AD656126

FINAL REPORT

OIL CONTAMINATION IN OXYGEN SYSTEMS

Contract NObs-94416
Project No. SF013-08-14, Task 3917

by

John B. Presti

Charles J. DeSimone, Jr.

Materials Engineering and Laboratory Services

GENERAL DYNAMICS
Electric Boat Division
Groton, Connecticut

Reviewed by: T. V. Bolles
T. V. Bolles, Supervisor
Chemical Engineering Group

Approved by: H. Wallman
H. Wallman, Chief
Chemistry/Chemical Engineering Section

U413-67-101

June 16, 1967

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

FOREWORD

This report covers the work performed under NAVSHIPS Contract No. NObs-94416 (Project No. SF013-08-14, Task 3917). The NAVSEC contract monitor was Mr. Herman Kraut.

The objective of this program was to collect the necessary experimental data on ignition and flame propagation in an oil contaminated oxygen system in order to more exactly define the required level of cleanliness for such systems. The results are to be incorporated into military specifications for oxygen systems to define the required cleanliness.

ACKNOWLEDGEMENTS

The authors wish to express special appreciation to Mr. Warren Goddard, Mechanical Test Engineer, and to Mr. Richard Canale, Instrumentation Engineer, for their concentrated efforts in carrying out the experimental program.

Acknowledgement is also extended to the following people who participated in the test program:

F. DeSouza	Supervisor, Mechanical Test
M. Schiller	Senior Instrumentation Engineer
R. Holden	Gas Analysis
A. Desmarais	Chemistry
J. Williams	Chemistry

INTRODUCTION

Under auspices of the Department of the Navy, NAVSEC, a study was undertaken to determine the compression ignition and flame propagation limits of hydrocarbons in a high pressure oxygen system.

Considerable work has been done concerning compression ignition and flame propagation in high pressure air systems, but very little has been done with pressurized oxygen systems. The limited work performed with oxygen did not employ conditions corresponding to the specific systems now in use, namely 3000 psi oxygen with 1/2" monel piping The program reported herein was designed to study that specific area

The study was primarily concerned with the determination of the acceptable levels of oil contamination (2190) on the internal surface of a 1/2" monel pipe below which compression ignition and flame propagation will not occur when pressurized with 3000 psi oxygen. It was also desired to determine that level of oil contamination where, upon ignition, a pressure rise will not exceed 25%.

The first phase of the program consisted of a literature survey to assemble and review all available information from previous studies in the area of compression ignition and flame propagation in high pressure air and oxygen systems. A summary of these earlier studies is presented in Section I.

Following the literature survey a test program was designed and initiated to accomplish the objectives of the contract. A description of the test apparatus used is presented in Section II, the testing procedure is described in Section III, and the results of the test program are presented in Section IV.

Throughout this report, the term "oil concentration" is used. This refers to the amount of oil coating, expressed as mg/ft^2, on the inside surface of the test pipe.

SUMMARY

A test program was conducted to determine the ignition limits of oil contamination in 1/2" monel pipe when pressurized with 3000 psi oxygen. The oils investigated were 2190 lubricating oil and Habcool #318 cutting oil. Thin films of these oils were applied to the internal surface of a 4 ft. section of 1/2" monel pipe. The pipe was then rapidly pressurized with 3000 psi oxygen. In addition, tests were made using oil droplets and varying the initial pipe wall temperature.

The test results showed little danger of compression ignitions at oil concentrations below 160 mg./ft^2 of 2190, or below 110 mg./ft^2 for Habcool. Concentrations of both oils above 260 mg./ft^2 will ignite when rapidly pressurized with 3000 psi oxygen. These concentrations must be compared to the present oxygen clean standards of 0.013 mg./ft^2 maximum allowable hydrocarbon concentration.

The results also showed that ignition will not occur with oil droplets or puddles smaller than 100 μl in size and that a pressure rise greater than 25% will not occur below oil concentrations of 500 mg./ft^2.

As a result of this test program, it is recommended that the oxygen clean standards be relaxed to 1.5 mg./ft^2. The level of oil concentration is a factor of 100 below the lower ignition limits defined by this test program. It is felt that such a safety factor more than compensates for any variation in the lower ignition limit due to effective pipe length, wall temperature, and non-uniformity in oil contamination.

I LITERATURE SURVEY

In recent years the phenomenon of compression ignition in pneumatic systems has been extensively studied. Such ignitions are induced in systems contaminated with sufficient quantities of a combustible organic material and exposed to rapid pressurization with an oxidizing gas.

Most of the work was concerned with high pressure air systems contaminated with lubricating oil from air compressors. Faeth and White[1] conducted a series of tests in which they investigated the combustion characteristics of 25 mg. samples of various lubricating oils placed at the dead end of a pipe exposed to rapid pressurization with air. They defined the combustion ranges as functions of various parameters including the rate of pressurization, air pressure, length of pipe, and the initial ambient system temperature. The results of these tests quantify the expected trends due to variation in the parameters. Of interest was the fact that the occurrence of combustion was greater, the shorter the length of pipe used down to a length of 1 ft. However, the change in combustion limit was only a mild function of the pipe length.

Wilson[2] and co-workers investigated the compression ignition characteristics of lubricating oils evenly coated on the internal surface of a 1 1/2" diameter test pipe. Using a 15 ft. length of pipe, they studied both auto-ignition and flame propagation using 2190 and Callulube lubricating oils. Wilson defined the lower combustible limit in the range of 1000 mg./ft^2 of oil. He also found that used degraded oil was much more reactive than new unused oils - attributing this to breakdown products in the oil. This conclusion was later verified by Zabetakis[3]. Both Wilson[2] and Perlee[4], concerned with this type of ignition caused by degraded oil blow-by from air compressors, recommend proper cleaning and maintenance to prevent dangerous conditions from arising.

Faeth[1] did a theoretical analysis of the rapid compression process in an attempt to predict whether conditions for ignition would exist in a given system. Predictions based on his analysis compared well with his observed experimental data.

Dallinger and McGill[6], concerned with high pressure air systems aboard submarines, surveyed work done in this field. They reported that an increase in pipe diameter increased the temperatures obtained during a rapid compression, thus lowering the concentration of oil necessary for ignition.

Russian interest in the problem of compression ignition with oxygen is indicated by the work of Gordeyev and coworkers[7]. They reported lower explosive limits of 26,000 mg./ft^2 of oil and lower combustion limits of 190 mg./ft^2. However, they used oils with Russian designations, making comparison with 2190 difficult, and they failed to report pertinent parameters such as rates of pressurization and pipe diameters.

The dangers inherent in high pressure air systems, due to compression ignition, lead to questions about parallel phenomenon in high pressure oxygen systems. Baum[8] and his coworkers investigated 7500 psi oxygen systems, looking at effects of system temperature, vibration, shock, extended storage, contamination, and material compatibility. In regard to ignition, Baum[8] recommended "absolute" cleanliness from organics, and homogeneous hydrocarbon concentrations less than 50 ppm.

In 1961, Kehat[9] studied ignition and flame propagation at pressures up to 1500 psi using gaseous oxygen. Using a 1/4" test pipe evenly coated with oil, he used a spark and an electric match to induce ignition. Kehat found no significant danger of ignition at concentrations up to 1000 mg./ft^2 of oil. Also of interest was Kehat's technique of evenly coating a small diameter pipe, 1/2", with oil - namely of dissolving the oil in a solvent, carbon tetrachloride, applying the solution to the pipe, and then allowing the solvent to evaporate, leaving a thin film of oil behind.

A summary of the literature survey is presented in Section 4.2.2 and compared with the recommendations of this current test program.

II TEST APPARATUS

2.1 General Description

The basic test apparatus is illustrated schematically in Figure 1.

The test apparatus basically consisted of a four foot section of 1/2 inch, schedule 80, monel pipe plugged at one end. The high pressure oxygen was supplied from a two tank system. One tank (15 ft^3 capacity) at 3800 psig was used to supply the second tank (9 ft^3) at 3000 psig which, in turn, supplied the test pipe. The instrumentation and control equipment consisted of flame probes, pressure transducers, thermocouples, external strain gauges, a 5000 psi relief valve, a gas sampling bomb, a manually operated ball valve, a quick opening Marotta valve, a check valve and a manually operated vent valve. Photographs of the test pipe, in place for a run, are shown in Figures 2, 3, 4, and 5. A more detailed description of the components is found in Table I.

A four foot length of pipe was selected as the optimum length. This selection is a compromise between the minimum length recommended by Faeth and White and the physical instrumentation requirements necessary to measure flame propagation.

This test apparatus was modified slightly during the test program to accommodate a sparking device. This alteration consisted of removing the pressure transducer (P_1) closest to the dead end and replacing it with the sparking device. This modification is shown in Figure 6.

In addition to the pipe just described, another test pipe was used during the final portion of testing with a minimum of instrumentation located adjacent to the dead end. This second pipe was also a 4 ft. length of 1/2" monel pipe, but it had only two instrumentation taps and a vent line. This test set up is shown schematically in Figure 7. Photographs of this test set up are shown in Figures 8 and 9. As can be seen in the figures a nichrome heating coil was added to the pipe to give the capability of operating at elevated initial temperatures.

TABLE I

LIST OF APPARATUS AND COMPONENTS

	Component	Description
1	3000 psig O_2 supply flask	9 ft^3, MIL-C-1511A
1	3800 psig O_2 supply flask	15 ft^3, MIL-C-2809B
1	Solenoid valve	Marotta M.V. 173
1	Pressure gauge	0 to 10,000 psig scale
1	Check valve	3/4"
3	Nipples	3/4" pipe, NiCu
1	Pipe union	1/2", NiCu
1	Pipe cap	1/2", NiCu
1	Flame arrestor*	1/2" I.P.S. NiCu
1	Pipe tee	3/4" monel
1	Test pipe	4 ft. Sch. 80, 1/2" Monel MIL-T-1368 Ty. 1, Cond. 1
1	Relief valve	5,000 psi relieve pressure
1	Ball valve	3/4", manual
1	Vent valve	1/4", manual
1	Gas sampler bomb	See Section 2.2
4	Strain gauges	"
3	Pressure transducers	"
3	Temperature probes	"
4	Flame probes	"

*The flame arrestor used in Runs A-1 through A-24, Runs D-1 through D-5, and F-36 was made of stainless steel.

For safety considerations, the test pipe was located in a concrete test pit and was surrounded by sand bags. The control and instrumentation read-outs were located in an adjacent test pit.

2.2 Instrumentation

Instrumentation on the basic test set-up consisted of four flame probes spaced 12 inches apart; three pressure transducers, 18 inches apart; four external strain gauges; and three thermocouples, 18 inches apart. The locations of this instrumentation can be seen in the figures presented in the previous section.

In addition to this basic instrumentation, a sparking device was used in an attempt to induce ignitions. The location of this sparking device can also be seen in the figures presented in the previous section. The outputs of the instrumentation probes were recorded on an oscillograph recorder with a paper speed of 64 inches/sec.

A close-up of a flame probe, a thermocouple, and the sparking device is shown in Figure 10; while a photograph of a pressure transducer, a strain gauge installation and the flame arrestor is shown in Figure 11.

A block diagram of the basic instrumentation is presented in Figure 12, while a schematic of the control circuitry is shown in Figure 13. A detailed list and description of the major instrumentation components is presented in Table II. The time sequence in which all the instrumentation and control circuitry operated is shown in Figure 14.

The instrumentation block diagram (Figure 12) shows the relationship of the control circuitry and the instrumentation probes to the recording device. The flame probes, the pressure transducers, and the strain gauges are energized by the circuitry; signals detected by them are then transmitted to the recorder. The thermocouples, using an ice water bath as a reference, generate voltages indicative of their temperatures and transmit them to the recorder. The sparking

TABLE II

LIST OF INSTRUMENTATION EQUIPMENT

	Description	Manufacturer
1.	Chromel/alumel thermocouples (400 milliseconds response time)	Thermoelectric, Inc.
2.	Chromel wire flame probes - porcelain base with 300 volt operating potential ($<$ 1.7 millisecond response time)	Electric Boat Division (not commercial)
3.	Pressure transducers - 10,000 lbs/in^2, air cooled type (.05 millisecond response time)	Norwood, Model 102
4.	UV light beam oscillograph recorder - galvonometer (1.7 millisecond response time)	Consolidated Electrodynamics Corp. (C.E.C.), Model #124
5.	3 kc. carrier amplifiers for recorder (15 units)	C.E.C., Model #1-113B
6.	Modulators for amplifiers (7 units) (2 milliseconds response time)	C.E.C., Model #15-605
7.	Oscillator power supplies (2 units)	C.E.C., Model #2-105B
8.	Variable AC Voltage Supply	Superior Electric
9.	Displacement Transducer ($<$ 1.7 millisecond response time)	Underwater Explosion Research Division (USN)
10.	Potentiometer and Switch (Auxilliary temperature measurements)	Leeds & Northrup
11.	120 OHM Strain Gauges	Baldwin-Lima-Hamilton

device discharges the electrical energy stored in its capacitors (Figure 13B) and this event is transmitted to the recorder. The potentiometer attached to the stem of the Marotta valve is energized by the circuitry and transmits the change in position of the valve to the recorder. The Marotta valve itself is activated by the control circuitry; while time delay relay 1 (TD-1) and (TD-2) are activated by the same circuitry and in turn control parts of this circuitry (Figure 13).

As seen in Figure 13A, the circuitry is activated by closing switch S-1 which energizes the indicating light plus the flasher and bell to warn personnel in the area that a test is in progress. A test is initiated by closing S_3 which activates relay K_1 and TD-1. Activation of relay K_1 closes contacts K_{1-1} which keeps itself activated without regard to the position of S_3. Activation of TD-1 closes the contacts TD1-1 which, in turn, activates TD-2, TD-3, and opens the Marotta valve. Activation of TD-2, after a preset period of time, shuts down the circuitry. Activation of TD-3, after a preset period of time, opens contacts TD3-1, closing the Marotta valve.

The circuitry of Figure 13B is activated by the closing of TD3-2, which has been closed by TD-3 of Figure 13A. With the contact TD3-2 closed, TD-5 is activated which in turn closes contacts TD5-1 activating K_2. K_2 closes contact K_{2-1} which discharges the spark. The 600 μf capacitors are charged by closing switch S_4. Contacts TD3-3 isolate this circuit while TD-3 is activated.

III TEST PROCEDURE

3.1 Preliminary Tests

Before proceeding with ignition tests, it was necessary to verify the proposed oil coating technique.

Preliminary tests were conducted to determine whether the oil coating technique selected would be satisfactory. This technique consisted of dissolving the oil in a low-boiling, non-combustible solvent Freon TF and then applying the resultant solution to the pipe. Upon evaporation of the Freon, a residual coating of oil was left on the pipe. In evaluating this technique, a sacrificial section of pipe was used. After the coating operation, the pipe was cut into small sections and the amount of oil present on each section was determined by chemical analysis. This analysis consisted of removing the oil from the pipe segments with a low boiling point solvent, then evaporating off the solvent. The amount of oil removed from each segment was then determined gravimetrically.

This same method of evaluation was used to determine the feasibility of other oil coating techniques as part of the verification. The other oil coating techniques evaluated were: a) applying the oil directly with a circular brush or swab, b) spraying the oil onto the pipe, c) partial removal of a heavy oil coating using a solvent.

3.2 Test Plan

The test plan included the following areas of investigation:
1) The coating of the test pipe with various concentrations of 2190 oil at ambient temperatures and attempting a compression ignition with 3000 psi oxygen; the oil coatings were increased in small increments in concentrations ranging from 0.08 mg/ft^2 to 640 mg/ft^2.
2) Placing droplets of 2190 oil near the dead end of the test pipe

and attempting a compression ignition with 3000 psi oxygen; the size of the oil droplets used ranged from 5 microliters (μl) to 90 μl. 3) Employing the combination of coating the test pipe with 2190 oil and placing a droplet of the oil near the dead end of the pipe, and attempting a compression ignition with 3000 psi oxygen; oil coating concentrations ranged from 12 mg/ft^2 to 88 mg/ft^2, while the oil droplets ranged in size from 10 μl to 100 μl. 4) Coating the test pipe with various concentrations of 2190 oil or of Habcool cutting oil, using an electrical spark to induce ignition in a 3000 psi oxygen atmosphere; the 2190 oil concentrations ranged from 0.16 mg/ft^2 to 640 mg/ft^2, while the Habcool concentrations ranged from 100 mg/ft^2 to 480 mg/ft^2. 5) Coating a modified test pipe (minimum instrumentation) with various concentrations of 2190 oil and of Habcool cutting oil, and attempting a compression ignition with 3000 psi oxygen; the 2190 oil concentrations ranged from 80 mg/ft^2 to 480 mg/ft^2, while the Habcool concentration ranged from 160 mg/ft^2 to 480 mg/ft^2.

The 2190 (MIL-L-17331A) lubricating oil was selected to be used during this test program because most of the previous investigations of compression ignition and flame propagation were performed using this lubricating oil. Thus, in order to compare results with the earlier work, 2190 was used in this investigation. Habcool #318 cutting oil was selected as a typical organic cutting oil used in a machine shop with which piping might be contaminated during fabrication in actual practice.

3.3 Testing Procedure

In making a test run the following procedure was used:

1. The test pipe was thoroughly cleaned by use of Freon (TF) rinses and a lint-free cloth.

2. With the instrumentation probes replaced by plugs, the pipe was filled with an oil/Freon solution of a known concentration.

3. The oil/Freon solution was emptied and the remaining Freon allowed to evaporate (15 to 20 minutes was allowed) leaving a thin, uniform oil film.

4. The instrumentation probes were replaced into their proper positions.

5. The test pipe was placed "on-line", putting the flame arrestor into position within the union.

6. The calibration of the instrumentation was checked as well as the electrical control circuitry.

7. The position of all hand-operated valves was checked.

8. The test area was cleared of all personnel and the test was made.

9. After the run was completed, the electrical power was turned off and all valves secured.

10. A gas sample was taken for analysis and the test pipe was vented down to ambient pressure.

11. The test pipe was disconnected and was visually inspected.

12. The test pipe and instrumentation probes were thoroughly cleaned in preparation for the next run.

The gas sample at the conclusion of a test was analyzed for carbon dioxide, hydrogen, carbon monoxide, oxygen and nitrogen using gas chromatography.

