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RESEARCH MEMORANDUM

EFFECT OF DISSOLVED OXYGEN ON THE FILTERABILITY
OF JET FUELS FOR TEMPERATURES
BETWEEN 300° AND 400° F

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SUMMARY

The effect of dissolved oxygen on the filter-clogging characteristics of three JP-4 and two JP-5 fuels was studied at 300° to 400° F in a bench-scale rig employing filter paper as the filter medium. The residence time of the fuel at the high temperature was approximately 6 seconds. For these conditions the clogging characteristics of the fuels increased with both increasing temperature and increasing concentration of dissolved oxygen. It appears that the amount of oxygen consumed in the fuel in the formation of gum at the high temperature was a small fraction of the amount of dissolved oxygen present. The amount of insoluble material formed at the high temperatures necessary to produce clogging of filters was very small, of the order of 1 milligram per gallon of fuel. No correlation was observed between the properties of fuels and their tendencies to clog filters.

INTRODUCTION

In some models of present-day turbojet engines, the engine lubricant is cooled in a heat exchanger by means of the fuel as it flows to the combustor. As a result, the fuel may be heated to temperatures high enough to cause the formation of insoluble, gum-like substances. These insoluble materials, if not removed or adequately dispersed, may either (1) foul the heat exchanger so that the lubricant is not adequately cooled, or (2) clog filter screens or injector orifices so that the fuel flow is reduced to the point of engine failure.

The thermal stability of jet fuels is affected not only by the temperature, but also by the residence time of the fuel in the heated zone. Since fuel-flow rates decrease with increasing altitude, the problem becomes more severe at high altitudes where both higher fuel temperatures and longer residence times are encountered. Fuel temperatures as high as 250° F at the exchanger outlet have been reported

(ref. 1). Additional heat received from the compressor-outlet air and from the combustion process may raise the fuel temperature to 350° F. Fuel residence times of about 10 seconds appear likely at high altitudes.

Military specifications provide for several jet-fuel cleanliness control tests such as distillation end-point tests, existent and potential gum tests, sulfur tests, and so forth. None of these properties, however, appears to be related to the filter-clogging behavior of aircraft fuels at high temperatures (ref. 1). Therefore, work is in progress to determine the underlying factors affecting the formation of filter-clogging substances in fuels at high temperatures. A bench-scale rig (manufactured by the Erdco Engineering Corp., Addison, Ill.) employing a sintered-metal filter disk is currently being used in a cooperative fuels-testing program by the Coordinating Research Council.

Reference 1 reports an experimental technique in which the fuel was heated from 240° to 350° F and filtered through 2-micron paper, and then the pressure drop across the paper measured. Reference 2 reports a method in which the fuel was pumped at 300° to 400° F through an orifice at constant pressure and the change in fuel-flow rate during a run noted. In reference 3 the fuel was passed over a heated plate and the amount of fouling was measured by a radioactive technique. In all these tests the fuel pressure was sufficiently high to keep the fuel in the liquid phase, simulating actual engine operating conditions. Reference 4 reports a fuels test in which the fuel was passed at essentially atmospheric pressure through glass coils immersed in a liquid bath at 400° F, and the coils were rated visually for fouling. In this test the fuel is partially vaporized.

Reference 5 shows that gum formed in fuels in storage may contain as much as 20 percent oxygen, as well as considerable amounts of nitrogen and sulfur. Reference 1 shows further that oxygen is present in filter-clogging insolubles in the form of carboxyl and aldehyde functional groupings. The source of this oxygen could possibly be the dissolved air in fuel, since most aircraft fuels contain dissolved air, although not always completely saturated. A study was therefore undertaken at the NACA Lewis laboratory to determine the effect of dissolved oxygen on the filterability of fuels for the temperature range 300° to 400° F. The work was done in a bench-scale rig using filter paper as the filter medium and employing fuel pressures sufficiently high to maintain the fuel in the liquid state. The results of this study are reported herein.

APPARATUS

A bench-scale test apparatus, designed to give fuel temperatures and residence times similar to those found in the oil-to-fuel exchanger

of a typical aircraft engine, was used for the filterability tests. The basic components of the test apparatus were a blow case, a pre-filter, a filter element (with a manometer attached) immersed in a high-temperature bath, a fuel cooler, a second filter element (with a manometer attached), a rotameter, a rate control valve, and a fuel recovery tank. A diagrammatic sketch of the equipment arrangement is shown in figure 1. No copper or brass fittings were used because of the possible catalytic effects of these materials.

Blow case. - The blow case, which was used in lieu of a pump, consisted of two 9-gallon tanks, one containing water and the other fuel. The blow case was maintained at constant pressure by means of a pressure regulator attached to the nitrogen cylinder.

Prefilter. - The fuel was prefiltered through a commercial 5-micron aircraft filter (manufactured by Bendix-Skinner Div., Bendix Aviation Corp.). This removed preformed insoluble gum from the fuel, as well as dirt, rust, lint, and so forth.

Fuel heating system. - The fuel was heated in a coil of Inconel tubing of 0.1 inch inside diameter, $8\frac{1}{2}$ -feet long, immersed in a refluxing constant-temperature bath. The bath was heated by two 1500-watt immersion-type heaters controlled by a variable transformer. The liquid used in the bath was a mixture of ethylene glycol and water for the temperatures 300° and 350° F, and a mixture of ethylene glycol and mineral oil for the temperature 400° F. Bath temperatures were measured by means of a thermometer, accurate to $\pm 1^\circ$ F.

Filter elements. - The filter elements used in the filterability tests were of the design shown in figure 2. Both were shop-made duplications of a $1\frac{1}{4}$ -inch pipe union with internal mountings to retain the filter paper. This type of filter element was easily assembled and was free of leaks at high temperatures and pressures. The elements had a filtering area of 0.196 square inch and gave a fuel residence time of 6 seconds at the high temperature.

Flow-control system. - The fuel flow through the apparatus was controlled by means of a needle valve located at the downstream end of the apparatus. The fuel-flow rate was measured by means of a rotameter, whose accuracy was checked periodically during runs by timing the flow of the fuel into a calibrated receiver (not shown in fig. 1).

Filter medium. - Preliminary studies were made on Skinner 5- and 10-micron paper to determine their change in porosity when exposed to fuels at filtration temperatures. When heated for 1 hour in fuel oil at 400° F, 10-micron paper showed less changes in porosity than

5-micron paper, and therefore was selected for the experimental work. The porosity of the paper was measured by timing the flow of isooctane through the paper under a constant head of liquid. The paper specimens used in the tests were of approximately the same porosity.

