for the jet fuel. Pseudocritical temperature and pressure were defined as

$$T_c = \sum_i y_i T_{ci} \qquad (15)$$

$$P_c = \sum_i y_i P_{ci} \qquad (16)$$

where y_i = mole fraction of component i
T_{ci}, P_{ci} = individual component critical properties

In addition, the acentric factor was obtained from experimental vapor pressure data, and the Rihani-Doraiswamy coefficients for the fuel were taken as molar averages of the coefficients for the individual normal paraffin components.

Liquid properties were revised in the following manner. Previous estimates of density were corrected to agree with an available experimental density at 60°F and the critical density as predicted by the equation of state. Liquid enthalpy and heat capacity, being based on the revised gas properties, were also revised:

$$H_l = H_g - \Delta H_v \qquad (17)$$

$$c_{pl} = c_{pg} - \frac{d(\Delta H_v)}{dT} \qquad (18)$$

where H_l, H_g = liquid and gas enthalpy, respectively
c_{pl}, c_{pg} = liquid and gas heat capacity, respectively
ΔH_v = enthalpy of vaporization

Also, revised values of liquid thermal conductivity were obtained by the Robbins-Kingrea correlation.[22] Previous estimates of vapor pressure, enthalpy of vaporization, and liquid viscosity were left unchanged.

The revised properties are considered to be better than previous values,[2] because the most recently proven correlations have been used and experimental data have been applied where possible. They agree well with published or predicted values for similar petroleum fractions. The greatest improvement has been made with liquid heat capacity and thermal conductivity. Comparison with heat transfer experiments made previously in the FSSTR[3] showed that the new heat capacity values are far superior to the old values.

Binary Mixtures of Methylcyclohexane and a Low Molecular Weight Hydrocarbon

Physical properties were estimated for binary mixtures of methylcyclohexane (MCH) and a low molecular weight hydrocarbon. These properties are tabulated in the Appendix for mixtures containing ethane, propane, and n-butane. Mixture properties were estimated from known properties of the individual constituents.[3,23]

The following properties were calculated as molar averages of the pure component properties:

Pseudocritical Temperature
Pseudocritical Volume
Pseudocritical Compressibility Factor
Acentric Factor
Heat of Formation
Net Heat of Combustion
Liquid Specific Gravity
Vapor Pressure

The above pseudocritical properties were used to calculate the pseudocritical pressure by the equation of state

$$P_c = \frac{RT_cZ_c}{V_c} \qquad (19)$$

where
P_c = pseudocritical pressure
T_c = pseudocritical temperature
Z_c = pseudocritical compressibility factor
V_c = pseudocritical volume
R = universal gas constant

The liquid viscosity was calculated by a molar average of the logarithimic function of viscosity:

$$\ln \mu = \sum_i x_i \ln \mu_i \qquad (20)$$

where μ = viscosity of mixture
μ_i = viscosity of pure component i
x_i = mole fraction of component i

The mixture enthalpy was estimated as the molar average of the pure component enthalpies at those conditions where both components are gases or liquids in their pure state. Nonideal mixing effects are not appreciable in these systems and were neglected in the calculations. At those conditions where the mixture is a gas dissolved in MCH, the calculated enthalpy was reduced to account for the heat of absorption of the gas.

The melting points for the mixtures are based on experimental data for mixtures of MCH and propane. Melting and freezing points were measured for MCH-propane mixtures of three different compositions (Figure 38). An equation of the Clausius-Clapeyron type can be used to relate composition and melting point:

$$\frac{1}{T_f} - \frac{1}{T_{fo}} = \frac{R}{\Delta H_f} \ln x_{MCH} \qquad (21)$$

where T_f = melting point of mixture
T_{fo} = melting point of MCH (-126.6°C = 146.6°K)
ΔH_f = heat of fusion of MCH
x_{MCH} = mole fraction of MCH

$$K_f = \frac{RT_{fo}^2}{\Delta H_f} = \text{melting point depression constant} \qquad (22)$$

Equation (21) can be approximated by

$$T_f - T_{fo} = -\frac{RT_{fo}^2}{\Delta H_f} (1 - x_{MCH}) \qquad (23)$$

Linear regression of the data was used to determine empirical coefficients for Equations (21) and (23) with the following results. For Equation (21)

$$\frac{1}{T_f} - \frac{1}{T_{fo}} = -\frac{K_f}{T_{fo}^2} \ln x_{MCH} \qquad (24)$$

where $K_f = 35.14°K$

For Equation (22)

$$T_f - T_{fo} = -K_f' (1 - x_{MCH}) \qquad (25)$$

where $K_f' = 40.86°K$

If the known heat of fusion (16.43 cal/gm)[24] is used in Equation (22), the theoretical melting point depression constant is found to be 26.47°K, quite different from the above values. Melting points predicted with this theoretical constant differ significantly from the data (Figures 38 and 39). Both Equations (24) and

Figures 38 and 39 follow

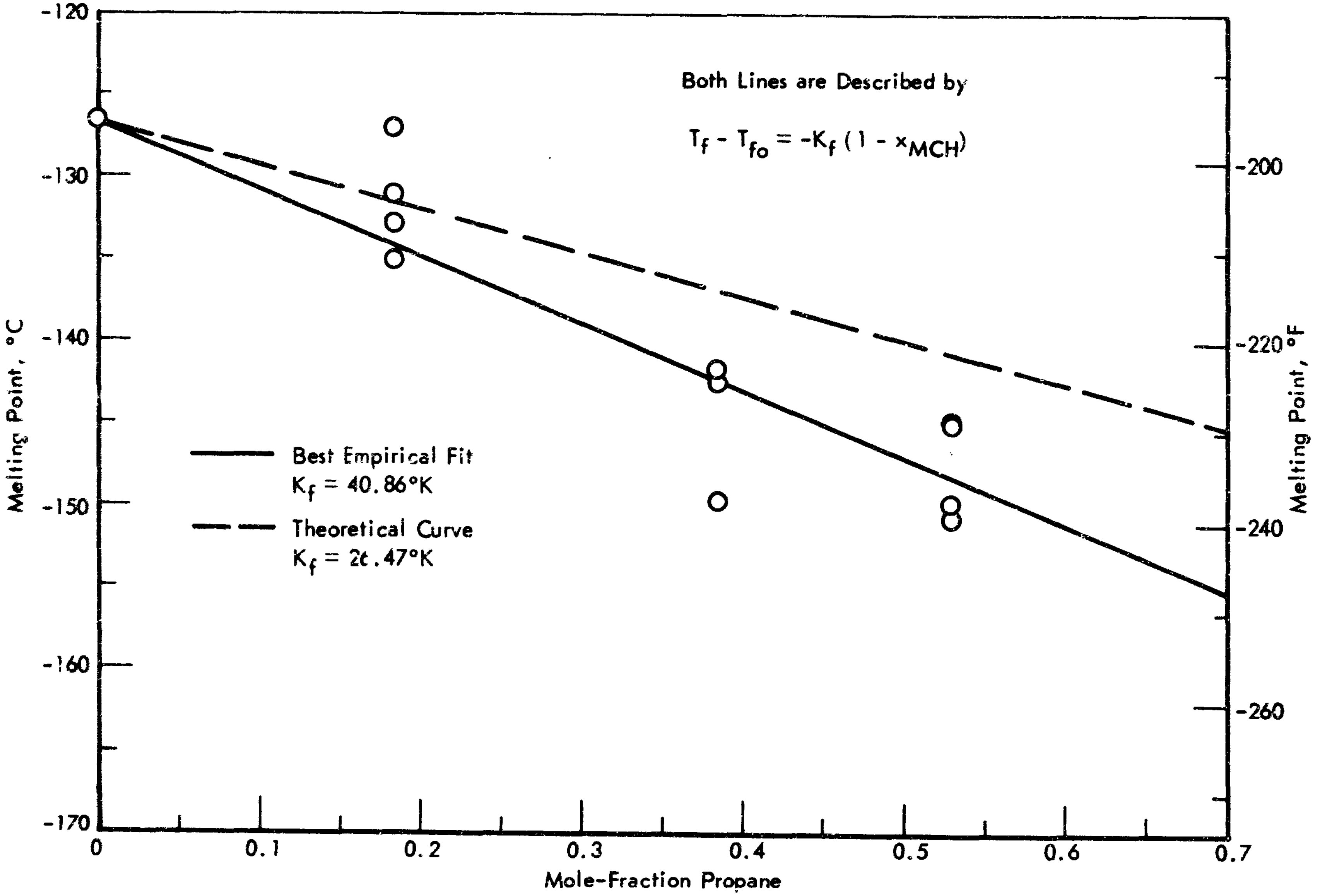


Figure 38 MELTING POINTS OF METHYLCYCLOHEXANE-PROPANE MIXTURES

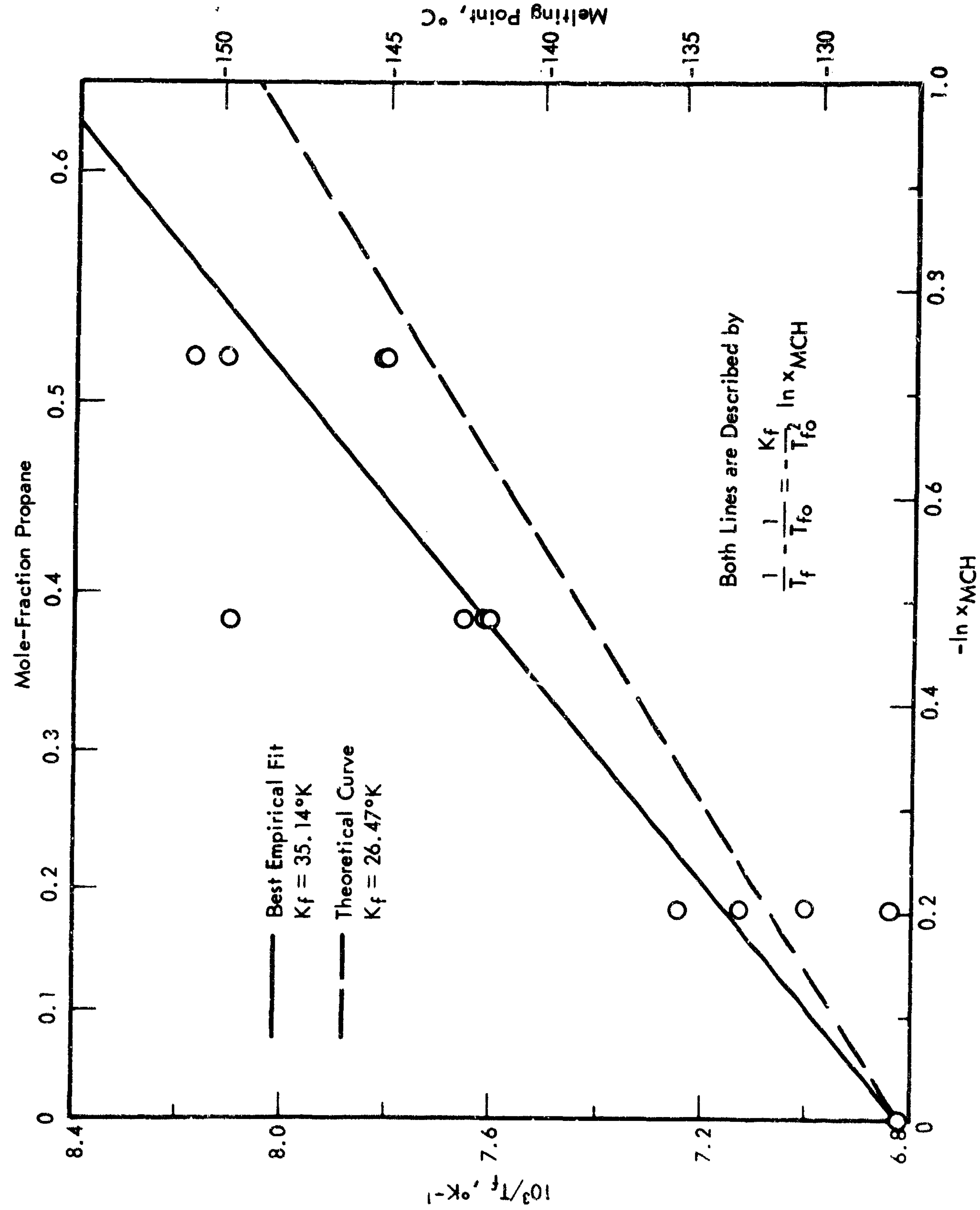


Figure 39. MELTING POINTS OF METHYLCYCLOHEXANE - PROPANE MIXTURES

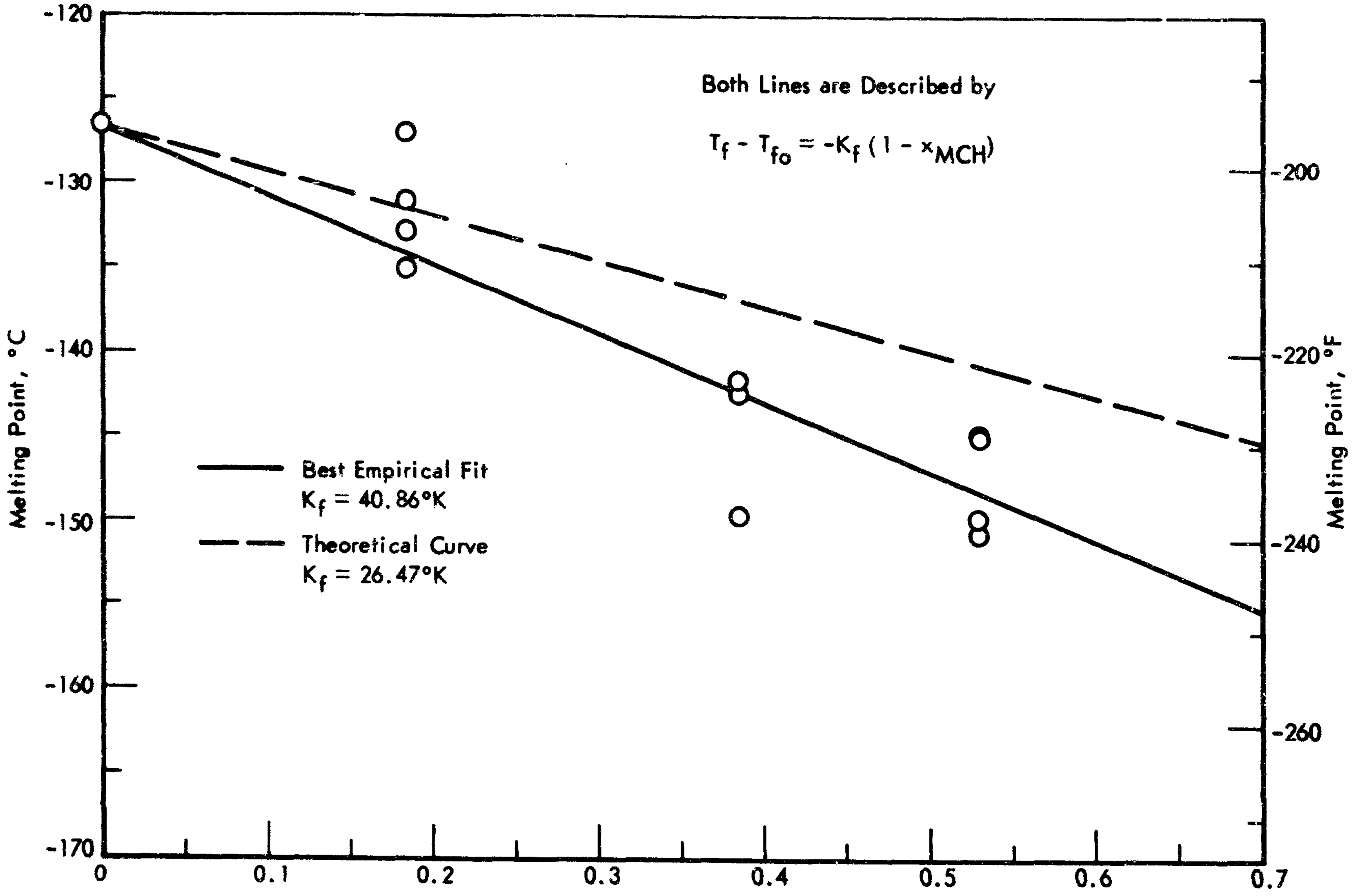


Figure 38. MELTING POINTS OF METHYLCYCLOHEXANE-PROPANE MIXTURES

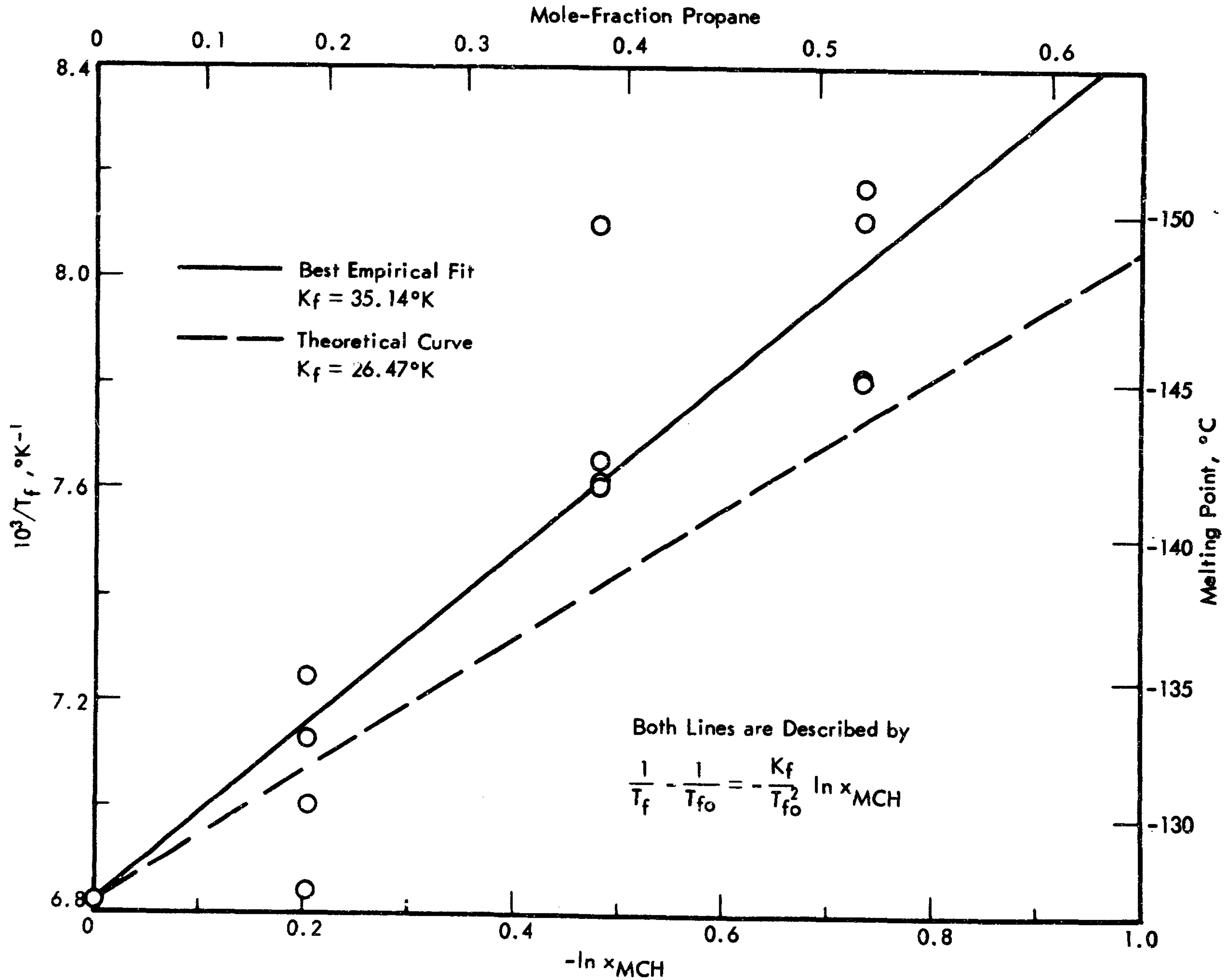


Figure 39. MELTING POINTS OF METHYLCYCLOHEXANE - PROPANE MIXTURES

(25) with the empirical coefficients lie within the accuracy of the data; they fit the data better than the theoretical predictions. Since Equation (25) is simpler, it was chosen to represent the melting points of low molecular weight hydrocarbons mixed with MCH. Calculated melting points are listed with the other physical properties of these mixtures in the Appendix.

SHELLDYNE-H® Hydrocarbon Fuel

The surface tension of SHELLDYNE-H® fuel has been measured at three temperatures by the du Nouy ring method. These data correlated quite well to fit

$$\gamma = a\ (T_c - T)^n \tag{26}$$

where γ = surface tension (dyne/cm)
T = temperature (°C)
T_c = critical temperature (530°C)
a = 0.010
n = 1.33

Measured and extrapolated values of the surface tension are given in Table 50 and Figure 40.

Table 50. SURFACE TENSION OF SHELLDYNE-H® FUEL

T, °C	Surface Tension (dyne/cm)	
	Measured	Predicted
0		42.0
25	39.4	39.4
50	36.7	36.8
75	34.3	34.3
100		31.8
200		22.4
300		13.8
400		6.5
500		0.9
530		0

SUPERSONIC COMBUSTION OF HYDROCARBONS

The methods used in obtaining and analyzing our supersonic combustion data have been re-evaluated. Some improvements in the equipment have been made. A new equation has been used to correlate the ignition delay times. Some new experimental data have been obtained. The rate of combustion of tetralin has been investigated.

Figure 40 follows

Experimental Equipment and Conditions

Several problems have been encountered in operating the shock tube with heavier hydrocarbon fuels. The tube had to be heated to 40-80°C. The resulting thermal stresses were hard on the resistance gauges which were used to measure the velocity of the shock wave. As constructed, the gauges were somewhat fragile. They consisted of a thin layer of platinum which had been sputtered onto a quartz disc encased in Bakelite. The differences in thermal expansion and the structural weaknesses led to frequent cracking and shorting. A sturdier device was designed and built. A similar design was used but the Bakelite body was replaced with aluminum. The quartz disc was replaced with Grade A Lava ceramic glued into the body with an epoxy resin. The platinum film was painted on as Liquid Bright Platinum, Hanovia No. 05-X. The improved resistance gauges have proved to be more reliable and have about the same dynamic response as the more fragile gauges used previously.

The mechanism for puncturing the shock tube diaphragms had to be modified by replacing the gasket with one able to withstand higher temperatures. A nylon tip is now used on the plunger which has improved the life and reliability of the plunger.

In order to prepare gas mixtures containing naphthalene, the mixture preparation system was modified. The hydrocarbons investigated to date have been gaseous or liquid at ambient conditions. Naphthalene, being a solid, presented a problem. The solution was to mount a tube, which could be isolated and removed, above the mixture cylinder. A schematic diagram of the system is shown in Figure 41. With the cylinder heated and evacuated, and the tube cold and detached at valve No. 1, a weighed amount of naphthalene crystals is added to the tube. The tube is then fastened to valve No. 1 and is evacuated by opening valve No. 1 to vacuum. When the air has been withdrawn, valve No. 1 is closed, valve No. 2 is opened, and the tube is heated to vaporize the naphthalene and drive the vapors into the cylinder. The other gases are added to the cylinder through valves No. 1 and No. 2 in the normal way.

The experimental data obtained have been on those hydrocarbons involved in the dehydrogenation of decalin, namely decalin, tetralin, and naphthalene. A summary of the conditions of the experiments is presented in Table 51. The complete data on ignition delay times may be found in the Appendix. The data have been obtained primarily at 9 psia and 15 psia and temperatures from 1140° to 1760°K, resulting in ignition delay times from 40 to 4000 μsec.

Shock Tube Attenuation

An attempt was made to improve the shock tube results by accounting for velocity attenuation by measurement. The results have shown that assuming an attenuation coefficient of 1×10^{-3}, constant for all conditions, is the most reasonable procedure.

There are many non-idealities in shock tube flow. One of these is the decrease in the velocity of the shock wave as it moves down the tube, caused by the build-up of a boundary layer at the wall of the tube. A review of wall effects has been made by Emrich and Wheeler,(25) where they present the attenuation equation:

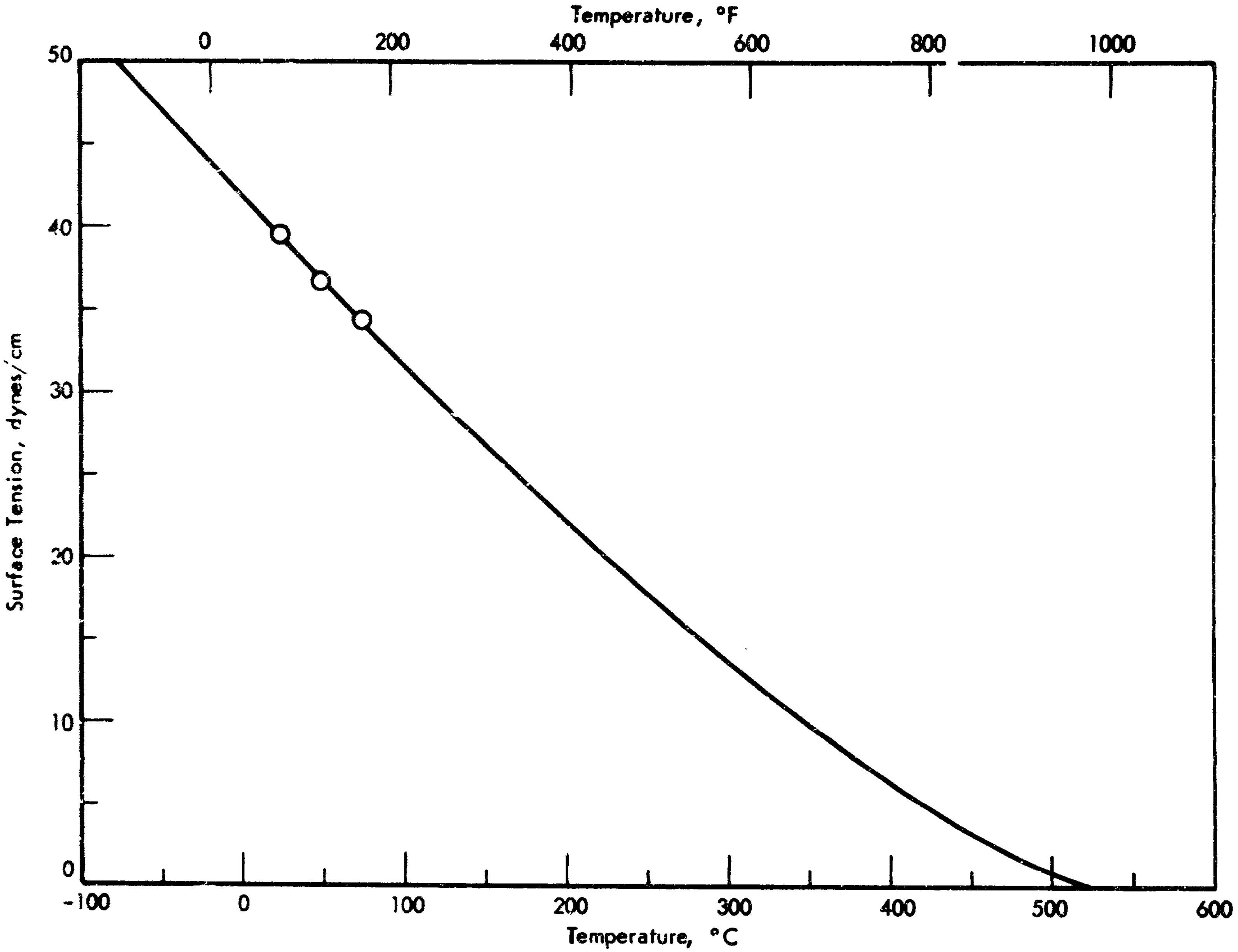


Figure 40. SURFACE TENSION OF SHELLDYNE-H® FUEL

Table 51. SUMMARY OF CONDITIONS OF SHOCK TUBE RUNS

Fuel	Equivalence Ratio*	Percent Argon
decalin	0.2	90
decalin	0.5	99
tetralin	0.1	99
tetralin	0.1	80
tetralin	0.11	90
tetralin	0.5	99
tetralin	0.57	90
tetralin	1.0	95
tetralin	1.0	99
tetralin	1.21	90
naphthalene	0.1	90

*Equivalence ratio is defined as the actual fuel to oxygen ratio divided by the stoichiometric fuel to oxygen ratio.

$$(P_{21} - 1) = (P_{21} - 1)_{ideal} \exp(-A \frac{x}{r}) \tag{27}$$

where P_{21} = ratio of pressures before and after shock wave
x = distance from diaphragm
r = hydraulic radius
A = attenuation coefficient

This equation is said to be accurate enough for most work. We have presented the same equation in a slightly different form:[3]

$$(M_s^2 - 1)_2 = (M_s^2 - 1)_1 \exp(-A \frac{x}{r}) \tag{28}$$

where M_s = Mach number
x = distance from point 1 to point 2.

Several experiments were performed to determine experimental values of attenuation coefficients. To date, values of 0.5×10^{-3} and 1×10^{-3} have been used for A. These values were obtained from measurements in the literature on similar shock tubes. The attenuation coefficients determined experimentally on our shock tube were correlated with initial channel pressure and the ratio of driver pressure to channel pressure. The resulting correlation was:[a]

$$A = \frac{1}{4}(0.00436 - 0.0000457\, P_1 + 0.0000698 \frac{P_4}{P_1}). \tag{29}$$

where P_4 = initial pressure of driver gas
P_1 = initial pressure of reaction mixture

A set of experiments has been performed measuring ignition delay times and velocity attenuation simultaneously. We are now in a position to compare three different ways of estimating attenuation and its effect on ignition delay time measurements: (1) using a constant value of the attenuation coefficient as in the past ($A = 1 \times 10^{-3}$), (2) using the correlation for attenuation coefficient, and (3) using the measured velocity attenuation. The ignition delay times as determined by the three methods for the combustion of a decalin-oxygen-argon mixture are shown in Figures 42 to 44. Figure 44 shows that using the correlation is clearly unsatisfactory. A comparison of Figures 42 and 43 reveal that the other two methods are approximately equivalent. The general scatter in Figure 43 is slightly less, but three points are badly misplaced. Overall, using the constant value of attenuation coefficient gives the best results. The reason for this is not immediately clear. One would think that measuring the variations in attenuation and allowing the coefficient to change should improve the results and decrease the data scatter, not increase it.

---

[a] We previously used the hydraulic diameter rather than radius. This introduces a factor of 4 into the correlation, i.e., $A' = 4A$.

Figures 41 through 44 follow

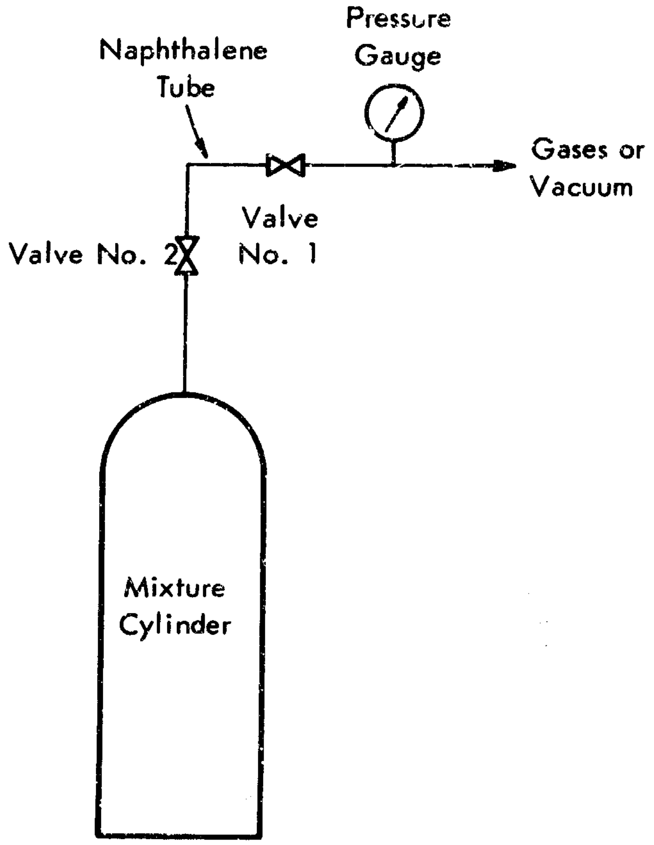


Figure 41. SYSTEM FOR PREPARATION OF GASEOUS COMBUSTION MIXTURES CONTAINING NAPHTHALENE

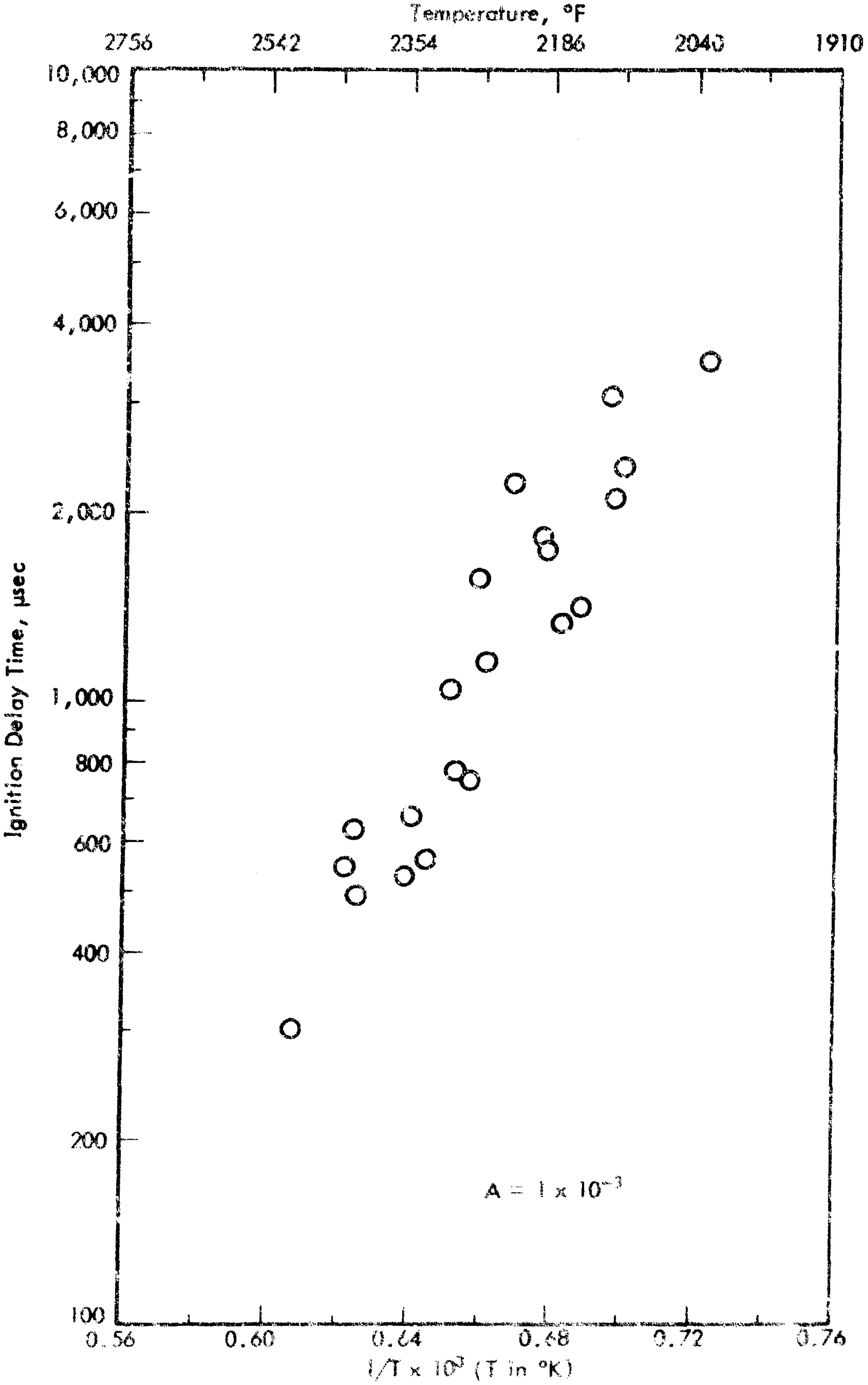


Figure 42. COMBUSTION OF DECALIN USING CONSTANT ATTENUATION

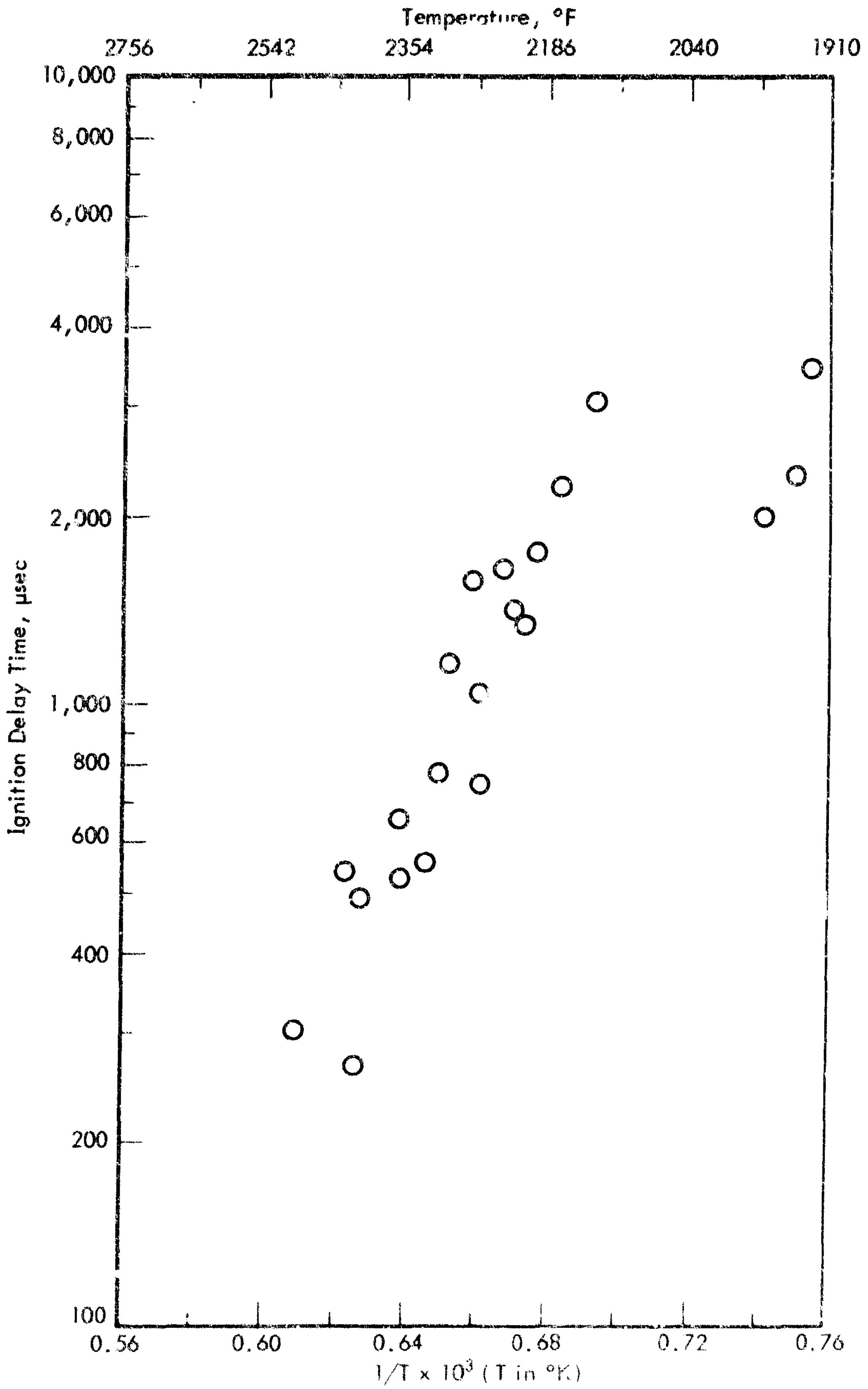


Figure 43. COMBUSTION OF DECALIN USING MEASURED ATTENUATION

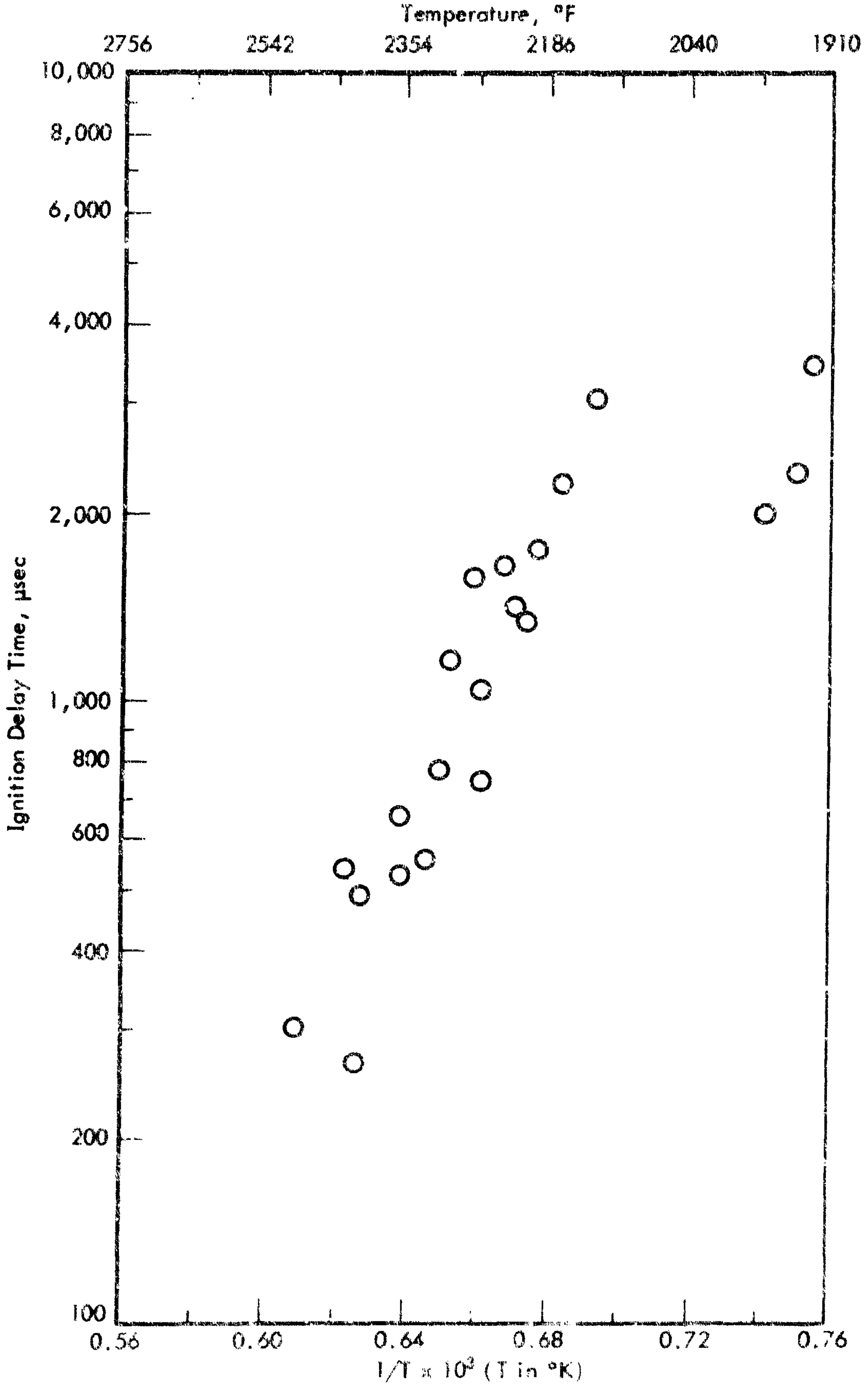


Figure 43. COMBUSTION OF DECALIN USING MEASURED ATTENUATION

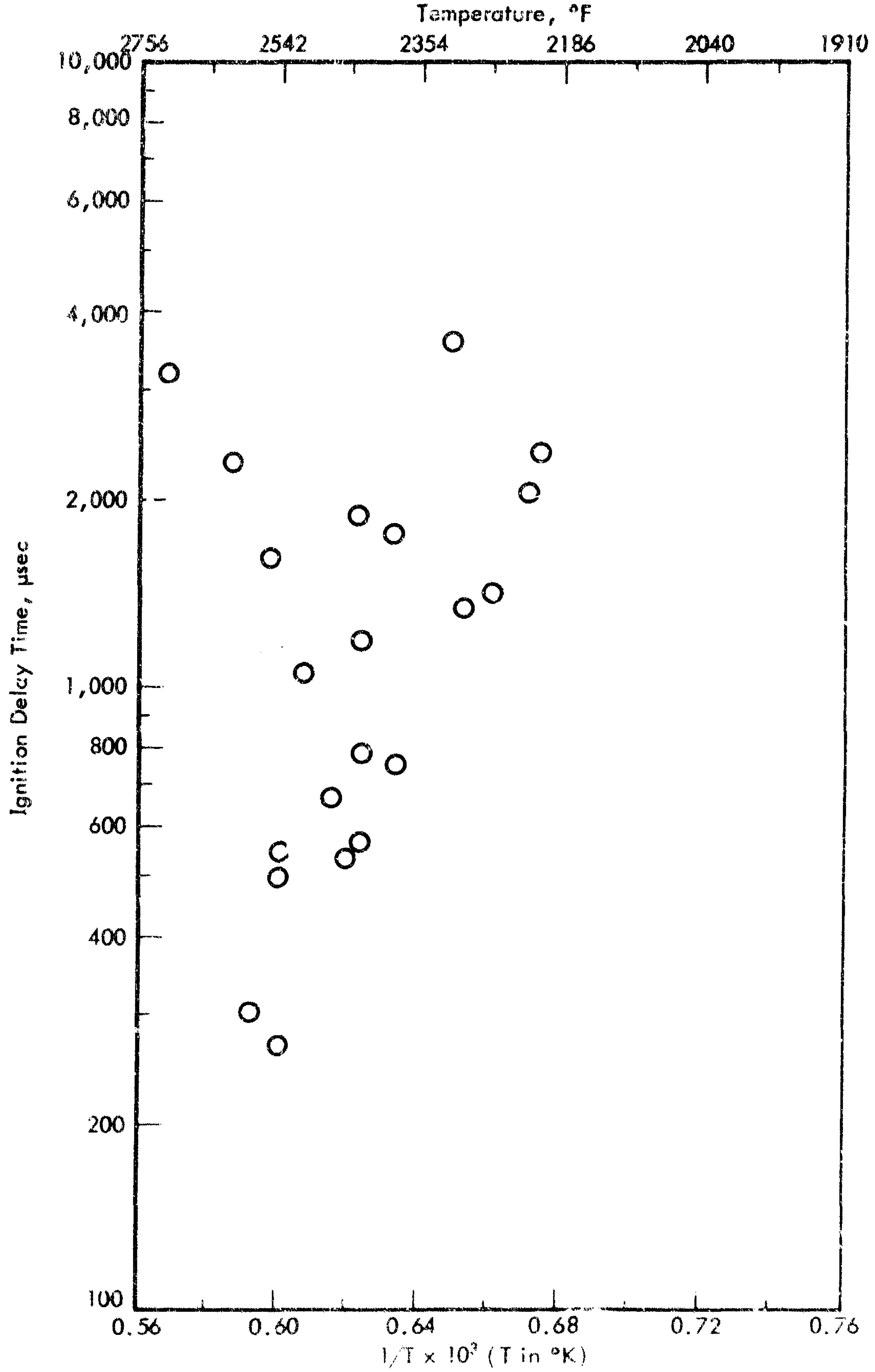


Figure 44. COMBUSTION OF DECALIN USING ATTENUATION CORRELATION

The explanation for this behavior appears to lie with the measurement of the shock wave velocity. Figure 45 shows a plot of average shock wave velocities at two points in the tube, in terms of the times of wave passage between point A and point B (18 inches) and between point B and point C (24 inches). The results do not fall precisely on a smooth curve, indicating either that the shock wave velocity fluctuates as it moves down the tube, or that there is appreciable error in the time measurements. A fluctuating shock wave velocity is fairly unlikely, although some variations can be caused by imperfect diaphragm breakage. The resolution of the time measurements is 1 μsec, but the errors in measurement could be higher. Typical scatter of the data is 2-3 μsec. The large effect of this apparently small scatter is shown by a plot of the attenuation coefficients calculated from the same data (see Figure 46). The values of A scatter between -0.09×10^{-3} and 1.7×10^{-3}, and do not correlate with anything, including shock velocity. This is the reason for the failure of the correlation for attenuation. It is interesting that the mean value of all of the coefficients is 0.99×10^{-3}, which is remarkably close to the value of 1×10^{-3} that was estimated from literature data. If the measurement of shock velocity was accurate, one would expect that using the measured values of A would reduce the scatter of ignition delay times. Since this improvement was not found, the problem must lie in the measurement of shock velocity. Efforts to improve velocity measurements would involve the purchase of more accurate electronic instrumentation and more instruments to measure the velocity at several points in the shock tube. This is probably not worth the expenditure of time and money required. Therefore, the best that can be done is to take the average value of A, determined experimentally to equal 1×10^{-3}, and use it as a constant in all calculations.

Correlation of Ignition Delay Times

A new correlating equation has been used to represent the experimental data on ignition delay times:

$$\ln \tau = b_0 + b_1 \ln (c_{O_2}) + \frac{E}{RT} + b_2 \ln (c_{\mathrm{Fuel}}) \tag{30}$$

where τ = ignition delay time, μsec
b_0, b_1, b_2, E = correlating parameters
c_{O_2} = oxygen concentration, gmole/liter
R = gas constant, 1.987×10^{-3} kcal/gmole-°K
T = absolute temperature, °K
c_{Fuel} = fuel concentration, gmole/liter

The methods of estimating the parameters have been investigated, as have the statistical techniques which are used to interpret the results.

The equation used to correlate the data up to now has been the same as Equation (30) without the last term, which describes the effect of the fuel composition. There was some question about the correlation for decalin, since it appeared that fuel concentration had some effect on the ignition delay times. So the decalin data were fit using Equation (30) plus an additional term describing the effect of pressure. The standard errors of the equation obtained by fitting with the addition of one term at a time are shown in Table 52. As can be seen, the improvement by including the effect of fuel concentration is substantial, while only slight improvement is found by including the pressure effect. Therefore, it was decided to drop the pressure effect from the correlation but retain the fuel effect, resulting in Equation (30) as the final correlating equation.

Table 52. ERRORS OF DIFFERENT EQUATIONS OF DECALIN IGNITION DELAY TIMES

Equation	Standard Error of $\ln \tau$
$\ln \tau = b_0$	0.87
$\ln \tau = b_0 + \frac{E}{RT}$	0.81
$\ln \tau = b_0 + \frac{E}{RT} + b_1 \ln(c_{O_2})$	0.68
$\ln \tau = b_0 + \frac{E}{RT} + b_1 \ln(c_{O_2}) + b_2 \ln(c_{Fuel})$	0.50
$\ln \tau = b_0 + \frac{E}{RT} + b_1 \ln(c_{O_2}) + b_2 \ln(c_{Fuel}) + b_3 \ln(P)$	0.48

In addition to the equation to be used, there is some question as to the best way to fit the data and the best way to weight the data. Equation (30) could also be written as

$$\tau = \exp(b_0)(c_{O_2})^{b_1}(c_{Fuel})^{b_2}\exp(\frac{E}{RT}) \qquad (31)$$

the obvious difference being that in this form the parameters cannot be determined by linear regression. However, there is another difference. The fitting techniques used here seek the least sum of squared deviations between the observed values and the calculated values. Using Equation (31) and equal weighting to fit the data would minimize the sum of $(\tau_{obs} - \tau_{calc})^2$ for all the data. Using Equation (30) (logarithmic form) would minimize the sum of $[\ln(\tau_{obs}) - \ln(\tau_{calc})]^2$ for all the data. The resulting equations will be different. The logarithmic form will tend to emphasize short ignition delay times, whereas Equation (31) treats all of the data as being equally important and equally accurate. It is not obvious which method is the proper one. The ignition delay data for decalin were fit using the logarithmic equation, Equation (30), using standard linear regression techniques. The results are shown in Figure 47 as the observed ignition

Figures 45 through 47 follow

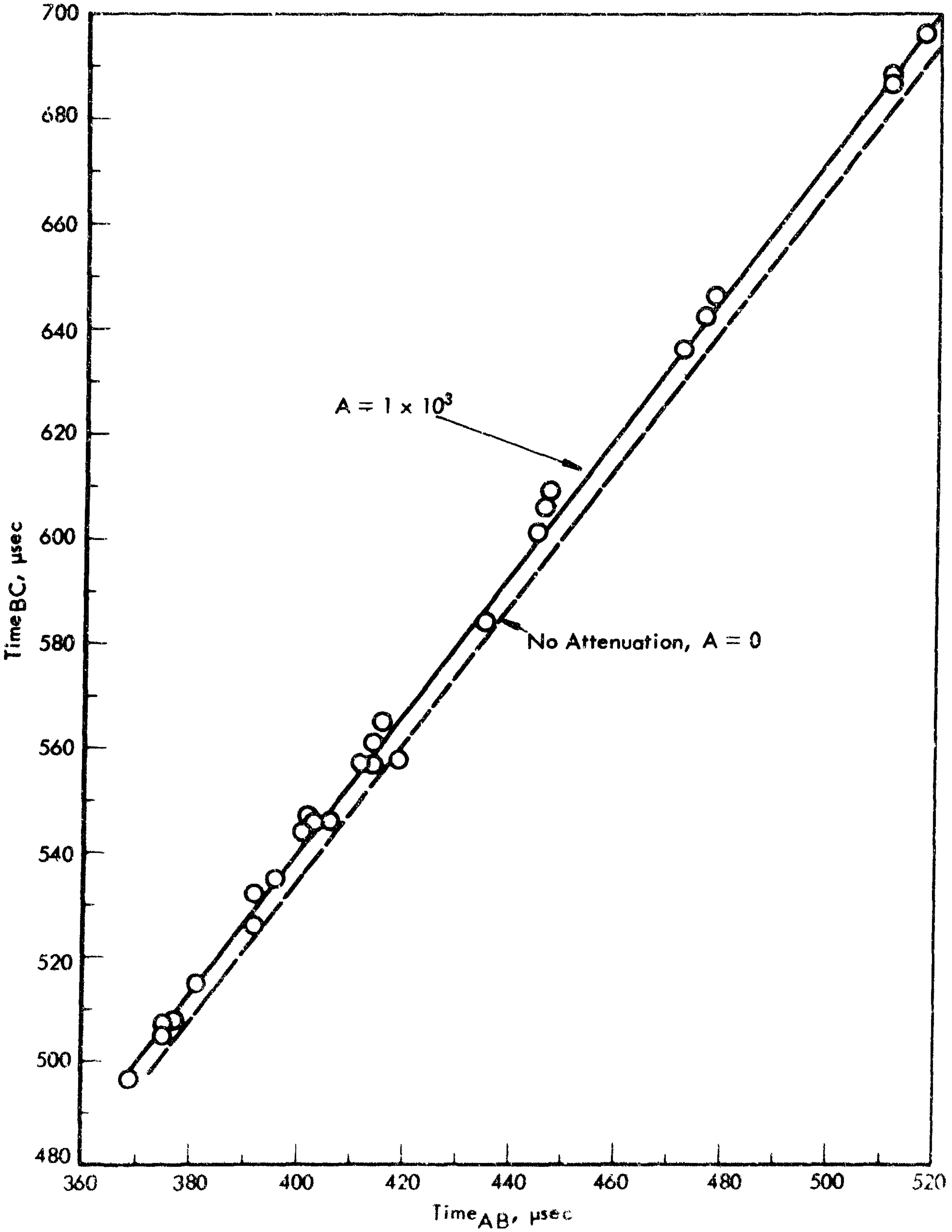


Figure 45. CORRELATION OF SHOCK WAVE VELOCITIES AT TWO POINTS IN TUBE

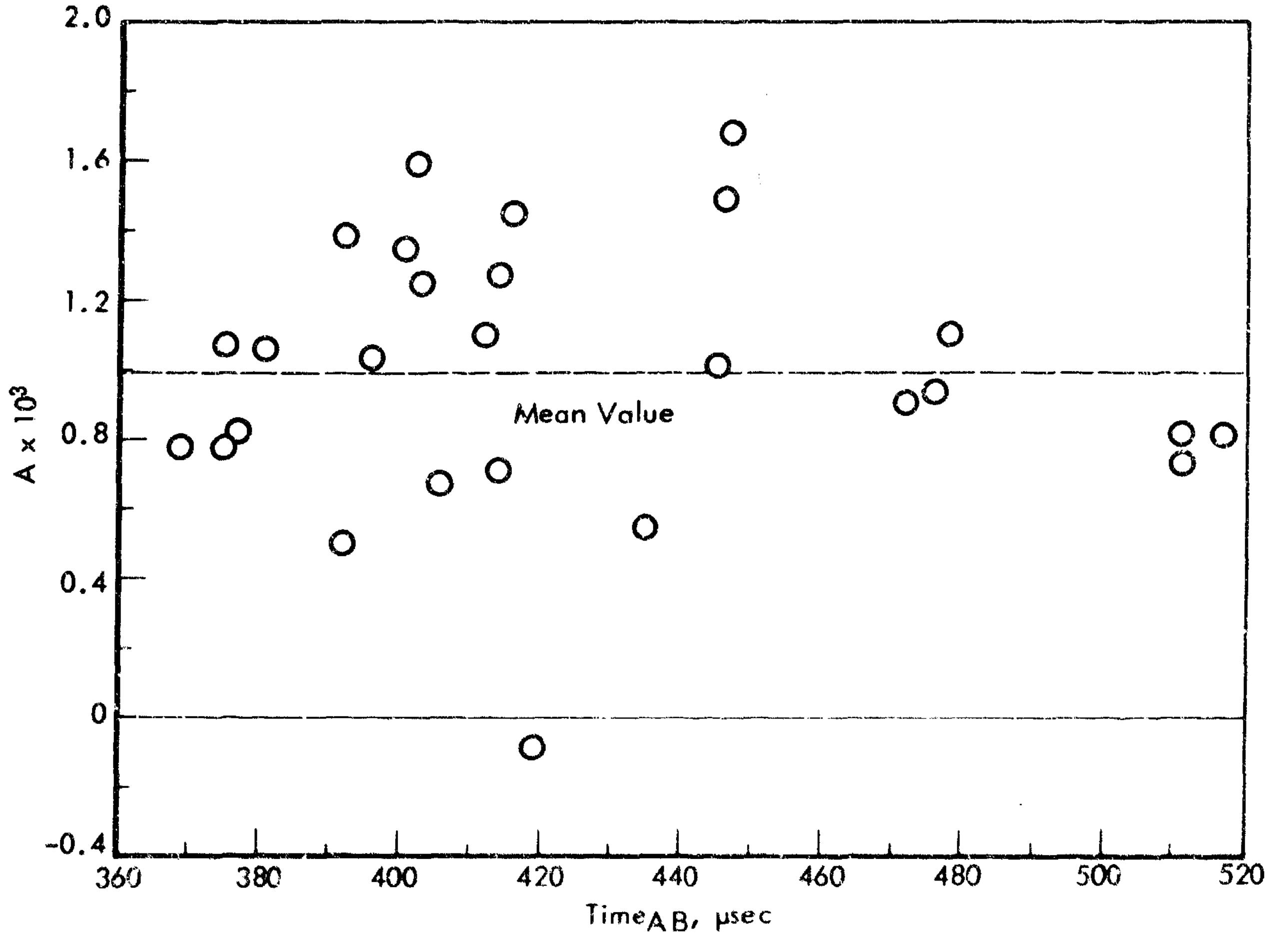


Figure 46. MEASURED ATTENUATION COEFFICIENTS

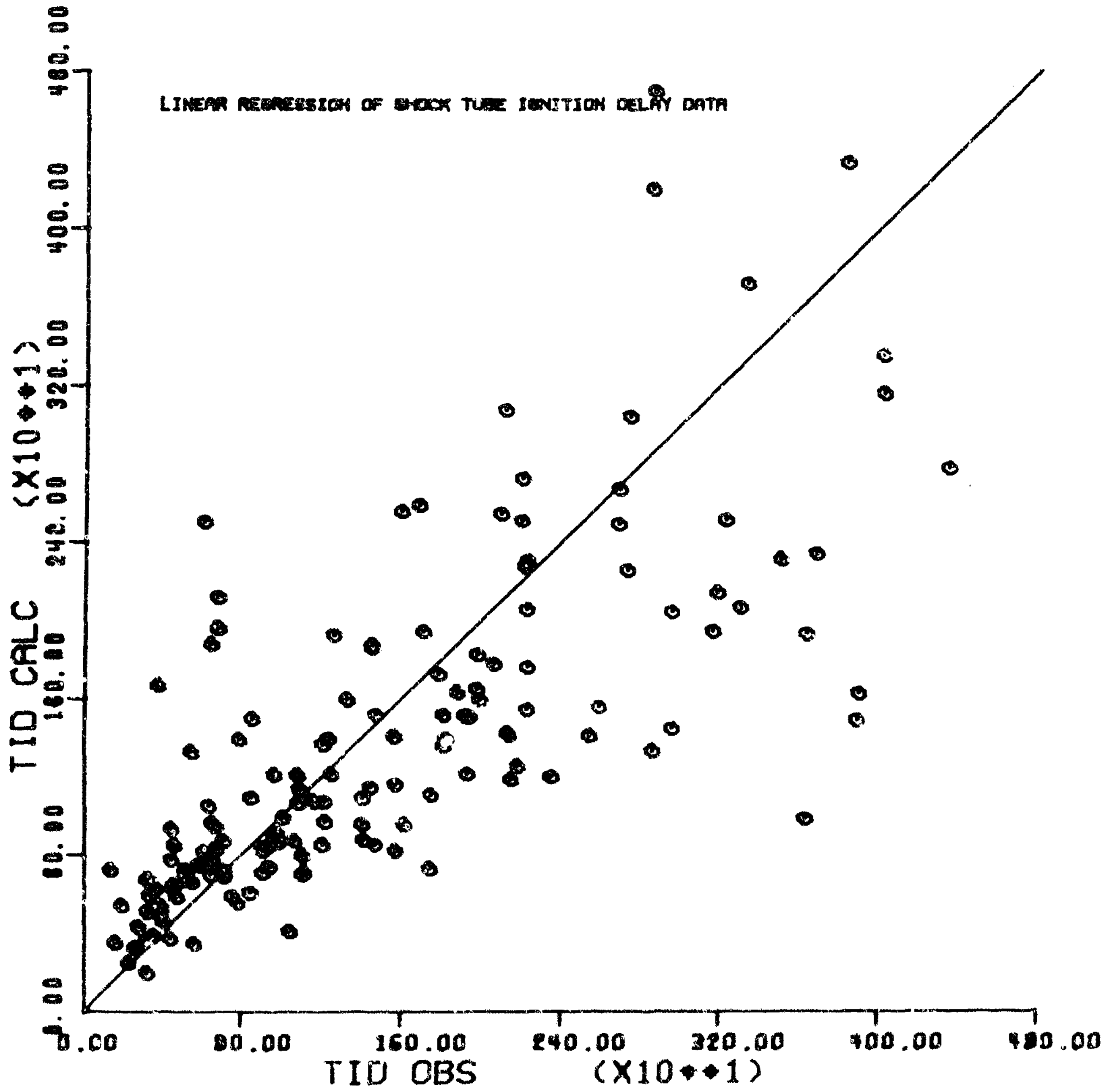


Figure 47. DECALIN DATA FITTED TO LOGARITHMIC EQUATION

delay times plotted against the calculated ignition delay times. The regression programs were set up to make these kinds of plots automatically. The correlation using equation (31) determined by nonlinear regression[a] is shown in Figure 48. The graphs show the expected result; the linear regression gives a better fit at short times and a poorer fit at long times. Also apparent from both plots is that the errors increase as the delay times increase. The problem was rerun using Equation (31) assuming that the variance of the data increased as the times increased. The results are shown in Figure 49. The plot shows that the short times are fit better and the long times much poorer than the other two methods. Since we are primarily interested in short delay times for supersonic engine applications, one of the good fits at short times should be used. On the other hand, the correlation should not almost totally disregard the long delay time data as the increasing variance method does. Therefore, the logarithmic form, Equation (30), using linear regression was chosen as a compromise method for correlating the data. The values of the parameters found by the three methods are given in Table 53.

Table 53. METHODS OF IGNITION DELAY DATA CORRELATION

Regression Method	b_0	b_1	b_2	E $\left(\frac{\text{kcal}}{\text{gmole}}\right)$
Linear, Logarithmic Form	-16.9	-1.27	0.79	55.7
Nonlinear, Constant Variance	-10.7	-1.05	0.74	44.2
Nonlinear, Changing Variance	-20.6	-1.18	0.49	55.0

Correlating equations and experimental data can be analyzed statistically with certain restrictions on the behavior of the errors. The most common approach is to assume that the errors are normally distributed and have a constant variance. Based on these assumptions, standardized techniques are available to determine the significance of the parameters, the significance of the correlation, the confidence limits of the parameters, and the confidence limits of the calculated values. As has already been mentioned, however, the errors in the correlation of the decalin data did not have constant variance. The other assumption was checked by performing a simple test to see if the errors were normally distributed. A probability plot was made of the residuals (errors) of the correlation of the data for tetralin. The residuals were plotted as $\left(\frac{r_i - \bar{r}}{n}\right)$, where r_i is the residual of the i-th data point, $\bar{r}$ is the mean residual, and n is the total number of points. The

---

[a] A proprietary computer program using a modified form of the damped least squares method of nonlinear estimation was used.

Figures 48 and 49 follow

values of this quantity were arranged in decreasing order and plotted at equal percentage intervals on a normal distribution scale. If the result is a straight line, then the errors are normally distributed. The result for the tetralin data using Equation (30) is shown in Figure 50. Clearly, the errors are not distributed normally. The results are similar for other fuels. This means that the standard statistical tests do not strictly apply. To see if the form of Equation (30), which involves a logarithmic transformation, caused the un-normality, the data were refit by nonlinear regression to Equation (31). The probability plot of the residuals is shown in Figure 51. The errors still are not normally distributed, so that the problem is not with the fitting method or form of the equation. Since the normality assumption does not hold and the variance is not constant, the standard statistical tests cannot be used. The shape of the probability plots also do not resemble any other common distribution, such as logarithmic, exponential, or chi-square type. As a result, no estimate of confidence limits or significance will be meaningful. Strictly as an approximation one can calculate the standard deviation (standard error) of the calculated values assuming that the errors are normally distributed. This quantity is defined as the square root of the ratio found by dividing the sum of squared residuals by the number of degrees of freedom (number of data minus the number of parameters).

The correlating equation was fit to the ignition delay data for many of the systems studied previously. Table 54 summarizes the results. The parameters for the improved correlation are presented, along with the range of delay times studied experimentally and the standard error of each correlation. The new data on decalin and tetralin have been included in the correlations. The new decalin data were not available when the various fitting procedures were investigated; therefore, the parameters for decalin presented in Table 54 are not the same as those in Table 53. Sufficient data have not been obtained with naphthalene to enable correlation. The numerical values of the parameters probably have little significance. The parameters b_0 and E are highly correlated with each other so that larger values of b_0 are associated with smaller values of E and vice versa. It does appear that since all of the values of b_1 are negative, oxygen has a beneficial effect by reducing ignition delay time, while for the most part, fuel seems to have a detrimental effect. Oxygen concentration seems to have a larger effect than fuel concentration, too. The values of E tend to fall into two ranges. Most of the fuels have values of about 40-50 kcal/gmole, while methylcyclohexane and its dehydrogenation products have values of about 20-30 kcal/gmole. The significance of this, if any, is not known. Figure 52 shows a plot of the correlations for a typical oxygen concentration and a stoichiometric fuel concentration. The uncertainty is typified by the standard error for the decalin correlation, which is shown graphically as the arrows in the margin of the figure. Figures 53 through 62 show plots of the fits to the data. The observed ignition delay times are shown against the calculated times.