No attempt was made to replace the air in the test pipe with pure O_2 before the rapid pressurization. This initial air is compressed to within 1/4" of the dead end during compression from 14.7 psi to 3000 psi and it was felt that this small amount of nitrogen, in comparison to the amount of oxygen present, would have a negligible effect on the results.

IV TEST RESULTS

4.1 Preliminary Tests

The oil coating tests showed that the selected technique of dissolving the oil in a non-combustible solvent, Freon TF, gave the best results. The oil was evenly coated onto the surface of the pipe and the concentration of oil on the pipe was proportional to the concentration of oil in the Freon. This relationship is shown in Table III. It was also found to be the best technique from an operational point of view - being less prone to technician error and having good reproducibility.

TABLE III
OIL COATING CONCENTRATIONS
(1/2" Monel Pipe)

Oil Concentration in Freon - PPM	Oil Coating on Pipe - mg/ft^2	Oil Film Thickness - microns
5	0.0125	1.2×10^{-3}
10	0.025	2.4×10^{-3}
100	0.25	2.4×10^{-2}
1000	2.5	0.24
10,000	24.6	2.4
50,000	123.0	12.0
100,000	246.0	24.0
200,000	492.0	48.0
300,000	738.0	72.0

4.2 Ignition Test Results

The results of the test program are presented in the following sections. The significant data are presented in Section 4.2.1 and Appendix A, while an interpretation and discussion of these data is found in Section 4.2.2.

4.2.1 Data

The parameters measured during each of the test runs are presented in Appendix A. The parameters include: oil concentration, ambient temperature, maximum pressure, rate of pressure rise, inside temperature, flame probe saturation, and strain gauge indication. The temperatures presented are the maximum temperatures recorded. Due to the [illegible] second response time of the thermocouples, the actual temperatures encountered are much higher.

It should be noted that at various points throughout the test program a blank runs were made - i.e. runs in which no oil was put into the test pipe. These runs were made to determine the time histories of the various parameters due only to the rapid pressurization of the test pipe with oxygen, and to serve as a check on the instrumentation. The results of all the blank runs were identical, therefore, the results of only one of these runs is presented.

4.2.2 Correlation and Interpretation of Results

The first test run with oil contamination resulted in a violent explosion causing extensive damage to the test apparatus. This damage is shown in Figures 15-20. A comparison can be made with the undamaged test pipe shown in previous sections.

As can be seen in the figures a two inch section of the test pipe, at the inlet end, was disintegrated along with part of the coupling; one of the pressure probes was blown out of its fitting; several of the electrical connectors to the instrumentation probes were burned; and the copper "O" ring seals on the two remaining pressure transducers were blown out. In addition, the flame arrestor was disintegrated and the check valve welded closed. It should be noted that for this run the coupling at the inlet end of the test pipe and the flamearrestor were both made of stainless steel.

After the explosion, it was felt that the level of oil contamination, 160 mg/ft^2, was well into the explosive range and that the testing should be conducted in a much lower range of oil concentration. Subsequent test runs showed, however, that levels of oil contamination higher than 160 mg/ft^2 can withstand rapid pressurization by pure oxygen without resulting in an explosion. These subsequent tests employed monel and nickel-copper components only, while the initial run at 160 mg/ft^2, which resulted in an explosion, had a stainless steel flame arrestor. In an attempt to duplicate the explosive run, a stainless steel flame arrestor was put into the system (Run F-3[illegible]). In this run, though the test pipe did not rupture, there was an ignition and flame propagation, as opposed to no indications of ignition or flame propagation under the same conditions using a monel flame arrestor (Run F-18).

No completely satisfactory explanation of the explosion is available, but it is significant that no indications of ignition were obtained with the monel flame arrestor, while very definite indications were observed with the stainless steel flame arrestor.

As a result of the explosion in the first run, subsequent tests were conducted (Runs A2-A24, F1-F28, F35) by evenly coating the test pipe with 2190 oil with concentrations of 0.08 mg./ft^2 up to 160 mg./ft^2 without any indication of ignition. At oil concentrations between 173 mg/ft^2 and 266 mg./ft^2 there were indications of ignition and flame propagation on some instrumentation probes but not on others. At oil concentrations above 266 mg./ft^2, there were definite indications of ignition and flame propagation. These results can be seen graphically in Figure 21.

On the supposition that it was possible to have sufficient oil in the test pipe to propagate a flame while not having a high enough concentration to cause an auto-ignition, a series of runs were conducted in which it was attempted to induce an ignition. Thus runs (Runs D1-D14, AD1-AD10) were made with small drops of oil placed near the dead end of the test pipe (thus giving a high local concentration of oil). Oil droplets ranging in size from $5\mu\ell$ to $100\mu\ell$ were used alone and in combination with a uniform oil film ranging in concentrations from 12 mg./ft^2 to 88 mg./ft^2. In Run D-12, the gas analysis after the run revealed the presence of CO_2, indicating combustion of the oil. However, the other instrumentation did not confirm this combustion, and the results could not be duplicated in subsequent tests at similar or more severe conditions (Runs AD-8 and AD-10).

In the test runs with oil droplets of 70μl or greater, H_2 was fo[illegible] in the gas after the test run. It is believed that this H_2 is a product of the thermal decomposition of the oil. However, oil drop- lets were used only in an attempt to induce ignitions. This they failed to do, so the appearance of H_2, though interesting, was no[illegible] investigated further. However, two things should be noted in thi[illegible] regard: 1) the occurrence of oil droplets, 70μl or greater, in a clean oxygen system is highly unlikely and 2) the H_2 appeared in concentrations well below its lower ignition limit.

Having failed to induce ignition using small droplets of oil, an attempt was made to induce ignition by means of an electrical spark. A series of runs were made using the sparking device (Runs F1-F28, F35, F36). In those runs in which ignitions were observed, they we[illegible] of the compression ignition type, and involved oil concentrations above 160 mg./ft^2. The spark did not initiate any ignitions nor affect flame propagation in any way.

Test runs made in which the pipe was evenly coated with Habcool a[illegible] 70°F (Runs F29-F34) indicated that the no ignition range was belo[illegible] about 110 mg./ft^2, while the ignition range was somewhere above 250 mg./ft^2. Comparison of these results with those obtained for 2190 (Figure 21) show Habcool to be somewhat more reactive.

In an attempt to attain higher temperatures from the rapid compression with pure oxygen, a series of tests were run using a pipe with a minimum of instrumentation located adjacent to the dead end. Because of the minimum amount of instrumentation, it was more difficult to get accurate indications of ignition and flame propagation. However, from the instrumentation available, the following results were obtained:

A. Using 2190 oil at 70°F, tests were run at concentrations of 80 mg./ft^2 to 480 mg./ft^2 (Runs C1-C6). No ignition was obta[illegible] below 160 mg/ft^2, while the ignition range was found to be above 200 mg/ft^2. These results approximate the results shown in Figure 21.

B. Using 2190 oil heated to 125°F, tests were run at concentrations ranging from 160 mg/ft^2 to 480 mg/ft^2 (Runs C7-C11). Indications of ignition were seen at the lower concentration of 160 mg/ft^2, indicating that the level of oil contamination necessary for ignition and flame propagation are somewhat lower at 125°F than at 70°F.

C. Using Habcool cutting oil at 70°F, tests were run at concentrations ranging from 160 mg/ft^2 to 480 mg/ft^2 (Runs C12-C16). Definite ignitions were obtained above 200 mg/ft^2, while the non-ignition range is somewhere below 160 mg/ft^2. The non-ignition and ignition ranges are about the same as those found with the regular test pipe.

D. Using Habcool oil at 125°F, tests were run at concentrations ranging from 160 mg/ft^2 to 480 mg/ft^2 (Runs C17-C21). The results from these tests were not distinguishable from those at 70°F.

A more quantitative correlation can be made by plotting the resultant % CO_2, the maximum recorded temperature, and maximum pressure obtained as functions of level of oil concentration. Such plots are shown in Figures 22, 23 and 24. It can be seen that these results match the non-ignition, transient, and ignition ranges earlier defined more qualitatively.

The carbon dioxide found was considerably less than would be dictated with 100% combustion of the oil. This is, however, consistent with the fact that carbon deposits and residual oil were found in the test pipe after ignitions, indicating considerably less than complete combustion.

It is possible to compare these results with those obtained by earlier investigators. Kehat reports little danger of ignition in oxygen systems up to 1500 psig at concentrations up to 1000 mg/ft^2. This compares to our lower ignition limit of 160 mg/ft^2 at 3000 psi. Kehat used a pure compound, n-hexadecane, for his work, while our work was performed with a commercial lubricating oil, 2190. Comparison of the properties of n-hexadecane and 2190 - e.g., molecular weights, auto-ignition temperature - and considering the differences in the oxygen pressures used reveal our results to be in reasonable agreement with Kehat.

It is also possible to compare our results with the results of Wilson et al. Wilson reports the lower ignition limit in high pressure air systems at 3000 psig of 2190 oil to be 1000 mg/ft^2. By extrapolating these results to pure oxygen at 3000 psig, a lower ignition limit would be approximately 200 $mg./ft^2$. This is in good agreement with the current results.

A summary comparison of the current results and those obtained by earlier investigators is presented in the following chart:

Investigator	Test Gas	Test Apparatus	Oil Used	Lower Ignition Limit
Kehat	O_2, 1500 psi	1/2" pipe	$C_{12}H_{26}$	1000 mg/ft^2
Wilson	Air, 3000 psi	1-1/2" pipe	2190	1000 mg/ft^2
Gordeyev	O_2	-	-	190 mg/ft^2
Presti	O_2, 3000 psi	1/2" pipe	2190	160 mg/ft^2
Baum	O_2, 1500 psi	(50 ppm homogeneous mixture - recommended lower limit)		

V CONCLUSIONS AND RECOMMENDATIONS

From the test results obtained the following conclusions can be drawn for 3000 psi oxygen systems:

1. Compression ignition and flame propagation will not occur below oil concentrations of 160 mg/ft^2 at oil temperatures below 125°F in a 1/2", schedule 80, monel pipe.

2. Compression ignitions will not occur with oil droplets or puddles smaller than 100 $\mu\ell$ in size.

3. Habcool cutting oil was found to be somewhat more reactive than 2190.

4. Present oxygen clean standards (as specified by Shipyard Standard Practice 1.9 Rev. F, Oxygen and Nitrogen Systems, paragraph 3.2.3.1d) which require oil film concentrations of 0.013 mg/ft^2 or less, are much too rigorous and can be relaxed. The oil film concentration of 0.013 mg/ft^2 corresponds to obtaining a concentration of 5 ppm in a Freon rinse, while 160 mg/ft^2 corresponds to 65,000 ppm in Freon.

   It is recommended that the allowable oil film concentration specified by the above Shipyard Standard Practice be set at 500 ppm oil concentration in a freon rinse. This concentration allows a safety factor of 100 over the values at which oil ignitions begin to occur.

It is felt that such a safety factor more than adequately allows for any variation in the lower ignition limit due to variations in effective pipe lengths below 4 feet which might be found in an actual pressurized oxygen system.

5. To obtain pressure rises greater than 25% requires oil concentrations greater than 500 mg./ft^2. This can be seen from Figure 24.

BIBLIOGRAPHY

(1) Faeth, G. M. and White, D. F., "Ignition of Hydraulic Fluids by Rapid Compression"; Journal of the American Society of Naval Engineers, Vol. 73 No. 3, August, 1961.

(2) Wilson, M. P., DeSouza, F., and Presti, J. B.; "Final Report on Oil-Air Explosion Hazards in High Pressure Air Systems". Report No. U411-61-166, General Dynamics Corp., Electric Boat Division, November, 1961.

(3) Zabetakis, M. G.,; "Flammability Characteristics of Combustible Gases and Vapors"; Bureau of Mines, Bulletin 627, 1965.

(4) Perlee, H. E., and Zabetakis, M. G.; "Compressor and Related Explosions"; Bureau of Mines Information Circular 8187; 1963.

(5) Faeth, G. M.; "Spontaneous Ignition During Charging Process in Pneumatic and Hydraulic Systems"; Final Report for USN Bu-Ships Contract No. NObs 78674, Index No. S-R001-0301; October, 1963.

(6) Dallinger, J. F., and McGill, J. E.; "Submarine High Pressure Air Systems"; presented at Annual Meeting of the Society of Naval Architects and Marine Engineers; New York, November, 1962.

(7) Gordeyev, V. Ye., Komos, V. F., and Troshin, Ya. K.; "On Detonation Combustion of Heterogeneous Systems"; Foreign Technology Division, Translation, FTD-TT-65-1106, December, 1965.

(8) Baum, J. V., Goobish, B., and Trainer, T. M.; "An Evaluation of High Pressure Oxygen Systems"; WP-AFB Technical Documentary Report No. AMRL-TDR-62-102; September, 1962.

(9) Kehat, E.; "Hazard Levels of Hydrocarbon Films in Systems con-taining Liquid and Gaseous Oxygen"; paper presented at Cryogenic Engineering Conference; August, 1961.

(10) Walde, R. A.; "The Relationship of the Chemical Structure of Cutting Oils to Their Oxygen Compatibility", Air Products and Chemicals, Inc.; Allentown, Pennsylvania.

(11) Kuchta, J. M. and Cato, R. J.; "Ignition Characteristics of Fuels and Lubricants"; Technical Report AFAPL-TR-65-18; March, 1965.

(12) Kuchta, J. M., et al; "Ignition Characteristics of Fuels and Lubricants"; Technical Report AFAPL-TR-66-21; March, 1966.

APPENDICES

DATE	RUN NO.	CONC. (mg/ft^2)	AMBIENT TEMP. (°F)	MAXIMUM PRESSURE IN X TIME (psig in x msec) P$_1$	P$_2$	P$_3$	RATE OF PRESSURE RISE INSIDE PIPE (psig/sec)	MAXIMUM INSIDE [illegible] (°F [illegible] msec) T$_1$	[illegible]
	BLANK	2190 0	70	3000 in 100	3000 in 100	3000 in 100	28000	200 in 100	[illegible]
10/6	A-1	160	70	>3000 in 90	>3000 in 90	>3000 in 90	30900	>2000 in 100	>20[illegible] 170
10/21	A-2	0.08	70	3000 in 100	3000 in 100	3000 in 100	23000	200 in 100	[illegible]
10/24	A-3	0.16	70					SAME AS RUN A-2	
10/24	A-4	0.32	70					SAME AS RUN A-2	
10/25	A-5	0.64	70					SAME AS RUN A-2	
10/26	A-6	1.60	70					SAME AS RUN A-2	
10/26	A-7	2.13	70					SAME AS RUN A-2	
10/26	A-8	2.67	70					SAME AS RUN A-2	
10/27	A-9	3.20	70					SAME AS RUN A-2	
10/27	A-10	4.00	70					SAME AS RUN A-2	
10/27	A-11	5.25	70					SAME AS RUN A-2	
10/28	A-12	7.82	70					SAME AS RUN A-2	
10/28	A-13	10.3	70					SAME AS RUN A-2	
10/28	A-14	12.8	70					SAME AS RUN A-2	
10/31	A-15	20.0	70					SAME AS RUN A-2	
10/31	A-16	24.6	70					SAME AS RUN A-2	
11/1	A-17	35.6	70					SAME AS RUN A-2	
11/2	A-18	45.7	70					SAME AS RUN A-2	
11/2	A-19	55.2	70					SAME AS RUN A-2	
11/2	A-20	64.0	70					SAME AS RUN A-2	
11/14	A-21	72.3	70	2900 in 139	2700 in 139	2700 in 139	28000	[illegible]	[illegible]
11/15	A-22	80.0	70	2960 in 141	2800 in [illegible]	2800 in 141	28000	[illegible]	[illegible]

A

[illegible]	[illegible]	[illegible] (in msec)				[illegible] PROBE [illegible] TIME ([illegible])				PER-CENT CO_2
		[illegible]	[illegible]	S_3	[illegible]	[illegible]	[illegible]	F_3	F_4	
[illegible]	[illegible]	[illegible]	[illegible]	150 in [illegible]	[illegible]	-	-	-	-	0
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	78	78	78	-
[illegible]	[illegible]	[illegible]	[illegible]	150 in [illegible]	[illegible]	-	-	-	-	0
[illegible]	76	-	161 in 139	156 in 139	[illegible] in 139	-	-	-	-	0
[illegible]	[illegible]	[illegible]	[illegible]	160 in [illegible]	[illegible]	-	[illegible]	-	-	0

Best Available Copy

DATE	RUN NO.	CONC. (mg/ft²)	AMBIENT TEMP. (°F)	MAXIMUM PRESSURE IN X TIME (psig in x msec) P₁	P₂	P₃	RATE OF PRESSURE RISE INSIDE PIPE (psig/sec)	MAXIMUM [illegible] T₁	T₂
		[2190]							
11/15	A23	87.2	70	3000 in 143	2800 in 143	2760 in 143	27000	240 in 153	165 [illegible]
11/15	A-24	94.1	70	2940 in 141	2800 in 141	2740 in 141	28000	225 in 160	160 [illegible]
		(μl)							
11/3	D-1	5	70	3000 in 133	2800 in 133	2760 in 133	28500	250 in 165	[illegible]
11/4	D-2	10	70					SAME AS RUN A-2	
11/4	D-3	15	70					SAME AS RUN A-2	
11/7	D-4	20	70					SAME AS RUN A-2	
11/7	D-5	5	70					SAME AS RUN A-2	
11/18	D-6	30	70	2900 in 105	2800 in 105	2720 in 105	37000	210 in [illegible]	[illegible]
11/18	D-7	40	70	2900 in 104	2800 in 109	2760 in 109	35000	225 in 180	[illegible]
11/21	D-8	50	70	2950 in 101	2840 in 101	2760 in 101	38500	235 in 195	[illegible]
11/21	D-9	60	70	2950 in 104	2880 in 104	2760 in 104	36500	215 in 175	150 [illegible]
11/22	D-10	70	70	2920 in 105	2840 in 105	2720 in 105	36500	215 in 155	[illegible]
11/22	D-11	80	70	2940 in 105	2720 in 105	2720 in 105	38000	225 in 190	[illegible]
11/23	D-12	90	70	3100 in 97	2760 in 97	2650 in 97	42000	245 in 285	200 [illegible]
11/8	D-13	10	125					SAME AS RUN A-2	
11/9	D-14	10 (Habcool)	125					SAME AS RUN A-2	
11/9	AD-1	12.3+ 10 μl	125					SAME AS RUN A-2	
11/10	AD-2	24.6+ 10 μl	125					SAME AS RUN A-2	
11/10	AD-3	35.6+ 10 μl	125					SAME AS RUN A-2	