PROCEDURE

Prior to each experiment, the fuel was saturated with a mixture of oxygen and nitrogen at a temperature of approximately 75° F. The oxygen-nitrogen mixtures were prepared from air and pure nitrogen, mixed in proportions necessary to vary the concentrations of oxygen dissolved in the fuels. The fuels were saturated by bubbling the gas through the fuel in the blow case for a period of 30 minutes. Saturation was carried out at atmospheric pressure with the exception of two runs with fuel C in which equilibrium pressures of 1.7 and 8.3 atmospheres were used.

Prior to each run, the entire test rig, except the fuel tank, was purged of air and pressurized with nitrogen at 115 pounds per square inch gage. The fuel was then forced through the system under a pressure of 115 pounds per square inch gage, and the flow rate was adjusted and kept constant by means of the rate control valve. Pressure drops across both filters were read from manometers and recorded every 10 minutes, or so. A run was continued until either (1) the filter paper of one of the filters was ruptured by the build-up of a large pressure drop (normally 35 to 45 in. Hg), or (2) no significant pressure increase was noted on either manometer over a period of 2 hours.

FUELS

Five fuels with varying degrees of gum-forming tendencies were used in this investigation. Three were JP-4 fuels (A, D, and E) and two were JP-5 fuels (B and C). The conventional inspection data of fuel properties are shown in table I. In addition to these analyses, the dissolved oxygen and peroxide contents of the fuels were determined by the following methods. The results of the dissolved oxygen and peroxide analyses are shown in table II.

Peroxides. - The peroxide content of the fuel was determined by dissolving 1 milliliter of fuel in 20 milliliters of a ferrous-salt - thiocyanate - absolute-menthol reagent (method of ref. 6). The ferric thiocyanate that was formed was then determined by means of a photoelectric colorimeter.

Dissolved oxygen. - The concentration of dissolved oxygen in the fuel, when saturated with a mixture of oxygen and nitrogen, was determined by a modified procedure of the manganous hydroxide method described in reference 7. In this procedure, a solution of manganous sulfate and a measured quantity of standard ferrous ammonium sulfate solution were placed in a flask and the air evacuated. The fuel and an excess of potassium hydroxide solution were added to the flask while it was still under vacuum, and the flask was shaken for 30 minutes. The reaction mixture was then acidified, the vacuum released, and the aqueous phase titrated with standard ceric sulfate to determine the amount of ferrous salt remaining. The ferrous salt oxidized by the oxygen in the fuel was calculated as the difference between the ferrous salt added originally and the ferrous salt present finally. Results of the dissolved oxygen analyses are shown in table II(b).

The accuracy of this method has been checked for only a few hydrocarbon compounds. The following table compares the results of this procedure with those of another technique (ref. 8).

Hydrocarbon	Temperature, °C	Dissolved oxygen, mg oxygen/100 ml sample	
		Calculated from data of ref. 8 ^a	Found ^b
Isooctane	25	9.21	9.60, 9.26, 9.25, 9.34, 9.50, 9.26 (av. = 9.36)
Toluene	25	5.98	6.09, 5.95, 5.96 (av. = 6.00)
Benzene	30	5.16	5.01, 4.95, 4.96, 4.94 (av. = 4.97)
<u>n</u> -Heptane	30	8.46	8.62, 8.36, 8.45, 8.41 (av. = 8.46)

^aBunsen coefficients for 25° C were determined by interpolation between 20° and 30° C data.

^bSaturation pressure, 745 mm Hg; fuel saturated with air at nearly infinite ratio of volume of gas to volume of liquid.

Bunsen absorption coefficients are listed in reference 8 for pure oxygen dissolved in various hydrocarbons. It was necessary to convert these solubility data from oxygen to air in order to make the previous comparison. The solubility of oxygen in air-saturated hydrocarbons was

calculated from the Bunsen coefficients using the partial pressures of oxygen in the gas in contact with the hydrocarbon. These calculations were based on the assumption that Henry's law is obeyed (i.e., the solubility of oxygen is directly proportional to the partial pressure of oxygen above the fuel).

It was anticipated that organic peroxides in the fuel would be determined as dissolved oxygen by the modified manganous hydroxide procedure since ferrous salts will react with some peroxides in acid solution; this, of course, would necessitate correction of the dissolved-oxygen results by separate analysis for peroxides (as indicated in table II(a)). However, a dissolved-oxygen analysis of a solution containing 330 parts per million of di-tert-butyl peroxide in isooctane (2.3 mg active oxygen/100 ml sample) showed that the correction necessary was only 0.03 percent by volume, which is small enough to be ignored. For this reason, the dissolved-oxygen values of table II(b) were not corrected for peroxides. These uncorrected oxygen values, however, may be slightly high, since it is not known whether the peroxides found in fuels would behave similar to di-tert-butyl peroxide.

RESULTS AND DISCUSSION

Treatment of Data

Figure 3 shows the test results for fuel B, initially saturated with air and filtered at 400° F, for a residence time of 6 seconds. This figure is presented to show the method of treatment of the data. It will be noted that after a short induction period the change of pressure drop with time remains linear until termination of the run. This is consistent with the filtration behavior noted in reference 1 in which filter paper was used as the filter medium. Inasmuch as the slope values of the pressure-drop - time curves are both constant and experimentally reproducible, they are considered a suitable criterion for comparison of fuel filter-clogging tendencies for variable experimental conditions. The pressure-drop - time curves may or may not contain induction periods, which are not considered in the calculation of the slopes. The induction period is indicated by a line of different slope at the initial portion of the curve. The lengths of the induction periods may vary considerably between runs for a fuel under identical experimental conditions, but these lengths have no effect upon the slopes of the pressure-drop - time curves, as figure 3 demonstrates.

Table III lists the slope values (referred to hereinafter as filter-clogging rates) for both the high-temperature and low-temperature filters. The data for the high-temperature filter were generally reproducible to 10 to 15 percent, which is sufficient to indicate definite effects of dissolved oxygen in the fuel. The low-temperature filter

data, however, did not reproduce very well and often were not obtained. They are listed in table III(b) since they give an indication of the relative amount of gum which is soluble at the high temperature but becomes insoluble when the fuel is cooled.