Rate of Combustion of Tetralin

The data on the combustion of tetralin have been analyzed to obtain rates of combustion. Some trends seem evident but more experiments are indicated. Tetralin is an intermediate in the dehydrogenation of decalin to naphthalene. It would generally be found in the presence of hydrogen, but its combustion behavior is of interest both with and without hydrogen. The data on the combustion of tetra-

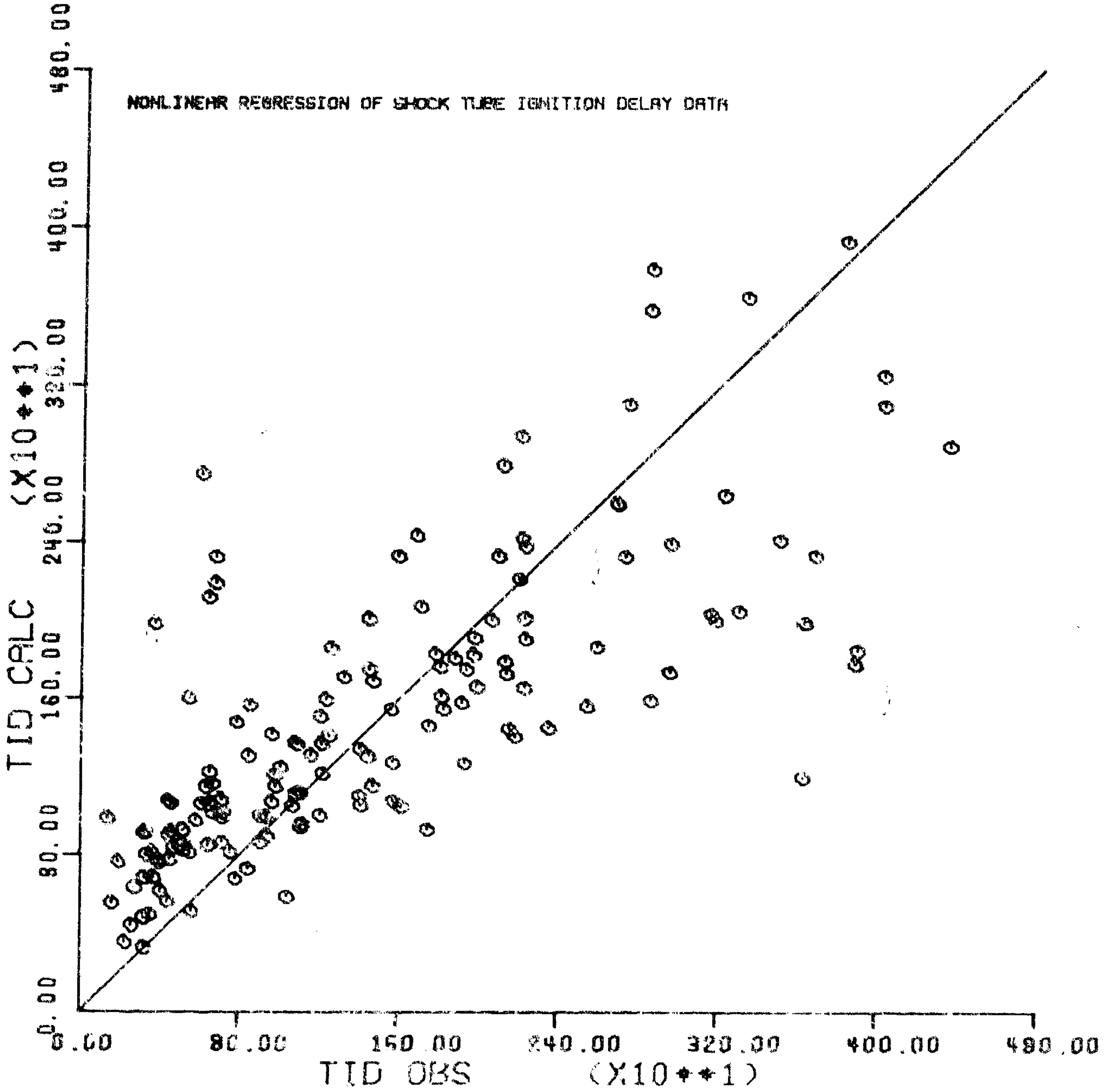


Figure 48. DECALIN DATA FITTED TO EXPONENTIAL EQUATION WITH EQUAL WEIGHTING (CONSTANT VARIANCE)

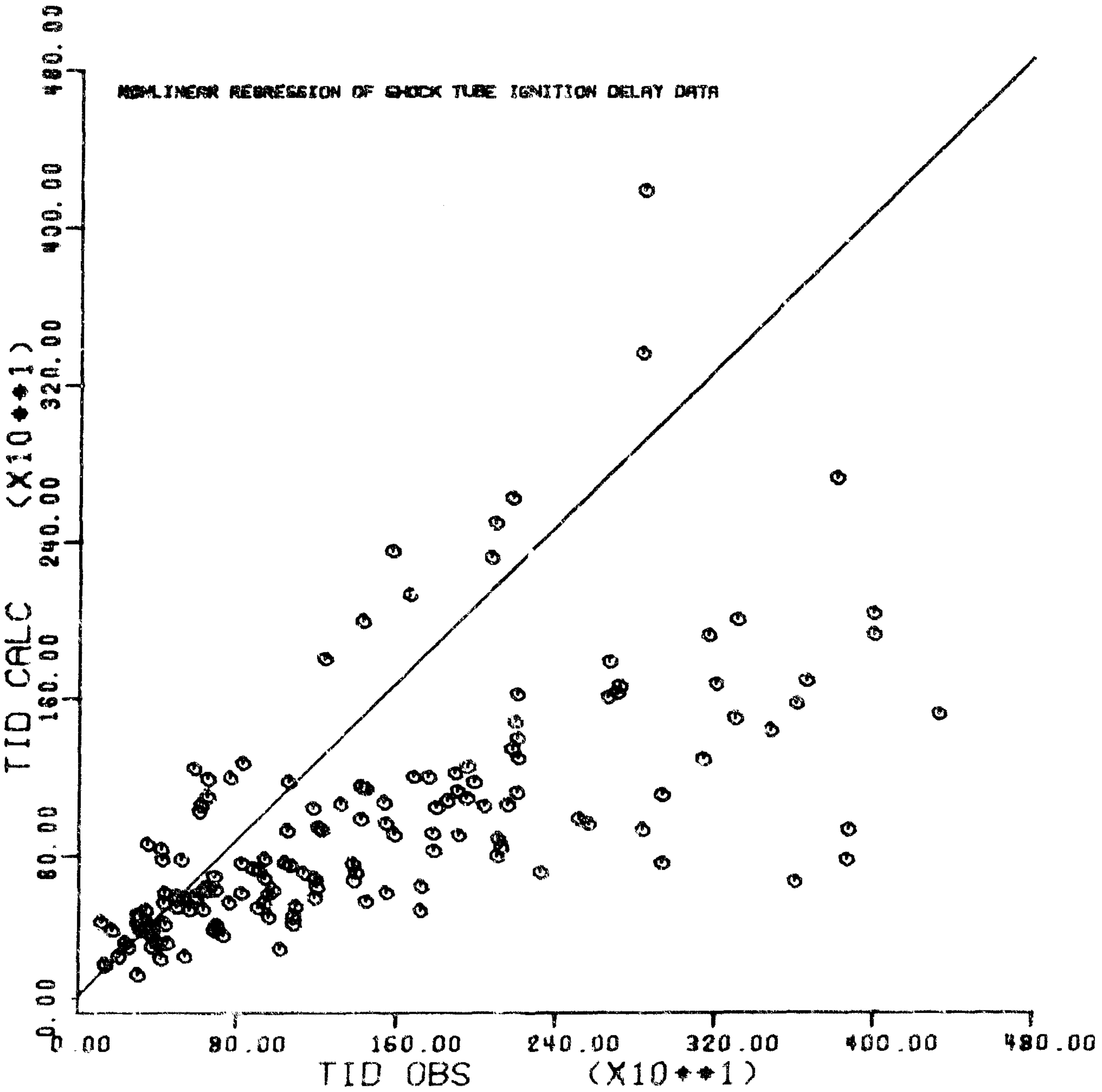


Figure 49. DECALIN DATA FITTED TO EXPONENTIAL EQUATION WITH CHANGING VARIANCE

Table 54. CORRELATIONS OF IGNITION DELAY TIMES

Fuel	b_0	b_1	b_2	E	Range of τ (μ sec)	Standard Error of ln τ
n-octane	-14.75	-0.76	0.15	41.1	70-4700	0.64
methylcyclohexane	- 2.89	-0.61	0.29	20.1	50-4100	0.61
toluene	- 5.84	-0.69	0.32	28.7	100-3400	0.39
toluene + H_2	- 7.03	-0.68	0.16	26.2	100-4000	0.38
MCH + toluene + H_2	- 5.36	-0.64	0.14	21.4	70-4400	0.58
dimethanodecalin	-19.56	-0.68	-0.33	45.8	80-4100	0.62
SHELLDYNE-H®	-13.80	-0.44	-0.28	35.6	60-3600	0.66
SHELLDYNE®	- 8.64	-0.94	0.60	41.0	80-3500	0.43
decalin	-10.94	-1.27	0.93	48.1	60-4300	0.50
tetralin	-15.99	-1.31	0.41	47.2	40-3800	0.68

Figures 50 through 62 follow

lin for ignition delay time measurements were analyzed to obtain combustion rates. The rate of combustion can be approximated by

$$r = \frac{dc}{dt} = k\,(c^* - c) \qquad (32)$$

where
r = the rate of appearance of CO_2
c^* = the ultimate concentration of CO_2
c = the current concentration of CO_2
k = the first order rate constant for combustion

Equation (32) can be integrated to give the reduced concentration of CO_2 as a function of time:

$$\ln \frac{c}{c^*} = -kt \qquad (33)$$

It is convenient to estimate k by finding the time required for c to reach half of the final value, $c^*/2$. Then k is found simply by

$$k = \ln 2/t_{\frac{1}{2}} \qquad (34)$$

Since the mixtures which were burned at lower temperatures encountered the reflected rarefaction shock wave before combustion was complete, much of the data on tetralin combustion could not be used, and values of c^* could not be determined. However, the acceptable data were analyzed using Equation (34). The results showed much scatter and did not seem to correlate with anything, including temperature. In fact, it seemed that the rate of combustion tended to decrease with increased temperature, which is not logical. In an effort to check this result, an experiment was conducted with the specific aim of finding the temperature dependence of the rate of combustion.

A mixture of 99% argon with tetralin and oxygen representing an equivalence ratio of 0.5 was prepared. Experiments were run, repeating the same conditions until the rate of combustion at a particular temperature could be estimated with confidence. Figure 63 shows the results for 9 psia. The temperatures were spread as far as was consistent with obtaining good combustion measurements. If the temperature was too high, there was no measureable ignition delay and often the mixture detonated. If the temperature was too low, the reflected rarefaction shock wave interfered with the combustion. Nevertheless, there appears to be a definite trend of increasing rate with increasing temperature, in spite of considerable scatter in the data. Figure 64 shows the results for 15 psia. The rates of combustion are somewhat higher but show about the same temperature dependence.

With the knowledge that the proper temperature dependence is found (increasing rates with increasing temperature) and that pressure has a beneficial effect on the combustion rate, the tetralin data were re-examined. There are too few points at each set of conditions to analyze the results statistically, but it

Figures 63 and 64 follow

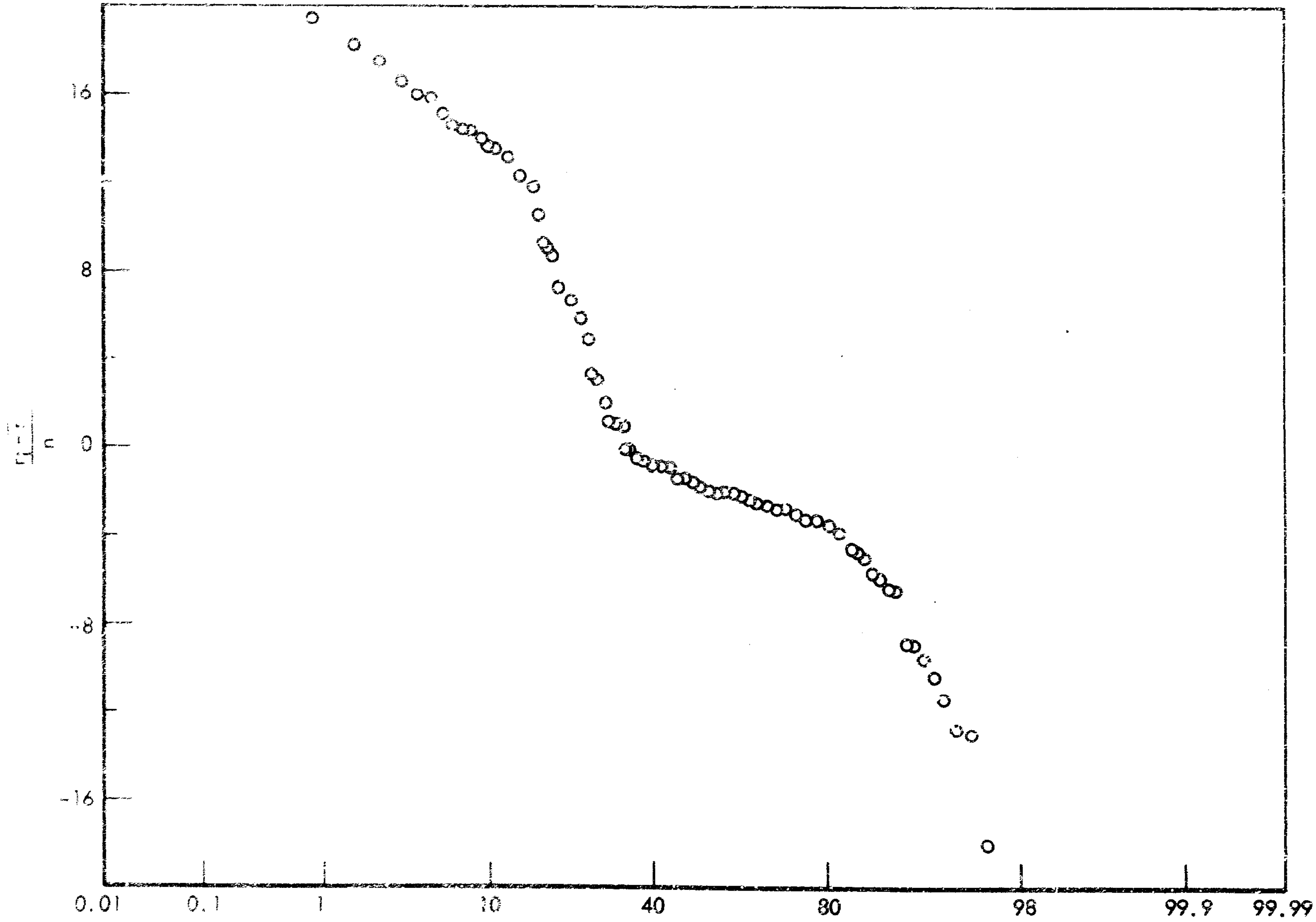


Figure 50. PROBABILITY PLOT OF TETRALIN DATA FOR LOGARITHMIC EQUATION

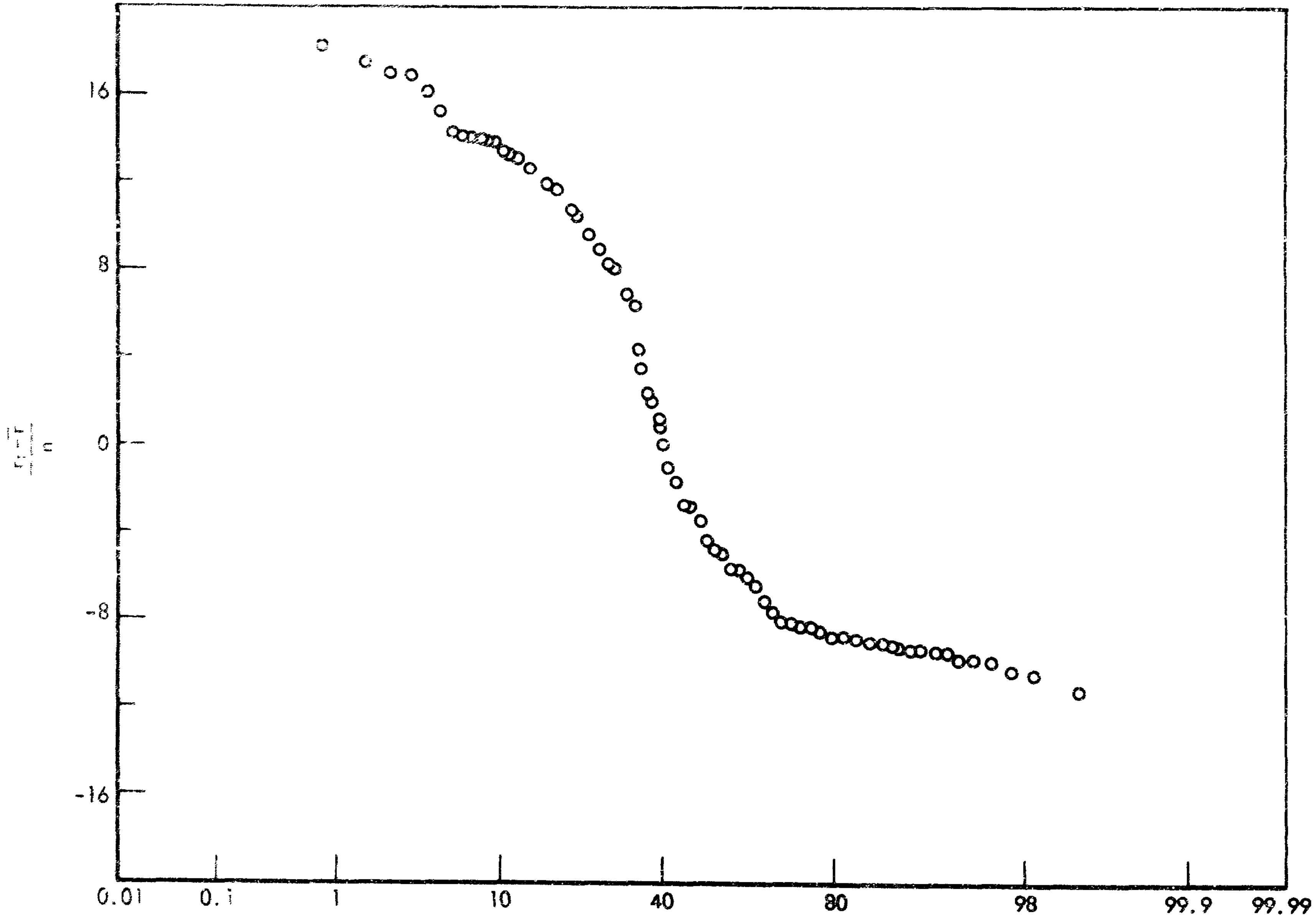


Figure 51. PROBABILITY PLOT OF TETRALIN DATA FOR EXPONENTIAL EQUATION

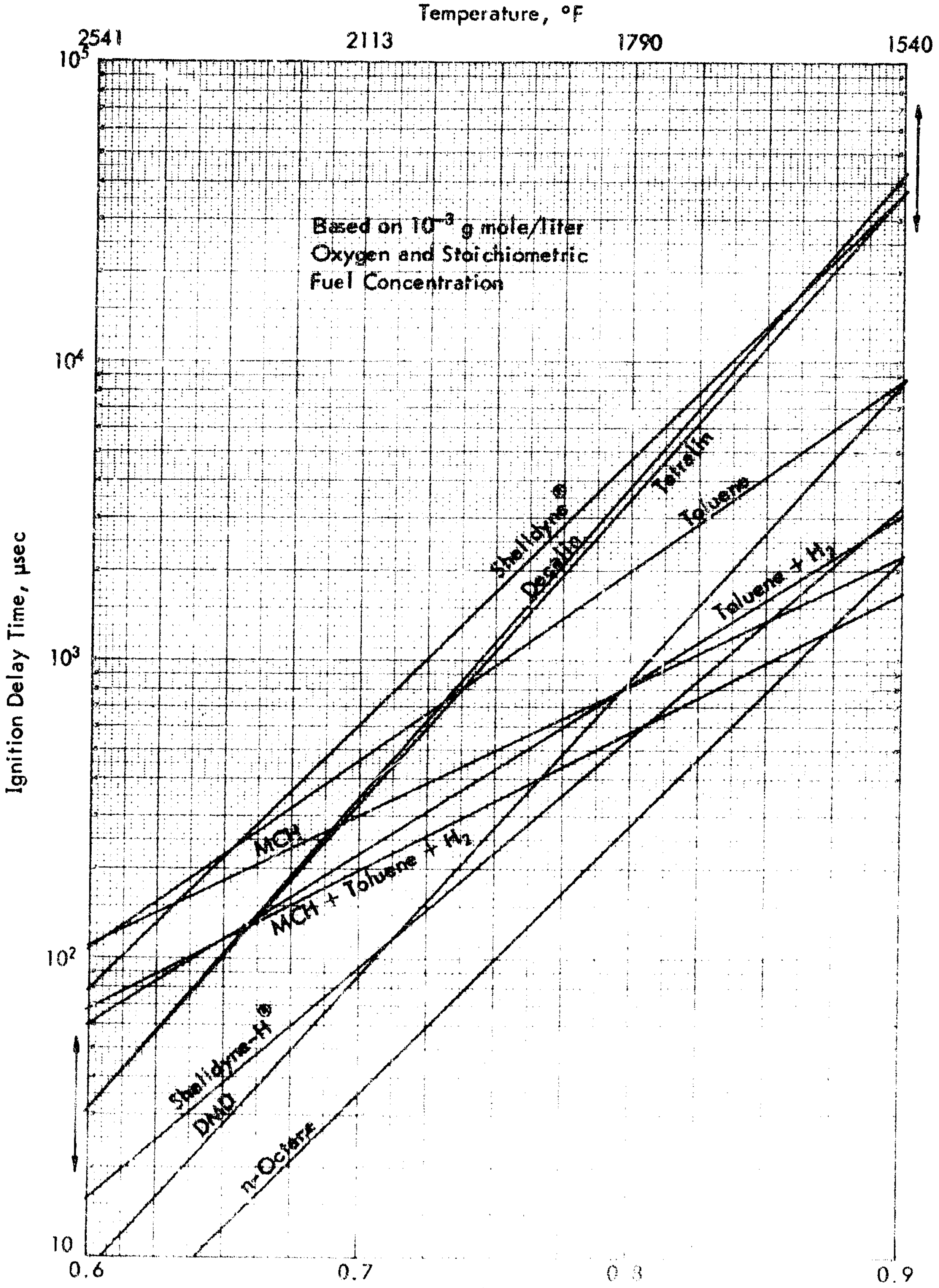


Figure 52. CORRELATIONS OF IGNITION DELAY TIMES

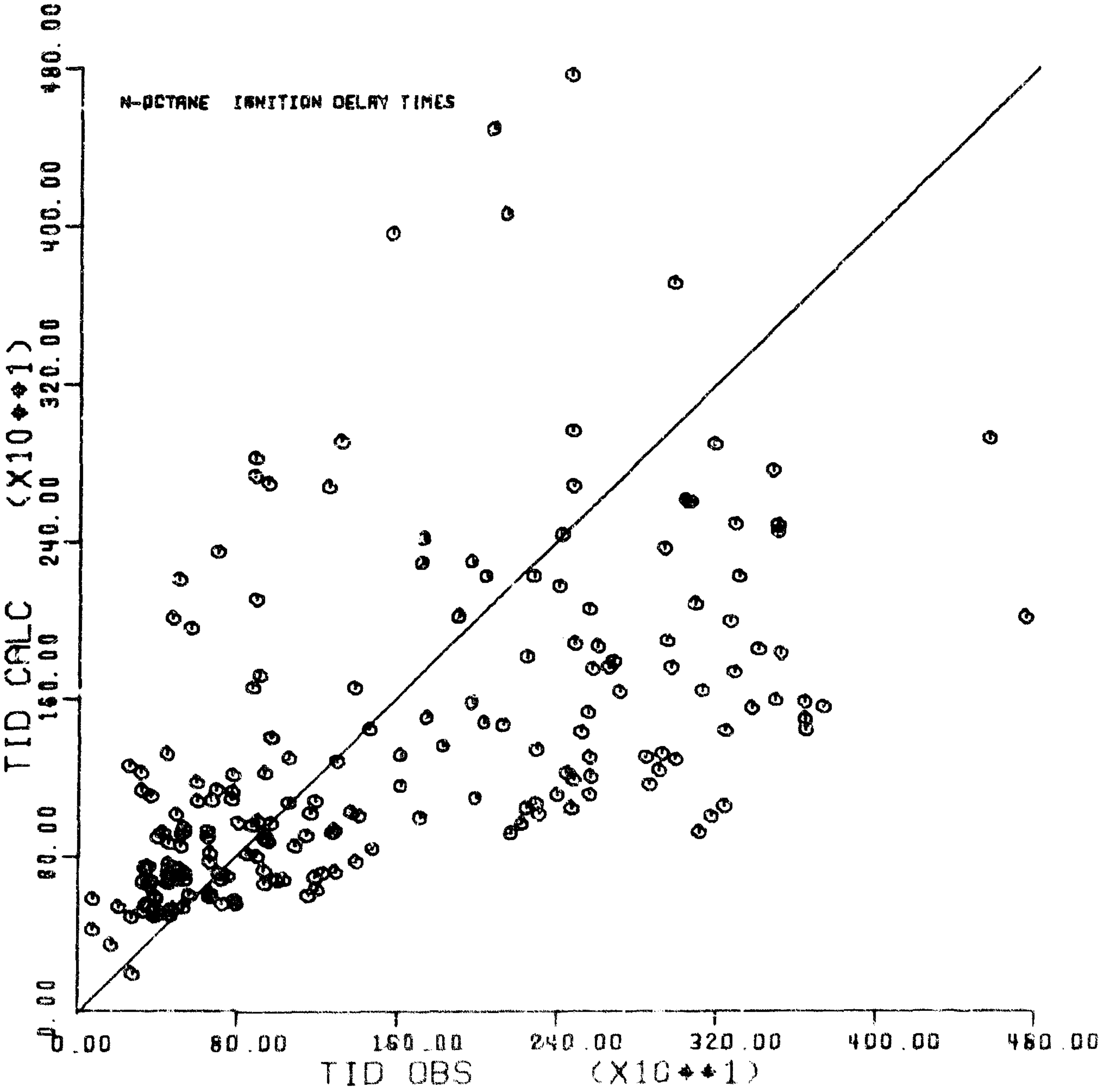


Figure 53. IGNITION DELAY TIMES OF n-OCTANE

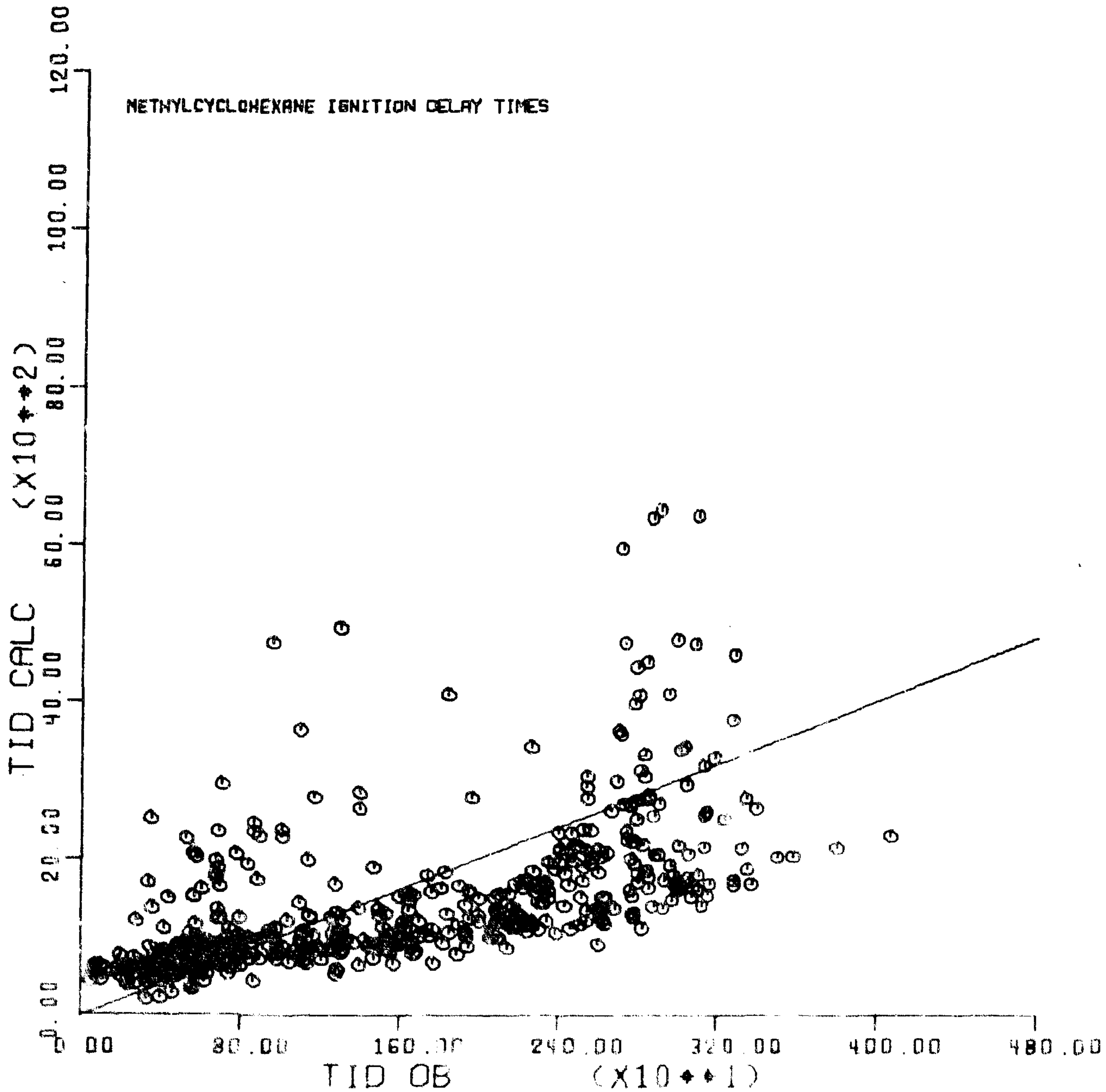


Figure 54. IGNITION DELAY TIMES OF METHYLCYCLOHEXANE

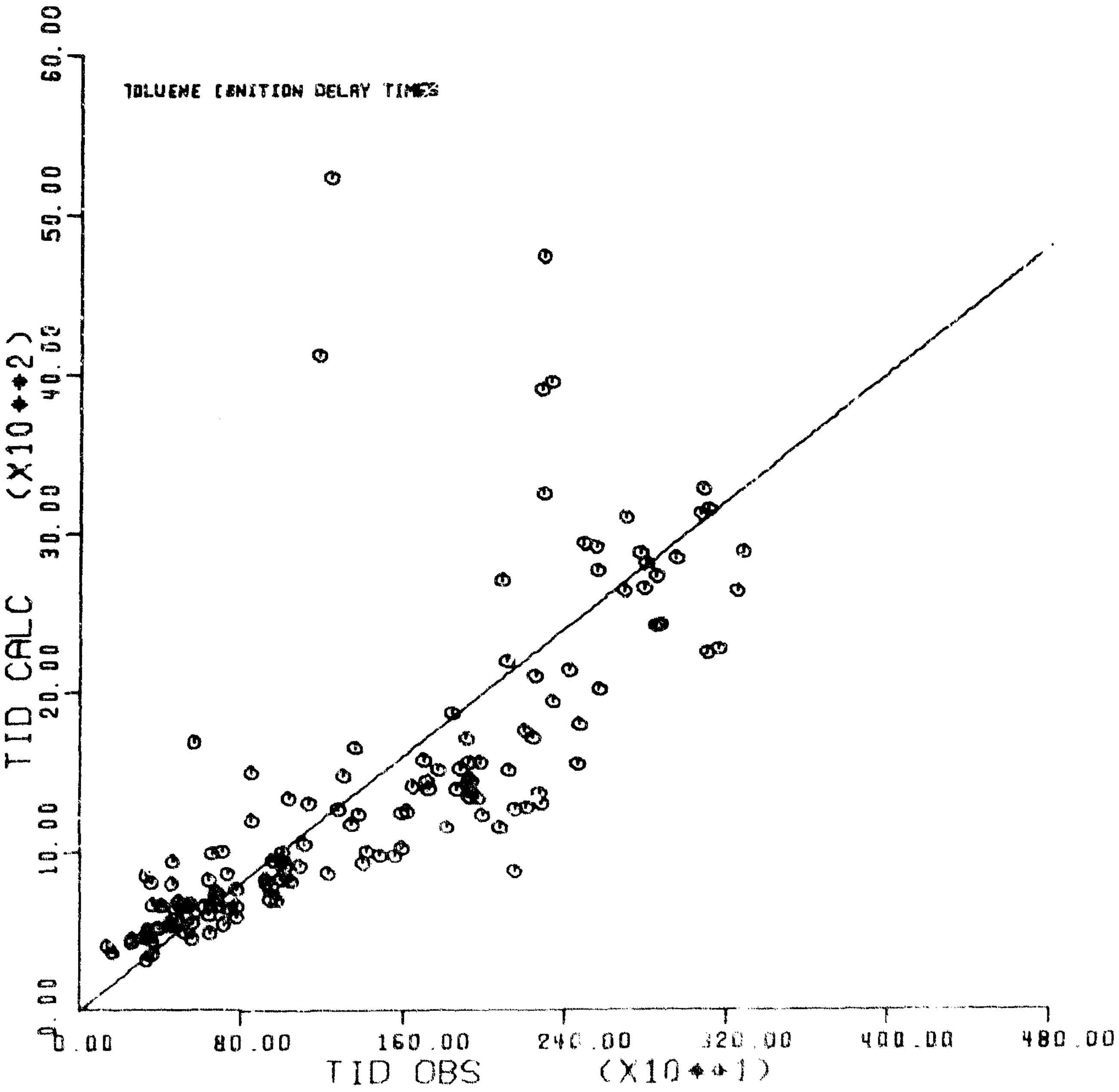


Figure 55. IGNITION DELAY TIMES OF TOLUENE

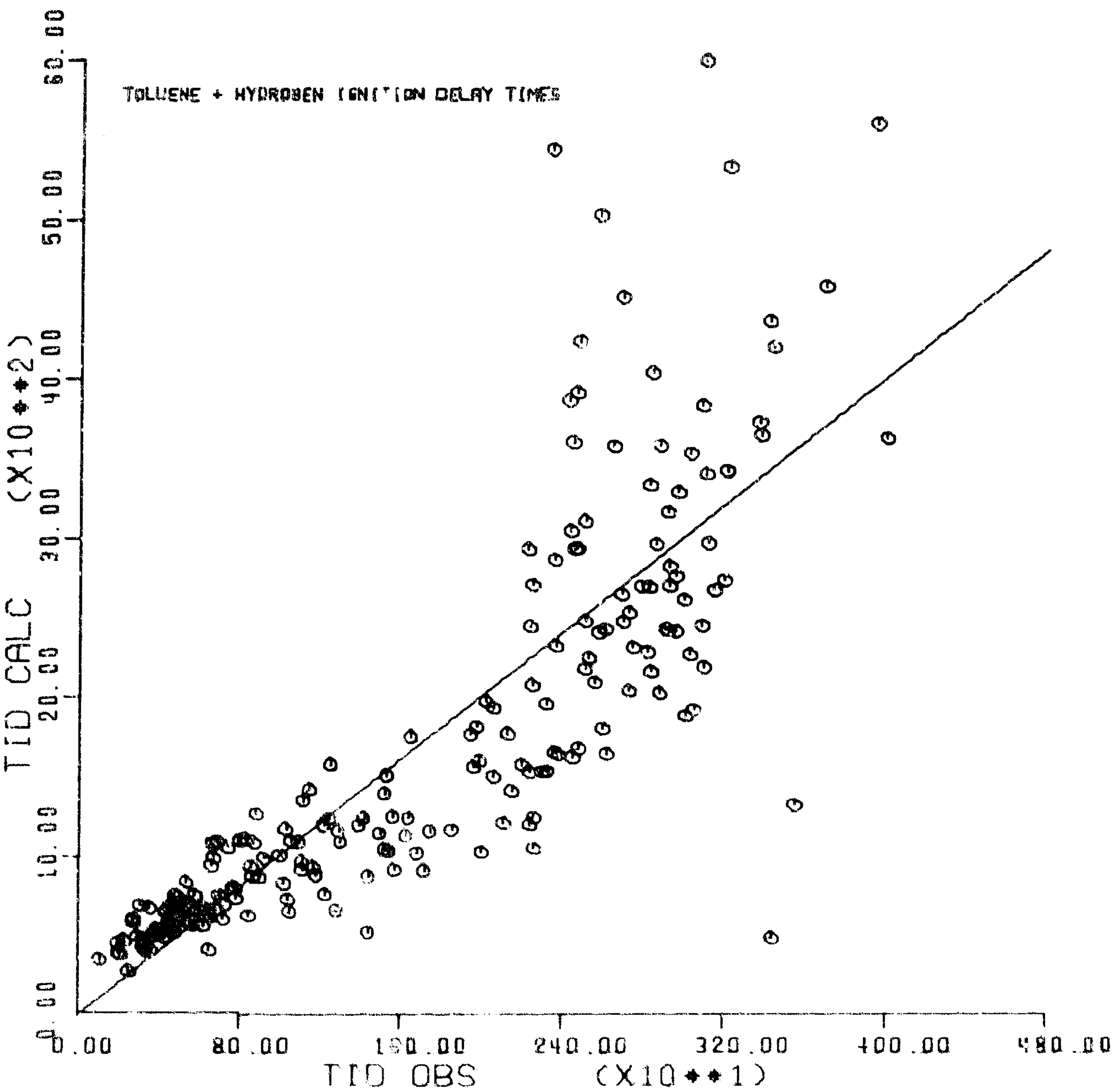


Figure 56. IGNITION DELAY TIMES OF TOLUENE-HYDROGEN MIXTURES

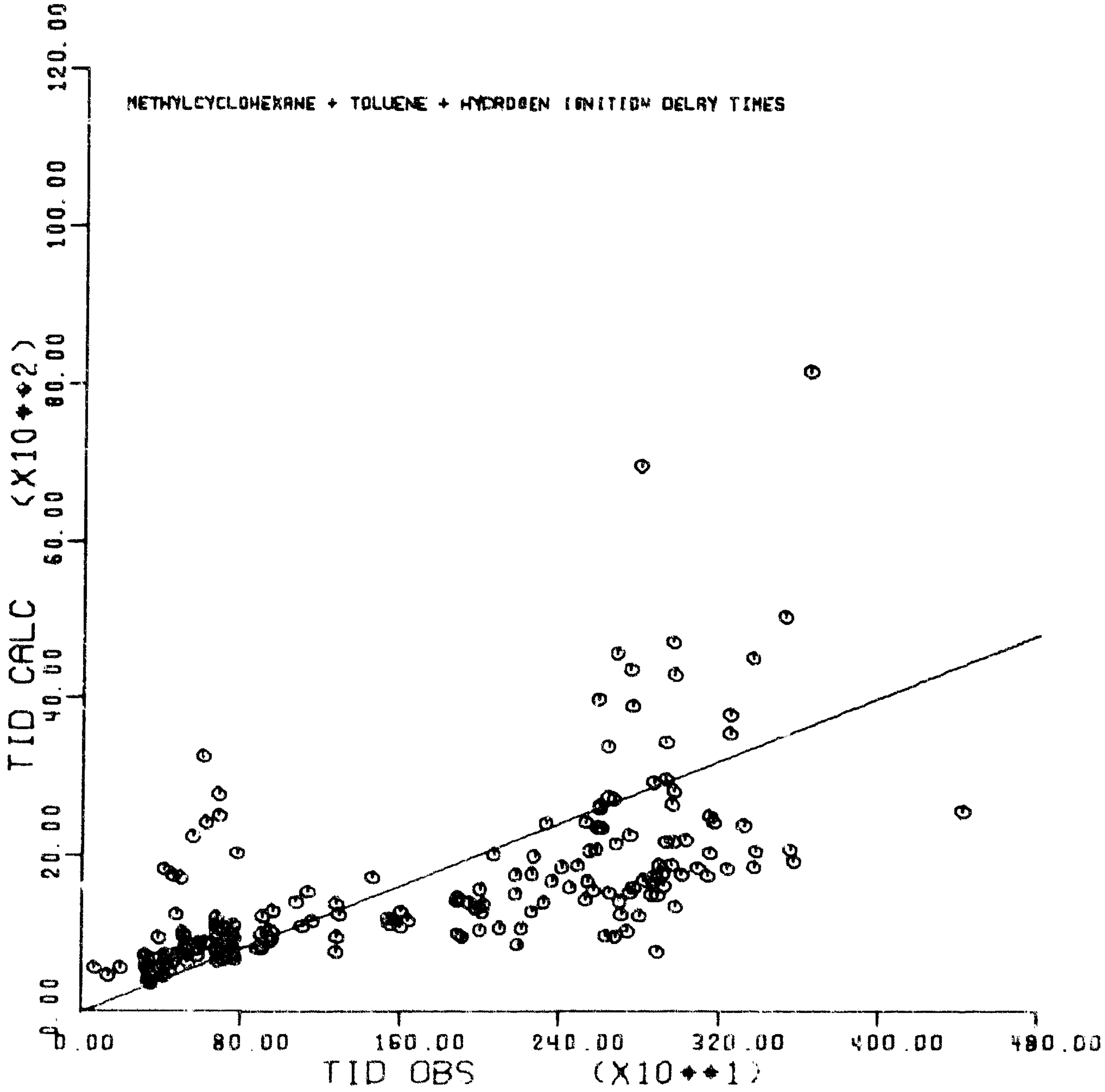


Figure 57. IGNITION DELAY TIMES OF METHYLCYCLOHEXANE-TOLUENE-HYDROGEN MIXTURES

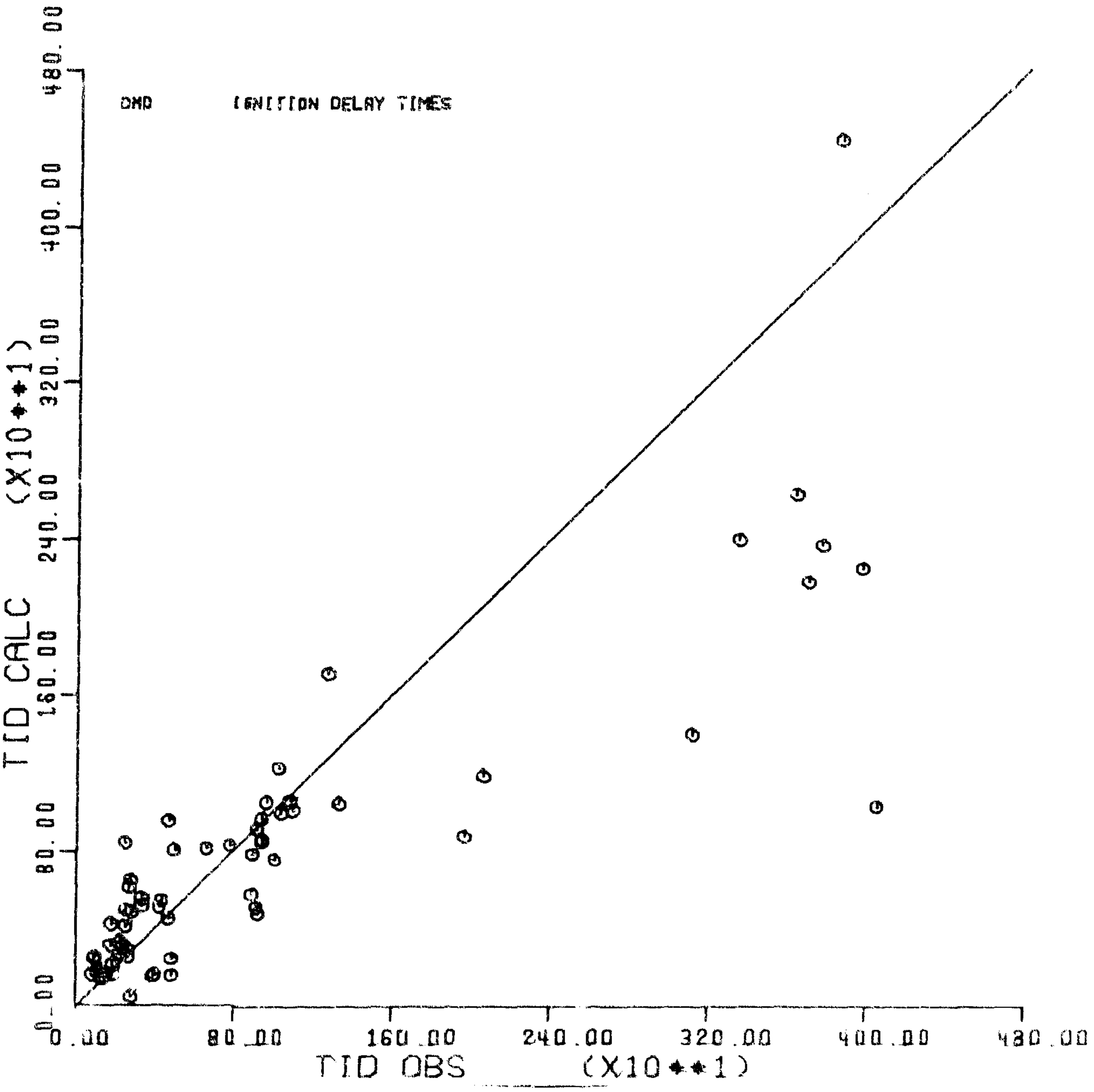


Figure 58. IGNITION DELAY TIMES OF DIMETHANODECALIN

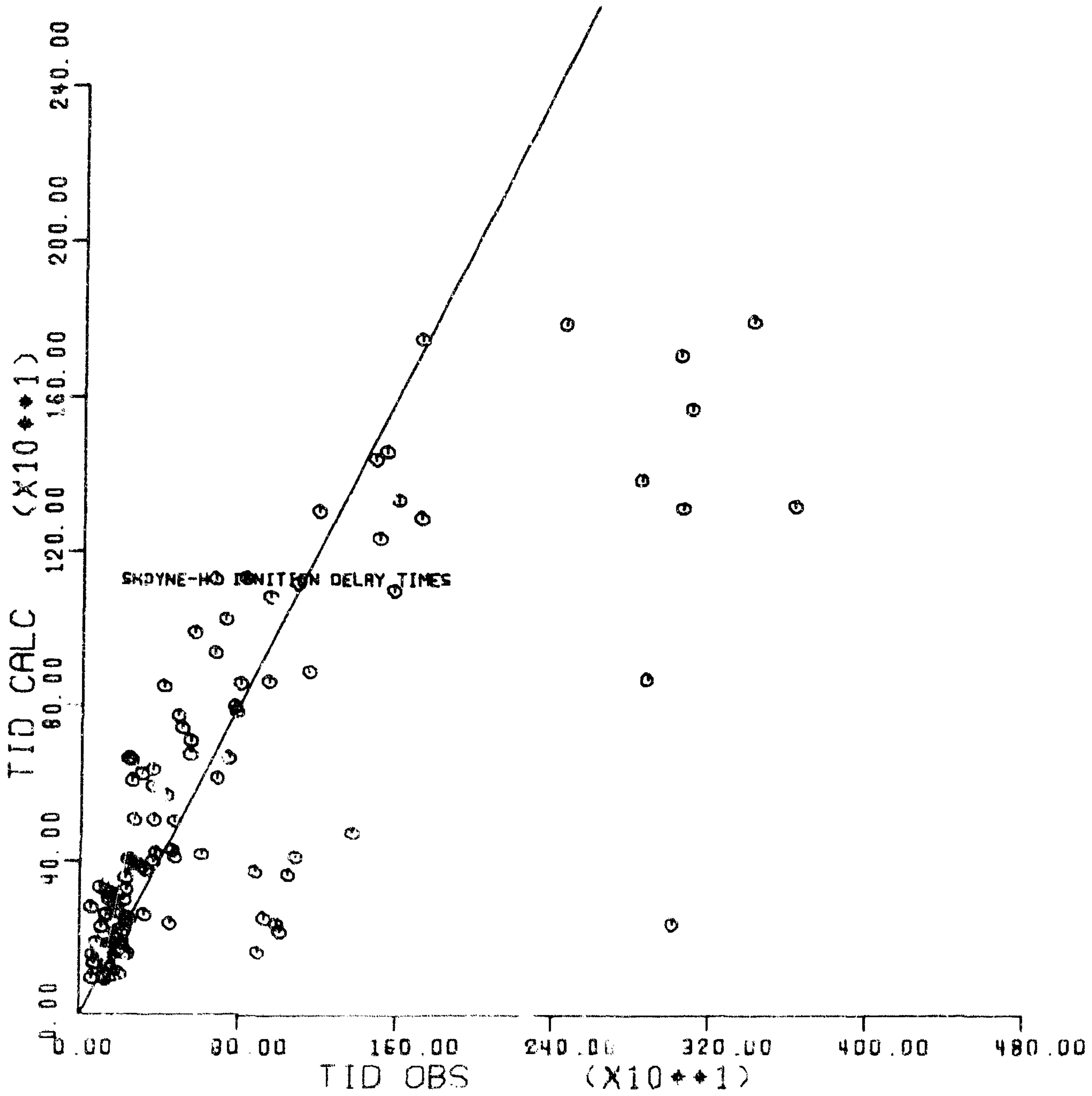


Figure 59. IGNITION DELAY TIMES OF SHELLDYNE-H® FUEL

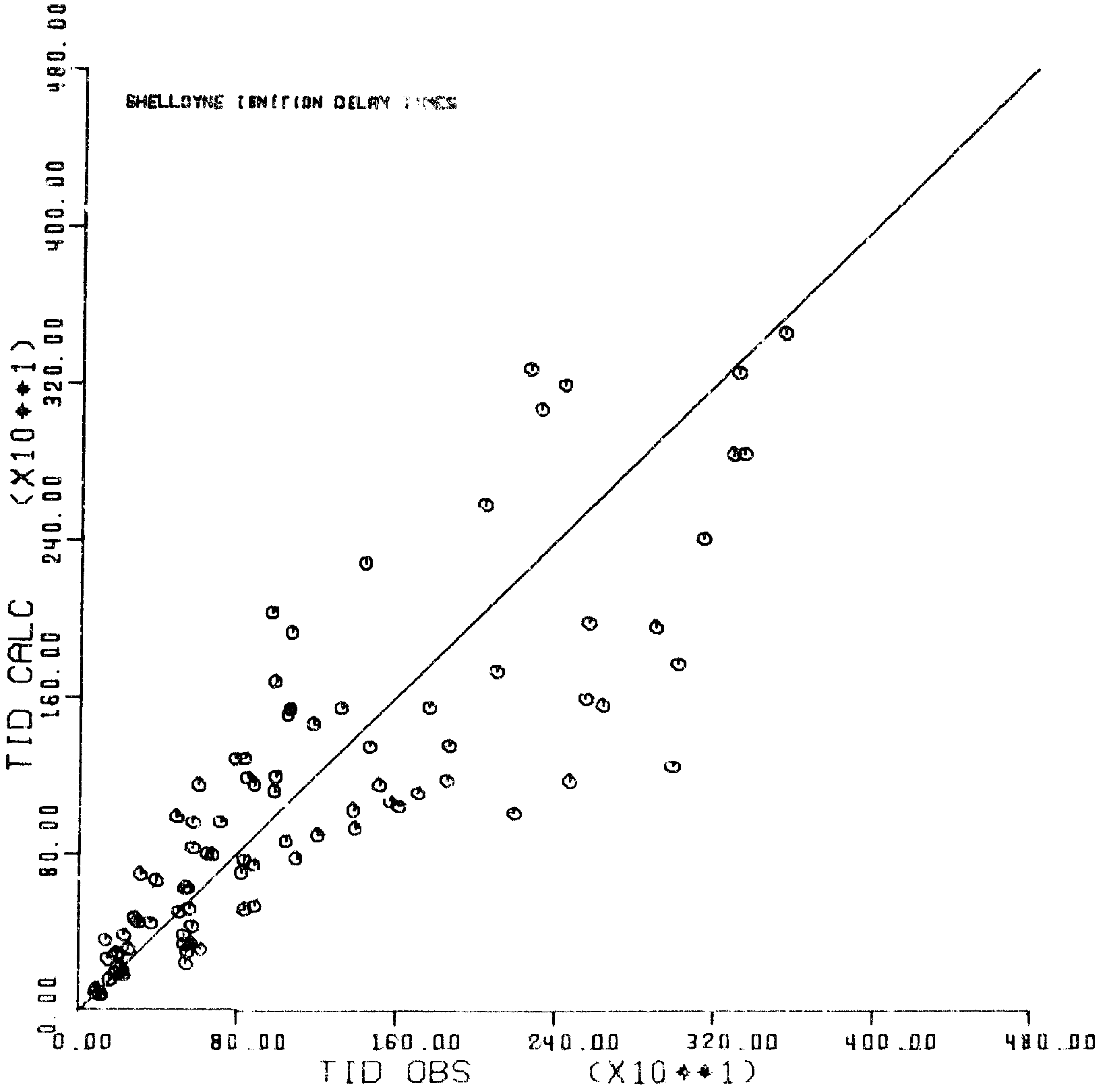


Figure 60. IGNITION DELAY TIMES OF SHELLDYNE® FUEL

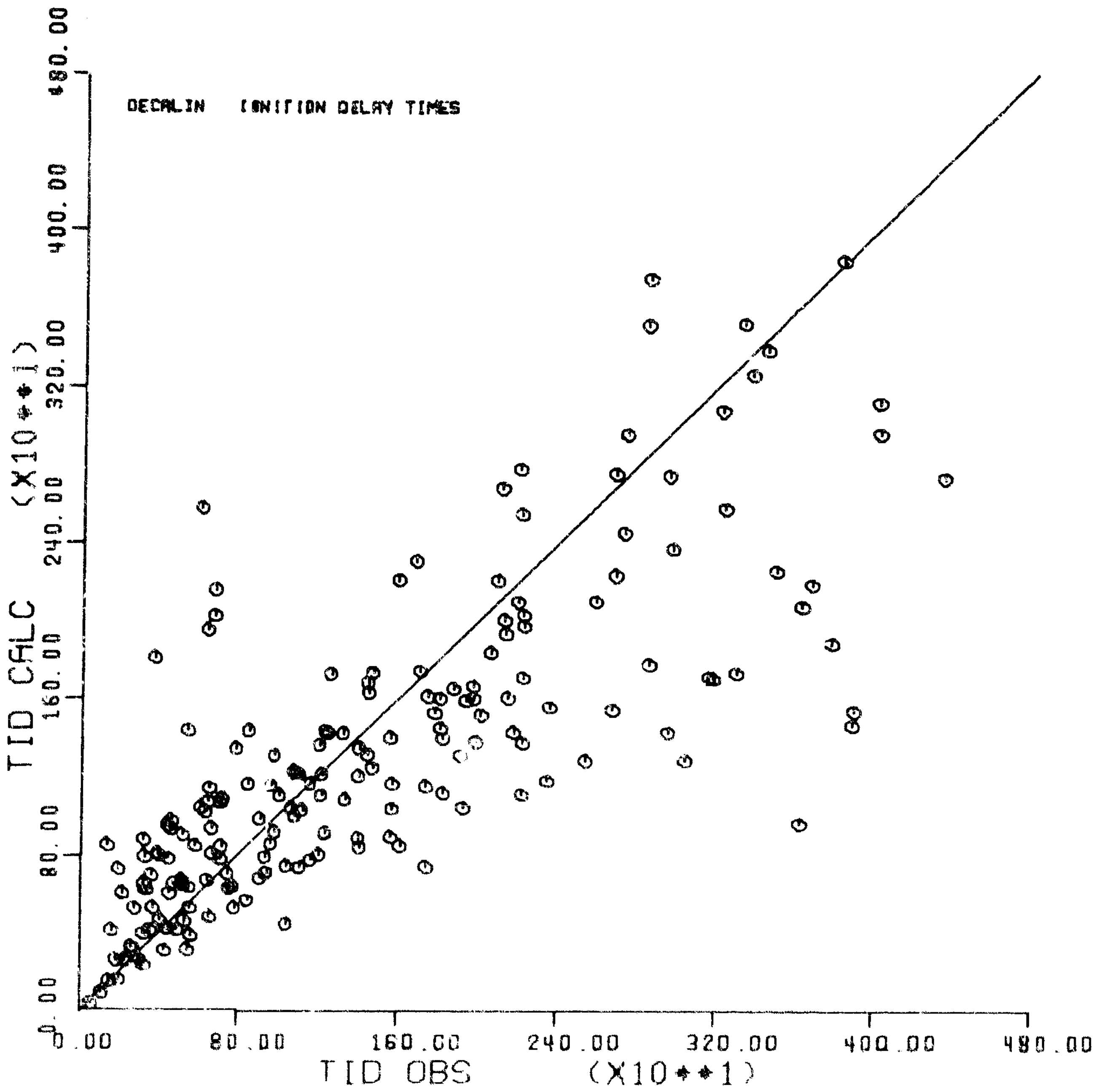


Figure 61. IGNITION DELAY TIMES OF DECALIN

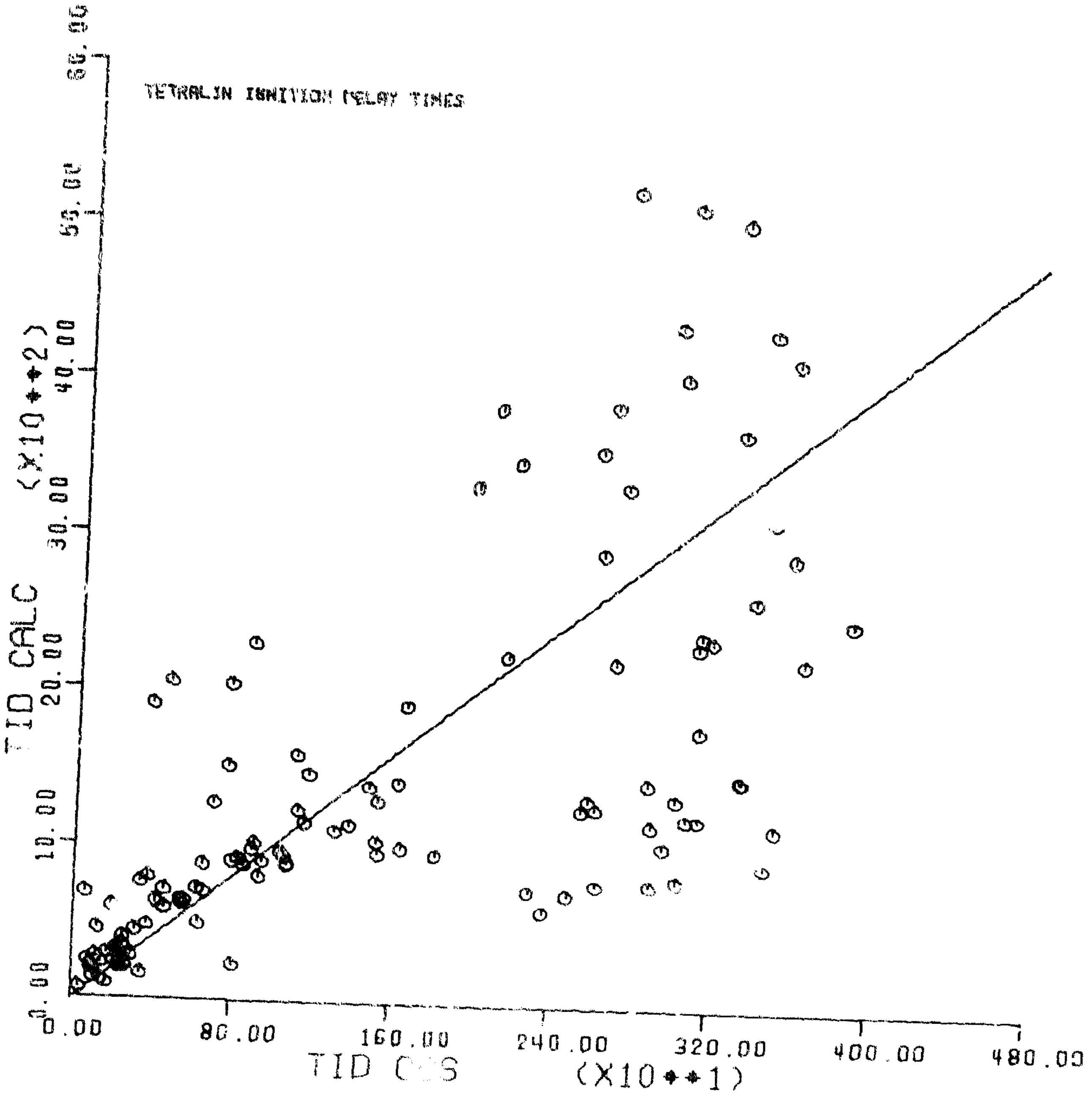


Figure 62. IGNITION DELAY TIMES OF TETRALIN

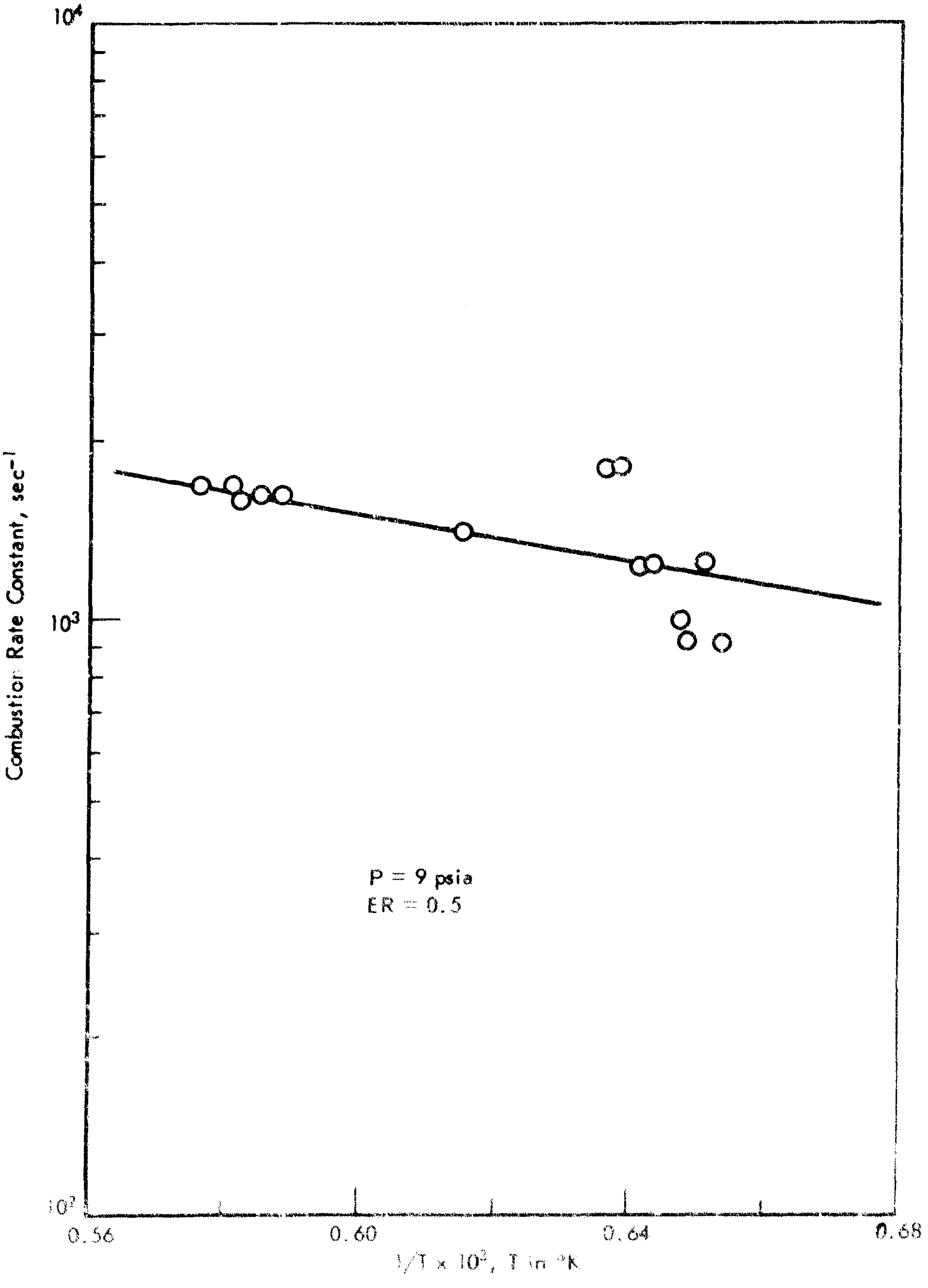


Figure 63. RATE OF COMBUSTION OF TETRALIN

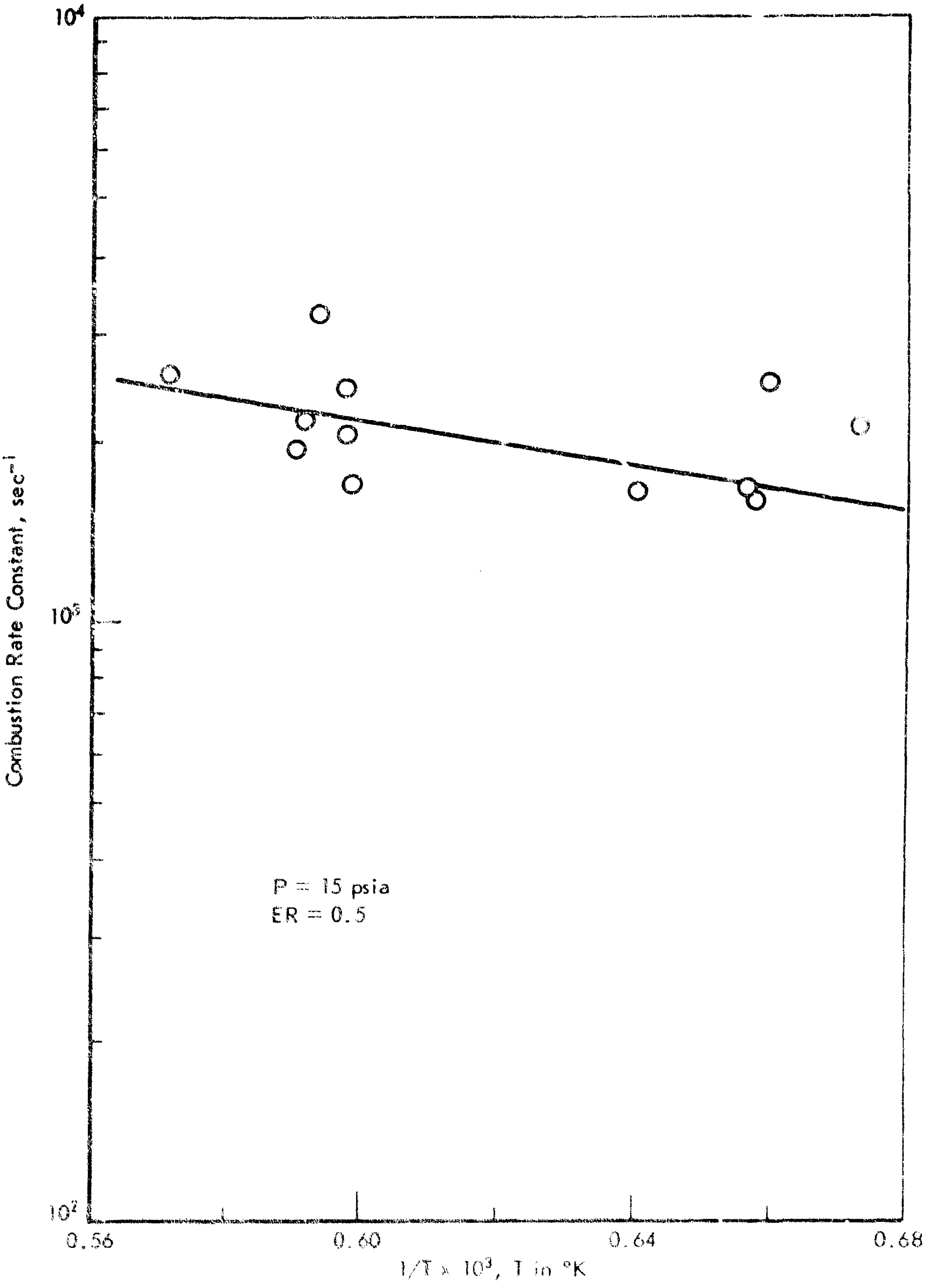


Figure 64. RATE OF COMBUSTION OF TETRALIN

appears that the results correlate fairly well. Figure 65 shows all of the tetralin combustion data, including the new data, with approximate correlating lines. The results show that fuel concentration has a beneficial effect on the rate, since the data for 99% argon with ER = 0.5 are higher than those for 99% argon with ER = 0.1. Also, as the amount of inert gas is decreased (at ER = 0.1) the rate of combustion increases.

