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MATERIALS PROBLEMS USING SYNTHETIC FUELS IN ENGINE COMBUSTORS

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This report summarizes the results of a project designed to anticipate materials deterioration problems resulting from the use of synthetic fuels (fuels not derived from petroleum) in engine combustors. The project consisted of surveying organizations engaged in testing and evaluating synthetic fuels in engine combustion tests. Also the compositions and properties of various synthetic fuels were compiled and analyzed while relating these

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data to possible materials problems when these fuels are burned in engine combustors.

This report identifies some rather minor materials problems encountered in the few short-term combustor tests run and reported upon to date. There appears to be no major materials problems associated with the use of snythetic fuels that cannot be remedied by special processing and treatments on the synthetic fuels.

Indeed, the use of synthetic fuels by the Navy as an alternative to petroleum fuel looks promising and is now mostly a matter of developing the technology to produce synthetic fuels that meet chemical composition specifications and performance requirements by processes that result in minimum production costs.

INTRODUCTION

The U. S. Government is becoming increasingly involved in many programs developing the technology to produce a competitively priced, domestic supply of synthetic fuels as one phase of Project Independence. A synthetic fuel (synfuel) is one not derived from petroleum. Of particular interest to the U. S. Navy is the use of synthetic liquid fuels to power Navy ships and aircraft as a practical alternative to petroleum fuels. The use of various synfuels, however, may be accompanied by problems involving fuel handling, materials compatibility and engine deterioration. Especially in gas turbine engines, hot corrosion and the build-up of deposits in the engine are critical problems which must be precluded or inhibited for successful long-term use.

Accordingly, this project was instigated to assess the current R, D, T and E on the use of synfuels in engine combustors and to anticipate any materials deterioration problems from their long-term use by the Navy. Specifically, this investigation accomplished the following:

1. Organizations engaged in testing and evaluating synfuels were surveyed pertaining to materials problems from engine combustion tests.
2. Data on the compositions and properties of various synfuels were gathered. From these data possible materials problems, when these fuels are used in engine combustors, were examined.

SYNFUEL PRODUCTION IN THE U. S.

The Western Hemisphere possesses enormous reserves of coal, tar sands and oil shale. These reserves are believed to possess a total energy potential 12 times that of Middle East petorleum reserves. Especially in the last few years, many private companies have been developing and testing numerous processes to produce synfuels with a wide-range of properties. However, the production facilities of even the most developed of these processes are still in the pilot plant stage. The current U. S. production of synfuels, although growing rapidly, is still relatively small. The current status and plans for the future on the production of liquid fuel from coal, tar sands, and oil shale have be been recently reviewed in References 1-5.

UNDESIRED IMPURITIES IN GAS TURBINE FUELS

Hot corrosion of marine gas turbine engines is an accelerated oxidation phenomenom primarily due to the presence of Na_2SO_4 and/or vanadium. Sea salt is about 11% Na_2SO_4. Additional Na_2SO_4 is formed within the gas turbine engine by the reaction between NaCl (from the salt in the air) and sulfur (an impurity in the fuel). Although the specification for JP-5 fuel calls for a maximum sulfur content of 0.4% (4000 ppm) it has been found that when the sulfur content is lowered to 0.0004% (4 ppm) or less, hot corrosion is reduced significantly (reference 6).

When the vanadium in the fuel is heated to high temperatures, it oxidizes into a highly corrosive liquid capable of fluxing the normal protective scale on the engine. As long as the vanadium content of JP-5 fuel is kept below a maximum of 0.5 ppm, the adverse effect of vanadium is negligible.(reference 7).

Sodium, potassium and lead in the fuel can also lead to hot-corrosion of gas turbines. Calcium can lead to hard-bonded deposits which are difficult to remove from gas turbines.

COMPOSITIONS OF SEVERAL SYNFUELS

As seen in Table 1 the sulfur content for all processed synfuels is relatively low. This is very fortunate and beneficial. In fact, the very low sulfur content of hydrogen treated COED (Char-Oil-Energy-Development) fuel for gas turbine may result in significantly less hot corrosion in the form of sulfidation than when using conventional JP-5 fuels over long periods of time. Similarly if tar sand fuel or shale oil fuel is further processed to yield gas turbine fuel, the sulfur contents may be greatly reduced from those values shown in Table 1.

