UNCLASSIFIED

NRL Report 5971

FILTERABILITY OF DISTILLATE FUELS

PART 2 - EFFECT OF FUEL VISCOSITY AND RELATED FACTORS

A. J. Chiantella and J. E. Johnson

Fuels Branch
Chemistry Division

September 12, 1963

U. S. NAVAL RESEARCH LABORATORY
Washington, D.C.

Previous Report in this Series

"Part 1 – Development of Methods and Effect of Filter Porosity," A.J. Chiantella and J.E. Johnson, NRL Report 5565, Nov. 3,1960

Copies available from Office of Technical Services
Department of Commerce – $.50

CONTENTS

Abstract	ii
Problem Status	ii
Authorization	ii
INTRODUCTION	1
APPARATUS AND PROCEDURES	1
RESULTS AND DISCUSSION	3
Relation of Fuel Flow and Filter Porosity	3
Relation of Fuel Flow Time to Filterability	4
Effect of Viscosity on Filterability	5
Effect of Temperature on Filterability	5
Effect of Head of Fuel on Filterability	7
Relation of Change in Head to Change in Calibration	12
Effect of Fuel Aging and of Soluble Gum on Viscosity	15
SUMMARY AND CONCLUSIONS	17
REFERENCES	18

ABSTRACT

Studies of additional factors influencing filterability of distillate fuels further substantiate the utility of a constant-head gravity-flow method for rating filterability. Quantitative relationships were made possible by selecting filter papers of uniform porosity as was suggested in Part 1 of this series.

It was shown that the filterability of a distillate fuel contaminated by a given amount of sediment is directly proportional to the fuel viscosity. The effect of temperature on filterability was proven to be due to the variation of viscosity with temperature. Filterability is also directly proportional to the fuel pressure (head) on the filter. It was shown that variations in filter porosity could be balanced by proper adjustment of fuel head.

No significant change in fuel viscosity was found due to aging, either normal or accelerated. It is proposed, therefore, that changes in fuel filterability due to aging are due to accumulation of insoluble residues in the fuel.

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

AUTHORIZATION

NRL Problem 61C01-03
Projects SR001-06-02, Task 0600, and RR 010-01-44-5850

Manuscript submitted May 20, 1963.

FILTERABILITY OF DISTILLATE FUELS

PART 2 - EFFECT OF FUEL VISCOSITY AND RELATED FACTORS

INTRODUCTION

The Navy sometimes must store distillate fuels for several years before they are used. It is known that fuels derived from petroleum deteriorate at different rates depending on the composition of the fuel and on storage conditions such as ambient temperature. One of the troublesome manifestations of fuel deterioration is the formation of sediment which must be removed by filtration when the fuel is used. If a fuel is unstable during storage, considerable sediment may be formed which can clog filters and require excessive filter changing. Consequently, it is important to select fuels for purchase which will have relatively good storage stability. In order to study fuel stability in the laboratory, it is necessary to have a bench-scale method which will measure the filterability of fuels after aging.

The stability of distillate fuels has been studied by evaluating the changes in many factors such as color, light transmission, light scattering, soluble gum, and insoluble residue (1,2). Although these criteria often give useful indications of the relative stability of fuels, it is usually of primary concern to know the filter-plugging tendencies of such fuels (3-7). Many different procedures and apparatus have been devised and used for laboratory evaluation of filterability (3,5,6,8-13). They are often designed to simulate systems actually in use.

The importance of good filterability in the use of a fuel made it desirable to learn more about the fuel properties which affect it. However, a reliable laboratory method for assaying fuel filterability was needed because, in general, small-scale methods had shown poor reproducibility. Therefore, the primary purpose of the present study was to explore the influence of each factor on the filterability of fuels.

The apparatus used here is a modification (12) of one developed for jet fuels by ASTM (10). In preliminary work it was learned that this simple gravity-flow method could be substituted satisfactorily for a differential pressure method which had been devised to simulate a diesel engine fuel filtration system (12); therefore, the gravity-flow method was chosen because of its simplicity and relative ease of operation. Aside from differences in the properties of the fuels themselves and the sediments dispersed in them, filter paper porosity was shown to be a major factor (12,13).