This work contrasts somewhat with the previous work done of the combustion of n-octane and SHELLDYNE-H® fuel[3]. At that time no effect of fuel-oxygen ratio or pressure was noted. Further work will be done to clarify and mathematically describe the results, and other systems will be investigated.

FUTURE PROGRAM

The study of the stability of platinum catalysts for the dehydrogenation of naphthenes is continuing. Future work will include investigations of the effects of metal dispersion and certain metal additives on catalyst stability. The most promising catalysts will be tested in 50 to 100 hour runs at constant reaction conditions. Screening of granular catalysts for dehydrogenation activity will continue on a limited scale as new knowledge indicates any promising compositions.

The search will continue for possible second generation endothermic fuels. Dehydrogenation of bridged-ring naphthenes such as bicyclooctane will yield 1500 to 1800 Btu/lb heat sink when dehydrogenated to bicyclooctatriene. Subsequent double bond isomerization to cyclopropane rings would increase the heat sink to about 2300 Btu/lb. Dehydrocyclization of alkyl naphthenes to the corresponding aromatics, such as 1,2-diethylcyclohexane to naphthalene, would give about 1500 Btu/lb. These studies will be done initially in a pulse reactor. In the near future we expect to examine the possibility of dehydrogenating a highly naphthenic jet fuel and to prepare and test a high molecular weight naphthenic type fuel in the light gas oil range.

We shall continue to search for additives that will enhance the rate of thermal cracking of hydrocarbons. The aim of this study is to reduce both the reaction temperature and the coke made during the cracking reaction.

As a possible method for reducing the pressure drop in the reactor tube, we have been searching for a dispersed-type catalyst. Such a catalyst could be either dissolved in the liquid feed, added as a vapor to the feed vapor, or added as a finely divided solid to the feed vapor. In our previous contract we examined additives that were dissolved in the liquid feed. Some encouraging results were obtained and this study is continuing.

Development will continue on the catalytic wall reactor. The most immediate problem is the measurement of the stability and life of a wall catalyst for dehydrogenation of naphthenes. Catalyst formulations which were found to be most promising in activity screening studies will be used in preparing catalytic coatings for longer stability tests in the bench-scale reactor. If results are favorable, tests will be made in the Fuel System Simulation Test Rig to assess fully the capability of wall catalysts for dehydrogenating naphthenes. These tests will

Figure 65 follows

be made in the Fuel System Simulation Test Rig to assess fully the capability of wall catalysts for dehydrogenating naphthenes. These tests will be of sufficient duration to determine catalyst activity and stability under various conditions. Concurrently, the search will continue for wall catalysts with even more improved mechanical properties, activity, and stability.

The mathematical model of the Catalytic Wall Reactor will be improved. The current model, which includes a kinetic model for methylcyclohexane dehydrogenation, will be used to design the experiments for the Fuel System Simulation Test Rig so as to obtain data at an optimum set of conditions. These data will help to improve the mathematical model. The reaction model can be used to study the effects of geometry, flow rate, heat flux, and fuel conditions on the performance of a wall catalyst. After further development of the reactor model, it will be possible to calculate the upper limits of heat flux, conversion, and temperature of each reaction system as determined by the stability and activity of the catalyst and fuel of that system.

A Catalytic Continuous Stirred Tank Reactor has been designed for use in measuring reaction kinetics and catalyst stability. Equipment modification will begin soon and the reactor will be available for experiments in a short time. The reactor will be used to measure the intrinsic kinetics of dehydrogenation reactions on the best catalyst candidates. Data will be used to formulate kinetic models for the reaction systems. Dehydrogenation of MCH will be studied first to check the reaction kinetics that are currently used. Later experiments will be run to determine an acceptable model for the decalin dehydrogenation system.

Further calibration and evaluation of the beta-ray backscatter instrument on tubes of different dimensions and on tubes made of other alloys will be made. Now that the beta-ray backscatter instrument is available for rating tubes, the Catalyst and Fuel System Test Rig will be used in evaluating the deposits formed by fuels in various physical and chemical states: liquid, gas, vaporizing mixture, reacting mixture, and product mixture. Studies will continue on the use of additives to enhance the thermal and storage stability of fuels. Tests on thermal stability will be conducted in the recently modified JFTOT in order to determine if results from a one-cycle test such as this are better than measurements from a recycle test in the SD/M-7 coker.

Combustion studies on the shock tube will continue with the decalin dehydrogenation system. Ignition delay times will be measured for mixtures of components from the system: decalin, tetralin, naphthalene, and hydrogen, in proportions representative of products from the dehydrogenation reaction. Further experiments will be made on the combustion of tetralin and other fuels to define more accurately the relation between the combustion rate, pressure, oxygen concentration, and fuel concentration.

RELATED DEVELOPMENTS AND APPLICATIONS

An interesting paper was presented by D. C. Thomas and P. H. Hayes26) entitled "High Performance Heat Transfer Surfaces." They showed that heat transfer coefficients through tube walls could be increased by combining rectangular fins on the outside with twisted tape or coiled wire on the inside. Although the

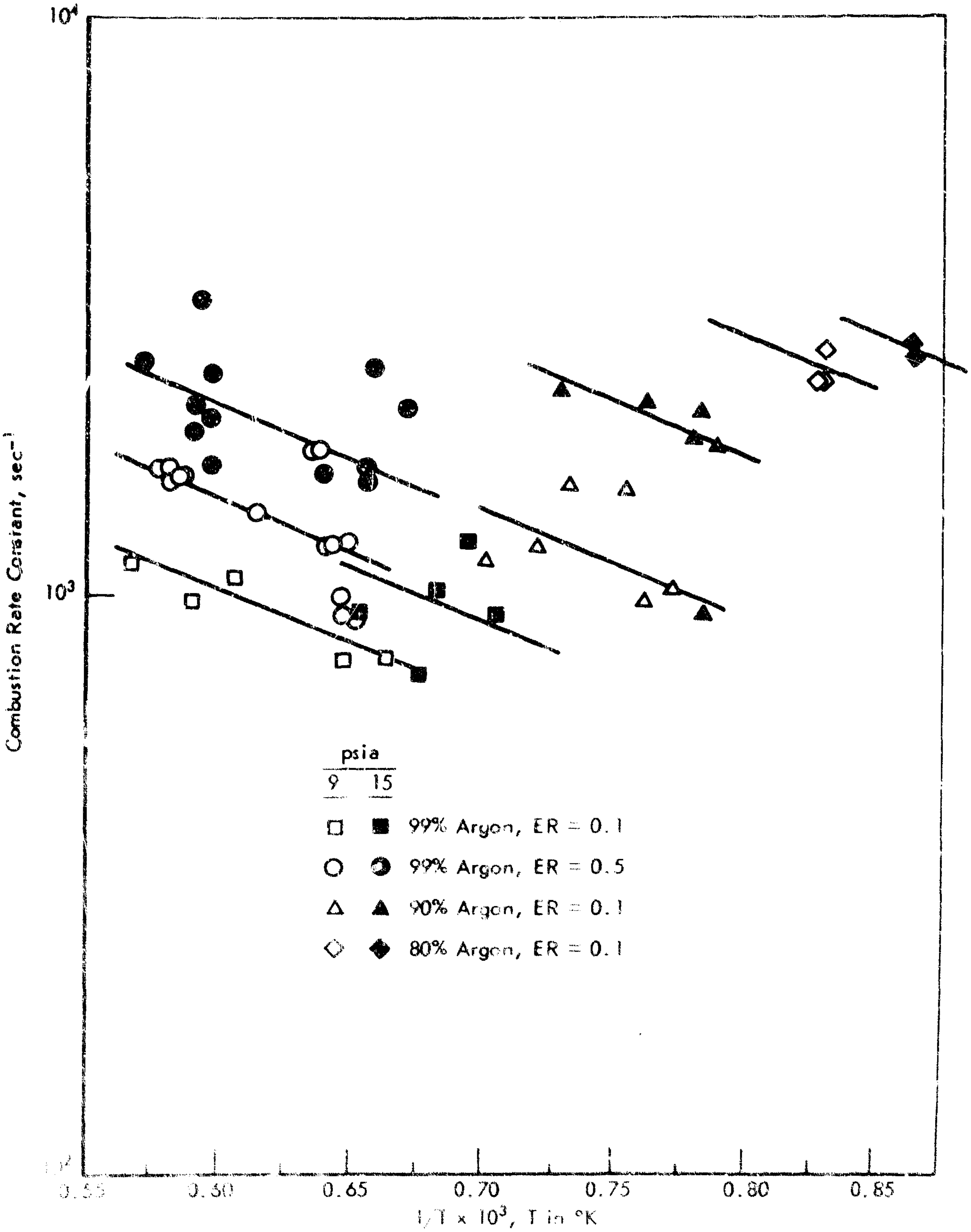


Figure 65. COMBUSTION OF TETRALIN

system studied involved condensing or evaporating water, the results showed benefits in heat transfer coefficients from two- to ten-fold and should be applicable to reacting systems with suitable modifications.

An article by Watkins and Jacobs27) details the use of hydrocracking to upgrade vacuum bottoms, low quality straight run, and catalytically cracked kerosene to commercial jet fuel specifications. Although the article applies only to the manufacture of commercial jet fuel, this method could be applied to selected petroleum feed stocks to produce naphthene concentrates which might serve as cheap endothermic fuels.

An article of interest by Whisman and Ward28) on the storage stability of high temperature fuels showed by means of fuel components labelled by C^{14} that the contribution to coker deposits in different thermally stable jet fuels was highest from aromatic compounds containing a C_5-ring, but the effect of any component was strongly dependent on the gross hydrocarbon environment. It also showed that an amine type antioxidant formed more filterable deposits in a high temperature environment than did a phenolic type.

An important paper delineating the problems inherent in extending flight speeds up to Mach 6 appeared in Aeronautics and Astronautics by M. P. Dunnam and H. I. Bush.29) The authors outlined the "broad range of technical advances which will enable turbomachinery to power demanding new missions and will pave the way for exotic new engines that may supplant rockets almost up to orbital speeds." An accompanying article by W. E. Lanar30) is also valuable.

Efforts to develop high temperature materials for advanced gas-turbine engines was reported by John C. Freche and Robert W. Hall31) of Lewis Research Center, NASA. "NASA Programs for Development of High Temperature Alloys for Advanced Engines" dealt chiefly with work on the development of nickel- and cobalt-base alloys, chromium-base alloys, materials strengthened by dispersion, composite materials, and protective coatings. The development of an advanced cast nickel-base alloy, NASA-TRW VI-A, was particularly significant. This was reported to have a high temperature life of 1000 hr at 1890°F.

Another interesting paper was "The Active Cooling of a Hydrogen Fueled Scram-Jet Engine" by L. L. Pagel and W. R. Warmbold32), McDonnell-Douglas Company, St. Louis. The results of this study indicate that Mach 12 flight at equivalence ratios of less than 1 can be achieved with a regenerative system using the hydrogen fuel as coolant in heat exchangers constructed from super alloys. Heat exchanger designs were based on TD Nickel-chromium construction. The authors suggest that this is a satisfactory material for use as a refractory metal in heat exchangers and that the use of ceramic coatings appears less urgent.

(This page is intentionally blank.)

REFERENCES

1. "Vaporizing and Endothermic Fuels for Advanced Engine Application," Technical Report AFAPL-TR-67-114, Part I. Contract No. AF 33(615)-3789, Shell Development Company, October, 1967.

2. "Vaporizing and Endothermic Fuels for Advanced Engine Application," Technical Report AFAPL-TR-67-114, Part II. Contract No. AF 33(615)-3789, Shell Development Company, September, 1968.

3. "Vaporizing and Endothermic Fuels for Advanced Engine Application," Technical Report AFAPL-TR-67-114, Part III. Contract No. AF 33(615)-3789, Shell Development Company, February, 1970.

4. "Vaporizing and Endothermic Fuels for Advanced Engine Application," Technical Documentary Report No. APL-TDR-64-100, Part III. Contract No. AF 33(657)-11096, Shell Development Company, September, 1966.

5. "Vaporizing and Endothermic Fuels for Advanced Engine Application," Technical Documentary Report No. APL-TDR-64-100, Part II. Contract No. AF 33(657)-11096, Shell Development Company, September, 1965.

6. Carberry, J. J., "Designing Laboratory Catalytic Reactors," Ind. and Eng. Chem., 56(11), 39 (1964).

7. Carberry, J. J., "Heat and Mass Diffusional Intrusions in Catalytic Reactor Behavior," Cat. Revs., 3(1), 61 (1969).

8. Butt, J. B., C. A. Walker, and R. H. Bliss, A.I.Ch.E. Journal, 8, 42 (1962).

9. Perkins, T. K. and H. F. Rase, A.I.Ch.E. Journal, 4, 351 (1958).

10. Bernard, J. R. and S. J. Teichner, "Un Nouveau Type de Reacteur a Circulation Pour l'Etude des Reactions de Catalyse Heterogene," Bull. Soc. Chim. (France), No. 11, 3798 (1969).

11. Relyea, D. L. and D. D. Perlmutter, "A Stirred Reactor with Porous Catalyst Wall," Ind. and Eng. Chem. Proc. Des. and Dev., 7(2), 261 (1968).

12. Brisk, M. L., R. L. Day, M. Jones, and J. B. Warren, "Development of a Stirred Gas-Solid Reactor for the Measurement of Catalyst Kinetics," Trans. Inst. Chem. Engrs., 46(1), T3 (1968).

13. Tajbl, D. G., J. B. Simons, and J. J. Carberry, "Heterogeneous Catalysis in a Continuous Stirred Tank Reactor," Ind. and Eng. Chem. Fund., 5, 171 (1966).

14. Tajbl, D. G., "Kinetics of Catalytic Ethane Hydrogenolysis: Stirred Reactor Study of Commercial Nickel Catalyst," Can. J. Chem. Eng., 47(4), 154 (1969).

15. Tajbl, D. G., "Hydrogenolysis of Ethane and of Propane over a Commercial Ruthenium Catalyst," Ind. and Eng. Chem. Proc. Des. and Dev., 8(5) 464 (1969).

REFERENCES (Contd)

16. Ma, Y. H., "Effectiveness Factors in a Liquid-Filled Porous Catalyst," Ph.D. Dissertation, M.I.T. (1966).

17. Koo, et al., Trans. A.I.Ch.E., 28, 56 (1932).

18. Sehr, R. A., Chem. Eng. Sci., 9, 145 (1958).

19. Redlich, O., F. J. Ackerman, R. D. Gunn, M. Jacobson, and S. Lau, Ind. Eng. Chem. Fund., 4, 369 (1965).

20. Redlich, O., and J. M. S. Kwong, Chem. Rev., 44, 233 (1949).

21. Rihani, D. N., and L. K. Doraiswamy, Ind. Eng. Chem. Fundamentals, 4, 17 (1965).

22. Robbins, L. A. and C. L. Kingrea, Hydrocarbon Processing and Petrol. Refiner, 41, 133 (1962).

23. "Technical Data Book - Petroleum Refining," American Petroleum Institute, Division of Refining, New York, 1966.

24. Perry, J. H., Ed., "Chemical Engineers' Handbook," 4th Ed., McGraw-Hill, New York, 1963.

25. Emrich, R. J. and D. B. Wheeler, Jr., "Wall Effects in Shock Tube Flow," Phys. Fluids, 1, 14 (1958).

26. Thomas, D. C., and P. H. Hayes, Ind. Eng. Chem., 62, 214 (1970).

27. Watkins, C. H., and W. L. Jacobs, The Oil and Gas J., 67 (47), 94 (Nov. 24, 1969).

28. Whisman, M. L., and C. C. Ward, "Storage Stability of High Temperature Fuels, Part II: The Effect of Storage Upon Thermally Induced Deposition of Labelled Fuel Components," USAF Technical Report AFAPL-TR-68-32, Part II, March, 1969.

29. Dunnam, M. P., and H. I. Bush, Aeronautics and Astronautics, 7(7), 64 (July 1969).

30. Lanar, W. E., Aeronautics and Astronautics, 7(7), 56 (July, 1969).

31. Freche, J. C., and R. W. Hall, J. Aircraft, 6, 424 (1969).

32. Pagel, L. L. and W. R. Warmbold, J. Aircraft, 6, 472 (1969).

APPENDIX

Tables 55 and 56 follow

Description of the Pulse Reactor

The pulse reactor was a 1/4-in. OD tube of stainless steel type 304 with 9-1/4 in. length and 0.035 in. wall thickness. Swagelok Tees were fastened at each end and one arm of the Tee served as an injection port. A rubber septum (GLC type) was held in place by the fitting nut and the feed was injected through this septum from a syringe. A 5-in. length of the reactor tube was surrounded by a secondary furnace liner and the whole was heated by an electric furnace. The secondary liner had seven radial drilled holes for thermocouples, and the holes were located as shown in Figure 66. A schematic diagram of the pulse reactor is shown in Figure 67.

All lines were 1/4-in. OD tubing of stainless steel type 304. About 28 in. of line just prior to the reactor was wrapped with heating tape and constituted a gas preheater. About 8 in. of the preheater section was filled with quartz chips (10-20 mesh size).

In the pulse reactor system the carrier gas was metered through a rotameter (Figure 67) and passed through the preheater section into the reactor. The exit gas passed into a manifold and then into the GLC. The purpose of the manifold was to maintain the exit gas pressure slightly greater than the gas pressure in the GLC. This was done by adjusting the pressure control valve and the vent valve. The manifold was wrapped with heating tape and was maintained at 302° to 356°F. The injection port temperature was about 450°F. The pressure control and the vent valves were needle valves (Hoke No. 1315) and the GLC valve was a lever operated valve (Hoke No. 490).

To carry out an experiment the reactor was brought to temperature, and the carrier gas flow rate, reactor pressure and manifold pressure were adjusted by means of the appropriate flow control valves. Then with inert gas flowing to the GLC a pulse was injected through the lower injection port and subsequently analyzed. This gave an analysis of the starting material. A pulse was then injected in the top injection port, passed over the catalyst, and analyzed.

In this system the space velocity was obtained from the inert gas flow rate. Figure 68 shows the pulse reactor system with the secondary furnace liner in place.

Figures 66, 67 and 68 follow

[illegible]

[illegible]

Pressure: 10 atm
LHSV: 100
Catalyst Charge: 2 ml
Feed: P-115 DHN

Run No. 11525-	171	172	173	176	177	178-1	178-2	179	181-1	181-2	182	183	184	185	187
Catalyst No.		10860-144				10860-145					[illegible]-145				1086
Temperature, °F															
Block	842	932	1022	842	932	1022	1112	1202	842	[illegible]	1022	1112	1202	842	9
Wall	752	793-97	864	707-04	650-61	854	857	[illegible]	730-44	[illegible]	[illegible]	[illegible]	1038-44	741-47	812
Catalyst Bed	614-30	655-75	711-53	604-15	630-50	673-80	711-54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1136-1181	614-21	589
Profile	619-24	653-60	608-705	635-10	647-44	673-75	708-11	[illegible]	[illegible]	[illegible]	[illegible]	711-29	912-1058	617-24	658
	626-[illegible]	663-68	711-12	610-15	646-5[illegible]	660-67	730-[illegible]	[illegible]	[illegible]	658-[illegible]	667	716	815-44	650-55	662
	640-46	587-91	745	628-32	671-75	720	770-[illegible]	[illegible]	657	[illegible]	707-34	757-4[illegible]	810-13	664-66	516
Product Analysis, %w															
Cracked, liq.	0.0	0.0	0.0	0.0	0.1	[illegible]	0.0b)	1.7	[illegible]	[illegible]	0.1	[illegible]	6.2e)	0.0	0
trans DHN	31.[illegible]a)	27.8a)	22.9	32.7a)	29.7a)	24.8	25.6n)	13.5	35.[illegible]	31.[illegible]a)	20.1	20.9	12.9a)	34.6a)	30
cis DHN	34.9	29.4	25.5	30.8	24.0	19.8	10.7	13.3	28.3	24.[illegible]	22.6	16.2	15.8	31.9	2
THN	17.8	9.2	5.9	16.4	12.7	8.3	5.[illegible]	5.7	16.4	14.4	7.6	5.[illegible]	4.1	12.7	9
N	22.0	33.7	45.7	21.1	33.4	47.1	58.9	67.7	[illegible]	31.5	4[illegible].6	[illegible]	57.7f)	20.8	30
Others	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	[illegible]	[illegible]	3.1	0.0	0
DHN Conversion, %w	33.5	42.7	51.4	37.2	48.0	55.2	65.7	73.3	36.[illegible]	[illegible]	[illegible]	22.6	71.2	33.2	39
Selectivity for THN + N %w	100	100	100	100	100	100	99.6	96.9	99.4	99.7	99.8	99.5	86.2	100	100
ΔT, °F	7	20	43	11	11	7	23	142	7	4	11	13	146	7	58

a) cis to trans isomerization during the run
b) two components
c) four components
d) appeared to be more than one component
e) eight components
f) two components that emerged after cis DHN and one component that emerged after trans DHN

h) emerged after cis DHN
m) catalyst almost completely deactivated at
n) emerged after trans DHN
p) twelve components
[illegible]) one component emerged after trans DHN (7.
r) five components

Run No. 11623-	16	17-1	17-2	18	20	21-1	21-2	22	23	24	25	26-1	26-2	27
Catalyst No.	<---	10860-137B		-->	<	---	10860-138B		>	<		10860-139B		>
Temperature, °F														
Block	842	932	1022	1112b)	842	932	1022	1112	1202	842	932	1022	1112	1202
Wall	763-65	835-42	914-20	990-1004	705-11	768-77	840-46	918-39	1144-75	745-46	804-15	876-94	956-99	1118-59
Catalyst Bed	795-97	887	972-77	1060-46	783-95	880-84	977-74	1060-67	1155-53	748	873-75	959-68	1053-67	1154
Profile	650-62	698-72	750-92	820-87	621-44	679-94	727-58	790-887	1132-55	650-68	694-718	740-93	826-64	1099-1159
	622-26	660-62	704-09	752-94	603-08	635-40	675	712-07	1028-1155	633-39	676-78	712-20	770-97	916-1008
	628-30	668	709-11	766-90	614	640-50	689-87	734-29	[illegible]-1152	[illegible]-41	684-86	729-30	7[illegible]-97	896-932
Product Analysis, %w														
Cracked, Liq.	1.7	0.0	0.0	0.0	0.0	0.0	0.[illegible]	0.2	6.1d)	0.0	0.0	[illegible]	0.2	1.8a)
trans DHN	32.8a)	28.2a)	24.2	16.8	34.1a)	31.3a)	25.1	18.9	20.5	29.2a)	26.4a)	[illegible].2	14.9	15.0
cis DHN	37.2	32.0	27.1	27.0	28.4	23.0	19.5	15.1	47.0	40.2	35.2	2[illegible].9	25.4	32.6
THN	9.4	8.7	5.4	3.2	15.7	12.8	8.5	4.1	4.4	9.5	7.1	4.1	4.6	7.8
N	16.8c)	31.1	43.3	55.0	21.8	32.9	46.9	61.7	7.7e)	21.1	31.2	4[illegible].8	54.8	40.7
Others	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.3	0.0	0.0	[illegible]	0.1	0.0
DHN Conversion, %w	29.7	39.6	48.5	56.0b)	37.2	45.5	55.2	65.9	32.2f)	30.3	40.0	44.7	59.5	52.2h)
Selectivity for THN + N, %w	86.9	100	100	100	100	100	100	100	67.0	100	100	100	99.5	96.5
ΔT, °F	13	23	41	67	23	20	31	97	-- f)	18	23	56	139	--h)

a) cis to trans isomerization during the run
b) reaction time 15 minutes
c) one component emerged after trans DHN (1.9%) and one component after cis DHN (0.2%)
d) eight components
e) one component emerged after trans DHN (4.8%) and one after cis DHN (9.5%)
f) reaction time 13 minutes
g) four components

h) reaction time 10 minutes
m) five components
n) emerged after trans DHN
p) tem components
[illegible]) emerged after cis DHN
r) six components
s) one component emerged after trans DHN (0.7%) and

Run No. 11623-	46	47	48-1	48-2	49	51	52	53-1	53-2	54	56-1	56-2	57	58
Catalyst No.	<---		10860-146		--->	<---		10860-146		--->	<---		10860-147	--->
Temperature, °F														
Block	842	932	1022	1112	1202c)	842	932	1022	1112	1202c)	842	932	1022	1112
Wall	748-52	819	887	945-39	1040-44	776-79	856-54	942-40	982-79	1058-80	727-32	794-99	862-74	945-10[illegible]
Catalyst Bed	689-98	748-63	802-30	864-920	1112	765	830-28	909-12	977-95	1067-62	701-74	853-56	943-56	1049-6[illegible]
Profile	603-10	635-44	665-76	707-22	892-930	599-604	630-35	658-71	700-11	763-806	648-68	694-716	748-88	873-10[illegible]
	601-04	635-53	665-67	707-05	783-99	597-99	628-30	669-75	700-696	765-831	644-51	687-93	734-43	802-6[illegible]
	603-05	635-57	665-69	707-05	783-813	597-601	626	668	702-[illegible]	767-833	660-66	711	765-66	831-5[illegible]
Product Analysis, %w														
Cracked, liq	0.0	0.0	0.0	0.1	3.7b)	0.0	0.0	0.0	0.2	3.5d)	[illegible]	0.0	0.1	0.7
trans DHN	36.2a)	31.0a)	25.0	18.3	10.5	36.7a)	29.9a)	14.7	15.8	10.2	26.1a)	23.7	20.5	18.1
cis DHN	19.9	16.6	12.7	9.8	7.8	19.4	16.1	12.9	9.[illegible]	5.6	43.5	39.3	36.1	37.5
THN	18.9	15.9	10.6	5.9	2.4	17.2	14.5	9.8	5.7	2.3	8.2	6.8	5.5	5.9
N	25.0	36.5	57.7	65.9	75.6	26.7	39.5	62.4	65.4	78.4	22.1	30.2	37.8	37.8
Others	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.[illegible]	0.0	0.0	0.0	0.0	0.0
DHN Conversion, %w	43.7	52.2	62.1	71.8	82.3c)	43.7	53.8	62.2	71.2	84.1c)	30.[illegible]	36.7	43.2	44.2
Selectivity for THN + N, %w	100	100	100	99.8	94.3	100	100	100	99.7	95.8	100	100	99.8	98.0
ΔT, °F	9	15	28	56	--	3	[illegible]	13	18	66	13	17	40	135

a) cis to trans isomerization during the run
b) seven components
c) reaction time 10 minutes
d) six components
e) four components
f) emerged after THN

[illegible]

[illegible] Feed Composition: [illegible]% trans-DHN

[illegible]% cis-DHN

ume: [illegible] [illegible]% THN

[illegible] DHN

18A	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7-1	7-2	8	9	11	12	13	14-1	14-2
[illegible]-132A					[illegible]-134A			[illegible]			10860-1[illegible]					10860-14[illegible]				
[illegible] 804-02 1072-06 711-29 716 747-42	[illegible] [illegible] [illegible] [illegible] [illegible] [illegible]	[illegible] 741-47 614-21 612-24 [illegible] 604-66	[illegible] 810-24 680-747 655-75 662-69 516-74	[illegible] 862-887 850-880 720-908 712-913 722-813	[illegible] 727-[illegible] 707-34 644-62 630-53 644-55	[illegible] 700-850 702-884 601-784 686-704 685-705	[illegible] 865-1000 981-86 916-77 727-970 772-956	842 730-43 723-22 [illegible] 635-40 635-42	[illegible] 808-[illegible]5 786-840 686-752 671-86 676-86	[illegible] 916-84 950-03 900-984 720-961 729-850	842 767-43 740-54 622-28 604-08 608-10	[illegible] 812-15 828-35 608-17 637-39 644	[illegible] 876-02 914-46 693-123 662-75 671-80	1112 948-77 957-1054 736-831 707-22 725-23	1202 1125-66 1150-55 1085-1139 885-1202 858-56	842 734-38 808-02 646-48 597-99 604-08	932 792-90 896-91 675-78 626 639-35	1022 856 982-77 712-20 651 662-66	1112 938-41 1061-98 734-48 682-85 707	1202 1006-18 1141-44 848-903 752 788-76
0.3$^{h)}$ 20.9 16.1 5.5 57.2 0.0	0.2 12.9 1[illegible].8 4.1 57.7 3.[illegible]	[illegible] 34.6$^{a)}$ 31.9 12.7 [illegible] [illegible]	0.0 30.6 29.6 9.2 31.6 0.0	0.4$^{c)}$ 28.6$^{a)}$ 37.4 5.5 27.0 1.1$^{h)}$	0.0 27.2$^{a)}$ 46.3 7.1 10.4 0.0	0.0 24.3 44.3 5.1 26.3 0.0	0.5$^{c)}$ 25.4$^{a)}$ 54.9 3.6 12.2 2.4$^{h)}$	0.0 28.8$^{a)}$ 43.7 6.9 20.6 0.0	0.0 25.7$^{a)}$ 39.5 5.0 29.8 0.0	0.0 24.4 41.9 2.2 29.0 1.6$^{n)}$	0.3 40.4$^{a)}$ 25.8 15.6 18.2 0.0	0.0 34.8$^{a)}$ 21.0 12.5 31.7 0.0	0.0 26.4$^{a)}$ 17.9 6.8 48.8 0.0	0.0 20.5 13.0 4.2 62.5 0.0	7.6$^{p)}$ 12.3 18.4 6.3 39.6 15.3$^{q)}$	0.0 55.3$^{a)}$ 23.0 17.8 23.9 0.0	0.0 30.9$^{a)}$ 18.2 10.1 34.8 0.0	0.0 23.7 13.5 13.0 49.8 0.0	0.1 17.1 11.6 8.2 63.0 0.0	2.5$^{r)}$ 11.6 10.7 3.6 71.3 0.2
62.6	71.[illegible]	33.2	39.5	33.7$^{m)}$	26.2	31.1	19.4$^{m)}$	27.2	34.5	33.4$^{m)}$	33.5	44.0	55.5	66.6	69.2$^{m)}$	41.4	50.7	56.3	71.2	77.6
99.5	86.[illegible]	1[illegible]	100	95.3	100	100	79.4	100	100	92.2	100	100	100	100	65.8	100	100	100	99.8	95.6
25	140	7	58	248	27	94	182	13	56	241	5	9	32	95	227	5	4	7	36	56

r cis DHN

st completely deactivated at the end of this run

r trans DHN

ents

t emerged after trans DHN (7.6%) and one component after cis DHN (7.9%)

ts

26-1	26-2	27	30-1	30-2	31	32-1	32-2	34-1	34-2	35	37	38-1	38-2	39	40	42-1	42-2	43	44-1	44-2
-10860-133			10860-135A					10860-143B			10860-136C					10860-146				
1022 878-94 959-68 740-95 112-20 729-30	1112 956-99 1053-67 826-64 770-97 780-97	1202 1118-59 1154 1090-1139 915-1000 596-932	842 747-50 812-795 640-57 617-24 622-26	932 812-13 884-76 687-96 655-57 662-60	1022 874-78 973-61 716-43 669-91 702-698	1112 946-52 1049-56 770-801 752-34 743-45	1202 1036-54 1134-48 869-1000 795-815 813-15	842 727-40 806-05 675-722 650-44 633-40	932 788-884 910-03 761-900 678-903 689-727	1022 982-1004 1006-995 1000 959-997 869-808	842 716-23 666-80 614-18 615-21 633-35	932 788 720-40 651-53 658 680-78	1022 860 770-95 689 702-698 734-25	1112 937 831-71 729-32 743 784-81	1202 1040-44 1004-49 819-22 822-19 873-62	842 730-32 615-28 586-91 597-601 612-14	932 817-10 657-71 621-22 635 651-49	1022 846-49 693-712 651 673-69 694-91	1112 954-57 738-74 684 714-11 747-43	1202$^{h)}$ 1040-46 873-92 759-72 792-817 833-73
0.0 25.2 29.9 4.1 40.8 0.0	0.2 14.9 25.4 4.6 54.8 0.1	1.8$^{a)}$ 15.0 32.6 7.8 40.7 0.0	0.0 33.7$^{a)}$ 31.2 13.7 21.4 0.0	0.0 30.9$^{a)}$ 26.3 9.9 32.9 0.0	0.0 26.0$^{a)}$ 21.6 6.2 46.2 0.0	0.2 18.5 16.5 4.2 60.6 0.0	1.4$^{m)}$ 13.0 14.9 3.6 67.1 0.0	1.2 30.1$^{a)}$ 40.7 7.9 18.7 1.4$^{n)}$	0.0 25.8$^{a)}$ 40.3 6.5 27.4 0.0	2.1$^{p)}$ 24.4 54.9 5.0 4.2 9.4$^{q)}$	0.0 28.2$^{e)}$ 36.0 11.8 24.0 0.0	0.0 24.8 31.3 8.7 34.2 0.0	0.0 19.7 26.6 6.0 47.7 0.0	0.4$^{g)}$ 16.8 21.3 3.7 57.8 0.0	2.6$^{r)}$ 12.8 18.3 3.6 62.5 0.1	0.0 36.4$^{a)}$ 20.2 18.5 24.9 0.0	0.0 31.1$^{a)}$ 16.7 15.4 36.8 0.0	0.0 24.8 12.8 10.2 52.2 0.0	1.2 19.0 9.8 4.8 64.5 0.7$^{[illegible])}$	4.3$^{p)}$ 9.5 6.5 2.3 76.4 1.0$^{s)}$
44.7	59.5	52.2$^{h)}$	34.8	42.6	52.2	64.9	72.[illegible]	28.9	33.6	20[illegible]$^{h)}$	35.5	43.7	53.5	61.7	68.8	43.2	52.0	62.2	71.1	83.9
100	99.5	96.5	0.0	0.0	0.0	99.7	97.9	90.7	100	43.1	100	100	100	99.3	95.5	100	100	100	96.9	93.3
56	139	--$^{h)}$	16	9	27	31	131	47	160	--$^{h)}$	14	20	25	40	47	13	14	20	54	--$^{h)}$

es

N

after trans DHN (0.7%) and one after cis DHN (0.3%)

-1	56-2	57	58	64	65-1	65-2	66	67	69	70-1	70-2	71-1	71-2
	10860-147			10860-135B					10860-163A				
 -32 -74 -68 -51 -66	932 794-99 853-58 694-716 687-93 711	1022 862-74 945-56 748-88 734-43 765-66	1112 945-1000 1049-67 873-1008 802-69 831-51	842 761-63 624 608-14 614-17 630-35	932 835-33 648-53 644-46 657-53 578-74	1022 905-07 680-89 680 698-94 729-25	1112 975-77 722-34 722 743-32 784-79	1202 1058-62 781-828 788 820-12 878-62	842 766-64 745-52 619-24 620-22 626-24	932 842-38 822-33 651-60 651-58 651-49	1022 912 905-42 656-704 689-93 698-94	1112 984-[illegible] 1013-42 7[illegible]9-77 725 734-25	1202 1148-79 1143-50 1011-1144 869-1139 842-1132
.0 .1$^{a)}$ .5 .2 .1 .0	0.0 23.7 39.3 6.8 30.2 0.0	0.1 20.5 36.[illegible] 5.5 37.8 0.0	0.7$^{e)}$ 18.1 37.5 5.9 37.8 0.0	 31 26.[illegible] 16.4 26.2 0.0	0.0 25.6 20.[illegible] 11.9 38.1 0.0	0.0 21.9 15.4 7.3 55.4 0.0	0.2 16.6 13.2 4.2 65.5 0.0	3.0$^{d)}$ 12.6 10.9 3.1 70.4 0.0	0.0 34.1$^{a)}$ 26.4 14.1 25.4 0.0	0.0 33.8$^{a)}$ 21.3 12.1 32.8 0.0	0.0 24.0 21.5 9.0 45.4 0.0	0.3 17.4 18.8 7.4 55.1 0.0	6.8 19.0 35.3 7.5 27.1 4.3$^{f)}$
.0	36.7	43.2	44.2	42.4	53.7	62.6	70.0	77.9	39.3	44.7	54.3	63.7	45.5
	100	99.8	98.0	100	100	100	100	94.4	100	100	100	99.5	75.2
	22	40	135	6	5	9	12	47	7	11	37	48	290

Table 55.

Table 55 (Contd). DEHYDROGENATION O

Run No. 11325-	146	147	148-1	148-2	149	99	100	101	105	106	107	102	103	104	111
Catalyst No.	← 9874-119B →					← 9874-186A →			← 9874-187A →			← 9874-189A →			← 98
Temperature, °F															
Block	842	932	1022	1112	1202	842	932	1022	842	932	1022	842	932	1022	842
Wall	704-07	759-65	824-30	905-18	1015-1175	725-29	788-99	858-997	727-32	790-813	873-1011	736-41	799-820	878-1008	761-828
Catalyst Bed	617-32	657-78	698-743	744-88	962-1156	650-60	707-81	806-995	669-89	723-824	685-997	667-04	718-810	844-907	770-817
Profile	603-09	635-44	671-80	712-34	815-1230	632-44	675-94	723-984	6114-55	687-723	752-997	644-51	684-723	750-995	691-815
	609-15	644-50	682-89	734-38	853-1017	637-44	680-87	725-905	648-53	689-700	740-997	649-53	691-702	743-992	658-799
	626-30	664-68	711-14	774-72	1015-1175	651-55	696-700	745-797	657-60	702-05	750-987	662-64	707-09	758-988	656-763
Product Analysis, %w															
Cracked, liq	0.0	0.0	0.1	0.6	4.2	0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.0	0.3	0.3
trans DHN	30.9a)	27.7a)	23.5	18.8	15.2	29.0a)	26.3a)	22.2	26.6a)	25.6	22.5	26.4a)	24.6	22.5	28.3a)
cis DHN	29.4	24.8	20.3	18.5	27.1	40.9	37.0	40.4	45.2	42.0	50.5	45.9	41.6	53.9	52.1
THN	17.9	14.2	9.3	5.1	5.2	9.9	7.7	6.5	8.2	6.1	5.1	7.8	6.0	4.4	5.3
N	21.8	33.3	46.8	56.9	46.9	20.1	28.8	28.9	20.0	26.3	19.4	19.9	27.8	15.0	11.0
Others	0.0	0.0	0.0	0.1b)	1.5c)	0.1b)	0.2b)	1.8d)	0.0	0.0	2.4e)	0.0	0.0	3.9f)	3.0g)
DHN Conversion, %w	39.3	47.1	55.8	62.6	57.4	29.7	36.3	37.0	27.8	32.0	26.6	27.3	33.4	23.2	19.2
Selectivity for THN + N, %w	100	100	99.8	98.4	90.1	99.3	99.4	97.0	100	100	90.6	100	100	81.9	82.8
ΔT, °F	14	22	45	133	389	20	74	261	20	101	257	16	92	248	140

a) cis to trans isomerization during run
b) emerged after cis DHN
c) one component emerged after trans DHN (0.7%) and one after cis DHN (0.7%)
d) one component emerged after trans DHN (0.9%), and one after cis DHN (0.9%)
e) one component emerged after trans DHN (1.0%), and one after cis DHN (1.4%)
f) one component emerged after trans DHN (1.5%), and one after cis DHN (2.4%)
g) emerged after cis and trans DHN

Run No. 11325-	138	139	140-1	140-2	141	118	119	120	126	127	128-1	128-2	129	130	131
Catalyst No.	← 10280-15A →					← 10280-50A →			← 10280-77A →					←	
Temperature, °F															
Block	842	932	1022	1112	1202	842	932	1022	842	932	1022	1112	1202	842	932
Wall	736-41	799-802	874-78	948-46	1044-49	802-26	885-920	972-1008	711-14	766-70	824-26	891-94	977-1035	640-42	680
Catalyst Bed	666-82	711-34	759-84	806-42	903-1010	797-802	873-900	950-88	617-28	650-64	687-709	770-840	892-1121	630-42	662-76
Profile	635-42	669-78	711-16	748-52	822-44	770-808	838-902	918-88	604-17	635-40	667-75	716-22	770-73	621-26	651-55
	635	669-71	711-08	750-43	822-17	686-812	806-903	894-988	615-26	646-57	682-86	732-29	797-804	628-32	662
	644	684	730-25	748-46	1044-49	802-26	788-903	889-988	633-42	671-74	714-16	770-65	853-33	640-42	680
Product Analysis, %w															
Cracked, liq	0.0	0.0	0.0	0.4	1.9	1.5	1.5	2.5	0.0	0.0	0.0	0.5	3.2	0.1	0.3
trans DHN	29.9a)	26.4a)	21.8	16.4	11.2	27.0a)	25.6a)	26.8a)	34.5a)	30.8a)	25.3	18.3	12.7	34.5a)	31.0a)
cis DHN	39.1	35.0	29.6	24.3	21.5	63.0	67.7	63.0	26.5	21.5	17.3	17.0	14.1	27.4	21.6
THN	11.0	9.2	8.1	7.2	5.6	2.1	1.7	1.8	17.5	14.3	10.5	6.7	4.1	14.6	11.5
N	20.0	29.5	40.5	51.4	59.4	1.7	0.9	1.0	21.3	33.3	46.9	57.2	64.7	23.4	35.5
Others	0.0	0.0	0.0	0.2b)	0.4c)	4.7d)	1.6d)	4.9d)	0.0	0.0	0.0	0.1b)	1.2e)	0.0	0.0
DHN Conversion, %w	30.6	38.3	48.2	59.3	66.9	9.6	5.7	10.2	38.1	47.2	57.0	64.3	72.8	37.6	47.0
Selectivity for THN + N, %w	100	100	100	98.1	96.6	35.4	40.4	23.5	100	100	100	98.8	94.0	99.7	99.4
ΔT, °F	16	23	25	36	107	126	--	--	13	14	22	170	229	13	14

a) cis to trans isomerization during run
b) emerged after naphthalene
c) two components - one emerged after trans DHN and one after cis DHN
d) emerged after cis DHN
e) three components, one of which emerged after trans DHN, cis DHN and naphthalene respectively
f) two components that emerged after cis DHN and naphthalene respectively

EHYDROGENATION OF DECALIN OVER VARIOUS CATALYSTS

105	104	111	112	113	96	97	98	93	94	95	142	143	144-1	144-2	108	109	110	114	115	116-1	116-2
9874-186A		9874-186B			9874-192A			9874-194A			9874-193A				9874-194B			10280-13			
932	1022	842	932	1022	842	932	1022	842	932	1022	842	932	1022	1112	842	932	1022	842	932	1022	1112
799-820	878-1008	761-828	826-918	961-1008	752-36	797-830	891-1011	725-30	790-97	855-988	734	797-802	869-92	965-1085	740-815	797-909	912-1004	727-32	797-801	869-959	968-1094
718-817	[illegible]-997	770-817	838-907	966-95	657-78	707-864	878-999	653-71	705-48	774-995	651-68	700-46	774-928	970-1074	743-806	784-900	927-990	651-66	698-736	748-986	966-1076
684-723	750-965	691-815	754-905	907-25	639-48	680-734	756-997	633-42	671-87	716-972	632-35	660-80	709-67	794-1064	671-799	704-894	831-990	628-37	668-80	707-904	812-1072
691-702	743-992	658-739	696-887	828-992	644-48	682-93	734-986	637-44	676-86	721-856	655-39	671-76	712-25	763-1040	650-761	689-860	765-986	633-37	673-80	714-768	788-1069
707-09	758-988	656-763	696-852	788-982	653	691-93	743-956	651-57	694-700	745-83	651-53	689-91	730-28	784-923	653-700	648-804	761-966	644-50	687-91	756-765	806-1069
0.0	0.3	0.3	0.6	1.4	0.0	0.0	0.4	0.0	0.0	0.2	0.0	0.0	0.0	1.1	0.3	0.7	1.4	0.0	0.0	0.2	4.0
24.6	22.5	28.3a)	26.2a)	23.3	29.1a)	24.6	22.6	27.5a)	25.3	22.1	28.7a)	26.4a)	22.7	17.4	30.0a)	27.0a)	22.5	27.2a)	25.2	22.8	21.5
41.6	53.9	52.1	50.6	55.6	41.5	7.7	46.5	42.3	37.2	37.0	41.6	36.8	34.[illegible]	39.0	48.1	46.8	51.5	42.1	36.5	35.3	54.1
6.0	4.4	5.3	6.0	5.6	9.4	7.4	5.8	9.5	7.3	5.5	9.7	7.9	7.2	7.4	5.9	6.1	6.2	10.2	7.9	5.5	3.5
27.8	15.0	11.0	12.3	7.9	20.0	28.0	20.6	20.6	30.0	33.6	20.0	28.9	36.1	30.2	13.9	16.0	11.6	20.5	30.4	36.2	7.6
0.0	3.9f)	3.0g)	4.3g)	7.4g)	0.0	0.2b)	4.0f)	0.1b)	0.2b)	1.6g)	0.0	0.0	0.0	4.9g)	1.8b)	3.4g)	6.8g)	0.0	0,0	0.0	9.3g)
33.4	23.2	19.2	22.8	20.7	29.0	35.2	30.4	29.8	37.9	40.5	29.3	36.4	42.9	43.2	21.5	25.8	25.6	30.3	37.9	41.3	24.0
100	81.9	82.8	78.5	63.3	100	99.4	85.5	99.7	99.2	95.6	100	100	100	86.1	90.2	84.1	68.0	100	100	99.8	43.8
92	248	140	191	194	22	[illegible]	252	18	43	256	17	45	154	272	123	215	--	14	38	238	281

129	130	131	132-1	132-2	133-1	121	122	123	124-1	124-2	134	135	136-1	136-2	137-2
	10280-119C					10380-124C					10280-157B				
1202	842	932	1022	1112	1202	842	932	1022	1112	1202	842	932	1022	1112	1202
977-1035	640-42	680	729-27	786-79	860-38	732-38	797-802	767-69	948-50	1058-1179	925-27	786-90	851-55	923	1006-02
892-1121	630-42	662-76	700-16	738-61	842-1013	662-82	704-3[illegible]	748-776	799-838	966-1157	637-53	676-98	716-43	763-94	833-91
770-73	621-26	651-55	684-87	725	788-803	651-62	691-702	736-47	790-801	896-1150	635-40	673-80	709-18	759-61	817-24
797-804	628-32	662	700-698	747-43	812-01	664-71	709-14	763-66	830-31	925-1146	644-51	684-89	725-29	779-77	842-38
853-33	640-42	680	729-27	785-[illegible]	860-38	662-87	797-802	799	880-76	981-1146	725-27	707-12	756-58	817-1[illegible]	885-78
3.2	0.1	0.3	0.5	1.2	3.6	0.6	1.2	2.2	3.2	7.6	0.0	0.0	0.2	0.3	1.9
12.7	34.5a)	31.0a)	26.7a)	20.8	13.1	27.3a)	25.9	23.3	19.1	16.9	30.3a)	27.9a)	24.3	19.6	13.9
14.1	27.4	21.6	16.6	11.6	9.4	47.0	39.7	33.5	27.5	36.6	39.5	33.8	28.1	23.7	17.8
4.1	14.6	11.6	7.9	5.2	3.9	5.6	4.7	4.6	5.4	7.9	7.3	6.1	4.4	3.2	2.5
64.7	23.4	35.5	48.0	60.7	69.0	19.5	28.3	35.8	42.5	25.4	22.9	32.2	42.8	53.0	63.4
1.2e)	0.0	0.0	0.1	0.3	0.3	[illegible]	0.0	0.6f)	2.3e)	5.6e)	0.0	0.0	0.2d)	0.2c)	0.5e)
72.8		47.0	56.3	67.0	77.1	25.3	34.0	43.2	53.4	46.5	29.8	37.9	47.2	56.3	67.9
94.0	99.[illegible]	99.4	98.6	97.6	94.0	97.6	95.9	92.6	89.0	70.8	100	100	99.2	98.1	96.5
229	13	14	16	23	171	20	29	27	40	234	16	22	31	58	

Table 55 (contd).

Table 56. DEHYDROGENATIONS OF METHYLCYCLOHEXANE OVER VARIOUS CATALYSIS

Catalyst Stability Tests

Feed:	Pure MCH
Catalyst Volume:	7 ml
Pressure:	1 atm
Block Temperature:	842°F
Reaction Time at Each LHSV:	30 minutes

[illegible]

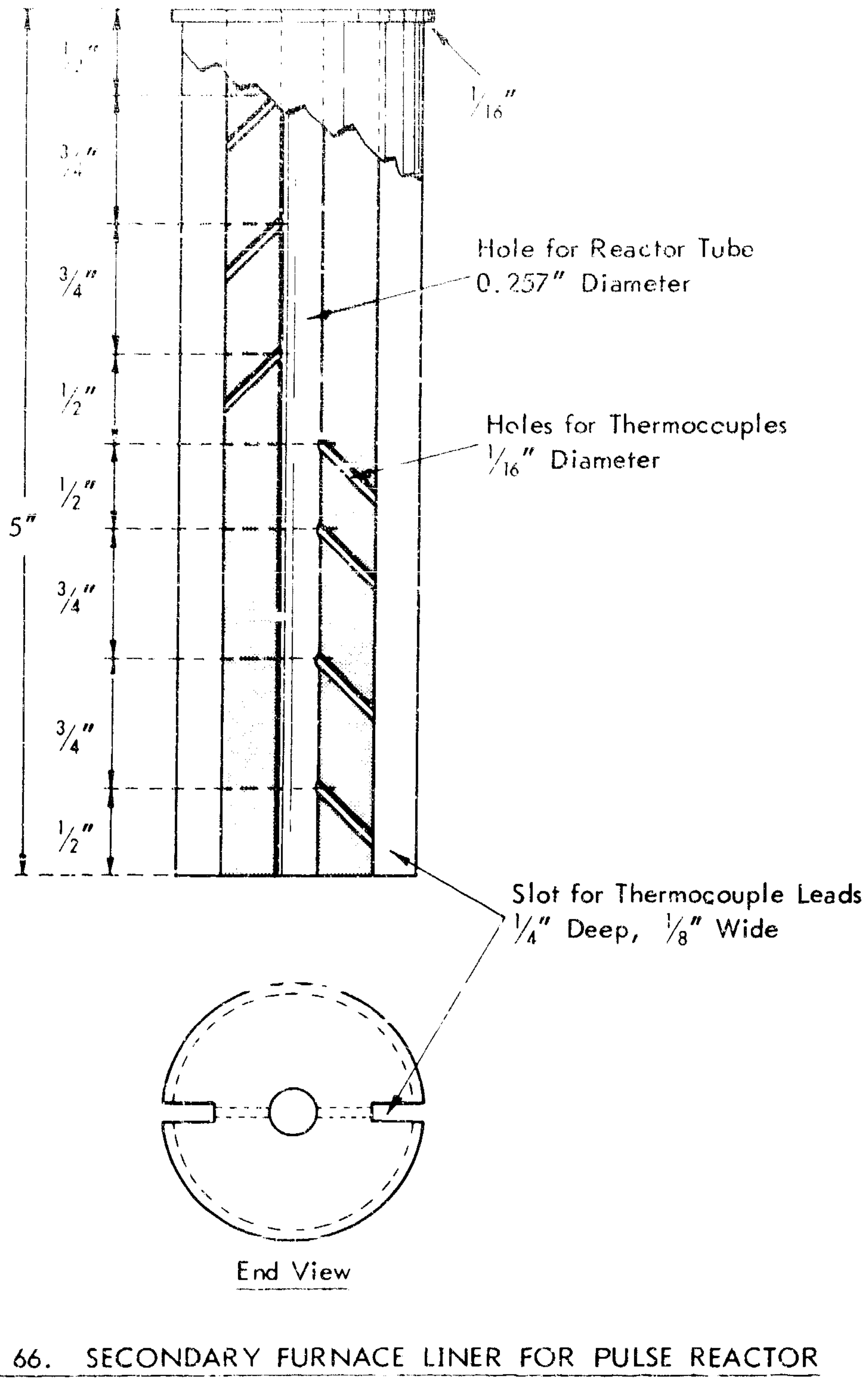


Figure 66. SECONDARY FURNACE LINER FOR PULSE REACTOR

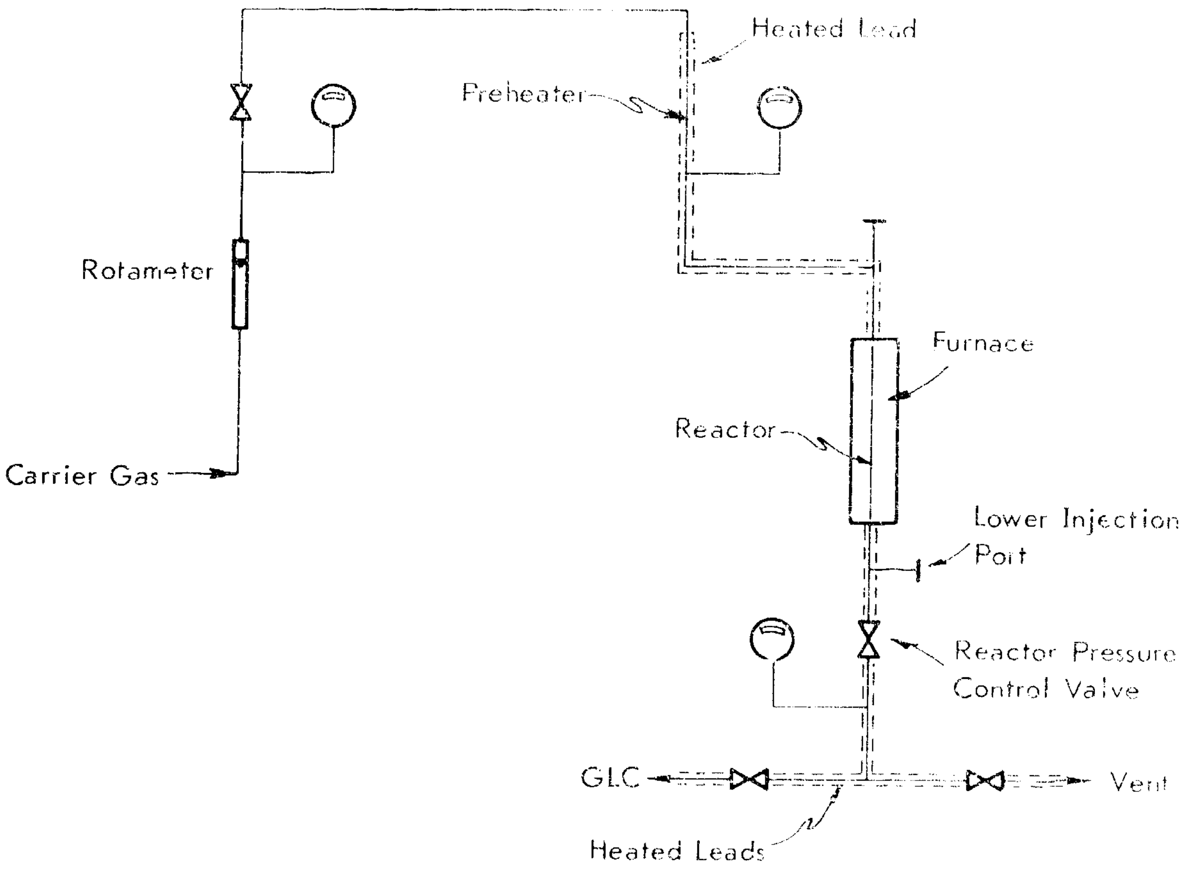


Figure 67. SCHEMATIC DIAGRAM OF PULSE REACTOR

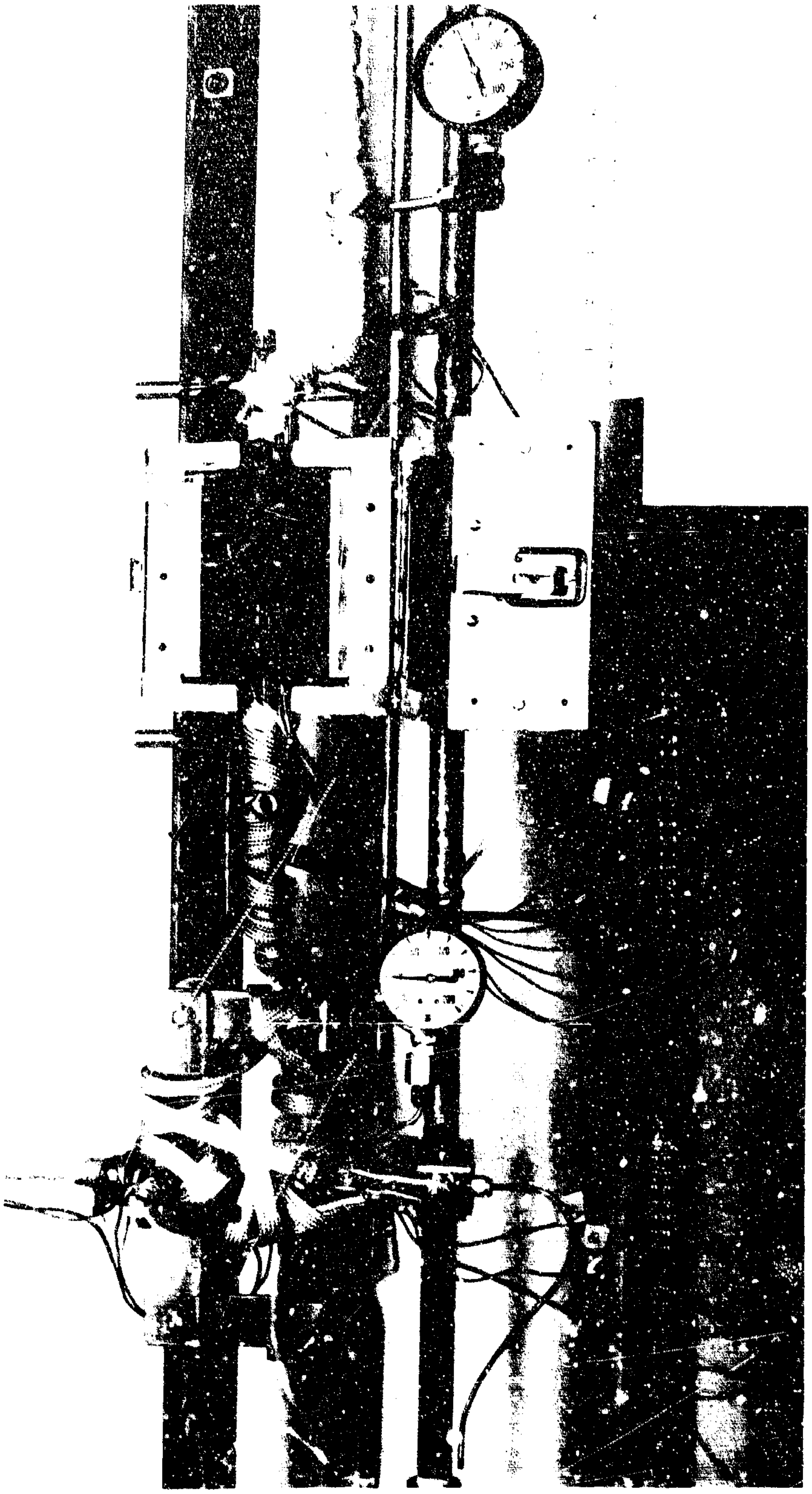


Figure 68. PULSE REACTOR SYSTEM

Calculation of Rate Constants (Bench-Scale Reactor)

First order rate constants were calculated based on the rate of disappearance of the starting material according to the following equation:

$$k = \frac{LHSV}{3600} \times \frac{\rho \times 22{,}412}{MW \times P} \times \frac{T}{273} \times 2.3 \log \left(\frac{1}{1 - f} \right) \qquad (35)$$

where: k = first-order rate constant in $\sec^{-1}$

LHSV = liquid hourly space velocity (i.e., volumes of feed/volume of catalyst bed per hour)

MW = molecular weight

P = reactor pressure in atmospheres

T = reaction temperature in °K (reactor wall temperature)

ρ = liquid density

f = fraction component reacted

Calculation of Reaction Products for the Thermal Reaction of Bicyclo(2,2,2)octane

Both BCO and TMB react thermally to form reaction products 1, 2, 3 and 4 (Tables 4 and 5). With BCO in TMB feed the amount of component A formed from TMB only is given by

$$X_A = \frac{C_T \, X_A^o}{C_T^o} \qquad (36)$$

where X_A = amount component A formed with BCO-TMB feed

C_T = fraction TMB reacted with BCO-TMB feed

X_A^o = amount component A formed with pure TMB feed

C_T^o = fraction TMB reacted with pure TMB feed

C_T and C_T^o are obtained at the same temperature and space velocity. X_A^o and C_T^o are obtained from Table 4.

As an example, consider component 4 in Runs 102-5 (Table 4) and 105-2 (Table 5):

$X_4^o = 18.7$

$C_T^o = 24.5$

$C_T = 11.1$

$$X_4 = \frac{11.1(18.7)}{24.5} = 8.5$$

Since the total amount of component 4 found by GLC was only 8.0%, all of it was formed from TMB. Hence, none of component 4 was formed from BCO.

Micro Catalyst Test Reactor

The Micro Catalyst Test Reactor (MICTR) and the operational techniques used for screening candidate catalysts have been described in previous reports.[1,2] No further changes have been made. Figures 87 through 89 of reference 1 show the apparatus in detail, except for changes noted in reference 2. Catalysts have been tested with MCH at LHSV 100, at 662, 752, and 842°F, and at 10 atm pressure without added hydrogen. It has been found that more consistent results are obtained if a fresh loading of the reference catalyst 9874-139, or its replacement catalyst 10860-70, is tested each week as a base point for calibration, rather than using the same reference tube over and over again, since the activity gradually declines. Also, prepared catalysts have been rescreened to 10-20 mesh to remove fines after impregnation and drying of the supports, and this gives more reproducible results. Tables 57 and 58 give the MICTR test data in chronological order.

Tables 57 and 58 follow

Table 57. DEHYDROGENATION OF METHYLCYCLOHEXANE WITH VARIOUS CATALYSTS IN MICTR

Runs 1061-1191

Conditions: 100 LHSV, 10 atm pressure, no added H_2, temperature variable. 0.9 ml catalysts diluted with 1:1 ml quartz chips (10-20 mesh) reduced in H_2 at 796°F. GLC samples normally taken at 3-, and 8-, and 13 minutes operation at each temperature.