11

[illegible]

[illegible] 30,000 [illegible]

[illegible]		FURNACE OUTSIDE TEMP. (°F)	[illegible] PROBE INDICATION [illegible] (x in in x msec)				FLAME PROBE INDICATION TIME (msec)				PER-CENT CO_2
[illegible]	T_2		S_1	S_2	S_3	S_4	F_1	F_2	F_3	F_4	
[illegible] 103	[illegible] in 24	70	150 in [illegible]	[illegible] in 138	155 in [illegible]	[illegible] in 136	-	-	-	-	0
[illegible]	[illegible] in 21	70	[illegible] in [illegible]	[illegible] in 141	153 in [illegible]	[illegible] in 141	-	-	-	-	0
[illegible]	[illegible] in 20	70	[illegible] in 133	[illegible] in 133	154 in [illegible]	[illegible] in 133	-	-	-	-	0
[illegible]	[illegible] in 20	70	[illegible] in 105	150 in 105	153 in 105	[illegible] in 105	-	-	-	-	0
[illegible]	[illegible] in 18	70	145 in 109	[illegible] in 109	153 in 109	[illegible] in 109	-	-	-	-	0
[illegible]	[illegible] in 20	70	150 in 101	153 in 101	156 in 101	150 in 101	-	-	-	-	0
[illegible]	[illegible] in 18	70	150 in 104	150 in 104	153 in 104	150 in 104	-	-	-	-	0
[illegible]	[illegible] in 22	70	150 in 105	150 in 105	145 in 105	150 in 105	-	-	-	-	0 0.9%H_2
[illegible]	95 in 18	70	153 in 105	153 in 105	153 in 105	150 in 105	-	-	-	-	0 1.0%H_2
[illegible]	[illegible] in 126	70	153 in 97	153 in 97	156 in 97	[illegible] in 97	-	-	-	-	6.58 1.1%H_2
		125									
		125									
		125									
		125									
		125									

[illegible]

Oxygen [illegible]

DATE	RUN NO.	CONC. (mg/ft^2)	AMBI-ENT TEMP. (^{0}F)	MAXIMUM PRESSURE IN X TEST (psig in x msec)			RATE OF PRESSURE RISE INSIDE PIPE (psig/sec)	[illegible]	
				P_1	P_2	P_3		T_1	T_2
		[2190]							
11/10	AD-4	45.7+ 10 μℓ	125					SAME AS RUN A-2	
11/14	AD-5	64.0+ 10 μℓ	125					SAME AS RUN A-2	
11/28	AD-6	55.2+ 70 μℓ	70				[illegible]	SAME AS RUN A-2	
11/29	AD-7	64.0+ 80 μℓ	70				38000	SAME AS RUN A-2	
11/29	AD-8	72.2+ 90 μℓ	70				38000	SAME AS RUN A-2	
11/30	AD-9	80.0+ 100 μℓ	70	2920 in 109	2840 in 109	2720 in 109	37000	210 in 300	[illegible]
11/30	AD-10	87.2+ 100 μℓ	70	2880 in 106	2760 in 106	2720 in 106	36000	230 in 250	155 [illegible]
3/30	F-1	0.16	70				38000	SAME AS RUN A-2	
3/30	F-2	1.60	70				38000	SAME AS RUN A-2	
3/31	F-3	7.81	70				38000	SAME AS RUN A-2	
3/31	F-4	15.2	70				38000	SAME AS RUN A-2	
3/31	F-5	24.6	70				38000	SAME AS RUN A-2	
4/3	F-6	35.6	70				38000	SAME AS RUN A-2	
4/3	F-7	45.8	70				38000	SAME AS RUN A-2	
4/3	F-8	55.2	70				38000	SAME AS RUN A-2	
4/4	F-9	64.0	70				38000	SAME AS RUN A-2	
4/4	F-10	72.3	70				38000	SAME AS RUN A-2	
4/4	F-11	80.0	70				38000	SAME AS RUN A-2	
4/4	F-12	87.2	70				38000	SAME AS RUN A-2	

[illegible]

[illegible] Rate: [illegible],000 [illegible]/sec

[illegible] TEMP. IN [illegible]		MATERIAL OUTSIDE TEMP. (°F)	STRAIN GAGE DEFLECTION IN X MSEC ([illegible]/in in x msec)				FLAME PROBE INDICATION TIME (msec)				PER-CENT CO_2
[illegible]	$T_{[illegible]}$		S_1	S_2	S_3	S_4	F_1	F_2	F_3	F_4	
		125									0
		125									0
		70									0 1.4% H_2
		90									0 1.3% H_2
		70									0 1.0% H_2
5 [illegible] 102	105 in 25	70	[illegible]0 in 109	150 in 109	150 in 109	145 in 10[illegible]	20	20	20	20	0
5 [illegible] 90	95 in 20	50	155 in 106	150 in 106	150 in 106	145 in 106	-	-	-	-	0

B

DATE	RUN NO.	CONC. (mg/ft²)	AMBIENT TEMP. (°F)	MAXIMUM PRESSURE IN X TIME (psig in x msec)			RATE OF PRESSURE RISE INSIDE PIPE (psig/sec)	MAXIMUM [illegible]	
				P_1	P_2	P_3		T_1	T_2
4/5	F-13	107	70				38000	SAME AS RUN A-2	
4/6	F-14	120	70				38000	SAME AS RUN A-2	
6	F-15	133	70				38000	SAME AS RUN A-2	
4/7	F-16	147	70	3000 in 100	3000 in 100	3000 in 100	38000	200 in 100	180 in [illegible]
7	F-17	147	70				38000	SAME AS RUN A-2	
/7	F-18	160	70				38000	SAME AS RUN A-2	
/10	F-19	133+ 10 µl	70	3000 in 100	3000 in 100	3000 in 100	38000	200 in 100	[illegible]
10	F-20	173	70	-	2930 in 121	2680 in 121	34500	207 in 580	[illegible]
/12	F-21	173	70	-	-	2800 in 100	35000	204 in 600	[illegible]
/12	F-22	266	70	-	3000 in 102	3000 in 102	36000	205 in 502	210 in [illegible]
13	F-23	266	70	-	2910 in 108	2680 in 108	40250	576 in 500	236 [illegible]
/14	F-24	373	70	-	2880 in 88	2660 in 88	40250	549 in 200	623 [illegible]
18	F-25	480	70	-	2960 in 98	2680 in 98	43000	290 in 550	[illegible]
/19	F-26	640	70	-	4000 in 79	3720 in 79	44000	670 in 132	775 in [illegible]
/20	F-27	640	70		4320 in 87	3880 in 89	40000	1034 in 140	728 [illegible]
24	F-28	640	70		4320 in 91	4120 in 92	38000	-	829 in [illegible]
/15	F-35	640	70		3760 in 88	3680 in 217	66500	1194 in 207	[illegible] in 177
16	F-36	160	70	2040 in 140	2760 in 140	-	28500	245 in 277	[illegible]
	HABCOOL								
26	F-29	160	70	..	3320 in 190	3040 in 190	35000	368 in 244	195 [illegible]
/27	F-30	160	70	..	2800 in 121	2520 in 121	32000	272 in 390	190 [illegible]
28	F-31	320	70	..	3000 in 125	2800 in 125	34400	420 in 400	20[illegible] in 1[illegible]
28	F-32	320	70	..	3120 in 113	2960 in 202	35400	447 in 510	[illegible] in 290
/28	F-33	480	70	..	4680 in 36	6520 in 35	[illegible]2000	2[illegible]70 in [illegible]03	87 in 221
3	F-34	107	70	..	3000 in 110	2950 in 110	37000	200 in [illegible]	[illegible]

K

[illegible]	[illegible] T_3	[illegible] (°F)	[illegible] (... in x msec) S_1	S_2	S_3	S_4	FLAME PROBE INDICATION TIME (msec) F_1	F_2	F_3	F_4	PERCENT CO_2
[illegible]	180 in 100	[illegible]	160 in 100	185 in 192	160 in 100	160 in 100	97	-	-	-	0
[illegible]	120 in 100	[illegible]	165 in 170	[illegible] in 183	160 in 373	[illegible]	[illegible]	[illegible]	359	402	<0.10
[illegible]	200 in 609	[illegible]	170 in 121	185 in 272	180 in 318	[illegible]	[illegible]	[illegible]	461	541	0
[illegible]	115 in 80	[illegible]	165 in 100	160 in 100	160 in 100	[illegible]	[illegible]	[illegible]	-	-	0
[illegible]	273 in 1202	[illegible]	150 in 102	165 in 102	160 in 252	[illegible]	[illegible]	[illegible]	428	528	0
[illegible]	300 in 678	[illegible]	1?? in 108	175 in 108	155 in 158	150 in 500	[illegible]	403	423	468	<0.10
300	433 in 800	[illegible]	[illegible] in 186	220 in 116	180 in 228	180 in [illegible]	[illegible]	155	281	448	<0.10
330	184 in 1000	[illegible]	[illegible] in 79	185 in 142	180 in 259	[illegible] in 330	[illegible]	157	298	500	0.45
162	650 in 272	[illegible]	390 in 80	285 in 246	275 in 246	250 in 246	[illegible]	80	117	140	2.00
[illegible]0	745 in 370	[illegible]	290 in 86	275 in 73	260 in 73	260 in 370	[illegible]	85	87	172	2.50
160	534 in 310	[illegible]	295 in 92	290 in 250	210 in 92	200 in 92	[illegible]	93	241	254	-
137	800 in 280	[illegible]	355 in 219	285 in 218	235 in 218	250 in 217	[illegible]	2	147	214	3.40
320	160 in 420	7[illegible]	145 in 140	150 in 140	140 in 140	130 in 130	[illegible]	258	351	470	0.16
114	217 in 144	7[illegible]	200 in 112	170 in 186	180 in 186	195 in 186	97	1000	91	74	0
[illegible]	127 in 20	[illegible]	150 in 130	140 in 130	140 in 130	140 in 130	-	-	-	-	0
1[illegible]	261 [illegible] 690	[illegible]	180 in 125	150 in 125	160 in 125	160 in 125	72	-	325	500	0
290	180 [illegible] 850	7[illegible]	[illegible]70 in 200	165 in 133	160 in 200	155 in 133	69	200	320	480	0.57
125	1270 [illegible] 35	[illegible]	465 in 35	300 in 35	1380 in 35	260 in 36	24	33	36	36	1.95
150	115 [illegible]	[illegible]	[illegible]30 in [illegible]	150 in 105	140 in 105	150 in 105	2	-	-	-	0

B

Oxygen [illegible]

DATE	RUN NO.	CONC. (mg/ft²)	AMBIENT TEMP. (°F)	MAXIMUM PRESSURE IN X TIME (psig in x msec)			RATE OF PRESSURE RISE INSIDE PIPE (psig/sec)	[illegible] (°F)	
				P_1	P_2	P_3		T_1	[illegible]
		2190							
5/8	C-1	80.0	70	3160 in 108	-	-	38600		
5/9	C-2	160	70	3000 in 102	-	-	38500		
5/9	C-3	240	70	3160 in 97	-	-	42500		
5/9	C-4	320	70	2960 in 104	-	-	40000		
5/9	C-5	400	70	3050 in 118	-	-	40000		
5/9	C-6	480	70	3240 in 96	-	-	45000		
5/10	C-7	160	125	[illegible] in 100	-	-	42500	[illegible]	[illegible]
5/10	C-8	240	125	3200 in 97	-	-	44500	66	
5/10	C-9	320	125	3070 in 94	-	-	40000	[illegible]	[illegible]
5/10	C-10	400	125	3100 in 90			45000	[illegible]	[illegible]
5/11	C-11	480	125	3190 in 72	-		40000	[illegible]	[illegible]
		HABCOOL							
5/11	C-12	160	70	2910 in 88		-	45000		
5/11	C-13	240	70	2880 in 87	-	-	47500		
5/11	C-14	320	70	2960 in 76	-	-	52000		
5/12	C-15	400	70	2910 in 73		-	[illegible]3500		
5/12	C-16	480	70	2910 in [illegible]	—	—	53500		
5/12	C-17	160	125	2800 in 81	-	-	[illegible]3000	84	107
5/12	C-18	240	125	2890 in 49	-	-	51000	92	112
5/12	C-19	320	125	2810 in 80	—	—	52000	88	107
5/12	C-20	400	125	3000 in 76	—	-	38000	90	115
5/12	C-21	480	125	2900 in 67	-	-	50000	94	115

A

[illegible]

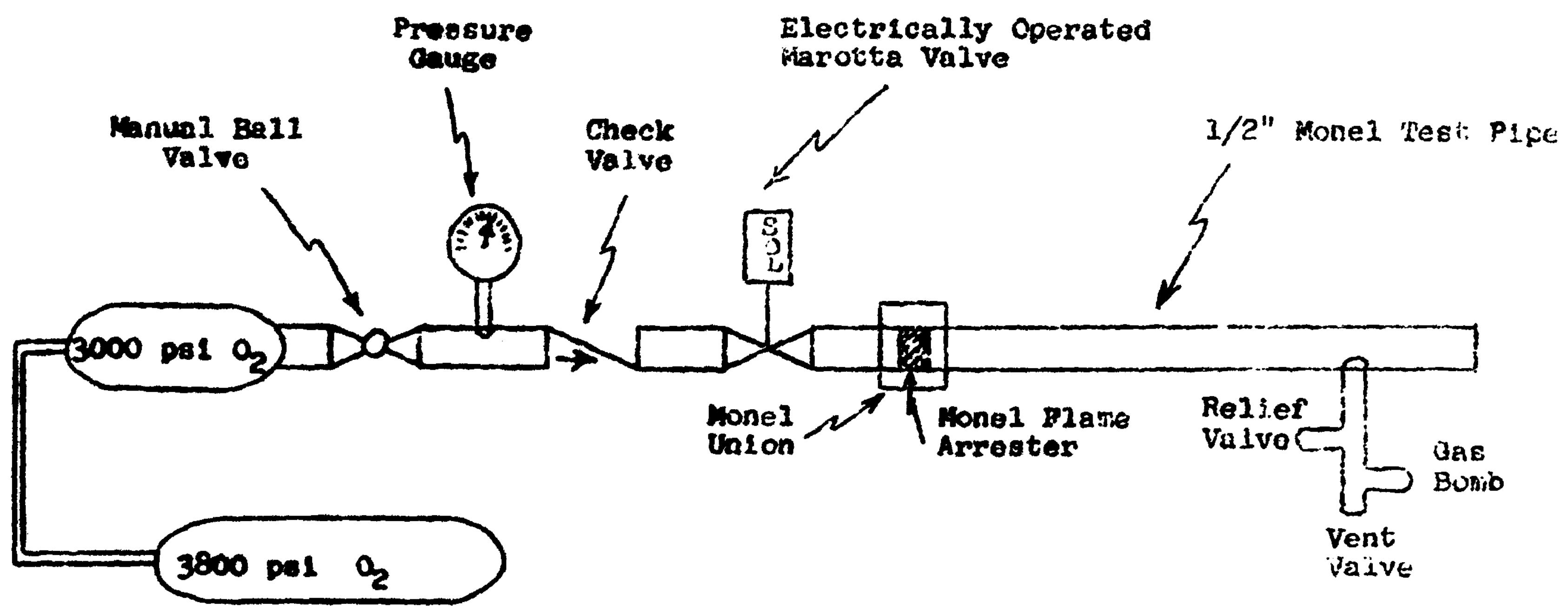
ter [illegible]

	SIDE [illegible] (°F) T_3		T_4	[illegible] (ft/in in x msec) S_1	S_2	S_3	S_4	FLAME PROBE INDICATION TIME (msec) F_1	PERCENT CO_2
				[illegible]	160 in 108	[illegible]	160 in 108	--	0
				[illegible]	160 in 102	[illegible]	155 in 102	--	0
				[illegible]	155 in 97	160 in 97	160 in 97	—	0.62
				[illegible]	150 in 10?	[illegible]	205 in 434	79	0.32
				[illegible]	210 in 253	[illegible]	355 in 448	3	0.68
				220 in 93	205 in 19?	[illegible]	170 in 96	3	1.97
	110	[illegible]	[illegible]	100 in 100	160 in 100	[illegible]	[illegible]	16	0.23
	[illegible]	[illegible]	[illegible]	210 in 97	265 in 97	140 in 97	[illegible]	64	0.23
	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	70	0.45
	126		92	[illegible] in 90	210 in 156	[illegible]	160 in 90	38	0.77
	[illegible]		[illegible]	[illegible]	265 [illegible]	[illegible]	[illegible]	9	2.25
				[illegible] in 88	[illegible]	175 in 88	175 in 88	—	0.12
				220 in 157	160 [illegible]	155 in 67	150 in 67	89	0.50
				265 in 106	890 [illegible]	[illegible]	165 in 76	[illegible]	1.32
				190 in 73	135 [illegible]	[illegible] in 73	[illegible] in 73	26	0.46
				150 in 95	170 [illegible]	160 in 73	160 in 75	30	1.85
	120	120	94	155 in 81	125 in 81	95 in 81	115 in 81	...	0
	134	134	90	180 in 72	265 in 72	140 in 72	160 in 72	49	0.23
	115	128	95	180 in 80	145 in 80	120 in 80	135 in 80	38	0.38
	22	126	97	270 in 76	210 in 76	55 in 60	160 in 10	9	1.09
3	[illegible]	128	103	210 in 67	175 in 67	–	160 in 67	14	1.58