In the present report, consideration is given to various properties of the fuels themselves, as well as temperature and pressure due to the column of the fuel (head), which might affect filterability.

APPARATUS AND PROCEDURES

An ASTM method (10) was modified for this study. Instead of the 500-ml leveling bulb, the fuel reservior was made from a 1-liter round-bottomed flask. Other details of the apparatus are shown in Fig. 1. The effective filtering area of the modified filter holder is

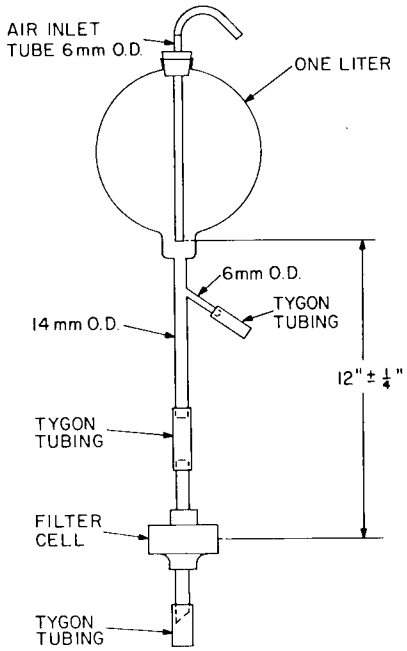

Fig. 1 – NRL apparatus used in fuel filterability studies

1 square centimeter. A 12-inch head* of fuel was used above the filter paper except for a few runs made with an 18-inch head.

Essentially, the procedure consisted of allowing the fuel to flow by gravity from the reservoir, through the filter and into a 100-ml graduate. The time of flow for each 10-ml increment was recorded. The total volume of fuel passing through the filter before the flow rate decreases to 10 ml/min is defined as the plugging volume.

The filter paper (Precision Scientific Co., Catalog No. 74698) was 10-micron paper specially selected for uniformity and set aside for correlation studies by Research Division V, Section B, ASTM Committee D-2. The porosity of each filter was determined by calibration with isooctane (10). The fuel reservoir of the apparatus was charged with 500 ml of isooctane, 300 ml of which was allowed to run through the filter noting the time elapsed for each 100-ml increment. The average of these is the paper calibration time. For the filters used in this work, the calibration times ranged from 23.5 to 30.0 sec/100 ml. Duplicate calibrations fell within ± 0.2 sec/100 ml. The fuel filtration was run immediately after each calibration to avoid disturbing the paper or otherwise changing the measured porosity. Normally, the reservoir was charged with 875 ml of fuel for each test.

To avoid the unknown variables likely to be associated with natural sediment resulting from fuel aging, it was decided to use an artificial sediment in fuels from which the natural sediment was removed. The choice, a carbon black (National Carbon Co. No. N-182) was ball-milled and graded to 1 to 15 microns in size. The carbon dispersions were prepared as follows: (a) the fuel was filtered through an 0.8-micron cellulose ester filter (Millipore Filter Corp., Watertown, Mass.), (b) a weighed quantity of carbon contained in an open piece of aluminum foil was introduced into the filtered fuel, and (c) the mixture was agitated by hand and then for 30 minutes on a shaker.

Most of the filtrations were made in a constant temperature room at 72° F in order to avoid variations in results due to uncontrolled temperature changes. The fuel was conditioned at this temperature for at least 24 hours before use. However, a few runs were made at 100° F for the purpose of showing the effect of temperature. The fuels and all equipment used including the filter paper were equilibrated in a constant temperature room maintained at 100° ± 2° F.

The fuels used in these experiments contained no additives and were all distillates and blends, mostly in the No. 2 burner oil and diesel fuel range (12).

Kinematic viscosities were determined by ASTM Method D-445 (14). Soluble gum determinations were made by steam jet evaporation at 500° F using ASTM Method D-381 (15).

*Head is the pressure due to the column of liquid between the lower end of the air inlet and the filter.