Run No.	Catalyst			% Conversion of MCH to Toluene, %w		
	No.	Description	wt., g	662	752	842°F
1061	9874-139	1% Pt/UOP R-8 type Al_2O_3 (ref.)	0.433	28,24,24	49,47,46	73,71,70
1062	6646-67	Bimetallic, 73, 27% (unsupported)	0.238	0,0	0,0	0,0
1063	6192-78	Monometallic, 47%/PO_4	0.305	0,0	0,0	0,0
1064	1003-41A	Bimetallic, 95, 5% (unsupported)	0.749	0,0	0,0	0,0
1065	7507-46	Trimetallic, 37, 23, 40% (unsupported)	0.749	0,0	0,0	0,0
1066	6749-52A	Trimetallic, 2, 21, 77% (unsupported)	0.755	0,0	0,0	0,0
1067	6187-145	Quadrametallic, 3,27, 27, 43 (unsupported)	0.866	0,0	0,0	0,0
1068	9874-139	1% Pt/UOP R-8 type Al_2O_3 (ref.)	0.435	28,26,26	50,48,47	72,73,71
1069	6749-14	Trimetallic, 11, 2, 87% (unsupported)	1.022	0,0	0,0	5,2,2
1070	3609-194	Trimetallic, 23, 43, 34% (unsupported)	0.697	0,0	0,0	0,0
1071	6646-72	Bimetallic, 69, 31% (unsupported)	0.350	0,0	0,0	0,0
1072	6646-86	Trimetallic, 54, 2, 44% (Unsupported)	1.065	0,0	0,0	0,0
1073	6187-168 D	Trimetallic, 58, 41, 1% (unsupported)	0.720	5,3,3	14,13,11	31,28,29
1074	6649-49	Trimetallic, 46, 2, 52% (unsupported)	0.633	0,0	0,0	0,0
1075	9073-10	Trimetallic, 54, 26, 20% (unsupported)	0.683	0,0	0,0	0,0
1076	6749-18	Trimetallic, 9, 2, 89% (unsupported)	0.760	0,0	4, 2, 1	11, 9, 9
1077	6749-13	Trimetallic, 7, 2, 91% (unsupported)	0.879	0,0	0,0	0,0
1078	7003-174	Bimetallic, 2, 2%/type 1 support	0.773	0,0	0,0	1, 1, 2
1079	9874-139	1% Pt/UOP R-8 type Al_2O_3 (ref.)	0.433	26, 26, 26	51, 48, 48	73, 73, 71
1080	9074-35	Quadrametallic, 8, 41, 41, 10 (unsupported)	0.481	0,0	0,0	0,0
1081	6187-148	Bimetallic, 74, 26% (Unsupported)	0.492	0,0	0,0	0,0
1082	6645-39	Trimetallic, 48, 4, 48% (unsupported)	0.544	0,0	0,0	0,0
1083	6749-52B	Trimetallic, 3, 4, 93% (unsupported)	1.147	0,0	0,0	0,0
1084	10860-119A	2% Pt/40% type 1 support (1),40% type 1 support (2),20% type 22 binder	0.357	20, 23, 24	55, 52, 51	79, 78, 78
1085	10860-119B	3% Pt/40% type 1 support (1),40% type 1 support (2),20% type 22 binder	0.392	31, 26, 23	51, 50, 48	79, 77, 75
1086	10860-119C	2% Pt/45% type 1 support (1),45% type 1 support (2), 10% type 22 binder	0.555	26, 24, 24	54, 53, 52	83, 81, 80
1087	10860-119D	3% Pt/45% type 1 support (1), 45% type 1 support (2), 10% type 22 binder	0.550	27, 25, 27	61, 57, 57	88, 85, 88
1088	10860-118	- 4% Pt/45% type 1 support (1), 45% type 1 support (2), 10% type 22 binder, coated tube No. 28	0.042	26, 23, 20	18, 17, 17	8, 7, 9
1089	10860-122	Alonized 1/4" tube	-	0,0	0,0	0,0
1090	9874-139	1% [illegible] R-8 type Al_2O_3 (ref.)	0.433	27, 27, 26	50, 49, 50	72, 73, 71
1091	10860-121	2% [illegible]pe 1 support[a)]	0.350	28, 29, 29	56, 57, 52	83, 82, 82
1092	10860-123	2% Pt[b)]/type [illegible] support[c)]	0.367	30, 29, 29	58, 53, 52	81, 80, 78
1093	9874-139	1% Pt/UOP R-8 type Al_2O_3 (ref.)	0.435	28, 25, 24	50, 48, 48	73, 74, 72
1094	10860-125A	2% Pt/40% type 1 Support (1) 40% type 1 Support (2) 15% [illegible] 6 Binder [illegible] 22 Binder	0.472	20, 21, 21	54, 52, 50	81, 79, 80
1095	10860-125B	3% Pt/40% type 1 Support (1) 40% type 1 Support (2) 15% type 6 Binder 5% type 22 Binder	0.468	24, 23, 20	53, 49, 48	76, 76, 76
1101	10860-126A	2% Pt/40% type 1 support (1) 40% type 1 support (2) 10% type 6 binder 10% type 22 binder	0.488	20,(28), 23	58, 57, 58	86, 85, 86
1097	10860-126B	3% Pt/40% type 1 support (1) 40% type 1 support (2) 10% type 6 binder 10% type 22 binder	0.477	30, 25, 25	60, 58, 56	86, 84, 83
1098	10860-128A	1% Pt/extruded type 6 support (low density)	0.290	20, 20, 20	47, 45, 43	71, 70, 68
1106	10860-128B	2% Pt/extruded type 6 support (low density)	0.286	22, 21, 20	50, 47, 47	77, 77, 76
1100	10860-128C	3% Pt/extruded type 6 support (low density)	0.301	28, 27, 25	54, 51, 50	80, 77, 77
1105	9874-139	1% Pt/UOP R-8 type Al_2O_3 (ref.)	0.435	23, 25, 26	48, 47, 47	71, 72, 71
1102	10860-129A	0.5% Pt, 0.5% metal G/ type 1 support	0.754	26, 25, 26	55, 54, 53	78, 78, 80
1103	10860-129B	1% Pt, 1% metal G/ type 1 support	0.743	28, 27, 26	56, 53, 52	80, 77, 79
1119	10860-132C	1% Pt, 1% metal G/ type 1 support	0.775	18, 19, 22	50, 50, 48	74, 72, 71
1115	10860-129C	2% Pt, 2% metal G/ type 1 support	0.771	23, 23, 22	54, 52, 50	83, 80, 80
1107	10860-129D	4% Pt, 4% metal G/ type 1 support	0.790	26, 25, 25	59, 56, 55	86, 86, 87
1109	10860-129E	4% Pt/type 1 support (control)	0.794	26, 25, 25	58, 56, 53	83, 83, 83
1110	10860-129F	0.5% Pt/type 1 support	0.746	26, 16, 23	52, 53, 51	83, 82, 81
1111	10860-129G	1% Pt/type 1 support	0.735	26, 25, 22	58, 54, 53	85, 84, 83
1112	10860-114B	3% Pt/type 6 support (low density)	0.310	18, 16, 17	41, 38, 38	66, 64, 64
1113	10860-114C	4% Pt/type 6 support " "	0.319	25, 23, 23	54, 53, 50	80, 78, 77
1108	12280-113	4% Pt/type 1 support (spheres, 9-16 mesh)	0.6153	21, 20, 19	48, 43, 43	71, 69, 69
1114	12280-113	4% Pt/type 1 support (spheres, 10-16 mesh)	0.705	21, 20, 19	47, 46, 46	71, 70, 68
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

1105	9874-139	1% Pt/UOP R-8 type Al_2O_3 (ref.)	0.435	23, 25, 26	48, 47, 47
1102	10860-129A	0.5% Pt, 0.5% metal G/ type 1 support	0.754	26, 25, 26	55, 54, 53
1103	10860-129B	1% Pt, 1% metal G/ type 1 support	0.743	28, 27, 26	56, 53, 52
1119	10860-132C	1% Pt, 1% metal G/ type 1 support	0.775	18, 19, 22	50, 50, 48
1115	10860-129C	2% Pt, 2% metal G/ type 1 support	0.771	23, 23, 22	54, 52, 50
1107	10860-129D	4% Pt, 4% metal G/ type 1 support	0.790	26, 25, 25	59, 56, 55
1109	10860-129E	4% Pt/type 1 support (control)	0.794	26, 25, 25	58, 56, 53
1110	10860-129F	0.5% Pt/type 1 support	0.746	26, 16, 23	52, 53, 51
1111	10860-129G	1% Pt/type 1 support	0.735	26, 25, 22	58, 54, 53
1112	10860-114B	1% Pt/type 6 support (low density)	0.310	18, 16, 17	41, 38, 38
1113	10860-114C	4% Pt/type 6 support " "	0.319	25, 23, 23	54, 53, 50
1108	10280-113	4% Pt/type 1 support (spheres, 9-16 mesh)	0.6153	21, 20, 19	48, 43, 43
1114	10280-113	4% Pt/type 1 support (spheres, 10-16 mesh)	0.705	21, 20, 19	47, 46, 46
1130	10860-137C	10280-113, muffled 932°F, 1/2 hr in air (9-16 mesh)	--	20, 21, 20	50, 47, 47
1116	9874-139	1% Pt/UOP R-8 type Al_2O_3	0.434	23, 25	49, 47, 48
1127	10860-132A	1% Pt/UOP R-8 type Al_2O_3	0.414	24, 24, 24	52, 49, 49
1118	10860-132B	4% Pt/UOP R-8 type Al_2O_3	0.450	24, 22, 24	47, 47, 47
1122	9874-139	1% Pt/UOP R-8 type Al_2O_3	0.435	24, 22, 24	50, 46, 47
1123	10860-134C	1% Pt/type 1 support	0.545	24, 23, 24	58, 54, 55
1134	10860-134C	1% Pt/type 1 support	0.526	33, 29, 23	53, 53, 53
1124	10860-134D	4% Pt/type 1 support	0.529	(20), (24), (21)	(49), (48), (48)
1135	10860-134D	4% Pt/type 1 support	0.558	25, 26	54, 53, 49
1125	10860-135C	1% Pt/type 1 support	0.525	25, 26, 25	59, 56, 54
1137	10860-135C	1% Pt/type 1 support	0.526	27, 25, 27	54, 52, 52
1126	10860-135D	4% Pt/type 1 support	0.572	27, 23, 24	53, 50, 51
1138	10860-135D	4% Pt/type 1 support	0.536	25, 24, 24	58, 53, 53
1128	10860-134A	0.5% Pt, 0.5% metal G/type 1 support	0.421	27, 25	46, 42, 41
1129	10860-134B	1% Pt, 1% metal G/type 1 support	0.422	21, 20, 22	46, 43, 43
1120	10860-135A	1% Pt/type 1 support	0.770	24, 21, 20	51, 48, 49
1121	10860-135D	4% Pt/type 1 support	0.809	25, 22, 22	58, 53, 55
1133	10860-137A	1% Pt/type 1 support	0.725	28, 23, 24	53, 50, 49
1139	10860-137B	4% Pt/type 1 support	0.723	26, 30, 27	57, 54, 52
1153	10860-144	4% Pt/type 1 support	0.833	34, 35, 35	62, 58, 58
1136	9874-139	1% Pt/UOP R-8 type Al_2O_3	0.435	22, 24, 24	50, 46, 47
1140	10860-138A	1% Pt/type 1 support	0.739	26, 24, 24	51, 49, 49
1142	10860-138A	1% Pt/type 1 support	0.747	22, 32, 30	55, 53, 53
1141	10860-138B	4% Pt/type 1 support	0.759	28, 25, 31	59, 56, 55
1145	10860-138B	4% Pt/type 1 support	0.775	33, 33, 28	60, 58, 58
1143	10860-139A	1% Pt/extruded type 6 support (low density)	0.309	23, 25, 24	44, 44, 42
1144	10860-139B	4% Pt/extruded type 6 support (low density)	0.317	26, 30, 27	53, 50, 50
1146	10860-141A	1% Pt/type 6 support (low density)	0.315	20, 19, 18	40, 35, 34
1147	10860-141B	4% Pt/type 6 support (low density)	0.337	27, 22, 21	48, 48, 47
1131	10860-136A	1% Pt/type 6 support (high density)	0.586	11, 12, 14	27, 26, 26
1132	10860-136B	4% Pt/type 6 support (high density)	0.598	16, 15, 15	35, 32, 32
1186	10860-154A	1% Pt/type 6 support (high density)	0.638	14, 17, 14	35, 37, 34
1191	10860-154B	4% Pt/type 6 support (high density)	0.657	26, 21, 19	38, 36, 35
1149	10860-142A	1% Pt/type 1 support	0.671	23, 23, 22	53, 55, 51
1150	10860-142B	4% Pt/type 1 support	0.718	30, 25, 24	62, 59, 58
1151	10860-143A	1% Pt/type 10 support	0.609	24, 22, 21	38, 36, 41
1152	10860-143B	4% Pt/type 10 support	0.662	25, 24, 21	44, 45, 46
1148	9874-139	1% Pt/UOP R-8 type Al_2O_3 (ref.)	0.434	26, 21, 21	48, 48, 47
1154	10860-70	1% Pt/UOP R-8 type Al_2O_3 (new ref.)	0.422	19, 22, 25	47, 46, 46
1156	10860-147	4% Pt/type 6 support (low density)	0.332	19, 20, 18	44, 41, 41
1157	10860-147	4% Pt/type 6 support (low density)	0.332	23, 21, 20	43, 41, 41
1176	10860-146	4% Pt/type 1 support	0.808	37, 38, 33	60, 58, 59
1177	10860-146	4% Pt/type 1 support	0.810	30, 31, 35	65, 59, 59
1181	10860-150	4% Pt/type 1 support (muffled 1112°F in air)	0.741	25, 23, 23	62, 58, 57
1163	10860-149A	4% Pt/type 6 support (as received)	0.307	24, 24, 23	47, 43, 45
1178	10860-149A	4% Pt/type 6 support (as received)	0.320	27, 22, 21	48, 44, 45
1160	10860-149B	4% Pt/type 6 support (1112°F muffled)	0.317	25, 16, 22	47, 45, 44
1172	10860-149B	4% Pt/type 6 support (1112°F muffled)	0.312	29, 28, 28	46, 43, 43
1164	10860-149C	4% Pt/type 6 support (as received)	0.324	23, 25, 24	51, 49, 48
1173	10860-149C	4% Pt/type 6 support (as received)	0.310	32, 24, 24	48, 48, 46
1169	10860-149D	4% Pt/type 6 support (1112°F muffled)	0.318	27, 23, 20	50, 46, 45
1179	10860-149D	4% Pt/type 6 support (1112°F muffled)	0.319	22, 20, 20	50, 47, 45
1168	10860-149E	4% Pt/type 6 support (as received)	0.307	27, 23, 21	42, 39, 38
1174	10860-149E	4% Pt/type 6 support (as received)	0.311	25, 23, 26	46, 45, 45
1170	10860-149F	4% Pt/type 6 support (1112°F muffled)	0.323	25, 23, 26	46, 45, 45
1175	10860-149F	4% Pt/type 6 support (1112°F muffled)	0.308	26, 24, 24	49, 49, 46
1162	10860-70	1% Pt/UOP R-8 type Al_2O_3 (new ref.)	0.410	31, 27, 23	51, 48, 48
1182	10860-151A	1% Pt[e]/type 1 support	0.716	26, 25, 23	59, 52, 53
1183	10860-151B	1% Pt[f]/type 1 support	0.718	27, 25, 23	53, 49, 48
1184	10860-151C	4% Pt[f]/type 1 support	0.784	25, 22, 22	57, 53, 54
1185	10860-151D	1% Pt/type 1 support (control)	0.754	34, 28, 27	65, 57, 57
1188	11408-71	Bimetallic, 1, 1%/type 6 support[g]	0.309	24, 18, 18	43, 40, 40
1189	11408-73	Bimetallic, 1, 1%/type 6 support[h]	0.340	22, 18, 17	43, 38, 38
1180	10860-70	1% Pt/UOP R-8 type Al_2O_3 (new ref.)	0.41	28, 21, 22	50, 45, 45

1105	71, 72, 71
1102	78, 78, 80
1103	80, 77, 79
1119	74, 72, 71
1115	83, 80, 80
1107	86, 86, [illegible]
1109	83, 83, 83
1110	83, 82, 81
1111	85, 84, 83
1112	66, 64, 64
1113	80, 78, 77
1108	71, 69, 69
1114	71, 70, 68
1130	73, 72, 71
1116	73, 71, 71
1127	76, 75, 75
1118	76, 78, 78
1122	70, 70, 70
1123	85, 84, 82
1134	82, 81, 81
1124	(77), (77), (76)
1135	79, 77, 76
1125	83, 81, 80
1137	81, 81, 80
1126	78, 77, 77
1138	83, 81, 81
1128	55, 63, 66
1129	65, 65, 64
1120	76, 76, 76
1121	83, 82, 83
1133	79, 78, 77
1139	82, 80, 81
1153	88, 87, 80
1136	69, 70, 71
1140	80, 76, 76
1142	82, 81, 80
1141	83, 82, 81
1145	87, 86, 85
1143	66, 63, 63
1144	75, 74, 73
1146	56, 55, 55
1147	71, 72, 70
1131	41, 39, 37
1132	48, 47, 46
1186	47, 41, 40
1191	50, 45, 45
1149	80, 80, 79
1150	89, 88, 88
1151	60, 57, 56
1152	70, 71, 71
1148	71, 72, 70
1154	68, 68, 67
1156	64, 61, 58
1157	65, 64, 63
1176	86, 86, 86
1177	89, 86, 86
1181	92, 89, 90
1163	68, 65, 65
1178	71, 70, 69
1160	69, 68, 66
1172	70, 69, 69
1164	74, 72, 72
1173	61, 60, 60
1169	70, 70, 68
1179	68, 70, 70
1168	59, 57, 57
1174	67, 65, 62
1170	67, 65, 64
1175	66, 63, 63
1162	77, 74, 73
1182	85, 81, 80
1183	80, 79, 77
1184	83, 80, 79
1185	87, 85, 84
1188	66, 63, 63
1189	62, 58, 58
1180	71, 69, 70

a) Catalyst muffled in air before testing.
b) Pt solution neutralised with an organic acid before impregnating support.
c) Catalyst muffled in air before testing.
d) On as received basis.
e) Impregnated with compound 30 (unneutralised).
f) Impregnated with compound 30 (neutralised).
g) Calcined in helium.
h) Calcined in air.

Table 57.

Table 58. DEHYDROGENATION OF METHYLCYCLOHEXANE WITH VARIOUS CATALYSTS IN MICTR Runs 1192-1276

Conditions: 100 LHSV, 10 atm pressure, no added H_2, temperature variable. 0.9 ml catalysts diluted with 1.1 ml quartz chips (10-20 mesh) reduced in H_2 at 796°F. GLC samples normally taken at 3-, and 8-, and 13 minutes operation at each temperature.

Run No.	Catalyst			% Conversion of MCH to Toluene, %w		
	No. 10860-	Description	wt., g.	662	752	842°F
1192	70	1% Pt/UOP R-8 type Al_2O_3 (ref)	0.411	23, 27, 25	51, 48, 48	73, 72, 72
1193	163A	3.2% Pt/80% type 1 support[a)] 20% type 6 binder	0.346	--, 26, 25	50, 50, 50	82, 81, 80
1194	163B	3.2% Pt/40% type 1 support (1)[a)] 40% type 1 support (2)[a)] 20% type 6 binder	0.371	26, 23, 23	54, 50, 49	81, 77, 77
1195	163C	1.6% Pt/40% type 1 support (1)[a)] 40% type 1 support (2) 20% type 6 binder	0.403	23, 23, 23	55, 53, 49	77, 76, 75
1196	160A	1% Pt/80% type 16 support 20% type 6 binder	0.346	23, 21, 19	50, 47, 47	74, 74, 73
1197	160B	2% Pt/ " " "	0.399	25, 24, 23	50, 47, 47	74, 72, 72
1198	160C	4% Pt/ " " "	0.371	25, 25, 25	57, 54, 55	83, 82, 82
1199	161A	3.2% Pt/80% type 1 support[a)] 20% type 6 binder	0.594	23, 20, 21	52, 45, 45	75, 73, 73
1200	161B	1.6% Pt/40% type 1 support (1) 40% type 1 support (2)[a)] 20% type 6 binder	0.442	21, 23, 22	50, 46, 46	77, 75, 74
1201	70	1% Pt/UOP R-8 type Al_2O_3 (ref)	0.410	26, 21, 22	48, 46, 46	72, 71, 70
1202	157A	1% Pt/type 1 support[i)]	0.562	24, 22, 22	55, 50, 50	79, 78, 78
1203	157E	4% Pt/ " "[i)]	0.596	26, 25, 25	60, 58, 58	85, 82, 83
1204	157B	1% Pt/type 1 support[i)]	0.545	25, 21, 23	53, 52, 52	81, 81, 79
1205	157F	4% Pt/ " "[i)]	0.562	28, 26, 27	60, 59, 56	87, 87, 87
1206	158A	1% Pt/type 1 support	0.535	27, 25, 24	56, 53, 53	84, 83, 83
1207	158B	2% Pt/ " "	0.542	29, 2[illegible], 24	54, 53, 51	81, 80, 82
1208	158C	4% Pt/ " "	0.567	32, 24, 24	57, 53, 53	83, 83, 83
1209[b)]	160B	2% Pt/80% type 16 support 20% type 6 binder	0.338	23, 23, 19	45, 43, 43	67, 65, 66
1210	157C	1% Pt/type 1 support[i)]	0.843	19, 18, 17	36, 35, 37	46, 48, 50
1211	157G	4% Pt/ " "[i)]	0.828	17, 18, 18	36, 35, 35	46, 46, 47
1212	157D	1% Pt/type 1 support[i)]	0.527	25, 22, 22	48, 46, 46	74, 74, 74
1213	157H	4% Pt/ " "[i)]	0.548	23, 23, 22	53, 50, 49	78, 77, 77
1214	70	1% Pt/UOP R-8 type Al_2O_3 (ref)	0.412	24, 20, 23	50, 45, 46	70, 69, 70
1215	164A	1% Pt/80% type 1 support 20% type 6 binder	0.430	22, 21, 22	50, 49, 48	76, 75, 76
1216	164B	2% Pt/ " "	0.431	30, 28, 26	53, 54, 56	84, 83, 84
1217	164C	3% Pt/ " "	0.458	30, 27, 27	59, 56, 57	85, 85, 85
1218	165[c)]	4% Pt/type 1 support	0.549	25, 29, 29	48, 51, 51	80, 79, 80
1219	165A[c)]	1% Pt/ " "	0.534	24, 27, 25	59, 59, 54	83, 81, 81
1220	166A	4% Pt[d)]/type 6 support	0.321	28, 22, 22	47, 43, 42	65, 72, 65
1221	166B	4% Pt[e)]/type 6 support	0.325	20, 22, 20	45, 43, 43	67, 67, 65

a) Platinised with 4% metal before formulation.
b) Repeat of run 1197.
c) Repeat preparations in quantity of 10860-158C and 158A, for bench scale tests.
d) Acetate neutralised $Pt(NH_3)_4(OH)_2$.
e) Inpregnate type 31.
f) Repeat of run 1219.
g) Repeat of run 1218.
h) Repeat of run 1198.
i) In-house support.

(Continued)

Table 58. (Contd-1) DEHYDROGENATION OF METHYLCYCLOHEXANE WITH VARIOUS CATALYSTS IN MICTR

Run No.	Catalyst			% Conversion of MCH to Toluene, %w		
	No. 10860-	Description	wt., g.	662	752	842°F
1222	167A	4% Pt/80% type 16 support 20% type 6 binder	0.461	24, 25, 23	50, 41, 41	61, 59, 60
1223	165A[f]	1% Pt/type 1 Support	0.528	23, 28, 22	57, 51, 53	82, 81, 81
1224	167B	4% Pt/type 16 support	0.384	24, 25, 23	50, 41, 41	61, 59, 60
1225	167C	3.2% Pt/80% type 16 support 20% type 6 binder	0.412	25, 20, 21	47, 43, 43	71, 69, 70
1226	165[g]	4% Pt/Type 1 support	0.555	25, 25, 22	56, 55, 54	85, 84, 82
1227	70	1% Pt/UOP R-8 type Al_2O_3 (ref)	0.413	21, 19, 23	48, 45, 45	71, 69, 69
1228	160C[h]	4% Pt/80% type 16 support 20% type 6 binder	0.363	25, 22, 23	51, 48, 48	74, 72, 71
1229	168	1.6% Pt/40% type 1 support 40% type 1 support[a] 20% type 1 binder	0.484	23, 22, 22	52, 49, 47	77, 74, 71
1230	172	1.6% Pt/40% type 16 support 40% type 1 support[a] 20% type 6 binder	0.444	24, 20, 20	49, 47, 46	72, 71, 71
1231	170B	4% Pt/type 1 support[i]	0.597	25, [illegible], 22	54, 51, 51	82, 81, 79
1232	70	1% Pt/UOP R-8 type Al_2C_3 (ref)	0.416	20, 22, 22	48, 45, 46	71, 69, 68
1233	171A	4% Pt/type 1 support	0.603	27, 23, 24	51, 49, 51	77, 77, 76
1234	171B	" " "	0.606	25, 25, 25	58, 56, 57	86, 85, 83
1235	173	1.6% Pt/41% type 16 support 41% type 1 support[a] 18% type 6 binder	0.498	27, 25, 24	55, 52, 50	79, 77, 77
1236	170A	4% Pt/type 1 support[i]	0.559	23, 24, 23	59, 57, 57	88, 87, 86
1237	171C	4% Pt/type 1 support[i]	0.541	30, 27, 27	55, 55, 54	82, 82, 82
1238	171D	1% Pt/type 1 support	0.711	21, 21, 21	50, 47, 49	72, 69, 72
1239	171E	4% Pt/type 1 support	0.747	21, 22, 22	52, 51, 52	82, 82, 82
1240	171F	2% Pt/type 1 support	0.762	22, 20, 20	52, 48, 48	77, 76, 76
1241	175	3.2% Pt/40% type 16 support[a] 40% type 1 support[a] 20% type 6 binder	0.492	27, 22, 22	49, 45, 44	74, 74, 72
1242	"	" " " "	0.505	31, 22, 21	55, 50, 50	80, 77, 77
1243	70	1% Pt/UOP R-8 type Al_2O_3(ref)	0.420	25, 20, 20	48, 45, 46	71, 71, 70
1244	177A	3% Pt/40% type 1 support (1) 40% type 1 support (2) 20% type 6 binder	0.405	23, 23, 24	53, 53, 55	82, 82, 82
1245	177B	4% Pt/ " " "	0.401	24, 24, 26	54, 53, 53	84, 82, 82
1246	177C	3% Pt/40% type 16 support 40% type 1 support 20% type 6 binder	0.478	29, 25, 27	54, 51, 50	79, 77, 77
1247	177D	4% Pt/ " " "	0.476	26, 24, 26	54, 51, 51	84, 80, 80
1248	184A	4% Pt/40% type 1 support (1) 40% type 1 support (2) 20% type 6 binder	0.404	30, 26, 25	58, 54, 55	85, 86, 83
1250	184C	4% Pt/80% type 1 support 20% type 6 binder	0.478	30, 25, 25	63, 60, 58	88, 89, 91

(Continued)

Table 58. (Contd-2) DEHYDROGENATION OF METHYLCYCLOHEXANE WITH VARIOUS CATALYSTS IN MICTR

Run No.	Catalyst			% Conversion of MCH to Toluene		
	No. 10860-	Description	wt., g.	662	752	842°F
1251	184D	4% Pt/80% type 1 support 20% type 6 binder	0.664	26, 25, 29	57, 54, 54	84, 84, 83
1252	184E	4% Pt/40% type 1 support (1) 40% type 1 support (2) 20% type 6 binder	0.480	25, 27, 30	56, 53, 52	86, 85, 84
1253	184B	4% Pt/40% type 16 support 40% type 1 support 20% type 6 binder	0.422	22, 22, 25	51, 49, 50	79, 79, 78
1254 1255	70 70	1% Pt/UOP R-8 type Al_2O_3 (ref) " " "	0.419 0.422	24, 20, 20 21, 20, 20	48, 44, 46 47, 44, 44	71, 69, 68 69, 68, 68
1256 1257 1258 1259	188A 188B 188C 188D	1% Pt/type 1 support (purified)[j] 1% Pt, 1% metal AB/type 1 support " , 2.3% " " " " " 4% " " " "	0.803 0.738 0.713 0.752	31, 27, 26 21, 23, 24 28, 23, 22 16, 16, 16	58, 52, 51 60, 55, 55 56, 51, 51 48, 44, 45	84, 81, 80 86, 84, 84 80, 79, 79 71, 68, 68
1260 1261 1262	189A 189B 189C	1% Pt, 1% metal AC/type 1 support " " 2.3% " " " " " 4% " " "	0.759 0.731 0.747	31, 28, 30 17, 18, 20 16, 15, 15	57, 51, 51 51, 48, 49 37, 37, 32	82, 81, 81 73, 68, 67 52, 48, 45
1264	70	1% Pt/UOP R-8 type Al_2O_3 (ref)	0.417	24, 22, 20	49, 46, 46	72, 70, 69
1263 1265 1266	190A 190B 190C	1% Pt, 1% metal AA/type 1 support " " 2.3% " " " " " 4% " " "	0.711 0.767 0.764	25, 22, 25 20, 21, 24 22, 21, 19	59, 54, 53 55, 51, 50 53, 47, 47	84, 81, 81 81, 81, 80 78, 77, 75
1267 1268 1269	191A 191B 191C	1% Pt, 1% metal AD/type 1 support " " 2.3% " " " " " 4% " " "	0.767 0.746 0.742	34, 29, 26 24, 20, 21 22, 21, 23	59, 54, 54 59, 52, 54 51, 54, 51	83, 82, 81 85, 85, 83 73, 73, 72
1270 1271 1272	192A 192B 192C	1% Pt, 1% metal AE/type 1 support " " 2.3% " " " " " 4% " " "	0.736 0.737 0.769	26, 23, 25 26, 25, 24 26, 23, 22	62, 58, 56 59, 53, 52 55, 50, 50	87, 87, 86 85, 83, 83 81, 79, 79
1273	195C	Formulation for 10860-184C, stored wet 53 days, before drying, calcining, and 4% Pt impreg.	0.440	22, 23, 23	56, 55, 56	84, 82, 80
1274	195A	Formulation for 10860-184A, stored wet 55 days, before drying, calcining, and 4% Pt impreg.	0.409	24, 23, 25	54, 52, 51	84, 82, 79
1275	195E	Formulation for 10860-184E, stored wet 48 days, before drying, calcining and 4% Pt impreg.	0.503	24, 23, 23	58, 54, 53	84, 84, 83
1276	195D	Formulation for 10860-184D, stored wet 54 days, before drying, calcining, and 4% Pt impreg.	0.975	22, 22, 23	58, 54, 54	86, 84, 83

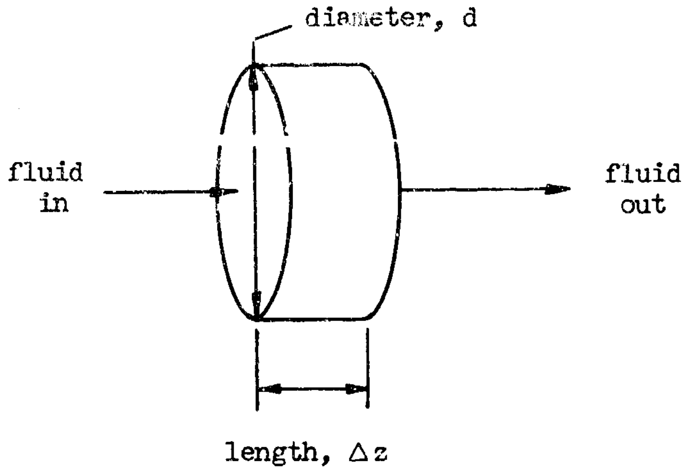
[j] Control for series 10860-188, 189, 190, 191, and 192.

BLANK PAGE

Derivations of Equations for the Catalytic Wall Reactor Model

Fluid Flow Equations

The fluid flow in the reactor is described by a mass balance, a momentum balance, and an energy balance. The differential equations are formed by writing the balances over a differential cylindrical element:



Mass Balance:

Since the flow is assumed to be at steady state,

rate of mass flow in = rate of mass flow out

$$\rho v A_c \Big|_{z} = \rho v A_c \Big|_{z+\Delta z} \qquad (37)$$

where

ρ = fluid density
v = fluid velocity
A_c = cross-sectional area = $\frac{\pi d^2}{4}$
d = diameter of flowing fluid

Since A_c is a constant, then ρv is also a constant, which is the mass flux:

$$\boxed{G = \rho v} \qquad (38)$$

Momentum Balance:

rate of momentum in - rate of momentum out + sum of forces on system = 0

rate in = $(\rho v A_c)v\big|_z$

rate out = $(\rho v A_c)v\big|_{z+\Delta z}$

pressure force = $PA_c\big|_z - PA_c\big|_{z+\Delta z}$

drag force = $-(\frac{1}{2}\bar{\rho}\bar{v}^2)A_s f$

where

P = fluid pressure
$\bar{\rho}$ = average value of ρ
$\bar{v}$ = average value of v
A_s= surface area of differential element
f = Fanning friction factor (drag force equation defines f)

$$GA_c(v\big|_{z+\Delta z} - v\big|_z) + A_c(P\big|_{z+\Delta z} - P\big|_z) + \tfrac{1}{2}\bar{\rho}\bar{v}^2 A_s f = 0 \tag{39}$$

Dividing by the volume of the differential element and taking the limit as Δz approaches zero gives the desired differential equation:

$$\frac{G(\frac{\pi d^2}{4})(v\big|_{z+\Delta z} - v\big|_z) \quad \frac{\pi d^2}{4}(P\big|_{z+\Delta z} - P\big|_z) + \frac{1}{2}\bar{\rho}\bar{v}^2 \pi d \Delta z f}{\frac{\pi d^2}{4}\Delta z} = 0 \tag{40}$$

$$\lim_{\Delta z \to 0} \quad G\,\frac{v\big|_{z+\Delta z} - v\big|_z}{\Delta z} + \frac{P\big|_{z+\Delta z} - P\big|_z}{\Delta z} + \frac{2\bar{\rho}\bar{v}^2 f}{d} = 0 \tag{41}$$

$$\boxed{G\,\frac{dv}{dz} + \frac{dP}{dz} + \frac{2\rho v^2 f}{d} = 0} \tag{42}$$

Note that the average values of ρ and v become the same as the point values as Δz approaches zero. The only forces considered here are pressure and drag or frictional force. Other forces such as gravitational, nuclear, radiative, and electromagnetic forces have been neglected. The gravitational force might be important in a vertical reactor at very low flow rates.

Energy Balance:

rate of kinetic energy in + rate of internal energy in - rate of kinetic energy out - rate of internal energy out + net rate of heat added - net rate of work done by system = 0

rate of kinetic energy in = $\frac{1}{2} G A_c v^2 \big|_z$

rate of internal energy in = $G A_c U \big|_z$

rate of kinetic energy out = $\frac{1}{2} G A_c v^2 \big|_{z+\Delta z}$

rate of internal energy out = $G A_c U \big|_{z+\Delta z}$

rate of heat added = $-q_1' A_s$

rate of work done by system = $P A_c v \big|_{z+\Delta z} - P A_c v \big|_z$

where U = specific internal energy
q_1' = heat flux from fluid to wall

Substituting H for $U + P/\rho$, and dividing by the volume element $\pi d^2 \Delta z/4$ gives

$$\frac{\frac{1}{2} G \left(v^2 \big|_{z+\Delta z} - v^2 \big|_z \right)}{\Delta z} + \frac{G \left(H \big|_{z+\Delta z} - H \big|_z \right)}{\Delta z} + \frac{4 q_1'}{d} = 0 \qquad (43)$$

Taking the limit as Δz approaches zero and dividing by G gives

$$v \frac{dv}{dz} + \frac{dH}{dz} + \frac{4 q_1'}{G d} = 0 \qquad (44)$$

We can obtain H in terms of P, T, and ρ. For an ideal gas, H is a function of T only:

$$\frac{dH}{dz} = \left(\frac{\partial H}{\partial T} \right)_P \frac{dT}{dz} \equiv c_P \frac{dT}{dz} \qquad (45)$$

The pressure effect can be added to give:

$$\frac{dH}{dz} = \left(\frac{\partial H}{\partial T} \right)_P \frac{dT}{dz} + \left(\frac{\partial H}{\partial P} \right)_T \frac{dP}{dz} \qquad (46)$$

The value of $\left(\frac{\partial H}{\partial T}\right)_P$ is known as the heat capacity at constant pressure, c_p, and may be calculated. From the well known equation

$$dH = TdS + VdP \tag{47}$$

we can obtain

$$\left(\frac{\partial H}{\partial P}\right)_T = T\left(\frac{\partial S}{\partial P}\right)_T + V \tag{48}$$

Substituting in one of Maxwell's Relations, gives

$$\left(\frac{\partial H}{\partial P}\right)_T = -T\left(\frac{\partial V}{\partial T}\right)_P + V \tag{49}$$

or written in terms of ρ instead of V,

$$\left(\frac{\partial H}{\partial P}\right)_T = -T\left(\frac{\partial (\frac{1}{\rho})}{\partial T}\right)_P + \frac{1}{\rho} \tag{50}$$

$$= \frac{T}{\rho^2}\left(\frac{\partial \rho}{\partial T}\right)_P + \frac{1}{\rho} \tag{51}$$

So, the final equation is

$$\boxed{v\frac{dv}{dz} + c_P\frac{dT}{dz} + \left[\frac{1}{\rho} + \frac{T}{\rho^2}\left(\frac{\partial \rho}{\partial T}\right)_P\right]\frac{dP}{dz} + \frac{4q_1'}{Gd} = 0} \tag{52}$$

We can rewrite the momentum balance by dividing by ρ to give

$$v\frac{dv}{dz} + \frac{1}{\rho}\frac{dP}{dz} + \frac{2\,v^2 f}{d} = 0 \tag{53}$$

Subtracting this from Equation (52) gives

$$c_P\frac{dT}{dz} + \frac{T}{\rho^2}\left(\frac{\partial \rho}{\partial T}\right)\frac{dP}{dz} + \frac{4q_1'}{Gd} - \frac{2v^2 f}{d} = 0 \tag{54}$$

Substituting G/ρ for v gives the final two equations for the fluid flow:

$$\frac{d}{\rho}\frac{\partial \rho}{\partial P}\frac{dP}{dz} + \frac{d}{\rho}\frac{\partial \rho}{\partial T}\frac{dT}{dz} - \frac{\rho d}{G^2}\frac{dP}{dz} - 2f = 0 \tag{55}$$

$$\frac{\rho^2 c_p d}{G^2}\frac{dT}{dz} + \frac{Td}{G^2}\frac{\partial \rho}{\partial T}\frac{dP}{dz} + \frac{4\rho^2 q_i'}{G^3} - 2f = 0 \tag{56}$$

Chemical Conversion

The model is presently based on a single chemical reaction. Again, the shell balance method is used to obtain a differential equation.

rate reactant in = rate reactant out + rate reacted

$$GA_c n\Big|_z = GA_c n\Big|_{z+\Delta z} + r v_c \Delta z \tag{57}$$

where

n = number of moles of reactant per unit weight feed
r = rate of reaction per unit volume of catalyst
v_c = volume of catalyst per unit length reactor

giving

$$-\frac{dn}{dz} = \frac{4rv_c}{G\pi d^2} \tag{58}$$

The volume of catalyst per unit length for a cylindrical layer on the inside of a tube is

$$v_c = \frac{\pi}{4}(D^2 - d^2) \tag{59}$$

where

D = inside diameter of tube
d = inside diameter of catalyst

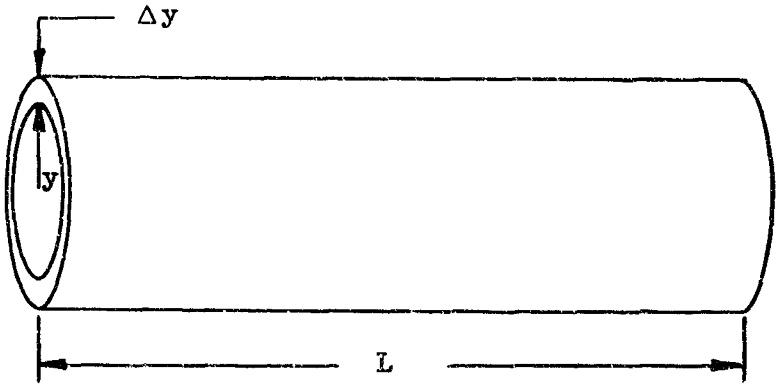
Rewriting Equation (58) in terms of x, number of moles converted per unit weight feed, gives

$$\boxed{\frac{dx}{dz} = \frac{r(D^2 - d^2)}{Gd^2}} \tag{60}$$

Wall Temperature Profiles

The temperature profiles in the catalyst layer and in the tube wall may be calculated knowing the heat fluxes and assuming that the heat generation is uniform across the section. This is probably a good assumption for the tube wall, since the heat generated depends on the electrical resistance, which depends on the temperature. The changes in temperature across the tube wall are generally small enough to neglect for this purpose. The assumption of uniform heat absorption in the catalyst layer is less acceptable, since the amount of heat is related directly to the rate of reaction, which is an exponential function of temperature. The temperature drops across the catalyst layer are also larger than those across the tube wall.

The temperature in a cylindrical layer may be found by making a shell balance over an cylindrical element of inside radius y, thickness Δy, and length L:



The heat balance consists of

rate of heat in + rate of heat generated = rate of heat out

rate of heat in = $2\pi y L q\big|_{y}$

rate of heat out = $2\pi y L q\big|_{y+\Delta y}$

rate of heat generated = $S(2\pi y L \Delta y)$

where

y = radius of element
Δy = thickness of element
L = length of element
q = heat flux in + y direction
S = rate of heat generated per unit volume

$$2\pi L\left[(y+\Delta y)q\big|_{y+\Delta y} - yq\big|_{y}\right] = 2\pi L\bar{y}\Delta y S \qquad (61)$$

Divide by $2\pi L\Delta y$ and take the limit as Δy approaches zero,

$$\lim_{\Delta y \to 0} \frac{\left[(y + \Delta y)q\big|_{y+\Delta y} - yq\big|_{y}\right]}{\Delta y} = yS \qquad (62)$$

$$\frac{d(yq)}{dy} = yS \qquad (63)$$

Integration gives

$$yq = \frac{Sy^2}{2} + c_1 \qquad (64)$$

or $$q = \frac{Sy}{2} + \frac{c_1}{y} \qquad (65)$$

where c_1 is a constant of integration. This equation applies to both layers. The boundary conditions are slightly different. In both cases, let y_o and y_i be the outer and inner radii of the layers, catalyst and tube. Then at the outer surface, the boundary condition is a heat flux at that surface:

$$q = q_o \quad \text{at} \quad y = y_o$$

Then from Equation (65)

$$q_o = \frac{Sy_o}{2} + \frac{c_1}{y_o} \qquad (66)$$

and $$c_1 = q_o y_o - \frac{Sy_o^2}{2} \qquad (67)$$

So $$q = \frac{Sy}{2} + \frac{1}{y}\left(q_o y_o - \frac{Sy_o^2}{2}\right) \qquad (68)$$

Introducing the Fourier equation for heat conduction

$$q = -k\frac{dT}{dy} \qquad (69)$$

gives $$\frac{dT}{dy} = \frac{Sy}{2k} - \frac{1}{ky}\left(q_o y_o - \frac{Sy_o^2}{2}\right) \qquad (70)$$

Integration gives

$$T = \frac{Sy^2}{4k} - \frac{1}{k} \ln y \left(q_o y_o - \frac{Sy_o^2}{2} \right) + c_2 \qquad (71)$$

where

T = temperature in layer
k = thermal conductivity
c_2 = constant of integration

The boundary condition for each layer is that at the inner surface, y_i; the temperature is T_i.

So $$T_i = - \frac{Sy_i^2}{4k} - \frac{1}{k} \ln y_i \left(q_o y_o - \frac{Sy_o^2}{2} \right) + c_2 \qquad (72)$$

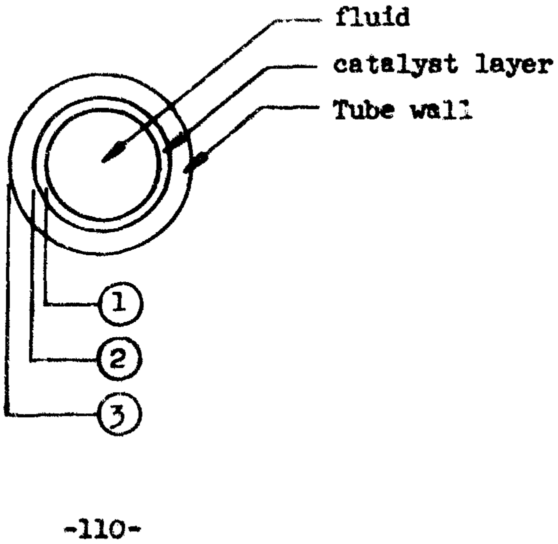
$$c_2 = T_i + \frac{Sy_i^2}{4k} + \frac{1}{k} \ln y_i \left(q_o y_o - \frac{Sy_o^2}{2} \right) \qquad (73)$$

giving $$T = - \frac{Sy^2}{4k} - \frac{\left(q_o y_o - \frac{Sy_o^2}{2}\right)}{k} \ln y + T_i + \frac{Sy_i^2}{4k}$$

$$+ \frac{1}{k} \ln y_i \left(q_o y_o - \frac{Sy_o^2}{2} \right) \qquad (74)$$

for each layer.

Equation (74) may now be applied to each layer. The subscripts refer to the surfaces shown:



The heat generated in the tube wall is written as q_G', the heat flux of generated heat, based on inner tube surface area:

$$S = q_G' \frac{\text{Btu}}{\text{hr ft}^2\text{(inner area)}} \quad \text{x} \quad \frac{\text{ft}^2\text{(inner area)}}{\text{ft}^3\text{(wall)}}$$

$$= q_G' \frac{2\pi y_2 L}{\pi(y_3^2 - y_2^2)\, L} \tag{75}$$

$$S = \frac{2y_2}{y_3^2 - y_2^2}\, q_G' \tag{76}$$

The heat flux at the outer surface (3) is q_3 and is corrected to be based on the inner surface:'

$$q_3 = \frac{y_2}{y_3}\, q_3' \tag{77}$$

Then Equation (74) after some rearrangement becomes

$$T - T_2 = \frac{1}{k}\left[q_G' \left(\frac{\frac{y_2}{2y_3}(y_2^2 - y^2) + y_2 \ln\left(\frac{y}{y_2}\right)}{1 - \left(\frac{y_2}{y_3}\right)^2}\right) - q_3' y_2 \ln\left(\frac{y}{y_2}\right)\right] \tag{78}$$

To get the temperature drop, y_3 and T_3 are substituted for y and T, and rearranged to give

$$\boxed{T_3 - T_2 = -\frac{q_G'\, y_2}{2k}\left[\frac{1 - \left(\frac{y_2}{y_3}\right)^2 + 2 \ln\left(\frac{y_2}{y_3}\right)}{1 - \left(\frac{y_2}{y_3}\right)^2}\right] + \frac{q_3'}{k} y_2 \ln\left(\frac{y_2}{y_3}\right)} \tag{79}$$

for the tube wall. By a similar procedure, the temperature in the catalyst layer is shown to be

$$T - T_1 = +\frac{q_R'\, y_2}{2k}\left[\frac{1 - \left(\frac{y}{y_1}\right)^2 + 2 \ln\left(\frac{y}{y_1}\right)}{1 - \left(\frac{y_2}{y_1}\right)^2}\right] - \frac{q_1' y_2}{k} \ln\left(\frac{y}{y_1}\right) \tag{80}$$

and the temperature difference across the catalyst layer is

$$\boxed{T_2 - T_1 = \frac{q_R' y_2}{2k}\left[\frac{1 - \left(\frac{y_2}{y_1}\right)^2 + 2 \ln\left(\frac{y_2}{y_1}\right)^2}{1 - \left(\frac{y_2}{y_1}\right)^2}\right] - \frac{q_1' y_2}{k} \ln\left(\frac{y_2}{y_1}\right)} \tag{81}$$

Description of the Beta-Ray Backscatter Apparatus for Rating Deposits

The instrument consists of the following functional blocks: The vacuum system, the scanning mechanism, the beta-ray source, and the detection system.

The vacuum system consists of a chamber made from a three-foot length of 6-inch sch 40 steel pipe with end plates sealed by O-rings. One end provides access for loading the coker tubes and the other holds the driving mechanism. A Welch 1402B fore pump is connected by rubber tubing to a pipe nipple welded to the vacuum chamber.

The rest of the vacuum system consists of a thermocouple gauge and a bleed valve.

The scanning mechanism serves to translate and rotate the coker tube past the source and detector. It consists of a track fastened to the inside of the vacuum chamber on which a carriage rides. The carriage holds the coker rod and is driven by a shaft and lead screw arrangement attached to the end plate of the vacuum system. The drive shaft in the test chamber connects through a vacuum seal to a variable speed reversible motor.

The beta-ray source is contained in a block which is mounted to the face of the detector. The source material was obtained from the target of a Texas Nuclear neutron generator. The block consists of layers of brass with two milled slots to direct the beta-ray beam to the coker tube, which is located at the intersection of the beams. Between the two slots for the beta-rays is a third slot which is aligned with the opening in the detector. This allows the backscattered radiation to enter the detector and be counted.

The detection system counts the radiation that is backscattered from the coker tube and presents the count rate on a strip chart recorder. The detector is a flow proportional counter with an ultra thin window operating on P-10 gas (90% Argon, 10% methane). The window is made of a thin film of cellulose nitrate. It is supported by a Buckbee Meers Co. nickel screen of 70% transmission. The detector is attached to a flange that provides a vacuum seal and can be moved while under vacuum to position the detector with the spout to the coker tube to focus the radiation.

The rest of the detection system is outside the vacuum chamber and consists of a high voltage power supply for the proportional counter, a low noise preamplifier, a linear amplifier, a count rate meter, and a strip chart recorder with an offset zero provision.

Table 59. IGNITION DELAY TIMES FOR DECALIN-OXYGEN-ARGON MIXTURES

Press, (atm)	Temp, (°K)	Delay, (μ sec)	Press, (atm)	Temp, (°K)	Delay, (μ sec)	Press, (atm)	Temp, (°K)	Delay, (μ sec)
			90%m Argon, ER = 0.2					
0.60	1440	110	1.08	1170	3380			
0.61	1390	200	1.20	1340	180			
0.67	1340	430	1.06	1190	3240			
0.61	1230	2680	1.28	1380	150			
0.63	1270	1230	1.44	1500	60			
0.64	1290	210	1.07	1190	2980			
0.60	1220	3790						
			99%m Argon, ER = 0.5					
0.55	1480	3040	0.91	1380	3450	1.56	1430	2010
0.53	1520	1570	0.94	1470	1740	1.61	1430	2360
0.54	1490	2220	0.91	1480	1830	1.50	1450	1400
0.53	1530	1040	0.92	1520	740	1.47	1460	1330
0.51	1640	300	0.91	1510	1160			
0.49	1600	490	0.90	1560	660			
			0.89	1550	560			
			0.88	1530	770			
			0.90	1560	530			
			0.92	1600	540			
			0.91	1600	270			

Table 60. IGNITION DELAY TIMES FOR TETRALIN-OXYGEN-ARGON MIXTURES

Press, (atm)	Temp, (°K)	Delay, (μ sec)	Press, (atm)	Temp, (°K)	Delay, (μ sec)
99%m Argon, ER = 0.1					
0.61	1510	650	1.00	1440	1310
0.59	1540	540	1.02	1420	1480
0.61	1650	210	1.05	1420	2570
0.60	1700	350	0.97	1480	330
0.57	1760	170	0.98	1530	120
			0.95	1470	1070
80%m Argon, ER = 0.1					
0.62	1210	3180	1.06	1140	3570
0.78	1470	40	1.08	1180	770
0.61	1210	880	1.04	1160	1970
0.62	1210	3110	1.02	1160	2730
0.62	1210	3130	1.06	1180	460
0.62	1210	2140	1.08	1190	370
0.61	1200	3390			
90%m Argon, ER = 0.11					
0.62	1320	3470	1.04	1280	1050
0.62	1300	3520	1.03	1300	650
0.59	1320	1060	1.07	1370	290
0.63	1370	630	1.07	1280	1040
0.61	1320	1530	1.11	1280	1810
0.61	1390	250	1.14	1270	2960
0.68	1430	810	1.11	1210	3890
0.60	1300	2540			
99%m Argon, ER = 0.5					
0.66	1520	3350	1.04	1490	2610
0.63	1540	1120	1.06	1530	930
0.65	1540	3070	1.05	1530	850
0.63	1520	1620	1.05	1520	790
0.65	1570	950	1.02	1560	410
0.64	1560	900	1.04	1680	260
0.63	1540	1150	1.05	1690	260
0.61	1570	820	1.04	1680	140
0.59	1630	460	1.04	1670	80
0.60	1720	240	1.10	1750	150
0.59	1700	220	1.05	1690	240
0.60	1720	120	1.13	1700	110
0.61	1740	210	1.05	1600	310
0.60	1710	180			
0.63	1530	3020			

(Contd)

Table 60. (Contd). IGNITION DELAY TIMES FOR TETRALIN-OXYGEN-ARGON MIXTURES

Press, (atm)	Temp, (°K)	Delay, (μ sec)	Press, (atm)	Temp, (°K)	Delay, (μ sec)
0.64	1560	890			
0.63	1550	1380			
0.62	1520	1170			
0.63	1530	1520			
90%m Argon, ER = 0.57					
0.66	1390	60	1.14	1250	3580
0.62	1270	3310	1.14	1260	2700
0.61	1280	3470	1.13	1260	3650
0.60	1270	2660	1.09	1230	2590
0.59	1270	2070	1.08	1250	2620
			1.06	1240	2180
95%m Argon, ER = 1.0					
0.58	1420	2880	1.08	1430	2280
0.62	1470	3040	1.03	1360	3130
0.61	1410	3340	1.03	1410	1640
0.67	1650	110	1.09	1450	190
0.62	1470	2630	1.09	1440	2360
0.63	1470	2900	1.04	1390	3130
0.63	1480	2480			
99%m Argon, ER = 1.0					
0.59	1530	1650	1.01	1580	620
0.59	1560	760	0.97	1600	530
0.61	1640	450	1.01	1740	90
0.62	1730	250	1.03	1630	370
0.61	1750	230	0.99	1520	690
0.59	1630	370	1.02	1540	1520
0.62	1650	560	0.95	1510	1110
			1.03	1530	2890
90%m Argon, ER = 1.21					
0.64	1280	2970	1.14	1230	3050
			1.14	1230	3290
			1.12	1230	2730
			1.12	1250	3450
			1.10	1250	3000

Table 61. IGNITION DELAY TIMES FOR NAPHTHALENE-OXYGEN-ARGON MIXTURES

Press, (atm)	Temp, (°K)	Delay, (μ sec)	Press, (atm)	Temp, (°K)	Delay, (μ sec)
90%m Argon, ER = 0.1					
0.63	1430	400	1.04	1400	400
0.60	1470	100	1.05	1430	240
0.60	1370	730	1.04	1370	530
0.63	1360	890	1.08	1350	690
0.62	1330	3020	1.06	1270	2650
0.60	1300	3550	1.09	1280	2910
0.61	1310	3790			

Table 62. PHYSICAL PROPERTIES OF METHYLCYCLOHEXANE/ETHANE MIXTURES

	MCH	Ethane
Weight %	90	10
Mole %	73.4	26.6

Average Molecular Weight	80.1
Melting Point	-215°F
Heat of Formation (Liquid at 25°C)	-885 Btu/lb
Net Heat of Combustion (25°C)	18,820 Btu/lb
Pseudocritical Properties	
Pressure	538 psia
Temperature	442°F
Compressibility Factor	0.260
Acentric Factor	0.207

Temp., °F	Vapor Pressure, psia	Liquid Specific Gravity	Liquid Viscosity, cp	Enthalpy, Btu/lb	
				0 psia	1000 psia
-200	0.24	0.856	12.9	123	-62
-100	8.4	0.803	2.02	139	-36
0	59.	0.746	0.723	164	0
100				197	45
200				237	97
300				283	156
400				334	222
500				391	296
600				453	384
700				520	467
800				591	555
900				667	640
1000				746	725

Table 62 (Contd). PHYSICAL PROPERTIES OF METHYLCYCLOHEXANE/ETHANE MIXTURES

	MCH	Ethane
Weight %	80	20
Mole %	55.1	44.9

Average Molecular Weight	67.6
Melting Point	-229°F
Heat of Formation (Liquid at 25°C)	-936 Btu/lb
Net Heat of Combustion (25°C)	18,980 Btu/lb

Pseudocritical Properties

Pressure	567 psia
Temperature	354°F
Compressibility Factor	0.266
Acentric Factor	0.182

Temp., °F	Vapor Pressure, psia	Liquid Specific Gravity	Liquid Viscosity, cp	Enthalpy, Btu/lb 0 psia	Enthalpy, Btu/lb 1000 psia
-200	0.40	0.816	5.04	112	-69
-100	14.2	0.759	1.07	139	-39
0	99.	0.696	0.470	165	0
100				200	48
200				240	102
300				265	164
400				339	231
500				397	306
600				459	393
700				527	477
800				598	565
900				675	649
1000				754	735

Table 63. PHYSICAL PROPERTIES OF METHYLCYCLOHEXANE/PROPANE MIXTURES

	MCH	Propane
Weight %	90	10
Mole %	80.2	19.8

Average Molecular Weight	87.5
Melting Point	-210°F
Heat of Formation (Liquid at 25°C)	-867 Btu/lb
Net Heat of Combustion (25°C)	18,770 Btu/lb
Pseudocritical Properties	
Pressure	520 psia
Temperature	498°F
Compressibility Factor	0.256
Acentric Factor	0.226

Temp., °F	Vapor Pressure, psia	Liquid Specific Gravity	Liquid Viscosity, cp	Enthalpy, Btu/lb	
				0 psia	1000 psia
-200		0.871	22.0	124	-60
-100	0.57	0.821	2.91	139	-35
0	7.5	0.769	0.898	164	0
100	38.1	0.713	0.430	197	44
200	124.	0.620	0.257	237	96
300				282	155
400				334	220
500				390	294
600				452	382
700				519	465
800				59	554
900				665	638
1000				744	723
1100				827	808
1200				913	895

Table 63 (Contd-1). PHYSICAL PROPERTIES OF METHYLCYCLOHEXANE/PROPANE MIXTURES

	MCH	Propane
Weight %	80	20
Mole %	64.2	35.8

Average Molecular Weight	78.8
Melting Point	-222°F
Heat of Formation (Liquid at 25°C)	-902 Btu/lb
Net Heat of Combustion (25°C)	18,880 Btu/lb
Pseudocritical Properties	
Pressure	536 psia
Temperature	440°F
Compressibility Factor	0.260
Acentric Factor	0.211

Temp., °F	Vapor Pressure, psia	Liquid Specific Gravity	Liquid Viscosity, cp	Enthalpy, Btu/lb	
				0 psia	1000 psia
-200		0.843	11.3	123	-64
-100	1.04	0.792	1.85	140	-37
0	13.5	0.737	0.646	166	0
100	67.6	0.675	0.340	199	46
200	215.	0.552	0.217	240	100
300				286	160
400				338	227
500				395	302
600				457	389
700				524	473
800				596	561
900				671	646
1000				751	751
1100				854	817
1200				921	905

Table 63.(Contd-2). PHYSICAL PROPERTIES OF METHYLCYCLOHEXANE/PROPANE MIXTURES

	MCH	Propane
Weight %	70	30
Mole %	51.2	48.8

Average Molecular Weight	71.8
Melting Point	-232°F
Heat of Formation (Liquid at 25°C)	-936 Btu/lb
Net Heat of Combustion (25°C)	18,990 Btu/lb
Pseudocritical Properties	
Pressure	550 psia
Temperature	392°F
Compressibility Factor	0.264
Acentric Factor	0.199

Temp., °F	Vapor Pressure, psia	Liquid Specific Gravity	Liquid Viscosity, cp	Enthalpy, Btu/lb 0 psia	Enthalpy, Btu/lb 1000 psia
-200		0.818	6.55	123	-69
-100	1.42	0.765	1.28	141	-39
0	18.4	0.707	0.494	167	0
100	91.6	0.641	0.281	202	49
200	289.	0.498	0.189	242	104
300				289	166
400				342	235
500				399	310
600				462	397
700				530	481
800				602	569
900				678	654
1000				758	739
1100				842	825
1200				929	914

Table 64. PHYSICAL PROPERTIES OF METHYLCYCLOHEXANE/n-BUTANE MIXTURE

	MCH	n-Butane
Weight %	90	10
Mole %	84.2	15.8

Average Molecular Weight	91.9
Melting Point	-207°F
Heat of Formation (Liquid at 25°C)	-859 Btu/lb
Net Heat of Combustion (25°C)	18,740 Btu/lb

Pseudocritical Properties

Pressure	512 psia
Temperature	528°F
Compressibility Factor	0.255
Acentric Factor	0.237

Temp., °F	Vapor Pressure, psia	Liquid Specific Gravity	Liquid Viscosity, cp	Enthalpy, Btu/lb	
				0 psia	1000 psia
-200		0.879	29.2	123	-59
-100		0.830	3.52	139	-35
0	1.21	0.781	1.034	164	0
100	9.5	0.730	0.473	196	44
200	40.6	0.675	0.277	236	95
300	123.	0.583	0.192	281	153
400				333	219
500				389	293
600				451	380
700				518	463
800				589	552
900				664	636
1000				743	721
1100				826	807

Table 64 (Contd-1). PHYSICAL PROPERTIES OF METHYLCYCLOHEXANE/n-BUTANE MIXTURE

	MCH	n-Butane
Weight %	80	20
Mole %	70.3	29.7

Average Molecular Weight	86.3
Melting Point	-218°F
Heat of Formation (Liquid at 25°C)	-886 Btu/lb
Net Heat of Combustion (25°C)	18,820 Btu/lb
Pseudocritical Properties	
Pressure	517 psia
Temperature	492°F
Compressibility Factor	0.258
Acentric Factor	0.231

Temp., °F	Vapor Pressure, psia	Liquid Specific Gravity	Liquid Viscosity, cp	Enthalpy, Btu/lb	
				0 psia	1000 psia
-200		0.860	18.1	122	-63
-100		0.810	2.54	139	-37
0	2.22	0.758	0.817	164	0
100	16.5	0.706	0.399	198	45
200	65.9	0.646	0.245	237	98
300	188.	0.528	0.175	284	158
400				336	224
500				393	299
600				455	386
700				522	470
800				594	558
900				670	643
1000				749	728
1100				831	813

Table 64 (Contd-2). PHYSICAL PROPERTIES OF METHYLCYCLOHEXANE/n-BUTANE MIXTURE

	MCH	n-Butane
Weight %	70	30
Mole %	58.0	42.0

Average Molecular Weight	81.4
Melting Point	-227°F
Heat of Formation (Liquid at 25°C)	-912 Btu/lb
Net Heat of Combustion (25°C)	18,910 Btu/lb
Pseudocritical Properties	
Pressure	523 psia
Temperature	459°F
Compressibility Factor	0.261
Acentric Factor	0.226

Temp., °F	Vapor Pressure, psia	Liquid Specific Gravity	Liquid Viscosity, cp	Enthalpy, Btu/lb 0 psia	Enthalpy, Btu/lb 1000 psia
-200		0.841	11.8	121	-67
-100		0.790	1.90	138	-39
0	3.11	0.737	0.664	165	0
100	22.8	0.683	0.343	199	47
200	88.3	0.620	0.221	239	100
300	246.	0.482	0.161	286	162
400				339	230
500				397	306
600				459	392
700				526	476
800				598	565
900				675	649
1000				754	734
1100				837	820

Table 65. LIQUID PROPERTIES OF JP-7 JET FUEL AT SATURATION

TEMP, F	VAPOR PRESS, PSIA	ENTHALPY OF VAP, BTU/LB	ENTHALPY, BTU/LB	ENTROPY, BTU/LB-R	SPEC HEAT AT CONST P, BTU/LB-R	DENSITY, LB/CU FT	VISCOSITY, LB/FT-HR	THERMAL COND, BTU/FT-HR-R
100	0.005	148.7	-54.7	-0.1287	0.5143	47.4	2.50	0.07756
200	0.147	138.8	0.0	0.0	0.5810	44.8	1.23	0.06899
300	1.59	127.7	61.83	0.1139	0.6646	42.1	0.734	0.06313
400	8.76	114.6	129.3	0.2163	0.7193	39.3	0.494	0.05496
500	31.3	98.8	200.9	0.3091	0.7916	36.0	0.354	0.04670
600	84.4	78.1	277.9	0.3963	0.9243	31.9	0.259	0.04210
700	192.	44.4	369.8	0.4875	1.409	25.5	0.175	0.03695

Gas Properties of JP-7 follows

GAS PROPERTIES OF JP-7

COMPRESSIBILITY FACTOR

TEMP, F	PRESSURE, PSIA 0	100	200	300	400	500	600	700	800	900	1000
100	1.0000+00										
200	1.0000+00										
300	1.0000+00										
400	1.0000+00										
500	1.0000+00										
600	1.0000+00										
700	1.0000+00	8.2964-01									
800	1.0000+00	8.7730-01	7.2330-01	4.9369-01	3.3074-01	3.4099-01	3.7269-01	4.0559-01	[illegible]	4.7537-01	5.1249-01
900	1.0000+00	9.1147-01	8.0800-01	6.8706-01	5.5820-01	4.8457-01	4.7413-01	4.8554-01	5.0496-01	5.3059-01	5.6040-01
1000	1.0000+00	9.3704-01	8.6593-01	7.8786-01	7.0847-01	6.4247-01	6.0596-01	5.9638-01	6.0169-01	6.1396-01	6.3078-01
1100	1.0000+00	9.5586-01	9.0761-01	8.5645-01	8.0522-01	7.5929-01	7.2533-01	7.0690-01	7.0217-01	7.0690-01	7.1731-01
1200	1.0000+00	9.6949-01	9.3716-01	9.0413-01	8.7208-01	8.4323-01	8.1993-01	8.0384-01	7.9555-01	7.9473-01	8.0022-01
1300	1.0000+00	9.7952-01	9.5847-01	9.3775-01	9.1849-01	9.0193-01	8.8910-01	8.8045-01	8.7580-01	8.7472-01	8.7715-01

COMPRESSIBILITY FACTOR

TEMP, F	PRESSURE, PSIA 1000	1100	1200	1300	1400	1500	1600
800	5.1249-01	5.5033-01	5.8837-01	6.2634-01	6.6418-01	7.0193-01	7.3965-01
900	5.6040-01	5.9187-01	6.2502-01	6.5908-01	6.9322-01	7.2703-01	7.6047-01
1000	6.3078-01	6.5093-01	6.7553-01	7.0459-01	7.3504-01	7.6577-01	7.9608-01
1100	7.1731-01	7.3079-01	7.4664-01	7.6536-01	7.8606-01	8.1200-01	8.4029-01
1200	8.0022-01	8.1032-01	8.2340-01	8.3824-01	8.5433-01	8.7251-01	8.9325-01
1300	8.7715-01	8.8347-01	8.9360-01	9.0669-01	9.2168-01	9.3785-01	9.5490-01

DENSITY, LB/CUFT

TEMP, F	PRESSURE, PSIA 0	100	200	300	400	500	600	700	800	900	1000
100	0.0000										
200	0.0000										
300	0.0000										
400	0.0000										
500	0.0000										
600	0.0000										
700	0.0000	1.7143+00									
800	0.0000	1.4925+00	3.6206+00	7.9567+00	1.5836+01	1.9199+01	2.1080+01	2.2598+01	2.3828+01	2.4790+01	2.5549+01
900	0.0000	1.3309+00	3.0027+00	5.2968+00	8.6927+00	1.2517+01	1.5351+01	1.7489+01	1.9219+01	2.0576+01	2.1647+01
1000	0.0000	1.2059+00	2.6098+00	4.3026+00	6.3797+00	8.7939+00	1.1188+01	1.3263+01	1.5024+01	1.6564+01	1.7914+01
1100	0.0000	1.1064+00	2.3303+00	3.7043+00	5.2533+00	6.9639+00	8.7478+00	1.0472+01	1.2049+01	1.3464+01	1.4743+01
1200	0.0000	1.0251+00	2.1209+00	3.2975+00	4.5583+00	5.8928+00	7.2723+00	8.6542+00	9.9935+00	1.1254+01	1.2419+01
1300	0.0000	9.5692-01	1.9559+00	2.9986+00	4.0820+00	5.1962+00	6.3254+00	7.4522+00	8.5619+00	9.6441+00	1.0686+01

DENSITY, LB/CUFT

TEMP, F	PRESSURE, PSIA 1000	1100	1200	1300	1400	1500	1600
800	2.5549+01	2.6172+01	2.6705+01	2.7177+01	2.7600+01	2.7981+01	2.8324+01
900	2.1647+01	2.2545+01	2.3290+01	2.3927+01	2.4499+01	2.5028+01	2.5522+01
1000	1.7914+01	1.9095+01	2.0073+01	2.0848+01	2.1522+01	2.2134+01	2.2711+01
1100	1.4743+01	1.5916+01	1.6996+01	1.7962+01	1.8815+01	1.9535+01	2.0136+01
1200	1.2419+01	1.3491+01	1.4483+01	1.5412+01	1.6285+01	1.7085+01	1.7801+01
1300	1.0686+01	1.1671+01	1.2587+01	1.3439+01	1.4238+01	1.4992+01	1.5705+01

```
                                              GAS PROPERTIES OF JP-7

                                                  FUGACITY,PSIA
 TEMP,
                                                  PRESSURE, PSIA
   F       0        100        200        300        400        500        600        700        800        900        1000
  100  0.0000
  200  0.0000
  300  0.0000
  400  0.0000
  500  0.0000
  600  0.0000
  700  0.0000   8.5250+01
  800  0.0000   8.4964+01  1.5625+02  2.0146+02  2.2492+02  2.4227+02  2.5850+02  2.7446+02  2.9038+02  3.0644+02  3.2279+02
  900  0.0000   9.1838+01  1.6750+02  2.2732+02  2.7207+02  3.0524+02  3.3295+02  3.5844+02  3.8292+02  4.0695+02  4.3101+02
 1000  0.0000   9.4089+01  1.7633+02  2.4688+02  3.0631+02  3.5608+02  3.9885+02  4.3747+02  4.7384+02  5.0898+02  5.4345+02
 1100  0.0000   9.5788+01  1.8311+02  2.6204+02  3.3289+02  3.9639+02  4.5377+02  5.0665+02  5.5657+02  6.0467+02  6.5176+02
 1200  0.0000   9.7049+01  1.8818+02  2.7345+02  3.5311+02  4.2760+02  4.9759+02  5.6389+02  6.2739+02  6.8894+02  7.4929+02
 1300  0.0000   9.7997+01  1.9199+02  2.8206+02  3.6841+02  4.5138+02  5.3142+02  6.0906+02  6.8480+02  7.5915+02  8.3251+02

                                                  FUGACITY,PSIA
 TEMP,
                                                  PRESSURE, PSIA
   F     1000       1100       1200       1300       1400       1500       1600
  800  3.2279+02  3.3955+02  3.5679+02  3.7455+02  3.9289+02  4.1184+02  4.3145+02
  900  4.3101+02  4.5532+02  4.8006+02  5.0537+02  5.3133+02  5.5800+02  5.8543+02
 1000  5.4345+02  5.7765+02  6.1193+02  6.4666+02  6.8208+02  7.1832+02  7.5544+02
 1100  6.5176+02  6.9830+02  7.4464+02  7.9107+02  8.3788+02  8.8536+02  9.3383+02
 1200  7.4929+02  8.0903+02  8.6861+02  9.2832+02  9.8839+02  1.0490+03  1.1105+03
 1300  8.3251+02  9.0534+02  9.7808+02  1.0511+03  1.1248+03  1.1993+03  1.2748+03

                                                  ENTHALPY, BTU/LB
 TEMP,
                                                  PRESSURE, PSIA
   F       0        100        200        300        400        500        600        700        800        900        1000
  100  9.3335+01
  200  1.3880+02
  300  1.6973+02
  400  2.4575+02
  500  3.0651+02
  600  3.7166+02
  700  4.4088+02  4.3179+02
  800  5.1386+02  5.0685+02  4.9765+02  4.8168+02  4.6117+02  4.5580+02  4.5318+02  4.5158+02  4.5051+02  4.4977+02  4.4926+02
  900  5.9032+02  5.8477+02  5.7819+02  5.6994+02  5.5935+02  5.4974+02  5.4438+02  5.4132+02  5.3938+02  5.3805+02  5.3711+02
 1000  6.6998+02  6.6547+02  6.6042+02  6.5470+02  6.4828+02  6.4169+02  6.3613+02  6.3218+02  6.2947+02  6.2757+02  6.2620+02
 1100  7.5258+02  7.4883+02  7.4478+02  7.4042+02  7.3580+02  7.3112+02  7.2678+02  7.2312+02  7.2026+02  7.1808+02  7.1644+02
 1200  8.3769+02  8.3469+02  8.3133+02  8.2782+02  8.2422+02  8.2063+02  8.1722+02  8.1416+02  8.1155+02  8.0941+02  8.0770+02
 1300  9.2560+02  9.2290+02  9.2002+02  9.1708+02  9.1411+02  9.1119+02  9.0840+02  9.0583+02  9.0354+02  9.0158+02  8.9992+02

                                                  ENTHALPY, BTU/LB
 TEMP,
                                                  PRESSURE, PSIA
   F     1000       1100       1200       1300       1400       1500       1600
  800  4.4926+02  4.4891+02  4.4869+02  4.4856+02  4.4852+02  4.4853+02  4.4861+02
  900  5.3711+02  5.3643+02  5.3594+02  5.3559+02  5.3535+02  5.3521+02  5.3514+02
 1000  6.2620+02  6.2519+02  6.2444+02  6.2388+02  6.2346+02  6.2316+02  6.2295+02
 1100  7.1644+02  7.1518+02  7.1421+02  7.1347+02  7.1289+02  7.1245+02  7.1212+02
 1200  8.0770+02  8.0632+02  8.0523+02  8.0437+02  8.0368+02  8.0313+02  8.0270+02
 1300  8.9992+02  8.9854+02  8.9740+02  8.9647+02  8.9571+02  8.9509+02  8.9459+02
```