Vanadium in COED fuel is less than 0.1 ppm and therefore presents no problem. Vanadium contents in fuels from tar sands and oil shale have not been published. Contents of sodium, potassium, lead and calcium in several of the snyfuels are shown in Table 2 with comparative requirements for Diesel Fuel #2 and Gas Turbine Fuel #2. The sodium concentration in Topped COED Fuel is very high. This may reflect contamination occuring during storage and handling in Navy facilities. Little difference in the other trace metal contents between the coal derived and petroleum distillate fuel is discernible.

Most liquid fuels are composed primarily of a mixture of four types of hydrocarbons: Paraffin, naphthenes, olefins, and aromatics. In general, paraffin hydrocarbons offer the most desirable combustion cleanliness characteristics for jet fuels. Naphthenes are the next most desirable hydrocarbons for this use. Although olefins generally have good combustion characteristics, their poor gum stability makes it necessary to limit their content in gas turbine fuels to about 5% or less. Aromatics generally have the least desirable combustion characteristics for gas turbine fuel. They tend to burn with a smoky flame resulting in carbon deposition which can contribute to hot corrosion of engine parts. Also they release a greater proportion of their chemical energy as undesirable thermal radiation than the other hydrocarbons. High aromatic fuels may also be degrading to certain rubber parts such as hoses, seals and o-rings. The specification for JP-5 fuel has a maximum of 25% total aromatic content.

From Table 1 it is seen that COED fuel is very high in aromatics unless it is given a special hydrogen treatment. Diesel fuel from tar sands is also high in aromatics (44%). Shale oil fuel is low in aromatics (7%) but high in olefins (65%). Therefore, special processing must be performed on fuels from all three sources to convert them to a larger percent of paraffins and naphthenes before they will be acceptable as gas turbine fuels.

The carbon residue is a measure of the carbonaceous material left in a fuel after all the volatile components are vaporized in the absence of air. It is a rough approximation of the tendency of a fuel to form carbon deposits. The COED fuel and shale oil fuel were found to have high percents of carbon residue.

The ash is the noncombustible material in a fuel. Ash particles can contribute to wear in the fuel system, to plugging of the fuel filter and the fuel nozzle, and to deposits on the heating surfaces. The synfuels appear to have marginally acceptable percent ash.

The copper strip corrosion test serves to indicate the presence or absence of chemicals that might corrode copper, brass and bronze components of the fuel system. All the synfuels were found to meet the specifications for this test.

RECENT ENGINE TESTS USING SYNFUELS

Project SEACOAL is the name given to the Navy's search to produce liquid fuels from coal to replace Navy Distillate Fuel. In November 1973 the Combat Systems Advisor Group of the Naval Material Command tested a coal-derived fuel in one boiler of the destroyer Johnston. The fuel tested was a topped crude product produced by the FMC Corporation using the COED process. The open ocean trials of the USS Johnston consisted of sustained runs of approximately 8 hours at 30%, 12 hours at 50%, 3 hours at 70% and 1 hour at 108% full power. No problem burning the COED fuel was encountered. The significant differences between the COED fuel and Navy Distillate Fuel are the following:

1. The COED fuel had a low flash point (80-90°F) which was raised to shipboard standards (140°F) by a topping process to remove the more volatile components.

2. The COED fuel had a pour point of about 60°F which is undesirably high and required the use of fuel tank heaters. However, both the flash point and the pour point of the COED fuel can be controlled in a production operation.

The Naval Air Propulsion Test Center (NAPTC) has been investigating the potential for the use of synthetic JP-5 jet fuel derived from coal, oil shale and tar sands. Current work by NAPTC on the three sources of synthetic fuels is as follows:

Coal: A contract program was started by NAPTC with the Sun Oil Company to produce JP-5 from coal. The JP-5 obtained will be evaluated by NAPTC by means of standard JP-5 specification tests, material compatibility tests, jet engine combustor tests and performance and exhuast emissions tests in a small gas turbine engine. Chemical characteristics of the fuel which may contribute to poor performance will be studied.

Oil Shale: Several experimental samples derived from oil shale were obtained from the Oil Shale Corporation for evaluation as JP-5 fuel. The most severely hydrogen-treated samples successfully passed the JP-5 specification tests. As greater quantities of these fuels become available, they will be subjected to hardware tests.

