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MIDDLE DISTILLATE FUEL STABILITY CHARACTERISTICS - A  
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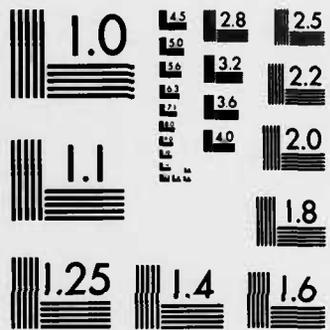
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**MIDDLE DISTILLATE FUEL  
STABILITY CHARACTERISTICS—  
A REVIEW**

**INTERIM REPORT  
AFLRL No. 168**

By

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Under Contract to

**U.S. Army Mobility Equipment Research  
and Development Command  
Materials, Fuels, and Lubricants Laboratory  
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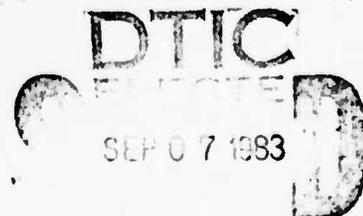
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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>Middle distillate fuel stability is of prime concern when long-term storage is necessary. Extensive work has been undertaken over the past half century in an attempt to establish the true chemical mechanism by which this degradation takes place.<br><br>This review was undertaken as part of a basic research program having as its goal the definition of fuel deterioration and additive-inhibition mechanisms. It is intended to report some of the more pertinent highlights so that the |                                     |   |

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20. ABSTRACT (Cont'd)

reader may obtain an overview of the current state-of-the-art in fuel stability research. An annotated bibliography has also been included so that more in-depth information may be readily obtained.

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FOREWORD

The review presented herein was prepared at the U.S. Army Fuels and Lubricants Research Laboratory (USAFLRL), Southwest Research Institute, San Antonio, Texas, under Contract DAAK70-82-C-0001. The work was funded by the U.S. Army Mobility Equipment Research and Development Command (USAMERADCOM), Ft. Belvoir, VA. Contracting Officer's representative was Mr. F.W. Schaekel, and the technical monitor was Mr. M.E. LePera, Fuels and Lubricants Division, Materials, Fuels and Lubricants Laboratory (DRDME-VF).

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## I. INTRODUCTION

### A. Purpose

The material presented in this review is an accumulation of information from many of the more significant presentations in literature. It is designed to be a ready reference document and, as such, does not contain some of the detailed information that an exhaustive review might cover. However, the inclusion of an annotated bibliography gives a base from which more specific information may be obtained in particular areas of interest.

### B. Historical Information

Petroleum-like bituminous materials were described by Herodotus, Plutarch and others (1)\* 2000 years ago. However, actual use of these materials spans at least 5000 years, dating to the Sumerians, Assyrians, and Babylonians. During those times, seepages were found on the Euphrates River, in Mesopotamia, and in the eastern Mediterranean areas.(2) Crude oil was probably obtained by dipping directly into the seep or by prior digging to enlarge the area and then dipping the material out.(1) Because of these seeps, the area now known as the Dead Sea was, in ancient times, known as Lake Asphaltites, because of the tarballs found on its shores.

The word "petroleum" is attributed to first use by a German mineralogist in a treatise on its recovery and refining published in 1556.(2) Other historical points are noted by Bacon and Hamor.(3)

The tars and oils which made up the substance of petroleum have been used in a wide variety of ways, including caulking, waterproofing, and illumination. In the early 19th century United States, animal fat (especially whale fat) was still the major source of illuminating oil, even though petroleum seeps had been found. With increasing population, a more abundant source of

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\*Underscored numbers in parentheses refer to the list of references at the end of this report.

refined oil became necessary. Distillation of coal was popular, but product volume was not sufficient to overcome the growing needs for less costly and greater volumes of lubricants and illuminating oil. These requirements and the approach of the Industrial Revolution led to completion of the first drilled oil well in the United States at Titusville, Pennsylvania in 1859. Refining of this crude took place in the already existing coal-oil refineries.<sup>(2)</sup> By 1900, Pennsylvania lubricants had displaced animal and vegetable materials as the primary oil source.<sup>(4)</sup> By this time, oil fields had been discovered in 14 states, Europe, and the Far East.<sup>(2)</sup>

From the beginning of this century to the present time, greater emphasis has continually been placed on particular specifications for various refined products. As noted, lubricants and illuminants headed the early product lists; now, approximately 2500 materials are produced, at least in part, from petroleum, not counting the 3000 petrochemicals also produced.<sup>(4)</sup>

### C. Processing

Methods for refinement of crude oils have also changed considerably over the years, due to increasing demands for specific products and better overall performance of those products. Several refinery processes are currently in use. Each is generally composed of three fundamental activities:<sup>(1)</sup>

1. Primary separation of raw materials
2. Preparation of process feed
3. Fractionation of the products

These may be accomplished by:<sup>(4)</sup>

1. Crude fractionation
2. Thermal decomposition
3. Catalytic cracking
4. Catalytic reforming
5. Hydrocracking

Crude fractionation is generally used as the first step before further processing. Light gasoline, naphtha, kerosene, gas oil, and topped crude are the products obtained from this process.(4) Materials from the process are designated as straight run products. Further refining, as described below, is required for the heavier products.

Successful cracking processes were demonstrated for use in World War I, but it was not until World War II that the thermal cracking process was maximized. Catalytic cracking became successful toward the end of World War II, but its growth has been optimized only within the past 20 years(4), now exceeding thermal cracking in terms of capacity.(5) Thermal cracking treats the feed material at temperatures of 850°-1150°F (454°-621°C) and pressures of 1 to approximately 110 atmospheres for 10 minutes or less. Catalytic cracking requires less severe conditions [750°-1000°F(399°-538°C) at 1-7 atmospheres] while using the catalytic material to accelerate and guide the cracking process to produce the desired final products.(5) Fluidized catalytic cracking (as opposed to the fixed bed process) began in 1942. In this process, vaporized feedstock lifts the powdered catalyst into the reaction bed, thus "fluidizing" the powdered material.

Catalytic reforming is not a popular process in the United States because much higher octane gasoline can be produced by alkylation and catalytic cracking. Reforming also leads to loss of light ends (gases) and therefore is not economically feasible. It does, however, substantially increase the aromatic content of naphthenic feedstock through partial dehydrogenation of the naphthenes.

Hydrocracking produces a final product almost exclusively composed of aliphatic and aromatic materials with little or no sulphur and no nitrogen.(4) This would be the process of choice except for the expense of the hydrogen involved. Even so, use of this process is increasing, and if some of the economic factors are overcome, it could replace catalytic cracking as the major refining process.

#### D. Demand

For FY 1977, the total U.S. petroleum energy demand was approximately 18.6

million barrels per day (of which DOD used 2.6 percent).(6) In 1980, total oil consumption in the U.S. was approximately 16.9 million barrels per day.(7) During this period (1978) demand for middle distillate fuel oil (diesel, jet fuel, etc.) was approximately 3.4 million barrels per day, or 18 percent of the total demand for that year.(8)

#### E. Fuel Stability Background

After a fuel is produced, the time lag prior to end use could vary from weeks to years. Long-term storage stability has been a requirement imposed on military fuels designed for tactical/combat uses.(9) However, storage stability (and the prediction of long-term fuel stability) for diesel and distillate fuels has long been recognized as a potential problem by both government and industry.(10-11) Many research programs have been undertaken to determine how fuel can be stabilized (by use of additives) as well as what causes degradation to occur (elucidation of reaction mechanisms). Various specifications have been formulated for specific use fuels. These specifications also include geographical allowances, particularly for temperature. A summary of fuel specifications for aviation and diesel fuels is given in Tables 1 and 2.

Almost a quarter of a century ago, the chemical character of fuel degradation products was postulated.(12) Well over one-half century ago, it was noted that the presence of diolefinic hydrocarbons in cracked distillates was at least partially responsible for gum formation in gasoline.(13) Several papers published in the late 1920's through the 1930's verify and expand upon this fact.(14) The following sections summarize current knowledge in the field of middle distillate fuel stability.