GAS PROPERTIES OF JP-7

ENTROPY, BTU/LB-R

PRESSURE, PSIA

TEMP, F	0	100	200	300	400	500	600	700	800	900	1000
100	1.3578-01										
200	2.1039-01										
300	2.8218-01										
400	3.5140-01										
500	4.1821-01										
600	4.8275-01										
700	5.4514-01	5.3909-01									
800	6.0549-01	6.0124-01	5.9539-01	5.8442-01	5.7013-01	5.6753-01	5.6677-01	5.6656-01	5.6658-01	5.6671-01	5.6690-01
900	6.6388-01	6.6076-01	6.5695-01	6.5201-01	6.4543-01	6.3958-01	6.3671-01	6.3536-01	6.3469-01	6.3435-01	6.3420-01
1000	7.2040-01	7.1799-01	7.1527-01	7.1212-01	7.0853-01	7.0483-01	7.0180-01	6.9978-01	6.9853-01	6.9775-01	6.9726-01
1100	7.7513-01	7.7320-01	7.7111-01	7.6884-01	7.6643-01	7.6397-01	7.6172-01	7.5987-01	7.5848-01	7.5747-01	7.5676-01
1200	8.2813-01	8.2654-01	8.2487-01	8.2311-01	8.2130-01	8.1949-01	8.1778-01	8.1626-01	8.1499-01	8.1397-01	8.1318-01
1300	8.7949-01	8.7814-01	8.7673-01	8.7529-01	8.7384-01	8.7240-01	8.7103-01	8.6977-01	8.6865-01	8.6770-01	8.6691-01

ENTROPY, BTU/LB-R

PRESSURE, PSIA

TEMP, F	1000	1100	1200	1300	1400	1500	1600
800	5.6690-01	5.6713-01	5.6737-01	5.6763-01	5.6788-01	5.6814-01	5.6840-01
900	6.3420-01	6.3415-01	6.3417-01	6.3424-01	6.3433-01	6.3445-01	6.3458-01
1000	6.9726-01	6.9695-01	6.9677-01	6.9666-01	6.9661-01	6.9659-01	6.9661-01
1100	7.5676-01	7.5625-01	7.5588-01	7.5563-01	7.5544-01	7.5532-01	7.5523-01
1200	8.1318-01	8.1256-01	8.1208-01	8.1171-01	8.1143-01	8.1120-01	8.1103-01
1300	8.6691-01	8.6625-01	8.6571-01	8.6527-01	8.6491-01	8.6462-01	8.6437-01

FREE ENERGY, BTU/LB

PRESSURE, PSIA

TEMP, F	0	100	200	300	400	500	600	700	800	900	1000
100	-2.0430+02										
200	-2.6654+02										
300	-3.4009+02										
400	-4.1870+02										
500	-5.04[illegible]02										
600	-5.96[illegible]02										
700	-6.944[illegible]+02	-6.9647+02									
800	-7.9885+02	-8.0050+02	-8.0234+02	-8.0448+02	-8.0699+02	-8.0910+02	-8.1076+02	-8.1209+02	-8.1318+02	-8.1409+02	-8.1484+02
900	-9.0924+02	-9.1054+02	-9.1195+02	-9.1348+02	-9.1513+02	-9.1678+02	-9.1823+02	-9.1946+02	-9.2049+02	-9.2136+02	-9.2209+02
1000	-1.0254+03	-1.0264+03	-1.0274+03	-1.0286+03	-1.0298+03	-1.0309+03	-1.0321+03	-1.0331+03	-1.0340+03	-1.0347+03	-1.0354+03
1100	-1.1471+03	-1.1478+03	-1.1486+03	-1.1494+03	-1.1503+03	-1.1511+03	-1.1520+03	-1.1527+03	-1.1534+03	-1.1540+03	-1.1546+03
1200	-1.2742+03	-1.2747+03	-1.2753+03	-1.2759+03	-1.2765+03	-1.2771+03	-1.2776+03	-1.2782+03	-1.2787+03	-1.2791+03	-1.2795+03
1300	-1.4065+03	-1.4069+03	-1.4073+03	-1.4077+03	-1.4081+03	-1.4085+03	-1.4089+03	-1.4092+03	-1.4095+03	-1.4098+03	-1.4101+03

FREE ENERGY, BTU/LB

PRESSURE, PSIA

TEMP, F	1000	1100	1200	1300	1400	1500	1600
800	-8.1484+02	-8.1547+02	-8.1601+02	-8.1645+02	-8.1682+02	-8.1713+02	-8.1739+02
900	-9.2209+02	-9.2271+02	-9.2323+02	-9.2367+02	-9.2403+02	-9.2434+02	-9.2459+02
1000	-1.0354+03	-1.0359+03	-1.0364+03	-1.0368+03	-1.0372+03	-1.0374+03	-1.0377+03
1100	-1.1546+03	-1.1550+03	-1.1554+03	-1.1558+03	-1.1561+03	-1.1563+03	-1.1565+03
1200	-1.2795+03	-1.2799+03	-1.2802+03	-1.2804+03	-1.2806+03	-1.2808+03	-1.2810+03
1300	-1.4101+03	-1.4103+03	-1.4105+03	-1.4107+03	-1.4108+03	-1.4109+03	-1.4109+03

GAS PROPERTIES OF JP-7

SPECIFIC HEAT AT CONSTANT PRESSURE, BTU/LB-R

PRESSURE, PSIA

TEMP, F	0	100	200	300	400	500	600	700	800	900	1000
100	4.2598-01										
200	4.8259-01										
300	5.3537-01										
400	5.8448-01										
500	6.3009-01										
600	6.7238-01										
700	7.1152-01	7.3593-01									
800	7.4768-01	7.6517-01	8.0102-01	9.8360-01	9.9521-01	9.2515-01	9.0148-01	8.8922-01	8.8154-01	8.7619-01	8.7219-01
900	7.8102-01	7.9324-01	8.1252-01	8.4922-01	9.1887-01	9.4042-01	9.1964-01	9.0486-01	8.9558-01	8.8935-01	8.8482-01
1000	8.1172-01	8.2051-01	8.3262-01	8.5025-01	8.7529-01	9.0106-01	9.1186-01	9.1007-01	9.0521-01	9.0064-01	8.9690-01
1100	8.3996-01	8.4640-01	8.5459-01	8.6508-01	8.7807-01	8.9205-01	9.0326-01	9.0897-01	9.1021-01	9.0925-01	9.0754-01
1200	8.6590-01	8.7069-01	8.7646-01	8.8335-01	8.9127-01	8.9964-01	9.0727-01	9.1293-01	9.1621-01	9.1756-01	9.1769-01
1300	8.8972-01	8.9325-01	8.9737-01	9.0207-01	9.0727-01	9.1266-01	9.1775-01	9.2201-01	9.2511-01	9.2705-01	9.2803-01

SPECIFIC HEAT AT CONSTANT PRESSURE, BTU/LB-R

PRESSURE, PSIA

TEMP, F	1000	1100	1200	1300	1400	1500	1600
800	8.7219-01	8.6903-01	8.6646-01	8.6429-01	8.6242-01	8.6077-01	8.5931-01
900	8.8482-01	8.8139-01	8.7867-01	8.7644-01	8.7456-01	8.7294-01	8.7151-01
1000	8.9690-01	8.9388-01	8.9142-01	8.8937-01	8.8764-01	8.8615-01	8.8485-01
1100	9.0754-01	9.0571-01	9.0400-01	9.0245-01	9.0107-01	8.9984-01	8.9874-01
1200	9.1769-01	9.1710-01	9.1638-01	9.1548-01	9.1457-01	9.1369-01	9.1286-01
1300	9.2803-01	9.2834-01	9.2822-01	9.2786-01	9.2737-01	9.2681-01	9.2624-01

SPECIFIC HEAT AT CONSTANT VOLUME, BTU/LB-R

PRESSURE, PSIA

TEMP, F	0	100	200	300	400	500	600	700	800	900	1000
100	4.1475-01										
200	4.7137-01										
300	5.2414-01										
400	5.7325-01										
500	6.1887-01										
600	6.6116-01										
700	7.0029-01	7.1436-01									
800	7.3645-01	7.4672-01	7.6355-01	8.2384-01	8.4491-01	8.3205-01	8.2862-01	8.2720-01	8.2646-01	8.2601-01	8.2570-01
900	7.6979-01	7.7660-01	7.8564-01	7.9949-01	8.2183-01	8.3423-01	8.3498-01	8.3497-01	8.3507-01	8.3524-01	8.3541-01
1000	8.0050-01	8.0595-01	8.1046-01	8.1722-01	8.2558-01	8.3426-01	8.4031-01	8.4325-01	8.4492-01	8.4600-01	8.4678-01
1100	8.2873-01	8.3176-01	8.3515-01	8.3898-01	8.4324-01	8.4768-01	8.5172-01	8.5486-01	8.5711-01	8.5870-01	8.5988-01
1200	8.5467-01	8.5664-01	8.5877-01	8.6105-01	8.6346-01	8.6592-01	8.6826-01	8.7039-01	8.7216-01	8.7359-01	8.7474-01
1300	8.7849-01	8.7965-01	8.8068-01	8.8217-01	8.8349-01	8.8463-01	8.8613-01	8.8736-01	8.8846-01	8.8943-01	8.9027-01

SPECIFIC HEAT AT CONSTANT VOLUME, BTU/LB-R

PRESSURE, PSIA

TEMP, F	1000	1100	1200	1300	1400	1500	1600
800	8.2570-01	8.2544-01	8.2522-01	8.2503-01	8.2483-01	8.2462-01	8.2441-01
900	8.3541-01	8.3556-01	8.3568-01	8.3577-01	8.3583-01	8.3585-01	8.3585-01
1000	8.4678-01	8.4734-01	8.4765-01	8.4822-01	8.4852-01	8.4875-01	8.4894-01
1100	8.5988-01	8.6078-01	8.6150-01	8.6207-01	8.6253-01	8.6292-01	8.6323-01
1200	8.7474-01	8.7567-01	8.7645-01	8.7705-01	8.7758-01	8.7802-01	8.7839-01
1300	8.9027-01	8.9096-01	8.9160-01	8.9212-01	8.9258-01	8.9297-01	8.9332-01

```
                                   GAS PROPERTIES OF JP-7

                                  RATIO OF SPECIFIC HEATS

TEMP,                                    PRESSURE, PSIA
  F        0         100        200        300        400        500        600        700        800        900       1000
 100  1.0271+00
 200  1.0238+00
 300  1.0214+00
 400  1.0196+00
 500  1.0181+00
 600  1.0170+00
 700  1.0160+00  1.0302+00
 800  1.0152+00  1.0247+00  [illegible]  1.1939+00  1.1779+00  1.1119+00  1.0879+00  1.0750+00  1.0667+00  1.0608+00  1.0563+00
 900  1.0146+00  1.0214+00  1.0342+00  1.0622+00  1.1181+00  1.1273+00  1.1014+00  1.0837+00  1.0725+00  1.0648+00  1.0591+00
1000  1.0140+00  1.0192+00  1.0273+00  1.0404+00  1.0602+00  1.0801+00  1.0853+00  1.0792+00  1.0714+00  1.0646+00  1.0592+00
1100  1.0135+00  1.0176+00  1.0233+00  1.0311+00  1.0413+00  1.0523+00  1.0605+00  1.0633+00  1.0620+00  1.0587+00  1.0554+00
1200  1.0131+00  1.0164+00  1.0206+00  1.0259+00  1.0322+00  1.0389+00  1.0449+00  1.0489+00  1.0505+00  1.0503+00  1.0491+00
1300  1.0128+00  1.0155+00  1.0187+00  1.0226+00  1.0269+00  1.0314+00  1.0357+00  [illegible]  1.0413+    1.0423+00  1.0424+00

                                  RATIO OF SPECIFIC HEATS

TEMP,                                    PRESSURE, PSIA
  F       1000       1100       1200       1300       1400       1500       1600
 800  1.0563+00  1.0525+00  1.0500+00  1.0476+00  1.0456+00  1.0438+00  1.0423+00
 900  1.0591+00  1.0549+00  1.0514+00  1.0487+00  1.0463+00  1.0444+00  1.0427+00
1000  1.0592+00  1.0549+00  1.0519+00  1.0485+00  1.0461+00  1.0441+00  1.0423+00
1100  1.0558+00  1.0522+00  1.0493+00  1.0469+00  1.0447+00  1.0428+00  1.0411+00
1200  1.0491+00  1.0474+00  1.0456+00  1.0438+00  1.0422+00  1.0406+00  1.0392+00
1300  1.0424+00  1.0419+00  1.0411+00  1.0401+00  1.0390+00  1.0379+00  1.0369+00

                                   SONIC VELOCITY, FT/SEC

TEMP,                                    PRESSURE, PSIA
  F        0         100        200        300        400        500        600        700        800        900       1000
 100  4.0185+02
 200  4.3558+02
 300  4.6688+02
 400  4.9622+02
 500  5.2391+02
 600  5.5022+02
 700  5.7532+02  4.7495+02
 800  5.9935+02  5.2552+02  4.2562+02  2.7040+02  3.6052+02  4.7805+02  5.6473+02  6.3079+02  6.8703+02  7.3911+02  7.8877+02
 900  6.2252+02  5.6797+02  5.0195+02  4.2517+02  3.6598+02  4.0701+02  4.9023+02  5.6162+02  6.2057+02  6.7526+02  7.2515+02
1000  6.4483+02  6.0518+02  5.5993+02  5.1185+02  4.7099+02  4.5947+02  4.9026+02  5.4370+02  5.9931+02  6.4980+02  6.9556+02
1100  6.6639+02  6.3808+02  6.0745+02  5.7673+02  5.5084+02  5.3778+02  5.4509+02  5.7236+02  6.1169+02  6.5514+02  6.9802+02
1200  6.8720+02  6.6744+02  6.4711+02  6.2807+02  6.1314+02  6.0592+02  6.0963+02  6.2513+02  6.5045+02  6.8236+02  7.1784+02
1300  7.0756+02  6.9417+02  6.8126+02  6.7019+02  6.6278+02  6.6103+02  6.6654+02  6.7977+02  6.9970+02  7.2439+02  7.5223+02

                                   SONIC VELOCITY, FT/SEC

TEMP,                                    PRESSURE, PSIA
  F       1000       1100       1200       1300       1400       1500       1600
 800  7.8877+02  8.3626+02  8.8157+02  9.2485+02  9.6636+02  1.0064+03  1.0454+03
 900  7.2515+02  7.7272+02  8.1857+02  8.6265+02  9.0453+02  9.4415+02  9.8179+02
1000  6.9556+02  7.3791+02  7.8014+02  8.2372+02  8.6597+02  9.0621+02  9.4404+02
1100  6.9802+02  7.3817+02  7.7570+02  8.1214+02  8.4825+02  8.8564+02  9.2434+02
1200  7.1784+02  7.5446+02  7.9055+02  8.2512+02  8.5800+02  8.9005+02  9.2336+02
1300  7.5223+02  7.8239+02  8.1423+02  8.4675+02  8.7901+02  9.1041+02  9.4083+02
```

GAS PROPERTIES OF JP-7

JOULE-THOMSON COEFFICIENT, R/PSI

TEMP,	PRESSURE, PSIA										
F	0	100	200	300	400	500	600	700	800	900	1000
100	3.9528-01										
200	2.7084-01										
300	1.9617-01										
400	1.4818-01										
500	1.1575-01										
600	9.2706-02										
700	7.5793-02	1.4600-01									
800	6.3000-02	1.0236-01	1.3827-01	2.5602-01	8.6671-02	3.7495-02	2.2074-02	1.4499-02	9.9800-03	6.9738-03	4.8273-03
900	5.3175-02	7.5469-02	8.9490-02	1.1071-01	1.2259-01	7.7247-02	4.2497-02	2.6316-02	1.7703-02	1.2476-02	8.9973-03
1000	4.5451-02	5.7963-02	6.4406-02	7.1635-02	7.6216-02	6.9631-02	5.1970-02	3.5693-02	2.4782-02	1.7739-02	1.3022-02
1100	3.9271-02	4.6045-02	4.9215-02	5.2109-02	5.3492-02	5.1371-02	4.4774-02	3.5792-02	2.7374-02	2.0732-02	1.5783-02
1200	3.4249-02	3.7675-02	3.9250-02	4.0404-02	4.0613-02	3.9240-02	3.5947-02	3.1151-02	2.5844-02	2.0895-02	1.6703-02
1300	3.0114-02	3.1761-02	3.2502-02	3.2861-02	3.2594-02	3.1463-02	2.9357-02	2.6414-02	2.2998-02	1.9526-02	1.6303-02

JOULE-THOMSON COEFFICIENT, R/PSI

TEMP,	PRESSURE, PSIA						
F	1000	1100	1200	1300	1400	1500	1600
800	4.8273-03	3.2175-03	1.9655-03	9.6406-04	1.4507-04	-5.3702-04	-1.[illegible]137-03
900	8.9973-03	6.5280-03	4.6899-03	3.2715-03	2.1454-03	1.2311-03	4.7471-04
1000	1.3022-02	9.7106-03	7.2854-03	5.4457-03	4.0093-03	2.8605-03	1.9233-03
1100	1.5783-02	1.2114-02	9.3542-03	7.2345-03	5.5716-03	4.2414-03	3.1584-03
1200	1.6703-02	1.3307-02	1.0590-02	8.4355-03	6.6967-03	5.2830-03	4.1200-03
1300	1.6303-02	1.3476-02	1.1073-02	9.0613-03	7.3842-03	5.9839-03	4.8090-03

VISCOSITY, LB/FT-HR

TEMP,	PRESSURE, PSIA										
F	0	100	200	300	400	500	600	700	800	900	1000
100	[illegible].2218-02										
200	1.4259-02										
300	1.6282-02										
400	1.8289-02										
500	2.0282-02										
600	2.2263-02										
700	2.4232-02	2.5819-02									
800	2.6192-02	2.7556-02	2.9910-02	3.7760-02	6.0295-02	7.4502-02	8.4061-02	9.2767-02	1.0013-01	1.0601-01	1.1097-01
900	2.8142-02	2.9348-02	3.1122-02	3.4544-02	4.1321-02	5.1199-02	6.0465-02	6.8802-02	7.6543-02	8.3324-02	8.9150-02
1000	3.0083-02	3.1169-02	3.2618-02	3.4793-02	3.8471-02	4.3491-02	4.9400-02	5.5400-02	6.1238-02	6.6981-02	7.2558-02
1100	3.2016-02	3.3007-02	3.4245-02	3.5838-02	3.8342-02	4.15[illegible]-02	4.5320-02	4.9458-02	5.3714-02	5.7964-02	6.2190-02
1200	3.3942-02	3.4856-02	3.5948-02	3.7269-02	3.9076-02	4.1419-02	4.4087-02	4.7036-02	5.0185-02	5.3436-02	5.6711-02
1300	3.5861-02	3.6711-02	3.7695-02	3.8837-02	4.0211-02	4.2087-02	4.4147-02	4.6373-02	4.8749-02	5.1253-02	5.3853-02

VISCOSITY, LB/FT-HR

TEMP,	PRESSURE, PSIA						
F	1000	1100	1200	1300	1400	1500	1600
800	1.1097-01	1.1526-01	1.1917-01	1.2278-01	1.2617-01	1.2936-01	1.3235-01
900	8.9150-02	9.4398-02	9.6948-02	1.0266-01	1.0624-01	1.0948-01	1.1274-01
1000	7.2558-02	7.7900-02	8.2673-02	8.6703-02	9.0391-02	9.3896-02	9.7343-02
1100	6.2190-02	6.6428-02	7.0643-02	7.4703-02	7.8538-02	8.1941-02	8.4928-02
1200	5.6711-02	5.9974-02	6.3227-02	6.6488-02	6.9754-02	7.2930-02	7.5930-02
1300	5.3853-02	5.6495-02	5.9126-02	6.1731-02	6.4319-02	6.6903-02	6.9480-02

GAS PROPERTIES OF JP-7

THERMAL CONDUCTIVITY, BTU/FT-HR-R

TEMP, F	PRESSURE, PSIA 0	100	200	300	400	500	600	700	800	900	1000
100	6.4701-03										
200	8.5403-03										
300	1.0805-02										
400	1.3237-02										
500	1.5813-02										
600	1.8510-02										
700	2.1310-02	2.1827-02									
800	2.4193-02	2.4641-02	2.5322-02	2.6926-02	3.1520-02	3.4023-02	3.5595-02	3.6962-02	3.8140-02	3.9106-02	3.9898-02
900	2.7143-02	2.7542-02	2.8070-02	2.8837-02	3.0242-02	3.2339-02	3.4139-02	3.5654-02	3.6990-02	3.8112-02	3.9046-02
1000	3.0148-02	3.0508-02	3.0947-02	3.1506-02	3.2240-02	3.3297-02	3.4574-02	3.5795-02	3.6924-02	3.7986-02	3.8977-02
1100	3.3193-02	3.3523-02	3.3903-02	3.4350-02	3.4881-02	3.5501-02	3.6319-02	3.7225-02	3.8112-02	3.8985-02	3.9783-02
1200	3.6268-02	3.6573-02	3.6912-02	3.7291-02	3.7714-02	3.8189-02	3.8693-02	3.9347-02	4.0049-02	4.0732-02	4.1405-02
1300	3.9365-02	3.9649-02	3.9957-02	4.0290-02	4.0649-02	4.1033-02	4.1437-02	4.1858-02	4.2397-02	4.2952-02	4.3512-02

THERMAL CONDUCTIVITY, BTU/FT-HR-F

TEMP, F	PRESSURE, PSIA 1000	1100	1200	1300	1400	1500	1600
800	3.9898-02	4.0568-02	4.1157-02	4.1689-02	4.2176-02	4.2623-02	4.3031-02
900	3.9046-02	3.9864-02	4.0568-02	4.1188-02	4.1760-02	4.2302-02	4.2821-02
1000	3.8977-02	3.9895-02	4.0692-02	4.1349-02	4.1939-02	4.2469-02	4.3022-02
1100	3.9783-02	4.0576-02	4.1342-02	4.2059-02	4.2719-02	4.329[illegible]-02	4.3790-02
1200	4.1405-02	4.2057-02	4.2688-02	4.3305-02	4.3909-02	4.4452-02	4.5213-02
1300	4.3512-02	4.4065-02	4.4602-02	4.5122-02	4.5626-02	4.6119-02	4.6602-02

PRANDTL NUMBER

TEMP, F	PRESSURE, PSIA 0	100	200	300	400	500	600	700	800	900	1000
100	8.0438-01										
200	8.0575-01										
300	8.0678-01										
400	8.0757-01										
500	8.0819-01										
600	8.0869-01										
700	8.0911-01	8.7055-01									
800	8.0945-01	8.5570-01	9.4614-01	1.3793+00	1.9038+00	2.0258+00	2.1289+00	2.2357+00	2.3182+00	2.3752+00	2.4258+00
900	8.0974-01	8.4525-01	9.0086-01	1.0169+00	1.2555+00	1.4889+00	1.6288+00	1.7461+00	1.8532+00	1.9443+00	2.0203+00
1000	8.0998-01	8.3826-01	8.7757-01	9.3893-01	1.0445+00	1.1769+00	1.3929+00	1.4085+00	1.5013+00	1.5881+00	1.6696+00
1100	8.1019-01	8.3339-01	8.6322-01	9.0256-01	9.6521-01	1.0438+00	1.1271+00	1.2078+00	1.2828+00	1.3526+00	1.4187+00
1200	8.1037-01	8.2982-01	8.5357-01	8.8283-01	9.2345-01	9.7587-01	1.0338+00	1.0913+00	1.1483+00	1.2038+00	1.2569+00
1300	8.1053-01	8.2707-01	8.4656-01	8.6954-01	8.9750-01	9.3611-01	9.7775-01	1.0215+00	1.0637+00	1.1062+00	1.1486+00

PRANDTL NUMBER

TEMP, F	PRESSURE, PSIA 1000	1100	1200	1300	1400	1500	1600
800	2.4258+00	2.4694+00	2.5087+00	2.5454+00	2.5799+00	2.6124+00	2.6430+00
900	2.0203+00	2.0871+00	2.1432+00	2.1846+00	2.2228+00	2.2592+00	2.2945+00
1000	1.6696+00	1.7554+00	1.8111+00	1.8649+00	1.9131+00	1.9583+00	2.0021+00
1100	1.4187+00	1.4826+00	1.5447+00	1.6029+00	1.6564+00	1.7031+00	1.7431+00
1200	1.2569+00	1.3079+00	1.3573+00	1.4056+00	1.4529+00	1.4980+00	1.5399+00
1300	1.1486+00	1.1902+00	1.2305+00	1.2694+00	1.3073+00	1.3445+00	1.3810+00

GAS PROPERTIES OF JP-7 AT SATURATION

TEMP, F	VAPOR PRESS, PSIA	COMP FACTOR	DENSITY, LB/CUFT	FUGACITY, PSIA	ENTHALPY, BTU/LB	ENTROPY, BTU/LB-R	FREE ENERGY, BTU/LB	SPEC HEAT AT CONST P, BTU/LB-R
100	4.9871-03	9.9995-01	1.4698-04	4.9858-03	9.3332+01	1.3578-01	-2.0430+02	4.2599-01
200	1.4869-01	9.9896-01	3.7216-03	1.4854-01	1.3874+02	2.1031-01	-2.6854+02	4.8284-01
300	1.5746+00	9.9223-01	3.4455-02	1.5625+00	1.8929+02	2.8170-01	-3.4016+02	5.3706-01
400	8.6986+00	9.6818-01	1.7238-01	8.4292+00	2.4408+02	3.4961-01	-4.1909+02	5.9075-01
500	3.1403+01	9.1082-01	[illegible]	2.8805+01	3.0206+02	4.1455-01	-5.0504+02	6.4480-01
600	8.5278+01	8.0231-01	1.6544+00	7.4012+01	3.6158+02	4.7530-01	-5.9826+02	7.0505-01
700	1.9084+02	6.0200-01	4.5387+00	1.3738+02	4.1865+02	5.2966-01	-6.9868+02	8.2012-01

GAS PROPERTIES OF JP-7 AT SATURATION

TEMP, F	VAPOR PRESS, PSIA	SPEC HEAT AT CONST V, BTU/LB-R	RATIO OF SPEC HEATS	SONIC VEL, FT/SEC	J-T COEF, R/PSI	VISCOSITY, LB/FT-HR	THERMAL COND, BTU/FT-HR-R	PRANDTL NUMBER
100	4.9871-03	4.1476-01	1.0271+00	4.0183+02	1.4470+00	1.2218-02	6.4701-03	8.0449-01
200	1.4869-01	4.7157-01	1.0239+00	4.3514+02	8.4060-01	1.4262-02	8.5414-03	8.0624-01
300	1.5746+00	5.2555-01	1.0219+00	4.6335+02	5.1346-01	1.6311-02	1.0815-02	8.1001-01
400	8.6986+00	5.7831-01	1.0215+00	4.6070+02	3.3300-01	1.8536-02	1.3287-02	8.1966-01
500	3.1403+01	6.2961-01	1.0241+00	4.7709+02	2.3790-01	2.0799-02	1.5988-02	8.3882-01
600	6.5278+01	6.8163-01	1.0344+00	4.3708+02	2.0653-01	2.3789-02	1.9009-02	8.5234-01
700	1.9084+02	7.5015-01	1.0953+00	3.1849+02	2.6652-01	2.9283-02	2.2739-02	1.0561+00

(This page is intentionally blank.)

BIBLIOGRAPHY

Advanced Fuels Including Endothermic and Vaporizing Fuels

1. Asher, W. J., CONCEPTUAL DESIGN STUDY OF DEMULSIFICATION OF FUEL EMULSIONS BY A COALESCENCE PROCESS. Esso Research and Engineering Co., Government Research Lab. Final Report, October 1967 - October 1968, U.S. Army Aviation Materiel Labs. Report No. USAAVLABS-TR-69-16, Contract No. DAAJ02-68-C-0011, April 1969, 43 pp. (AD 688 973) (N69-37621)

2. Atkinson, A. J., EVALUATION OF EXPERIMENTAL SAFETY FUELS IN A CONVENTIONAL GAS TURBINE COMBUSTION SYSTEM. U.S. Naval Air Propulsion Test Center Report No. NA-69-1, U.S. Federal Aviation Admin. Report No. FAA-DS-68-27, April 1969. (AD 686 840) (N69-23422)

3. Atlantic Research Corp., RESEARCH AND DEVELOPMENT ON AN ADVANCED SLURRY FUEL FOR NAVAL APPLICATIONS. Report No. ARC-TR-PL-9869. (AD 506 436L)

4. Atlantic Research Corp., RESEARCH ON OPERATIONAL SLURRY FUELS. U.S. Air Force Report No. AFAPL-TR-68-104. (AD 392 967)

5. Atlantic Research Corp., SLURRY FUEL PERFORMANCE. U.S. Air Force Report No. AFAPL-TR-66-73. (AD 389 945L)

6. Atlantic Research Corp., RESEARCH ON OPERATIONAL SLURRY FUELS. Quarterly Report No. 3, Oct - Dec 1967. Contract F33615-67-C-1356. Jan 31, 1968. (AD 389 087) (Report Classified Confidential)

7. Atlantic Research Corp., RESEARCH ON OPERATIONAL SLURRY FUELS. Quarterly Progress Report No. 2, Jul - Sep 1967. Contract F33615-67-C-1356. Oct 27, 1967. (AD 385 075) (Report Classified Confidential)

8. Barnes, R. L. and Dinsmore, R. L. (Atlantic Richfield Co.), A FUEL FOR MACH 3-3.5 JETS. U.S. 3,493,491 (Cl. 208-144), February 3, 1970, Appl. May 21, 1969, Div. of Abandoned Ser. 658,066, Appl. August 3, 1967 which is a continuation-in-part of U.S. 3,367,860, Appl. October 13, 1966 which is a continuation-in-part of Abandoned Ser. 324,881, Appl. November 19, 1963.

9. Barnes, R. L., Dinsmore, R. L., HIGH-DENSITY JET FUEL. U.S. 3367860 (Cl. 208-15), 06 Feb 1968, Appl. 19 Nov 1963-13 Oct 1966.

10. Barrick, H. A., (Atlantic Research Corp.), RESEARCH AND DEVELOPMENT ON ADVANCED SLURRY FUELS FOR NAVY APPLICATIONS. Quarterly Report No. 1, 15 Oct 68 - 15 Jan 69. February 1969. (AD 500 889L) Quarterly Report No. 2, 15 Jan - 15 Apr 69. June 1969. (AD 502 960L) Contract No. N00019-69-C-0195. (Reports Classified Confidential)

11. Burk, J. W., AN INVESTIGATION OF THE COMPATIBILITY OF FAA 1069-1 KEROSENE FUEL GEL WITH COMMERCIAL JET TRANSPORT FUEL SYSTEMS. Boeing Co. Report No. D6-15230, February 1969, 34 pp. (AD 686 522) (N69-32795)

BIBLIOGRAPHY (Contd)

12. Cohen, C. A., Muessig, C. W. (Esso Research and Engineering Co.), EXO ISOMERS OF TETRAHYDRODICYCLOPENTADIENE OR TETRAHYDRODIMETHYLDICYCLOPENTADIENE FOR USE AS JET AND ROCKET FUEL. U.S. 3,381,046 (Cl. 260-666), 30 Apr 1968, Appl. 15 Aug 1966.

13. Custard, G. H., A VULNERABILITY EVALUATION OF EMULSIFIED FUELS FOR USE IN ARMY AIRCRAFT. Falcon Research and Development Co. Final Report 1 January - 31 December 1967, Report No. 6204-2-F, U.S. Army Aviation Labs. Report No. USAAVLABS-TR-68-20, Contract No. DA-44-177-AMC-415(T), April 1968. (AD 670 935) (N68-31872)

14. Dow Chemical Company, EXPLORATORY DEVELOPMENT OF PYROPHORIC ALUMINUM ALKYL FUELS. Report No. AF-1Q-69. (AD 504 393L)

15. Esso Research and Engineering Co., PREPARATION OF FUELS HAVING A HIGH ENERGY POTENTIAL. Fr. 1,537,241 (Cl. C 10 1), August 23, 1968, U.S. Appl. August 15, 1966.

16. Esso Research and Engineering Co., EXO-TETRAHYDRODICYCLOPENTADIENE AS FUEL FOR JET OR ROCKET ENGINES. Brit. 1,192,610, Publ. February 25, 1970, U.S. Appl. August 15, 1966, corresponds to U.S. 3,381,046 (68-5314).

17. Greenberg, S. (United Aircraft Corp., Pratt and Whitney Aircraft Div.), METHANE FUEL SYSTEMS FOR HIGH MACH NUMBER AIRCRAFT. Society of Automotive Engineers, National Aeronautic and Space Engineering and Manufacturing Meeting, Los Angeles, Calif., October 6-10, 1969, Paper 690668, 16 pp. (A70-15835)

18. Harris, J. C. and Steinmetz, E. A., INVESTIGATION AND ANALYSIS OF AIRCRAFT FUEL EMULSIONS. Monsanto Research Corp., U.S. Army Aviation Labs. Report No. USAAVLABS-TR-67-7C, Contract No. DA-44-177-AMC-445(T), December 1967. (AD 668 248) (N68-26526)

19. Harris, J. C. and Steinmetz, E. A., OPTIMIZATION OF JP-4 FUEL EMULSIONS AND DEVELOPMENT OF DESIGN CONCEPTS FOR THEIR DEMULSIFICATION. Monsanto Research Corp. Final Report, U.S. Army Aviation Labs. Report No. USAAVLABS-TR-68-79, Contract No. DAAJ02-67-C-0107, November 1968. (AD 683 597) (N69-25508)

20. Joslyn, C. L., THE POTENTIAL OF METHANE AS A FUEL FOR ADVANCED AIRCRAFT. Aviation and Space: Progress and Prospects. ASME, 1968, pp. 351-5.

21. Kobish, T. R., Roberts, R. A., Schwartz, H. R., Gordon, R. E., Ault, E. A., EMULSIFIED FUELS COMBUSTION STUDY. Pratt and Whitney Aircraft Report No. PWA-3515, U.S. Army Aviation Mater. Labs. Report No. USAAVLABS-TR-69-4, Contract No. DAAJ02-67-C-0094, February 1969. (AD 687 325) (N69-34102)

22. Kolfenbach, J. J. and Wiese, H. K. (Esso Research and Engineering Co.), TETRAHYDROGENATED DIMERS OF CYCLOPENTADIENES AS JET FUEL. Ger. Appl. 1,418, [illegible], Open October 9, 1969, filed U.S. April [illegible]. Corresponds to Can. 625,006.

BIBLIOGRAPHY (Contd)

33. Krafft, O., Kubicka, R., Mraz, V., and Hala, S., MANUFACTURING FUEL FOR SUPERSONIC AIRCRAFT. Czech. 122,575 (Cl. F 02k), April 15, 1967, Appl. Nov. 8, 1961.

34. Kuchta, J. M., Furno, A. L., Martindill, G. H., Imhof, A. C. (U.S. Bureau of Mines), CRASH FIRE HAZARD RATING SYSTEM FOR CONTROLLED FLAMMABILITY FUELS. Federal Aviation Agency Report Nos. FAA-NA-69-17, FAA-DS-68-25, March 1969. (N69-20285)

35. Lamart, R. M. and Mello, J. D (Chandler Evans, Inc.), EMULSIFIED FUEL AND FUEL CONTROL SYSTEMS. ASME, Annual Gas Turbine Conference and Products Show, 14th, Cleveland, Ohio, March 9-13, 1969, Paper 69-GT-40. (A69-22486)

36. Lawton, E. A., Weilmuenster, E. A., Levy, A. (Battelle Development Corp.), MONOALKYL PENTABORANE (11). U.S. 3,391,194 (Cl. 260-606.5), 02 Jul 1968, Appl. 12 Oct 1955.

37. Lissant, K. J., A THIXOTROPIC HYDROCARBON-IN-WATER EMULSION FUEL. U.S. 3,490,237, January 20 (Cl. 60-217) 1970, Appl. July 18, 1966.

38. Meier Zu Koecker, H., GAS TURBINE FUELS. PROBLEMS AND DEVELOPMENT. Brennst.-Chem. 50(4), 105-12 (April 1969).

39. Nixon, A. C., et al. (Shell Development Co.), VAPORIZING AND ENDOTHERMIC FUELS FOR ADVANCED ENGINE APPLICATION: PART I. STUDIES OF THERMAL AND CATALYTIC REACTIONS, THERMAL STABILITIES, AND COMBUSTION PROPERTIES OF HYDROCARBON FUELS. U.S. Air Force Report No. AFAPL-TR-67-114-PT-1. (AD 822 827)

40. Nixon, A. C., et al., (Shell Development Co.), VAPORIZING AND ENDOTHERMIC FUELS FOR ADVANCED ENGINE APPLICATION. PART II. STUDIES OF THERMAL AND CATALYTIC REACTIONS, THERMAL STABILITIES, AND COMBUSTION PROPERTIES OF HYDROCARBON FUELS. U.S. Air Force AFAPL-TR-67-114-PT-2. (AD 844 671)

41. Nixon, A. C., Ackerman, G. H., Faith, L. E., Henderson, H. T., Ritchie, A. W., Ryland, L. B., and Shryne, T. M., VAPORIZING AND ENDOTHERMIC FUELS FOR ADVANCED ENGINE APPLICATION. PART III. STUDIES OF THERMAL AND CATALYTIC REACTIONS, THERMAL STABILITIES, AND COMBUSTION PROPERTIES OF HYDROCARBON FUELS. VOLUMES I AND II. Shell Development Co., A Division of Shell Oil Co., U.S. Air.Force Report No. AFAPL-TR-67-114, Part III, Vols. I and II. Contract No. AF 33(615)-3389, February 1970.

42. Nixon, J., Beerbower, A., Philippoff, W., Lorenz, P. A., and Wallace, T. J., INVESTIGATION AND ANALYSIS OF AIRCRAFT FUEL EMULSIONS. Esso Research and Engineering Co., Government Research Lab. Technical Report U.S. Army Report No. USAAVIABS-TR-67-6[illegible]. Contract No. DA-44-177-AMC-387(T). November 1967. (AD 827 05[illegible])

43. Nixon, J. Philippoff, W. and Siminski, V. J. (Esso Res. and Eng. Co.), OPTIMIZATION OF NONAQUEOUS FUEL EMULSIONS. Final Report Oct 67 - Oct 68. Report No. GR-3-AFE-68. Contract DAAJ02-68-C-00[illegible]3, Proj. DA-1-F-162203-A-520, USAAVIABS TR-69-[illegible] May 1969. (AD 85[illegible])

BIBLIOGRAPHY (Contd)

44. Noddings, C. R. and Kelly, J. A. (to Dow Chemical Co.), ENDOTHERMIC FUEL SYSTEM FOR AIR-BREATHING AIRCRAFT. U.S. 3,438,602 (Cl. 244-135), April 15, 1969, Appl. October 20, 1967.

45. Olin Mathieson Chemical Corp. (S. Papetti) A CARBORANE OR A NEOBORANE COMPOUND USEFUL AS HIGH-ENERGY LIQUID FUEL FOR ROCKETS, JET ENGINES, AND RAM JETS. U.S. 3,497,540. February 24, 1970, Appl. September 20, 1967. C.I.P. of abandoned Ser. 310, 979, filed September 20, 1963 and of abandoned Ser. 375,278, filed June 15, 1964.

46. Posey, K., Jr., INVESTIGATION OF MODIFIED TURBINE FUELS FOR REDUCTION OF CRASH FIRE HAZARD. Western Co. of North America, Res. Div. Final Report No. NA-69-10, U.S. Federal Aviation Admin. Report No. FAA-DS-69-1, Contract No. FA 68NF-269, May 1969. (AD 694 008) (N69-26151)

47. Saia, J. C. (Federal Aviation Admin., Office of Supersonic Transport Dev.), FUEL CONSIDERATIONS IN THE U.S. SUPERSONIC TRANSPORT PROGRAM. Jet Fuel Quality Symp., San Antonio, October 22-24, 1968, Paper, 28 pp. (AD 096 588)

48. Schneider, A. (to Sun Oil Co.), METHYLADAMANTANE AND DIMETHYLADAMANTANES. U.S. 3,356,751 (Cl. 260-666), Dec. 5, 1967, Appl. April 8, 1966.

49. Spengler, G., FUELS AND LUBRICANTS FOR SUPERSONIC FLIGHT. Oesterr. Ges. Erdoelwiss.-Deut. Ges. Mineraloelwiss. und Kohlechem. Joint Ann. Mtg., Salzburg, October 8, 1968; Erdoel Kohle 22(8), 473-7 (August 1969) (in German).

50. Spengler, G. and Erlmeier, R., FUELS FOR FLIGHT SPEEDS UP TO MACH 3.5. DVL-Nachrichten 1969 (39), 439-42 (March) (in German). (A69-25422) (N69-35977)

51. Stockton, W. W. and Olsen, C. M., FEASIBILITY OF BURNING EMULSIFIED FUEL IN A 7LM100 ENGINE. General Electric Co., U.S. Army Aviation Labs. Report No. USAAVLABS-TR-67-74, Contract No. DAAJ02-67-C-0038, February 1968. (AD 667 902) (N68-26428)

52. Urban, C. M., Bowden, J. N., Gray, J. T., EMULSIFIED FUELS CHARACTERISTICS AND REQUIREMENTS. Southwest Research Inst., Army Fuels and Lubricants Research Lab. Final Report, U.S. Army Aviation Materiel Labs. Report No. USAAVLABS-TR-69-24, Contract No. DAAD05-67-C-0354, March 1969. (AD 688 167) (N69-37034)

53. U.S. Air Force, Wright Air Development Center, APPLICATION OF HIGH ENERGY FUELS TO GAS TURBINE SYSTEMS. Report No. WADC-TR-59-460. (AD 504 279L)

54. U.S. Air Force, Wright Air Development Center, LOW TEMPERATURE FUEL CHARACTERISTICS. Report No. WADC-TN-55-157. (AD 855 991L)

BIBLIOGRAPHY (Contd)

55. Weber, R. J., A REVIEW OF THE POTENTIAL OF LIQUID-METHANE FUEL FOR SUPERSONIC TRANSPORTS. Cryog. Eng. Cong., Cleveland, August 19-21, 1968, Paper; U.S. National Aeronautics and Space Admin. Report No. NASA-TM-X-52466, 1968. (N68-33584)

56. Weber, R. J., THE BOILOFF PROBLEM WITH METHANE FUEL IN SUPERSONIC AIRCRAFT. U.S. National Aeronautics and Space Admin. Report No. NASA-TM-X-1604, July 1968. (N68-28155)

57. Whitlow, J. B., Jr., Eisenberg, J. D., Shovlin, M. D., POTENTIAL OF LIQUID-METHANE FUEL FOR MACH-3 COMMERCIAL SUPERSONIC TRANSPORTS. National Aeronautics and Space Admin. Report No. NASA-TN-D-3471, 1966.

BIBLIOGRAPHY (Contd)

Physical and Chemical Properties of Fuels

1. Akhmedov, A. G., CALCULATION OF THE HEAT CAPACITY OF LIQUID FUELS. Khim. i Tekhnol. Topl. i Masel 14 (6), 52-3 (1969) (in Russian).

2. Anderson, K. M., Pulkrabek, W. W., Ibele, W. E., Eckert, E. R. G., MEASUREMENT OF PRANDTL NUMBER AND THERMAL CONDUCTIVITY. University of Minnesota, Heat Transfer Lab. Summary Report No. HTL-TR-88, U.S. National Aeronautics and Space Administration Report No. NASA-CR-54634, Contract No. NAS3-7910, December 1968, (N69-24819).

3. Appeldoorn, J. K. and F. F. Tao, Esso Research and Engineering Company, Products Research Div., LUBRICITY PROPERTIES OF HIGH-TEMPERATURE JET FUELS, Quarterly Report No. 9, 15 May - 15 Aug 67. Contract AF 33(615)-2828. (AD 822 760)

4. Appeldoorn, J. K., Goldman, I. B. and Tao, F. F., Esso Research and Engineering Company, Products Research Division, LUBRICITY OF JET FUELS, Quarterly Report No. 11, 15 Nov 67 - 15 Feb 68, and LUBRICITY PROPERTIES OF HIGH-TEMPERATURE JET FUELS, Quarterly Report No. 10, 15 Aug - 15 Nov 67, Contract AF 33(615)-2828. (AD 832 180) (AD 826 456)

5. Armstrong, G. T. and Dohalski, E. S., A SURVEY OF THERMODYNAMIC PROPERTIES OF THE COMPOUNDS OF THE ELEMENTS CHNOPS. U.S. National Bureau of Standards Progress Report, 1 Jan - 30 June 1969, Report No. NBS-10-070, U.S. National Aeronautics and Space Admin. Report No. NASA-CR-105 268, NASA Order N-12-758, July 1969. (N69-35766)

6. Bahn, G. S., Marquardt Corporation, "GREY" AND "VERY GREY" THERMOCHEMICAL TABLES FOR SOME C-H AND C-H-O SPECIES. Combustion Institute, Fall Meeting, Menlo Park, Calif., October 28, 28, 1968, Paper 68-38.

7. Banes, B., McIntyre, R. W., Sims, J. A., PROPERTIES OF AIR AND COMBUSTION PRODUCTS WITH KEROSINE AND HYDROGEN FUELS. Volume 1: THERMODYNAMIC PROPERTIES AND EQUILIBRIUM COMPOSITION: AIR. Volume 2: THERMODYNAMIC PROPERTIES FOR FUEL-WEAK MIXTURES: C_nH_{2n}/AIR. Volume 3: EQUILIBRIUM COMPOSITION FOR FUEL-WEAK MIXTURES: C_nH_{2n}/AIR. Volume 4: EQUILIBRIUM COMPOSITION FOR FUEL-WEAK MIXTURES: C_nH_{2n}/AIR. Volume 5: THERMODYNAMIC PROPERTIES FOR STOICHIOMETRIC AND FUEL-RICH MIXTURES: C_nH_{2n}/AIR. Volume 6: EQUILIBRIUM COMPOSITION FOR STOICHIOMETRIC AND FUEL-RICH MIXTURES: C_nH_{2n}/AIR. Volume 7: EQUILIBRIUM COMPOSITION FOR FUEL-RICH MIXTURES: C_nH_{2n}/AIR. Volume 8: THERMODYNAMIC PROPERTIES FOR FUEL-WEAK MIXTURES: HYDROGEN/AIR. Volume 9: EQUILIBRIUM COMPOSITION FOR FUEL-WEAK MIXTURES: HYDROGEN/AIR. Volume 10: EQUILIBRIUM MIXTURES: HYDROGEN/AIR. Volume 11: THERMODYNAMIC PROPERTIES FOR STOICHIOMETRIC AND FUEL-RICH MIXTURES: HYDROGEN/AIR. Volume 12: EQUILIBRIUM COMPOSITION FOR STOICHIOMETRIC AND FUEL-RICH MIXTURES: HYDROGEN/AIR. Volume 13: EQUILIBRIUM COMPOSITION FOR FUEL-RICH MIXTURES: HYDROGEN/AIR. NATO, Advisory Group for Aerospace Research and Development, 1967, (N68-23629 - N68-23641) (AD 831 985 - AD 831 997).

Khim. Tekhnol. Topl. Masel 13(1), 59-61(1968) (Russ).

10. Desai, P. D., THE ENTHALPIES OF COMBUSTION OF EIGHT BRANCHED ISOMERIC ALKANES FROM C_8 TO C_{14}. Texas A and M Univ. Diss. (Summer 1968); API Res. Proj. 44 Rep. Invest. January 15, 1968

BIBLIOGRAPHY (Contd)

8. Brokow, R. S., TRANSPORT PROPERTIES OF HIGH TEMPERATURE GASES. Intern. Symp. on High Temp. Technol., 3rd, Pacific Grove, Calif., Sept 17-20, 1967, Paper; U.S. National Aeronautics and Space Administration Report No. NASA-TM-X-52315, 1967, (N68-27697).

9. Chulkov, P. V. (Groznensk. Proizv.-Tovar. Kontora, Grozny)., CALCULATIVE AND GRAPHIC METHODS FOR DETERMINING THE HEAT OF COMBUSTION OF PETROLEUM PRODUCTS. Khim. Tekhnol. Topl. Masel 13(1), 59-61(1968) (Russ).

10. Desai, P. D., THE ENTHALPIES OF COMBUSTION OF EIGHT BRANCHED ISOMERIC ALKANES FROM C_9 TO C_{16}. Texas A and M Univ., Diss. (January 1968); API Res. Proj. 44 Rep. Invest., January 15, 1968.

11. Edmister, W. C. (Oklahoma State University), APPLIED HYDROCARBON THERMODYNAMICS 33. ISOTHERMAL CHANGES IN ENTHALPY AND ENTROPY FROM THE REDLICH-KWONG EQUATION. Hydrocarbon Process. 47 (10), 145-9 (October 1968).

12. Eggertsen, F. T., Seibert, E. E., Stross, F. H. (Shell Development Company), VOLATILITY OF HIGH BOILING ORGANIC MATERIALS BY A FLAME IONIZATION DETECTION METHOD. Anal. Chem. 41(10), 1175-9 (August 1969).

13. Esso Research and Engineering Company, Products Research Division, LUBRICITY PROPERTIES OF HIGH-TEMPERATURE JET FUELS. U.S. Air Force Report No. AFAPL-TR-66-89-Pt-3. (AD 840 522)

14. Gallant, R. W. (Dow Chemical Company), PHYSICAL PROPERTIES OF HYDROCARBONS. 40. TOLUENE AND XYLENE. Hydrocarbon Process. 48(12), 113-9 (December 1969).

15. Callant, R. W. (Dow Chemical Company), PHYSICAL PROPERTIES OF HYDROCARBONS. 39. BENZENE COMPOUNDS. Hydrocarbon Process. 48(11, 263-9 (November 1969).

16. Good, W. D. and Smith, N. K., ENTHALPIES OF COMBUSTION OF TOLUENE, BENZENE, CYCLOHEXANE, CYCLOHEXENE, METHYLCYCLOPENTANE, 1-METHYLCYCLOPENTENE, AND N-HEXANE. J. Chem. and Eng. Data 14(1), 102-6 (January 1969).

17. Good, W. D. (U.S. Bureau of Mines), THE ENTHALPIES OF COMBUSTION AND FORMATION OF 11 ISOMERIC NONANES. API Res. Proj. 62 Prepubl. Rep. No. PR 5, May 1968.

18. Good, W. D. and Smith, N. K. (U. S. Bureau of Mines), THE ENTHALPIES OF COMBUSTION OF TOLUENE, BENZENE, CYCLOHEXANE, CYCLOHEXENE, METHYLCYCLOPENTANE, 1-METHYLCYCLOPENTENE, AND n-HEXANE. API Res. Proj. 62 Prepubl. Rep. No. PR 6, May 1968.

19. Hirata, M. and Suda, S., PHYSICAL PROPERTIES OF HYDROCARBONS. 5. LATENT HEATS OF VAPORIZATION. Sekiyu Gakkai Shi 12(10), 796-800 (October 1969) (in Japanese).

20. Horton, T. E. and Menard, W. A., SHOCK-TUBE THERMOCHEMISTRY TABLES FOR HIGH-TEMPERATURE GASES - AIR. VOLUME 1. California Institute of Technology, Jet Propulsion Lab., Environmental Sciences Div., November 1969, (N70-10776).

BIBLIOGRAPHY (Contd)

21. Institute of Petroleum, Method Evaluation Subcommittee, COMBUSTION PROPERTIES OF KEROSINE TYPE JET FUELS. J. Inst. Petrol. 55(545), 330-7 (September 1969).

22. Kanitkar, D. and Thodos, G., THE THERMAL CONDUCTIVITY OF LIQUID HYDROCARBONS. Can. J. Chem. Eng. 47(4), 427-30 (August 1969).

23. Kay, Webster B., and Hissong, Douglas (Ohio State University, Columbus, Ohio), THE CRITICAL PROPERTIES OF HYDROCARBONS. I. SIMPLE MIXTURES. Proc. Div. Refining, Amer. Petrol. Inst. 47, 653-722 (1967).

24. Kessel'man, P. M., A FORM OF THE EQUATION OF STATE OF A REAL GAS. Inzh.-Fiz. Zh. (Moscow) 2(1), 68-75(1959); National Research Council at Canada Trans. NRC-TT-1262, 1967, (N68-16593).

25. Kuras, M., Hala, S., and Landa, S. (Khim.-Tekhnol. Inst., Prague, Czech.). CALORIFIC VALUE OF HYDROCARBONS ISOLATED FROM KEROSINE FRACTIONS OF ROMASHKINO PETROLEUM. Sb. Vys. Sk. Chem.-Technol. Praze, Technol. Paliv 13, 105-23(1967)(Russ.).

26. Moore, R. T., Harrison, R. H., Douslin, D. R., METHANE: BIBLIOGRAPHY OF THE THERMODYNAMIC AND TRANSPORT PROPERTIES ABOVE 300 K. U.S. Bureau of Mines, 1969, (PB 186 243).

27. Morsy, Tawfik E., HEAT OF VAPORIZATION OF HYDROCARBONS. Gas- Wasserfach 109(13), 335 (1968) (Ger).

28. Panchenko, V. T., TENSOMETRIC METHOD FOR EVALUATION THE LUBRICATING CAPACITY OF JET FUELS. USSR Pat. No. 207, 466, October 28, 1966; U.S. Air Force Trans. No. FTD-HT-23-1415-68, May 1969, (AD 694 791).

29. Poferl, D J., Svehla, R. A., Lewandowski, K., THERMODYNAMIC AND TRANSPORT PROPERTIES OF AIR AND THE COMBUSTION PRODUCTS OF NATURAL GAS AND OF ASTM-A-1 FUEL WITH AIR. U.S. National Aeronautics and Space Admin. Report No. NASA-TN-D-5452, October 1969, (N69-37936).

30. Predvoditelev, A. S., HIGH-TEMPERATURE PROPERTIES OF GASES, PHYSICAL GAS DYNAMICS, THERMODYNAMICS, AND PHYSICS OF COMBUSTION. Moscow, Izd. Nauka, 1967; Trans. by Israel Program for Scientific Translations, Ltd., 1969. National Science Foundation Trans. by A. Barouch, 1969. (N69-35365)

31. Prothero, A. (Shell Res. Ltd.), COMPUTING WITH THERMOCHEMICAL DATA. Combust. Flame 13(4), 399-408 (August 1968).

32. Rao, A. V., Ibrahim, S. H., Kuloor, N. R. (Indian Inst. Sci., Bangalore, India) SIMPLE NOMOGRAM PREDICTS CRITICAL TEMPERATURES OF ORGANIC LIQUIDS. Chem. Age India 19(8), 564-7 (1968). NOMOGRAM PREDICTS CRITICAL VOLUMES OF ORGANIC LIQUIDS. Chem. Age India 19(8), 561-3 (1968).

BIBLIOGRAPHY (Contd)

33. Rimpel, G. and Meffert, A., APPROXIMATION POLYNOMIALS FOR CALORIC VARIABLES OF STATE OF VARIOUS GASES. West Ger. Deutsche Versuchsanstalt fuer Luft- und Raumfahrt Report No. DLR-FB-68-19, DVL-735, March 1968, (in German). (N68-24190).

34. Roy, Dipak, Thodos, George (Northwestern Univ., Evanston, Ill.), THERMAL CONDUCTIVITY OF GASES. HYDROCARBONS AT NORMAL PRESSURES. Ind. Eng. Chem., Fundam. 7(4), 529-34 (1968) (Eng).

35. Rykov, V. I. (Kishinevsk. Gos. Univ., Kishinev), PHYSICAL PROPERTIES OF A NORMAL LIQUID IN A LIQUID-VAPOR SYSTEM. Zh. Fiz. Khim. 41(9), 2177-80(1967) (Russ).

36. Salakhutdinov, M. I., THERMODYNAMIC PROPERTIES OF A MATERIAL IN THE CRITICAL REGION. Akad. Navk. Tadzhikskoi SSR, Doklady 11(11), 24-7(1968)(in Russian).

37. Samuylov, E. V., et al., THERMODYNAMIC PROPERTIES AND COMBUSTION-PRODUCT TRANSFER PROPERTIES OF HYDROCARBON FUELS AT TEMPERATURES UP TO 4000 K. USSR, IM-107/162, U. S. Air Force Trans. No. FTD-MT-24-130-68, Aug 1968, (N69-28779). (AD 683-132)

38. Sastri, S. R. S., Doraiswamy, L. K., et al., A GENERALISED (GROUP CONTRIBUTIONS) METHOD FOR ESTIMATING THE LATENT HEAT OF VAPORISATION OF ORGANIC COMPOUNDS (FROM THEIR STRUCTURE). Brit. Chem. Eng. 14(7), 959-63 (July 1969).

39. Sastri, S. R. S., ESTIMATE HEATS OF VAPORISATION OF HYDROCARBONS. Brit. Chem. Eng. 13(8), 1159 (August 1968).

40. Schick, I. M., Prausnitz, J. M. (Univ. of California, Berkeley, Calif.). CORRELATION OF CRITICAL PROPERTIES OF MIXTURES, A.I.Ch.E. J., 14(4), 673 (1968) (Eng.).

41. Sims, J. A., K DF. 9 PROGRAMME FOR EVALUATING TRANSPORT PROPERTIES OF GAS MIXTURES; A0005. Bristol Siddeley Engines, Ltd. (England), Advanced Propulsion Performance Dept. Report No. AP-5473, Sept. 1967, (N69-33177).

42. Shelton, R. J., COMPUTER PROGRAM FOR CALCULATING FLASH EQUILIBRIUM CHARACTERISTICS AND HEAT CONTENTS OF HYDROCARBON SYSTEMS. Chem. Engr. No. 223, CE 385 - CE 398 (November 1968).

43. Steenken, W. G., PERFORMANCE OF AN OPPOSED FLOW SHOCK TUBE FOR THE MEASUREMENT OF GAS THERMAL CONDUCTIVITY. Ph.D. Thesis, Univ. of Wisconsin, 1967, Univ. Microfilms Order No. 67-4959. (N68-28346)

44. Stein, W. A., BOUNDARY CONDITIONS FOR THE EQUATIONS OF STATE OF PURE FLUIDS AT THE CRITICAL POINT. Verein Deutscher Ingenieure, Thermodynamik - Kolloquium, Bad Mergentheim, W. Ger., Oct. 5, 1967; Forschung im Ingenieurwesen 35(1), 13-6 (1969) (in German).

45. Tang, A. M. P., FIND THERMODYNAMIC PROPERTIES OF n-ALKYL CYCLOPENTANES. Hydrocarbon Process. 48(10), Sect. 1, 136-40 (October 1969).

BIBLIOGRAPHY (Contd)

46. Tans, A. M. P., FIND THERMODYNAMIC PROPERTIES OF n-ALKYL CYCLOHEXANES. Hydrocarbon Process. 48(12), 120-4 (December 1969).

47. Tans, A. M. P., FIND PROPERTIES OF n-PARAFFINS. Hydrocarbon Process, 47(4), 169-73 (1968).

48. Tao, F. F. and Appeldoorn, J. K. (Esso Research and Engineering Company), THE BALL-ON-CYLINDER TEST FOR EVALUATING JET FUEL LUBRICITY. ASLE, Annual Meeting, 23rd, Cleveland, Ohio, May 6-9, 1968, Preprint 68AM 4A-2; ASLE Transactions 11, 345-51 (October 1968).

49. University of Dayton, Research Institute, PHYSICAL AND CHEMICAL PROPERTIES OF JP-4 JET FUEL FOR 1967. Report No. UDRI-TR-68-39, U.S. Air Force AFAPL-TR-68-130. (AD 844 8

50. Vere, R. A. (Esso Research Centre), LUBRICITY OF AVIATION TURBINE-FUELS. SAE Nat. Aeronaut. and Space Eng. and Mfg. Meeting, Los Angeles, Califor October 6-10, 1969, Paper No. 690 667.

51. Wong, Shaio-Wen Sun (Univ. of Michigan, Ann Arbor, Mich.). ENTHALPIES OF COMBUSTION OF SELECTED COMPOUNDS COMPOSED OF GLOBULAR OR POLYNUCLEAR AROMATIC MOLECULES. Diss. Abstr. B 28(6), 2383 (1967).

52. Wyeth, H. W. G. and Timmins, G. W., (Royal Aircraft Establishment, Farnborough, England), SURVEY OF AVIATION KEROSINE VAPOR PRESSURES AND FLASH POINTS. Technical Report, January 1969. Report No. RAE-TR-69002. (AD 856 992)

53. Zwolinski, B. J. and Wilhoit, R. C. (Texas A and M Univ.), HEATS OF FORMATION AND HEATS OF COMBUSTION. API Res. Proj. 44 and Thermodyn. Res. Center Data Proj. Rep. Invest., January 15, 1968.

BIBLIOGRAPHY (Cont'd)

Thermal Stability of Fuels

1. Albright, C. S., Schwartz, F. G., Ward, C. C., STORAGE STABILITY OF GASOLINE — COMPARISON OF STORAGE AND RAPID BOMB AGING. U.S. Bureau of Mines Report No. BM-RI-7084, February 1968, (N68-15348).

2. Bol'shakov, G. F., Bushueva, E. M. Glebovskaya, E. A. and Bespolov, I. E., EFFECT OF THE HYDROCARBON STRUCTURE OF FUELS ON THE COMPOSITION OF DEPOSITS RESULTING FROM OXIDATION. Neftepererab. Neftekhim. 1967(9), 24-7 (Russ.).

3. Bol'shakov, G. F., COMPOSITION AND STRUCTURE OF A SOLID PHASE FORMED DURING THE OXIDATION OF HYDROREFINED AVIATION FUEL. Izv. Vyssh. Ucheb. Zaved., Neft Gaz 11(2), 55-8(1968)(Russ.).

4. Bol'shakov, G. F., INSTRUMENT FOR STUDYING THE OXIDIZABILITY OF PETROLEUM HYDROCARBONS AT HIGH TEMPERATURES. Vyssh. Ucheb. Zaved., Izv., Neft' i Gaz 1964(9), 61-3; Johns Hopkins Univ., Applied Physics Lab. Trans. TG-230-T533, U.S. Navy Contract NOW-62-0604-C, October 1967, (AD 663 076) (N68-15844).

5. Bonnier, J. M. and Gelus, M. (Fac. Sci., Grenoble, France), THERMAL STABILITY OF SOME METHYL DERIVATIVES OF AROMATIC HYDROCARBONS. C. R. Acad. Sci., Paris, Ser. C 265(8), 472-5(1967)(Fr.).

6. Boss, B. D. and Hazlett, R. N., DIFFUSION-LIMITED LIQUID-PHASE OXIDATION OF n-DODECANE AT 200 C. U.S. Naval Research Lab. Report No. NRL-6788, December 1968. (AD 684 763)

7. Chertkov, Ya. B., Kuzmina, N. A., and Gureev, A. A. (Mosk. Inst. Neftekhim. Gaz. Prom. im. Gubkina, Moscow). STABILIZATION OF INTERMEDIATE DISTILLATE FRACTIONS BY MEANS OF PRELIMINARY OXIDATION. Izv. Vyssh. Ucheb. Zaved., Neft Gaz. 10(11), 29 (1967) (Russ).

8. Esso Research and Engineering Company, Government Research Lab., THE STUDY OF HYDROCARBON FUEL VAPOR PHASE DEPOSITS. Report No. GR-4-VPD-67. (AD 823 792)

9. Esso Research and Engineering Company, Government Research Lab. THE STUDY OF HYDROCARBON FUEL VAPOR PHASE DEPOSITS. Report No. GR-5-VPD-68. (AD 829 094)

10. Esso Research and Engineering Company, Government Research Labs., DEVELOPMENT OF THERMALLY STABLE LIQUID FUEL. Report No. GR-1-TSF-68, U.S. Air Force AFRPL-TR-68-115. (AD [illegible] 134)

11. Gavrilov, B. G., Kurakin, N. V. and Tarasov, A. K., STRUCTURAL STABILITY OF METHANE HYDROCARBONS AT VARIOUS TEMPERATURES. Prevrashch. Uglevodorodov Nefti, Leningrad. Gos. Univ. 1967, 66-71(Russ.).

12. Goodman, H., Bradley, R. P., and Sickles, R. P. (North American Rockwell Corp. Los Angeles Div.), HIGH TEMPERATURE HYDROCARBON FUELS RESEARCH IN AN ADVANCED AIRCRAFT FUEL SYSTEM SIMULATOR. Report No. NA-68-426, U.S. Air Force AFAPL-TR-69-5 ON FUEL AFFB-10-67. (AD 846 566). Report No. NA-67-[illegible], U.S. Air Force Report No. AFAPL-TR-68-25, Contract No. AF 33(615)-[illegible], ON FUEL AFFB

BIBLIOGRAPHY (Contd)

9-67. February 1968. (AD 828 739). Report No. NA-69-144, U.S. Air Force AFAPL-TR-69-88 ON FUEL AFFB-11-68. (AD 860 647). Final Report No. 69-950, U.S. Air Force AFAPL-TR-70-13, Contract No. AF 33(615)-3228, March 1970.

13. Henderson, H. T. and Nixon, A. C. (Shell Development Company), STUDIES ON THE MEASUREMENT OF THERMAL STABILITY OF ADVANCED AIRCRAFT FUELS, Amer. Chem. Soc., Nat. Mtg., 158th, New York, September 7-12, 1969, Amer. Chem. Soc. Div. Petrol. Inc. Preprints 14(3), B153-B161 (September 1969).

14. Lewis, A. (Shell Research, Ltd.), HIGH THERMAL STABILITY FUELS FOR SUPERSONIC AIRCRAFT. Chemie-Ingenieur-Technik 40(15), 740-5 (August 12, 1968).

15. Lozovoi, A. V., Mulkova, S. S., Ionov, I. F., Lavrovskaya, E. V., Muselevich, D. L., EFFECT OF THE CHEMICAL STRUCTURE OF HYDROCARBONS ON THEIR THERMAL OXIDATION STABILITY. Khim. Tverd. Topliva (USSR) 1967, no. 2, 66-9; U.S. Air Force Trans. No. FTD-HT-23-1236-68, March 1969, (AD 694 800).

16. Nartsissov, B., CURRENT INFORMATION ON LUBRICATION AND FUEL TECHNOLOGY. U.S. Library of Congress, Aerospace Technology Div. Surveys of Foreign Scientific and Technical Literature (Report No. 60), Report No. ATD-67-38, November 1967, (AD 695 792).

17. Schirmer, R. M., MORPHOLOGY OF DEPOSITS IN AIRCRAFT FUEL SYSTEMS. Phillips Petroleum Co. Research Div. Report No. 5029-68R, U.S. Navy Contract N00019-68-C-0252, August 1968. (AD 841 540L).

18. Smith, J. D., (Shell Research, Ltd.), FUEL FOR THE SUPERSONIC TRANSPORT - EFFECTS OF DEPOSITS ON HEAT TRANSFER TO AVIATION KEROSINE. Ind. Eng. Chem., Process Design and Development 8, 299-308 (July 1969).

19. Spengler, G. and Pahl, E., THE EFFECT OF OXYGEN ON n-HEXADECANE IN THE LIQUID PHASE AT HIGH TEMPERATURE. GUM FORMATION. Brennst. - Chem. 50(11), 324-31, (November 1969).

20. Spengler, G. and Pahl, E., THE EFFECT OF TEMPERATURE ON SOLUBILITY OF AIR IN LIQUID HYDROCARBONS. Brennst. - Chem. 50(9), 276-81 (Sept. 1969).