Effect of Dissolved Oxygen and Temperature

Figure 4(a) shows the effect of dissolved oxygen in the fuel on the filter-clogging rates at 400° F. (Fuel E was run at 350° F rather than 400° F because of its extreme clogging tendency.) Because fuel C in two runs was saturated with air at pressures greater than 1 atmosphere, the partial pressures of the oxygen in the oxygen-nitrogen mixtures used for saturation were plotted against the slope values rather than the dissolved-oxygen analyses shown in table II(b). All the fuels studied showed an increase in filter-clogging rate with increase in dissolved-oxygen content at this temperature. This increase in filter-clogging tendency, however, was not general throughout the range of dissolved-oxygen concentrations studied, since fuels A and C showed no further significant increases when certain concentrations of dissolved oxygen were reached. Two points indicated for fuel C (at oxygen partial pressure of 0.57 and 1.97 atm) suggest a decrease in clogging tendency at very high concentrations of dissolved oxygen. These points were based on single determinations, which could be in error, and it is not believed that, in general, the use of high concentrations of dissolved oxygen would necessarily result in reduced clogging tendencies. Two fuels (A and B) showed substantially no filter-clogging tendency at 400° F when no dissolved oxygen was present.

Figures 4(b) and (c) show the effect of both dissolved oxygen and temperature on the filter-clogging rates of fuels A and C. Noteworthy is the marked increase in filter-clogging rate for both fuels for a temperature increase of only 50° F (350° to 400° F).

Two test samples of fuel C, initially saturated with air and filtered at 400° F, were taken downstream of the rate control valve and analyzed for dissolved oxygen. These analyses were made to estimate the amount of dissolved oxygen consumed in heating the fuel to test conditions. The analytical results are shown in the following table:

	Dissolved oxygen in fuel, mg oxygen/100 ml of sample
Before heating	5.32, 5.25, 5.35 (av. = 5.31)
After heating (test 1)	3.77, 3.74, 3.87 (av. = 3.79)
After heating (test 2)	3.89, 3.95, 3.90 (av. = 3.91)

These results indicate that about 25 percent of the dissolved oxygen initially present was consumed in the fuel on heating. However, in taking fuel samples, a small amount of gaseous phase was released during depressurization of the fuel across the rate control valve and this gas was lost completely to the fuel. Since this gas probably contained some oxygen, the indicated 25-percent oxygen consumption is a maximum, with actual consumption being somewhat less.

Effect of Fuel Variables

The data of table III(a) show that the relative order of clogging tendencies of the fuels investigated was $B < C < A < D < E$. Examination of table I shows no apparent relations between this order and the values of any of the fuel properties listed. There is also no relation between this order and the peroxide contents shown in table II(a). The peroxide contents of the fuel did not change much in passing through the rig. Apparently, none of the usual analysis data of fuel properties can be used effectively to estimate the filter-clogging tendencies of air-saturated fuels.

Since filter-clogging rate is little influenced by such factors as volatility and hydrocarbon type, the minor, and often undetermined, components of fuels were considered as precursors of insoluble gum. Reference 9 shows that small amounts of polar compounds in the fuel are largely responsible for the fouling of the surfaces of a plate exposed to hot fuels. These compounds, representing only 0.7 percent of the fuel (by volume), were isolated by chromatography. A similar conclusion can be drawn from the results of one test in which fuel D was repeatedly washed with 5 percent sulfuric acid before testing. This acid removed some of the constituents contributing to the color of the fuel, largely polar compounds, but nonetheless was not expected to have a measurable effect upon any of the fuel properties listed in table I. Results of this test show that acid washing reduced the filter-clogging rate from 46.3 to 1.8 inches of mercury per hour. Since the effect of acid treatment was tested with only one fuel, it is not proposed that dilute acid washing will, in general, be beneficial to all fuels with high filter-clogging tendencies.

Nature of Filter Deposits

Two experimental runs were made with fuels B and D solely for the purpose of estimating the weight of gum deposit on the high-temperature filter. In these runs stainless steel, sintered-metal disks, $1/2$ inch in diameter, were used as the filter medium. These disks were weighed both before and after each experimental run. Fuel B, a good quality JP-5 fuel, gave a deposit of 0.46 milligram of gum per gallon of fuel

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over a run of 5 hours at 400° F. Fuel D, a poor quality JP-4 fuel, gave a deposit of 1.32 milligrams of gum per gallon of fuel for a run of $3\frac{1}{2}$ hours at 350° F. In both runs the fuel was initially saturated with air. The amount of insoluble material deposited on the high-temperature filters was much less than the amount of gum that was initially present in these fuels. Table I shows fuels B and D to have initial gum (steam jet gum) of 0.2 and 6.6 milligrams per 100 milliliters or, 7.6 and 250 milligrams per gallon, respectively. These initial gum concentrations are roughly 20 and 200 times the concentration of solids caught on the filter for fuels B and D. The amount of insolubles deposited on the filters was also only a small fraction of the amount of available dissolved oxygen in the fuel, the concentration of dissolved oxygen being about 200 milligrams per gallon of fuel.

Microscopic examinations of filter papers removed from the apparatus after tests seemed to indicate that plugging of the papers was largely due to the formation of large clusters of gum particles about very small nuclei within the papers. The clusters were made up of particles many times smaller than the openings in the paper. The gum particles appeared to be very tacky in consistency, readily adhering to all exposed surfaces of the fibers of the paper. Figure 5 shows photomicrographs of three paper specimens at a magnification of 140.

Apparently there are factors other than the amount of solids deposited that affect the tendency of insolubles formed at high temperatures to clog filters. Reference 10 shows that with some fuels large amounts of solids were deposited on the filter without appreciably increasing the pressure drop across the filter. In the case of other fuels, on the other hand, relatively small amounts of solids produced larger pressure-drop increases. It is possible that these differences in filter-clogging tendencies may be related to either (or both) (1) the particle size and general agglomeration characteristics of the solids or (2) the surface characteristics and type of material of the filter medium. Some fuel solids may adhere more readily to one type of surface than to another. These differences may result in poor correlation among various types of bench-scale filter test rigs, or between bench-scale test rigs and full-scale mock-up systems.

SUMMARY OF RESULTS

The effect of dissolved oxygen on the filterability of JP-4 and JP-5 fuels was studied for the temperature range of 300° to 400° F. Results of the investigation may be summarized as follows:

1. Dissolved oxygen increased the filter-clogging tendencies of all fuels studied at temperatures above 350° F. As a rule, the rate of

filter clogging increased with increased oxygen concentration, but there were apparent limits to the range of oxygen concentrations to which this increase applied. These limits varied with the particular fuel in question.