## II. MECHANISMS OF GUM FORMATION

### A. Oxidation/Autoxidation

This mechanism is considered to be the most prominent of the degradation

TABLE 1. SUMMARY OF FUEL SPECIFICATION PROPERTIES  
OF AVIATION TURBINE FUELS

| Specification:<br>Product:<br>NATO Code No.:  | MIL-T-5624K* Amendment 1 |                       | MIL-T-83133A**                  | ASTM D 1655***      |                    |
|---|--------------------------|-----------------------|---------------------------------|---------------------|--------------------|
|   | Grade JP-4<br>F-40       | Grade JP-5<br>F-44    | Grade JP-8<br>F-34              | Jet A/Jet A-1<br>-- | Jet B<br>--        |
| <u>Properties</u>   |                          |                       |                                 |                     |                    |
| Distillation Temp., °C<br>(D 2887 limits in parentheses)  |                          |                       |                                 |                     |                    |
| 10% recovered, max temp   | --                       | 205(185)              | 205(186)                        | 204.4               | --                 |
| 20% recovered, max temp   | 145(130)                 | --                    | --                              | --                  | 143.8              |
| 50% recovered, max temp   | 190(185)                 | --                    | --                              | --                  | 187.8              |
| 90% recovered, max temp   | 245(250)                 | --                    | --                              | --                  | 243.3              |
| End point, max temp   | 270(320)                 | 290(320)              | 300(330)                        | 300                 | --                 |
| Residue, vol%, max (D 86)   | 1.5                      | 1.5                   | 1.5                             | 1.5                 | 1.5                |
| Loss, vol%, max (D 86)  | 1.5                      | 1.5                   | 1.5                             | 1.5                 | 1.5                |
| Flash Point, °C(°F), min  | --                       | 60(140)               | 38(100) or<br>41(105) <u>1/</u> | 37.8(100)           | --                 |
| Vapor Pressure, 37.8°C(100°F),<br>kPa<br>(psi)  | 14-21<br>(2.0-3.0)       | --                    | --                              | --                  | --<br>(3 max)      |
| Freezing Point, °C(°F), max   | -58(-72)                 | -46(-51)              | -50(-58)                        | 2/<br>8             | -50                |
| Viscosity, @ -20°C, cSt, max  | --                       | 8.5                   | 8.0                             | 8                   | --                 |
| Water Reaction,<br>Interface rating, max<br>Separation rating, max                                  | 1b<br>1                  | --                    | 1b<br>--                        | 1b<br>2             | 1b<br>2            |
| Water Separation Index,<br>mod., min  | 70                       | 85                    | <u>3/</u>                       | --                  | --                 |
| Total Acid No., mg KOH/g, max   | 0.015                    | 0.015                 | <u>0.015</u>                    | 0.1                 | --                 |
| Aromatics, vol%, max  | 25.0                     | 25.0                  | 25.0                            | 20 <u>4/</u>        | 20 <u>4/</u>       |
| Olefins, vol%, max  | 5.0                      | 5.0                   | 5.0                             | --                  | --                 |
| Mercaptan Sulfur, wt%, max  | 0.001                    | 0.001                 | 0.001                           | 0.003               | 0.003              |
| Sulfur, total wt%, max  | 0.40                     | 0.40                  | 0.3                             | 0.3                 | 0.3                |
| Copper Strip Corrosion, 2 hr<br>@ 100°C (212°F), max  | 1b                       | 1b                    | 1b                              | No. 1               | No. 1              |
| Density, kg/m <sup>3</sup> , min<br>(°API, max) <sub>3</sub> @ 15°C                                 | 751(57.0)                | 788(48.0)             | 775(51.0)                       | 775.3(51)           | 750.7(57)          |
| Density, kg/m <sup>3</sup> , max<br>(°API, min) @ 15°C  | 802(45.0)                | 845(36.0)             | 840(37.0)                       | 839.8(37)           | 801.7(45)          |
| Thermal Stability (JFTOT),<br>Change in pressure drop, mm<br>of Hg, max                             | 25                       | 25                    | 25                              | 25                  | 25                 |
| Preheater deposit code,<br>less than  | 3                        | 3                     | 3                               | 3                   | 3                  |
| Existent Gum, mg/100 mL, max  | 7.0                      | 7.0                   | 7.0                             | 7                   | 7                  |
| Particulate Matter, mg/liter,<br>max <u>8/</u>  | 1.0                      | 1.0                   | 1.0                             | --                  | --                 |
| Filtration Time, minutes,<br>max <u>8/</u>  | 15                       | --                    | --                              | --                  | --                 |
| Heating Value, Aniline-gravity<br>product, min, or<br>Net heat of combustion,<br>MJ/kg (Btu/lb), mi | 5,250<br>42.8(18,400)    | 4,500<br>42.6(18,300) | --<br>42.8(18,400)              | --<br>42.8(18,400)  | --<br>42.8(18,400) |
| Hydrogen content, wt%, min, or  | 13.6                     | 13.5                  | 13.5                            | --                  | --                 |
| Smoke point, mm, min, or  | 20.0                     | 19.0                  | 25                              | 25                  | 25                 |
| Smoke point, mm, min, and   | --                       | --                    | 19                              | 20                  | 20                 |
| Naphthalenes, vol%, max   | --                       | --                    | 3.0                             | 3                   | 3                  |
| Fuel System Icing Inhibitor,<br>vol%  | 0.10-0.15                | 0.10-0.15             | 0.10-0.15                       | --                  | --                 |
| Fuel Electrical Conductivity,<br>pS/m   | --                       | --                    | 200-600                         | 50-300 <u>5/</u>    | 50-300 <u>5/</u>   |

\* Dated 12 November 1976

\*\* Dated 5 May 1976

\*\*\* Dated 1978

- 1/ The minimum flash point shall be 38°C as measured using ASTM D 3243 and 41°C as measured using ASTM D 93.
- 2/ The maximum freezing point for Jet A is -40°F and for Jet A-1 it is -50°C (-58°F).
- 3/ The minimum water separation index, modified, rating shall be 85 for JP-8 fuel without both the corrosion inhibitor and the electrical conductivity additives present OR 70 for JP-8 fuel containing all required additives except for the electrical conductivity additive.
- 4/ Jet A with an aromatics content over 20 volume % but not exceeding 25 volume % and Jet A-1 or Jet B with an aromatics content over 20 volume % but not exceeding 22 volume % is permitted provided the supplier (seller) notifies the purchaser of the volume, distribution and aromatic content under conditions mutually agreeable to both parties. This footnote is subject to reapproval in 1979.
- 5/ Applies only when an electrical conductivity additive is used.