OIL CONTAMINATION IN OXYGEN SYSTEMS

DIAGRAM OF TEST APPARATUS

FIGURE 1



TEST PIPE LAYOUT OF INSTRUMENTATION (TOP VIEW)

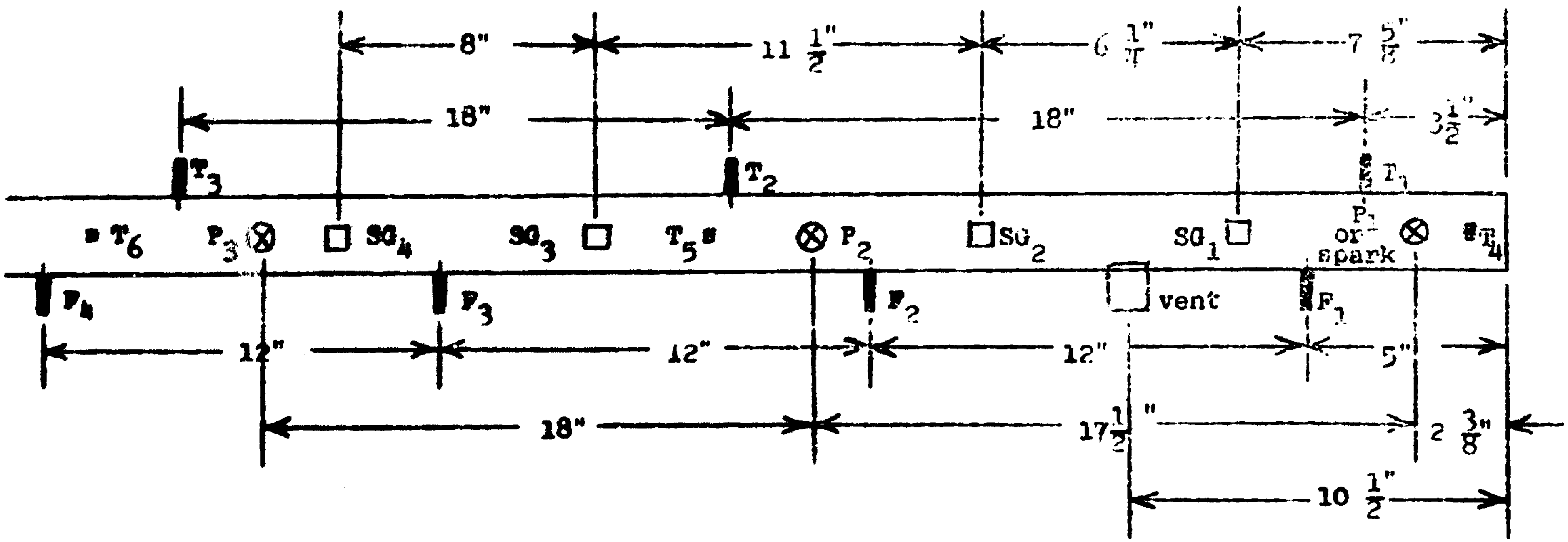
FIGURE 1A

T - Thermocouple

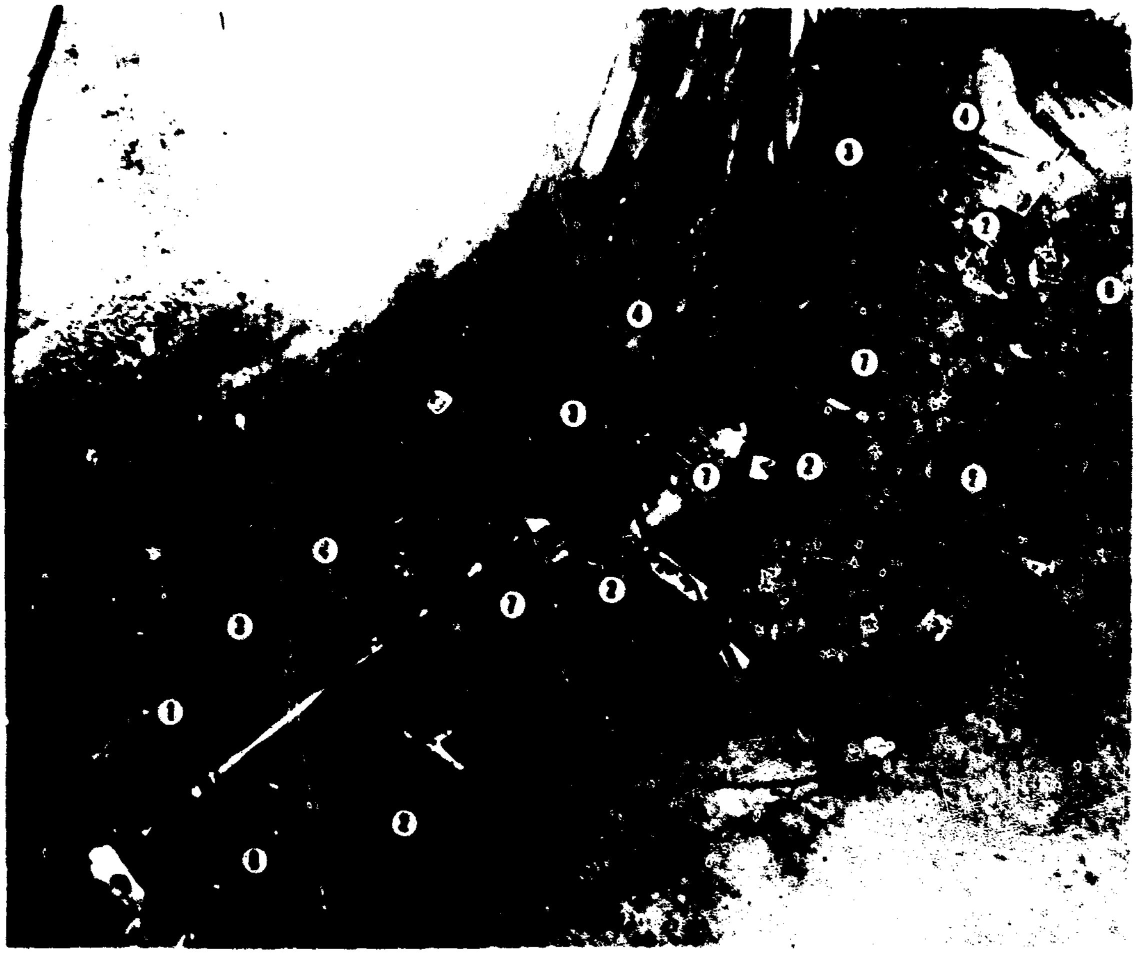
F - Flame Probe

P - Pressure Transducer

SG - Strain Gauge

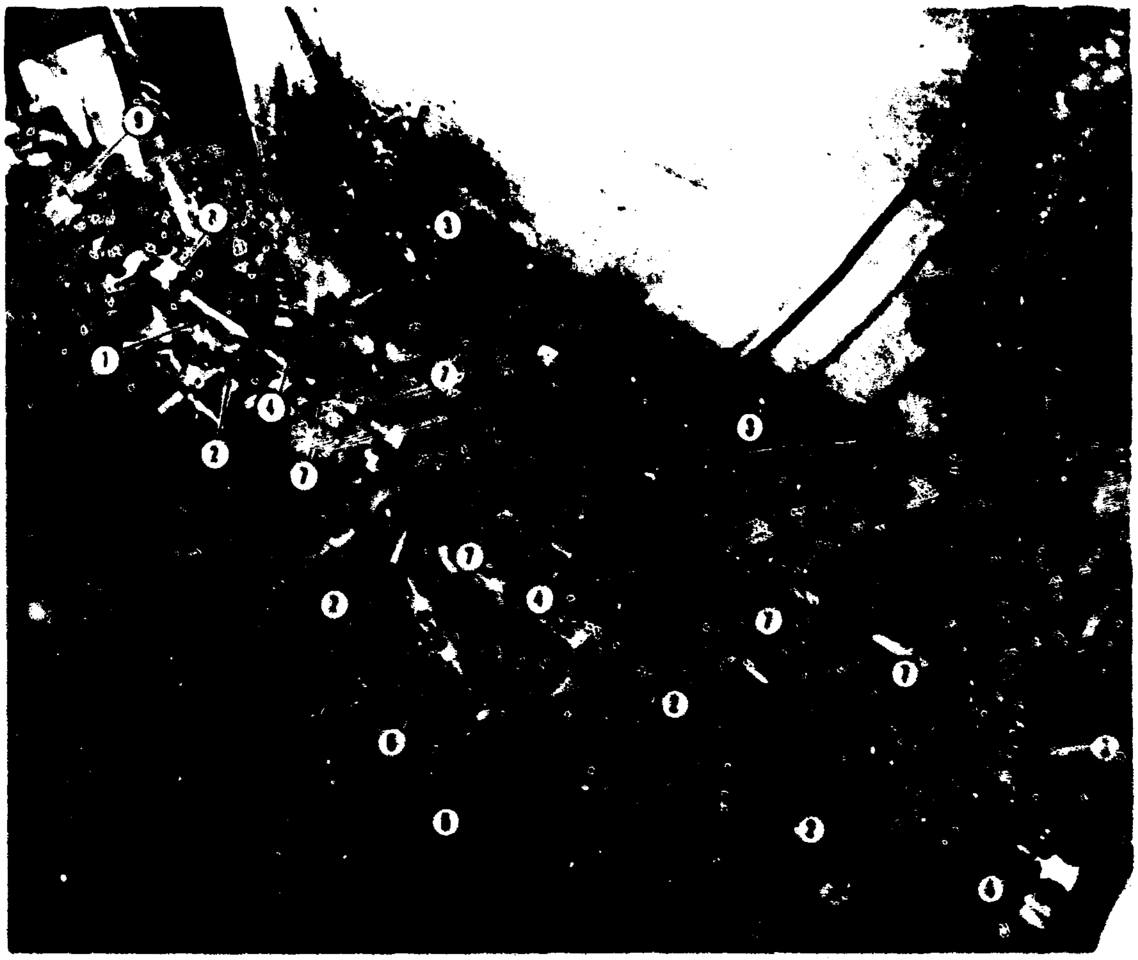


Pipe Length: 48"



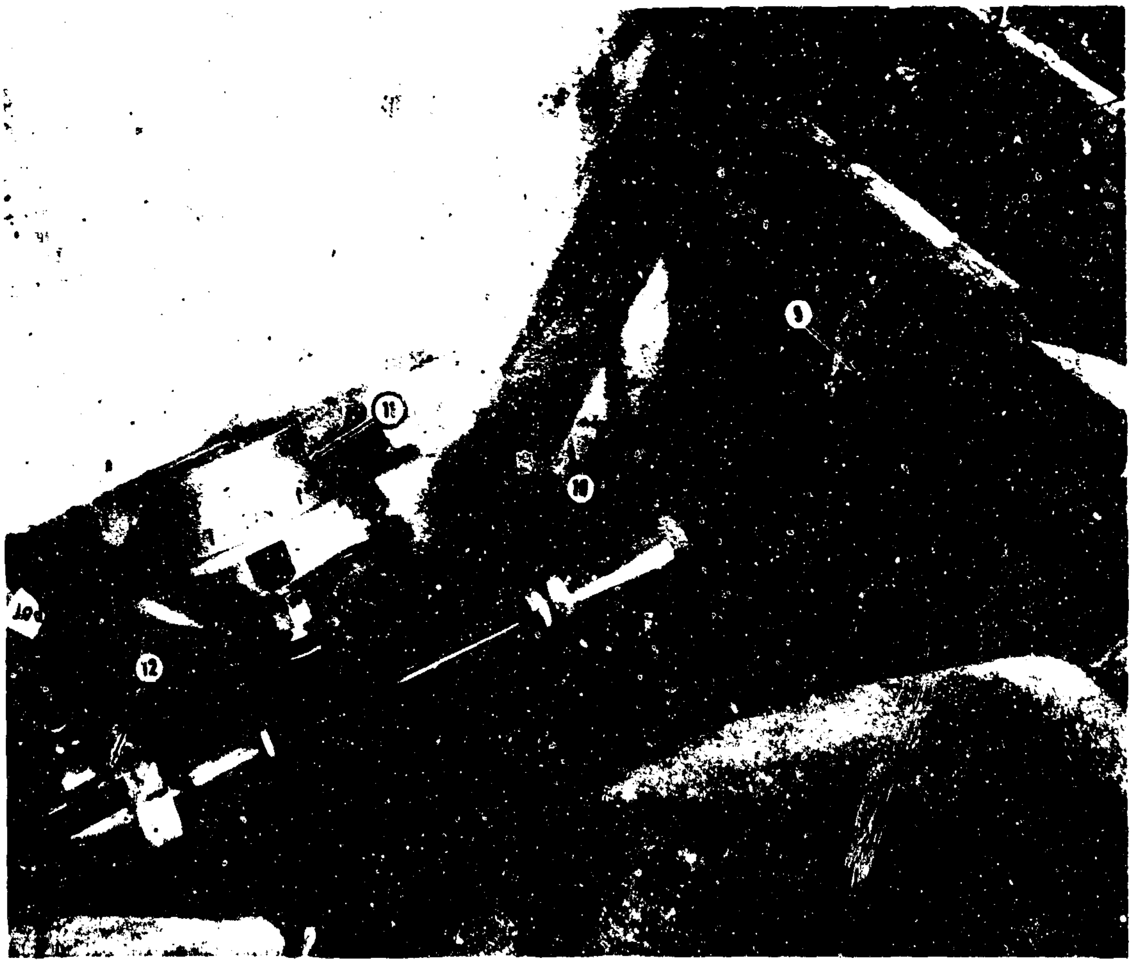
TEST PIPE
FIGURE 2

1) 1/2" MONEL PIPE
2) FLAME PROBES
3) TEMPERATURE PROBES
4) PRESSURE TRANSDUCERS
5) RELIEF VALVE
6) GAS SAMPLE BOMB
7) STRAIN GAUGES
8) MONEL UNION (FLAME ARRESTER INSIDE)



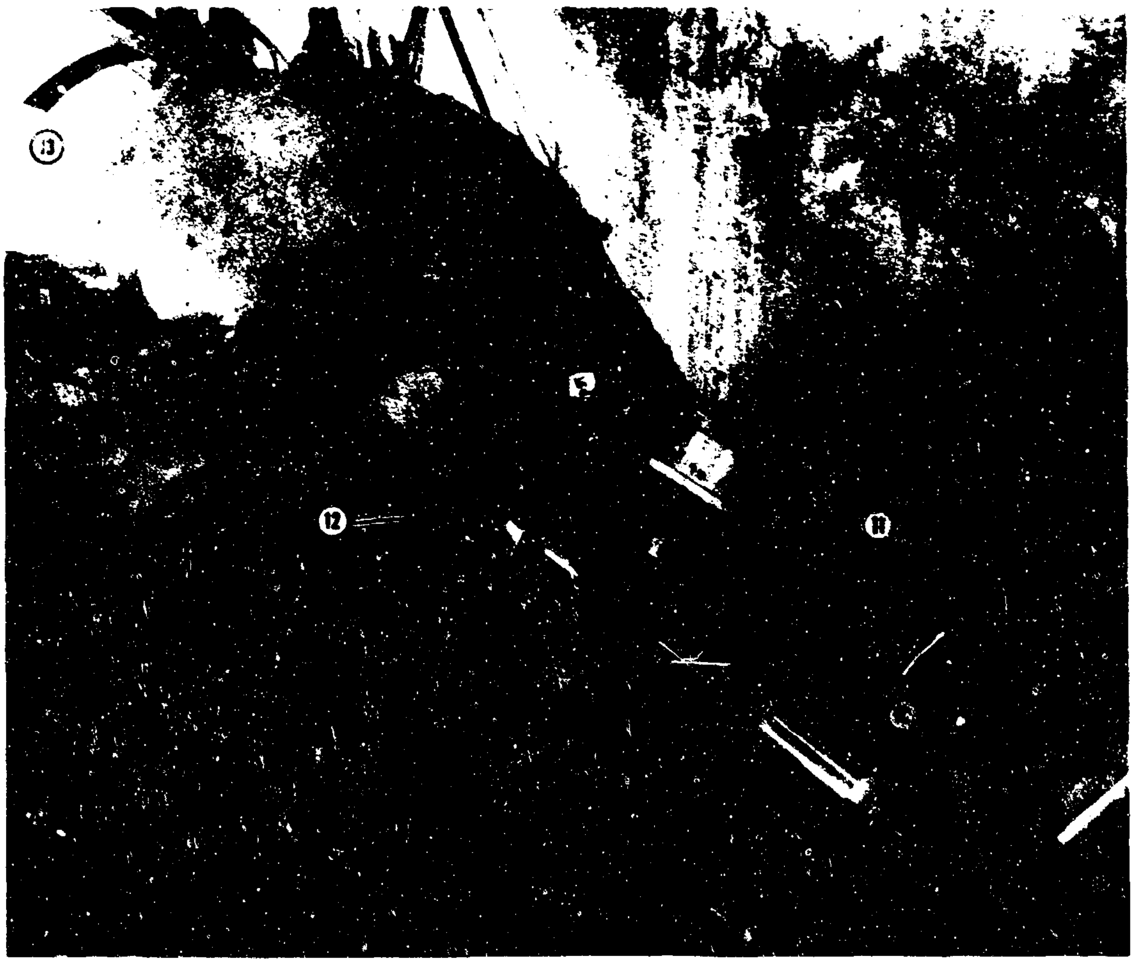
TEST PIPE
FIGURE 3

1) 1 2" MONEL PIPE
2) FLAME PROBES
3) TEMPERATURE PROBES
4) PRESSURE TRANSDUCERS
5) RELIEF VALVE
6) GAS SAMPLE BOMB
7) STRAIN GAUGES
8) MONEL UNION
9) MAROTTA VALVE