2. The effect of temperature on filter-clogging rates was studied for two fuels. Both fuels showed increased filter-clogging rates with increased temperature, which became more pronounced as the dissolved-oxygen concentration was increased.

3. No relations were apparent between the filter-clogging tendencies of these fuels and any of the usual inspection data of fuel properties.

4. The amount of insoluble materials filtered at high temperatures was very small, of the order of 1 milligram per gallon. This amount was much less than both the existent gum initially present in the fuel and the concentration of dissolved oxygen present in air-saturated fuels.

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TABLE I. - PROPERTIES AND ANALYSES OF TEST FUELS

Fuel property	Fuel				
	A	B	C	D	E
Reid vapor pressure, lb/sq in. at 100° F	2.3	---	---	2.4	2.4
Specific gravity, 60° F/60° F	.825	.815	.813	.793	.794
Hydrogen-carbon ratio	.159	.160	.160	.154	.158
Aniline point, °F	104.0	148.6	152.6	104.0	116.8
Aromatics					
Silica gel, percent by volume	26.5	13.7	12.2	28.1	21.6
Bromine number, g/100 g	7.0	1.0	.5	38.0	7.8
Sulfur content, percent by weight	.07	.08	.03	.06	.23
Steam jet gum at 400° F, mg/100 ml	6.4	0.2	1.4	6.6	4.0
Accelerated gum at 212° F (16 hr), mg/100 ml	57.2	5.0	3.8	67.0	12.4
Doctor test	Sweet	Sweet	Sweet	Sweet	Sweet
A.S.T.M. Distillation, °F					
Initial boiling point	146	360	328	136	146
Percentage evaporated					
5	198	373	370	176	192
10	235	382	384	217	224
20	278	399	398	267	267
30	312	409	408	304	295
40	339	419	418	329	321
50	359	429	428	348	341
60	393	439	440	367	361
70	434	449	452	385	381
80	477	459	466	403	407
90	521	473	486	423	445
95	540	481	506	439	475
Final boiling point	572	502	536	476	510
Residue, percent	1.2	1.0	1.5	1.2	1.2
Loss, percent	.8	1.0	0	.8	.8

TABLE II. - DISSOLVED OXYGEN AND PEROXIDE ANALYSES OF FUELS

(a) Organic peroxides in fuel.

	Peroxide content of fuel, mg active oxygen/100 ml of fuel				
	Fuel				
	A	B	C	D	E
Fresh fuel	2.88	0.32	0.48	1.84	2.24
After run at 400° F, fuel initially saturated with oxygen at a partial pressure, atm					
0.05	----	----	----	0.88	----
.10	----	----	----	.80	----
.21	----	0.14	0.40	2.24	----

(b) Dissolved oxygen in fuel when saturated with various oxygen-nitrogen mixtures at 75° F.

Fuel	Dissolved oxygen in fuel, mg oxygen/100 ml fuel				
	Partial pressure of dissolved oxygen in saturation gas, atm				
	0.02	0.05	0.10	0.15	0.21
A	0.43	1.11	1.95	----	4.68
B	----	1.18	2.35	----	4.76
C	----	----	----	----	5.31
D ^a	.44	1.17	2.21	3.44	5.01
E ^a	----	----	----	----	4.78

^aFuel washed with dilute acid before saturation in order to remove color bodies that would interfere with color of titration indicator.

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TABLE III. - FILTERABILITY TEST DATA

(a) High-temperature filter.

Run	Fuel temperature when filtered, °F	Fuel-flow rate, ml/min	Pressure-drop - time slopes, $\frac{d(\Delta P)}{dt}$, in. Hg/hr							
			Partial pressure of oxygen in gas used for saturation, atm							
			0.0	0.02	0.05	0.10	0.15	0.21	0.57	1.97
Fuel A										
1	300	60	0.1	----	----	----	----	0.4	----	----
2			.3	----	----	----	----	.7	----	----
Average			.2	----	----	----	----	.6	----	----
1	350	60	.9	----	----	----	----	.7	----	----
2			.6	----	----	----	----	.4	----	----
Average			.8	----	----	----	----	.6	----	----
1	400	60	.0	3.2	13.4	33.9	----	33.3	----	----
2			.0	2.8	13.3	35.0	----	36.8	----	----
3			.1	----	----	33.0	----	39.6	----	----
Average			.0	3.0	13.4	34.0	----	36.6	----	----
Fuel B										
1	400	60	2.5	----	0.3	2.7	----	12.0	----	----
2			1.5	----	.9	1.3	----	6.8 ^a	----	----
3			---	----	.8	----	----	12.2	----	----
Average			2.0	----	.7	2.0	----	12.1	----	----
Fuel C										
1	400	90	7.2	----	----	----	----	18.5	16.7	10.2
2			8.7	----	----	----	----	14.2	----	----
Average			8.0	----	----	----	----	16.3	16.7	10.2
Fuel D										
1	300	60	---	----	----	----	----	0.15	----	----
1			350	60	0.8	----	5.0	12.5	37.2	48.0
2			1.2	----	5.4	14.0	----	28.5 ^a	----	----
3			---	----	----	----	----	44.5	----	----
Average			1.0	----	5.2	13.3	37.2	46.3	----	----
1	400	60	8.5	30.0	56	158	----	----	----	----
2			6.7	30.0	----	166	----	----	----	----
Average			7.6	30.0	56	162	----	----	----	----
Fuel E										
1	350	60	30.4	----	----	----	----	50.6	----	----
Fuel D (washed with dilute acid)										
1	350	60	---	----	----	----	----	1.8	----	----

^aValue not used in average.

TABLE III. - Concluded. FILTERABILITY TEST DATA

(b) Low-temperature filter (75° F).