TABLE 2. SUMMARY OF FUEL SPECIFICATION PROPERTIES OF DIESEL AND DISTILLATE FUELS

| Specification:<br>Product:<br>NATO Code No.:               | VV-F-800C* |          |          | DF-2 CONUS |          | DF-2 OCONUS |          | NATO F-54** |                  | MIL-F-16884C***  |                  | MIL-F-24397****  |                  |
|--|------------|----------|----------|------------|----------|-------------|----------|-------------|------------------|------------------|------------------|------------------|------------------|
|  | DF-A       | DF-1     | DF-2     | CONUS      | DF-2     | OCONUS      | F-54     | Diesel Fuel | DF-M             | F-76             | ND               | ND               |                  |
| Distillation, °F(°C)                                       | Report     | Report   | Report   | Report     | Report   | Report      | Report   | Report      | Report           | Report           | Report           | Report           | Report           |
| 50% evaporated, max  | 550(288)   | 550(288) | 640(338) | 640(338)   | 675(357) | 675(357)    | 675(357) | 675(357)    | 675(357)         | 675(357)         | 675(357)         | 675(357)         | 675(357)         |
| 90% evaporated, max  | 572(300)   | 626(330) | 700(370) | 700(370)   | 700(370) | 700(370)    | 700(370) | 700(370)    | 700(370)         | 700(370)         | 700(370)         | 700(370)         | 700(370)         |
| End point, max   | 3          | 3        | 3        | 3          | 3        | 3           | 3        | 3           | 3                | 3                | 3                | 3                | 3                |
| Residue, vol%, max   | 100(38)    | 100(38)  | 125(52)  | 125(52)    | 133(56)  | 133(56)     | 133(56)  | 133(56)     | 133(56)          | 133(56)          | 133(56)          | 133(56)          | 133(56)          |
| Flash Point, °F(°C), min                                   | -60(-51)   | 2/       | 2/       | 2/         | 2/       | 2/          | 2/       | 2/          | 2/               | 2/               | 2/               | 2/               | 2/               |
| Cloud Point, °F(°C), max                                   | Report     | Report   | Report   | Report     | Report   | Report      | Report   | Report      | Report           | Report           | Report           | Report           | Report           |
| Pour Point, °F(°C), max                                    | 1.1-2.4    | 1.3-2.1  | 1.1-4.1  | 1.1-4.1    | 1.8-9.5  | 1.8-9.5     | 1.8-9.5  | 1.8-9.5     | 1.8-4.5          | 1.8-4.5          | 1.8-4.5          | 1.8-4.5          | 1.8-4.5          |
| Viscosity @ 104°F(340°C), cSt                              | Report     | Report   | Report   | Report     | Report   | Report      | Report   | Report      | Report           | Report           | Report           | Report           | Report           |
| Viscosity @ 68°F(20°C), cSt                                | 0.05       | 0.50     | 0.50     | 0.50       | 0.10     | 0.10        | 0.10     | 0.10        | 0.30             | 0.30             | 0.30             | 0.30             | 0.30             |
| Total Acid Number, mg KOH/g, max                           | 0.25       | 0.50     | 0.50     | 0.50       | 0.70     | 0.70        | 0.70     | 0.70        | 1.00             | 1.00             | 1.00             | 1.00             | 1.00             |
| Sulfur, % wt., max   | 3          | 3        | 3        | 3          | 1        | 1           | 1        | 1           | 1                | 1                | 1                | 1                | 1                |
| Copper Strip Corrosion, 3 hrs @ 122°F(50°C), max           | 0.01       | 0.01     | 0.01     | 0.01       | 0.02     | 0.02        | 0.02     | 0.02        | 0.005            | 0.005            | 0.005            | 0.005            | 0.005            |
| 3 hrs @ 212°F(100°C), max                                  | Report     | Report   | Report   | Report     | Report   | Report      | Report   | Report      | Record           | Record           | Record           | Record           | Record           |
| Ash, % wt., max  | 0.01       | 0.01     | 0.01     | 0.01       | 0.01     | 0.01        | 0.01     | 0.01        | 0.01             | 0.01             | 0.01             | 0.01             | 0.01             |
| Gravity, °API  | Report     | Report   | Report   | Report     | Report   | Report      | Report   | Report      | Report           | Report           | Report           | Report           | Report           |
| Density @ 15°C, kg/L                                       | Report     | Report   | Report   | Report     | Report   | Report      | Report   | Report      | Report           | Report           | Report           | Report           | Report           |
| Accelerated Stability, total Insolubles, mg/100 mL, max 4/ | 1.5        | 1.5      | 1.5      | 1.5        | 1.5      | 1.5         | 1.5      | 1.5         | 2.5              | 2.5              | 2.5              | 2.5              | 2.5              |
| Water & Sediment, % vol, max                               | 0.01       | 0.01     | 0.01     | 0.01       | 0.01     | 0.01        | 0.01     | 0.01        | 0.01             | 0.01             | 0.01             | 0.01             | 0.01             |
| Carbon Residue on 10% bottoms, % wt., max 5/               | 0.10       | 0.15     | 0.35     | 0.35       | 0.20     | 0.20        | 0.20     | 0.20        | 0.2              | 0.2              | 0.2              | 0.2              | 0.2              |
| Particulate Contamination mg/L, max                        | 10         | 10       | 10       | 10         | 10       | 10          | 10       | 10          | 10               | 10               | 10               | 10               | 10               |
| Cetane Number, min   | 40         | 45       | 45       | 45         | 45       | 45          | 45       | 45          | 45               | 45               | 45               | 45               | 45               |
| Appearance, visual   | Report     | Report   | Report   | Report     | Report   | Report      | Report   | Report      | Bright and Clear |
| Color (ASTM D 1500), max                                   | Report     | Report   | Report   | Report     | Report   | Report      | Report   | Report      | 3                | 3                | 3                | 3                | 3                |
| Demulsification, min, max                                  | Report     | Report   | Report   | Report     | Report   | Report      | Report   | Report      | 10               | 10               | 10               | 10               | 10               |

\* Dated 15 September 1980.  
 \*\* From Annex C to STANAG 2845, 21 September 1978.  
 \*\*\* Amendment 1 dated 22 March 1978.  
 \*\*\*\* Cancelled 23 May 1977.

1/ DF-2 intended for entry into the Central European Pipeline System shall have a minimum value of 58°C.  
 2/ DF-2 destined for Europe and S. Korea shall have a maximum limit of 9°F(-13°C).  
 3/ DF-2 destined for Europe and S. Korea shall have a maximum limit of 0°F(-18°C).  
 4/ This requirement is applicable only for military bulk deliveries intended for tactical, OCONUS, or long term storage (greater than six months) applications (i.e., Army depots, etc.).  
 5/ See Appendix of VV-F-800C. The maximum limits do not apply for samples containing cetane improvers. In those instances, the test must be performed on the base fuel blend.

mechanisms since air ( $O_2$ ) is normally present at all times and temperatures. The mechanism for oxygen addition to organic compounds, particularly diolefins, appears to be well agreed upon. (15-18) The reaction is free radical in nature with an oxygen molecule adding to the host hydrocarbon, forming a peroxy radical which can then reform to either a hydroperoxide or a dialkylperoxide. From this point, polymerization may occur, forming the gums.

## B. Acid/base Reactions

### 1. Sulfur Compounds

Certain materials, such as the polysulfides, have been shown to have a greater effect on gum formation than either mercaptans or thiophenols. (19) Other studies (20,21) using various sulfur compounds in conjunction with 2,5-dimethylpyrrole (stability decriaser) showed that the synergistic properties were different than the properties of the sulfur compounds alone. For example, sulfide compounds had little effect on sediment formation, while thiols showed inhibitory effects and sulfonic acids acted to increase sediment formation.

### 2. Nitrogen Compounds

Organo-nitrogen compounds and their effect on fuel storage stability have been the subject of many studies. (19-26) A large number of nitrogen compounds have been shown to have no effect or even an inhibitory effect on certain gum-forming reactions. However, 2,5 substituted pyridines and 2,5 substituted pyrroles have been shown to be quite active in sediment formation, particularly when the latter compound is placed in the fuel prior to aging the sample.

## C. Metal Catalysis

Certain metals, when in solution, behave as catalysts for on-going reactions, particularly the decomposition of hydroperoxides to free radicals.

For example: (18)



or (16)



Iron and nickel also act in a manner similar to that illustrated for copper above.

#### D. Polymerization/Condensation

There are two types of polymerization reactions: (1) addition (free radical and ionic), and (2) condensation. Addition reactions occur through coupling of complete molecules to form a larger molecule. Condensation occurs with the loss of some product, usually water.

Polymerization requires the presence of a small amount of initiator (usually a peroxide). The difference between this type of reaction and autoxidation is that the final product does not necessarily include oxygen.

Examples of a condensation reaction are that which occurs between carboxylic acids and amines to yield amides or acid/alcohol to yield esters. If both components have more than one functional group, polymerization can occur. (27)

#### E. Biological Activity

The effect of biological growth in fuel systems can be considered as causing fuel degradation from two points of view. The first actually does not cause chemical transformation of the fuel components but as the microbes grow, they form particulate matter or a film-like colony which can cause filter and/or injector fouling. The second mode of degradation is from the acidic nature of the growth byproducts. This change in pH can affect either the container (metal solubility), thus increasing potential catalytic activity or act as an initiator for a polymerization reaction (see above). Although

many types of fungal and bacterial growth have been observed in fuel tanks and on filters, the overall most abundant is the fungus Cladosporium resinae. Examples of common yeasts and bacteria are Candida and Pseudomonas aeruginosa, respectively. (28-33).

### III. REACTION PRODUCT COMPOSITION

One of the first postulations of a "typical" sediment molecule is shown in Figure 1.(12) Variations in this structure are also suggested by replace-

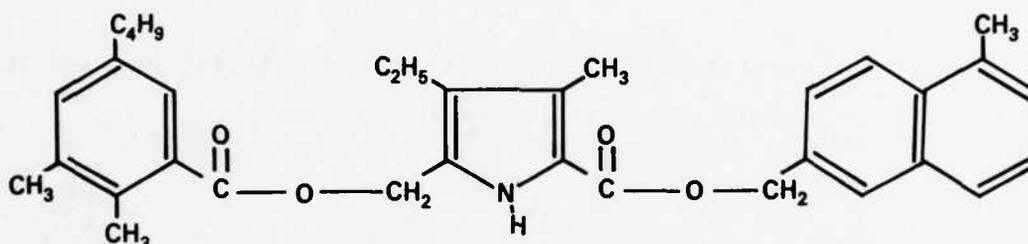


FIGURE 1. TYPICAL SEDIMENT MOLECULE

ment of one or more of the three ring groups with other components. The ester linkage remains present in each form. Some of the products resulting from reaction of 2,5 dimethylpyrrole are given in Figure 2.(23)

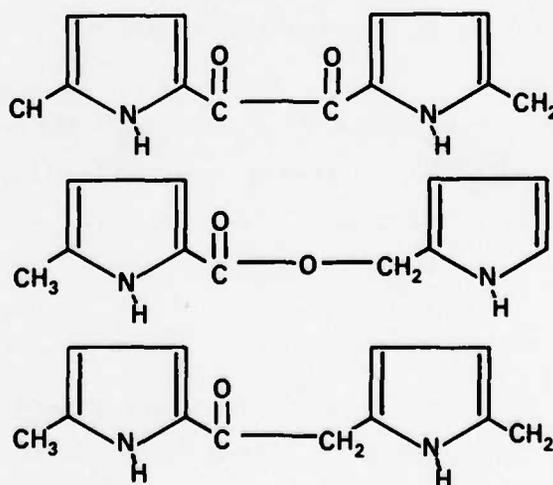


FIGURE 2. PRODUCTS FROM THE REACTION OF 2,5-DIMETHYLPYRROLE

TABLE 3. ELEMENTAL ANALYSIS OF GUMS

| Element | Gums From Heating Oil(10), % | Gums From Gasoline(17), % |
|---------|------------------------------|---------------------------|
| C       | 60-78                        | 70-80                     |
| H       | 6.0-7.5                      | 7-10                      |
| N       | 1.5-2.8                      | 0.2                       |
| S       | 0.9-3.6                      | 0.4-3                     |
| O       | 7.4-17.5                     | 10-20                     |

The empirical formula developed from averaging the above data is  $C_{6.3}H_{7.0}NO_{1.67}$ . Elemental analysis has also been performed on various gums. The results of these analyses are shown in Table 3.