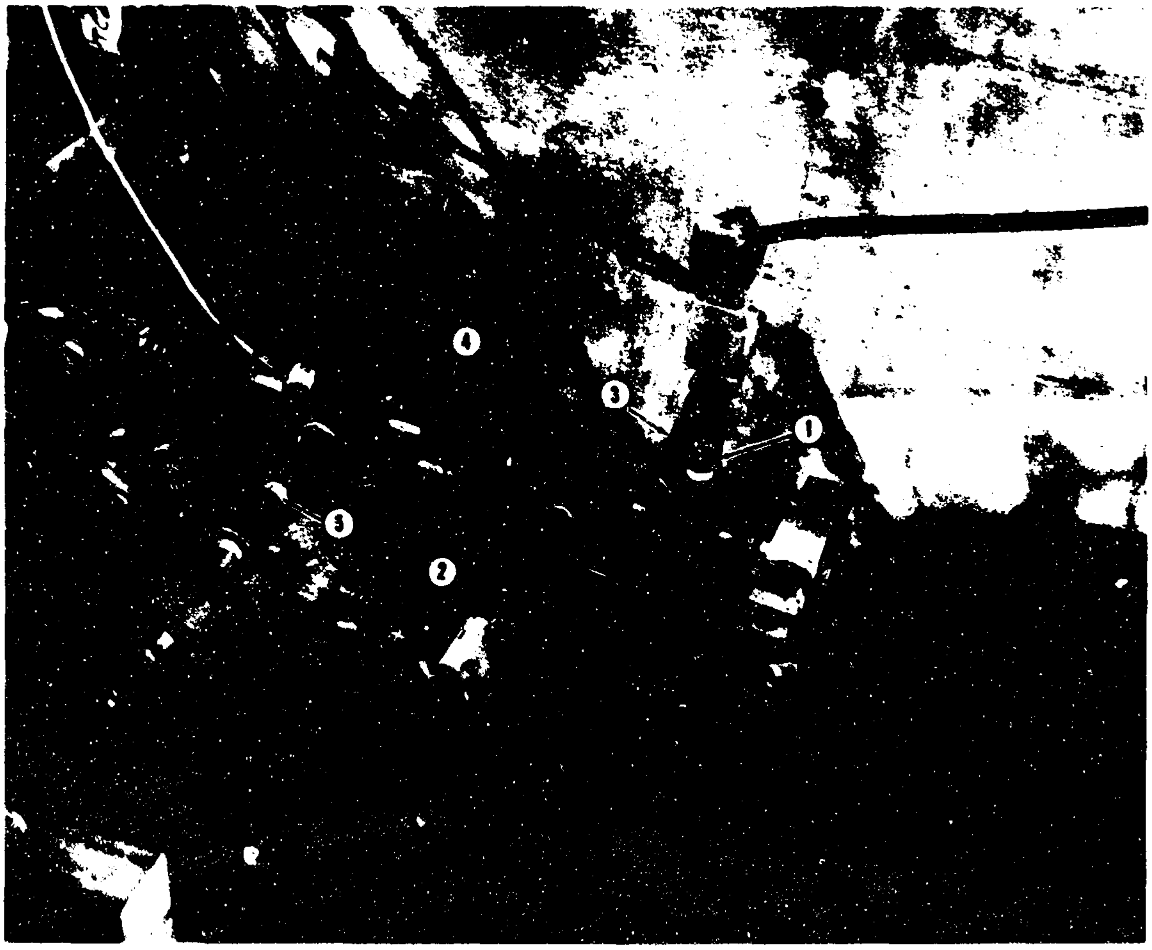
OXYGEN SUPPLY PIPING
FIGURE 4

9) MAROTTA VALVE
10) CHECK VALVE
11) PRESSURE GAUGE
12) HAND OPERATED BALL VALVE



OXYGEN SUPPLY PIPING
FIGURE 5

10) CHECK VALVE
11) PRESSURE GAUGE
12) HAND OPERATED BALL VALVE
13) 3000 PSI OXYGEN SUPPLY TANK



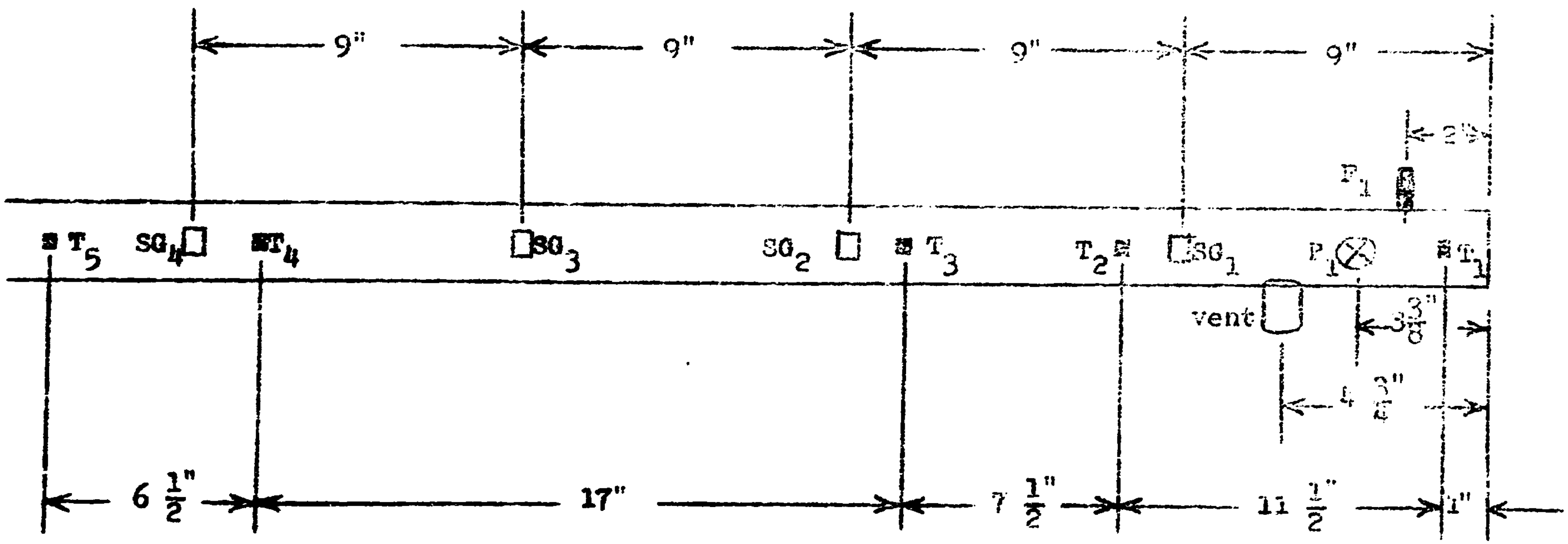
TEST PIPE WITH SPARKING DEVICE
FIGURE 6

1) SPARKING DEVICE
2) FLAME PROBE
3) TEMPERATURE PROBE
4) STRAIN GAUGE
5) VENT LINE

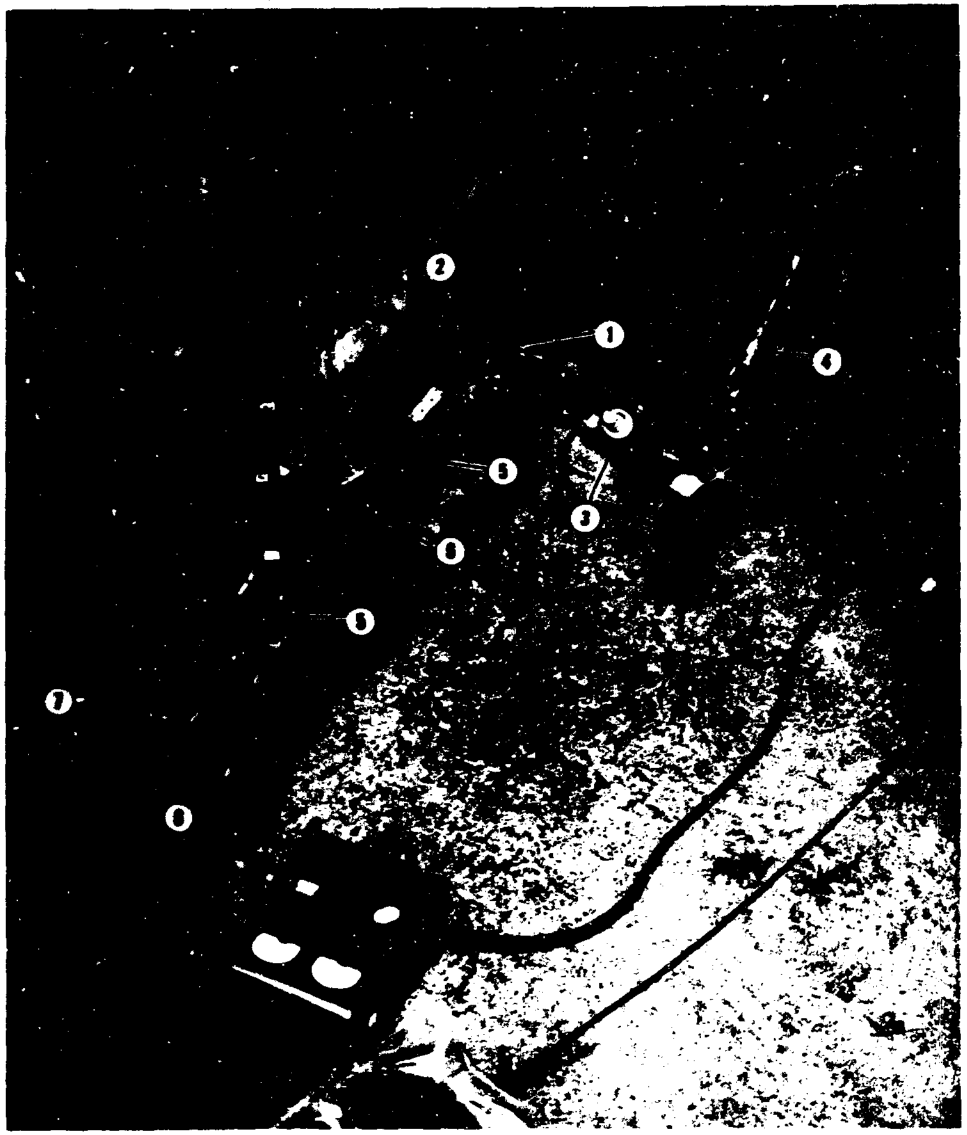
[illegible] TEST PIPE - LAYOUT OF INSTRUMENTATION (TOP VIEW)

FIGURE 7

T - Thermocouple
F - Flame Probe
P - Pressure Transducer
SG - Strain Gauge

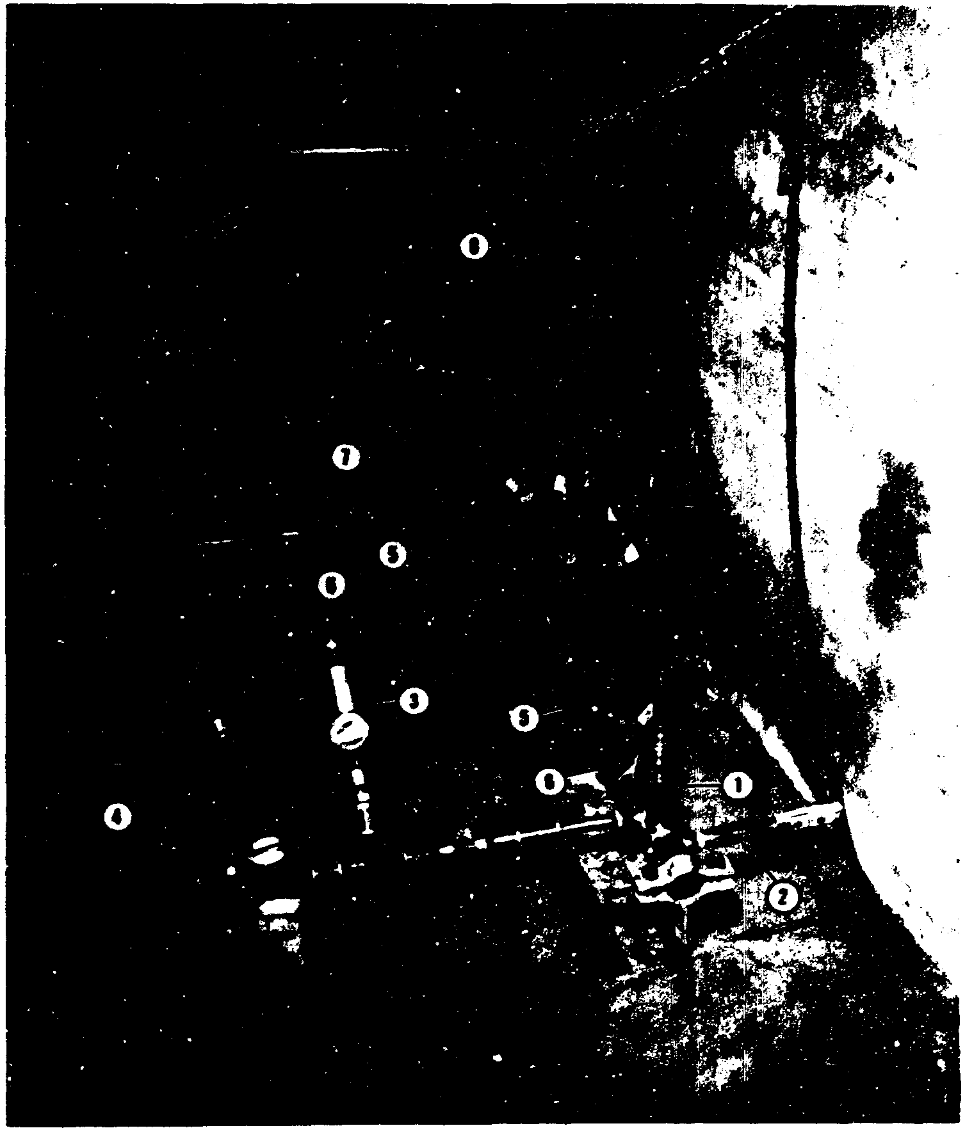


Pipe Length: 45 1/2"



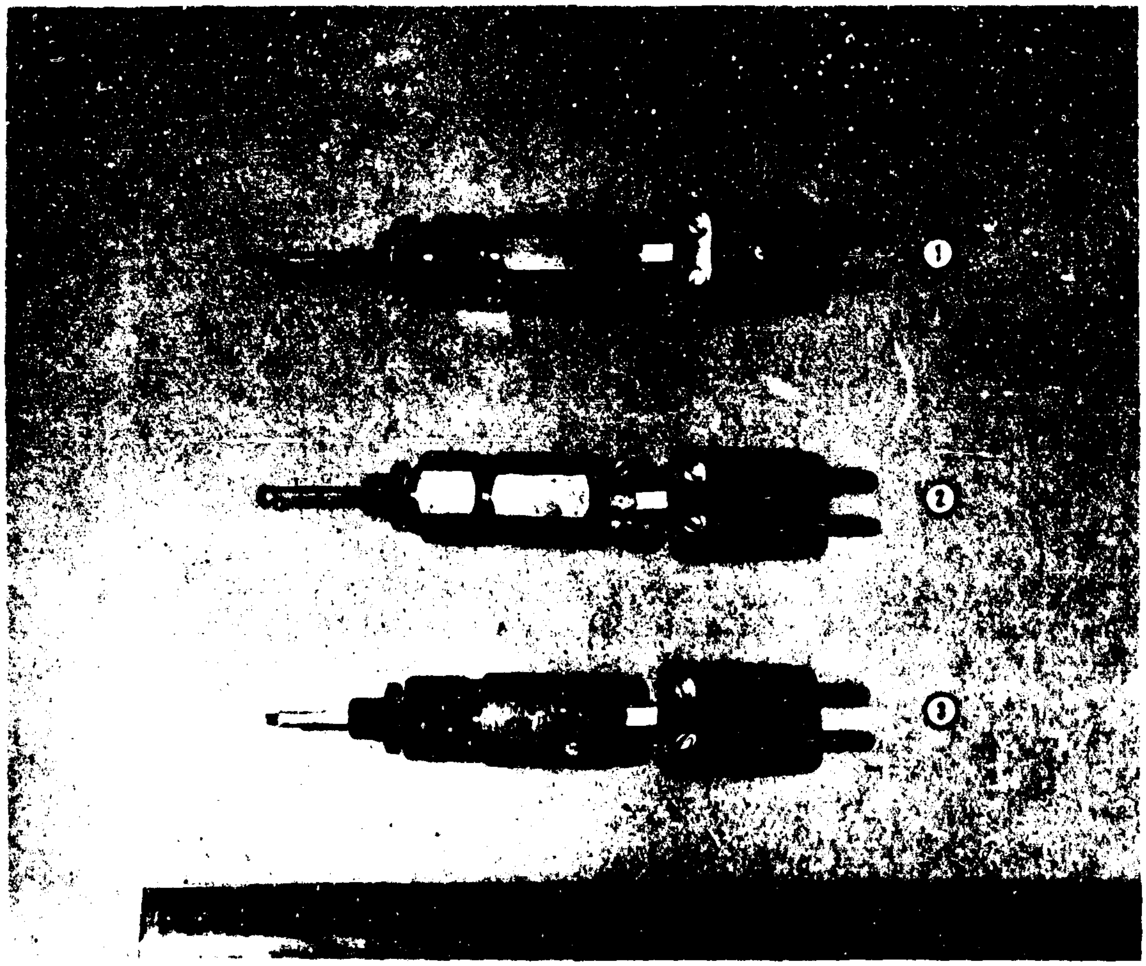
MODIFIED TEST PIPE
FIGURE 8

1) PRESSURE TRANSDUCER
2) FLAME PROBE
3) RELIEF VALVE
4) GAS SAMPLING BOMB
5) STRAIN GAUGES
6) HEATING WIRE
7) MONEL UNION