21. Strigner, P. L., LONG TERM STORAGE OF HYDROCARBON FUELS IN COATED DRUMS. PART III: EXAMINATION OF FUELS AFTER FIVE YEARS OF STORAGE. National Research Council of Canada, Div. of Mechanical Engineering. Report No. DME-MP-30, March 1964, (AD 678 478).

22. Taylor, William F. and Wallace, Thomas J. (Esso Res. and Eng. Co., Linden, N.J.), KINETICS OF DEPOSIT FORMATION FROM HYDROCARBON FUELS AT HIGH TEMPERATURES. I. GENERAL FEATURES OF THE PROCESS. Ind. Eng. Chem., Prod. Res. Develop. 6(4), 258 (1967).

23. Taylor, William F., Wallace, Thomas J. (Govt. Res. Lab., Esso Res. and Eng. Co., Linden, N.J.), KINETICS OF DEPOSIT FORMATION FROM HYDROCARBONS. II. EFFECT OF TRACE SULFUR COMPOUNDS. Ind. Eng. Chem., Prod. Res. Develop. 7(3), 198-202 (1968).

BIBLIOGRAPHY (Contd)

24. Taylor, W. F. and Wallace, T. J., KINETICS OF DEPOSIT FORMATION FROM HYDROCARBONS. Amer. Chem. Soc., Div. Petrol. Chem., Inc. Preprints 13(3) 89-95, September 8-13, 1968.

25. Taylor, W. F. (Esso Research and Engineering Co.), KINETICS OF DEPOSIT FORMATION FROM HYDROCARBONS. FUEL COMPOSITION STUDIES. I and EC Product Research and Development 8(4), 375-38 (December 1969).

26. Taylor, W. F., KINETICS OF DEPOSIT FORMATION FROM HYDROCARBONS, PART IV. J. Appl. Chem. 19, 222 (1969).

27. Taylor, W. F. (Esso Research and Engineering Co.), KINETICS OF DEPOSIT FORMATION FROM HYDROCARBONS. V. FUEL COMPOSITION STUDIES. Amer. Chem. Soc. Div. Petrol. Chem., Inc., Preprints 14(3), B144-B152 (September 1969).

28. Taylor, W. F., THE STUDY OF HYDROCARBON FUEL VAPOR PHASE DEPOSITS. Esso Research and Engineering Co. Report No. G.R.-10-VPD-69, U.S. Air Force Report No. AFAPL-TR-69-77, Contract No. AF 33(615)-3575, September 1969, (AD 863 604).

29. Taylor, W. F. (Esso Research and Engineering Co.), MECHANISM OF DEPOSIT FORMATION IN WING TANKS. SAE, Aeronautics and Space Engineering and Manufacturing Meeting, Los Angeles, Calif., October 7-11, 1968, Paper 680733. (A69-13439)

30. Taylor, W. F. (Esso Research and Engineering Co.), MANY VARIABLES CAN AID FORMATION OF DEPOSITS IN "EMPTY" JET FUEL TANKS. SAE Meeting. Paper No. 680733 (1968); (Adapt) SAE Journal 77(11), 50-5 (November 1969).

31. U.S. Air Force, Wright Air Development Center, HIGH TEMPERATURE FUEL STABILITY TESTS IN A J57-P3 ENGINE. Report No. WADC-TR-55-655. (AD 503 238L).

32. U.S. Air Force, Wright Air Development Center, CONFERENCE ON HIGH TEMPERATURE FUEL STABILITY, 27 SEPTEMBER 1954, Report No. WADC-TN-WCLP-54-193. (AD 855 058L).

33. Vol'f, M. B., Kozik, B. L., Morozova, G. P., ON THE THERMAL STABILITY OF HYDROCARBON FUELS. Tr. UFA Bashkirsk. Nauchn. Issled. Inst. po Pererabotke Nefti (USSR), 1960(3), 51; U.S. Air Force Trans. FTD-MT-65-320, September 1967, 19 pp. (AD 661 441) (N68-13227).

34. Watt, J. J., Evans, A., Jr., Hibbard, R. R., FOULING CHARACTERISTICS OF ASTM JET A FUEL WHEN HEATED TO 700°F IN A SIMULATED HEAT EXCHANGER TUBE. U.S. National Aeronautics and Space Administration Report No. NASA-TN-D-4958, December 1968, (N69-12831).

35. Whisman, M. L., Goetzinger, J. W., Ward, C. [illegible], STORAGE STABILITY OF AVIATION TURBINE FUELS: A RADIOTRACER TECHNIQUE FOR ESTIMATING COMPONENT CONTRIBUTION TO THERMALLY INDUCED DEPOSITS. U.S. Bureau of Mines Report of Investigations, Report No. RI-7325, December 1969, (AD 698 [illegible]).

BIBLIOGRAPHY (Contd)

36. Whisman, M. L. and Ward, C. C., STORAGE STABILITY OF HIGH TEMPERATURE FUELS. Part I: MICRO FUEL COKER TESTS OF FUEL RADIOTRACER BLENDS BEFORE STORAGE. U.S. Bureau of Mines Technical Report, March 1967 - March 1968, U.S. Air Force AFAPL-TR-68-32. March 1968, (AD 667 818) (N68-23807).
Part II: THE EFFECT OF STORAGE UPON THERMALLY INDUCED DEPOSITION OF LABELED FUEL COMPONENTS. U.S. Bureau of Mines Annual Report, March 1968 - March 1969, U.S. Air Force Report No. AFAPL-TR-68-32-Pt-2. Contract No. F 33615-67-M-5003, March 1969. (AD [illegible]) (N69 30203)

BIBLIOGRAPHY (Contd)

Fuel Contaminants and Additives

1 [illegible]dresen, [illegible] J., Jr. (Mobil Oil Corp.), TETRA-AMINE SALT ANTISTATIC ADDITIVE FOR GASOLINE, JET FUEL, AND TURBINE FUEL. Ger. Appl. 1.905,960, open Sept. [illegible] 1969, U.S. Appl. March 5, 1968, Corresponds to U.S. 3,449,097.

2. Be[illegible]ke, [illegible] A. and Rosen, W. E., A BIS(2-HYDROXYPHENYL)ACETIC ACID, USEFUL AS AN ANTIMICROBIAL AGENT IN JET FUEL. U.S. 3,471,537, October 7, 1969, Appl. October 2[illegible], 19[illegible].

3. Bol'shakov, G. F., EFFECT OF SULFUR-ORGANIC COMPOUNDS ON THE COMPOSITION OF THE SOLID PHASE WHICH FORMS DURING THE OXIDATION OF JET FUEL. Khim. i Tekh. Topliv i Masel [illegible](10), 44-7 (1969).

4. Chertkov, Ya. [illegible], Spirkin, V. G., [illegible]ov, [illegible] G., EFFECT OF SULFIDES CONTAINED IN FUELS ON THEIR OPERATIONAL PROPERTIES. Khim. i Tekh. Topliv i Masel 14(1), [illegible]-5 ([illegible]) (in Russian).

5. Cooney, J. J., EFFECTS OF POLYURETHANE FOAMS ON MICROBIAL GROWTH IN FUEL-WATER SYSTEMS. Applied Microbiology 17, 22[illegible]-31 (February 1969).

6. Crane, [illegible] R. and Sanders, [illegible] C., EVALUATION OF A BIOCIDAL TURBINE-FUEL ADDITIVE. U.S. Federal Aviation Admin., Office of Aviation Medicine Report No. FAA-[illegible]-67-21, Aug. 1967 (N68-170[illegible]9) (AD 665 6[illegible]1).

7. De Gray, [illegible] J. and Killian, [illegible] (to Standard Oil Co., Ohio), [illegible]EROSINE ADDITIVE FOR STORAGE. U.S. 3,34[illegible],646 (Cl. 44-[illegible]6), Oct. [illegible], 1967, Appl. Oct. 24, 196[illegible], [illegible] 20, 1965, June 2, 1966 and Jan. 16, 1967.

8. Dimitroff, E. and Dietzmann, H. E. (U.S. Army Fuels and Lubric. Lab., S.W. Res. Inst.), FUEL CRYSTALLIZATION. ADDITION BEHAVIOR AND COMPATIBILITY. Amer. Chem. Soc. Nat. Meet., 158th, New York, September 7-12, 1969, Amer. Chem. Soc. Div. Petrol. Chem., Inc. Preprints 14([illegible]), B1[illegible]-B1[illegible]3 (September 1969).

9. Doering, H. V. (Nav. Ship Res. and Develop. Center) and Bergman, P. (General Electric Co.), CONSTRUCTION AND OPERATION OF A HOT CORROSION TEST FACILITY. Mater. Res. Stand. 9(9), [illegible], 72, 74 (September 1969).

10. Doering, H. V. and Bergman, P. A., CONSTRUCTION AND OPERATION OF A HOT-CORROSION TEST FACILITY. U.S. Naval Ship Research and Development Lab. Report No. [illegible] 281 [illegible], March 1969 (AD [illegible]).

11 [illegible], P. and [illegible]so, A. C. (Defence Standards Labs., [illegible], Australia), THE ANALYSIS OF FUEL SYSTEM ICING INHIBITORS (FSII) BASED ON ETHYLENE GLYCOL MONOMETHYL ETHER. Report No. DSL-309, March 1968. (AD 835 [illegible]).

12 Dunworth, W. [illegible] (DuPont), N, [illegible] AS STABILIZER IN DISTILLATE [illegible]. Ger. Appl. [illegible], open [illegible], [illegible], corresponds to Can. [illegible].

BIBLIOGRAPHY (Contd)

13. Eckert, G. W. (to Texaco, Inc.), JET FUEL COMPOSITIONS. U.S. 3,346,355 (Cl. 44-66), Oct. 10, 1967, Appl. July 10, 1964.

14. Eckert, G. W. (to Texaco, Inc.), JET FUEL ANTIWEAR ADDITIVE. U.S. 3,476,533 (Cl. 44-58), November 4, 1969, Appl. July 15, 1965.

15 Edmonds, P. and Cooney, J.J. (Univ. of Dayton, Dayton, Ohio), MICROBIAL GROWTH IN A FUEL-WATER SYSTEM CONTAINING POLYESTER URETHANE FOAM. Appl. Microbiol. 16(2), 426-7(1968).

16. Engel, W. B., and Swatek, F. E. (Douglas Aircraft Co), THE STUDY AND RELATION OF METALS AND PELLICLES TO FUEL-UTILIZING BACTERIA. Develop. Ind. Microbiol. 9, 331-44 (1967).

17. Fitzgibbons, W. O., (to Standard Oil Co., Ohio), INDICATOR COMPOSITION FOR VIABLE MICROORGANISMS, ESPECIALLY IN HYDROCARBON FUELS. Can. 827,050, November 11, 1969, corresponds to U.S. 3,418,212, U.S. Appl. July 28, 1965.

18. Forster, E. O., (to Esso Res. and Eng. Co.), ANTISTATIC ADDITIVES FOR LIQUID FUELS. U.S. 3,322,519 (Cl. 44-56), May 30, 1967, Appl. June 24, 1963.

19. Gary, J. H. (to Frontier Research Co.), HYDROCARBON FUEL ADDITIVES. U.S. 3,363,999 (Cl. 44-55), Jan. 16, 1968, Appl. Dec. 14, 1964.

20. Godar, R.L. (to Petrolite Corp.), INHIBITORS FOR THERMAL DEPOSITS OF HYDROCARBONS. U.S. 3,342,723 (Cl. 208-48), Sept. 19, 1967, Appl. Aug. 25, 1965.

21. Grechushkina, N. N. and Netts, I. T., GROWTH OF MICROORGANISMS IN MEDIA WITH PETROLEUM FUELS. Vestnik Moscow Univ., Seriya 6: Biologiya, Pochvovedenie (USSR) 23(2), 22-4 (1968); U.S. Army Foreign Science and Technology Center Trans. No. FSTC-HT-23-785-68, 1968. (AD 680 804).

22. Herron, W. [illegible] (Lockheed Aircraft Corp., Lockheed - Georgia Co.) and Mettler, G. W. (Products Research and Chemical Corp.), CORROSION AND CORROSION CONTROL OF AIRCRAFT INTEGRAL FUEL TANKS. Materials Protection 8, 43-7 (April 1969).

23. Hill, E. C., Evans, D. A. and Davies, I. (Univ. Coll., Cardiff, Wales), THE GROWTH AND SURVIVAL OF MICROORGANISMS IN AVIATION KEROSINE. J. Inst. Petrol. 53(524), 280-4(1967).

24. Hinkamp, J. B., Bartleson, J. D., and Irish, G. E. (to Ethyl Corp.), 2,6-DIALKYLPHENYLBORATE ANTIOXIDANTS. U.S. 3,35[illegible],707 (Cl. 260-462), Dec. 5, 1965, Appl. April 19, 1956, May 5, 1968. Continuation-in-part of U.S. 3,014,061 (CA 57:865g).

25. Inoue, [illegible] (Inst. Def. Agency, Tokyo, Japan), MICROBIAL CORROSION OF LIGHT ALLOYS. Boshoku [illegible], 453-62([illegible])(Japan).

26. Jefferson, T. H. (Army Mobility Equipment Res. and Dev. Center, Fort Belvoir, Va.), INVESTIGATION OF NEW CONCEPTS FOR THE DECONTAMINATION OF MILITARY HYDROCARBON FUELS. Technical Report No. USAMERDC-1947, Proj. DA-1-J-662708-[illegible], April 1969. (AD 854 345)

BIBLIOGRAPHY (Contd)

27. Jones, H. F. and French, E., AN EVALUATION OF THE EFFECTIVENESS OF A STATIC DISSIPATOR FUEL ADDITIVE AFTER TRANSPORT IN A FULL SCALE FUEL DISTRIBUTION SYSTEM. U.S. Air Force, Aero Propulsion Lab. Technical Report, January-August 1968, Report No. AFAPL-TR-69-23, May 1969. (AD 691 804) (N69-40364)

28. Krein, S. E., INFLUENCE OF MICROORGANISMS ON THE PROPERTIES OF PETROLEUM-BASED FUELS. Priklad. Biokhimiya i Mikrobiologiya (USSR) 5(2), 233-6 (1969); U.S. Army Foreign Science and Technology Center Trans. No. FSTC-HT-23-539-69, September 1969. (AD 695 092).

29. Legator, M. (Shell Internationale Research, Maatschappij, N.V.), LIQUID HYDROCARBON FUELS WITH RESISTANCE TO DECOMPOSITION BY MICROORGANISMS. Ger. 1,247,742 and 1,247,743 (Cl. C10l), Aug. 17, 1967, Appl. April 28, 1965.

30. Legator, M. (Shell Internationale Research, Maatschappij, N.V.), BACTERIA-RESISTANT HYDROCARBON FUELS. Ger. 1265488 (Cl. C 10e), 04 Apr 1968, Appl. 28 Apr 1965.

31. Lipshtein, R. A., Avetisyan, A. S., Kosobokova, E. M., METHOD FOR PREVENTING VANADIUM CORROSION OF GAS TURBINE BLADES CAUSED BY LIQUID FUEL. U.S.S.R. 191.027, August 22, 1964; U.S. Air Force Trans., April 1969. (AD 693 460).

32. Mahoney, L. R., ANTIOXIDANTS. Angew. Chem. in English 8, 547-55 (August 1969)

33. Markov, S., STUDY OF ANTIMICROBIAL ADDITIVES FOR PETROLEUM FUEL. U.S. Library of Congress Aerospace Technology Div. Report No. ATD-68-122-28-6, May 1968. (AD 696 616).

34. Markov, S., CURRENT INFORMATION ON LUBRICATION AND FUEL TECHNOLOGY. RECENT SOVIET RESEARCH ON THE FORMATION OF PARTICULATE CONTAMINANTS, SEDIMENTS, AND DEPOSITS IN JET FUELS. U.S. Library of Congress Aerospace Technology Div. Report No. 58. June 29, 1968. Report No. ATD-67-54. (AD 860 618)

35. Marumo, Hideo, Ninomiya, M., Matsuzaki, Y. and Takei, M. (to Lion Fat and Oil Co., Ltd.). ANTISTATIC FUEL ADDITIVES. U.S. 3,359,086 (Cl. 44-62), Dec. 19, 1967, Appl. Feb. 1, 1965.

36. Marumo, H. and Ninomiya, M., ANTISTATIC AGENTS. 25. MECHANISM OF METAL SALTS OF AMPHOTERIC SURFACE ACTIVE AGENTS AS ANTISTATIC AGENTS FOR LIQUID HYDROCARBONS. Kogyo Kagaku Zasshi 72(4), 955-58, A 47 (April 1969).

37. McDermott, J. P. (Esso Research and Engineering Co.), HYDROCARBON FUELS WITH INCREASED CONDUCTIVITY. Ger. 1,258,179 (Cl. C 10l), Jan. 4, 1968, Appl. Oct. 12, 1950.

38. Mosley, [illegible] (to National Aeronautics and Space Administration), DECONTAMINATION OF PETROLEUM PRODUCTS. U.S. 3,393,059 (Cl. 44-77), 16 Jul 1968, Appl. 18 May 1965.

39. Neumann, E. (Polytech. Univ., Budapest, Hung.), ELIMINATION OF MERCAPTANS FROM JET FUELS WITH CALCIUM OXIDE. Period. Polytech., Chem. Eng. (Budapest) 11 (3-4), 303-10 (1967).

BIBLIOGRAPHY (Contd)

40. Opperman, R. A. (Nalco Chemical Co.), MICROBIOLOGICAL CONTROL IN HYDROCARBON FLUIDS. U.S. 3,393,058 (Cl. 44-68), 16 Jul 1968, Appl. 07 Nov. 1963.

41. Paushkin, Ya. M., Rabotnova, I. L., et al., ANTIMICROBIAL ADDITIVES FOR PETROLEUM FUELS. Khim. i Tekh. Topliv i Masel Chem. and Technology of Fuels and Oils 1968, no. 3-4, 295-9 (March-April 1968).

42. Paushkin, Ya. M., Gureev, A. A., Vishnyakova, T. P., Tugolukov, V. M., Krylov, I. F., Faltynek, T. A., Vlasova, I. D., EFFECTIVENESS OF ANTISTATIC ADDITIVES AND THEIR EFFECT ON THE PHYSICAL-CHEMICAL PROPERTIES OF FUELS. Neftepererab. Neftekhim. (Moscow) 1968, (9), 9-13 (Russ.).

43. Phillips Petroleum Company, Research Division, EFFECT OF SULFUR IN JP-5 FUEL ON HOT CORROSION OF COATED SUPERALLOYS IN MARINE ENVIRONMENT Report No. 4886-67R. (AD 822 901L).

44. Phillips Petroleum Company, Research Division, EFFECT OF SULFUR IN JP-5 FUEL ON HOT CORROSION OF COATED SUPER-ALLOYS IN MARINE ENVIRONMENT. Report No. 5058-68R. (AD 834 682).

45. Phillips Petroleum Company, Research and Development Dept., EFFECT OF SULFUR IN JP-5 FUEL ON HOT CORROSION OF COATED SUPERALLOYS IN MARINE ENVIRONMENT. Report No. 5226-68. (AD 846 450L)

46. Phillips Petroleum Company, Research and Development Dept., EFFECT OF SULFUR IN JP-5 FUEL ON HOT CORROSION OF COATED SUPER ALLOYS IN MARINE ENVIRONMENT. Report No. 5423-69. (AD 860 191L)

47. Phillips Petroleum Company, Research and Development Dept., PROGRAM TO EVALUATE THE EFFECT OF SULFUR IN JP-5 FUEL ON HOT CORROSION OF TURBINE BLADE MATERIALS. Report No. 5549-69. (AD 864 270L)

48. Raymond, R. L., Douros, J. D., Jr., and Melchiore, J. J. (to Sun Oil Co.), NAPHTHALENE COMPOUNDS AS SLUDGE INHIBITORS. U.S. 3,361,545 (Cl. 44-70), Jan. 2, 1968, Appl. Jan 15, 1962.

49. Raymond, R. L., Douros, J. D., Jr., and Melchiore, J. J. (to Sun Oil Co.), NAPHTHALENE COMPOUNDS AS SLUDGE INHIBITORS. U.S. 3,361,546 (Cl. 44-70), Jan. 2, 1968. Appl. Jan. 15, 1962.

50. Rentz, W. A., Walters, J. J., Freeman, W. R., Jr., (AVCO Lycoming Div.), A DYNAMIC HOT-CORROSION RIG TESTING PROCEDURE. ASTM Ann. Mtg., 71st, Test Methods for Conducting High-Temperature Oxidation and Corrosion Studies Symposium, San Francisco, June 23-28, 1968; J. Mater. 4(3), 520-39 (Sept. 1969).

51. Rogers, M. R., Kaplan, A. M. (Pioneering Res. Div., U.S. Army Natick Lab., Natick, Mass.), SCREENING OF PROSPECTIVE BIOCIDES FOR HYDROCARBON FUELS. Develop. Ind. Microbiol. 9, 448-76 (1967).

52. Housh, M. S., Scott, R. B., Fujii, H., STUDY OF EFFECTS OF LEADED FUELS ON TURBINE HOT SECTION MATERIALS. Garrett Corp., AiResearch Mfg. Div., Feb. 1963. (AD 601 708).

BIBLIOGRAPHY (Contd)

53. Rozhkov, I. V., Churshukov, E. S., et al., OPERATIONAL CHARACTERISTICS OF JET FUELS PURIFIED OF MERCAPTANES. Khim. i Tekh. Topliv i Masel 13(10), 47-9 (1968).

54. Sawabe, H. and Ohgake, R., AN ANALYTICAL STUDY OF PARTICULATE CONTAMINANTS IN AVIATION JET FUEL. Sekiyu Gakkai Shi 12(7), 525-30 (July 1969).

55. Schirmer, R. M., and Quigg, H. T. (Phillips Petrol. Co., Bartlesville, Okla.), EFFECT OF JP-5 SULFUR CONTENT ON HOT CORROSION OF SUPERALLOYS IN MARINE ENVIRONMENT. Amer. Soc. Test. Spec., Tech. Publ. No. 421, 270-96(1966) (Pub. 1967).

56. Schirmer, R. M. and Quigg, H. T. (Phillips Petrol. Co.), EFFECT OF SULFUR IN JP-5 FUEL ON HOT CORROSION OF COATED SUPERALLOYS IN MARINE ENVIRONMENT. Ann. Nat'l. Conf. on Environmental Effects on Aircraft and Propulsion Systems, 8th, Proceedings. Institute of Environmental Sciences, Mount Prospect, Ill., 1968.

57. Shell Internationale Research Maatschappij N.V., HYDROCARBONS WITH IMPROVED AGING STABILITY. Neth. Appl. 6,602,038 (Cl. C 101), Aug. 18, 1967, Appl. Feb. 17, 1966.

58. Small, Norman J. H. (Shell Internationale Research Maatschappij N.V.), JET FUEL ADDITIVE. Brit. 1,128,640 (Cl. C 101), 25 Sep 1968, Appl. 28 Sep 1966.

59. Strickland, B. R. and Berkowitz, L. (to Esso Research and Engineering Co.), ADDITIVES FOR PETROLEUM DISTILLATE FUELS. U.S. 3,346,353 (Cl. 44-62), Oct. 10, 1967, Appl. June 20, 1963.

60. U.S. Air Force, Wright Air Development Center, CORROSION BY JP-4 FUEL. Report No. WADC-TN-WCLP-54-88. (AD 854 977L)

61. U.S. Air Force, Wright Air Development Center, J57 ENGINE FUEL SYSTEM ICING EVALUATION OF JP-4, AVIATION GASOLINE, AND PHILLIPS NUMBER 52 FUEL ADDITIVE. Report No. WADC-TN-59-164. (AD 855 408L)

62. U.S. Air Propulsion Test Center, Aeronautical Engine Dept., DEVELOPMENT OF AN AIRCRAFT FUEL ADDITIVE TO SUPPRESS THE BULK FLAMMABILITY OF FUEL. Report No. NAPTC-AED-1904. (AD 853 159L)

63. U.S. Naval Air Material Center, Aeronautical Engine Lab., EVALUATION OF THE EFFECT OF PHOSPHOROUS-BASE FUEL CORROSION INHIBITORS ON THE 'HOT-END' COMPONENTS OF TURBOJET ENGINES. Report No NAMC-AEL-1666. (AD 824 940L)

64. U.S. Naval Air Propulsion Test Center, Aeronautical Engine Dept., TEST METHODS FOR THE QUALITATIVE ANALYSIS OF SOLID CONTAMINATION IN AVIATION FUELS. Report No. NAPTC-AED-1876. (AD 835 755L)

65. Vitsina, O.D. (Ya. M. Sverdlov Plant), PREVENTION OF THE ACCUMULATION OF STATIC ELECTRICITY IN HYDROCARBON FUELS. U.S.S.R. 195,589 (Cl. C 10m), May 4, 1967, Appl. May 15, 1963.

[illegible]
[illegible], J. Inst. Petrol.

[illegible]

Catalysis and Catalytic Reactions

1. Aliev, V. S. and Aliev, A. M., CATALYTIC AROMATIZATION OF NARROW GASOLINE FRACTIONS FROM SELECTED SURAKHANY PETROLEUM. Azerb. Neft. Khoz. 46, 39 (1967) (Russ).

2. Agronomov, A. E. and Lisichkin, G. V., DEHYDROGENATION OF CYCLOHEXANE ON CHROMIUM BLACK OBTAINED BY THERMAL DECOMPOSITION OF THE AMALGAM. Vestn. Mosk. Univ., Ser. II 22, 60 (1967) (Russ).

3. Allam, M. I., van de Graaff, M., de Haan, E. P., and Vlugter, J. C. (Technol. Univ., Delft, Neth.), AROMATIZATION OF KEROSINE FRACTIONS CONTAINING BICYCLIC NAPHTHENES. IV. REACTIONS OF ALKYL DERIVATIVES OF DECALIN ON PLATINUM REFORMING CATALYST CK-303. J. Inst. Petrol. 53, 285 (1967) (Eng).

4. Allam, M. I., Kalse, H. D., and Vlugter, J. C. (Technol. Univ., Delft, Neth.), AROMATIZATION OF KEROSINE FRACTIONS CONTAINING BICYCLONAPHTHENES. V. HYDRODEALKYLATION OF 1,6-DIMETHYLNAPHTHALENE AND THE AROMATIZATION AND DEALKYLATION OF INDUSTRIAL OIL FRACTIONS. J. Inst. Petrol. 53, 328 (1967) (Eng.).

5. Amerik, B. K. and Zinov'ev, V. R., EFFECTIVENESS OF SECTIONALIZING OF A REACTOR FOR N-HEXANE DEHYDROCYCLIZATION. Tr. Grozn. Neft. Nauch.-Issled. Inst. No. 23, 25 (1967) (Russ.).

6. Ashley, J. D. and Swenson, T. A., Jr. (to Dow Chemical Co.), DEHYDROCYCLIZATION OF AROMATICS OVER CERIUM AND NICKEL ON ALUMINA. Can. 808,701. March 18, 1969, Appl. November 7, 1966; corresponds to U.S. 3,299,156.

7. Balandin, A. A., Kazanskii, B. A., Vasserberg, V. E., Isagulyants, G. V., Levi. G. I.; Editors, SCIENTIFIC SELECTION OF CATALYSTS (Davey: Hartford, Conn.). 1968. Translated from Russ.

8. Becker, K., Blume, H. and Klotzsche, H., ON RESULTS FROM THE DEVELOPMENT OF NEW REFORMING CATALYSTS. Chem. Tech. 21(6), 348 (1969).

9. Bischoff, K B., A GENERAL SOLUTION OF THE EQUATIONS REPRESENTING THE EFFECTS OF CATALYST DEACTIVATION IN FIXED-BED REACTORS. Ind. Eng. Chem., Fundam. 8, 665 (November 1969).

10. Block, H. S. (Universal Oil Products Co.), CATALYTIC DEHYDROGENATION OF [illegible] HYDROCARBONS. U.S. 3379786 (Cl. [illegible]), 23 April 1968, Appl. 11 May 1966.

11. Bloch, H. S. (Universal Oil Products Co.), CATALYTIC DEHYDROGENATION OF PARAFFINIC HYDROCARBONS ENHANCED BY BENZENE. U.S. 3,391,218 (Cl. 260-683.3), 02 Jul 1968, Appl. 12 Sep 1966.

12. Boutry, P., Montarnal, R. and Blejean, C. (Inst. Francais Petrole, Rueil-Malmaison, France), EFFECT OF THE REACTION MEDIUM ON THE DEHYDROGENATING ACTIVITY OF CHROMIUM OXIDE. DETERMINATION OF THE NATURE OF CATALYTICALLY ACTIVE SITES. Bull. Soc. Chim. Fr. 1967(10), 3690.

BIBLIOGRAPHY (Contd)

13. Bursian, N. R., Kogan, S. B., Davydova, Z. A., INVESTIGATION OF STATE OF PLATINUM IN PLATINUM DEHYDROCYCLIZATION CATALYSTS BY EXTRACTION METHOD. Kinetika i Kataliz. Kinetics and Catalysis 8, 1085 (1967).

14. Bursian, N. R., Kogan, S. B., Davydova, Z. A., STATE OF PLATINUM IN PROMOTED PLATINUM CATALYSTS AND NATURE OF ACTIVITY OF METALLIC CATALYSTS IN DEHYDROCYCLIZATION OF PARAFFIN HYDROCARBONS Kinetike i Kataliz. Kinetics and Catalysis 9, 546 (1968).

15. Caldwell, A. D. and Calderbank, P. H., CATALYST DILUTION. A MEANS OF TEMPERATURE CONTROL IN PACKED TUBULAR REACTORS. Brit. Chem. Eng. 14, 1199 (1969).

16. Carberry, J. J. (Univ. of Notre Dame), DIFFUSIONAL FACTORS AFFECTING SELECTIVITY IN HETEROGENEOUS CATALYSIS. Int. Ind. Catal. Congr., 20th, Milan, May 19-21, 1969. Chim. Ind. (Milan) 51, 951 (1969).

17. Carberry, J. J., HEAT AND MASS DIFFUSIONAL INTRUSIONS IN CATALYTIC REACTOR BEHAVIOR. Catal. Rev. 3, 61 (1969).

18. Carra, S. and Ragaini, V., STRUCTURE AND CATALYTIC ACTIVITY OF SUPPORT METALS. Int. Congr. Ind. Catal., Milen, May 17-25, 1969; Ital. Abstr., Chim. Ind. (Milan) 51, 745, (1969).

19. Chevron Research Co., LOW-PRESSURE CATALYTIC REFORMING OF NAPHTHA OVER PLATINUM AND RHENIUM ON INORGANIC OXIDE. Brit. 1,175,022, publ. Dec. 23, 1969, filed U.S. March 29, 1966, March 13, 1967, corresponds to U.S. 3,434,960.

20. Coughlin, R. W. (Lehigh Univ., Bethlehem, Pa.), HEAT-TRANSFER ANALOGY FOR DIFFUSION AND FIRST-ORDER CHEMICAL REACTION IN A CATALYST PORE. A.I.Ch.E. J. 13, 1031 (1967).

21. Csicsery, S. M. (Chevron Research Co.). CATALYTIC REACTIONS OF n-PENTYLBENZENE AND 2-PHENYLPENTANE. J. Catal. 15, 111 (1969).

22. Csicsery, S. M. (Chevron Research Co.), CATALYTIC REACTIONS OF PHENYLBUTENES. J. Catal. 12, 183 (1968).

23. Csicsery, S. M. (Chevron Research Co.), DEHYDROCYCLODIMERIZATION OF LOW MOLECULAR WEIGHT PARAFFINS. Amer. Chem. Soc., Div. Petrol. Chem. Inc., Preprints, 14(4), B124 (Sept. 1969).

24. Csuha, R. S. and Happel, J., THE STRUCTURE OF RATE EQUATIONS FOR HETEROGENEOUS CATALYSIS. A.I.Ch.E. Ann. Mtg., 62nd, Washington, D.C., November 16-20, 1969, Preprint No. 56a.

25. Dadashev, B. A., Abbasov, S. G., and Kasimova, S. A., EFFECT OF RARE ELEMENT OXIDES ON THE POROUS STRUCTURE AND CATALYTIC ACTIVITY OF ALUMINO MOLYBDENUM CATALYST DURING AROMATIZATION OF n-HEXANE AND CYCLOHEXANE. Azerb. Khim. Zh. 1966(6), 60 (Azerbaijani).

BIBLIOGRAPHY (Contd)

26. Dadashev, B. A., Kasimova, S. A., Davydova, Z. A. (Inst. Neftekhim. Protsess., Baku, USSR), EFFECT OF RARE ELEMENT OXIDE CONTENT ON THE ACTIVITY OF AN INDUSTRIAL ALUMINOMOLYBDENUM CATALYST DURING THE AROMATIZATION OF n-HEXANE AND CYCLOHEXANE. Azerb. Khim. Zh. 1967(6), 96(Russ).

27. Debus, H. R., Cahen, R. M., Aga, R. L. (Labofina, S. A.), REFINING PROCESS DEVELOPMENTS/ FOR BETTER JET FUELS OR SOLVENTS. Hydrocarbon Process. 48(9), 137 (September 1969).

28. Dimitrov, Khr. and Popova, Z. (Univ. Sofia, Bulg.), DEHYDROCYCLIZATION OF α-AMYLNAPHTHALENE ON SILICA-ALUMINA CATALYST. J. Catal. 9, 1 (1967).

29. Drehman, L. E. (to Phillips Petroleum Co.), PRODUCTION OF JET FUELS. U.S. 3,359,338 (Cl. 260-666), Dec. 19, 1967, Appl. Sept. 28, 1960.

30. Druz', V. A., Utegulov, N. I., and Sokol'skii, D. V., THE ROLE OF HYDROGEN IN THE DEHYDROGENATION OF CYCLOHEXANE ON PLATINUM. Zh. Fiz. Khim. 40,1483(1966).

31. Erivanskaya, L. A., Shevtsova, G. A., Komissarova, N. L., Plate, A. F. (Mosk. Gos. Univ. im. Lomonosova, Moscow, USSR), DEHYDROCYCLIZATION OF 2-BUTYLNAPHTHALENE ON AN ALUMINA-PLATINUM CATALYST. Neftekhimiya 8,192 (1968)(Russ.)

32. Erofeev, B. V., Isagulyants, G. V., Urbanovich, I. I., PROPYLENE CONVERSION DURING DEHYDROCYCLIZATION ON A MOLYBDENUM TRIOXIDE-γ-ALUMINA CATALYST. Vestsi Akad. Navuk Belarus, SSR, Ser. Khim. Navuk 1967, 28 (Russ.)

33. Erofeev, B. V., Nikiforova, N. V., Volkova, G. I. (Inst. Fiz.-Org. Khim., Minsk), EFFECT OF THE CARRIER STRUCTURE ON THE ACTIVITY OF CATALYSTS. I. CATALYTIC ACTIVITY OF COPPER ON ALUMINA DURING THE DEHYDROGENATION OF CYCLOHEXANE. Vestsi Akad. Navuk Belarus. SSR, Ser. Khim. Navuk 1967, 5 (Russ.)

34. Faith, L. E. and Vermeulen, T. (Univ. of California, Berkeley), KINETICS OF COMPLEX, ISOTHERMAL REVERSIBLE FIRST-ORDER REACTION SYSTEMS INVOLVING THREE COMPONENTS. A.I.Ch.E. J. 13, 936(1967).

35. Ferraiolo, G. and Reverberi, A. (Ist. Chim. Fac. Ingegneria, Genoa), VARIATION IN CATALYST SELECTIVITY AND ACTIVITY DURING REACTOR USE. Ann. Chim. (Rome) 57, 1151(1967), (Ital.)

36. Filinovskii, V. Yu., Gaziev, G. A. and Yanovskii, M. I., CHROMATOGRAPHIC DETERMINATION OF THE RATE CONSTANT OF CATALYTIC REACTION FROM THE CURVE ON PRODUCT YIELD. Metody Issled. Katal. Katal. Reakts., Akad. Nauk SSSR, Sib. Otd., Inst. Katal. 3, 313 (1965) (Russ.).

37. Fogelberg, L. G., Gore, R. and Ranby, B. (Roy. Inst. Technol., Stockholm), AROMATIZATION OF PARAFFIN HYDROCARBONS. I.AROMATIZATION OF OCTANE. II. AROMATIZATION OF C_8 HEPTANES AND HEXANES OVER PLATINUM/ALUMINA CATALYSTS. Acta Chem. Scand. 21, 2041, 2050 (1967) (Eng.).

38. Fomichev, Yu. V., Gostunskaya, I.V., Kazanskii, B. A. (Mosk. Gos. Univ. im. Lomonosova, Moscow, USSR). Dokl. Akad. Nauk SSSR 180, 383 (1968) (Russ.).

39. Fomichev, Yu. V., Gostumskaya, I. V., Kazanskii, B. A. (Mosk. Gos. Univ. im. Lomonosova, Moscow, USSR), ROLE OF C_5-DEHYDROCYCLIZATION DURING AROMATIZATION OF n-PARAFFINS IN THE PRESENCE OF AN ALUMINOPLATINUM CATALYST. Izv. Akad. Nauk SSSR, Ser. Khim. 1968, 1112 (Russ.).

40. Fridshtein, I. L., Shul'man, M. L., and Sycheva, Yu. V., CARBONIZATION AND HYDROGEN SORPTION ON CHROMIA-ALUMINA CATALYSTS. Kinet. Katal. 8, 921 (1967).

41. Fry, W. R. and Pines, H. (Northwestern Univ., Evanston, Ill.), ALUMINA: CATALYST AND SUPPORT. XXXVI. 1,2-, 1,3-, AND 1,4-PHENYL MIGRATIONS IN 1-METHYL-1-PHENYLCYCLOHEXANE. DEHYDROISOMERIZATION OF 1-METHYL-^{14}C-1-PHENYLCYCLOHEXANE OVER NONACIDIC CHROMIA-ALUMINA. J. Org. Chem. 33(2), (1968).

42. Gadzhi-Kasumov, V. S., Kiperman, S. L., Isagulyants, G. V., and Balandin, A.A., KINETICS OF CYCLOHEXANE DEHYDROGANATION OVER CHROMIUM OXIDE IN A GRADIENTLESS SYSTEM. II. Kinet. Katal. 8, 609 (1967) (Russ).

43. Gaube, J., USE OF A MATHEMATICAL MODEL FOR SIZING TUBULAR REACTORS HOUSING ENDOTHERMIC GAS REACTIONS. Brennst.-Chem. 49, 232 (1968).

44. Graham, R. R., Vidaurri, F. C., Jr., Gully, A. J., (Texas Technol. Coll., Lubbock, Tex.), CATALYTIC DEHYDROGENATION OF CYCLOHEXANE: A TRANSPORT CONTROLLED MODEL. A.I.Ch.E. J. 14, 473 (1968) (Eng.).

45. Gryaznov, V. M., Mal'donado, K., Oluoch-Okeio, D. K., Sanchez, A., Khazhzhar, E., and Khaffar, M., (Univ. Druzhby Narodov im. Lumumby, Moscow, USSR), CONVERSION OF n-HEPTANE, n-OCTANE, AND TOLUENE ON A PALLADIUM-SILVER ALLOY. Dokl. Akad. Nauk SSSR 178, 631 (1968) (Russ.).

46. Hancil, V. and Mitschka, P., THE ENHANCEMENT OF THE RATE OF CATALYTIC REACTIONS BY EXTERNAL DIFFUSION. Chem. Eng. Sci. 24, 1400 (1969).

47. Harrison, D. P., THE ACTIVITY OF NYLON-PLATINUM HYDROGENATION CATALYSTS AS DETERMINED BY THE STRUCTURE OF VARIOUS NYLON CARRIERS. Diss. Abstr. B 27(8), 2691 (1967).

48. Harrison, D. P. and Rase, H. F., NYLON-PLATINUM CATALYSTS WITH UNUSUAL GEOMETRIC AND SELECTIVE CHARACTERISTICS. Ind. Eng. Chem., Fund. 6, 161 (1967).

49. Hawthorn, R. D., Ackermann, G. H., and Nixon, A. C. (Shell Develop. Co., Emeryville, Calif.), MATHEMATICAL MODEL OF A PACKED-BED HEAT-EXCHANGER REACTOR FOR DEHYDROGENATION OF METHYLCYCLOHEXANE: COMPARISON OF PREDICTIONS WITH EXPERIMENTAL RESULTS. A.I.Ch.E. J. 14, 69 (1968).

50. Hishida, T., Uchijima, T., Yoneda, Y. (Univ. Tokyo, Tokyo, Japan), LINEAR FREE ENERGY RELATIONS IN HETEROGENEOUS CATALYSIS. VIII. REACTIVITY OF RING HYDROGENS IN CATALYTIC DEHYDROGENATION OF CYCLOHEXANES. J. Catal. 11, 71 (1968).

51. Ismailov, R. G., Aliev, S. M., Vezirov, Sh. S., DEHYDROGENATION OF DIETYLTOLUENES IN A FLUIDIZED BED OF "STYRENE-CONTACT CATALYST". Dokl. Akad. Nauk Azerb. SSR 24, 16 (1968).

BIBLIOGRAPHY (Contd)

52. Jacobson, R. L., Kluksdahl, H. E., McCoy, C. S., Davis, R. W., PLATINUM-RHENIUM CATALYST. Midyear Mtg., 34th, Am. Petrol. Inst., Div. Refining, Chicago, May 1969, Preprint 51-69.

53. Jaworska-Galas, Z. and Wrzyszcz, J., SOME AGENTS INFLUENCING THE SURFACE AREA OF PLATINUM IN REFORMING CATALYSTS. Chem. Stosowana, Ser. A 10, 105 (1966).

54. Just, H.-J., Gelbin, D., Roethe, K.-P., THE EFFECT OF COMPRESSION ON THE PORE STRUCTURE OF CATALYST PELLETS. Tech. Hochsch. Magdeburg-Kammer Tech. Chem. Eng. Group., 7th, "Commercial Reaction and Fluidized Bed Technol." Joint Mtg., Magdeburg. September 3-5, 1969; (Ger. Abstr.) Chem. Tech (Berlin) 21, 440 (1969).

55. Keith, C. D. (to Engelhard Industries, Inc.), PREPARATION OF CATALYTIC STRUCTURE. U.S. 3,437,605 (Cl. 252-463), April 8, 1969, Appl. Jan. 26, 1965.

56. Kesten, A. S. (United Aircraft Corp., United Aircraft Research Labs.), ANALYTICAL STUDY OF CATALYTIC REACTORS WHICH PROMOTE ENDOTHERMIC REACTIONS OF HYDROCARBON FUELS. AIAA, Thermophysics Conference, 4th, San Francisco, Calif., June 16-18, 1969, Paper 69-588. (A69-33265)

57. Kesten, A. S. (United Aircraft Research Labs.), INTEGRAL EQUATION METHOD FOR EVALUATING EFFECTS OF FILM AND PURE DIFFUSION OF HEAT AND MASS ON REACTION RATES IN POROUS CATALYST PARTICLES. A.I.Ch.E. Journal 15, 128 (1969).

58. Kim, K. J. and Lee, J. G., EFFECT OF REACTION ON HEAT TRANSFER IN A CATALYTIC BED. Chosun Kwahakwon Tongbo No. 4, 26 (1966) (Korean).

59. Krylova, I. V., Kozunenko, O. I., and Kobozev, N. I., CHROMIUM DEHYDROGENATION CATALYSTS. CHRONIUM OXIDE ON SILICA GEL. ACTIVITY IN THE DEHYDROGENATION OF ETHYLBENZENE. Vestn. Mosk. Univ., Ser. II 22, 108 (1967) (Russ).

60. Kubota, H. and Yamanaka, Y., REMARKS ON APPROXIMATE ESTIMATION OF CATALYST EFFECTIVENESS FACTOR. J. Chem. Eng. Jap. 2, 238 (1969).

61. Lester, G. R. (UOP), DIFFERENT MECHANISMS OF AROMATIZATION OF TRIMETHYLPENTANES OVER CHROMIA/ALUMINA AND PLATINUM/ALUMINA CATALYSTS. J. Catal. 13, 187 (1969).

62. Lester, G. R. (to Universal Oil Products Co.), DEHYDROGENATION PROCESS. U.S. 3,361,839 (Cl. 260-669), Jan. 2, 1968, Appl. Oct. 28, 1964.

63. Levinter, M. E., Panchenkov, G. M., Tanatarov, M. A., and Morozov, B. F. (Ufimsk. Neft. Inst.. Ufa), KINETICS OF THE DEPOSITION OF COKE ON CATALYSTS. Zh. Fiz. Khim. 41, 2799 (1967) (Russ).

64. Lumpkin, R. E., Jr., Smith, W. D., Jr., Douglas, J. M., IMPORTANCE OF THE STRUCTURE OF THE KINETIC MODEL FOR CATALYTIC REACTIONS. Ind. Eng. Chem., Fundam. 8, 407 (1969).

BIBLIOGRAPHY (Contd)

65. Maatman, R., Blankespoor, R., Ligtenberg, K., Verhage, H., METAL CHLORIDE PROMOTION AND DEACTIVATION OF CHROMIA-ALUMINA-CATALYZED DEHYDROGENATION OF CYCLOHEXANE. J. Catalysis 12, 398 (1968).

66. Mencier, B., Figueras, F., Mourgues, L. and Trambouze, Yves (Inst. Rech. Catal., C.N.R.S., Villeurbanne, Fr.), EFFECT OF HYDROGEN ON THE DEHYDROGENATION OF CYCLOHEXANE OVER PLATINUM. C. R. Acad. Sci., Paris, Ser. C 266, 596 (1968) (Fr).

67. Paal, Z., Tetenyi, P. (Hung. Acad. Sci., Budapest, Hung.), DEHYDROCYCLIZATION ON METAL CATALYSTS. IV. PARALLELISM OF THE DEHYDROGENATION OF CYCLOHEXANE AND DEHYDROCYCLIZATION. Acta Chim. (Budapest) 55, 273 (1968) (Eng.).

68. Paal, Z. and Tetenyi, P. (Hung. Acad. Sci., Budapest), INVESTIGATION OF DEHYDROCYCLIZATION ON METAL CATALYSTS. III. DEHYDROCYCLIZATION OF n-HEXANE. Acta Chim. Acad. Sci. Hung. 54, 175 (1967) (Eng.).

69. Panchenkov, G. M., Kuznetsov, O. I., and Zhorov, Yu. M., KINETICS OF CONTACT DEHYDROCRACKING OF n-HEXADECANE. Tr.,Mosk. Inst. Neftekhim. Gazov. Prom. No. 69, 98 (1967) (Russ.).

70. Panchenkov, G. M., Kazanskaya, A. S., Ivanova, A. P., and Pershin, A. D., A COMPARATIVE APPRAISAL OF VARIOUS CATALYSTS IN PROPANE DEHYDROCRACKING. Tr., Mosk. Inst. Neftekhim. Gazov. Prom. No. 69, 105 (1967 (Russ.).

71. Peri, J. B. and Hensley, A. L., Jr. (American Oil Co.), THE SURFACE STRUCTURE OF SILICA GEL. J. Phys. Chem. 72, 2926 (1968).

72. Pharis, J. M. (to Universal Oil Products Co.), SELECTIVE CATALYTIC DEHYDROGENATION, U.S. 3,456,031 - July 15, 1969.

73. Pines, H. (Northwestern Univ.), MECHANISM OF AROMATIZATION OF ALKANES OVER CHROMIA-ALUMINA CATALYSTS. Amer. Chem. Soc. Nat. Mtg., 158th, New York, Sept. 7-12, 1969, (Abstr.) Amer. Chem. Soc., Div. Petrol. Chem., Inc. Preprints 14 [illegible] (Sept. 1969).

74. Pines, H. and Abramovici, M. (Northwestern Univ.), ALUMINA: CATALYST AND SUPPORT. 38. AROMATIZATION OF HYDROCARBONS. 21. DEHYDROGENATION AND SKELETAL ISOMERIZATION OF 2-PHENYLPROPANE-2-^{14}C AND ETHYLBENZENE-β-^{14}C OVER "NONACIDIC" (ALKALI METAL OXIDE-PROMOTED) CHROMIA-ALUMINA. J. Org. Chem. 34, 70 (1969).

75. Pollitzer, E. L., Hayes, J. C., Haensel, V., THE CHEMISTRY OF AROMATICS PRODUCTION VIA CATALYTIC REFORMING. Amer. Chem. Soc. Nat. Mtg., 158th, New York, September 7-12, 1969; Amer. Chem. Soc., Div. Petrol. Chem., Inc. Preprints 14(4), D8-D17 (September 1969).

76. Polymer Corp. Ltd, DEHYDROGENATION CATALYSTS OF IMPROVED ACTIVITY. Brit. 1,084,698 (Cl. C 07c), Sept. 27, 1967; Can. Appl. July 27, 1965.

BIBLIOGRAPHY (Contd)

77. Polinin, V. L., Rozengart, M. I., and Kazanskii, B. A., MECHANISM OF SIDE REACTIONS DURING DEHYDROCYCLIZATION OF n-OCTANE. Izv. Akad. Nauk SSSR, Ser. Khim. 1967, 1435 (Russ.).

78. Ritchie, A. W., Nixon, A. C. (Shell Develop. Co., Emeryville, Calif.), DEHYDROGENATION OF MONOCYCLIC NAPHTHENES OVER A PLATINUM ON ALUMINA CATALYST WITHOUT ADDED HYDROGEN. Ind. Eng. Chem., Process Des. Develop. 7,209(1968).

79. Ritchie, A. W. and Nixon, A. C., DEHYDROGENATION OF MONOCYCLIC NAPHTHENES ON ALUMINA CATALYST WITHOUT ADDED HYDROGEN. Ind. Eng. Chem. Product Research and Development 7, 209 (1968).

80. Ritchie, A. W., Bailey, J. E., Nixon, A. C. (Shell Develop. Co.), EFFECT OF PORE SIZE ON THE STABILITY OF PLATINUM-ALUMINA CATALYSTS IN NAPHTHENE DEHYDROGENATION. Amer. Chem. Soc., Div. Petrol. Chem., Inc., Preprints 14(3), B44-B51 (September 1969).

81. Roth, J. F. and Schaefer, A. R. (to Monsanto Co.), THE DEHYDROGENATION OF PARAFFINS, MONOOLEFINS, OR ALKYLAROMATICS OR HYDROCYCLIZATION OF C_8-C_{20} PARAFFINS AND OLEFINS. U.S. 3,446,865 (Cl. 260-669), May 27, 1969, Appl. May 2, 1968. Continuation-in-part of Ser. 465,735, Abandoned, Appl. June 21, 1965.

82. Ryashentseva, M. A., Minachev, Kh. M., Kolesnikov, I. M., and Panchenkov, G.M. (Inst. Org. Khim. im. Zelinskogo, Moscow), KINETICS OF CYCLOHEXANE DEHYDROGENATION UNDER REFORMING CONDITIONS. Kinet. Katal. 8, 917(1967) (Russ).

83. Schmalzer, D. K. (Univ. Pittsburgh), CATALYTIC ACTIVITY AND PORE SIZE DISTRIBUTIONS. Chem. Eng. Sci. 24, 615 (1969).

84. Sergienko S. R., Medvedeva, V. D. and Klimenko, P. L., DEHYDROGENATION OF n-PARAFFINS OVER OXIDE CATALYSTS. Izv. Akad. Nauk Turkm. SSR, Ser. Fiz.-Tekh., Khim. Geol. Nauk 1967, 56 (Russ).

85. Setzermann, U., (DEHYDROGENATION OF METHYLCYCLOHEXANE IN) AN EXPERIMENTAL DIFFERENTIAL FLOW CYCLE PRESSURIZED REACTOR FOR A REACTION SYSTEM HAVING A CONDENSED PHASE. Tech. Hochsch. Magdeburg, Kammer Tech. Chem. Eng. Group, 7th, "Commercial Reaction and Fluidized Bed Technol." Joint Mtg., Magdeburg, September 3-5, 1969, (Ger. Abstr.) Chem. Tech. (Berlin) 21, 440 (1969).

86. Shell Internationale Research Maatschappij N. V., A CATALYST FOR THE DEHYDROGENATION AND DEHYDROCYCLIZATION OF PARAFFINS. Neth. Appl. 69,01,865, Appl. August 12, 1969, U.S. Appl. February 8, 1968.

87. Shimulis, V. I., Moskovskaya, M. F., Takano, E. (Univ. Druzhby Nar. im. Lumumby, Moscow, USSR), EFFECT OF THE STEPWISE HETEROGENEITY OF A PALLADIUM SURFACE ON THE KINETICS OF CYCLOHEXENE DEHYDROGENATION. I. STEPWISE DEPENDENCE OF THE REACTION RATE ON PRESSURE. Kinet. Katal. 9, 577 (1968) (Russ.).

88. Shimulis, V. I., Riofrio, V., Moskovskaya, N. F. (Univ. Druzby Nar. im. Lumumby, Moscow, USSR), EFFECT OF THE STEPWISE INHOMOGENEITY OF THE PALLADIUM SURFACE ON THE KINETICS OF CYCLOHEXENE DEHYDROGENATION. II. TREATMENT OF KINETIC DATA BY COMPUTER. Kinet. Katal. 9, 883 (1968) (Russ.).

89. Skarchenko, V. K. (USSR), MECHANISM OF THE CATALYTIC DEHYDROCYCLIZATION OF PARAFFINIC HYDROCARBONS. Probl. Kinet. Katal., Akad Nauk SSSR 12, 207 (1968).

90. Skarchenko, V. K. and Kruglikova, N. S. (Inst. Chem. Polym. Monomers, Kiev), SELECTIVITY OF DEHYDROCYCLIZATION CATALYSTS. Neft. Gazov. Prom. 1967, 42.

91. Tartarelli, R., STRUCTURE OF CATALYST PORES AND THEIR EFFECT ON PROCESS KINETICS. Soc. Chim. Ital. Tuscany Sect. Mtg., Siena June 6, 1969; Cond., Chim. Ind. (Milan) 51(8) 851 (August 1969).

92. Tetenyi, P., Babernics, L., Schaechter, K., KINETICS OF THE CATALYTIC DEHYDROGENATION OF HYDROAROMATIC COMPOUNDS. 10. DEHYDROGENATION OF CYCLOHEXENE IN THE PRESENCE OF NICKEL AND PLATINUM AT 180°-310°C. Acta Chim. Acad. Sci. Hung. 58, 321 (1968).

93. Turkevich, J. (Princeton Univ.), PREPARATION AND CHARACTERIZATION OF FINELY DIVIDED METALS SUPPORTED ON A VARIETY OF MATERIALS. Amer. Inst. Chem. Eng. Mtg., 67th, Atlanta February 15-18, 1970, Paper No. 106.

94. Usov, Yu. N., Skvortsova, E. V., Nasledskova, G. G., Shestova, L. S., Elovatskaya, L. A., and Zubanova, L. G. (Saratovsk. Gos Univ. im. Chernyshevskogo, Saratov), CONVERSIONS OF CYCLIC HYDROCARBONS IN THE PRESENCE OF OXIDE REFORMING CATALYSTS. Neftekhimiya 7, 172 (1967) (Russ).

95. Voronin, V. V., Levitskii, I. I., Minachev, Kh. M., THE EFFECT OF HYDROGEN PRESSURE ON THE SELECTIVITY OF PLATINUM CATALYSTS IN THE HYDROGENOLYSIS OF METHYLCYCLOPENTANE. Izv. Akad. Nauk SSSR, Ser. Khim. 1969, 832.

96. Wagh, M. S. and Venkatachalam, K. A. (Nagpur Univ., Nagpur), DEHYDROGENATION OF CYCLOHEXANE ON NICKEL-ZINC OXIDE CATALYST. Petrol. Hydrocarbons 2(3),103 (Pub. in Chem. Age India 18(10)) (1967).

97. Weitkamp, A. W. (to Standard Oil Co.), PREPARATION OF CIS ISOMERS OF POLYCYCLIC AROMATIC HYDROCARBONS WITH RUTHENIUM CATALYSTS. U.S. 3,349,140 (Cl. 260-667), Oct. 24, 1967, Appl. June 4, 1964, and Oct. 28, 1966.

98. Wennerberg, A. N. (to Standard Oil Co.). DEHYDROGENATION-CYCLIZATION OF MONO-OLEFIN HYDROCARBONS. U.S. 3,325,552 (Cl. 260-673.5), June 13, 1967, Appl. Aug. 16, 1963.

99. Yates, D. J. C. and Sinfelt, J. H. (Esso Research and Engineering Co), AN INVESTIGATION OF THE DISPERSION AND CATALYTIC PROPERTIES OF SUPPORTED RHENIUM. J. Catal. 14, 182 (1969).

100. Yates, D. J. C. (Esso Research and Engineering Co.), CHARACTERIZATION OF SUPPORTED METAL CATALYSTS BY CHEMISORPTION TECHNIQUES. Amer. Inst. Chem. Eng. Mtg., 67th, Atlanta, February 15-18, 1970, Paper No. 10d.

101. Zaidman, N. M., Dzis'ko, V. A., Karnaukhov, A. P., Krasilenko, N. P., Koroleva, N. G., Vishnyakova, G. P. (Inst. Katal., Novosibirsk, USSR), PLATINUM CRYSTALLIZATION ON CARRIERS. I. DISPERSION AND ACTIVITY OF PLATINUM ON ALUMINUM OXIDE AS FUNCTIONS OF SURFACE CONCENTRATION AND CARRIER PROPERTIES. Kinet. Katal. 9. 863(1968)(Russ).

102. Zengel, A. E., A STUDY OF METHYLCYCLOHEXANE DEHYDROGENATION OVER A PLATINUM-ON-ALUMINA CATALYST AT 602°F. U.S. Air Force Aero Propulsion Lab. Technical Report, August 1966 - December 1967, Report No. AFAPL-TR-67-160, April 1968. (AD 670 164) (N68-30179)

103. Zhorov, Yu. M., Panchenkov, G. M., and Rudyk, L. G. (Mosk. Inst. Neftekhim. Gaz. Prom. im. Gubkina, Moscow), DEHYDROCYCLIZATION OF n-HEPTANE AND n-HEPTENES ON AN OXIDE CATALYST. Neftekhimiya 7, 868 (1967) (Russ).

BIBLIOGRAPHY (Contd)

Heat Transfer and Fluid Mechanics

1. Anon., HEAT TRANSFER AND FLUID DYNAMICS OF NEAR CRITICAL FLUIDS. Symp. arranged by Thermodyn. and Fluid Mech. Group of Inst. Mech. Eng., March 27, 1968, Univ. Bristol, Engl.; Inst. Mech. Eng. (Proc. 1967-68, p. 182, pt 3I), London, 1968, 71 pp.

2. Andrews, D. G., Hooper, F. C., Butt, P. (Univ. Toronto, Toronto, Ont.), VELOCITY, SUBCOOLING, AND SURFACE EFFECTS IN THE DEPARTURE FROM NUCLEATE BOILING OF ORGANIC BINARIES. Can. J. Chem. Eng. 46(3), 194-9 (1968).

3. Back. L. H., Massier, P. F. and Cuffel, R. F. (Jet Propulsion Lab., Pasadena, Calif.), FLOW PHENOMENA AND CONVECTIVE HEAT TRANSFER IN A CONICAL SUPERSONIC NOZZLE. J. Spacecraft Rockets 4(8), 1040-7 (1967)(Eng).

4. Beech, J. C.,(Explosives Res. and Dev. Establishment, England), HEAT TRANSFER TO SUPERCIRITCAL KEROSINE. Report No. ERDE-14/R/66, February 27, 1967. (AD 824 271)

5. Beech, J. C. and Ziebland, H., HEAT TRANSFER TO KEROSINE. D. Eng. R. D. 2495, AT SUPERCRITICAL AND SUBCRITICAL PRESSURES. Gt. Brit. Explosives Research and Dev. Estab. Rpt. No. ERDE Report No. 5/R/63, May 1963. (AD 420 775)

6. Boothroyd, R. G., HEAT TRANSFER IN FLOWING GASEOUS SUSPENSIONS. Chem. Process Eng. 50(10), 108-14 (October 1969).

7. Capey, E. C., ALLEVIATION OF LEADING-EDGE HEATING BY CONDUCTION AND RADIATION. Gt. Brit. Aeronautical Research Council Report No. ARC-R and M-3540, Supersedes RAE-TR-66311, ARC-28924, 1968, 24 pp. (N69-10899)

8. Chao, B. T. (ed.), ADVANCED HEAT TRANSFER. Urbana, Ill, University of Ill. Press, 1969. 467 pp. Partial Contents:
   Chao, B. T., SELECTED TOPICS ON CONVECTIVE HEAT TRANSFER, p. 1-72.
   Hering, R. G., SELECTED TOPICS ON RADIATIVE HEAT TRANSFER. p. 74-154.
   Clausing, A. M., NUMERICAL METHODS IN HEAT TRANSFER. p. 156-216.
   Fauske, H. K., CRITICAL TWO-PHASE FLOW. p. 263-276.
   Chung, P. M., HEAT TRANSFER IN CHEMICALLY REACTING GASES. p. 319-338.
   Soo, S. L., HEAT TRANSFER PROCESSES OF PARTICULATE SUSPENSIONS. p. 415-437. (A69-28138).

9. Dil'man, V. V., THE THEORY OF HEAT AND MASS TRANSFER IN TURBULENT FLOW. Teor. Osn. Khim. Tekhnol. 1(4), 438-45 (1967)(Russ).

10. East, R. A. and Scott, D. J. G., AN EXPERIMENTAL DETERMINATION OF THE HEAT TRANSFER RATES AT A CARET WING AT HYPERSONIC SPEEDS. Southampton Univ., England, Dept. of Aeronautics and Astronautics Report No. AASU-273, November 1967, 47 pp. (N68-15305)

11. Erhlich, R. and Slattery, J. C., APPROXIMATE SOLUTIONS FOR TWO-PHASE FLOW PROBLEMS. A.I.Ch.E. Ann. Mtg., 62nd, Washington, D.C., November 16-20, 1969, Paper No. 48c.

BIBLIOGRAPHY (Contd)

12. Everett, M., FORCED CONVECTION HEAT TRANSFER INSIDE TUBES. TURBULENT FLOW. Chem. Eng. (London) 1969(231), CE 159 (September).

13. Faris, G. N. and Viskanta, R. (Purdue Univ.), AN ANALYSIS OF LAMINAR COMBINED FORCED AND FREE CONVECTION HEAT TRANSFER IN A HORIZONTAL TUBE. Int. J. Heat Mass Transfer 12(10), 1295-1309 (October 1969).

14. Filimonov, S. S., et al., ON THE ANALYSIS OF COMPLEX HEAT EXCHANGE. Teploobmen. Gidrodin. i Teplofizich. Svoista Veshchestva. Moscow, Nauka, 1968, p. 107; Lockheed Missiles and Space Co. Trans., 1968, Avail. National Translation Center, John Crerar Library, Chicago, Ill. (N69-23215)

15. Graham, R. W., PENETRATION MODEL EXPLANATION FOR TURBULENT FORCED-CONVECTION HEAT TRANSFER OBSERVED IN NEAR-CRITICAL FLUIDS. U.S. National Aeronautics and Space Admin. Report No. NASA-TN-D-5522, October 1969. (N69-40437)

16. Harrje, D. T., HEAT TRANSFER IN OSCILLATING FLOW. Princeton Univ., Guggenheim Labs for the Aerospace Propulsion Sciences Final Rept. 1958-1967, No. Rept. -483g, U.S. Navy Contract Nonr-1858(29), October 1967. (N68-18442)

17. Hartnett, J. P. (ed.), and Irvine, T. F., Jr., ADVANCES IN HEAT TRANSFER. Academic Press, New York, 1968, 538 pp. VOL. 4, Academic Press, New York, 1967, 458 pp.

18. Kafengauz, N. L., Fedorov, M. I. (USSR), CONDITIONS FOR THE ONSET OF PSEUDO-BOILING DURING HEAT TRANSFER WITH TURBULENT LIQUID FLOW. Inzh.-Fiz. Zh. 14(5), 923-4 (1968) (Russ).

19. Kalinin, E. K. and Yarkho, S. A., ALTERNATION OF FLOW AND HEAT EXCHANGE UNDER THE CONDITIONS OF ARTIFICIAL TURBULIZATION OF FLOW IN TUBES. Vestsi Akad. Navuk Belarusk SSR, Ser. Fiz.-Tekh. Navuk (Minsk) 1966(2), 62-4; U.S. Air Force Trans. No. FTD-HT-23-360-68, July 1968. (AD 684 994) (N69-29935)

20. Kato, H., Nishiwaki, N., Hirata, M., STUDIES ON HEAT TRANSFER OF FLUIDS AT SUPERCRITICAL PRESSURE. 1. Bull. Japan Soc. Mech. Engrs. 11(46), 654-63 (August 1968).

21. Petukhov, B. S. (Inst. Vys. Temp., Moscow, USSR), HEAT TRANSFER IN A SINGLE-PHASE MEDIUM AT NEAR-CRITICAL CONDITIONS (OF STATE). Teplofiz. Vys. Temp. 6(4), 732-45 (1968) (Russ).

22. Petukhov, B. S., HEAT TRANSFER AND RESISTANCE IN THE LAMINAR FLOW OF LIQUIDS IN TUBES. VOLUME 1. Teploobmen i Soprotivlenie pri Laminarnom Techenii Zhidkosti v Trubakh, Moscow, 1967; U.S. Air Force Trans., August 1969. (AD 699 198)

23. Petukhov, B. S., HEAT TRANSFER AND RESISTANCE IN THE LAMINAR FLOW OF LIQUIDS IN TUBES. VOLUME 2. Teploobmen i Soprotivlenie pri Laminarnom Techenii Zhidkosti v Trubakh, Moscow 1967; U.S. Air Force Trans., August 1969. (AD 699 198)

BIBLIOGRAPHY (Contd)

24. Sergeyev, V. I., METHODS FOR MEASURING LARGE HEAT FLUXES. Inzh. Fiz. Zh. (Moscow) 9(4), 427-32 (1965); U.S. Air Force Trans. FTD-HT-67-57, September 1967. (AD 666 743) (N68-23068)

25. Shiraikar, B. S. and Griffith, P., THE DETERIORATION IN HEAT TRANSFER TO FLUIDS AT SUPER-CRITICAL PRESSURE AND HIGH HEAT FLUXES. Mass. Inst. of Tech., Dept. of Mechanical Engineering Report No. 70332-51, March 1968, 61 pp. (N68-25021)

26. Singh, A., THE THERMAL CONDUCTIVITY OF STATIONARY AND FLOWING SUSPENSIONS. Ph.D. Thesis, Univ. of Minnesota, Univ. Microfilms Order No. 68-12287, 1968, 200 pp. (N69-19802)

27. Thomas, D. G. and Hayes, P. H., HIGH PERFORMANCE HEAT TRANSFER SURFACES, Ind. Eng. Chem. 62(2), 4 (1970).

28. Timmerhaus, K. D., Kreith, F., Simpson, A. U., Jones, M. C., HEAT AND MASS TRANSFER IN DISPERSED TWO-PHASE, SINGLE-COMPONENT FLOW. International J. of Heat Mass Transfer 12(9), 1141-55 (September 1969).

29. Tomich, J. F. and Weger, E. (Wash. Univ., St. Louis, Mo.), SOME NEW RESULTS ON MOMENTUM AND HEAT TRANSFER IN COMPRESSIBLE TURBULENT FREE JETS. A.I.Ch.E. J. 13(5), 948-54 (1967).

30. Tong, L. S. (At. Power Div., Westinghouse Elec. Corp., Pittsburgh, Pa.), BOUNDARY-LAYER ANALYSIS OF THE FLOW BOILING CRISIS. Int. J. Heat Mass Transfer 11(7), 1208-11 (1968).

31. Walters, F. M., COOLANT PASSAGE IN HEAT TRANSFER AND PRESSURE DROP PERFORMANCE. AiResearch Mfg. Co. Rept. No. AP-69-5348, U.S. National Aeronautics and Space Admin. Report No. NASA-CR-66844, Contract No. NAS 1-6666, August 1969. (N69-41183)

32. Wasan, D. T. and Ahluwalia, M. S. (Ill. Inst. Technol.), CONSECUTIVE FILM AND SURFACE RENEWAL MECHANISM FOR HEAT OR MASS TRANSFER FROM A WALL. Chem. Eng. Sci. 24(10), 1535-42 (October 1969).