Run	Fuel temperature before cooling, °F	Fuel-flow rate, ml/min	Pressure-drop - time slopes, $\frac{d(\Delta P)}{dt}$, in. Hg/hr					
			Partial pressure of oxygen in gas used for saturation, atm					
			0.00	0.02	0.05	0.10	0.15	0.21
Fuel A								
1	300	60	0.8	----	----	----	----	5.5
2			1.3	----	----	----	----	14.5
Average			1.1	----	----	----	----	10.0
1	350	60	2.1	----	----	----	----	14.5
2			2.9	----	----	----	----	26.2
Average			2.5	----	----	----	----	20.4
1	400	60	62	12.5	88	43.2	----	61
2			46.5	49.0	78	59	----	46.5
3			17.7	----	----	61	----	46.4
Average			42.1	30.7	83	54.4	----	51.3
Fuel B								
1	400	60	2.0	----	0.0	0.6	----	1.6
2			1.2	----	.1	1.0	----	1.9
3			----	----	.3	----	----	1.4
Average			1.6	----	.2	.8	----	1.6
Fuel C								
1	400	90	0.8	----	----	----	----	2.9
2			3.4	----	----	----	----	19.0
Average			2.1	----	----	----	----	11.0
Fuel D								
1	300	60	----	----	----	----	----	0.7
1	350	60	3.7	----	0.5	0.3	1.2	2.0
2			0.5	----	1.2	2.4	----	4.0
3			----	----	----	----	----	1.9
Average			2.1	----	.9	1.4	1.2	2.6
1	400	60	.5	8.0	3.7	2.4	----	----
2			3.5	1.1	----	9.0	----	----
Average			2.0	4.5	3.7	5.7	----	----
Fuel E								
1	350	60	4.2	----	----	----	----	----

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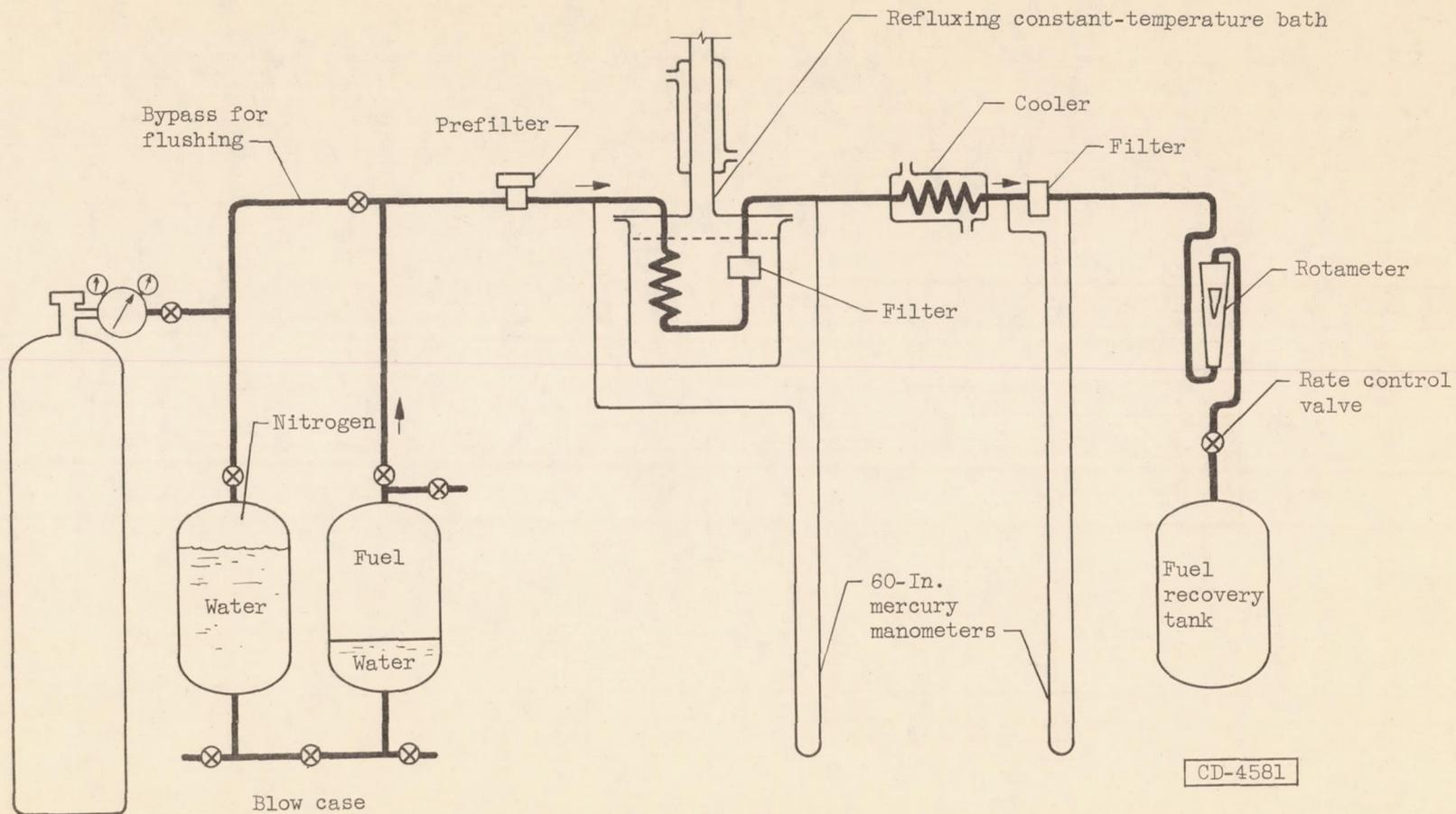


Figure 1. - Schematic diagram of filterability test facilities.

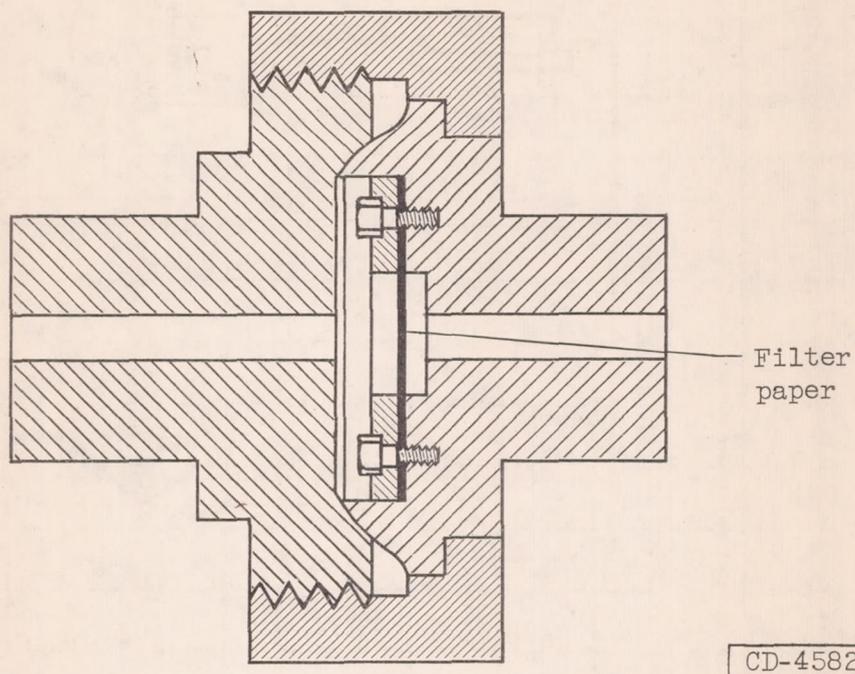


Figure 2. - Filter holder details.