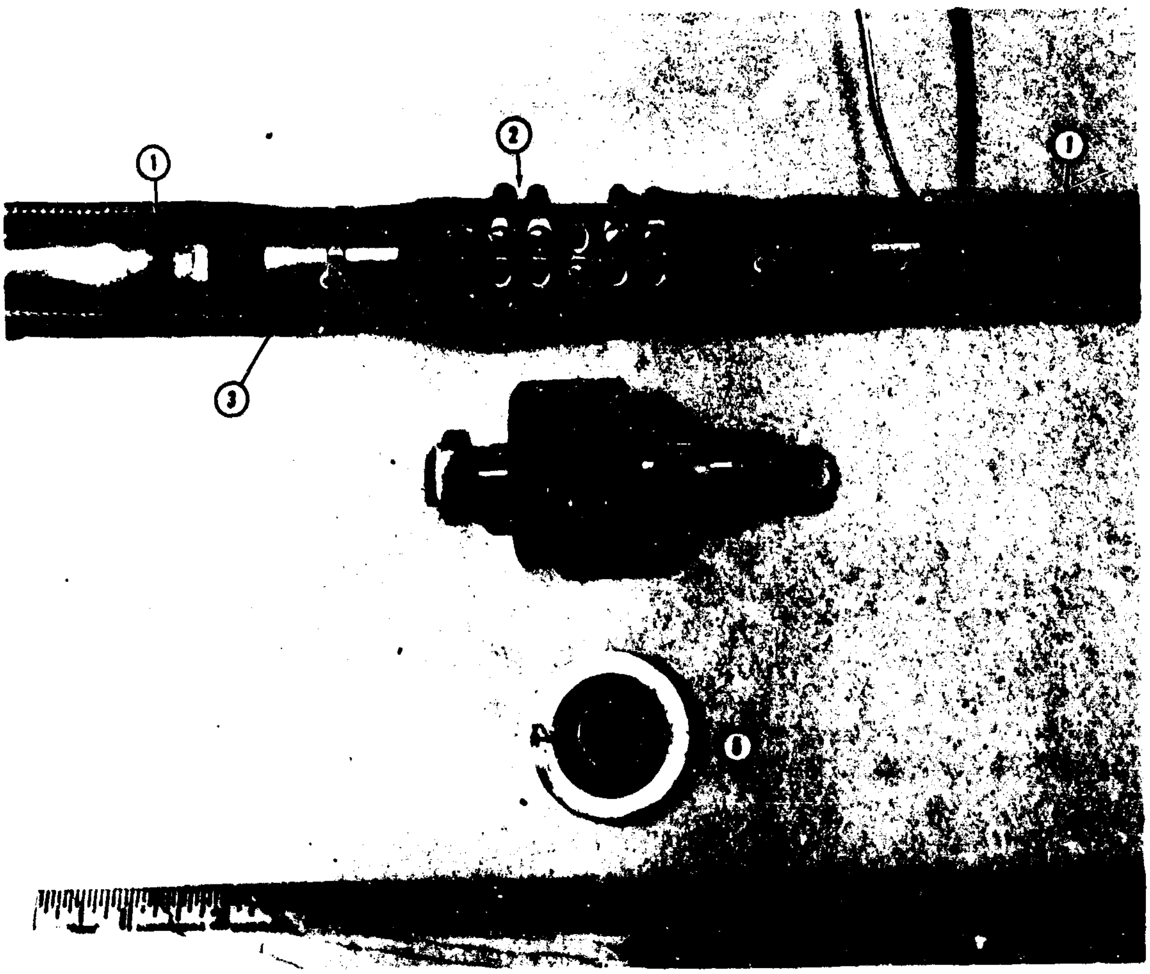
MODIFIED TEST PIPE
FIGURE 9

1) PRESSURE TRANSDUCER
2) FLAME PROBE
3) RELIEF VALVE
4) GAS SAMPLING BOMB
5) STRAIN GAUGES
6) HEATING WIRE
7) MONEL UNION
8) MAROTTA VALVE



INSTRUMENTATION PROBES
FIGURE 10

1) SPARKING DEVICE
2) THERMOCOUPLE
3) FLAME PROBE

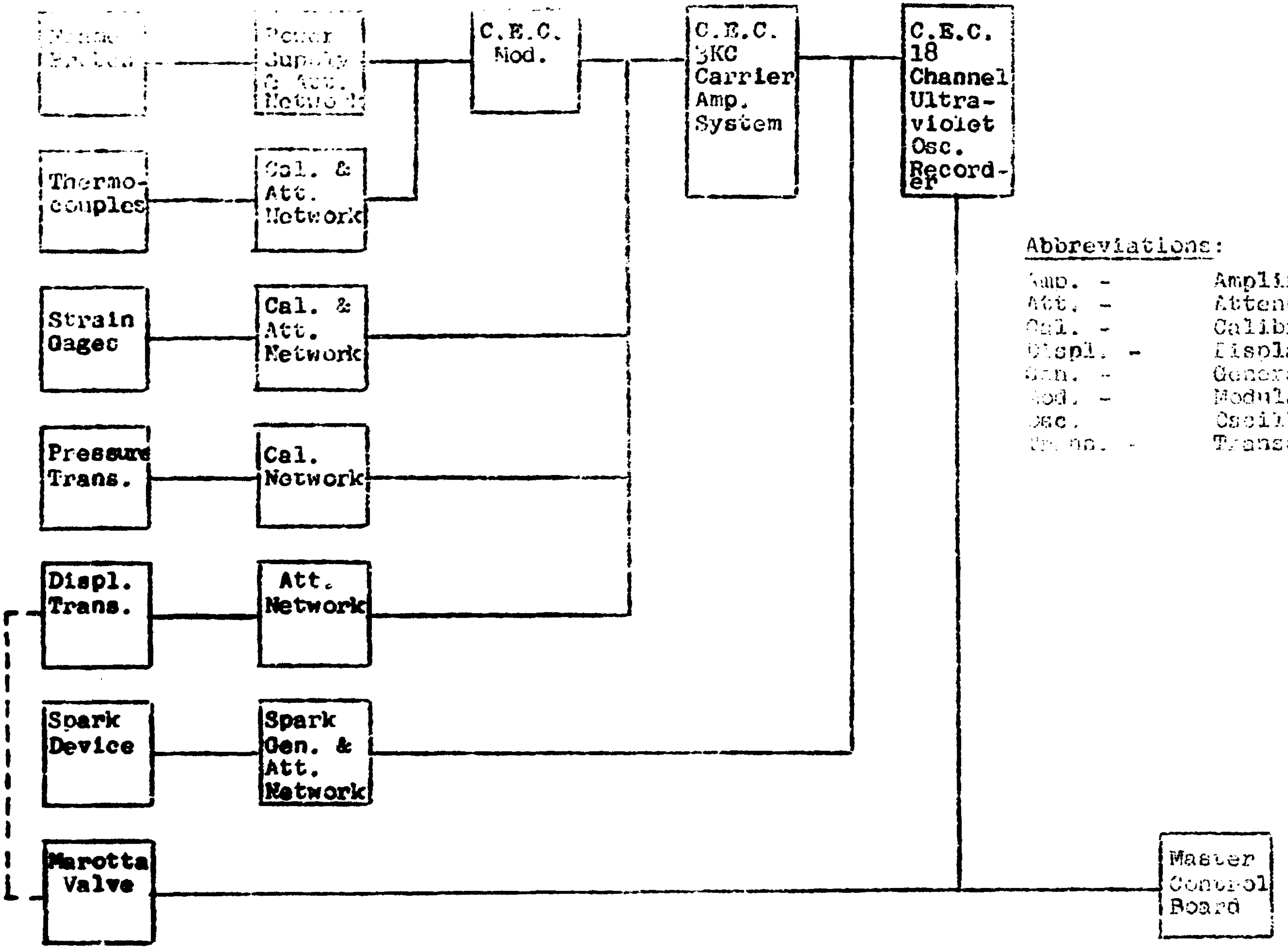


TEST PIPE COMPONENTS
FIGURE 11

1) STRAIN GAUGE
2) TERMINAL FOR STRAIN GAUGES
3) HEATING COIL
4) PRESSURE TRANSDUCER
5) FLAME ARRESTOR

OIL CONTAMINATION IN OXYGEN SYSTEMS

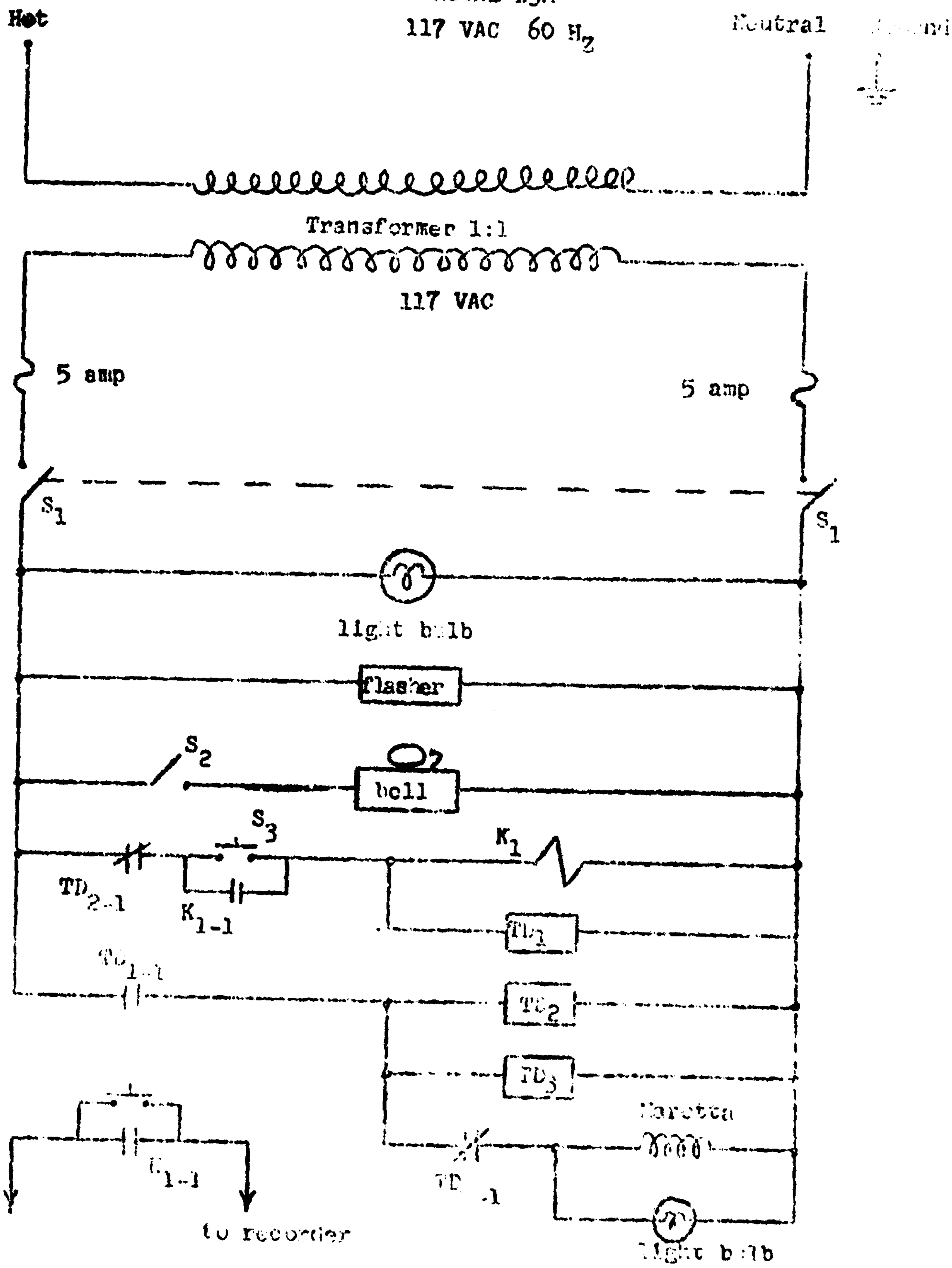
INSTRUMENTATION BLOCK DIAGRAM - FIGURE 12



Abbreviations:

Amp. - Amplifier
Att. - Attenuator
Cal. - Calibration
Displ. - Displacement
Gen. - Generator
Mod. - Modulator
Osc. - Oscillograph
Trans. - Transducer