RESULTS AND DISCUSSION

It was established earlier (12,13) that filter paper porosity is an important factor in filter plugging. An example of the data substantiating this conclusion is given in Fig. 2, which is reproduced from the Part 1 of this series (12). The particular curve for each fuel studied showed a linear relationship between filter paper porosity and the plugging volume of the fuel.

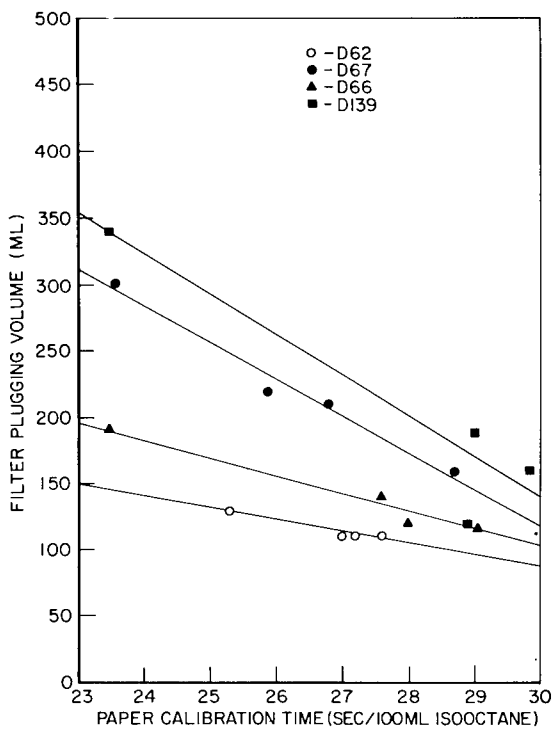

Fig. 2 – Effect of filter paper porosity on the filterability of fuels contaminated with 2.0 mg carbon/100 ml

Consideration of the curves given in this figure leads to the conclusion that filter paper porosity is not the only significant factor affecting the filterability of fuels containing sediment. If it were the sole factor of importance, the curves in Fig. 2 should be approximately superimposed. In fact, except for experimental error, the data should be expressible by a single curve. On the contrary, however, there are large regular differences in filterability from fuel to fuel as shown by the data. Since the temperature was held constant at 72°F and the sediment was standardized by using a single batch of carbon, it followed that these large differences in filterability were due to intrinsic differences among the fuels themselves.

Relation of Fuel Flow and Filter Porosity

In order to get a better appreciation of the role of the fuels themselves, the flow properties of the fuels were examined in a clean condition, uncontaminated by solid material.

The fuels were filtered through 0.8-micron cellulose ester filters. This pore size is many times finer than that of the 10-micron paper used in the timed filtration tests. The flow time of each sediment-free fuel was measured using calibrated papers. The data were taken with the NRL apparatus (Fig. 1) at 12-inch and 18-inch head. Additional data were obtained with an ASTM apparatus (11) which has an 18-inch head.

The data obtained in this manner are shown graphically in Fig. 3 where the fuel flow is plotted against calibration time, both quantities expressed as the time in seconds required to pass 100 ml of fluid through the filter. It is observed that a family of curves (straight lines fitted to the data) resulted. It should be noted that the range of the data has been greatly extended by obtaining the flow times at two heads of fuel, 12 inches and 18 inches. Any effect of changing the head of fuel was reflected proportionally on the fuel and on the isooctane. The fact that the curves in Fig. 3 are linear over such a wide range of calibration times emphasizes the validity of this relationship.

Relation of Fuel Flow Time to Filterability

If the data curves of Fig. 3 are cut by drawing a vertical line at a paper calibration time of 25 seconds, it is found that the fuel flow varies from 80 sec/100 ml for fuel D139 to 190 sec/100 ml for D62.