The involvement of sulfur in the analysis of gum material has led to the postulation of the formula shown in Figure 3.

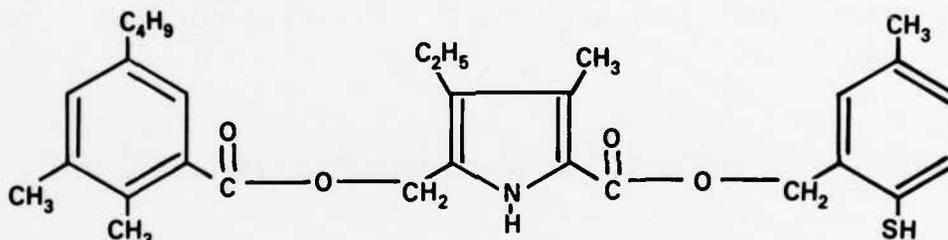


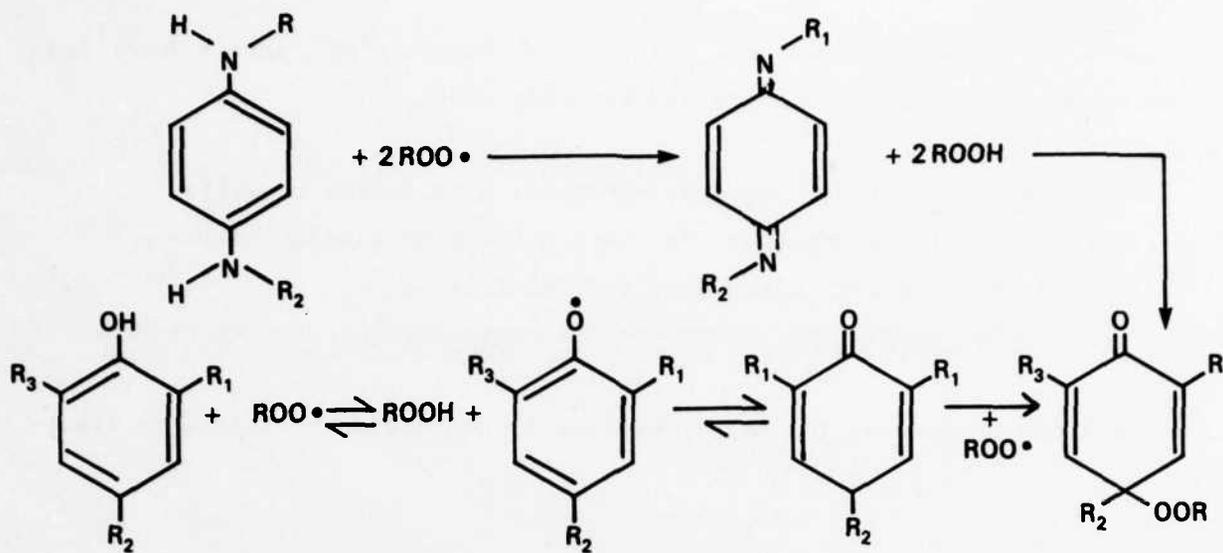
FIGURE 3. SEDIMENT MOLECULE

#### IV. FUEL STABILIZERS/ENHANCERS

The preceding discussion has concerned itself with the degradation of neat, middle distillate fuels. The following sections will be concerned with methods by which that degradation may be controlled.

##### A. Antioxidants

To prevent oxidation of a fuel, it is normally considered that a "chain-breaking" molecule or free radical "scavenger" needs to be employed. Phenylene diamines or hindered phenols are most commonly used for this purpose. The reactions which occur are:(18)



### B. Dispersants

Particulate material, whether derived from fuel decomposition or external sources, can agglomerate to form still larger particles, which may eventually clog filters, fuel lines, and/or injector nozzles. In order to maintain a minimum of particles of large size, surfactants are employed to prevent settling. Generally, nitrogen-based chemicals are the better materials of choice. Oleoylamide is a good example. Salts of alkylbenzenesulfonic acid may also be used. To be effective, the amount of dispersant used must be in excess of that required; otherwise, it will be depleted and settling of particulates will reoccur.

### C. Metal Deactivators

Elimination of the catalytic effect of dissolved metals may be effectively accomplished through addition of chelating materials to the fuel. A common chelating agent is *N,N'*-disalicylidene propylenediamine.

### D. Sweetening

Product quality in general may be improved by treatment of the original crudes prior to further processing. For many years, a sulfuric acid wash

followed by aqueous alkali and addition of "sweetening" agents have been used. Four sweetening processes are commonly used.

1. Doctor process: Requires treatment with sodium plumbite.
2. Lead sulfide process: Involves a reaction similar to the doctor process, using lead sulfide instead.
3. Copper sweetening: Involves treatment with cupric chloride.

In the above processes, the major reaction is conversion of thiols to disulfides.

4. Merox process: The newest of these processes, this process follows use of a chelate catalyst(4) which allows this process to be used either as a sweetening agent or solvent extraction process.

#### V. METHODS USED TO STUDY FUEL DECOMPOSITION MECHANISMS

##### A. Accelerated Decomposition

Many methods have been used to accelerate or "test" the ability of any given fuel to degrade. It is normally assumed that the prevailing mechanism is that of oxidation. The following procedures are most commonly employed.(29)

- |                      |                           |
|----------------------|---------------------------|
| 1. Storage at 43.3°C | 4. ASTM D 873 (modified)  |
| 2. Storage at 80°C   | 5. ASTM D 2274 (modified) |
| 3. Storage at 150°C  | 6. ASTM D 3241 (modified) |

The first three procedures may be carried out for any time duration of interest; normally, the higher the temperature, the shorter the time of experiment, e.g., 43.3°C maximum 6 months to 1 year, 150°C usually <10 hours. The containers, normally borosilicate glass, may be vented to the atmosphere, or sealed under nitrogen or any other gas as per study emphasis.

ASTM D 873 (modified) requires a volume of filtered fuel to be aged at 100°C for 16 hours under 100 psi oxygen.

ASTM D 2274 (modified) requires a volume of filtered fuel to be aged at 95°C for 16 hours at ambient pressure with oxygen continuously bubbled through the sample.

ASTM D 3241 (modified), also known as the jet fuel thermal oxidation test (JFTOT), requires a volume of filtered fuel to be pumped past an electrically heated metal tube, then through a 17- $\mu\text{m}$  filter across which the pressure drop is measured.

In each of the above methods, "insoluble" particulates are measured by passing an aliquot of the aged fuel through a preweighed filter. The modification noted generally indicates a change in nominal pore size of this filter; usually 0.8  $\mu\text{m}$  rather than the specified 1.2  $\mu\text{m}$ . Adherent gums are dissolved in toluene-acetone-methanol (TAM) after a prewash with heptane. The TAM solution is then placed in a preweighed beaker and the solvent evaporated. Soluble gums may be determined by the steam jet or air jet process.

## B. Correlation Between Acceleration Techniques

### 1. Experimental Results

The techniques listed above, plus storage at 93.3°C in a soft glass container and a chromic acid oxidation test, were employed in an extensive matrix involving six test fuels.<sup>(34)</sup> Each fuel was evaluated for particulates (adherent and suspended), steam jet gum, color, light absorbance and acid number.

The Pearson Product-Moment correlation coefficient was calculated with major emphasis on total insolubles, steam jet gum, and total gum. The overall conclusion reached in this study was that the 43.3°C storage data did not follow a trend predictable by any one of the other test methods. However,

the 80°C test appeared to yield the closest prediction. Reference 19 also details the results of an extensive correlation test matrix with the conclusion that significant correlations are minimal.