OIL CONTAMINATION IN OXYGEN SYSTEMS
AUTOMATIC REMOTE CONTROL CIRCUIT
FIGURE 13A

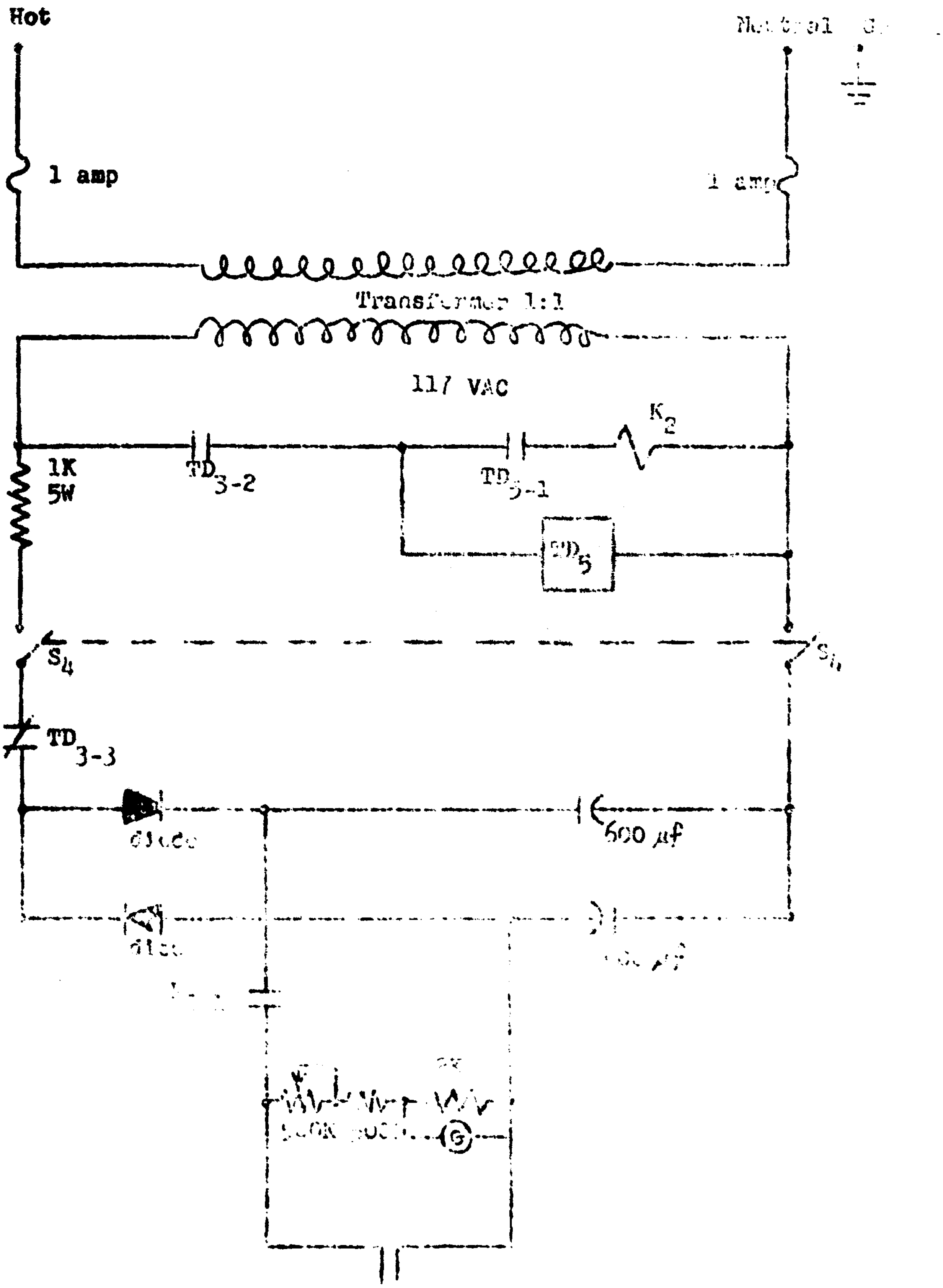


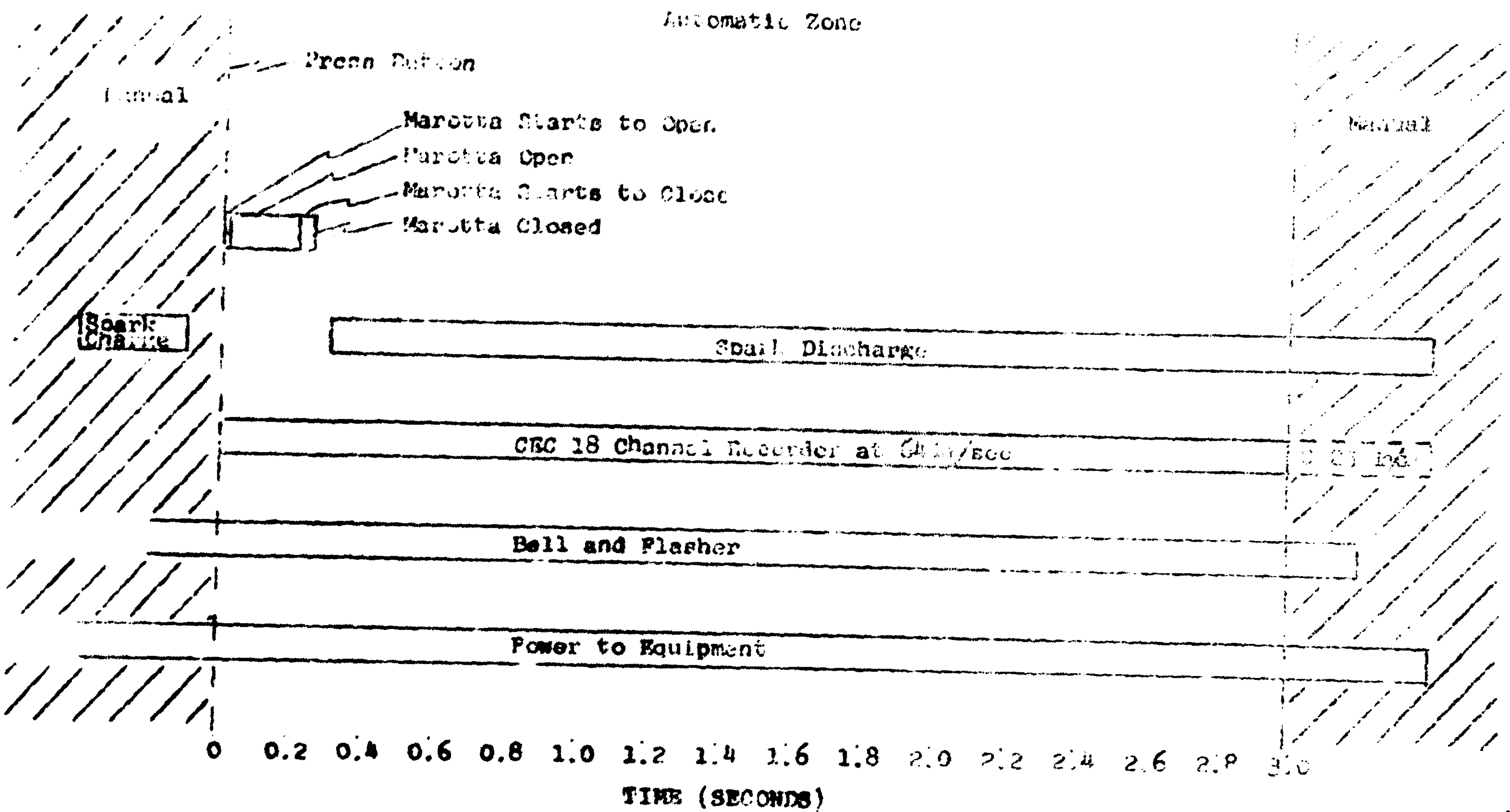
OIL CONTAMINATION IN OXYGEN SYSTEMS

SPARK GENERATOR CIRCUIT

FIGURE 13B

117 VAC 60 Hz

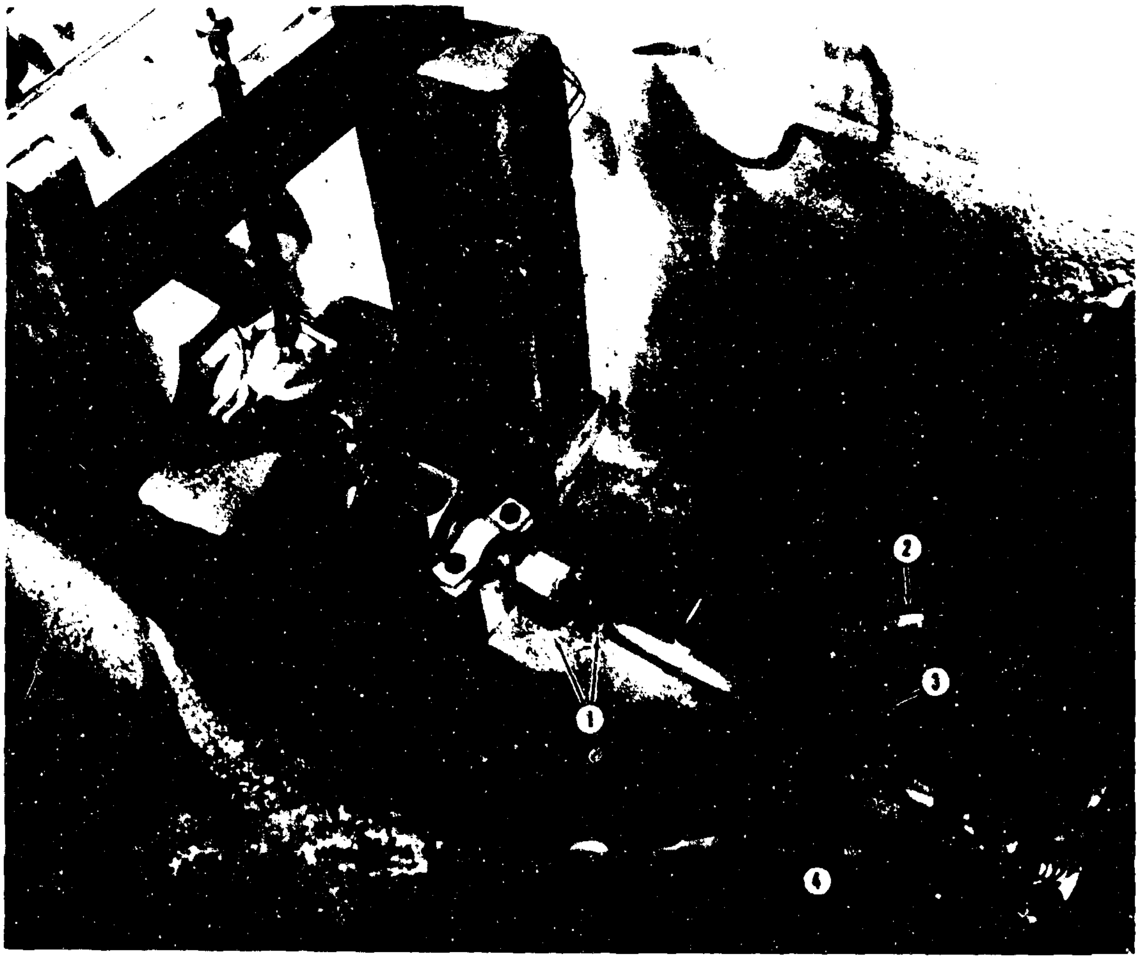




Automatic Zone
Press Button
Manual
Marotta Starts to Open
Marotta Open
Marotta Starts to Close
Marotta Closed
Spark Charge
Spark Discharge
CEC 18 Channel Recorder at
Bell and Flasher
Power to Equipment
0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0
TIME (SECONDS)

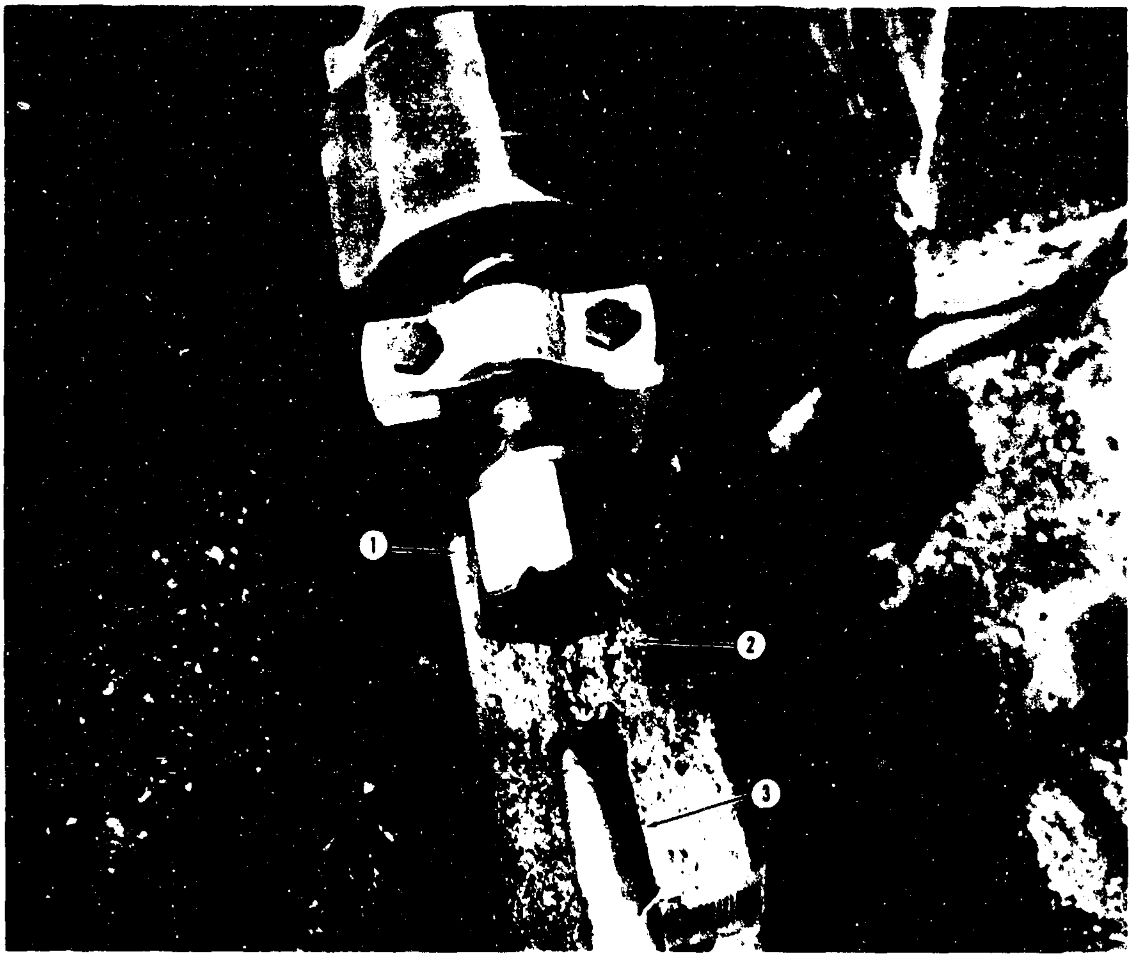
<u>TEST PIPE AFTER EXPLOSION</u>
FIGURE 15

1) BURNED UNION AND TEST PIPE FITTING
2) CHARRED, BENT FLAME PROBE
3) BENT THERMOCOUPLE CONNECTOR
4) MELTED, EMPTY PRESSURE TRANSDUCER BOSS
5) DISPLACED STRAIN GAUGE TERMINALS
6) DISPLACED COPPER O-RING ON PRESSURE TRANSDUCER
7) RELIEF VALVE



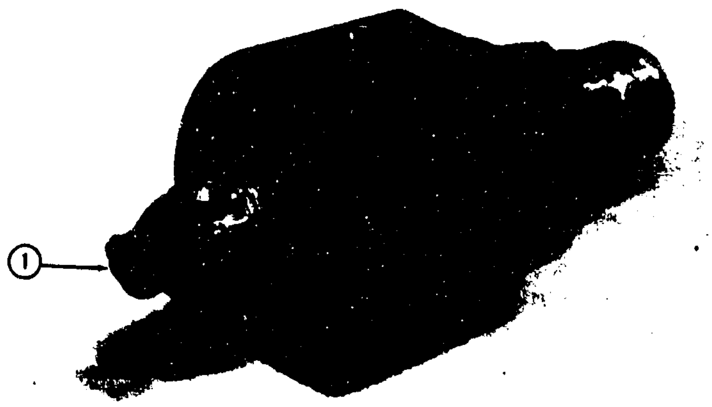
TEST PIPE AFTER EXPLOSION
FIGURE 16

1) MELTED UNION AND TEST PIPE FITTING
2) BROKEN THERMOCOUPLE
3) MELTED, EMPTY PRESSURE BOSS
4) DISPLACED STRAIN GAUGE TERMINAL



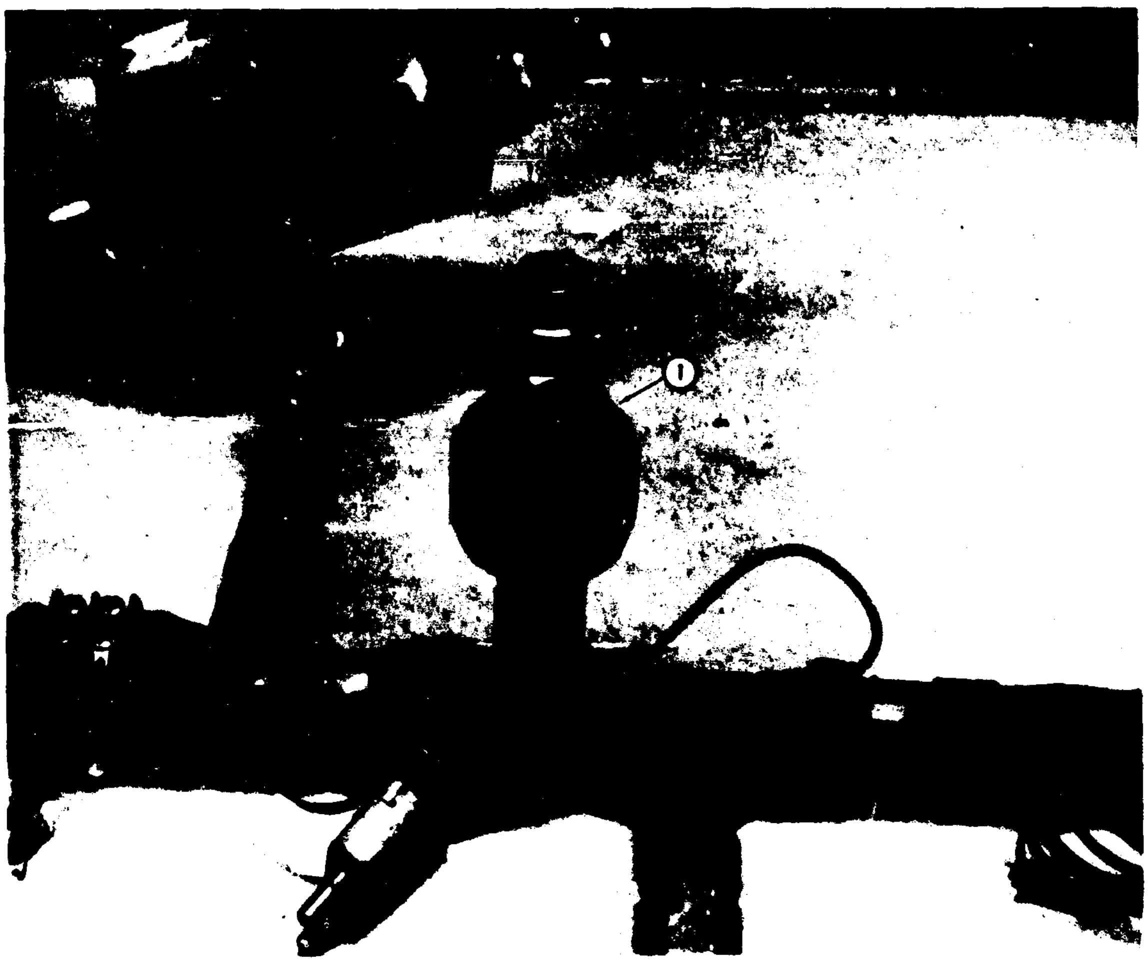
TEST PIPE AFTER EXPLOSION
FIGURE 17

1) MELTED UNION
2) MELTED TEST PIPE FITTING FRAGMENTS
3) TEST PIPE



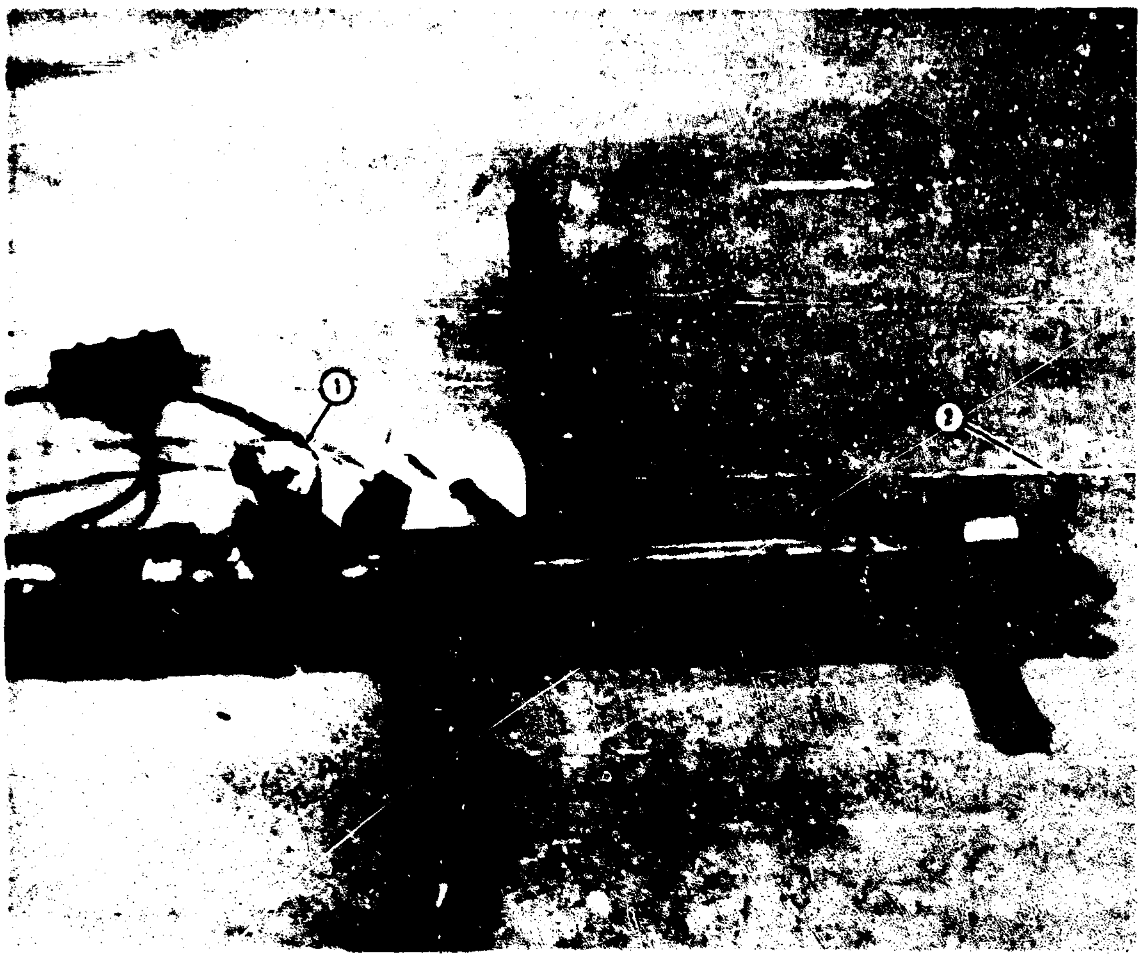
PRESSURE TRANSDUCER AFTER EXPLOSION
FIGURE 18