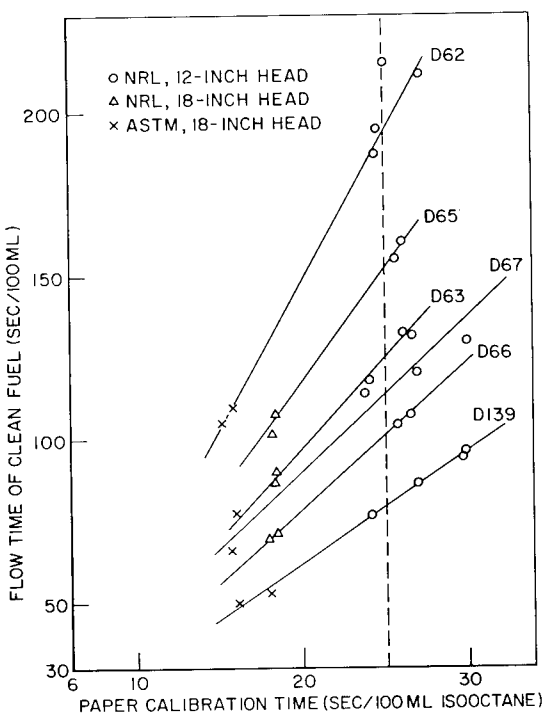

Fig. 3 – Effect of filter paper porosity on fuel flow, using two heads of fuel (72°F)

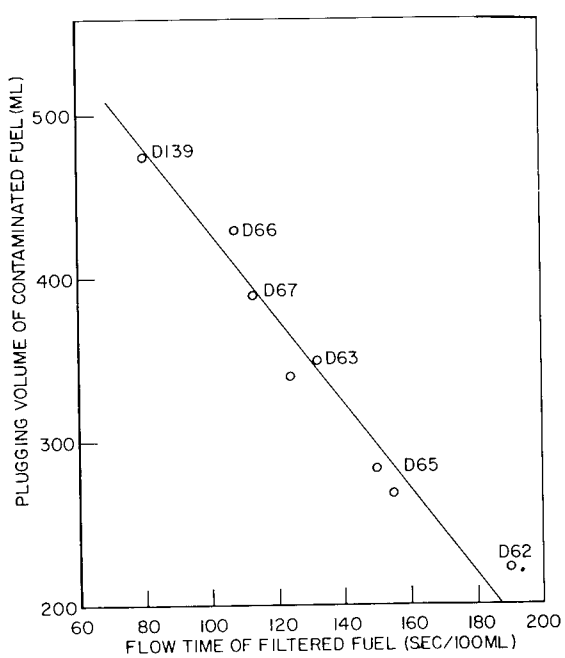

Fig. 4 – Flow of filtered fuel compared to filterability of fuel containing 1.0 mg carbon/100 ml (72°F)

In Fig. 4 the flow times of the filtered fuels so obtained from Fig. 3 were compared with the plugging volumes of the carbon-contaminated fuels, also taken at 25-second calibration. This plot yields a very good correlation of these two values. It shows that the

plugging volume must indeed be a function of some property which varies from fuel to fuel. This property is closely related to the flow time of clean fuel through filter paper of constant calibration.

Effect of Viscosity on Filterability

The foregoing results suggested that viscosity is the fuel property which causes such large variations in the relative filter plugging of fuels; therefore, the viscosities of the fuels used were measured at 72° F, the temperature of the filtration runs. The filter plugging volumes of the fuels (contaminated with 1.0 and 2.0 mg carbon/100 ml) at a constant calibration value of 25 seconds are plotted against fuel viscosity in Fig. 5. An excellent correlation was obtained, showing that fuel viscosity is undoubtedly the fuel property having a major influence on filterability.

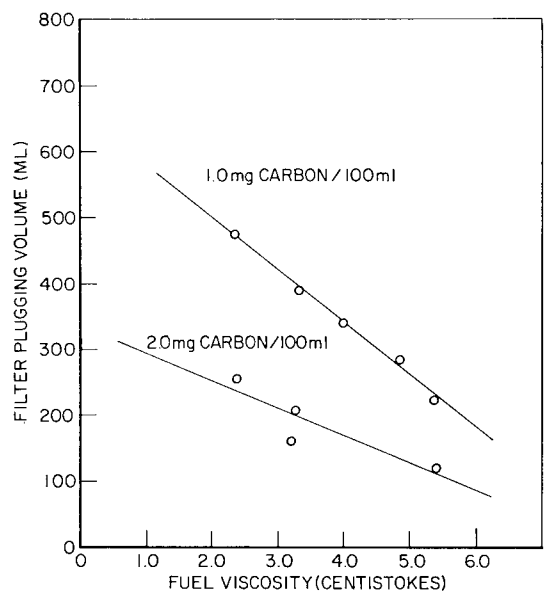

Fig. 5 – Effect of fuel viscosity on filtration of fuel contaminated with carbon (72 °F)