There are several possible reasons for this. First, different reaction mechanisms may predominate at different temperatures, particularly above 160° to 180°F (71° to 82°C). Also, as temperature increases, thermal degradation, rather than oxidation, becomes the predominant mechanism. Secondly, filtration and comparison of material retained on the filter presuppose that particle size is reproducible from one experiment to the next; however, there are no published studies yielding information on this point. Other possible reasons for the variability may be sample volume (surface to volume ratio), type of filter used, flow rate through the filter, methods of drying the filters, temperature required for sample workup (particularly steam jet gum), etc. Many of these variables could be eliminated by procedural change and subsequent verification of the resulting experiments. It is obvious that, at this time, each of the tests listed must be interpreted on an individual basis, with the results perhaps being valid within a range rather than as a specific number.

## 2. The Arrhenius Equation

Attempts to predict correlative temperatures may also be undertaken in a theoretical sense. The equation needed for this prediction is based on the one developed by Arrhenius;  $k = Ze^{-E_a/RT}$  where  $E_a$  is the energy of activation,  $R$  is the gas constant, and  $T$  is the temperature. Including a pressure correction term (for accelerated aging due to increased ambient pressure such as in a bomb) and assuming that  $k$  is proportional to  $\frac{1}{t}$  and integrating, the equation becomes(19)

$$\ln \frac{t_1}{t_2} = A\left(\frac{1}{T_1} - \frac{1}{T_2}\right) + B \ln \frac{P_1}{P_2}$$

The term  $A$  equals  $E_a/R$  where  $R = 1.9869 \text{ cal}(15^\circ)/^\circ\text{C mole}$ , and  $t$  is the time required for a specific amount of material to be formed. By rearrangement, the equation may also be used to predict amounts of material that will be formed in a given time and assuming that  $P_1/P_2 \approx 1$ :(21)

$$\ln \frac{M_2}{M_1} = A \left( \frac{1}{T_2} - \frac{1}{T_1} \right)$$

where M is the amount of material formed.

Several values have also been suggested for the energy of activation.

| <u>Type of Fuel</u> | <u>Ea <math>\left(\frac{\text{kCal}}{\text{mole}}\right)</math></u> |
|---------------------|---|
| Jet fuels           | 21.0(19), 10.0(34)  |
| #2 Diesel           | 10.7(21)  |
| JP-8                | 14.4(21)  |

## VI. REFERENCES

1. Gruse, W.A. and Stevens, D.R., Chemical Technology of Petroleum, 3rd edition, McGraw-Hill, NY, 1960.
2. Author Unknown, "Petroleum," Encyclopedia Britannica, 15th edition, Vol. 14, pp. 164-169, 1974.
3. Bacon, R.F. and Hamor, W.A., The American Petroleum Industry, Vol. I, McGraw-Hill, NY, 1916.
4. Kirk-Othmer, Encyclopedia of Chemical Technology, 2nd edition, Wiley Interscience, NY, Vol. 15, p. 4, 1968.
5. Bell, H.S., American Petroleum Refining, 4th edition, D. Von Nostrand Company, Inc., Princeton, NJ, 1959.
6. Lukens, L.A., "Conference on Composition of Transportation Synfuels Panel on Defense Mobility Fuels," CONF-7810176, Opening Remarks to Proceedings, October 11-13, 1978.
7. Keller, B.D. and Wagner, T.O., "Trends in Motor Fuels," Presented to National Petroleum Association Meeting, San Antonio, TX, 1981.
8. Author unknown, "Petroleum Statement," Annual, Final Summary, Department of Energy Information Administration, DOE/EIA-0109, 1981.
9. Stavinoha, L.L. and LePera, M.E., "A Review of Diesel Fuel Deteriora-

- tion and Related Problems," U.S. Army Fuels and Lubricants Research Laboratory Interim Report AFLRL No. 88, Contract No. DAAG-53-76-C-0003, AD A043566, May 1977.
10. LePera, M.E. and Sonnenburg, J.G., "Storage Stability of Automotive Diesel Fuels," National Technical Information Service, October 1972.
  11. Stavinoha, L.L., Cauldwell, G.S. and Kemp, M.D., "An Overview of Army Mobility Energy Research and Development," Interim Report AFLRL No. 146, Contract No. DAAK70-80-C-0001, AD A109182, October 1981.
  12. Sauer, R.W., Weed, A.F. and Headington, C.E., "A Mechanism for Organic Sediment Formation in Heating Oils," Petrol Division Preprints, American Chemical Society Meeting, Chicago, IL, September 1958.
  13. Gruse, W.A. and Stevens, D.R., The Chemical Technology of Petroleum, 2nd edition, McGraw-Hill, NY, 1942.
  14. Gruse, W.A. and Stevens, D.R., The Chemical Technology of Petroleum, 2nd edition, McGraw-Hill, NY, pp. 129-130, 1942.
  15. Nixon, A.C., "Autoxidation and Antioxidants of Petroleum," Autoxidation and Autoxidants, W.O. Lundberg, ed., Vol. 2, 1962.
  16. Por, N., "Long Term Storage Stabilities of Liquid Fuels and Mechanisms of Their Breakdown," Israel Institute of Petroleum and Energy, January 1981.
  17. Henderson, H.T. and Nixon, A.C., "Effect of Oxygen Concentration on the Thermal Stability of Naphthenes," J. Aircraft, Vol. 8, No. 10, pp. 831-834, October 1971.
  18. Schrepfer, M.W. and Stansky, C.A., "Inhibiting Gum Formation in Modern Gasolines," Universal Oil Products Process Division Technology Conference, 1980.
  19. Cole, C.A. and Nixon, A.C., "Storage Stability of Jet Turbine Fuels," Prepared for Wright-Air Development Center, Technical Report 53-63, November 1953.
  20. Frankenfeld, J.W. and Taylor, W.F., "Continuation Study of Alternate Fuels Nitrogen Study," Final Technical Report, Contract No. N00019-78-C-0177, Department of the Navy, February 1979.
  21. Frankenfeld, J.W. and Taylor, W.F., "Fundamental Synthetic Fuel Stability Study," Annual Report, Bartlesville Energy Technical Center, Vol. 4, 1980.

22. Frankenfeld, J.W. and Taylor, W.F., "Alternate Fuels Nitrogen Chemistry," Contract N00019-76-C-0675, Final Technical Report, Prepared for Department of the Navy, November 1977.
23. Frankenfeld, J.W., Taylor, W.F. and Brinkman, D.W., "Fundamental Synthetic Fuel Stability Study," Final Report, Department of Energy Contract DE-AC19-79BC 10045, 1982.
24. Nowack, C.J., Del Fosse, R.J., Speck, G., Solash, J. and Hazlett, R.N., "Relation Between Fuel Properties and Chemical Composition; Article IV; Stability of Oil Shale Derived Jet Fuel," American Chemical Society, Division of Fuel Chemistry Preprints, Vol. 25, No. 3, pp. 40-50, 1980.
25. Worstell, J.H. and Daniel, S.R., "Deposit Formation in Liquid Fuels; Article II, The Effect of Selected Compounds on the Storage Stability of Jet A Turbine Fuel," Fuel, Vol. 60, pp. 481-484, 1981.
26. Worstell, J.H., Daniel, S.R. and Fraunhoff, G., "Deposit Formation in Liquid Fuels; Article III, The Effect of Selected Nitrogen Compounds on Diesel Fuel," Fuel, Vol. 60, pp. 485-487, 1981.
27. Morrison, R.T. and Boyd, R.N., Organic Chemistry, Allyn and Bacon Inc. Boston, MA, 1959.
28. Bailey, C.A. and Neihof, R.A., "Biocidal Properties of Anti-Icing Additives for Jet Aircraft Fuels," Naval Research Laboratory, and Memorandum Report 3230, March 1976.
29. Neihof, R.A., Klemme, D.E., Patouillet, C.D., Hannan, P.J., "Microbial Contamination of Ship Fuels," Distillate Fuel Stability and Cleanliness ASTM STP 751, L.L. Stavinoha and C.P. Henry, eds., ASTM, pp. 126-135, 1981.
30. Rogers, M.R., Kaplan, A.M., "Role of Microbial and Nonmicrobial Contaminants in Diesel-Fueled Vehicle Malfunctions," Developments in Industrial Microbiology, Vol. 23, Chapter 12, Society for Industrial Microbiology, 1982.
31. Fass, R., Miller, G., "Microbial Growth in Storage of Jet Fuel and Diesel Fuel," translated by Harold Rossmoore, Annual Report, Israel Institute for Biological Research, October 1980.
32. Neihof, R.A., May, M.E., "Survey of Contamination in Fuel Tanks of DD-963 Class Ships," Final Report, Naval Research Laboratory #4853, July 1982.