1) PRESSURE TRANSDUCER FITTING



PRESSURE TRANSDUCER AFTER EXPLOSION
FIGURE 19

1) DISPLACED, BENT COPPER O-RING ON PRESSURE TRANSDUCER



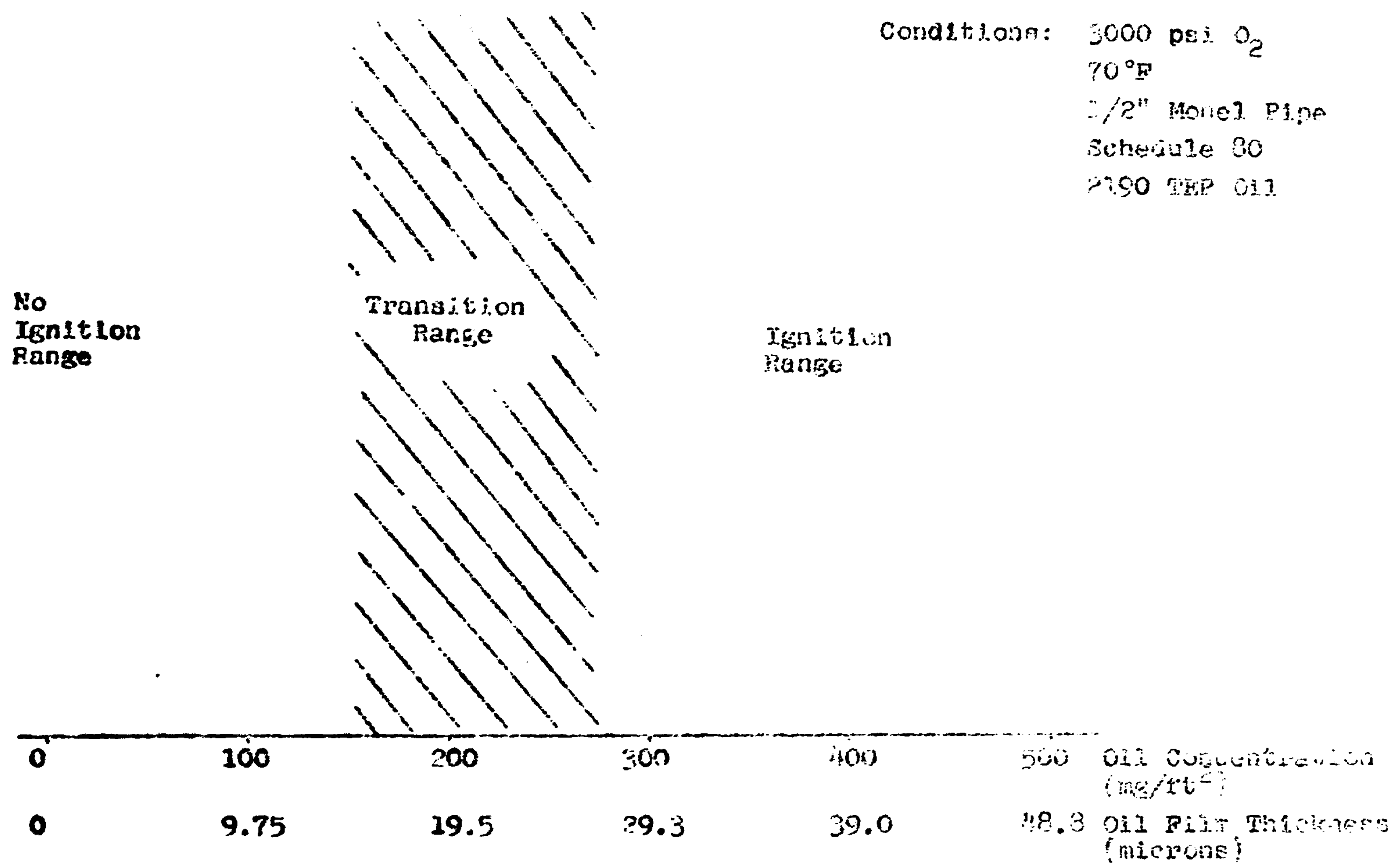
INSTRUMENTATION BOSS AFTER EXPLOSION
FIGURE 20

1) MELTED PRESSURE TRANSDUCER BOSS
2) MELTED TEST PIPE FITTING

OIL CONTAMINATION IN OXYGEN SYSTEMS

IGNITION/NO IGNITION RANGES

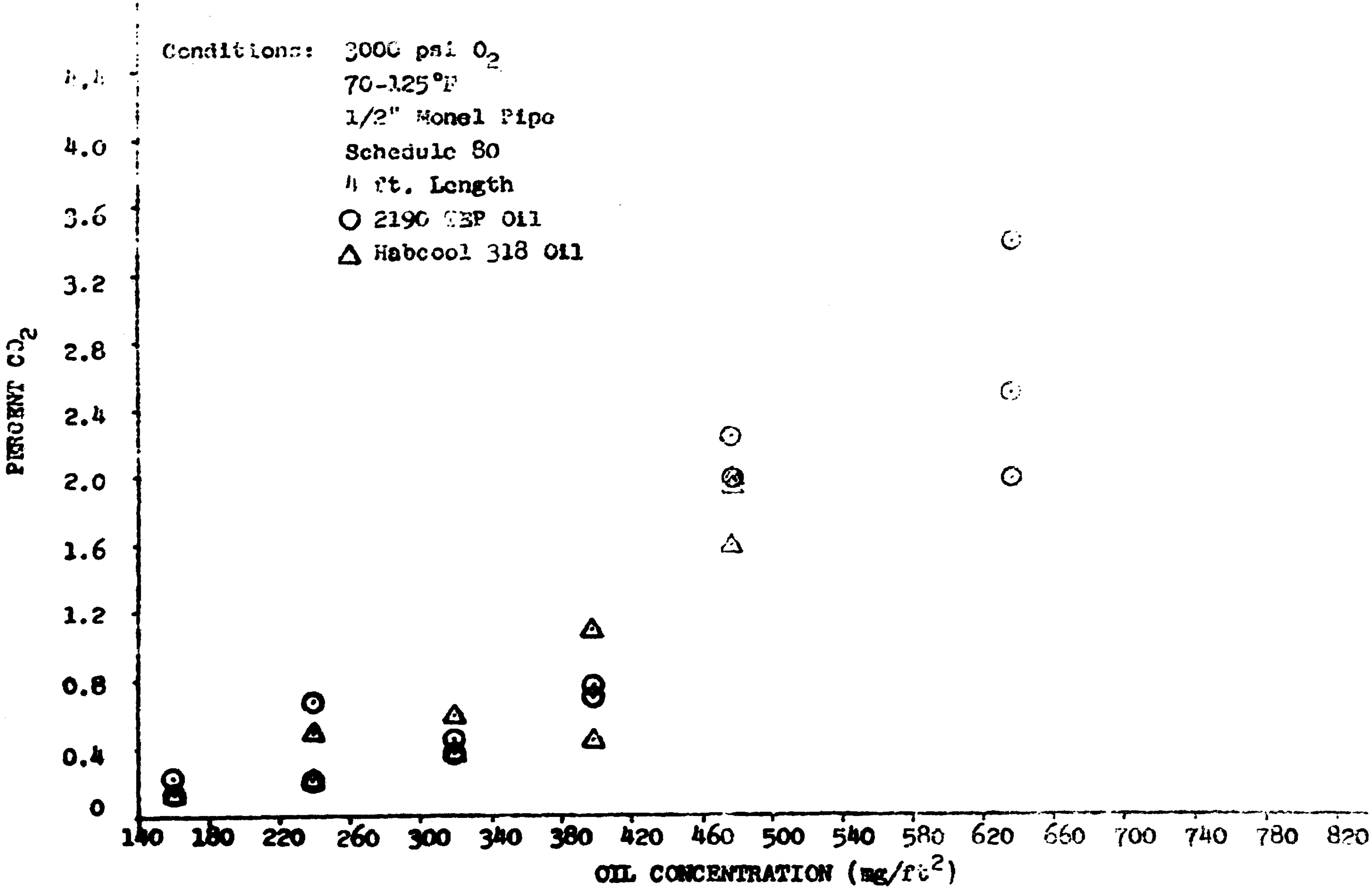
FIGURE 21



OIL CONTAMINATION IN OXYGEN SYSTEMS

PERCENT CO_2 vs. OIL CONTAMINATION

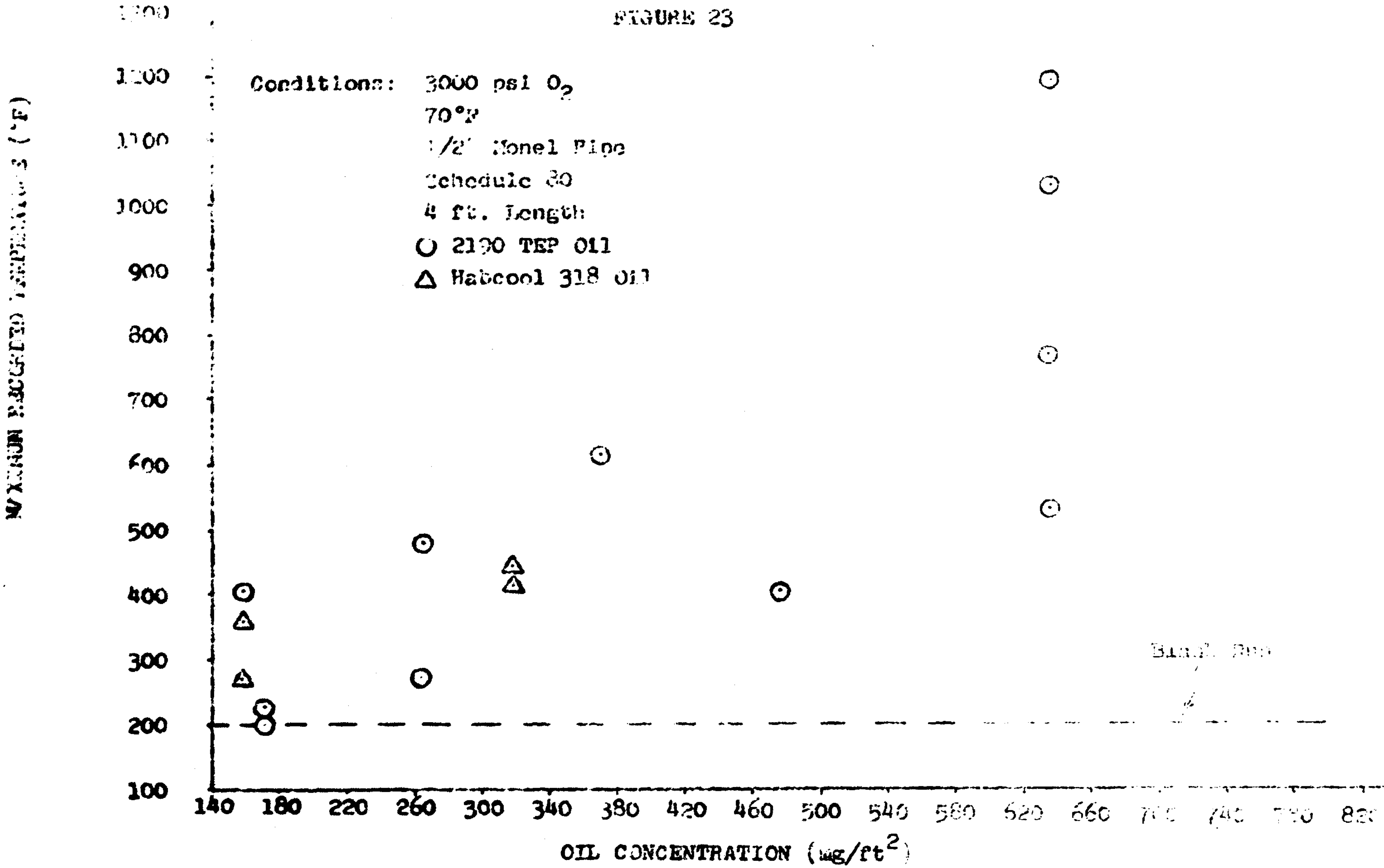
FIGURE 22



OIL CONTAMINATION IN OXYGEN SYSTEMS

MAXIMUM RECORDED TEMPERATURE vs. OIL CONCENTRATION

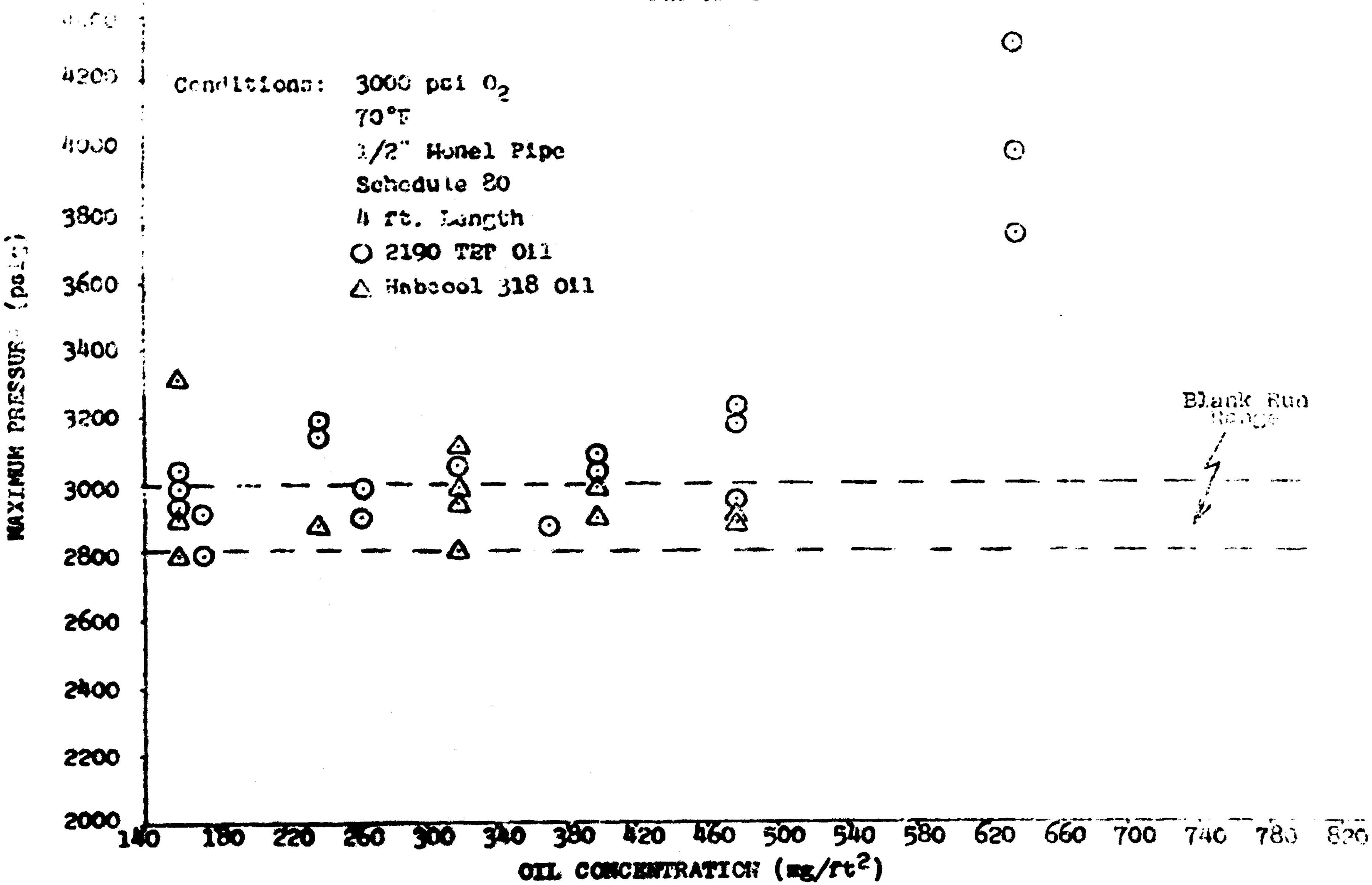
FIGURE 23



OIL CONTAMINATION IN OXYGEN SYSTEMS

MAXIMUM PRESSURE VS. OIL CONCENTRATION

FIGURE 24



UNCLASSIFIED
Security Classification

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) Electric Boat Division of General Dynamics Eastern Point Road Groton, Connecticut	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE

Oil Contamination in Oxygen Systems

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report (July [illegible] - May 19[illegible]7)

5. AUTHOR(S) (Last name, first name, initial)

[illegible]sti, John [illegible].
DeSimone, Charles J., Jr.

6. REPORT DATE June 19[illegible]7	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
8a. CONTRACT OR GRANT NO. NObs-[illegible] b. PROJECT NO. SF013-0[illegible]-14 c. Task No. 3017 d.	9a. ORIGINATOR'S REPORT NUMBER(S) [illegible]413-[illegible]7-101 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	

10. AVAILABILITY LIMITATION NOTICES

Distribution of this document is unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Ship Systems Command Department of the Navy Washington, D. C.

13. ABSTRACT

The ignition limits of [illegible] lubricating oil and Cutcool #31[illegible] cutting oil evenly coated on a 1/[illegible] monel pipe exposed to 3000 psi O[illegible] were determined. Little danger of ignition or flame propagation exists below oil concentrations of 1[illegible]0 mg/ft[illegible]; while concentrations above [illegible]0 mg/ft[illegible] will ignite in a pure O_2 atmosphere.

DD FORM 1 JAN 64 1473

UNCLASSIFIED
Security Classification

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Compression Ignition Oxygen Systems Cleaning Procedures						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year, or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

UNCLASSIFIED

Security Classification