It is not surprising that the more viscous fuels do yield lower plugging volumes, but the magnitude of this effect is striking considering that the total viscosity spread of the fuels used was not great. This raises the possibility that a relatively stable fuel containing a small amount of sediment may plug sooner than a less stable fuel containing more sediment, if the latter fuel has a lower viscosity. The curves in Fig. 5 show that a fuel of viscosity of 5.5 centistokes containing 1.0 mg carbon/100 ml did plug sooner than a fuel with 2 mg carbon/100 ml which had a viscosity of 2.5 centistokes.

A plot of viscosity vs flow time of clean, filtered fuels is given in Fig. 6. This corroborates the close relationship of fuel flow and fuel viscosity. Similar data for isooctane fit neatly on the curve extrapolated from the fuel data.

Effect of Temperature on Filterability

In order to limit the variable factors, the previous experimentation was carried out at a constant temperature of 72° ± 2° F. It was thought that variations in temperature might have an appreciable effect on the filterability of fuels which could confuse interpretation of the effects of the other factors being studied. Temperature control proved to be basic because filterability is greatly dependent on viscosity (Fig. 5) and viscosity changes with temperature.

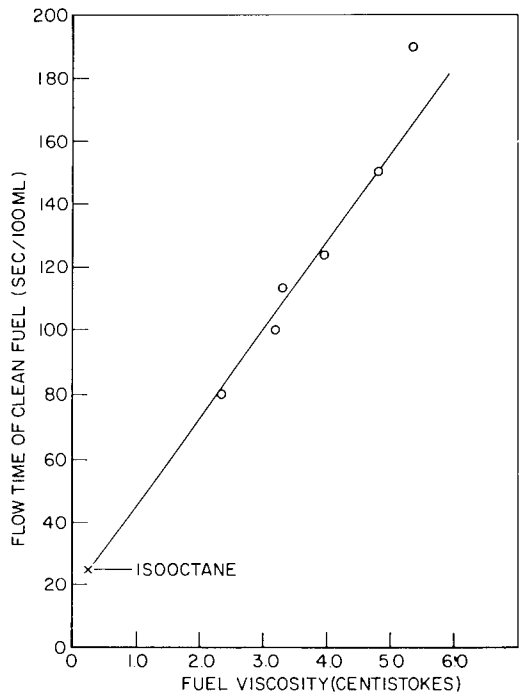

Fig. 6 – Effect of fuel viscosity on fuel flow through filter paper of 25-second isooctane calibrations (72 °F)

A series of experiments was run in a constant-temperature chamber held at 100° ± 2° F in order to verify the above conclusion and to establish the quantitative relationships (Table 1). Filterability runs were made with each fuel on two different filterability apparatuses. The contaminant loading was 1.0 mg of carbon per 100 ml of fuel.

The plugging volumes obtained at 100° F for four fuels are plotted against similar data at 72° F in Fig. 7. Fuel D139 did not plug at 100° F whereas it did plug at 72° F. Although the data are limited in number, there appears to be a linear relationship between the plugging volumes at the two different temperatures.

The plugging volumes of the fuels at 100° F are plotted against the kinematic viscosities of the clean fuels at 100° F in Fig. 8. The resulting curve is a good corroboration of the relationship of fuel viscosity and filterability which had been established earlier in this report. The steep slope of the curve emphasizes the profound effect of the viscosity of a given fuel on its plugging volume.

Viscosity data for these fuels taken at both 72° and 100° F are plotted in Fig. 9, and show the expected result, that the viscosities at the two temperatures are directly proportional.