33. Holmes, S., "The Microbiology of Hydrocarbon Fuels," Petrolite Corporation, date unknown.
34. Stavinoha, L.L., Westbrook, S.R. and Brinkman, D.W., "Accelerated Stability Test Techniques for Diesel Fuels," Department of Energy BC/10043-12, October 1980.
35. Taylor, W.F. and Wallace, T.J., "Kinetics of Deposit Formation From Hydrocarbon Fuels at High Temperatures," Industrial and Engineering Chemical Product Research and Development, Vol. 6, No. 4, pp. 258-262, 1967.

## VII. ANNOTATED BIBLIOGRAPHY

1. Affens, W.A., Hall, J.M., Beal, E., Hazlett, R.N., Nowack, C.J. and Speck, G., "Relationship Between Fuel Composition and Properties; III. Physical Properties of U.S. Navy Shale II Fuels," ACS, Division of Fuel Chemistry, August 1980.

This paper is a summary of the work on physical and related properties of three military-type fuels derived from shale (JP-5, JP-8, and DFM).

2. Bowden, J.N. and Brinkman, D.W., "Stability Characteristics of Some Shale and Coal Liquids--Final Report," DOE/BETC/4162-10 (available NTIS), November 1980.

Liquid hydrocarbon fuels derived from coal and from oil shale were made available for characterization and thermal and storage stability investigations. The shale-derived fuels were refined to meet the requirements of military specification jet fuels JP-8 and JP-5 and marine diesel fuel (DFM). Virtually all the specification requirements were met, and the fuels were found to be thermally and storage stable. During the 32-week, 43°C storage tests conducted on these liquids, periodic measurements were made of precipitate fuel-insolubles, fuel-soluble gum, dissolved oxygen content and peroxide number.

3. Bowden, J.N., et al., "Military Fuels Refined From Paraho-II Shale Oil," Interim Report AFLRL No. 131, AD A101069, March 1981.

Shale-derived JP-5, JP-8, aviation turbine fuels and marine diesel fuel were analyzed for compliance with military specifications and evaluated for storage stability, corrosion tendencies, additive response, compatibility with petroleum fuels, and microbiological growth susceptibility.

4. Bowden, J.N., et al., "Shale-Derived Distillate Fuels," reprinted from the June 1982 issue of Energy Progress, Vol. 2, No. 2.

The purpose of this program was to evaluate these products for specification requirements and other properties not necessarily defined by specification testing, and to ascertain their performance in Army engine systems as part of the overall program to develop a capability for consuming multisource fuels within the Department of Defense.

5. Brinkman, D.W., Bowden, J.N., Frankenfeld, J. and Taylor, B., "Synfuel Stability: Degradation Mechanisms and Actual Findings," ACS Symposium Series No. 163, Oil Shale, Tar Sands and Related Materials, H.D. Stauffer, editor, 1981.

Synfuels which are currently available have demonstrated degradation problems that were predicted from work with petroleum. This paper presents basic and applied data which should aid in the tradeoff decisions between further costly processing and product stability. Various degradation mechanisms were discussed.

6. Brinkman, D.W., Whisman, M.L, and Bowden, J.N., "Stability Characteristics of Hydrocarbon Fuels From Alternative Sources," BETC/RI-78/23, DOE, March 1979.

The objectives of the current work are to determine the storage characteristics of representative liquid fuels derived from coal, oil shale, and tar sands, to analyze representative gasolines, diesel fuels and jet fuels for hydrocarbons and nonhydrocarbons that are known precursors of deterioration products, and to provide information that will guide refiners in selecting processes to minimize fuel deterioration through removal or inhibition of reactive components.

7. Butrill, S.E., Jr., "Analysis of Middle Distillate Fuels by Field Ionization Mass Spectrometry," prepared for Naval Research Laboratory by SRI International Semi-Annual Technical Progress Report No. 1, covering 10 September 1979 to 10 March 1980.

The purpose of this research contract is to develop additional data,

methodology, computer software, and mass spectrometer facilities needed to provide quantitative analyses of these fuels.

8. Cole, C.A. and Nixon, A.C., "Storage Stability of Jet Turbine Fuels," Wright Air Dev. Center, Technical Report No. 50-63, November 1953.

This investigation was initiated to ascertain the variables influencing the storage stability of jet fuels and to determine the simplest and most practical methods of controlling these variables for a resultant increase in the permissible storage life of the fuels.

9. Dahlin, K.E., Daniel, S.R. and Worstell, J.H., "Deposit Formation in Liquid Fuels; I. Effect of Coal-Derived Lewis Bases on Storage Stability of Jet A Turbine Fuel," Fuel, 60, p. 477-480, June 1981.

The title subject was investigated using soft glass bottles. JFTOT was used for deposit formation.

10. Davis, J.W., Schwartz, F.G. and Ward, C.C., "Effects of Polar Components of a Petroleum Distillate Fuel on Storage Stability," Report No. 5798 Bureau of Mines, 1961.

The storage stability characteristics of a diesel-type fuel were determined to evaluate the effect of the polar compounds in the fuel.

11. Frankenfeld, J.W. and Taylor, W.F., "Alternate Fuels Nitrogen Chemistry," Final Technical Report for Department of the Navy, Contract No. N00019-76-C-0675, November 1977.

Syncrudes, particularly from shale rock, contain much higher N levels than petroleum materials. This work was to determine the magnitude of the N-caused sediment problem with respect to compound types, effects of light, investigate structure, and mechanism of formation of the sediment.

12. Frankenfeld, J.W. and Taylor, W.F., "Continuation Study of Alternate

Fuels Nitrogen Chemistry," Final Technical Report for Department of the Navy, Contract No. N00019-78-C-0177, February 1979.

Syncrudes, particularly from shale rock, contain much higher N levels than petroleum materials. This work was to determine the magnitude of the N-caused sediment problem with respect to compound types, effects of light, and to investigate structure and mechanism of formation of the sediment.

13. Frankenfeld, J.W. and Taylor, W.F., "Effects of Flow Improver Additives on Distillate Fuels From Oil Shale," SAE Paper No. 801376, 1980.

The primary objective of this program was to evaluate the potential of additives for improving the low-temperature flow properties of synthetic diesel fuels derived from oil shale.

14. Frankenfeld, J.W. and Taylor, W.F., "Fundamental Synthetic Fuel Stability Study," BETC Annual Report, DOE Contract No. DE-AC19-78BC10045, Fiscal Year 1980.

A report on the first year of a multi-year program. JP-8, n-decane, and No. 2 diesel fuel were used at 110°F and 150°F in the dark. Summary only. c.f. Frankenfeld & Taylor, First Annual Report 1980.

15. Frankenfeld, J.W., Taylor, W.F., and Brinkman, D.W., "Fundamental Synthetic Fuel Stability Study--First Annual Report" (1 May 1979 to 30 April 1980), DOE/BC/10045-12, February 1980.

This report was prepared by Exxon Research and Engineering Company, Linden, NJ. A variety of organic nitrogen compounds were evaluated for their tendencies to promote sediment in hydrocarbon fuels under accelerated storage conditions. The most deleterious species to fuel stability were found to be alkylated heterocyclic nitrogen compounds. The most reactive compounds were those with two or more alkyl groups, at least one of which was situated on a carbon adjacent to the nitrogen.

16. Garner, M.Q. and White, E.W., "The Storage Stability of Navy Distillate

Fuel for Ships--Final Report," Naval Ship Research and Development Center, Report No. 4198, April 1974.

Experiments started in 1969 to ascertain the storage stability of the new MIL-F-24397 Navy distillate fuel have been completed. Long-term experiments simulating actual storage at ambient temperatures and accelerated tests for predictive purposes were run.

17. Hazlett, R.N., et al., "Pyrolysis of Shale Oil Residual Fractions," Naval Research Laboratory, no date available.

JP-5, the Navy jet fuel, must meet many stringent requirements if satisfactory performance in aircraft and fuel-handling and storage systems is to be attained. In considering JP-5 derived from alternate fossil fuels, several properties are affected more by the chemical characteristics of the fuel than by the physical properties, and explanation of these properties are covered in this publication.

18. Hazlett, R.N. and Hall, J.M., "Studies to Develop a Test to Determine the Potential of a Fuel for Hydroperoxide Formation," CRC Group on Oxidation Stability of Gas Turbine Fuels, May 1981.

ASTM D 1563 is studied with respect to repeatability and ability to distinguish between samples.

19. Henderson, H.T. and Nixon, A.C., "Effect of Oxygen Concentration on the Thermal Stability of Naphthenes," JET AIRCRAFT, 8 (10), p. 831-834, October 1971.