Tar Sands: A kerosene portion of synthetic crude oil from Athabasca Tar Sands has been evaluated by NAPTC. It passed all JP-5 specification requirements and was tested in a T63 helicopter engine for 60 hours. Performance of the fuel in this test was satisfactory. The post-test condition of the engine indicated no harmful effects. Additional chemical and compatibility tests of this fuel will be carried out. Some of this fuel was sent to NSRDL for evaluation of properties pertinent to non-aviation shipboard use such as in diesel engines.

Recently Detroit Diesel Allison (DDA) evaluated three coal derived liquid fuels in a standard T63 gas turbine combustor (references 8 & 9). The fuels tested were a light and a heavy fraction derived from Utah coal by FMC's COED process. A mixture of 20% by weight of the light fraction and 80% by weight of the heavy fraction represents the total liquid product from Utah coal processing. The third fuel tested was the topped COED as used in the USS Johnston. A fourth material analyzed but not combustor tested was Synthoil, a low-hydrogenated coal derived liquid produced by the Pittsburgh Energy Research Center of the Bureau of Mines. The trace metals analyses of these fuels are shown in Table 2. From their gas turbine combustor tests, DDA had the following conclusions:

1. At 100% speed, both coal derived crude fractions and the petroleum reference fuels exhibited 99.8+% combustion efficiency. At lower speed conditions, the combustion

efficiency variations appeare- to be primarily a function of the volatility levels of the various fuels.

2. Higher NO_x exhaust emissions were experienced with the coal derived fuels. The relative NO_x concentrations varied with the fuel-bound nitrogen concentrations measured in the fuels. This fuel-bound nitrogen content is believed to be contributing significantly to the NO_x emissions observed. The reduction of fuel-bound nitrogen conversion by combustor modification does not appear promising.

3. SAE exhaust smoke readings were sharply higher for the coal derived fuels. This was anticipated from the higher aromatic contents of these fuels.

4. No other deleterious combustion performance trends could be discerned in these tests at operating conditons up to 105 psia burner inlet pressure.

CONCLUSIONS AND RECOMMENDATIONS

From a survey of various organizations engaged in the testing and evaluation of synfuels (see Appendix A), it was found that only short-term combustion tests have been run on a few synfuels, mainly COED products. The chief reason for the absence of long-term combustion tests is the lack of sufficient quantities of the various synfuels available. From the fuel analyses and the short-term combustor tests reported upon to date, no significant materials problems have been noted. Moreover, the following observations are noteworthy:

1. The sulfur content of synfuels is low due to the processing treatments. If the sulfur content of the synfuel is very low (less than 10 ppm), the long-term hot corrosion of gas turbines due to sulfidation may be significantly less than when using conventional JP-5 fuels.

2. The synfuel contents of trace metals such as vanadium, sodium, potassium, calcium and lead have been found comparable to those in petroleum base fuels. Since deposit build-up and hot corrosion of gas turbines can result from the presence of significant quantities of these trace metals, their contents in future synfuels should be monitored carefully. If their contents are found to be relatively high, special fuel treatments and inhibitors can be used to reduce the possible adverse effects (see reference 10).

3. The percent of aromatics contained in synfuels from coal and tar sands were found to be relatively high using current processing techniques. This high aromatic content may result in the following adverse effects when used in engine combustors:

   a. smoky flame
   b. carbon deposits in combustors (possible sites for hot corrosion)

c. less efficient heating

d. degradation of certain rubber parts (seals and o-rings)

However, the aromatic content may be lowered by special processing techniques.

4. The percent of olefins in shale oil fuel was found to be high resulting in poor gum stability.

5. The percent carbon residue of synfuels from coal and shale oil was found to be high.

Of all the undesirable properties of the synfuels analyzed and tested to date, there is no problem from their use in engine combustors that cannot be remedied by special processing and treatments on the synfuels. The final fuel properties and its performance in the combustor are very sensitive to the processing and treatment received. Therefore, R, D, T and E is recommended to develop the technology to produce synfuels with the optimal properties to meet Navy requirements at minimum cost.