33. Wilson, D. M., A CORRELATION OF HEAT-TRANSFER AND SKIN FRICTION DATA AND AN EXPERIMENTAL REYNOLDS ANALOGY FACTOR FOR HIGHLY COOLED TURBULENT BOUNDARY LAYERS AT MACH 5.0. U.S. Naval Ordnance Lab., March 1969. (AD 690 454)

34. Yoshikawa, K. K., THE COUPLING EFFECT OF RADIATIVE HEAT ON CONVECTIVE HEAT TRANSFER. National Aerospace Lab., Japan, Report No. NAL-TR-173T, February 1969, 8 pp. (N69-36542)

35. Zoby, E. V., EMPIRICAL STAGNATION-POINT HEAT-TRANSFER RELATION IN SEVERAL GAS MIXTURES AT HIGH ENTHALPY LEVELS. U.S. National Aeronautics and Space Admin. Report No. NASA-TN-D-4799, October 1968, 21 pp. (N68-35468)

BIBLIOGRAPHY (Contd)

Combustion

1. Adams, D. M., A REALISTIC MEASURE OF COMBUSTION EFFICIENCY. AIAA Journal 7, 1398 (1969). (A69-41919)

2. Advisory Group for Aeronautical Research and Development (France), SELECTED COMBUSTION PROBLEMS: FUNDAMENTAL AND AERONAUTICAL APPLICATIONS. Proceedings of Combustion Colloquim, Cambridge Univ., England, Dec. 7-11, 1953, Pergamon Press, Inc., Long Island City (AD 695 273)

3. Agafonova, F. A., Gurevich, M. A., Tarasova, E. F., SELF-IGNITION AND THE INDUCTION PERIOD OF A DROP OF LIQUID FUEL. Teplo- i Massoperenos (USSR) 4, 241 (1966); U.S. Air Force Trans. No. FTD-MT-24-130-68, June 1968. (AD 679 516)

4. Alvermann, W., Ulken, R., Ahlswede, M., FLOW INVESTIGATIONS IN COMBUSTORS WITH AERODYNAMIC FLAME STABILIZATION. PART 3: PREHEATED FLOW WITH AFTERBURNING. West. Ger. Deutsche Forschungsanstalt fur Luft- und Raumfahrt. Report No. DLR-FB-68-02, January 1968, in German; English summary.(N68-21199)

5. Alvermann, W. and Ulken R., FLOW INVESTIGATIONS COMBUSTORS WITH AERODYNAMIC FLAME STABILIZATION. PART 2: PREHEATED FLOW. W. Ger. Deutsche Forschungsanstalt fur Luft- und Raumfahrt port No. DLR-FB-67-77, Pt. 2, Sept. 1967. (N68-17486)

6. Anderson, G. Y. and Vick, A. R., AN EXPERIMENTAL STUDY OF FLAME PROPAGATION IN SUPERSONIC PREMIXED FLOWS OF HYDROGEN AND AIR. U.S. National Aeronautics and Space Admin. Report No. NASA-TN-D-4631, June 1968. (N68-28100)

7. Aslanov, S. K., INVESTIGATION OF THE HYDRODYNAMIC STABILITY OF NORMAL COMBUSTION IN GASES. Priklad. Mekhanika 4, 112-6 (Sept. 1968) (A69-10087)

8. Aslanov, S. K., ONE-DIMENSIONAL STABILITY OF NORMAL COMBUSTION OF GASES. Inzhenerno-Fizicheskii Zh. 15, 298 (1968) (in Russian). (A69-10107)

9. Aslanov, S. K., THEORY OF FLAME STABILITY. Inzhenerno-Fiz. Zh. (USSR) 11, 472 (1966); E. Harter, U.S. Air Force Trans. No. FTD-HT-23-472-68, July 1968. (AD 683 124)

10. Avdeev, E. F., Aliev, F., Lapin, Yu. V., TURBULENT MIXING OF TWO SEMI-INFINITE STREAMS OF REACTING GASES. Tr. Leningr. Politekhn. Inst., No. 265, 1966; U.S. Air Force Trans. FTD-MT-24-361-67, January 1968. (AD 674 045) (N68-38464)

11. Averson, A. E. and Rozenband, V. I., APPROXIMATE METHODS OF CALCULATING THE CRITICAL CONDITIONS OF IGNITION. Fizika Goreniia i Vzryva 4, 519 (1968) (in Russian) (A69-25191)

12. Bahn, G. S. (Marquardt Corp.), EVOLUTION OF A FIRST-ROUND REACTION KINETICS PACKAGE FOR PYROLYSIS/COMBUSTION OF A LARGE ALIPHATIC HYDROCARBON MOLECULE. Combustion Institute, Fall Meeting, Menlo Park, Calif., October 28, 29, 1968, Paper 68-37. (A69-18353)

BIBLIOGRAPHY (Contd)

13. Barrere, M. and Prud'homme, R. (ONERA), AEROTHERMOCHEMISTRY OF TWO-PHASE FLOW. APPLICATION TO GAS-LIQUID AND GAS-SOLID REACTORS AND TO "GAS POCKET" REACTORS. Chim. Ind. Genie Chim. 102(5), 657.

14. Basevich, V. Ia. and Kogarko, S. M., PROMOTION OF COMBUSTION. Fizika Gorenila i Vzryva 5, 99 (March 1969). (A69-33139)

15. Bayes, K. D., FLAMES: KINETICS AND SPECTROSCOPY. Univ. of Calif., Los Angeles, Final Report 1 Oct 1964 - 30 Sept 1968, U.S. Air Force Report No. AFOSR-68-2199, Grant No. AF-AFOSR-687-64, 1968. (AD 677 337)

16. Berlad, A. L. (Convair Scientific Research Lab - San Diego, Ca.), FLAME REACTION RATES. Research Note Report No. RN-10, July 1957. (AD 829 020)

17. Bert, J. L., COMBUSTION OF HEPTANE DROPLETS IN A HOT GAS FLOW. Univ. of Calif., Lawrence Radiation Lab. Report No. 17438 (M. S. Thesis), Contract No. W-7405-ENG-48, Oct 1967. (N68-16886)

18. Bespolov, I. E., Khaikin, M. D., Komarov, B. I., Medvedev, S. P., EFFECT OF AROMATIC HYDROCARBONS ON THE COMBUSTION CHARACTERISTICS OF JET FUEL. Khim. i Tekh. Topliv i Masel 14, 42 (1969) (in Russian). (A69-35382)

19. Bhaduri, D., EFFECT OF TURBULENCE ON PREMIXED GASEOUS FLAMES. Central Mechanical Engineering Research Inst., India Report No. CMERI-B6, Feb. 1968. (PB 178 864) (N69-11829) (N68-25770)

20. Bhaduri, D., Baxi, C. B., Gill, B. S., THEORETICAL EVALUATION OF THE NORMAL VELOCITY OF FLAME PROPAGATION. Indian Journal of Technology 6, 247 (1969). (A69-22695)

21. Billig, F. S. and Dugger, G. L. (Johns Hopkins Univ., Applied Physics Lab.), EXTERNAL BURNING IN SUPERSONIC STREAMS. APL Technical Digest 8, 2 (November-December 1968). (A69-24261)

22. Bowman, C. T. and Seery, D. J., (United Aircraft Corp., United Aircraft Research Labs.), IGNITION MECHANISMS OF HYDROCARBON FUELS - METHANE AND ACETYLENE. Combustion Institute, Fall Meeting. Menlo Park, Calif., Oct 28, 29, 1968, Paper 68-41. (A69-18356)

23. Bray, K. N. C. (Northern Research and Engineering Corp., Cambridge, Mass.), THE IGNITION AND SUSTAINING OF COMBUSTION BY ENERGY ADDITION IN TURBULENT SUPERSONIC FLOWS. Annual progress rept. (final) for period ending 16 Mar 68, Report No. 1123-1. Contract F44620-67-C-0071, Proj. AF-9711, Task 971101. AFOSR 69-0786TR. January 1969. (AD 849 755)

24. Brenchley, D. L., AN EXPERIMENTAL INVESTIGATION OF COMBUSTION PRODUCTS THROUGH A FLAT, LAMINAR, PREMIXED HYDROCARBON-AIR FLAME. Ph.D. Thesis, Oregon State Univ., Univ. Microfilms Order No. 68-11911, 1968. (N69-20971)

BIBLIOGRAPHY (Contd)

25. Bryce, C. A., AN INVESTIGATION OF NONEQUILIBRIUM EFFECTS ON COMBUSTION IN SUPERSONIC STREAMS. Ph. D. Thesis, Purdue Univ., U.S. National Aeronautics and Space Admin. Report No. NASA-CR-106356, Grants No. NGR-15-005-013, NSG-592, January 1969. (N69-40454)

26. Brzustowski, T. A., McDonald, A. G. Newman, J. A. and Keshavan, R., HEAT TRANSFER FROM A PROPANE-OXYGEN-ALUMINUM FLAME. Pyrodynamics 5, 203 (1967).

27. Campbell, D. T. and Chadwick, W. D. (Rocketdyne, Canoga Park, Calif.), COMBUSTION INSTABILITY ANALYSIS AT HIGH CHAMBER PRESSURE. Final Report 1 Dec 66 - 30 Jun 68. Report No. R-7561. Contract F04611-67-C-0036. AFRPL TR-68-179. August 1968. (AD 842 960)

28. Chappell, M. S. and Cockshutt, E. P., GAS TURBINE CYCLE CALCULATIONS: THERMODYNAMIC DATA TABLES FOR AIR AND COMBUSTION PRODUCTS. Canadian National Aeronautical Estab. Report No. NAE-LR-517, NRC-10698, January 1969. (AD 690 716) (N69-33150)

29. Chen, C. S.-Y., EXPERIMENTAL AND THEORETICAL STUDIES OF BURNING DROPS OF HYDROCARBON FUELS. Ph.D. Thesis, Univ. of Wisconsin, Univ. Microfilms Order No. 68-15972, 1968. (N70-19236)

30. Chervinskv, A., TURBULENT SWIRLING JET DIFFUSION FLAMES. AIAA Journal 7, 877 (1969).

31. Chervinsky, A., TURBULENT SWIRLING JET DIFFUSION FLAMES. Haifa, Israel Inst. Technology, Dept. Aeronautical Eng. Report No. 87. January 1969.

32. Chervinsky, A. and Manheimer-Timnat, Y. M. Y., EFFECT OF SWIRL ON FLAME STABILIZATION. Israel J. Technology 6, 25 (1968).

33. Chervinsky, A. and Tinmat, Y. M., EXPERIMENTAL INVESTIGATION OF TURBULENT SWIRLING FLAMES. Israel J. Technology 5, 39 (1967).

34. Chrans, L. J. (Naval Postgraduate School, Monterey, Ca.), THE EFFECT OF STAGNATION TEMPERATURE AND MOLECULAR WEIGHT VARIATION ON GASEOUS INJECTION INTO A SUPERSONIC STREAM. Master's thesis. Sept. 1968. (AD 851 864)

35. Chung, P. M. and Blankenship, V. D., EQUILIBRIUM STRUCTURE OF THIN DIFFUSION FLAME ZONE. Aerospace Corp. Technical Report, February - August 1965, Report No. TR-669 (56240-10)-1 BSD-TR-66-32, U.S. Air Force Contract AF 04(695)-669, December 1965. (AD 477 791)

36. Clarke, J. F. and Stegen, G. R., SOME UNSTEADY MOTIONS OF A DIFFUSION FLAME SHEET. J. Fluid Mechanics 34, 343 (1968). (A69-13014)

37. Cohen, L. S. and Guile, R. N., INVESTIGATION OF THE MIXING AND COMBUSTION OF TURBULENT, COMPRESSIBLE FREE JETS. United Aircraft Corp., U.S. National Aeronautics and Space Admin. Report No. NASA-CR-1473, Contract NAS 1-7255, December 1969; AIAA Propulsion Joint Specialist Conf., 5th, Colorado Springs, Colo., June 9-13, 1969, Paper No. AIAA-69-538.

BIBLIOGRAPHY (Contd)

38. Cookson, R. A., SUPERSONIC COMBUSTION STUDIES. I. DESIGN, [illegible]ION AND PERFORMANCE OF A HIGH-ENTHALPY FACILITY. College of Aerona[illegible] Cranfield, England, Report No. C_0A-NOTE-AERO-200, November 1967. (AD 6[illegible]

39. Cushing, B. S., Faucher, J. E., Gandbhir, S., Shipman, C. W. (Worcester Polytech. Inst., Worcester, Mass.), TURBULENT MASS TRANSFER AND RATES OF COMBUSTION IN CONFINED, TURBULENT FLAMES. Symp. Combust. 1966, 11, 817 (1967).

40. Da-Riva, I., Linan, A., Fraga, E., Urrutia, J., DIFFUSION FLAMES AND SUPERSONIC COMBUSTION. Instituto Nacional de Tecnica Aeroespacial (Spain), Final Scientific Report April 1967 - April 1968, U.S. Air Force AFOSR-69-2165TR, Grant No. AF-EOAR-43-67, June 1969. (AD 693 341)

41. Da Riva, I. and Urrutia, J. L., IGNITION DELAY IN DIFFUSIVE SUPERSONIC COMBUSTION. AIAA Journal 6, 2095 (1968).

42. Da Riva, I., Fraga, E., Linan, A., Urrutia, J. L., DIFFUSION FLAMES AND SUPERSONIC COMBUSTION. Institu Nacional de Technica Aeroespacial, Spain, Final Report, U.S. Air Force AFOSR-68-0066, Grant AF-EOAR-66-41, October 1967. (AD 663 741) (N68-17929)

43. deBoer, P. C. T. and Frohn, A., MEASUREMENT OF IONIZATION RELAXATION TIMES SHOCK TUBES. Shock Tube Symposium, The Physics of Fluids Supplement 1, 54 (1969). (AD 697 344)

44. Dixon-Lewis, G. (Univ. Leeds, Leeds, England), FLAME STRUCTURES AND FLAME REACTION KINETICS. II. TRANSPORT PHENOMENA IN MULTICOMPONENT SYSTEMS. Proc. Roy. Soc., Ser. A 1968, 307(1488), 111.

45. Dragnov, B. Kh., MIXING OF GAS STREAMS IN COMBUSTION CHAMBERS. Energ. Mashinostr. (USSR) 1966, 68; U.S. Air Force Trans. No. FTD-MT-24-757-68, Sept. 1968. (AD 684 657) (N69-28323)

46. Drewry, J. E., Dunn, R. G., Scaggs, N. E., SUPERSONIC COMBUSTION STUDIES AT LOW DENSITY CONDITIONS. U.S. Air Force Aerospace Research Labs. Report No. ARL-69-0159, September 1969. (Presented at AIAA Propulsion Joint Specialist Conf. (5th), Colorado Springs, Colo., June 9-13, 1969, Paper No. 69-458. (AD 699 206)

47. Dudin, L. A. and Kosterin, V. A., FLAME STABILIZATION AT VARIOUS FLOW TEMPERATURES. Kazanskii Aviatsionnyi Institut, Trudy, Raboty Aspirantov i Soiskatelei, No. 101, 1968, (in Russian). (A69-38859)

48. Dunn, R. G., Drewry, J. E., Scaggs, N. E., SUSTAINED SUPERSONIC COMBUSTION IN THE LABORATORY UNDER LOW DENSITY CONDITIONS. Conference on Airbreathing Propulsion for Advanced Missiles and Aircraft Naval Training Center, San Diego, Calif., March 4-6, 1969, Paper; U.S. Air Force Aerospace Research Labs. Report No. ARL-69-0035, March 1969. (AD 689 393) (N69-37158)

BIBLIOGRAPHY (Contd)

49. Dunn, R. G., SUPERSONIC COMBUSTION SIMULATION. U.S. Air Force, Office of Aerospace Res. Proc. of the OAR Res. Appl. Conf., March 1967, 157. (N68-16384)

50. Dunn, R. C., Drewry, J. E., Scaggs, N. E. (U.S. Air Force, Aerospace Research Labs.), SUSTAINED SUPERSONIC COMBUSTION IN THE LABORATORY UNDER LOW DENSITY CONDITIONS. Conference on Airbreathing Propulsion for Advanced Missiles and Aircraft, Naval Training Center, San Diego, Calif., March 4-6, 1969. (AD 689 393)

51. Edelman, R. B., Schmofolocha, S., Slutsky, S., COMBUSTION OF LIQUID HYDROCARBONS IN A HIGH-SPEED AIR STREAM. AIAA Aerospace Sciences Meeting, 8th, January 19-21, 1970, Paper No. AIAA 70-88.

52. Edelman, R. B. and Fortune, O. F. (General Applied Science Labs., Inc.), A QUASI-GLOBAL CHEMICAL KINETIC MODEL FOR THE FINITE RATE COMBUSTION OF HYDROCARBON FUELS WITH APPLICATION TO TURBULENT BURNING AND MIXING IN HYPERSONIC ENGINES AND NOZZLES. AIAA, Aerospace Sciences Meeting, 7th, New York, January 20-22, 1969, Paper 69-86. (A69-18119)

53. Edse, R. (Ohio State Univ. Res. Foundation, Columbus, Ohio), SUPERSONIC BURNING AND COMBUSTION. Final Rept. 1 Feb 66 - 31 Mar 67, Rept. No. 3, Contract AF-AFOSR-203-66-Proj. RF-2153, AF-9711, Task 971101, AFOSR 68-0578. November 9, 1967. (AD 831 152)

54. Eickhoff, H., STATIC PRESSURE AND TURBULENCE IN ROTATIONALLY SYMMETRIC FREE JETS AND FREE JET FLAMES. Karlsruhe, Technische Universitat, Dr.-Ing. Dissertation, 1968. (in German) (A69-31190)

55. Ellis, C. F., Chase, J. O., Horn, R. W., COMBUSTION AND RELATED PHENOMENA IN A CONSTANT VOLUME BOMB. U.S. Bureau of Mines Report for 1948-1960, BM-Open file-5-69, 1962. (PB 184 706)

56. Emmenthal, K. D., ON THE COMBUSTION AND FLOW PROCESSES IN PREHEATED GAS FLOW WITH HIGH PRESSURE. W. Ger. Deutsche Forschungsunstalt fur Luft- und Raumfahrt Report No. DLR-FB-68-80, September 1968. (in German; English Summary) (N69-22397)

57. Ershin, Sh. A. and Voichak, V. P., AERODYNAMIC INVESTIGATION OF TURBULENT FLAME, DEVELOPING IN A FINITE COAXIAL WAKE JET. Problemy Teploenergetika i Prikladnoi Teplofiziki (USSR) 1967, No. 4; U.S. Air Force Trans. No. FTD-MT-24-451-68, February 1969. (AD 688 688) (N69-36470)

58. Ershin, Sh. A., et al., AERODYNAMICS OF A TURBULENT DIFFUSION FLAME JET IN A WAKE FLOW. Vestn. Akad. Nauk Kaz. SSR (Alma-Ata) 18(4)(205), 46 (1962); Johns Hopkins, Applied Physics Lab. Trans. No. APL-CLB-3-T-579, U.S. Navy Contract No. NOW-62-0604C, February 1969. (AD 686 461) (N69-30913)

59. Faeth, G. M., AN INVESTIGATION OF NEAR CRITICAL AND SUPERCRITICAL BURNING OF FUEL DROPLETS. Penn. State Univ., Dept. of Mechanical Engineering Annual Report, 1 Sept 1968 - 31 Dec 1969, Report No. AR-3, U.S. National Aeronautics and Space Admin. Report No. NASA-CR-108 904, Grant No. NGR-39-009-077, January 1970. (N70-20416)

BIBLIOGRAPHY (Contd)

60. Faeth, G. M., AN INVESTIGATION OF NEAR CRITICAL AND SUPER-CRITICAL BURNING OF FUEL DROPLETS. Penn. State Univ. Annual Report, 1 Sept 1967 - 1 Sept 1968, Report No. AR-2, U.S. National Aeronautics and Space Admin. Report No. NASA-CR-73654, Contract No. NGR-39-009-077, Sept. 1968. (N69-16871)

61. Faeth, G. M., Dominicis, D. P., Olson, D. R., AN INVESTIGATION OF NEAR CRITICAL AND SUPER-CRITICAL BURNING OF FUEL DROPLETS. Penn. State Univ. Annual Report U.S. National Aeronautics and Space Agency NASA-CR-72314, Grant NGR-39-009-077, Sept. 1967. (N68-10170)

62. Faeth, G. M. and Olson, D. R., IGNITION OF HYDROCARBON FUEL DROPLETS IN AIR. SAE Meeting, May 20-24, 1968, SAE Paper No. 680465.

63. Faith, L. E., Nixon, A. C., Anshus, B. E. (Shell Development Co.), SHOCK TUBE STUDIES OF THE OXIDATION OF HEAVY HYDROCARBONS. Amer. Chem. Soc. Nat. Mtg., 158th, New York, September 7-12, 1969; Amer. Chem. Soc., Div. Petrol. Chem., Inc., Preprints 14(3), B172-B177 (September 1969).

64. Fedoseyev, V. A., TRACE METHOD AND ITS APPLICATION TO THE INVESTIGATION OF DISPERSED-FUEL COMBUSTION KINETICS. Teplofiz. i Teplotekhn. (Kiev) 1964,136; U.S. Air Force Trans. FTD-HT-66-706, June 1967. (AD 661 898) (N68-13238)

65. Franklin, J. L. (Rice Univ., Houston, Tex.), MECHANISMS AND KINETICS OF HYDROCARBON COMBUSTION. Annu. Rev. Phys. Chem. 18, 261 (1967).

66. General Applied Science Labs., Inc., HIGH SPEED COMBUSTION PROCESSES. Report No. GASL-TR-657, U.S. Air Force AFOSR 69-01 84 TR. (AD 850 345)

67. General Applied Science Labs., Inc., RESEARCH ON COMBUSTION PROCESSES AT HIGH SPEED AND AT LOW PRESSURES. Report No. GASL-TR-682, U.S. Air Force AFOSR-68-0467. (AD 832 924)

68. General Applied Science Labs., Inc., IGNITION AND COMBUSTION OF LIQUID HYDROCARBON FUELS IN SUPERSONIC FLOW. Report No. GASL-TR-724. (AD 855 766)

69. General Applied Science Labs., Inc., APPLICATION OF MIXING AND COMBUSTION TO SHOCKLESS TRANSITION. Report No. GASL-TR-678, U.S. Air Force AFAPL-TR-68-4. (AD 390 265L)

70. General Applied Science Labs., Inc., MIXING AND COMBUSTION IN SUPERSONIC FLOW WITH LATERAL PRESSURE GRADIENT EFFECTS. Final Report No. GASL-TR-636, U.S. National Aeronautics and Space Admin. Report No. NASA-CR-97068, Contract No. NAS 7-590, August 1968. (N68-35782)

71. Ghezzi, V., CALCULATION OF THE TRANSMISSION COEFFICIENTS IN THE COMBUSTION ZONE. Istituto Internazionale delle Comunicazioni, Convegno Internazionale delle Comunicazioni, 16th, Genoa, Italy, Oct. 8-12, 1968, Paper. (A69-20585)

BIBLIOGRAPHY (Contd)

72. Gilinskii, S. M., et al., SUPERSONIC FLOW AROUND OF A SPHERE BY A COMBUSTIBLE MIXTURE OF GASES WITH CONSIDERATION OF IGNITION DELAY TIME. Izv. Akad. Nauk SSSR, Mekham. Zhidkosti i Gaza (USSR) 1968, 20; U.S. Air Force Trans. No. FTD-MT-24-287-68, August 1968. (AD 684 639) (N69-28691)

73. Gilinskii, S. M. and Zapryanov, Z. D., TRANSITION OF A COMBUSTION MIXTURE FROM SUPERSONIC FLOW TO THE CHAPMAN-JOUGET REGIME. Izv. Akad. Nauk SSSR, Mekham. Zhidk. Gaza (USSR) 1967, 137;U.S. Air Force Trans No. FTD-MT-24-280-68, July 1968. (AD 681 597)

74. Gilinskii, S. M., Zapryancv, Z. D., Chernyi, G. G., SUPERSONIC FLOW OF A COMBUSTIBLE GAS MIXTURE OVER A SPHERE. Izv. Akad. Nauk SSSR, Mekham. Zhidkosti i Gaza (USSR) 1966, 8; U.S. Air Force Trans. FTD-HT-23-1068-67, August 1967. (AD 673 822) (N68-35867)

75. Glassman, I., Hansel, J. G., Eklund, T. (Princeton Univ.), HYDRODYNAMIC EFFECTS IN THE FLAME SPREADING, IGNITABILITY AND STEADY BURNING OF LIQUID FUELS. Combustion and Flame 13, 99 (1969). (A69-24484)

76. Goldaev, I. P., et al., ENGINEERING METHOD FOR THERMODYNAMIC CALCULATIONS OF JET-TYPE COMBUSTION CHAMBERS USING HYDROCARBON FUEL AND AIR. Samoletostroenie i Tekhn. Volzdushnogo Flota (USSR) 1967, 10 ; U.S. Air Force Trans. No. FTD-HT-23-842-68, Sept. 1968. (AD 684 693) (N69-28754)

77. Goldaev, I. P. and Cherepanov, V. P., THERMODYNAMIC CALCULATION OF COMBUSTION-CHAMBER PROCESSES IN THE CASE OF EXCESS OXIDIZER. Samoletostroenie i Tekhnika Vozdushnogo Flota, ed. by Iv. N. Alekseev, Kharkov, Izdatel'stvo Khar'Kovskogo Gosudarstvennogo Universiteta (Respublikanskii Mezhuedomstvennyi Nauchno-Tekhnicheskii Sbornik, No. 13) (in Russian). IAA 9, 684.(A69-14486)

78. Gruemmer, K., Trommsdorff, W. and Zhuber-Okrog, G., A DEVICE FOR INTERMITTENT AND PULSATING COMBUSTION. Deutsche Forschungs- und Versuchsanstalt fuer Luft- und Raumfahrt e v Porz-wahn (W. Germany); Report No. DLR-FB-69-82. (Nov. 1969) (AD 863 858)

79. Grishin, A. M., IGNITION OF A REACTING GAS BY A HEATED SURFACE WITH ALLOWANCE FOR CONCENTRATED DIFFUSION. Inzhenerno- Fizicheskii Zhurnal 16, 811 (May 1969) (in Russian). (A69-31955)

80. Gruzdev, V. N. and Talantov, A. V., INFLUENCE OF THE TURBULENCE CHARACTERISTICS OF THE FLOW ON FLAME STABILIZATION BY MEANS OF A BLUFF BODY. Aviatsionnaia Tekhnika 12, 69 (1969). (in Russian) (A69-43078)

81. Guarise, G. B. and Menin, G., THE COMBUSTION EFFICIENCY OF THE GASEOUS OXYGEN/JP-4 PROPELLANT SYSTEM. Riv. Combust. 22, 585 (1968).

82. Gussak, L. A., Sprintsina, E. N., Shchelkin, K. I., STUDY OF THE STABILITY OF A NORMAL FLAME FRONT. Fizika Goreniia i Vzryva 4, 358 (1968). (in Russian). (A69-20344)

BIBLIOGRAPHY (Contd)

83. Hersh, S., Frey, H. M., and Gerstein, M. (Dynamic Science, Monrovia, Ca.), COMBUSTION CHEMISTRY AND MIXING IN SUPERSONIC FLOW. PHASE I. Final Report April 1, 1966 - March 31, 1968, Report No. DS-TR-A-69-101, Contract AF 49(638)-1712, Proj. AF-9711, Task 971101. AFOSR 69-0104TR. (Jan. 10, 1969) (AD 849 506)

84. Heyman, R. J., Sanderson, R. J., Steel, P. C. (Martin Marietta Corp.), COMBUSTION IN COMPRESSIBLE MIXING FLOWS. Combustion Institute, Fall Meeting, Menlo Park, Calif., Oct. 28, 29, 1968, Paper 68-28. (A69-17794)

85. Horn, K. P., Kolpin, M. A., Reichenbach, R. E., A STUDY OF PENETRATION OF A LIQUID INJECTANT INTO A SUPERSONIC FLOW. Aerospace Corp. TR-0158(3220-10)-1; SAMSO-TR-67-65, Contract F04695-67-C-0158, October 1967. (N68-17908)

86. Ise, H. and Yamazaki, K., RELATION OF ADIABATIC FLAME TEMPERATURE WITH THE TYPE OF HYDROCARBONS. Sekiyu Gakkai Shi 12, 519 (1969). (in Japanese)

87. Ise, H. and Yamazaki, K., SURFACE IGNITION OF GASEOUS (AND LIQUID) HYDROCARBONS. Kogyo Kagaku Zasshi 72, 867, A42 (1969). (in Japanese).

88. Istratov, A. G., and Librovich, V. V., STABILITY OF FLAMES. Gidromekhanika, Moscow, 1965; U.S. Air Force Trans., October 1969. (AD 695 726)

89. Ivanov, V. M., Alekseyev, A. M., Volnyanskaya, L. A., EFFECT OF MIXTURE FORMATION ON THE COMBUSTION PROCESS OF GASEOUS FUEL IN A HIGH SPEED STREAM. Novyye Metody Szhiganiya Toppiv i Vopr. Teorii Goreniya (USSR), 1965; U.S. Air Force Trans. FTD-HT-23-509-67, September 1967. (AD 671 586) (N68-32387)

90. Johns Hopkins Univ., Applied Physics Lab., AN EXPLORATORY STUDY OF ORGANOMETALLIC FUEL COMBUSTION IN A SUPERSONIC COMBUSTOR. Report No. APL-TG-1025, IDEP-563.700.00.00-56-01. (AD 846 294L)

91. Johns Hopkins Univ., Applied Physics Lab., RESEARCH AND EXPLORATORY DEVELOPMENT FOR THE OFFICE OF AERONAUTICAL RESEARCH, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION. Report No. APL-NQR 69-3; U.S. Navy Contract NOW-62-0604. (AD 506 460)

92. Kaganov, S. A., STATIONARY THEORY OF THERMAL SELF-IGNITION. Zh. Prik. Mekhan. i Techn. Fiz. (Moscow) 1963, 221; U.S. Air Force Trans. FTD-MT-64-84, April 1967. (AD 663 337) (N68-17722)

93. Kassoy, D. R. and Williams, F. A. (Univ. of Calif., San Diego), VARIABLE PROPERTY EFFECTS ON LIQUID DROPLET COMBUSTION. AIAA Aerospace Sciences Meeting (6th), New York, January 22-24, 1968, Paper 68-181;AIAA Journal 6, 1961 (1968). (AD 680 132)

94. Klimov, A. M., THE MECHANISM OF TURBULENT COMBUSTION. Teoriya i Praktika Szhiganiya Gaza, Leningrad, 1967, 167; U.S. Air Force Trans. No. FTD-HT-23-1407-68, April 1969. (AD 695 215)

BIBLIOGRAPHY (Con'd)

95. Knorre, G. F., Arefev, K. M., Blokh, A. G., Nakhapetyan, E. A., Paleev, I. I., THEORY OF COMBUSTOR PROCESSES. VOLUMES I AND II. Moscow/Leningrad, 1966; U.S. Air Force Trans., December 1968. (AD 696 296) (AD 696 297)

96. Kondrat'ev, V. N., KINETICS OF THE COMBUSTION REACTIONS OF GASEOUS-PHASE SYSTEMS. Fizika Goreniia i Vzryva 4, 446 (1968). (in Russian)(A69-25185)

97. Kosterin, V. A., Dudin, L. A., Motylinskii, I. P., Khismatullin, A. Ia., Giliazov, M. Sh., GENERALIZATION OF EXPERIMENTAL DATA CONCERNING THE LIMITS OF FLAME STABILIZATION BY MEANS OF JETS. Aviatsionnaia Tekhnika 11, 59 (1968) (in Russian). (A69-12956)

98. Kotake, S. and Okazaki, T., EVAPORATION AND COMBUSTION OF A FUEL DROPLET. International J. Heat Mass Transfer 12, 595 (1969). (A69-37520)

99. Kowalewicz, A., MECHANISM OF SPARK IGNITION OF LIQUID FUEL DROPLETS ATOMIZED IN AIR. Archiwum Budowy Maszyn 15, 545 (1968) (in Polish). (A69-22220)

100. Kudryavtsev, A. V., THE INFLUENCE OF EVAPORATION OF FUEL ON THE IGNITION DELAY OF TWO-PHASE MIXTURES. Fizika Goreniya (Combustion Physics), Kiev, 1966, 94; U.S. Air Force Trans. No.FTD-HT-23-289-68, June 1969. (AD 693 454)

101. Kurkov, A. P., A THEORETICAL STUDY OF FLAME EXTINCTION BY A COLD WALL AND FLAME IGNITION BY A HOT SURFACE. Ph.D. Thesis, Univ. of Michigan, Univ. Microfilms Order No. 68-7652, 1967. (N69-15107)

102. LaPointe, C. W. (Michigan Univ., Ann Arbor, Mich.), AN EXPERIMENTAL STUDY OF COAXIAL TURBULENT MIXING OF LIQUID AND GASEOUS FUEL WITH AIR. Annual Technical Report No. 2, 15 Nov 67 - 15 Nov 68. Contract F33615-67-C-1122, AFAPL TR-69-64. (August, 1969) (AD 857 637)

103. LaPointe, C. W. (Michigan Univ., Ann Arbor, Mich.), SUPERSONIC MIXING AND COMBUSTION. Annual Technical Report No. 1, 15 Nov 66 - 15 Nov 67. Contract F33615-67-C-1122, AFAPL TR-68-12. (March, 1968) (AD 831 896)

104. Ledwell, T. A. and Brzustowski, T. A., A SIMPLE QUASISTEADY MODEL OF THE COMBUSTION OF A FUEL DROPLET WITH CONVECTION, INCLUDING THE EFFECT OF PRESSURE. AIAA, Aerospace Sciences Meeting, 7th, New York, January 20-22, 1968, Paper 69-147. (A69-18114)

105. Lee, J. H., and Knystautas, R., LASER SPARK IGNITION OF CHEMICALLY REACTIVE GASES. AIAA Aerospace Sciences Meeting, 6th, New York. January 22-24, 1968, Paper No. 68-146; AIAA Journal 7, 312 (1969).

106. Linan, A., Urrutia, J. L., Fraga, E.(Inst. Nac. Tec. Aeroespacial, Madrid, Spain), DIFFUSIVE SUPERSONIC COMBUSTION. Aerosp. Proc., London 1966, 2, 607.

107. Long, G. A., IGNITION OF FUEL DROPLETS IN HOT STAGNANT GASES. Univ. of Ca., Lawrence Radiation Lab. Report No. UCRL-17811 (M.S. Thesis), Contract No. W-7405-ENG-48, September 1967. (N68-16885)

BIBLIOGRAPHY (Contd)

108. Luebben, M., COMBUSTION AND MIXING PROCESSES IN TURBULENT DIFFUSION FLAMES. Ph.D. Thesis, Technische Hochschule Hannover, West Germany, 1966. (in German) (N68-15044)

109. Macfarlane, J. J. and Topps, J. E. C. (National Gas Turbine Establishment, Farnborough, England), AN EXPERIMENTAL STUDY OF HEAT RELEASE RATES DURING THE EXPANSION OF DISSOCIATED COMBUSTION PRODUCTS. Report No. NGTE-R-295, December 1967. (AD 843 223)

110. Malte, D. C. (Martin Marietta Corp.), TURBULENT TRANSPORT IN A COMBUSTING SHEAR FLOW. Combustion Institute, Fall Meeting, Menlo Park, Calif., Oct. 28, 29, 1968, Paper 68-27. (A69-17793)

111. Marquardt Corp., SUPERSONIC COMBUSTION OF HYDROCARBON FUELS WITH AIR PILOTS, Report No. MR-S-936, U.S. Air Force AFAPL-TR-69-71. (AD 505 181)

112. Meyer, S. W. and Schieler, L., ACTIVATION ENERGIES AND RATE CONSTANTS COMPUTED FOR THE COMBUSTION OF HYDROCARBON AND HYDROGEN FUELS. Aerospace Corp., Aerodynamics and Propulsion Research Lab. Report No. SAMSO-TR-68-188, TR-0158(9210-02)-3, Contract F04695-67-C-0158, March 1968. (AD 669 827) (N68-30840)

113. McHale, E. T., SURVEY OF VAPOR PHASE CHEMICAL AGENTS FOR COMBUSTION SUPPRESSION. Atlantic Research Corp., U.S. National Aeronautics and Space Admin. Report No. NASA-CR-73263, Contract NAS 2-4988, August 1968. (N68-37380)

114. Meier zu Koecker, H. (Univ. Karlsruhe Tech. Hochsch., Karlsruhe, Ger.), HIGH-PRESSURE COMBUSTION IN OXYGEN DIFFUSION FLAMES. V. EFFECT OF THE OXYGEN-FUEL RATIO AND OXYGEN PRESSURE ON THE COMBUSTION RATE. Brennst.- Chem. 49, 141 (1968).

115. Metzler, A. J. and Lezberg, E. A., A HOT GAS GENERATOR FOR LARGE SCALE SUPERSONIC COMBUSTOR TESTING. Presented at the AIAA Propulsion Joint Specialist Conf., 4th, Cleveland, June 10-14, 1968; U.S. National Aeronautics and Space Admin. Report No. NASA-TM-X-52433, 1968. (N68-34354)

116. Miller, W. J., FLAME IONIZATION AND COMBUSTION INHIBITION. Aerochem. Res. Labs., Inc., Report No. TP-151; TR-1, Contract No. CST-102, January 1967. (N68-17035) PB 173 993, U.S., Clearinghouse Fed. Sci. Tech. Inform.

117. Miller, W. J. (Aerochem. Res. Labs., Inc.). IONIZATION IN COMBUSTION PROCESSES. Oxidation and Combustion Revs. 3, 97 (1968).

118. Mironenko, B. A., CALCULATION OF FLAMEOUT CONDITIONS IN THE WAKE OF A BLUFF BODY FROM THE IGNITION TIME DELAY. Aviatsionnaia Tekhnika 9, 68 (1966); Soviet Aeronautics 9, 42 (Summer 1966)(A69 39092)

119. Mironenko, B. A., USE OF DERIVATIONS OF THERMAL IGNITION THEORY TO DETERMINE THE GENERAL FLAME STABILIZATION CONDITION WITH A BLUFF BODY. Izv. Vysshikh Uchebn. Zavedenii, Aviats. Tekhn. (Kazan) 1, 140 (1966); U.S. Air Force Trans. FTD-HT-23-1066-67, Dec. 1967. (AD 677 215) (N69-14422); Soviet Aeronautics 9, 76 (Spring 1966). (A69-32141)

BIBLIOGRAPHY (Contd)

120. Monaghan, M. T., Siddall, R. G., and Thring, M. W. (Univ. Sheffield, Sheffield England), THE INFLUENCE OF INITIAL DIAMETER ON THE COMBUSTION OF SINGLE DROPS OF LIQUID FUEL. Combust. Flame 12, 45 (1968).

121. Morrison, M. E. and Scheller, K., SPECTRAL CHARACTERISTICS OF HYDROCARBON-AIR FLAMES CONTAINING ALUMINUM, MAGNESIUM AND BORON. U.S. Air Force Report No. ARL-69-0095, Revision of report dated June 1968, October 1968; Combustion and Flame 13, 93 (1969). (AD 690 719)

122. Morrison, M. E., and Scheller, K., THE EFFECT OF BURNING VELOCITY INHIBITORS ON THE IGNITION OF HYDROCARBON-OXYGEN-NITROGEN MIXTURES. U.S. Air Force Aerospace Research Labs. Report No. ARL-WSCI-69-14, April 1969. (AD 691 793) Western Section of the Combustion Inst. Paper No. WSCI-69-14, April 28, 29, 1969.

123. Mullins, B. P. (Gt. Brit. National Gas Turbine Estab.), SPONTANEOUS IGNITION OF LIQUID FUELS. Advisory Group for Aeronautical Research and Development Report No. AGARDograph-4, U.S. Air Force Contract No. AF 18(600)-972, 1955. (AD 688 922)

124. Myers, B. F. and Bartle, E. R., (General Dynamics/Convair, San Diego, Ca.), REACTION TIMES OF HYDROCARBON OXIDATION BEHIND INCIDENT SHOCK WAVES IN A SHOCK TUBE. Report for 15 Jan - 20 Oct 1967, U.S. Air Force Report No. AFAPL-TR-67-152. Contract F 33615-67-C-1382. (January 1968) (AD 826 588)

125. Myers, B. F. and Bartle, E. R. (General Dynamics/Convair), SHOCK-TUBE STUDY OF THE RADIATIVE PROCESSES IN SYSTEMS CONTAINING ATOMIC OXYGEN AND CARBON MONOXIDE AT HIGH TEMPERATURE. J. Chem. Phys. 47, 1783 (1967).

126. Neill, D. W. T., HEAT TRANSFER FROM UNCONTROLLED BUOYANT DIFFUSION FLAMES. Ph.D. Thesis, Univ. of Oklahoma, Univ. Microfilms Order No. 68-9042, 1968. (N69-16774)

127. Newhall, H. K. (Univ. of California, Berkeley), THEORETICAL AND EXPERIMENTAL INVESTIGATION OF CHEMICAL KINETICS DURING RAPID EXPANSIONS OF HIGH-TEMPERATURE COMBUSTION PRODUCTS. Diss. Abstr. B 28(4), 1466 (1967).

128. Nikolayev, S. N., INTENSIFICATION OF A PRESSURE WAVE IN A COMBUSTION ZONE. Chuvashskiy Gosudarstvennyy Pedsgogicheskiy Institut. Uchenyye Zapiski, USSR, No. 20, 1964, 12; U.S. Air Force Trans.FTD-HT-23-34-68, January 1968. (AD 672 905) (N68-35408)

129. Oklahoma Univ. Research Inst., HEAT TRANSFER FROM FLAMES. Report No. OURI-1604-FR. (AD 842 444L)

130. Orth, R. C., Schetz, J. A., Billig, F. S., THE INTERACTION AND PENETRATION OF GASEOUS JETS IN SUPERSONIC FLOW. Johns Hopkins, Applied Physics Lab., U.S. National Aeronautics and Space Admin. Report No. NASA-CR-1386, NASA Order R-76, U.S. Navy Contract NOW-62-0604-C, July 1969. (N69-32480)

BIBLIOGRAPHY (Contd)

131. Osgerby, I. T., SIMPLIFIED METHOD FOR SOLVING PROBLEMS INVOLVING CHEMICALLY REACTING ONE-DIMENSIONAL FLOW. Arnold Engineering Development Center Final Report January - April 1967, Report No. AEDC-TR-68-268, Contract No. F 40600-69-C-0001, prepared in cooperation with ARO, Inc., March 1969. (AD 683 260)

132. Palm-Leis, A. and Strehlow, R. A. (Univ. of Illinois, Urbana), ON THE PROPAGATION OF TURBULENT FLAMES. Combust. Flame 13, 111 (1969). (A69-28452)

133. Pantazopol, D. and Comanescu, Tr., SUPERSONIC COMBUSTION AROUND A CONICAL OBSTACLE. Revue Roumaine des Sciences Techniques, Serie de Mecanique Appliquee 13, 785 (1968) (in French). (A69-31007)

134. Parsons, R. J., SUPERSONIC COMBUSTION RESEARCH TECHNIQUES IN A HYPERSONIC SHOCK TUNNEL. Doctoral Thesis, Sheffield Univ. (England), Dept. of Fuel Technology and Chemical Engineering, March 1969. (AD 700 143)

135. Peeters, J. Vinckier, C., Van Tiggelen, A., FORMATION AND BEHAVIOR OF CHEMI-IONS IN FLAMES. Oxidation and Combustion Reviews 4, 93 (1969).

136. Penner, S. S., Linnett, J. W., Mullins, B. P., Crocco, L., Surugue, J., TECHNICAL PRESENTATIONS BEFORE THE AGARD COMBUSTION PANEL. Advisory Group for Aeronautical Research and Development (France) Report No. AGARD-AG/P2, December 1952. (AD 688 682)

137. Peters, C. E., Phares, W. J., Cunningham, T. H. M., THEORETICAL AND EXPERIMENTAL STUDIES OF DUCTED MIXING AND BURNING OF COAXIAL STREAMS. J. Spacecraft and Rockets 6, 1435 (1969).

138. Peters, C. E., TURBULENT MIXING AND BURNING OF COAXIAL STREAMS INSIDE A DUCT OF ARBITRARY SHAPE. Arnold Engineering Development Center Final Report No. AEDC-TR-68-270, Contract F 40600-69-C-0001, prepared in cooperation with ARO, Inc., January 1969. (AD 680 397) (N69-24561)

139. Pistolesi, E. and Marini, M., PENETRATION AND INTERACTION OF A TRANSVERSE JET AND A SUPERSONIC STREAM. Univ. of Pisa, Italy, Inst. of Aeronautics, U.S. Air Force AFOSR-68-1409, Grant No. AF-EOAR-47-65, May 1968. (AD 671 508) (N68-33258)

140 Plastinin, Iu. A., RADIATIVITY AND SPECTRUM ABSORPTION COEFFICIENTS OF COMBUSTION PRODUCTS. Prikl. Mekhn i Tech. Fiz (USSR) 1969, 86; Lockheed Missiles and Space Co. Trans. (N69-34076)

141. Polvektov, V. A., Pshezhetskii, S. Ya., Cherednichenko, V. M., THE EFFECT OF FLUORINE ON THE CRITICAL CONDITIONS OF IGNITION WITH OXYGEN OF SOME HYDROCARBONS. Zh. Fiz. Khim. 43, 1747 (1969).

142. Pogorel'skii, A. E. (USSR), CALCULATION OF MINIMUM IGNITION ENERGY AND ITS DEPENDENCE ON CONSTANTS OF EXPLOSIVE MIXTURES. Sb. Nauch. Tr., Gos. Inst. Proekt. Issled. Vzryvobezop. Elektrooborud. "Giproniselektroshakht" 1967, 14, (Russ) From Ref. Zh., Khim. 1968, Abstr. No. 8B969.

BIBLIOGRAPHY (Contd)

143. Polymeropoulos, C. E. and Peskin, R. L. (Rutgers Univ.), IGNITION AND EXTINCTION OF LIQUID FUEL DROPS -- NUMERICAL COMPUTATIONS. Combust. Flame 13, 166 (1969). (A69-28456)

144. Rao, N.. DETERMINATION OF THE STABILITY LIMITS OF FLAMES. Chem.-Ing.-Tech. 40 , 771 (1968).

145. Rein, C. R., A METHOD FOR MEASURING THE TEMPERATURE DISTRIBUTION IN STABILIZED FLAMES. Tulane Univ., Diss., 1968; (Abstr.) Diss. Abstr. B29(5), 1696B-7B (November 1968).

146. Rozlovskii, A. I., THE THERMAL CONDITIONS OF BURNING RICH HYDROCARBON-CONTAINING MIXTURES OF SUBCRITICAL COMPOSITION. Dokl. Akad. Nauk SSSR 186, 373 (1969) (in Russian).

147. Saad, M. A. and Goldwasser, S. R., ROLE OF PRESSURE IN SPONTANEOUS IGNITION. AIAA Journal 7, 1574 (1969).

148. Salooja, K. C. (Shell Research, Ltd.), COMBUSTION STUDIES OF OLEFINS AND OF THEIR INFLUENCE ON HYDROCARBON COMBUSTION PROCESSES. Combustion and Flame 12, 401 (1968). (A69-12309)

149. Salooja, K. C. (Shell Research, Ltd.), IGNITION BEHAVIOURS OF MIXTURES OF HYDROCARBONS. Combustion and Flame 12, 597 (1968). (A69-17935)

150. Sanematsu, H. S. (Univ. of Southern Calif.), TURBULENT FLAME PROPAGATION IN A HOMOGENEOUS GAS MIXTURE. Combustion and Flame 13, 1 (1969). (A69-24473)

151. Sanematsu, H. S. (Univ. of Southern Calif.), TURBULENT FLAME PROPAGATION PARAMETERS. Combustion and Flame 13, 91 (1969). (A69-24482)

152. Scaggs, N. E. and Dunn, R. G., A TEST FACILITY FOR SUSTAINED SUPERSONIC COMBUSTION AT LOW DENSITIES. U.S. Air Force Aerospace Research Labs. Rept. No. ARL-69-0057, April 1969; Proc. AIAA Aerodynamic Testing Conf., 4th, Cincinnati, Ohio, April 28-30, 1969, AIAA Paper 69-340. (AD 690 418)

153. Schetz, J. A. (Johns Hopkins Univ.), ANALYSIS OF THE MIXING AND COMBUSTION OF GASEOUS AND PARTICLE-LADEN JETS IN AN AIR STREAM. AIAA, Aerospace Sciences Meeting, 7th, New York, Jan. 20-22, 1969, Paper 69-33. (A69-18146)

154. Schetz, J. A., Gilreath, H. E., Waltrup, P. J. and Lewis, D. P. (Maryland Univ., College Park, Dept. of Aerospace Engineering), RESEARCH ON SLOT INJECTION INTO A SUPERSONIC AIR STREAM. Final Report 16 Jan 67 - 16 Aug 68, Report No. Aero-68-1, Contract F 33615-67-C-1805, Proj. AF-3012, Task 301206, AFAPL TR-68-97. (Sept. 1968) (AD 839 872)

155. Schwar, M. J. R. and Weinberg, F. J., LASER TECHNIQUES IN COMBUSTION RESEARCH. Combust. Flame 13 , 335 (1969).

156. Sforza, P. M. and Porter, L. P., COUPLED RADIATION AND CONDUCTION IN FREE MIXING. Polytechnic Inst. of Brooklyn Report No. PIBAL-1005, July 1967. (AD 659 475) (N68-10588)

BIBLIOGRAPHY (Contd)

157. Shchetinkov, E. S., THE PHYSICS OF THE COMBUSTION OF GASES. VOLUMES I AND II. Moscow, 1965; U.S. Air Force Trans., May 1969. (AD 696 520) (AD 696 318)

158. Simon, H. D., MEASUREMENT OF EMISSION VARIATIONS IN TURBULENT DIFFUSION FLAMES. Chem.-Ing.-Tech. (Weinheim/Bertstrasse) 40, 121 (1968); National Lending Library for Science and Technology, Boston Spa, England Trans. SMRE-TRANS-5611, June 1968. (N68-32592)

159. Sioui, R. H., A STUDY OF THE BURNING CONSTANTS OF HYDROCARBON FUEL DROPLETS. Ph.D. Thesis, Univ. of Mass., Univ. Microfilms Order No. 69-4185, 1968. (N70-20187)

160. Skinner, J. H. (General Electric Co., Research and Development Center), DEVELOPMENT OF STEADY FLOW IN THE WAKE OF A PLANE FLAME. ASME, Applied Mechanics and Fluids Engineering Conference, Evanston, Ill., June 16-18, 1969, Paper 69-FE-33. (A69-37993)

161. Slack, M. W., Bray, K. N. C., East, R. A., Pratt, N. H., THE STEADY EXPANSION OF SHOCK HEATED GASES FOR RECOMBINATION STUDIES. Presented at Intern. Shock Tube Symp., 6th, Freiburg, April 12-14, 1967; Southampton Univ. (England), Dept. of Aeronautics and Astronautics Rept. No. AASU-272, 1967. (N68-19201)

162. Smoot, L. D., Coates, R. L., Simonsen, J. M. (Brigham Young Univ.), MIXING AND COMBUSTION OF COMPRESSIBLE, PARTICLE-LADEN DUCTED FLOWS. AIAA, Propulsion Joint Specialist Conference, 5th, U.S. Air Force Academy, Colorado Springs, Colo., June 9-13, 1969, Paper 69-460. (A69-32650)

163. Sokolik, A. S., Karpov, V. P., Semenov, E. W., THE TURBULENT COMBUSTION OF GASES. Fiz. Goreniya i Vzryva (USSR) 1967, 61; National Lending Library for Science and Technology, Boston Spa, England Trans. No. 1142, May 1968. (N68-33612)

164. Sokolik, A. S., Karpov, V. P., and Semenov, E. S., MACROKINETIC CHARACTERISTICS OF TURBULENT FLAMES. KINETIC ANALYSIS OF PULSATING FLAME PROPAGATION MODELS. Teor. Prakt. Szhiganiya Gaza, Nauch.-Tekh. Obshchest. Energ. Prom. 3, 150 (1967) (Russ.); U.S. Air Force Trans. FTD-MT-24-289-68, October 1968. (AD 685 958) (N69-32987)

165. Solokhin, E. L. and Mironenko, V. A., EXPERIMENTAL INVESTIGATION OF FLAME STABILIZATION IN A HIGH-TEMPERATURE AIR JET AT LOW PRESSURE. Aviatsionnaia Tekhnika 11, 138 (1968) (in Russian). (A69-12968)

166. Spadaccini, L. J., Chinitz, W. (Gen. Appl. Sci. Lab. Inc.), SUPERSONIC COMBUSTION OF PROPANE. AIAA J. 6, 1391 (1968).

BIBLIOGRAPHY (Contd)

167. Spengler, G. and Kern, J., STUDIES OF DIFFUSION FLAMES. CONCENTRATION DISTRIBUTION IN A HEXANE DIFFUSION FLAME. Brennst.-Chem. 50(11), 321 (1969).

168. Strehlow, R. A. (Univ. of Illinois), FUNDAMENTALS OF COMBUSTION. International Textbook Co., Scranton, Pa., 1968. (A69-10906)

169. Sviridov, Yu. B., THE NATURE OF IGNITION OF ATOMIZED FUELS FROM THE DIFFUSION AND KINETICS POINT OF VIEW. Tr. Akad. Nauk SSSR, Inst. Dvigatelei 1960, 98; U.S. Air Force Trans. No. FTD-MT-24-84-68, May 1968. (AD 680 994)

170. Swithenbank, J. and Parsons, R. J. (Sheffield Univ., England), EXPERIMENTAL TECHNIQUES FOR SUPERSONIC COMBUSTION RESEARCH IN A SHOCK TUNNEL. Propulsion and Energetics Panel Meeting on New Exptl. Tech. in Propulsion and Energetics Probl. (30th), Munich, Sept. 1967. (N68-11770)

171. Talantov, A. V., RESEARCH ON COMBUSTION IN FLOW. Izv. Vysshikh Uchebnykh Zavedinii. Aviatsionnaya Tekhnika (USSR), 40th Jubilee, 55, 1967; U.S. A.F. Trans. FTD-MT-24-209-68, August 1968. (AD 685 422)

172. Talantov, A. V., INVESTIGATION OF COMBUSTION IN A FLOW. Izv. Vyssh. Ucheb. Zaved. Aviats. Tekhn. (Kazan) 1967, 55; National Lending Library for Science and Technology, Boston Spa, England Trans. SMRE-TRANS-5599, August 1968. (N68-35810)

173. Thring, M. W., Ducarme, J., Fabri, J. and Price, P. H., SELECTED COMBUSTION PROBLEMS. II. TRANSPORT PHENOMENA; IGNITION; ALTITUDE BEHAVIOUR AND SCALING OF AEROENGINES. Advisory Group for Aeronautical Research and Development (France). (AD 853 935)

174. Tiul'panov, R. S. and Alimpiev, A. I., EXPERIMENTAL STUDY OF THE STABILITY OF FUEL DROPLET COMBUSTION IN A TURBULENT FLOW. Fizika Goreniia i Vzryva 4, 377 (1968) (in Russian). (A69-20345)

175. Toong, Tau-Yi, (Mass. Inst. of Tech. Dept. of Mech. Eng.), BASIC MECHANISMS OF COMBUSTION INSTABILITY AND SHOCK INITIATED SUPERSONIC COMBUSTION. Final Scientific Report, January 1969. Contract AF 49(638)-1354, Proj. AF-9711, Task 971101. AFOSR 69-0187TR. (AD 849 630)

176. Tsai, R. S. (Wright-Patterson AFB, Dayton, Ohio), DISCUSSION OF THE FORMULA USED IN COMPUTING THE AMOUNT OF FUEL REQUIRED TO PRODUCE COMBUSTION GASES AT A GIVEN TEMPERATURE IN A COMBUSTION CHAMBER OR AN AFTERBURNER. (1965). (AD 625 788)

177. Tyulpanov, R. S. and Sobolev, O. P., COMBUSTION OF A POLYDISPERSE LIQUID FUEL JET. Fiz. Goreniya i Vzryva (USSR) 3, 94 (1967); Johns Hopkins Univ., Applied Physics Lab. Trans. No. APL-Trans-2128, Contract No. NOW-62-0604, March 1968. (AD 689 785)

178. van Tiggelen, P. and Duval, A., THE CONCEPT OF A MEAN TEMPERATURE IN THE FLAME REACTION ZONE. Bull. Cl. Sci., Acad. Roy. Belg. 53, 326 (1967).

BIBLIOGRAPHY (Contd)

179. van Tiggelen, A., REACTION KINETICS IN DIFFERENT TYPES OF DEFLAGRATIONS. Louvain Univ. (Belgium), Propulsion Div. Final Report, U.S. Air Force Report No. AFOSR-68-2634, Grant No. AF-EOAR-44-66, October 1968. (AD 678 214)

180. van Tiggelen, A., and DeJaegere, S., IONS PRODUCED BY CHEMICALLY REACTING SYSTEMS. Louvain Univ., Belgium, May 1969. (AD 695 498)

181. Vilyunov, V. N., HEAT THEORY OF IGNITION. Fiz. Goreniya i Vzryva (USSR) 1966, 77; U.S. Air Force Trans. No. FTD-HT-23-739-68, Sept. 1968. (AD 684 636)

182. Vilyunov, V. N., CRITICAL CONDITION OF IGNITION OF GAS MIXTURES BY A HOT FOCUS, AND THE LAWS OF ESTABLISHMENT OF STEADY FLAME PROPAGATION. Fizika Goreniia i Vzryva 4, 513 (1968) (in Russian). (A69-25190)

183. Vinckier, J. and van Tiggelen, A., STRUCTURE AND BURNING VELOCITY OF TURBULENT PREMIXED FLAMES. Combustion and Flame 12 , 561 (1968). (A69-17931)

184. Vinogradov, N. S., PRINCIPLES AND METHODS OF FLAME MODELING IN GAS TURBINE COMBUSTION CHAMBERS. Nauchno-Tekhnicheskoe Obshchestvo Energeticheskoi Promyshlennosti Tsentralnoe Pravlenie Sektsiya Gazifikatsii Teoriya i Praktika Szhiganiya Gaza, Leningrad, 1967; U.S. Air Force Trans. FTD-MT-24-523-68, June 1969. (AD 694 779)

185. Voinov, A. N. and Skorodelov, D. I., INVESTIGATION OF THE PECULARITIES OF PREFLAME PROCESSES AND IGNITION OF HYDROCARBONS OF VARIOUS STRUCTURES. PART I: VARIATION OF COOL FLAME DELAY AND IGNITION DELAY WITH COMPRESSION TEMPERATURE AND PRESSURE. Kinetika i Kataliz (USSR) 8, 252 (1967); Shell Research Ltd. Trans. No. 1137, 1967. (N68-19175)

186. Vranos, A. and Nolan, J. J., SUPERSONIC MIXING OF A LIGHT GAS IN AIR. AIAA Propulsion Joint Specialist Conference, Colorado Springs, Colo., June 1965. (Not Preprinted).

187. Vulis, L. A., Erchin, Sh. A., Iarin, L. P., CHAPTER 4. COAXIAL TURBULENT JETS AND FLAMES. "PRINCIPLES OF GAS FLAME THEORY". Transl. into English from Energiia Press (Leningrad), 1968. (N68-36195)

188. Vulis,L. A., Erchin, Sh. A., Iarin, L. P., CALCULATION OF A HOMOGENEOUS TURBULENT GAS FLAME. Fizika Goreniia i Vzryva 1966, 79 ; Combustion, Explosion, and Shock Waves 2,45 (Spring 1966).(A69-19998)

189. Walburn, P. G., ACTIVATION ENERGIES IN A BAFFLE STABILIZED FLAME. Combustion and Flame 12, 550 (1968). (A67-17930)

190. Walker, D. W., Drehl, L. A., Strauss, W. A., and Edse, R.,(Ohio State Univ., Columbus, Ohio), INVESTIGATION OF THE IGNITION PROPERTIES OF FLOWING COMBUSTIBLE GAS MIXTURES. Final Technical Report. 15 Apr 68 - 14 Jul 69. Contract F 33615-68-C-1580, Proj. AF-3012, Task 301206, AFAPL TR-69-82. (September, 1969). (AD 863 260)

BIBLIOGRAPHY (Contd)

191. Walker, W. F., A NUMERICAL SOLUTION FOR THE INTERACTION OF A MOVING SHOCK WAVE WITH A TURBULENT MIXING REGION. Oklahoma State Univ. Ph.D., Univ. Microfilms No. 67-7309, 1966. (N68-19814)

192. Watton, A., Jr., THE MECHANISM OF THE FUEL-MIXING PROCESS IN DIFFUSION-TYPE SUPERSONIC COMBUSTION. Ohio State Univ., Diss. (1968); (Abstr.) Diss. Abstr. B 29(12), 4630 B (June 1969).

193. Watton, A. (U.S. Air Force), THE FUEL-MIXING MECHANISM IN DIFFUSION-TYPE SUPERSONIC COMBUSTION. AIAA, Aerospace Sciences Meeting, 7th, New York, Jan. 20-22, 1969, Paper 69-32. (A69-19266)

194. Watton, A., Jr., THE MECHANISM OF THE FUEL-MIXING PROCESS IN DIFFUSION-TYPE SUPERSONIC COMBUSTION. U.S. Air Force, Aeronautical Systems Div. Report No. ASD-TR-68-52, September 1968. (AD 685 781) (N69-31825)

195. White, D. R. (Gen. Elec. Co., Schenectady, N.Y.), SHOCK-WAVE-INDUCED REACTIONS. U.S., Clearinghouse Fed. Sci. Tech. Inform. (AD 646 559)

196. Williams, A., MECHANISM OF COMBUSTION OF DROPLETS AND SPRAYS OF LIQUID FUELS. Oxidation and Combustion Revs. 3, 1 (January 1968).

197. Winterfield, G., FLAME STABILIZATION IN SUPERSONIC FLOWS AT LOW GAS TEMPERATURES. Presented at Ann. Meeting of WGLR, Bad Godesberg, W. Germany, Oct. 1966; Gt. Brit. Royal Aircraft Estab. Trans. No. RAE-LIB-TRANS-1230, June 1967. (N68-12850)

198. Wislicki, B., ASSESSMENT OF KEROSENE FUELS FOR TURBINE ENGINES USING MODEL COMBUSTION CHAMBERS. Technika Lotnicza i Astronautyczna 24, 22 (1969) (in Polish). (A69-27932)

199. Wood, B. J., and Rosser, W. A., Jr., AN EXPERIMENTAL STUDY OF FUEL DROPLET IGNITION. AIAA Journal 7, 2288. (1969)

200. Yarin, L. P., MATHEMATICAL ANALYSIS OF DIFFUSION COMBUSTION IN THE BOUNDARY LAYER OF A HIGH-VELOCITY STREAM. Problemy Teploenergetiki i Prikladnoi Tiplofizik, (USSR)No. 3, 80; A.I. Schidlovsky, Johns Hopkins Univ., Applied Physics Lab. Trans. No. APL-CLB-3-T-575, U.S. Navy Contract NOW-62-0604, February 1969. (AD 684 569)

201. Yeh, P. S., A THEORETICAL STUDY OF THE EFFECT OF CONVECTION ON IGNITION AND COMBUSTION OF LIQUID FUEL DROPLETS. Ph.D. Thesis, Rutgers Univ., 1967, Univ. Microfilms Order No. 67-14772. (N68-32341)

202. Zimont, V. L. and Trushin, Yu. M., IGNITION DELAY OF HYDROCARBON FUELS AT HIGH TEMPERATURES. Fiz. Goreniya Vzryva 3, 86 (1967) (Russ).

203. Zotin, V. K. and Talantov, A. V., INFLUENCE OF INITIAL TEMPERATURE ON THE PROPAGATION VELOCITY OF A FLAME IN A TURBULENT FLOW OF A HOMOGENEOUS MIXTURE. Aviatsionnaia Tekhnika 9, 115 (1966); Soviet Aeronautics 9, 90 (Spring 1966). (A69-32138)

BIBLIOGRAPHY (Contd)

Advanced Engine Development

1. Abramoski, J. W., TV-23 FUEL SYSTEM FUNCTIONAL TEST AND COMPONENT INSPECTION. Lockheed Missiles and Space Co. Report No. LMSD-3147, U.S. Air Force Contract AF 33(600)-28692, January 1957. (AD 802 638).

2. Advisory Group for Aerospace Research and Development, France, ADVANCED COMPONENTS FOR TURBOJET ENGINES, PART 2. Meeting of the Propulsion and Energetics Panel of AGARD, 32nd, Toulouse, September 9-13, 1968, Report No. AGARD-CP-34-PT-2, September 1968, (N69-26526). Partial Contents:
Quillevere, A., DEVELOPMENT OF HIGH INTENSITY COMBUSTION CHAMBERS.
Odgers, J., HIGH INTENSITY COMBUSTION: SOME THOUGHTS ON ITS ATTAINMENT WITHIN AIRCRAFT GAS TURBINE COMBUSTION CHAMBERS.
Winterfield, C., ON THE BURNING LIMITS OF FLAME HOLDER-STABILIZER FLAMES IN SUPERSONIC FLOW.
Horgan, J. J. and Waring, D. B., SUPERSONIC NOZZLES.
Bauger, L., THE EFFECT ON OUTPUT OF REHEATING TURBOREACTORS INTENDED FOR SUPERSONIC PLANES.

3. AMSA System Studies. Task S-14j. AMSA SUPERSONIC STUDY. North American Rockwell Corp., Los Angeles Div. Report No. NA-68-884. (AD 393 528L)

4. Anderson, L. R. and Heiser, W. H. (United Aircraft Corp., Pratt and Whitney Aircraft Div.), SYSTEMATIC EVALUATION OF COOLED TURBINE EFFICIENTY. ASME, Annual Gas Turbine Conference and Products Show, 14th, Cleveland, Ohio, March 9-13, 1969, Paper 69-GT-63. (A69-22517)

5. Army Materiel Command, Washington, D.C., ENGINEERING DESIGN HANDBOOK. ELEMENTS OF AIRCRAFT AND MISSILE PROPULSION. July, 1969, Report No. AMC-PAM-706-285. (AD 861 082)

6. Back, L. H., Cuffel, R. F., Massier, P. F. (Calif. Inst. Technol.), LAMINARIZATION OF A TURBULENT BOUNDARY LAYER (OF A GAS) IN NOZZLE FLOW-BOUNDARY LAYER AND HEAT TRANSFER MEASUREMENTS WITH WALL COOLING. Amer. Soc. Mech. Eng. - A.I.Ch.E. Joint Heat Transfer Conference, Aug. 3-6, 1969, Paper No. 69-HT-56 (Abstr. Mech. Eng. 91(11), 65-73 (Nov. 1969).