Determined the title study with oxygen concs. <3 ppm up to saturation of approximately 300 ppm. In <3 ppm, no effect was noted; in 3-10 ppm, rapid decrease in thermal stability moderating up to 15 ppm and little response beyond that.

20. Henderson, H.T. and Nixon, A.C., "Studies on the Measurement of Thermal Stability of Advanced Aircraft Fuels," presented before the Div. of

Petroleum Chemistry, Inc., American Chemical Society, New York City Meeting, September 7-12, 1969.

Fuel thermal stability has become a fuel property of increasing importance as engine designers have turned to the problems of the SST and higher Mach number aircraft.

21. Keller, B.K. and Wagner, T.O., "Trends in Motor fuels," AMOCO Oil Co. (IL) Paper No. AM-81-39, presented at the NPRA Annual Meeting, San Antonio, TX March 29-31, 1981.

The following topics were discussed: U.S. energy consumption, liquid fuels' demand and sources of supply, alternative sources of liquid fuels, effects of diesel vehicles on fuels' demand and quality, and effects of electric-powered vehicles on fuels' demand.

22. Kirk-Othmer, "Encyclopedia of Chemical Technology (3rd edition, Vol. II)," published by John Wiley and Sons, New York, NY.

Current chemical technology including descriptions of methods for processing synthetic fuel sources.

23. Lauer, J.L., "Analysis of Fuel Deposits by Infrared Emission Spectroscopy," Rensselaer Polytechnic Institute, Troy, NY 12181, 1981.

A slow-scanning Fourier infrared Michelson interferometer was converted into an emission microspectrophotometer by replacement of the commercial source with a reflecting microscope objective (36X) focused on an adsorbate on a metal surface maintained at a temperature somewhat higher than that of the detector and with appropriate optical interfaces.

24. LePera, M.E., "Thermal-Oxidative Stability of Automotive Diesel Fuels," AD A758146 NTIS, February 1973.

Fuel-oriented problems occurring in the field prompted an investigation to examine the thermal-oxidation characteristics of diesel fuels.

25. LePera, M.E., et al., "Storage Stability of Automotive Diesel Fuels," AD 752906 NTIS, October 1972.

The storage stability characteristics of diesel fuels meeting the requirements of Federal Specification VV-F-800a (Fuel Oil, Diesel) were investigated by conducting a 2-year storage program involving four different diesel fuels.

26. Lieberman, M. and Taylor, W.F., "Effect of Refining Variables on the Properties and Composition of JP-5, Final Report," September 1978-February 1980," by Exxon Products Research Division for Department of the Navy, 1980.

This task summarizes the effect of some projected potential changes in JP-5 composition/properties and processing that may have an important impact on fuel technical problem areas.

27. Mayo, F.R. and Buttrill, S.E., "FINAL REPORT--Chemistry of Fuel Deposits and Sediments and Their Precursors--4 September 1980 to 8 September 1981," prepared for NASA Lewis Research Center by SRI International, Project No. PYO-2115, October 1, 1981.

The objective of this work is to obtain information on the mechanism of deposit and sediment formation from jet turbine fuels by looking for development, during fuel oxidations, of precursors of decreasing solubilities, and increasing oxygen contents and molecular weights. See SRI International Notebook for Monthly Progress Reports.

28. Mayo, F.R. and Buttrill, S.E., Jr., "Chemistry of Fuel Deposits and Sediments and Their Precursors," prepared for NASA Lewis Research Center by SRI International, Final Report October 1, 1981, Monthly Report Nos. 1, 2, 3, 6, 7, 9, January 1, 1982-September 30, 1982.

The objective of this work is to obtain information on the mechanism of deposit and sediment formation from jet turbine fuels by looking for development, during fuel oxidations, of precursors of decreasing solubilities, and increasing oxygen contents and molecular weights.

29. Mayo, F.R., et al., "Basic Study of Fuel Storage Stability," prepared for U.S. Army Research Office by SRI International, Monthly Report Nos. 2, 3, 4, 5, and 6, March 1 through July 31, 1982.

The object of this work is to determine the mechanism by which gum and deposits are formed in diesel fuels, and thus how to predict and prevent their formation.

30. Nixon, A.C., "Auto-oxidation and Anti-oxidants of Petroleum in Auto-oxidation and Anti-oxidants," Vol. II, edited by W.O. Lundberg, John Wiley and Sons, 1962.

An extensive review of the subject covering virtually all aspects.

31. No author, "Abstracts of Some Recent U.S. Navy Reports on Jet Fuel Stability, Composition and Properties," April 1981.

Compilation of various articles by different authors relating to jet fuel stability, composition, and properties.

32. No author, "Petroleum," The New Encyclopedia Britannica, 15th Edition, Vol. 14, p. 165, 1974.

Origin and early use of the word "petroleum" is explained.

33. No author, "Proceedings--High-Energy Hydrocarbon Fuels Workshop," Naval Air Systems Command Research and Technology Group, November 1981.

Abstracts of papers presented at the High Energy Hydrocarbon Fuels Workshop under the sponsorship of the U.S. Naval Air Systems Command.

34. No author, "Summary Report--Mobility Fuels Supply and National Security Seminar," sponsored by Naval Material Command, 2 February 1981.

This seminar was held with the objective of helping to clarify the situation relating to the supply and demand outlook for mobility fuels and related influential factors.

35. Nowack, C.J., Del Fosse, R.J., Speck, G., Solask, J. and Hazlett, R.N., "Relation Between Fuel Properties and Chemical Composition, IV. Stability of Oil Shale-Derived Jet Fuel," ACS, Division of Fuel Chemistry, Preprints 25 (3), 40-50, August 1980.

Some aspects of stability of a jet fuel prepared from Paraho-I shale oil are reported.

36. Osenga, Mike, "What's the Problem With Diesel Fuel," Diesel and Gas Turbine Progress, April 1980.

Current state of diesel fuel and what the industry is doing about it is discussed.

37. Por, Nahum, "Long-Term Storage Stabilities of Liquid Fuels and Mechanisms of Their Breakdown," Oil Refineries Ltd.; Israel Institute of Petroleum and Energy, Tel-Aviv, Israel, January 1981.

N. Por's publication covers (a) study on subject stabilities in general and their behavior during long-term storage in particular; (b) an investigation on the effect of various storage and environmental conditions on stabilities of liquid fuels, (c) definition of mechanisms governing breakdown processes; and (d) inclusion of products of wide ranges of compositions.

38. Por, Nahum, "The Accelerated Oxidation Test and Resistance to Oxidative Processes of Diesel Fuels," The Israel Institute of Petroleum and Energy, Haifa, Israel, April 1981.

Reproducibilities and significance of the ASTM D 2274 test for oxidation stabilities of diesel fuels are studied.

39. Ritchie, J., "A Study of the Stability of Some Distillate Diesel Fuels," Journal of the Institute of Petroleum, Vol. 51, No. 501, September 1965.

Six distillate diesel fuels have been stored at Rosyth for six years, and their behaviour studied both in storage and in laboratory tests.

40. Schrepfer, M.W. and Stansky, C.A., "Gasoline Stability Testing and Inhibitor Application," paper presented at National Fuels and Lubricants Meeting, 1981.

FCC is discussed relative to stability of gasolines. Mechanism of gum formation is discussed. Types of inhibitors are also discussed. c.f. Inhibiting Gum Formation in Modern Gasolines, 1980 UOP Process Division Technology Conference, April-September 1980.

41. Schriesheim, A. and Kirshenbaum, I., "The Chemistry and Technology of Synthetic Fuels," American Scientist, 69, September-October 1981.

A synthetic fuels industry could start contributing to our energy supply within a decade and could assume significant proportions by the end of the century.

42. Solash, J., Hazlett, R.N., Burnett, J.C., Beal, E. and Hall, J.M., "Relation Between Fuel Properties and Chemical Composition, II. Chemical Characterization of U.S. Navy Shale II Fuels," ACS, Division of Fuel Chemistry, Preprints 25, (3), p. 22-30, August 1980.

This paper describes the chemical characterization of JP-5 and DFM from the Shale-II project.

43. Stansky, C.A., "Future of Distillate Fuel," (unpublished).

General information is given with regard to fuel specifications, gum formation and structure, types of inhibitors, etc.

44. Stavinocha, L.L. and LePera, M.E., "A Review of Diesel Fuel Deterioration and Related Problems, "Interim Report AFLRL No. 88, Contract No. DAAG53-76-C-003, AD A043566, NTIS, May 1977.

This report represents an "overview" as presented at a seminar sponsored by ARO in April 1977 to promote basic research in the area of "Diesel Fuel Stability". Generally covers fuel deterioration primarily with diesel or distillate fuels used in compression ignition engines which power Army tactical vehicles. Selected field problems outlined.