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F U E L	Sulfur %	Vanadium ppm	Carbon Residue on 10% Bottoms %	Ash %	Aromatics %	Pour Point °F	Flash Point °F	Kinematic Viscosity at 100°F Centistokes
JP-5 Mil-T-5624G	0.4 max	Nil	Nil	Nil	25 max	-51 max	140 min	1.9
Marine Diesel Fuel Mil-F-16884G	1.0 max	<0.3	0.2	0.005	16 max	20 max	140 min	2.1-6.0
Navy Distillate Fuel (ND) Mil-F-24397	1.3 max	0.5 max	0.4 max	0.01 max	—	25 max	150 min	10.0 max
COED, Topped as used in USS Johnston	0.02	<0.1	2.6	0.02	47	55	145	9.8
COED, Utah Light	<0.01	—	—	<0.01	32	<-65	<80	0.9
COED, Utah Heavy	0.05	—	—	<0.01	45	60	120	6.8
COED, 390-525°F Cut	0.007	<0.1	—	—	61	—	—	—
COED, Hydrogen Treated	0.001	<0.1	—	—	0-5	—	—	—
Synthoil	0.21	—	—	0.26	64	20	200	144
Diesel Fuel from Athabasca Tar Sand	0.12	—	0.13	—	44	-30	185	4.3
Shale Oil Fuel	0.6	—	18	0.04	7	10	<15	1.9

TABLE 1 PROPERTIES OF VARIOUS FUELS

TABLE 2

TRACE METALS ANALYSES OF FUELS BY ATOMIC ABSORPTION
(from Reference 9)

Fuel	TRACE METAL CONTENT (ppm)			
Fuel	Na	K	Ca	Pb
Utah Lite	0.92	1.81	<0.61	0.74
Utah Hvy	6.13	0.38	28.3	<0.54
Topped COED	342.	2.49	12.7	<0.53
Synthoil	4.29	1.01	3.35	<0.48
Diesel Fuel #2	<0.29	<0.29	<0.58	<0.58
Gas Turbine Fuel #2 (D2880)	*	*	10. max	5. max

Note
* Sodium plus potassium = 5 ppm max.

APPENDIX A

Synfuel Contacts

CDR P. A. Petzrick Naval Material Command NSRDL	301-267-2470
Dr. John F. Jones, Louis J. Scott Mgr of Project COED FMC Corp., Princeton, New Jersey	609-452-2300
Frank Verkamp, Max Harden Detroit Diesel Allison	317-243-4687
Larry Magitti, K. H. Guttmann NAV AIR PROP TEST CENT (NAPTC)	8-234-1770
John F. Boyle NAVSEC PHILA	215-755-3922/3587
Richard Rudey, Jack Grobman NASA Lewis Res Center	216-433-4000 ext 6160
Mr. Churchill, Mr. Delaney Fuel Branch, Fuel & Lub Div Propulsion Lab, WPAEF	513-255-5106
M. E. LePera, J.T. Gray Army F & L Labs Petroleum and Materials Dept Ft Belvoir, VA	703-664-3576
E. T. Hayes, H. R. Johnson, G. A. Mills Bureau of Mines	
M. Hauschildt NAVSEC	
E. W. White NSRDL	

APPENDIX B

PROPOSED NAVY SYNTHETIC FUEL PROGRAM FOR FY75

Synthetic Fuels Tailored to Military Specifications

The Interior Department, Office of Coal Research, has agreed to supply to the Department of Defense developmental quantities of military operational fuels such as JP-4, JP-5, and Navy distillates, derived from coal and oil shale. Requirements as to quantity and type have been agreed to for the five year period through 1980.

Synthetic Fuel for Jet Aircraft Propulsion

A program started in December 1973, undertakes the qualification of a synthetic JP-5 for ultimate use in the fleet air arm. The program will seek to examine a "wide range" of synthetic fuel characteristics such as thermal stability, material compatibility, and hazards in order to develop the confidence required for full utilization. A major program milestone will be the ground testing of a jet engine scheduled for early 1975 as a prelude to flight evaluation.

Syn-Crude Source Optimization

Synthetic crude stock can be derived from a variety of natural resources; coal, oil shale, tar sands, and extracted in numerous ways. The resulting refinery feed stocks have widely varying characteristics and some will require intermediate processing to assure compatibility with terminal processing steps. A program of sampling and laboratory analysis will seek to identify the best resources and extraction techniques for producing military fuels and lubricants.

Synthetic Fuels and Lubricants for Marine Gas Turbines

Activity in FY75 will be devoted largely to fuel sub-component evaluation such as injectors, filters, seals and pumps. It is expected that synthetic lubricants will require new additives to suppress corrosion, oxidation and to modify viscosity. A key program milestone, hinging on funding levels, will be the static test of a marine gas turbine, as well as other power systems in FY75, in order to identify operational problems.