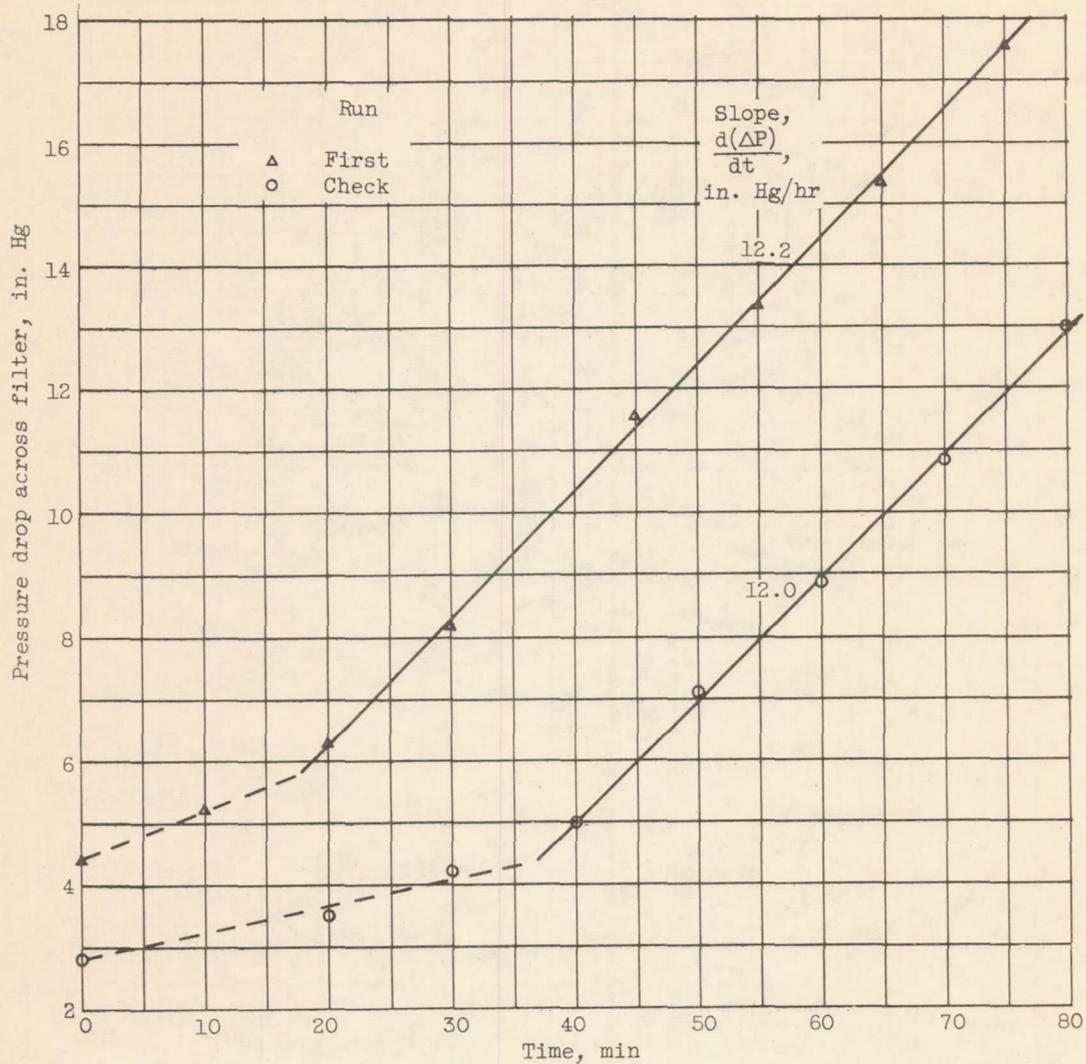
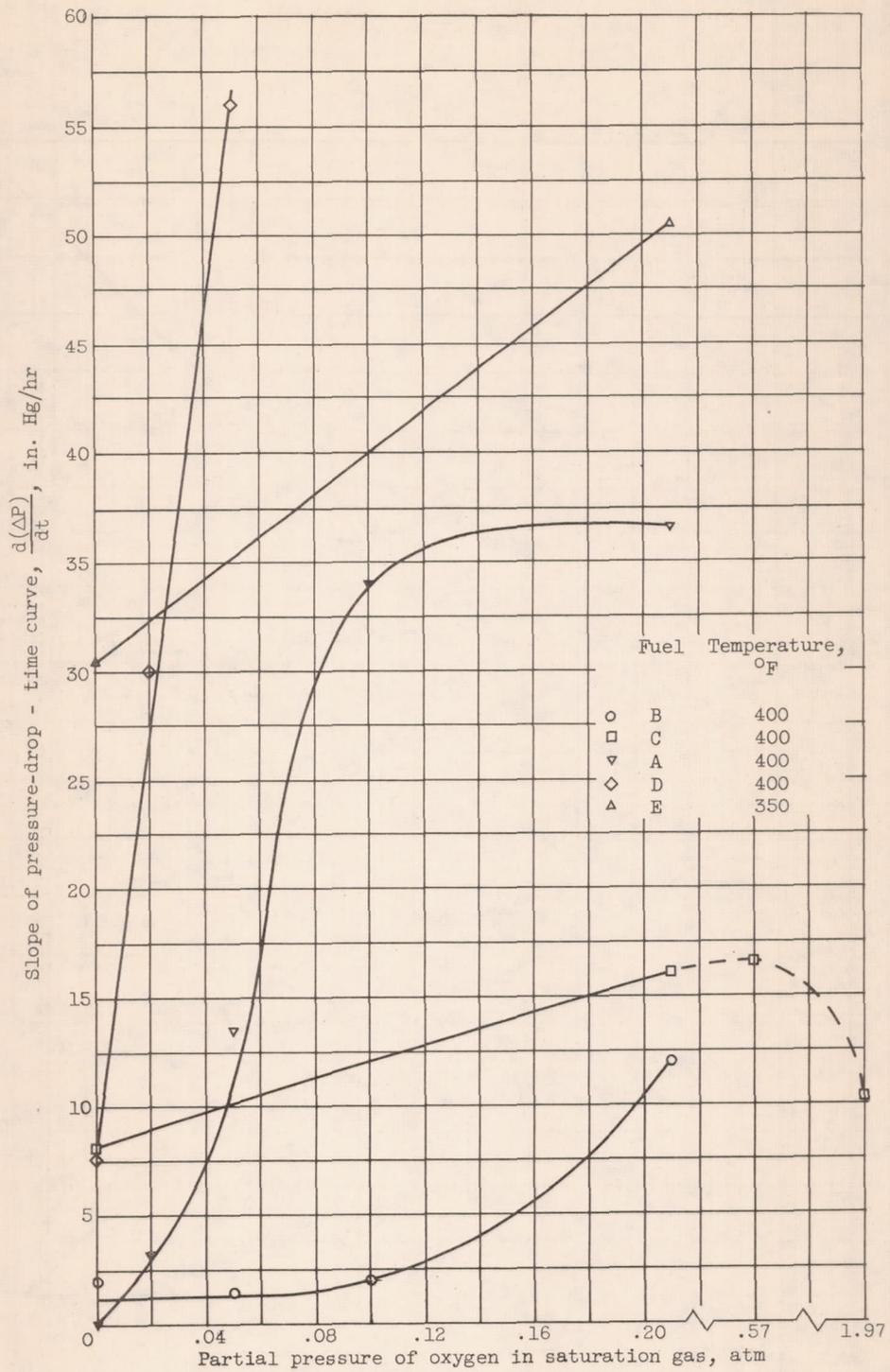