45. Stavinocha, L.L., et al, "Lubricant Volatility Related to Two-Cycle Diesel-Engine Piston-Ring/Cylinder-Liner Wear," presented as an American Society of Lubrication Engineers paper at the ASME/ASLE Lubrication Conference in San Francisco, CA, August 18-21, 1980, Lubrication Engineering, January 1982.

This paper describes the results of a program to develop laboratory volatility test methods and to correlate volatility data with engine wear performance data using lubricants which have shown volatility-related performance.

46. Stavinocha, L.L. and Westbrook, S.R., "Accelerated Stability Techniques for Diesel Fuels," DOE/BC/10043-12, October 1980.

This report covers a program initiated to review and selectively evaluate laboratory test techniques in an effort to develop and/or optimize accelerated stability test techniques for diesel fuels.

47. Stavinocha, L.L., Westbrook, S.R., and Brinkman, D.W., "Optimization of Accelerated Stability Test Techniques for Diesel Fuels--Final Report," DOE/BC/10043-25, June 1981.

The purpose of this 2-year project was to study the formation of dele-

terious products in middle distillate fuels; and apply the results toward development of more reliable test methods for fuel stability. During first year, eight accelerated stability tests were chosen and evaluated using a set of 6 test fuels. During the second year, primary emphasis was placed on testing 43°C and 150°C tests which are being cooperatively developed by ASTM. In general, test results at 43°C, 80°C, 150°C, and ASTM D 2274 provided directional agreement. In an effort to standardize the 43°C and 150°C tests, planning and cooperative testing was provided to ASTM Committee D-2, Technical Division E-V.

48. Stavinoha, L.L., Westbrook, S.R., and LePera, M.E., "Army Experience and Requirements for Stability and Cleanliness of Diesel Fuel," Interim Report AFLRL No. 128, Contract No. DAAK70-80-C-0001, AD A088008, July 1980.

This report reviews fuel deterioration. Primary emphasis is placed on diesel fuels used in compression ignition engines of the Army tactical and combat vehicles. Field problems regarding fuel stability and related problems are outlined. Information places in perspective the background which has prompted current research activities to detect, predict, and prevent fuel stability-associated equipment failures. Army's needs for diesel fuel stability and cleanliness are identified.

49. Taylor, W.F. and Wallace, T.J., "Kinetics of Deposit Formation From Hydrocarbon Fuels at High Temperatures," I&EC Product Research and Development, 6, (4), December 1967.

Initial results are reported from studies designed to elucidate the variables which control the rate of deposit formation from hydrocarbon jet fuels exposed to high temperature stress.

50. Trayser, D.A., et al., "Final Report--Deterioration of Fuels and Fuel-Using Equipment," Battelle Memorial Institute, August 1967.

This report covers the results of studies which were aimed at estab-

lishing more precisely the deterioration characteristics of fuels and equipment in storage and devising standby storage techniques.

51. Vere, R.A., "Fuel Composition Data From Deposit Analysis," CRC Group on Oxidation Stability of Gas Turbine Fuels Symposium on Jet Fuel Stability, 30 April 1981.

Data from a modified JFTOT procedure is used to obtain carbon values which are related to fuel type, anti-oxidant, fuel end point.

52. Vere, R.A., "Lubricity of Aviation Turbine Fuels," SAE Transactions, 78 (4), p. 2237-2245, 1969.

A laboratory test rig has shown more highly refined fuels to have poorer lubricity. A 10 to 20 percent blend of conventional treated fuel improves lubricity to normal. Addition of highly polar compounds from conventionally treated fuels significantly improves lubricity.

53. Vilyanskaya, E.D., et al., "New Conditions in Test Method for Determining Thermal-Oxidative Stability of Inhibited Turbine Oils," Chemistry and Technology of Fuels and Oils, 17 (3-4) 1981.

The most important turbine oil quality index, which determines the service life of the oil, is the oil's resistance to effects from atmospheric oxygen at elevated temperatures, is discussed.

54. Vranos, A., "Fuel Thermal Stability," Monthly Technical Progress Reports for September 1-30, 1981, and November 1-30, 1981, for NASA Lewis Research Center by United Technical Research Center.
55. Vranos, A. and Martinez, P.J., "Experimental Study of the Stability of Aircraft Fuels at Elevated Temperatures," Report CR165165, Contract No. NAS 3-21593, NASA/Lewis, December 1980.

IR spectra of fuels and deposits were obtained for heating oil and Jet A fuels.

56. Wasilk, N.J. and Robinson, E.T., "The Commercial Scale Refining of Paraho Crude Shale Oil Into Military Specification Fuels," from paper preprints presented at San Francisco CA, August 24-29, 1980, Vol. 25, No. 3.

Program objective was to demonstrate that shale oil could be converted into stable, specification military fuels utilizing conventional refining technology and in sufficient volumes to support an extensive engine testing program.

57. Westbrook, S.R., et al., "A Field Monitor for the Stability and Cleanliness of Distillate Fuel," Interim Report AFLRL No. 137, AD A110694, December 1981.

This report details the development of a portable device to measure the cleanliness and stability of diesel fuels in both bulk and vehicle fuel cell storage.

58. Worstell, J.H. and Daniel, J.H., "Deposit Formation in Liquid Fuels, II. The Effect of Selected Compounds on the Storage Stability of Jet A Turbine Fuel," Fuel, 60, p. 481-484, June 1981.

The influence of substituted quinolines, pyrroles, indoles, and pyridines on deposit formation in a diesel fuel is evaluated.

59. Worstell, J.H., Daniel, S.R., and Frauenhoff, G., "Deposit Formation in Liquid Fuels, III. The Effect of Selected Nitrogen Compounds on Diesel Fuel," Fuel, 60, p. 485-487, June 1981.

The influence of substituted pyridines, pyrroles, indoles, and quinolines on storage stability of conventional Jet A turbine fuel is evaluated.

60. Zamulinskii, I.M., "Distribution of Total and Basic Nitrogen in Crude

Oil Cuts," Crude Oil and Product Research, Plenum Publishing Corp., 1981.

How the contents of total and basic nitrogen in straight-run petroleum cuts are related to the average boiling point of the cut is presented.

## GLOSSARY OF TERMS

1. Additive - A chemical agent employed to assure the presence of certain desirable characteristics in fuels or other materials.
2. Adherent gum - See insoluble gum.
3. Barrel - A unit of measure fixed for certain commodities (42 gallons for petroleum).
4. Bituminous - Resembling or containing various mixtures of hydrocarbons (a tar) often together with their nonmetallic derivative.
5. Break point - 1) The time at which the rate of formation of insoluble particulates significantly increases compared to the induction period.  
2) The time at which the weight of filterable particulates exceeds a specified value by 20 mg/100 mL.
6. Crude - Unrefined petroleum.
7. Diesel fuel - A hydrocarbon fuel used in diesel engines.
8. Distillate fuel - A fuel obtained by distillation of crude materials into fractions according to temperature.
9. Existent gum - The evaporation residue of aircraft fuel or heptane-insoluble portion of the evaporation residue of motor gasoline.
10. Free radical - An atom or group of atoms possessing an unpaired electron normally formed by cleavage of the parent molecule.
11. Gum - Varnish-like, tacky, noncombustible deposits formed during deterioration of petroleum and its products.
12. Insoluble gum - Deposit adhering to the sample container after removal of the aged fuel.
13. Petroleum - A complex oily, flammable liquid mixture composed of hydrocarbons and small amounts of other substances which may vary from almost colorless to black.
14. Potential Gum - The sum of soluble and insoluble gum.
15. Precipitate - Sediment and suspended material with aged fuel.
16. Sediment - Foreign particulate matter which settles to the bottom of a storage container.
17. Soluble gum - Deterioration products existing in solution in the aged fuel and the benzene-acetone soluble portion of the deposits on the container wall. Determined by air jet gum method.

18. Storage Stability - Resistance of a fuel to spontaneous formation of deleterious products when stored over long periods of time.
19. Tar - A dark odorous, viscous liquid obtained by destructive distillation of organic material.
20. Thermal stability - Relating to the tendency to form deposits at high temperature.
21. Total potential residue - Sum of the potential gum and precipitate.
22. Unwashed gum - The evaporation residue of motor gasoline consisting of existent gum and non-volatile additive components.

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MAT-08E (MR ZIEM) 1  
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BASE ATLANTIC  
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CDR  
WARNER ROBINS AIR LOGISTIC  
CTR  
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ATTN MR ECKLUND 1  
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SCI & TECH INFO FACILITY  
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BALTIMORE/WASH INT AIRPORT MD 21240

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