7. Balanin, B. A., LENGTH OF THE MIXING CHAMBER OF A SUPERSONIC NOZZLE AT A ZERO NOZZLE COEFFICIENT. Inzh. - Fiz. Zh. (Moscow) 13(4), 564-7 (1967); U.S. Air Force Trans. No. FTD-MT-24-346-68, October 1968; U.S. National Aeronautics and Space Admin. Trans. No. NASA-TT-F-11739, June 1968. (AD 685 496) (N68-28525)

8. Barber, R. E., EFFECT OF PRESSURE RATIO ON THE PERFORMANCE OF SUPERSONIC TURBINE-NOZZLES. Sunstrand Aviation-Denver, Barber-Nichols Eng. Co., Summary Report, Report No. AER-486, Contract No. N00014-66-C-02-04, 1967, 44 pp. (AD 689 384) (N69-37168)

BIBLIOGRAPHY (Contd)

9. Barningham, R. C., COMPONENT PROPULSION PROGRAM FOR FUTURE HIGH-PERFORMANCE STRATEGIC AIRCRAFT. Pratt and Whitney Aircraft Semiannual Report No. 3, 1 August 1966 - 31 January 1967. U.S. Air Force Contract AF 33(657)-14903. February 1967. (Report Classified Confidential)
   VOLUME III. CYCLE PERFORMANCE STUDIES. Report No. PWA-2991-Vol-3. (AD 379 042L)
   VOLUME IV. ENGINE DESIGN STUDIES. Report No. PWA-2991-Vol-4. (AD 379 043L)
   VOLUME V. INLET SCALE MODEL. Report No. PWA-2991-Vol-5. (AD 379 044L)
   VOLUME VI. FAN AND LOW PRESSURE COMPRESSOR. Report No. PWA-2991-Vol-6. (AD 379 045L)
   VOLUME VII. HIGH PRESSURE COMPRESSOR. Report No. PWA-2991-Vol-7. (AD 379 046L)
   VOLUME IX. BURNERS. Report No. PWA-2991-Vol-9. (AD 379 047L)
   VOLUME X. TURBINE AERODYNAMICS. Report No. PWA-2991-Vol-10. (AD 379 048L)
   VOLUME XI. TURBINE COOLING. Report No. PWA-2991-Vol-11. (AD 379 049L)
   VOLUME XII. AUGMENTERS. Report No. PWA-2991-Vol-12. (AD 379 050L)
   VOLUME XIII. NOZZLES. Report No. PWA-2991-Vol-13. (AD 379 051L)
   VOLUME XV. BEARINGS. Report No. PWA-2991-Vol-15. (AD 379 052L)
   VOLUME XVI. SEALS. Report No. PWA-2991-Vol-16. (AD 379 053L)
   VOLUME XVII. CONTROLS. Report No. PWA-2991-Vol-17. (AD 379 054L)
   VOLUME XVIII. DEMONSTRATOR ENGINE. Report No. PWA-2991-Vol-18. (AD 379 055L)

10. Barrere, M. and Williams, F. A., COMPARISON OF COMBUSTION INSTABILITIES FOUND IN VARIOUS TYPES OF COMBUSTION CHAMBERS. Presented at the 12th Intern. Symp. on Combust., Poitiers, France, July 14-20, 1968; Office National d'Etudes et de Recherches Aerospatiales, Paris France, Report No. ONERA-TP-570, 1968. (N69-18263)

11. Behrens, H., THE UTILIZATION OF THE FIRING TECHNIQUE IN THE SCRAMJET EXPERIMENTS. Institut Franco-Allemand de Recherches (France) Report No. ISL-N-51 67, September 1967. (In German) (N69-17919)

12. Billig, F. S. and Dugger, G. L. (Johns Hopkins Univ., Applied Physics Lab.), THE INTERACTION OF SHOCK WAVES AND HEAT ADDITION IN THE DESIGN OF SUPERSONIC COMBUSTORS. Combustion Institute, International Symposium on Combustion, 12th, Proceedings, Pittsburgh, Combustion Institute, 1969, p. 1125-34, Comments, 1135-39. (A70-12043)

13. Blanc, J. J. (Sud-Aviation, France), AIR BREATHING BOOSTER PROPELLED BY A SUPERSONIC RAMJET. Association Franqaise des Ingenieurs et Techniciens de l'Aeronautique et de l'Espace, Colloque d'Aerodynamique Appliquee, 5th, Poitiers, France, November 6-8, 1968, Paper (in French); Boeing Co., Office of International Operations Trans., January 1969. (N69-29792) (A69-22608)

14. Blondi, D. and Draizen, S., DEVELOPMENT OF A TURBOJET COMBUSTOR WITH A SEGMENTALLY CONSTRUCTED LINER. Curtis-Wright Corp. Final Summary Report No. WAD-R-437. U.S. National Aeronautics and Space Admin. Report No. NASA-CR-54635, Contract No. NAS3-7908, June 1968. (N69-1086[illegible])

BIBLIOGRAPHY (Contd)

15. Boeing Company, Military Aircraft Product Development, ADVANCED MANNED STRATEGIC AIRCRAFT. (AMSA). TASK S-7. TECHNICAL REPORT (FINAL) PROPULSION. Report No. D6-25022-4. (AD 387 404L)

16. Burge, H. L. and Rodewald, N. C., ADVANCED ROCKET ENGINE COOLING CONCEPT PROGRAM, Final Report, July 1968 - January 1969. TRW Systems Group, Science and Technology Div., February 1969. (N69-38273)

17. Burgner, G. R. (Naval Weapons Center, China Lake, California), FEASIBILITY OF PULSEJETS AND INTERMITTENT COMBUSTION DEVICES AS MODERN PROPULSION POWER PLANTS. Report No. NWC-TP-4536. (October, 1968). (AD 845 634)

18. Butze, H. F. Trout, A. M., and Moyer, H. M., PERFORMANCE OF SWIRL-CAN TURBOJET COMBUSTORS AT SIMULATED SUPERSONIC COMBUSTOR-INLET CONDITIONS. U.S. National Aeronautics and Space Admin. Report No. NASA-TN-D-4996, January 1969. (N69-16154)

19. Campanaro, P., FLAME STABILIZATION IN CAN-TYPE COMBUSTORS. Politecnico di Torino, Instituto di Macchine z Motori per Aeromobili Publ-67, Contract CNR-115-0375-200, March 1967. (In Italian; English summary) (N69-35869)

20. Chauvin, J. (ed.), SUPERSONIC TURBO-JET PROPULSION SYSTEMS AND COMPONENTS. Advisory Group for Aerospace Research and Development (France), Report No. AGARDograph-120, Circa Publications, Inc., Pelham, N.Y., August 1969. (AD 701 115) (N70-19902). Partial Contents:
Johnson, E. G., INTRODUCTION TO LECTURES ON SUPERSONIC TURBOMACHINERY.
Hurd, R., SUPERSONIC INLETS.
Chauvin, J., Breugelmans, F., Janigro, A., SUPERSONIC COMPRESSORS.
Ferri, A., SUPERSONIC COMBUSTION TECHNOLOGY.
Halls, G.A., AIR COOLING OF TURBINE BLADES AND VANES.
Casci, C., Ferri, A., Carriere, P., Chauvin, J., Halls, G.A., et al., DISCUSSION ON FUTURE PROBLEMS OF SUPERSONIC FLUID MACHINERY.

21. Chen, T. S., MODEL SCALING RULES FOR TURBOJET AND GAS TURBINE COMBUSTION CHAMBERS. Chi Hsien Kung Ch'eng Hsueh Pao (Peking) 11(4), 41-63 (1963); U.S. Air Force Trans. No. FTD-HT-23-1483-67, August 1968. (AD 683 222)(N69-27137)

22. Collinson, E. S., Gleason, C. C., Kutzko, G. G., TURBO-PROPULSION COMBUSTION SYSTEM EXPLORATORY DEVELOPMENT PROGRAM. General Electric Co. Report No. R66FPD271, U.S. Air Force AFAPL-TR-66-113, November 1966.

23. Colwill, T., Curran, W., Stiglic, P. (Garrett Corp., AiResearch Mfg. Co.), HYPERSONIC RESEARCH ENGINE INTEGRATED PROPULSION CONTROL. AIAA, Propulsion Joint Specialist Conference, 5th, U.S. Air Force Academy, Colorado Springs, Colorado, June 9-13, 1969, Paper 69-546, (A69-32744).

24. Cookson, R. A., SUPERSONIC COMBUSTION STUDIES. 1: DESIGN, CONSTRUCTION AND PERFORMANCE OF A HIGH ENTHALPY FACILITY. College of Aeronautics, Cranfield, England, Report No. CoA-NOTE-AERO-200, November 1967, (N68-28367).

BIBLIOGRAPHY (Contd)

25. Curbishley, G., Jones, O., Larson, W., INVESTIGATION OF MATERIALS TO RESIST HOT CORROSION IN SMALL GAS TURBINE ENGINE RECUPERATORS. Garrett Corp., AiResearch Mfg. Div. Quarterly Report. 1 June - 31 August 1968, QR-5, HT-67-2512-5, U.S. Army Contract No. DAAJ02-67-C-0048, September 1968. (AD 676 182)

26. Deacon, W. (Gt. Brit. Ministry of Technology, National Gas Turbine Estab.), A SURVEY OF THE CURRENT STATE OF THE ART IN GAS TURBINE COMBUSTION CHAMBER DESIGN. Institution of Mechanical Engineers, Technical Advances in Gas Turbine Design, Warwick, England, April 9-11, 1969, Paper 3. (A69-25789)

27. Dettmering, W. and Fett, F., METHODS OF THRUST INCREASE (FOR AIR-BREATHING JET ENGINES) AND THEIR EVALUATION. Zeitschrift fur Flugwissenschaften 17, 257-67 (August 1969). (A69-41578)

28. Dobrowolski, A. and Allen, J. L., CONCEPTUAL STUDY OF ROCKET-SCRAMJET HYBRID ENGINES IN A LIFTING REUSABLE SECOND STAGE. U.S. National Aeronautics and Space Admin. Report No. NASA-TM-D-5218, May 1969. (N69-24922)

29. Donachie, M. J., Jr. and Bradley, E. F. (United Aircraft Corp., Pratt and Whitney Aircraft Div.), JET ENGINE MATERIALS FOR THE 1970'S. Metal Progress 95, 60-4 (March 1969). (A69-22061)

30. Donachie, M. J., Varin, J. D., Berkley, S. G., Sprague, R. A. (United Aircraft Corp., Pratt and Whitney Aircraft Div.), MATERIALS FOR ADVANCED AIR-BREATHING ENGINES. Amer. Soc. for Metals, Materials Engineering Exposition and Congress, Detroit, Mich., October 14-17, 1968, Paper D8-25.2. (A69-38133)

31. Drain, D. I., Burton, W. M., Paulovich, F. J., AIRBREATHING PROPULSION SYSTEM TESTING USING SWEEP FREQUENCY TECHNIQUES. U.S. National Aeronautics and Space Admin. Report No. NASA-TN-D-5485, October 1969. (N69-39185) (A69-35648)

32. Dugan, J. F., Jr. (NASA, Lewis Research Center), FUTURE TECHNOLOGY TRENDS IN AIRBREATHING PROPULSION. AIAA, Aircraft Design and Operations Meeting, Los Angeles, California, July 14-16, 1969, Paper 69-774.

33. Dugger, G. L. (ed.), RAMJETS. New York, American Institute of Aeronautics and Astronautics (AIAA Selected Reprint Series, Volume 6), 1969. (A69-32608). Contents:
Dugger, G. L., PREFACE.
Avery, W. H., TWENTY-FIVE YEARS OF RAMJET DEVELOPMENT.
Rudnick, P., MOMENTUM RELATIONS IN PROPULSIVE DUCTS.
Oswatitsch, Kl., PRESSURE RECOVERY IN MISSILES WITH REACTION PROPULSION AT HIGH SUPERSONIC SPEEDS -- THE EFFICIENCY OF SHOCK DIFFUSERS.
Connors, J. F. and Obery, L. J., SOME CONSIDERATIONS OF HYPERSONIC INLETS.
Foa, J. V. and Rudinger, G., ON THE ADDITION OF HEAT TO A GAS FLOWING IN A PIPE AT SUBSONIC SPEED.
Tsien, H. S. and Beilock, M., HEAT SOURCE IN A UNIFORM FLOW.
Longwell, J. P., COMBUSTION PROBLEMS IN RAMJETS.
Dugger, G. L., RECENT ADVANCES IN RAMJET COMBUSTION.
Avery, W. H. and Hart, R. W., COMBUSTOR PERFORMANCE WITH INSTANTANEOUS MIXING.
Scurlock, A. C., FLAME STABILIZATION AND PROPAGATION IN HIGH-VELOCITY GAS STREAMS.

BIBLIOGRAPHY (Contd)

aum, N., THE GRIFFON AIRCRAFT AND THE FUTURE OF THE TURBO-RAM-JET COMBINATION IN THE PROPULSION OF SUPERSONIC AEROPLANES.
Weber, R. J. and Mackay, J. S., AN ANALYSIS OF RAMJET ENGINES WITH SUBSONIC AND SUPERSONIC COMBUSTION.
Billig, F. S., SUPERSONIC COMBUSTION OF STORABLE FUELS IN MACH 3.0 TO 5.0 AIR STREAMS.

34. Dumnam, M. P. and Bush, H. I. (U.S. Air Force, Aero Propulsion Lab.), AIR-BREATHING PROPULSION -- OPPORTUNITIES UNLIMITED. Astronautics and Aeronautics 7, 64-70 (July 1969). (A69-35339)

35. Fear, J. S. and Tacina, R. R., PERFORMANCE OF A TURBOJET COMBUSTOR USING NATURAL GAS FUEL HEATED TO 1200 F (922K). U.S. National Aeronautics and Space Admin. Report No. NASA-TN-D-5672, February 1970, (N70-18955).

36. Fear, J. S., PRELIMINARY EVALUATION OF A PERFORATED SHEET FILM-COOLED LINER IN A TURBOJET COMBUSTOR. U.S. National Aeronautics and Space Admin. Report No. NASA-TM-X-52705, November 1969. (N70-18941)

37. Fu, Ming, SURVEY OF MODERN AIRCRAFT POWERPLANTS. Hang Kung Chih Shih (Communist China) 2(5), 7-9 (1965); U.S. Air Force Trans. No. FTD-HT-23-859-67, August 1968, (AD 683 164) (N69-27416).

38. General Applied Science Labs, Inc., EXPERIMENTAL INVESTIGATION OF THE TURBO-BURNER CONCEPT. Report No. GASL-TR-663. U.S. Air Force AFAPL-TR-67-102. (AD 385 141L)

39. General Applied Science Labs, Inc., A FEASIBILITY STUDY OF THE SCRAMJET-IN-TUBE CONCEPT. Report No. GASL-TR-669, U.S. Air Force AFAPL-TR-67-131. (AD 388 535)

40. General Applied Science Labs., Inc., INVESTIGATION OF THE LOW SPEED FIXED GEOMETRY SCRAMJET. 'INLET DESIGN PRACTICE MANUAL'. Report No. GASL-TR-667. U.S. Air Force Report No. AFAPL-TR-68-7. (AD 829 332L)

41. General Applied Science Labs, Inc., INVESTIGATION OF LOW SPEED FIXED GEOMETRY SCRAMJET. Report No. GASL-TR-670, U.S. Air Force Report No. AFAPL-TR-68-105. (AD 394 474L)

42. General Applied Science Labs, Inc., LOW SPEED SCRAMJET PARAMETRIC ENGINE DATA. Report No. GASL-TR-707. (AD 392 805)

43. General Applied Science Labs, Inc., LOW SPEED SCRAMJET. APPLICATION STUDIES BASELINE ENGINE DESIGN. Report No. GASL-TR-709. (AD 393 649)

44. General Applied Science Labs, Inc., SUPERSONIC COMBUSTION RAMJET DEVELOPMENT. Report No. GASL-TR-686. (AD 389 272)

BIBLIOGRAPHY (Cont'd)

45. General Electric Co., Aircraft Engine Group, COMPONENT PROPULSION PROGRAM FOR FUTURE HIGH PERFORMANCE STRATEGIC AIRCRAFT.
VOLUME I. PART I. DEMONSTRATOR ENGINE PROGRAMS. Report No. R68 AEG 177-PT-1 (AD 388 2 3L)
VOLUME I. PART 2. DEMONSTRATOR ENGINE PROGRAMS. Report No. R68 AEG 177-PT-2 (AD 388 229L)
VOLUME II. COMPONENT PROGRAMS. Report No. R68 AEG 178. (AD 388 230L)
VOLUME III. AMSA MISSION STUDIES. Report No. R67 FPD 340. (AD 386 476L)

46. General Electric Co., Airdraft Engine Group, COMPONENT PROPULSION PROGRAM FOR FUTURE HIGH PERFORMANCE STRATEGIC AIRCRAFT.
VOLUME I. DEMONSTRATOR ENGINE PROGRAMS. BOOK 1 (SECTIONS 1 AND 2). Report No. R69 AEG 133-Vol-1-Bk-1. (AD 502 038L)
VOLUME I. DEMONSTRATOR ENGINE PROGRAMS. BOOK 2 (SECTIONS 3, 4, 5 AND 6) Report No. R69 AEG 133-Vol-1-Bk-2. (AD 502 039L)
VOLUME II. AMSA (GE9) IR SUPPRESSION DESIGN DATA. Report No. R69 AEG 13 (AD 502 611L)
VOLUME III. AMSA (GE9) INFRARED RADIATION SUPPRESSION. Report No. R69 AEG 135. (AD 502 612L)

47. Gejewski, T. (Foreign Technology Div., Wright-Patterson Air Force Base, Ohio), WORKING CHARACTERISTICS OF SUPERSONIC NOZZLES OF TURBOJET ENGINES. 17 July 1967, Report No. FTD-HT-67-397. (AD 834 082)

48. Gilzin, K. A., ENGINES OF UNPRECEDENTED SPEEDS. Dvigateli Nevidanny Kh Skorostei, Moscow, 1965; U.S. Air Force Trans. No. FTD-MT-24-303-68, January 1969. (AD 691 591) (N69-41012)

49. Gogish, L. V., INVESTIGATION OF SHORT SUPERSONIC NOZZLES. Izv. Akad. Nauk SSSR, Mekhan. Zhidkosti i Gaza (Moscow), 1966(2) 175-80; U.S. Air Force Trans. No. FTD-HT-23-1079-67, August 1967, (AD 669 526) (N68-29623)

50. Goldaev, I. P. and Cherepanov, V. P., ENGINEERING METHOD FOR THERMODYNAMIC CALCULATIONS OF JET-TYPE COMBUSTION CHAMBERS USING HYDROCARBON FUEL AND AIR. Samoletostroenie i Tekhnika Vozdushnogo lota (USSR), 1967, no. 10, 14-19; U.S. Air Force Trans. No. FTD-HT-23-842-68, September 1968. (AD 684 693)

51. Gorton, R. E. (United Aircraft Corp., Pratt and Whitney Aircraft Div.), TEMPERATURE MEASUREMENT FOR AIRCRAFT-TURBINE-ENGINE DEVELOPMENT. Society for Experimental Stress Analysis, Annual Spring Meeting, Ottawa, Canada, May 16-19, 1967, Paper; Experimental Mechanics 9, 27N (May 1969). (A69-28886)

52. Grady, H. F. and Jordon, H. S. (AVCO Corp., AVCO Lycoming Div.), ENGINES OF THE FUTURE. Vert. Flite 15, 2-9 (February 1969). (A69-21387)

53. Great Brit. Royal Aircraft Estab., RAMJET PROPULSION FOR HYPERSONIC AIRCRAFT. Report No. RAE-TM-AERO-917. (AD 828 166)

54. Greenbert, S. (Pratt and Whitney Aircraft), METHANE FUEL SYSTEMS FOR HIGH MACH NUMBER AIRCRAFT. Soc. Automotive Engrs. National Aeronautic and Space Engineering and Manufacturing Meeting, Los Angeles, Calif., October 6-10, 1969, Paper 690668.

BIBLIOGRAPHY (Contd)

55. Hannen, D. and Mathesius, H., APPLICATION OF HIGH-TEMPERATURE MATERIALS IN AIRCRAFT JET ENGINES. Deutsche Edelstahlwerke A.G., West Germany, DEW - Technische Berichte 9(2), 335-43 (1969) (In German; English Summary) (N69-37672).

56. Holighaus, R., INVESTIGATION OF FILM VAPORIZATION OF FUEL IN COMBUSTION CHAMBERS. Darmstadt, Technische Hochschule, Dr.-Ing. Dissertation, 1968, (In German). (A69-37921)

57. Homburg, A., INVESTIGATIONS IN THE PROBLEM OF JET MIXING TAKING PARTICULAR ACCOUNT OF APPLICATIONS TO AIRCRAFT ENGINES. Darmstadt, W. Ger., Technische Hochschule, Dr. Ing. Dissertation, 1967. (A69-21305)

58. Hoyt, J. W. (Naval Ordnance Test Station, China Lake, California), COMPARISON OF SUPERSONIC TURBINE PERFORMANCE WITH VARIOUS FUEL SYSTEMS. Report No. NOTS-350, 17 Feb 51, NAVORD 1280. (AD 389 543) (Report Classified Confidential)

59. Hubble, P. E., A NUMERICAL APPROACH TO THE ESTIMATION OF GAS TURBINE COMBUSTION CHAMBER PERFORMANCE. Combustion in Advanced Gas Turbine Systems; College of Aeronautics, International Propulsion Symposium, College of Aeronautics, Cranfield, Beds, England, April 1967, Proceedings. Ed. by I. E. Smith, Oxford, Pergamon Press, Ltd. (Cranfield International Symposium Series. Volume 10), 1968, (A69-22621)

60. Iakovlev, Iv. P., REGENERATIVE COOLING OF COMBUSTION CHAMBERS AND ENGINE NOZZLES WITH A SUPERCRITICAL HEAT-TRANSFER. Aviatsionnaia Tekhnika 11(3), 147-9 (1968) (in Russian). (A69-12970)

61. Jarlett, F. E. (Convair Division of General Dynamics), THE HYDROGEN FUELED HYPERSONIC TRANSPORT. Aviation and Space; Progress and Prospects, Annual Aviation and Space Conference, June 16-19, 1968, Beverly Hills, Calif., American Society of Mechanical Engineers, New York, 1968.

62. Jilly, L. F. (ed), BRAZE ALLOY INVESTIGATION. AiResearch Mfg. Co. Report No. AP-68-3813, U.S. National Aeronautics and Space Admin. Report No. NASA-CR-66845, Contract NAS1-6666, May 1969. (N69-41061)

63. Johns Hopkins University, Applied Physics Lab., DEVELOPMENT OF A LIQUID-FUELED HYPERSONIC RAMJET ENGINE. Report No. APL-TG-939. (AD 500 742L)

64. Johns Hopkins University, Applied Physics Lab., PERFORMANCE OF A COMBUSTOR DESIGNED FOR AN INTEGRAL ROCKET-RAMJET PROPULSION SYSTEM. Report No. APL-TG-1020. (AD 500 142L)

65. Johns Hopkins University, Applied Physics Lab., FUELS RESEARCH FOR SUPERSONIC COMBUSTION. Report No. APL-FQR/69/3, (AD 862 212). Report No. APL-FQR/69/2, (AD 858 540L). Report No. APL-FQR/69/1, (AD 853 492L). Report No. APL-FQR/68/4, (AD 848 620L). Report No. APL-FQR/68/3, (AD 844 256).

BIBLIOGRAPHY (Contd)

66. Johns Hopkins University, Applied Physics Lab., RESEARCH AND EXPLORATORY DEVELOPMENT FOR THE OFFICE OF AERONAUTICAL RESEARCH, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION. (Supersonic Combustion). Report No. APL-NQR/69-3, (AD 506 460). Report No. APL-NQR/69-2, (AD 504 551). Report No. APL-NQR/69-1, (AD 502 081). Report No. APL-NQR/68-3, (AD 864 423). Report No. APL-NQR/67-4, (AD 387 436).

67. Johns Hopkins University, Applied Physics Lab., RESEARCH AND DEVELOPMENT PROGRAMS. VOLUME IV. (SUPERSONIC COMBUSTION RAMJET ENGINES). Report No. APL-C-RQR/67-4. (AD 387 438)

68. Johns Hopkins University, Applied Physics Lab., RESEARCH AND DEVELOPMENT PROGRAMS. (SCRAMJET). Report No. APL-C-RQR/67-3. (AD 386 134L)

69. Jones, R. E. and Niedzwiecki, R. W., COMBUSTION STABILITY OF SINGLE SWIRL-CAN COMBUSTOR MODULES USING ASTM-A1 LIQUID FUEL. U.S. National Aeronautics and Space Admin., October 1969. (N69-40080)

70. Kallergis, M., ON THE SUPPLY OF FLUID AND GASEOUS MEDIUMS IN SUPERSONIC STAGES. Deutsche Forschungsanstalt für Luft- und Raumfahrt Report No. DLR-FB-68-26, March 1968, in German, English summary. (N68-34189)

71. Khaylov, V. M., MEANS FOR GRAPHIC INTERPOLATION OF THE RESULTS OF CALCULATIONS OF CHEMICAL NONEQUILIBRIUM FLOWS IN NOZZLES. Teplofiz. Vysokikh Temperatur (USSR) 7(2), 284-7 (1969); U.S. National Aeronautics and Space Admin. Trans. No. NASA-TT-F-12557, September 1969. (N69-39412)

72. Kirk, H. F., RAMJET TECHNOLOGY. CHAPTER 13: FACILITIES AND TESTING. Johns Hopkins University, Applied Physics Lab. Report No. APL-TG-610-13-REV., June 1968. (PB-179 067) (N69-12 466)

73. Kitts, D. L., DEVELOPMENT OF A SHORT-LENGTH TURBOJET COMBUSTOR. Pratt and Whitney Aircraft Report No. PWA-FR-2433, U.S. National Aeronautics and Space Admin. Report No. NASA-CR-54560, Contract NAS3-7905, March 1968. (N68-18974)

74. Klopp, W. D., RECENT DEVELOPMENTS IN CHROMIUM AND CHROMIUM ALLOYS. U.S. National Aeronautics and Space Admin. Report No. NASA-TM-X-1867, September 1969, (N69-35764)

75. Ko, Y. and Lu, C., EXPERIMENTATION ON AIR-COOLED GAS TURBINE ROTORS. Chi Hsieh Kung Ch'eng Hsueh Pao (Peking) 13(4), (1965); U.S. Air Force Trans. FTD-HT-23-958-67, July 1967. (AD 669 427) (N68-33577)

76. Kordzinski, W., SIMILARITY CONDITIONS IN TURBINE-ENGINE TESTS. Technica Lotnicza i Astronautyczna 23, 16-19 (November 1968). (A69-16028)

77. Krakow, B., Tourin, R. H., Penzias, G. J., POSSIBLE TECHNIQUES FOR OPTICAL MEASUREMENT OF TEMPERATURE AND CONCENTRATION PROFILES IN A SUPERSONIC RAMJET. Warner and Swasey Co., Control Instrument Div. Report No. W/S-TR-39, U.S. National Aeronautics and Space Admin. Report No. NASA-CR-66112, Contract No. NAS1-5533, 1969. (N70-15082)

BIBLIOGRAPHY (Contd)

77. Lane, R. J. (Rolls-Royce, Ltd., Bristol Engines Div.), ADVANCES IN ENGINE TECHNOLOGY. Royal Aeronautical Society, Canadian Aeronautics and Space Institute, and American Institute of Aeronautics and Astronautics, Anglo-American Aeronautical Conference, 11th, London, England, September 8-12, 1969, RAeS Paper 20. (A69-40499)

78. Lee, B. H. K., NON-UNIFORM PROPAGATION OF MODERATE STRENGTH BLAST WAVES IN WEDGE AND CONICAL HYPERSONIC NOZZLES. National Aeronautical Estab., Canada, Report No. NAE-LR-505, NRC-10409, June 1968. (AD 680 471) (N69-24502)

79. Lefebvre, A. H., DESIGN CONSIDERATIONS IN ADVANCED GAS TURBINE COMBUSTION CHAMBERS. Combustion in Advanced Gas Turbine Systems; College of Aeronautics, International Propulsion Symposium, College of Aeronautics, Cranfield Beds., England, April 1967, PROCEEDINGS, ed. by I. E. Smith, Oxford, Pergamon Press, Ltd. (Cranfield International Symposium Series, Volume 10), 1968. (A69-22612)

80. Lefebvre, A. H., FACTORS CONTROLLING GAS TURBINE COMBUSTION PERFORMANCE AT HIGH PRESSURE. Combustion in Advanced Gas Turbine Systems; College of Aeronautics, International Propulsion Symposium, College of Aeronautics, Cranfield, Beds., England, April 1967, PROCEEDINGS, ed. by I. E. Smith, Oxford, Pergamon Press, Ltd. (Cranfield International Symposium Series, Volume 10), 1968. (A69-22620)

81. Lefebvre, A. H. and Norster, E. R., THE DESIGN OF TUBULAR GAS TURBINE COMBUSTION CHAMBERS FOR OPTIMUM MIXING PERFORMANCE. Institute of Mechanical Engineers, Technical Advances in Gas Turbine Design, Warwick, England, April 9-11, 1969, Paper 15. (A69-25795)

82. Lehnert, G., PROTECTIVE COATINGS AGAINST HIGH TEMPERATURE CORROSION IN AIRCRAFT TURBINE ENGINES. Deutsche Edelstahlwerke A. G., Germany, DEW-Technische Berichte, 9(2), 285-90 (1969) (in German; English summary). (N69-37664)

83. Levenberg, V. D., EFFICIENCY OF A LOW-ADMISSION SHROUDLESS SUPERSONIC TURBINE STAGE. Energomashinostroenie (USSR) 14(5), 40-1 (1968); U.S. Air Force Trans. FTD-HT-23-107-69, June 1969. (AD 691 668) (N69-40158)

84. Lockheed - California Co., HYPERSONIC SCRAMJET VEHICLE STUDY.
VOLUME I. MISSION ANALYSIS. Report No. LAC-619051. LR-21137-VOL-1. (AD 387 038L)
VOLUME II. OPERATIONAL EFFECTIVENESS ANALYSIS. Report No. LAC-619052. LR-21137-VOL 2. (AD 387 039L)
APPENDICES TO VOLUME II. OPERATIONAL EFFECTIVENESS. ANALYSIS. Report No. LAC-619053. LR-21137-VOL-2-APP. (AD 387 040L)
VOLUME III. COMPETITIVE SYSTEMS COMPARISON. Report No. LAC-618904, LR-21137-VOL-3. (AD 387 041L)
VOLUME IV. PART A. VEHICLE DESIGN AND PERFORMANCE. ANALYSIS. Report No. LAC-619054. LR-21137-VOL-4-PT-A. (AD 387 042L)
VOLUME IV. PART B. VEHICLE DESIGN AND PERFORMANCE. ANALYSIS. Report No. LAC-619055. LR-21137-VOL-4-PT-B. (AD 387 043L)
VOLUME V. SUMMARY. Report No. LAC-619056. LR-21137-VOL-5. (AD 387 044L)

BIBLIOGRAPHY (Contd)

85. Lowrie, R., RESEARCH ON PHYSICAL AND CHEMICAL PRINCIPLES AFFECTING HIGH TEMPERATURE MATERIALS FOR ROCKET NOZZLES. Union Carbide Research Inst., Tarrytown, N.Y., September 1964. (AD 448 483)

86. Marchal, R., GAS TURBINES WITH PULSATING COMBUSTION CHAMBERS. Entropie (Paris) 22, 15-9 (July-August 1968); Gt. Brit. National Lending Library for Science and Technology Trans. No. NLL-EE-Trans.-1883 (3774.5), April 1969. (N69-37546)

87. Marchionna, N. R. and Trout, A. M., TURBOJET COMBUSTOR PERFORMANCE WITH NATURAL GAS FUEL. U.S. National Aeronautics and Space Admin. Report No. NASA-TN-D-5571, February 1970. (N70-19011)

88. Marinchenko, N. I., Chertkov, Ya. B., Piskunov, V. A., SCALE FORMATION IN TURBOJET ENGINES. Khim. i Tekhnol. Topliv i Masel (Moscow) 1964 (1), 51-5; U.S. Air Force Trans. FTD-HT-23-825-67, August 1967. (AD 671 650) (N68-33472)

89. Marquet, R. and Huet, C., RESEARCH OF AN OPTIMUM SOLUTION FOR A FIXED GEOMETRY RAMJET, IN THE MACH 3 - MACH 7 RANGE, WITH SUCCESSIVELY SUBSONIC AND SUPERSONIC COMBUSTION. AFITAE Colloq. on Appl. Aerodyn., Poitiers, France, Nov. 6-8, 1968; Office National d'Etudes et de Recherches Aerospatiales, France, Report No. ONERA-TP-656E, 1968. (N69-20800)

90. Marquet, R. and Huet, C., STUDY OF AN OPTIMAL SOLUTION OF A STATOREACTOR WITH FIXED GEOMETRY OF 3-7 MACH WITH SUBSONIC AND THEN SUPERSONIC COMBUSTION. Presented at AFITAE 5th Appl. Aerodyn. Colloq., Poitiers, France, November 6-8, 1968. (N69-15862) (in French)

91. Marquardt Corp., SUPERSONIC CHEMICAL PROPULSION FEASIBILITY FLIGHT DEMONSTRATION FOR A LOW ALTITUDE SHORT RANGE MISSILE. VOLUME I. SUMMARY. VOLUME II: PROPULSION SYSTEM DESIGN AND DEVELOPMENT. VOLUME II: Part 2: PROPULSION SYSTEM INTEGRATION AND TESTING. VOLUME II: Part 3: PROPULSION SYSTEM GROUND TEST TRANSIENT EVALUATIONS. VOLUME V: FLIGHT TEST DEMONSTRATION. VOLUME VII: PROPULSION SYSTEM ADVANCED TECHNOLOGY STUDIES. Report Nos. MR-6122, 6123, 6126, 6145, U.S. Air Force ASD-TR-67-2-Vol-1,2,5,7. (AD 500 063)

92. Marquardt Corp., Aerospace Products Div., APPLICATION OF COMPOSITE MATERIALS TO RAMJET INLET STRUCTURES. VOLUME I. STRUCTURAL DESIGN AND EVALUATION OF MATERIALS. VOLUME II. RAMJET APPLICATIONS ANALYSIS. Report No. MR-25241-VOLS-1,2; U.S. Air Force Report No. AFML-TR-68-85-VOLS-1,2. (AD 832 813) (AD 390 758)

93. Marquardt Corp., DUAL MODE SCRAMJET. PART I: INLET DESIGN AND PERFORMANCE CHARACTERISTICS. PART II: COMBUSTOR DESIGN AND PERFORMANCE CHARACTERISTICS. PART III: ENGINE DESIGN AND PERFORMANCE CHARACTERISTICS. Report Nos. MR-S-837-Parts 1-2, and MR-S-891, U.S. Air Force AFAPL-TR-67-132-Parts 1-3. (AD 385 990L) (AD 385 991L) (AD 390 881)

BIBLIOGRAPHY (Contd)

94. Marquardt Corp., 1966 ADVANCED RAMJET CONCEPTS PROGRAM. VOLUME I: EJECTOR RAMJET SYSTEMS DEMONSTRATION. (AD 391 474)
VOLUME II: EJECTOR SCRAMJET TECHNOLOGY. (AD 390 942)
VOLUME III: LOW VOLUME RAMJET ANALYSES AND TESTS. (AD 390 589)
VOLUME IV: APPLICATION OF ALL-FLUID CONTROLS TO DUAL MODE SCRAMJET ENGINES. (AD 385 669)
VOLUME V: ADVANCED NOZZLES AND RAMJET STRUCTURES. (AD 389 481)
VOLUME VI: ADVANCED PROPULSION APPLICATIONS INVESTIGATION. (AD 385 395L)
VOLUME VII: RAMLACE/SCRAMLACE PPOPULSION SYSTEM ANALYSIS AND DESIGN. (AD 388 240)
VOLUME VIII: EJECTOR RAMJET ENGINE TESTS. PHASE I. (AD 386 900)
Report No. MR-25222, Vols 1-7, and MR-20413, U.S. Air Force AFAPL-TR-67-118-Vols 1-8.

95. Marquardt Corp., CALENDAR YEAR 1965 ADVANCED RAMJET CONCEPTS PROGRAM. Nos. PR-5400-parts 11-14. (AD 504 249L) (AD 504 250L) (AD 504 251L) (AD 504 272L)

96. Marquardt Corp., PRELIMINARY PERFORMANCE SPECIFICATION FOR THE MARQUARDT MODEL MA 145-XAC RAMJET ENGINE. Report No. MR-S-897. (AD 392 687)

97. Marquardt Corp., ADVANCED DESIGN STUDY OF A FLIGHT TEST VEHICLE POWERED BY THE MARQUARDT MA 145 XAB HYPERSONIC RAMJET. U.S. Air Force AFAPL-TR-68-16. (AD 389 866L)

98. Marquardt Corp., LOW VOLUME RAMJET PROGRAM. Report No. MR-6141, U.S. Air Force AFAPL-TR-68-52. (AD 390 788L)

99. Marquardt Corp., SCRAMJET INCREMENTAL FLIGHT TEST PROGRAM. VOLUME I: SUMMARY. (AD 388 239)
VOLUME II: MODULE AEROTHERMODYNAMICS. (AD 389 144)
VOLUME III: SCRAMJET PROPULSION SYSTEM. (AD 385 994)
VOLUME IV: SCRAMJET FLIGHT TEST SYSTEM. (AD 386 731)
Report No. MR-6131-6134, U.S. Air Force AFAPL-TR-67-112-Vols 1-4.

100. Marquardt Corp., TESTS OF REGENERATIVELY COOLED COMPONENTS FOR HYPERSONIC RAMJET PROPULSION SYSTEMS. VOLUME I: CONCEPT TEST RIG RESULTS. (AD 394 114)
VOLUME II: DEMONSTRATION OF PERFORMANCE AND STRUCTURAL CAPABILITIES. (AD 504 116) Report Nos. MR-6138 and MR-6139, U.S. Air Force AFAPL-TR-68-125-Vols 1-2.

101. Marquardt Corp., APPLICATION STUDIES FOR THE HYDROCARBON FUELED SCRAMJET. Report No. MR-6148, U.S. Air Force Report No. AFAPL-TR-69-53. (AD 503 277L)

102. Marquardt Corp., HYPERSONIC RAMJET HEAT TRANSFER AND COOLING PROGRAM. VOLUME IV: RESULTS OF STRUCTURAL TEST MODEL EXPERIMENTS. Report No. MR-6110. U.S. Air Force Report No. AFAPL-TR-66-84-Vol-4. (AD 388 243L)

102. Marquardt Corp., ANALYTICAL EVALUATION OF THE EJECTOR RAMJET ENGINE. Report Nos. MR-25237 and MR-25259, U.S. Air Force Report No. AFAPL-TR-68-86. (AD 500 389L) (AD 385 919)

103. Marquardt Corp., SCRAMJET THERMAL PROTECTION PROGRAM. Report No. MR-6144, U.S. Air Force AFAPL-TR-68-79. (AD 394 544)

104. Marquardt Corp., TEST AND EVALUATION OF ENDOTHERMICALLY COOLED PYROLYTIC GRAPHITE NOZZLES. Report No. MR-6150, U.S. Air Force Report No. AFRPL-TR-69-233. (AD 506 590)

105. Marquardt Corp., AAM RAMBURNER TECHNOLOGY. Report No. MR-S-942. (AD 504 831)

106. Marquardt Corp., Aerospace Products Div., DEMAND-MODE INTEGRAL ROCKET-RAMJET. Report Nos. MR-25242, 25256, 25261, 25271, 25285, 25288, 25293, and 25301. (AD 389 560) (AD 390 495) (AD 391 081L) (AD 393 342) (AD 500 862L) (AD 501 586) (AD 503 316) (AD 505 344)

107. Mascitti, V. R., A SIMPLIFIED EQUILIBRIUM HYDROCARBON-AIR COMBUSTION GAS MODEL FOR CONVENIENT USE IN AIR-BREATHING ENGINE CYCLE COMPUTER PROGRAMS. M.S. Thesis, Univ. of Virginia, U.S. National Aeronautics and Space Admin. Report No. NASA-TM-X-61530, 1968. (N69-19694)

108. Mascitti, V. R. (Langley Res. Center, Hampton, Va.), A SIMPLIFIED EQUILIBRIUM HYDROCARBON-AIR COMBUSTION GAS MODEL FOR USE IN AIR-BREATHING ENGINE CYCLE COMPUTER PROGRAMS. NASA Tech. Note 1968, NASA-TN-D-4747.

109. McDonnell Douglas Astronautics, Western Div., SCRAMJET PARAMETRIC STUDY. McDonnell Douglas-PAPER-10056. (AD 502 599L)

110. McDonnell Aircraft Co., HYPERSONIC SCRAMJET VEHICLE STUDY. VOLUME I: PROGRAM SUMMARY. (AD 385 169L)
VOLUME IV: TECHNOLOGY DEMONSTRATION AND DEVELOPMENT. (AD 385 174L)
VOLUME V: AERODYNAMICS. (AD 385 175L)
VOLUME VI: PROPULSION SYSTEMS. (AD 385 176L)
VOLUME VII: STRUCTURES AND WEIGHTS. (AD 385 177L)
VOLUME VIII: THERMODYNAMICS. (AD 385 178L)
Report No. MAC-F666-Vol 1 and Vols 4-8.

111. McGill Univ., (Canada), Mechanical Engineering Research Labs., HYPERSONIC PROPULSION LABORATORY. Annual Progress Report, November 1968 - October 1969. Report No. Memo-69-4, Contract No. APL-271798, Grant Nos. DRB-9550-06; NRC A-4190; NRC A-5158; NRC A-5167; NRC A-5189, October 1969. (N70-12963)

112. Miller, B. A., ANALYSIS OF SEVERAL METHANE-FUELED ENGINE CYCLES FOR MACH 3.0 FLIGHT. U.S. National Aeronautics and Space Admin. Report No. NASA-TN-D-4699, July 1968. (N68-29378)

113. Miller, I. M., AN EVALUATION OF COATED MOLYBDENUM AND COLUMBIUM ALLOYS IN HIGH-TEMPERATURE SUPERSONIC AIRSTREAMS. U.S. National Aeronautics and Space Admin. Report No. NASA-TN-D-4877, November 1968. (N69-10764)

BIBLIOGRAPHY (Contd)

114. Moore, V. S., Malik, R. K. and Stetson, A. R., HOT CORROSION OF COATED SUPERALLOYS IN A GAS TURBINE ENVIRONMENT. Solar, San Diego, California, Progress Report No. 4, 1 April - 1 Sept. 1969. Report No. RDR-1626-4, Contract N00019-68-C-0532, Sept. 15, 1969. (AD 860 864)

115. Moyer, H. M. and Niedzwiecki, R. W., PERFORMANCE OF A 48-MODULE SWIRL-CAN TURBOJET COMBUSTOR SEGMENT AT HIGH TEMPERATURES USING ASTM-A1 FUEL. U.S. National Aeronautics and Space Admin., December 1969. (N70-13476)

116. Nelms, L. T. (Arnold Engineering Development Center, Arnold Air Force Station Tennessee), DESIGN OF MINIMUM LENGTH SUPERSONIC NOZZLE CONTOUR AND ASSOCIATED SUBCONTOURS. Final Report 11 Mar - 21 Aug 1968, U.S. Air Force AEDC-TR-68-212. Contract F40600-69-C-0001, Project ARO-BT8002, November 1969. (AD 843 755)

117. Nesterenko, G., BETWEEN THE STRATOSPHERE AND SPACE. 1. HYPERSONIC AIRCRAFT AND ENGINES. Kryl'ya Rodiny (Moscow) 19(9), 26-7 (1968); U.S. Air Force Trans. No. FTD-MT-24-57-69, June 1969. (AD 691 670) (N69-41000)

118. Niedzwiecki, R. W., PRELIMINARY TESTS OF A SIMPLIFIED MODULAR TURBOJET COMBUSTOR. U.S. National Aeronautics and Space Admin. Technical Note No. NASA TN D-5688, March 1970.

119. Niedzwiecki, R. W., and Jones, R. E., COMBUSTION STABILITY OF SINGLE SWIRL-CAN COMBUSTOR MODULES USING ASTM-A1 LIQUID FUEL. U.S. National Aeronautics and Space Admin. Report No. NASA-TN-D-5463, October 1969. (N69-40080)

120. Norgren, C. T. and Humenik, F. M., DILUTION -- JET MIXING STUDY FOR GAS-TURBINE COMBUSTORS. U.S. National Aeronautics and Space Admin. Report No. NASA-TN-D-4695, August 1968. (N68-30128)

121. Norgren, C. T., Roudebush, W. H., Humenik, F. M. (To NASA), GAS TURBINE COMBUSTOR. U.S. Patent Appl. - SN-839 994, Filed July 8, 1969, U.S. National Aeronautics and Space Admin. Report No. NASA-Case-10286-1, (N69-32864)

122. North American Rockwell Corp., Los Angeles Div., HYPERSONIC SCRAMJET VEHICLE STUDY. VOLUME I. SUMMARY. (AD 385 328L)
VOLUME II. MISSION ANALYSIS AND SELECTION. (AD 385 324L)
VOLUME III. VEHICLE PARAMETRIC STUDIES. (AD 385 329L)
VOLUME IV. THREAT DEFINITION AND HYPERSONIC VEHICLE SURVIVAL. (AD 385 330L)
VOLUME V. SPECIAL STUDIES OF THE WORTH OF HYPERSONIC SPEED. (AD 385 331L)
VOLUME VI. COMPARATIVE ANALYSIS. (AD 385 325L)
VOLUME VII. ATTRACTIVE SCRAMJET APPLICATIONS. (AD 385 326L)
VOLUME VIII. TECHNICAL ASSESSMENTS. (AD 385 332L)
VOLUME IX. COST ANALYSIS. (AD 385 333L)
Report No. NA-67-789-Vols 1-9.

BIBLIOGRAPHY (Contd)

123. Northern Research and Engineering Corp., COMPUTER PROGRAM FOR THE ANALYSIS OF ANNULAR COMBUSTORS. VOLUME 1: CALCULATION PROCEDURES. (N68-17557) VOLUME 2: OPERATING MANUAL. (N68-17556) Final Report No. 1111-1 and 2, U.S. National Aeronautics and Space Admin. Report No. NASA-CR-72374 and NASA-CR-72375, Contract NAS3-9402, January 1968.

124. Odgers, J., FACTORS INFLUENCING HEAT RELEASE IN COMBUSTION CHAMBERS AND CONSIDERATION OF THE RELATED MATERIALS AND STRUCTURES. Combustion in Advanced Gas Turbine Systems; College of Aeronautics , International Propulsion Symposium, College of Aeronautics, Cranfield, Beds., England, April 1967, Proceedings, ed. by I. E. Smith, Oxford, Pergamon Press, Ltd. (Cranfield International Symposium Series, Volume 10). (A69-22619)

125. O'Loughlin, J. R., VARIOUS STUDIES OF JET FLAMEHOLDERS. Tulane Univ., Mechanical Engineering Dept. Final Report, U.S. Army AROD-4981.7-E, Contract No. DA-31-124-ARO(D)-240, June 1968. (AD 669 634) (N68-29659)

126. Orlov, B. V., et al., DESIGN PRINCIPLES OF ROCKET-RAMJET ENGINES FOR UNMANNED FLIGHT VEHICLES. Osnovy Proyektirovaniya Raketno-Poyamotochnykh Dvigateley Dlya Bespilotnykh Letatel'nykh Apparatov, Moscow, Izv. Mashinostr., 1967, 1; U.S. Air Force Trans. FTD-MT-24-108-68, July 1968. (AD 672 900) (N68-35235)

127. Osgerby, I.T., Smithson, H. K., Wagner, D. A., DEVELOPMENT OF A DOUBLE-OBLIQUE-SHOCK SCRAMJET MODEL IN A SHOCK TUNNEL. U.S. Air Force Arnold Engineering Development Center Report No. AEDC-TR-69-59, Contract No. F40600-69-C-0001, prepared in cooperation with ARO, Inc., August 1969. (AD 692 466)

128. Osgerby, I. T., Smithson, H. K., Wagner, D. A., SUPERSONIC COMBUSTION TESTS WITH A DOUBLE-OBLIQUE-SHOCK SCRAMJET IN A SHOCK TUNNEL. U.S. Air Force Arnold Engineering Development Center prepared in cooperation with ARO, Inc., February 1970. (AD 700 321)

129. Osgerby, I. T., Smithson, H. K., Wagern, D. A., (ARO, Inc.), SUPERSONIC COMBUSTION TESTS WITH A DOUBLE-OBLIQUE-SHOCK SCRAMJET IN A SHOCK TUNNEL. AIAA, Propulsion Joint Specialist Conference, 5th, U.S. Air Force Academy, Colorado Springs, Colo., June 9-13, 1969, Paper 69-827. (A69-32673)

130. Otsuka, T., Suzuki, K., Ishii, A., and Hirose, T., EXPERIMENTAL STUDIES ON THE PRIMARY ZONE OF HIGH-INTENSITY COMBUSTORS. Japanese National Aerospace Lab. Report No. NAL-TR-143, 1967; U.S. National Aeronautics and Space Admin. Trans. No. NASA-TT-F-11922, June 1969. (N69-29142) (N68-19567)

131. Ovarov, V. V., DETERMINATION OF THE COMBUSTION CHAMBER LENGTH NECESSARY FOR COMPLETE COMBUSTION TAKING INTO ACCOUNT FRICTION OF GAS FLOW DURING ITS MOTION. Izv. Vysshikh Uchebn. Zavedenii, Aviats. Tekhn. (Kazan) 1965(3), U.S. Air Force Trans. FTD-HT-23-1355-67, Jan. 1968. (AD 676 192) (N69-12101)

132. Owens, M. C., SERVICING AND FUNCTIONAL TESTING OF THE COMPLETE FUEL SYSTEM, XB-70A AIRVEHICLE. North American Aviation, Inc., Los Angeles Div. Report No. Spec-IA-0210-032, September 1966. (AD 814 241)

BIBLIOGRAPHY (Contd)

133. Pagel, L. L. and Warmbold, W. R. (McDonnell Aircraft Co.), ACTIVE COOLING OF A HYDROGEN-FUELED SCRAMJET ENGINE. AIAA Annual Meeting and Technical Display, 5th, October 21-24, 1968, Paper 68-1091, J. Aircraft 6(5), 472-4 (1969).

134. Papok, K. K., Piskunov, V. A., Yoremya, P. G., TEMPERATURE METHOD OF RATING CARBON DEPOSITION OF SCALE FROM FUELS. Khim. i Tekh. Topliv i Masel 1968 (2), 42-5 (Feb.); Chem. and Technology of Fuels and Oils 1968, No. 1, 129-32, (Jan. - Feb.).

135. Pawlik, E. V. and Jones, R. E., EXPERIMENTAL EVALUATION OF SWIRL-CAN ELEMENTS FOR PROPANE FUEL COMBUSTOR. U.S. National Aeronautics and Space Admin. Memo NASA Memo 5-15-59E, 1959.

136. Perkins, P. J., Schultz, D. F., Wear, J. D., COMPARISON OF ASTM-A1 AND NATURAL GAS FUELS IN AN ANNULAR TURBO JET COMBUSTOR. U.S. National Aeronautics and Space Admin. Report No. NASA-TM-X-52700, October 1969. (N70-12102)

137. Pratt and Whitney Aircraft, COMPONENT PROPULSION PROGRAM FOR FUTURE HIGH-PERFORMANCE STRATEGIC AIRCRAFT. Volume XI. TURBINE COOLING. Report No. PWA-3153-Vol-11. (AD 385 905L)

138. Pratt and Whitney Aircraft, ADDITIONAL AMSA PROPULSION DEVELOPMENT EFFORT.
VOLUME I. TECHNICAL DISCUSSION. Report No. PWA-3478-Vol-1. (AD 391 828L)
VOLUME II. APPENDIX. Report No. PWA-3478-Vol-2. (AD 391 830L)
VOLUME III. JTF 2C DESIGN REVIEW. Report No. PWA-3316-Vol-3. (AD 387 214L)

139. Purdue University, Jet Propulsion Center, PROJECT SQUID. Semiannual Progress Reports, 1 Oct 1967 - 31 Mar 1968, (AD 670 538); 1 Apr 1968 - 30 Sept 1968, (AD 677 936); 1 Oct 1968 - 31 Mar 1969, (AD 687 431); Oct 1969 (AD 698 541). Contract No. N00014-67-A-0226-0005.

140. Reissner, H. J. and Torda, P., PROJECT SQUID. Polytechnic Inst. of Brooklyn. Final Report Phase 1, Report Nos. SQUID-TM-P1B-11, P1BAL-141, Contract No. N6ori-098(02), Sept 1948. (AD 686 438)

141. Richmond, J. K., Parsons, R. J., Swithenbank, J., ON SHOCK-TUNNEL SIMULATION OF SCRAMJET COMBUSTION CHAMBER PERFORMANCE. Boeing Scientific Research Labs. Flight Science Lab. Report No. D1-82-0804, prepared in cooperation with Sheffield Univ. (England), Department of Fuel Technology and Chamber Eng., Nov. 1968. (AD 682 127)

142. Richmond, J. K. (Boeing Co.) and Swithebank, J. (U. of Sheffield, England) and Parsons, R.J., ON SHOCK-TUNNEL SIMULATION OF SCRAMJET COMBUSTION CHAMBER PERFORMANCE. AIAA, Aerospace Sciences Meeting, 7th, New York, January 20-22, 1969, Paper 69-84. (A69-18165)

143. Roudebush, W. H. (NASA, Lewis Research Center), SHORTER COMBUSTORS FOR HIGH-TEMPERATURE JET ENGINES. Space/Aeronautics 51, 74-7 (April 1969). (A69-29433)

144. Roudebush, W. H., STATE OF THE ART IN SHORT COMBUSTORS. Congr. of the Intern. Council of the Aeron. Sci., 6th, Munich, Sept 9-13, 1968, Paper; U.S. National Aeronautics and Space Admin. Report No. NASA-TM-X-52449, 1968, (N68-33215).

145. Rusnak, J. P. and Shadowen, J. H., DEVELOPMENT OF AN ADVANCED ANNULAR COMBUSTOR. Pratt and Whitney Aircraft Final Rept., 30 June 1966 - 24 Apr 1968, Report No. PWA-FR-2832, U.S. National Aeronautics and Space Admin. Rept. No. NASA-CR-72453, Contract No. NAS3-9403, May 1969. (N69-27411)

146. Savelev, Yu. N., Batyuk, G. S., Kryzhanovskii, V. N., Khristich, V. A., Shevchenko, A. M., INCREASING THE OPERATIONAL RELIABILITY OF A JET IGNITER; THE QUESTION OF COOLING EFFICIENCY OF A PERFORATED FLAME TUBE OF A GAS TURBINE COMBUSTION CHAMBER. Vestn. Politekhnicheskii Inst., Ser. Teploenergetiki (USSR) 1964(1), 40, 50; U.S. Air Force Trans. No. FTD-MT-24-92-68, June 1968. (AD 680 567)

147. Scott, R. D., BERYLLIDE COMPOSITION. 2400-DEGREE TURBINE/MATERIALS RESEARCH PROGRAM. Garrett Corp., AiResearch Mfg. Div. Summary Test Report No. MP-5242-R, U.S. Army Contract DA-44-177-AMC-183(T), Jan 1967. (AD 653 632)

148. Silverstien, C. C., PRELIMINARY EVALUATION OF GAS TURBINE REGENERATORS EMPLOYING HEAT PIPES. Final Technical Rept., U.S. Army Aviation Labs. Report No. USAAVLABS-TR-68-10, Contract No. DAAJ02-67-C-0053, April 1968. (AD 671 028) (N68-31316)

149. Strahle, W. C. (Inst. for Defense Analyses, Sci. and Tech. Div., Arlington, Va.), COMBUSTION EFFECTS ON BASE PRESSURE IN SUPERSONIC FLIGHT AND APPLICATIONS. Research Paper, Feb 68, Rept. No. RP-P-389. Contract DAHC15-67-C-0011. IDA/HQ 67-204. (AD 389 863) (Report Classified Confidential)

150. Strawson, H. and Lewis A., PREDICTING FUEL REQUIREMENTS FOR CONCORDE. SAE Meeting, Oct 7-11, 1968. SAE Paper No. 680734.

151. Stephanov, S.E., Ward, T.E., Holmgren, J.S. (McDonnell Douglas Corp., McDonnell Douglas Astronautics Co.), APPLICATION OF HEAT PIPE TECHNOLOGY TO ROCKET ENGINE COOLING. AIAA, Propulsion Joint Specialist Conf., 5th, U.S. Air Force Academy, Colorado Springs, Colo., June 1969, Paper 69-582. (A69-32668)

152. Stoffels, P. H., THEORETICAL AND EXPERIMENTAL INVESTIGATIONS OF A COMBUSTION CHAMBER FOR HIGH-POWER ENGINES IN THE CASE OF CONTINUOUS AND INTERMITTANT LIQUID-FUEL INJECTION. Aachen, Ger., Technische Hochschule, Dr. Ing. Dissertation, 1967, 137 pp. (in German) (A69-20762)

153. Storozhuk, Ya. P. and Asoskov, V.A., FUEL BURNUP AND HOT-FLOW MODELING OF COMBUSTION CHAMBERS. Tsentralnyi Nauchno-Issledovatelskii i Proektno-Konstruktorskii Kotloturbinnyi Inst., Trudy (USSR) No. 75,(1967); U.S. Air Force Trans., Aug 1969. (AD 698 105)

BIBLIOGRAPHY (Contd)

154. Sturgess, G. J., FILM COOLING OPTIMIZATION FOR MINIMUM COOLING AIRFLOW IN AIRCRAFT GAS-TURBINES. Combustion in Advanced Gas Turbine Systems; College of Aeronautics, International Propulsion Symposium, College of Aeronautics, Cranfield, Beds., England, April 1967, Proceedings, ed. by I. E. Smith, Oxford, Pergamon Press, Ltd., (Cranfield International Symposium Series. Volume 10), 1968. (A69-22623)

155. Thompson, H. D., Ransom, V. H., Hoffman, J. D., and Kentzer, C. P. (Purdue University), AN ANALYTICAL STUDY OF THE SCRAMJET EXHAUST EXPANSION SYSTEM. PARTS I AND II. Technical Reports 1 Sept 66 - 31 Aug 67, and 1 Sept 67 - 31 Aug 68. Contract F33615-67-C-1068, Proj. AF-3012, Task 301206. AFAPL TR-67-142-Pt-1 and 2. (AD 824 194) (AD 848 964)

156. Tiul'panov, R. S., BURN-OUT CALCULATIONS FOR ATOMIZED HYDROCARBON FUEL IN GAS TURBINE COMBUSTION CHAMBERS. Fizika Goreniia i Vzryva 1966, No. 1,88; Combustion, Explosion, and Shock Waves 2,50 (Spring 1966). (A69-19999)

157. Tron, J. (Sud-Aviation, France), PROPULSION SYSTEMS FOR HIGH-SPEED AIRCRAFT ($M_\infty = 7$). Assoc. Technique Maritime et Aeronautique, Session, Paris, France May 6-10, 1968; Assoc. Technique Maritime et Aeronautique, Bulletin, No. 68, 451 (1968) (in French).(A69-20656)

158. Trushin, V. A. and Lokai, V. I., INFLUENCE OF ROTATION ON HEAT EXCHANGE BETWEEN THE GAS AND THE COMPONENTS OF THE AIR-GAS FLOW AREA OF A GAS TURBINE. Aviatsionnaia Tekhnika 11(3), 85(1968)(in Russian). (A69-12959)

159. Tsuji, S., A STUDY ON VAPORIZING COMBUSTOR FOR GAS TURBINES. I. Ishikawajima-Harima Engineering Review 9, 233-47 (May 1969) (In Japanese, English Abstract). (A69-38607)

160. Tu, C., Yin, K., Chen, N., HEAT TRANSFER IN TURBOJET COMBUSTION CHAMBERS AND EXPERIMENTATION OF FILM COOLING EFFECTS. Chi Hsieh Kung Ch'eng Hsueh Pao (Peking) 13(4), 1965; U.S. Air Force Trans. FTD-HT-23-958-67, July 1967. (AD 669 427) (N68-33576)

161. U.S. Air Force Aero Propulsion Lab., PROCEEDINGS OF THE CONFERENCE ON AIR-BREATHING PROPULSION FOR ADVANCED MISSILES AND AIRCRAFT. San Diego, Calif., 4-6 March 1969. Report No. AFAPL-TR-69-52. (AD 505 368)

162. U.S. Air Force, Wright Air Development Div., ADVANCED RAMJET COMPONENT DEVELOPMENT PROGRAM. Report No. WADD-TN-60-77. (AD 504 074L)

163. U.S Naval Missile Center, RHO-BEE RAMJET FLIGHT EXPERIMENT. Report No. NMC-TM-68-22. (AD 393 247L)

164. U.S. Naval Ordnance Test Station, AIRBREATHING PROPULSION SIMULATION: ENGINE DESIGN, PERFORMANCE TABULATION, AND TRAJECTORY SIMULATION. Report No. NOTS-TP-4341. (AD 833 074L)

165. U.S. Naval Research and Development Center, Aerodynamics Lab., WIND TUNNEL TESTS OF A SUPERSONIC COMBUSTION RAMJET MISSILE AT MACH NUMBERS OF 6.39 AND 9.47. Report No. NSRDC-TEST-AL-C-44. (AD 389 350L)

BIBLIOGRAPHY (Contd)

166. United Aircraft Corp., Research Labs., HYDROCARBON-FUELED SCRAMJET. VOLUME I. HYDROCARBON FUELED SCRAMJET ENGINE INVESTIGATION. (AD 385 821L)
VOLUME II. SCRAMJET ENGINE/STRUCTURE COOLING WITH HYDROCARBON FUELS. (AD 385 822L)
VOLUME III. EFFECTIVENESS STUDIES OF HYDROCARBON SCRAMJET ENGINES. (AD 385 834L)
Report No. UACRL-F910531-14-VOLS-1-3. U.S. Air Force Report No. AFAPL-TR-67-134-VOLS-1-3.

167. United Aircraft Corp., Research Labs., HYDROCARBON-FUELED SCRAMJET. VOLUME I. INLET INVESTIGATION. (AD 500 716L)
VOLUME II. NOZZLE INVESTIGATION. (AD 500 717L)
VOLUME III. EFFECTIVENESS STUDIES. (AD 501 175L)
VOLUME IV. COMBUSTOR INVESTIGATION. (AD 501 648L)
VOLUME V. COOLING INVESTIGATIONS. (AD 502 726L)
VOLUME V. SUPPLEMENT. USERS MANUAL FOR COMPUTER PROGRAM FOR THERMAL ANALYSIS OF DUAL-MODE RAMJETS. (AD 854 467L)
VOLUME VI. LITERATURE SURVEY OF COMBUSTION TECHNOLOGY. (AD 853 942L)
VOLUME VII. FUEL DISTRIBUTION INVESTIGATION.
VOLUME VII. SUPPLEMENT I: TABULATION OF DATA AND DATA REDUCTION PROCEDURES FOR FUEL DISTRIBUTION INVESTIGATION.
Report No. UACRL-G910755-VOLS 1-7, U.S. Air Force AFAPL-TR-68-146-VOLS 1-7, Contract No. AF 33(615)-5153.

168. United Aircraft Corp., Research Labs., ANALYSIS OF AN ADVANCED AIR-AUGMENTED PROPULSION CONCEPT. Report No. UACRL-J970839-7. (AD 506 873L)

169. Vanco, M. R. and Goldman, L. J., COMPUTER PROGRAM FOR DESIGN OF TWO DIMENSIONAL SUPERSONIC NOZZLE WITH SHARP EDGED THROAT. U.S. National Aeronautics and Space Admin. Report NASA-TM-X-1502, January 1968. (N68-14747)

170. Vasil'yev, Yu. N., THEORY OF A SUPERSONIC GAS EJECTOR WITH A CYLINDRICAL MIXING CHAMBER. Lopatochniye Mashini i Struynyye Apparati, Sbornik Statey, Moscow, Mashinostr. Press, 1967, 171; Aztec School of Languages, Inc. Trans., U.S. National Aeronautics and Space Admin. Trans. NASA-TT-F-11554, Contract NASW-1692, April 1968. (N68-22037)

171. Verduzio, L. and Campanaro, P., THEORETICAL EVALUATION OF AIR FLOW - RATE PENETRATING IN PRIMARY ZONE OF COMBUSTION FOR GAS TURBINES AND EXPERIMENTAL VERIFICATION OF RESULTS OBTAINED. Politecnico di Torino, Istituto di Macchine e Motori per Aeromobili Publ. -101, Contract CNR-115-0375-0-C666, August 1968. (In Italian; English Summary) (N69-55620)

172. Verduzio, L. and Campanaro, P., THE AIR RECIRCULATION RATIO IN CAN-TYPE GAS TURBINE COMBUSTION CHAMBERS. Politecnico di Torino, Istituto di Macchine e Motori per Aeromobili Pub. - 107, Dec. 1968. (N69-35726)

173. Weber, R. J., Dugan, J. F., Jr., Luidens, R. W., METHANE-FUEL PROPULSION SYSTEMS. AIAA Paper 66-685, June 1966.

BIBLIOGRAPHY (Contd)

174. Weiss, M. A. and Morgenthaler, J. H., RAMJET TECHNOLOGY, CHAPTER 8: AIRFUEL MIXTURE PREPARATION. Johns Hopkins Univ., Applied Physics Lab. Report No. APL-TG-610-8-Rev., June 1968. (PB-179 068) (N69-12450)

175. Wolanski, P. (Foreign Technology Div., Wright Patterson Air Force Base, Ohio) SUPERSONIC COMBUSTION AND ITS APPLICATION IN HYPERSONIC JET ENGINES. -- TRANSLATION. Report No. FTD-HT-23-1123-67, 16 Nov 1967. (AD 837 257)

176. Yakovlev, Yu. P., REGENERATIVE COOLING FOR COMBUSTION CHAMBERS AND ENGINE NOZZLES WITH SUPERCRITICAL HEAT TRANSFER. Izv. Vyssh. Ucheb. Zaved., Aviats. Tekh. (Kazan), 1968, No. 3, 147-9; Laboratoire de Recherches Balistiques et Aerodynamiques (France), Report No. IRBA-69-0456; 1969. (in Russian and French) (N70-18506)

177. Zhuber-okrog, G., ON THE OPERATION OF PULSE-JETS. Deutsche Versuchanstalt fur Luft- und Raumfahrt (West Germany). Report No. DLR-FB-68-49, DVL-767, August 1968. (in German, English Summary) (N68-36543)

178. Zysina-Molozhen, L. M. and Polyak, M. P., CALCULATION OF THE TEMPERATURE FIELDS IN A BLADE OF A HIGH TEMPERATURE GAS TURBINE DURING INTERNAL COOLING. Teplo- i Massoperenos, Minsk, Nauka i Tekh. Press, Vol. 6, 261, 1966; U.S. National Aeronautics and Space Admin. Trans. NASA-TT-F-11183, January 1968. (N68-15795)

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Shell Development Company A Division of Shell Oil Company Emeryville, California 94608	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

HYDROCARBON FUELS FOR ADVANCED SYSTEMS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Technical Report for 1 September 1969 to 31 August 1970

5. AUTHOR(S) (Last name, first name, initial)
Ackerman, G. H., Faith, L. E., Heck, C. K., Henderson, H. T., Ritchie, A. W., Ryland, L. B.

6. REPORT DATE November 1970	7a. TOTAL NO. OF PAGES 210	7b. NO. OF REFS 32
8a. CONTRACT OR GRANT NO. Contract F33615-70-C-1038 b. PROJECT NO. 9326 Project 3048 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) S-14108 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFAPL-TR-70-71, Part I	

10. AVAILABILITY/LIMITATION NOTICES This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Air Force Aero Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio 45433.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Air Force Aero Propulsion Laboratory Air Force Systems Command, U.S. Air Force Wright-Patterson Air Force Base, Ohio 45433

13. ABSTRACT

The general objective of this investigation is the development of new fuels and new fuel systems which will provide the cooling and propulsion requirements of advanced air-breathing engines. In previous studies on the utilization of endothermic reactions of hydrocarbon fuels, the catalytic dehydrogenation of naphthenes showed the most promise for practical applications. In continuing these studies, a large number of catalysts were prepared and tested for activity and stability for the dehydrogenation of methylcyclohexane and decalin. The stability of supported platinum catalysts for these reactions was affected by the physical properties and chemical composition of the support and by the metal content and metal composition of the catalyst. Bicyclo(2,2,2)octane was dehydrogenated to bicyclooctene in low yield with a supported platinum catalyst. Additives were found which enhanced the rate of thermal cracking of paraffins. Improved wall catalysts were formulated for the dehydrogenation of naphthenes and a mathematical model was developed for a catalytic wall reactor. Various fuels were evaluated for thermal stability, in both our standard ASTM Coker and a special Alcor JFTOT unit designed for operation up to 1000°F and 1000 psi. The high temperature thermal stability of fuels was improved by means of additives. The deposit profiles on coker tubes were reproducibly determined with a recently developed beta-ray backscatter instrument which is capoble of measuring deposit thicknesses up to 2500 Å. The physical properties of JP-7 jet fuel were recalculated using improved methods. The supersonic combustion of decalin, tetralin and naphthalene was investigated using the shock tube. A literature survey was made of articles and patents of interest to this and related programs.

KEY WORDS

Endothermic Fuels
Thermally Stable Fuels
Storage Stability of Fuels
Catalytic Dehydrogenation
Supported Platinum Catalysts
Supersonic Combustion
Shock Tube Studies
SHELLDYNE-H® Fuel