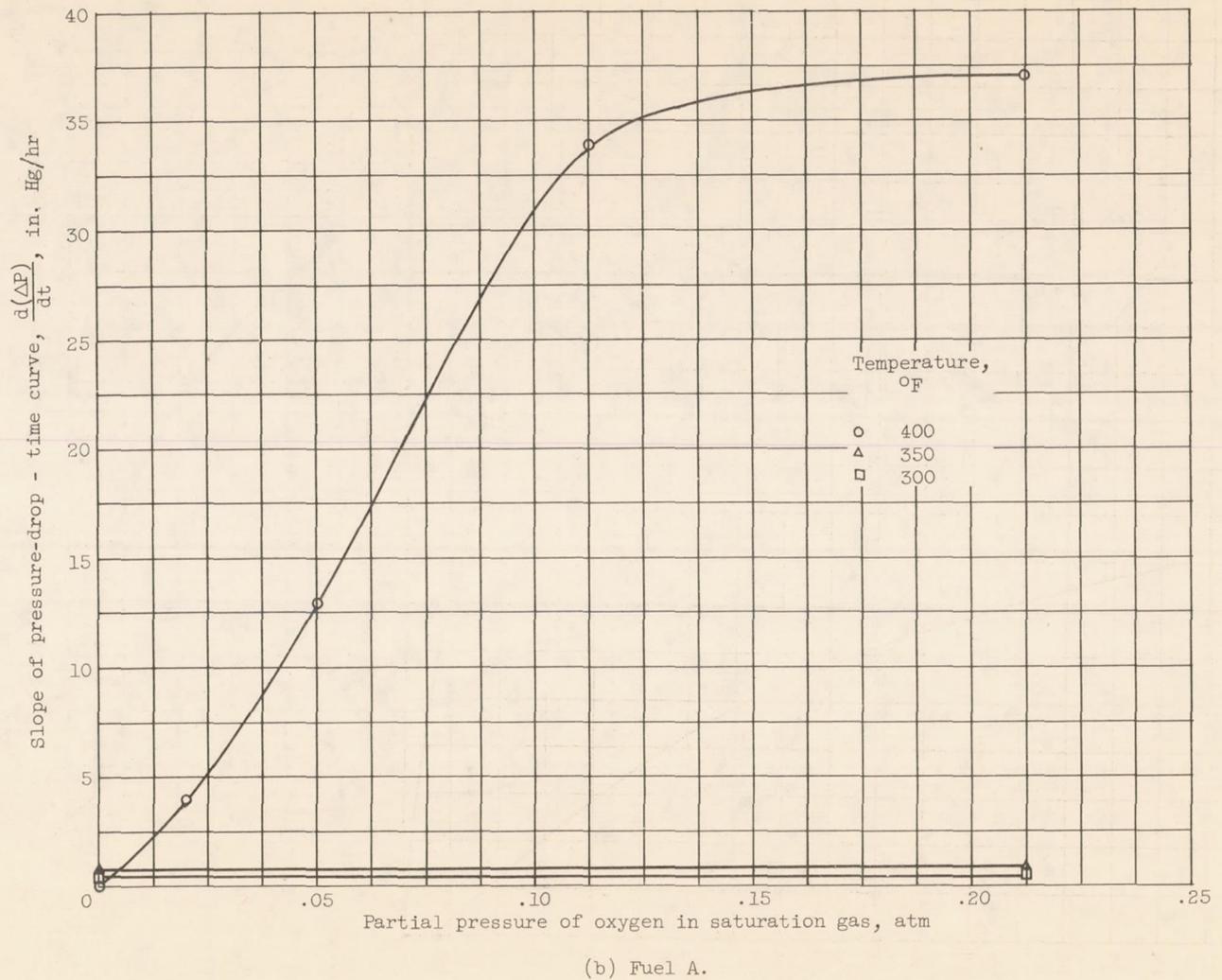


Figure 3. - Results of fuel stability tests for fuel B filtered at 400° F for a residence time of 6 seconds. Fuel initially saturated with air.

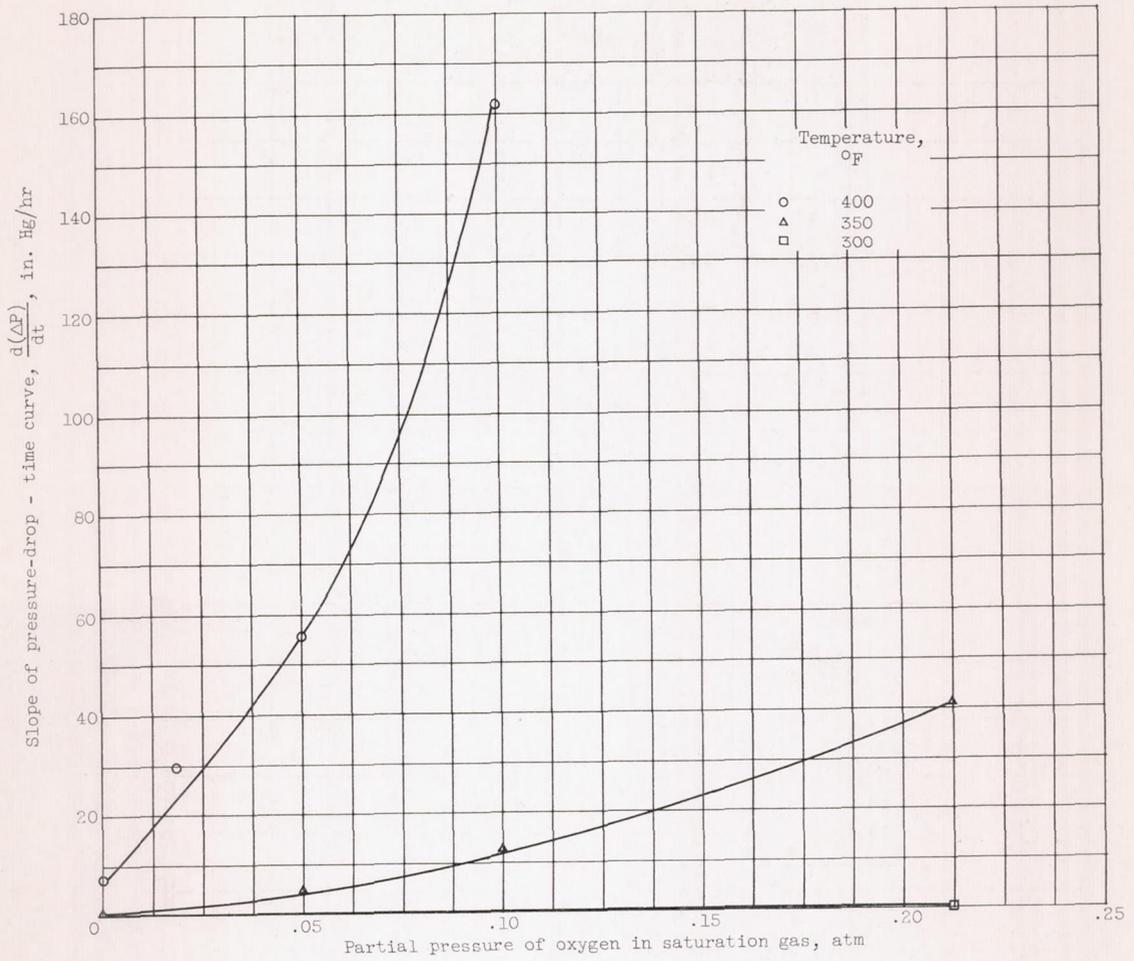


(a) Comparison of fuels A to E.

Figure 4. - Effect of dissolved oxygen and temperature on filterability of various fuels.

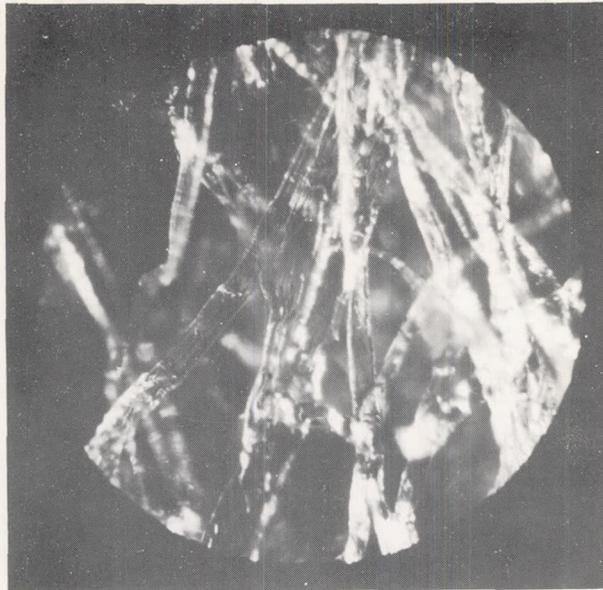


(b) Fuel A.
 Figure 4. - Continued. Effect of dissolved oxygen and temperature on filterability of various fuels.

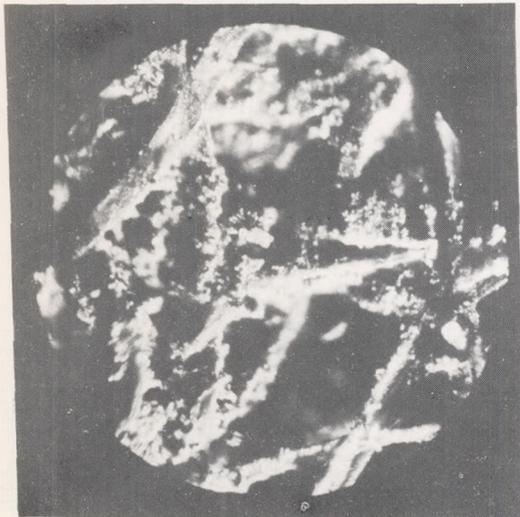


(c) Fuel D.

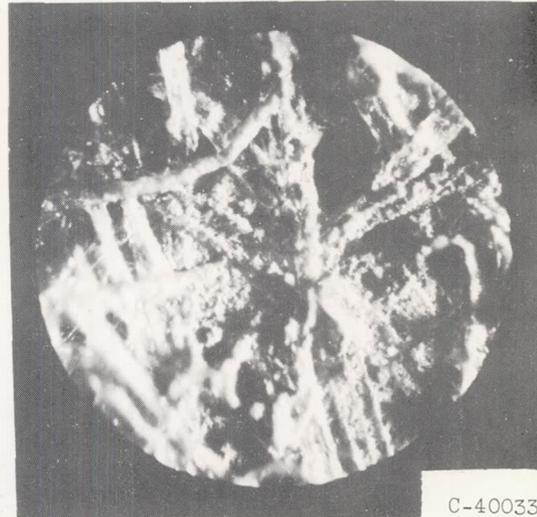
Figure 4. - Concluded. Effect of dissolved oxygen and temperature on filterability of various fuels.



(a) Unused 10-micron paper.



(b) Deposit of fuel D at 400° F; initially saturated with 5 percent oxygen, 95 percent nitrogen mixture.



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(c) Deposit of fuel B at 400° F; initially saturated with air.

Figure 5. - Photomicrographs of filter-paper specimens. X140.