Additional supporting evidence may be derived from the data in Table 1 for viscosity, calibration, and fuel flow time. Plotting the ratio of the fuel flow time to the calibration against the viscosity should give a straight line if the following assertions are correct:

1. Fuel flow time and calibration are linearly related (Fig. 3); therefore, the ratio of the fuel flow time to the calibration is constant.

2. The fuel flow time is linearly dependent on its viscosity (Fig. 6).

Table 1
Fuel Filterability Data Taken at 100° F

Fuels*	Viscosity	Calibration (sec/100 ml)	Fuel Flow (sec/100 ml)	Ratio Fuel Flow to Calibration	Plugging Volume
D62	3.60	22.8	(117.4)†	(5.150)†	360
		22.6	(116.4)†	(5.150)†	385
		22.4	(115.4)†	(5.150)†	410
			116.4 §	5.150 §	385 §
D65	3.26	23.0	109.1	4.743	470
		22.5	103.6	4.604	450
			106.4 §	4.674 §	460 §
D67	2.40	23.4	79.3	3.389	660
		22.7	76.6	3.374	810
			78.0 §	3.382 §	735 §
D66	2.35	22.9	75.6	3.301	770
		23.4	77.2	2.299	770
			76.4 §	3.300 §	770 §
D139	1.78	23.1	58.4	2.528	NP‡
		22.9	56.7	2.476	NP‡
			57.6 §	2.502 §	NP

*Contaminated with 1 mg carbon/100 ml of fuel.
†Extrapolated from data in Fig. 10.
‡NP – did not plug filter.
§Averages.

The averages of the experimental values were plotted in Fig.10 and the data did fit a straight line. The fuel flow times for fuel D62 given in Table 1 were not determined experimentally but the ratio for fuel D62 was extrapolated from Fig. 10 and the flow times of fuel D62 derived from the ratio. Hence knowing the viscosity of a fuel and the calibration of the filter, the flow time of the fuel may be calculated. In addition, in Fig. 11 when the average flow times (including that calculated for D62) were plotted against the average plugging volumes the data again fitted a straight line. This indicates that if the filter calibration, fuel viscosity, and carbon contamination are known, then the plugging volume can be calculated.

Effect of Head of Fuel on Filterability

In the previous experiments, most of the filterability runs were made with the head of fuel maintained at 12 inches. To gain some idea of the quantitative effect of increasing the head of fuel on plugging volumes, runs were made comparing the filterability of each fuel at a head of 12 and 18 inches. The data are given in Table 2. The plugging volumes at both heads are plotted in Fig. 12. A straight line is drawn as the best estimate of the relationship. This linearity is strengthened by the plot in Fig. 13 of the flow time of the clean fuel at 12 and 18 inches head. This is further confirmed by the study of the effect of head of fuel on calibration time discussed later.

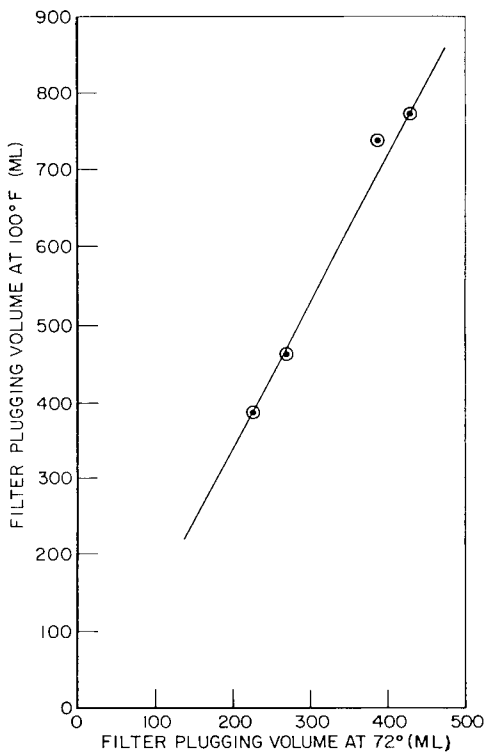

Fig. 7 – Comparison of filterability of fuels contaminated with 1.0 mg carbon/100 ml (72° and 100°F)

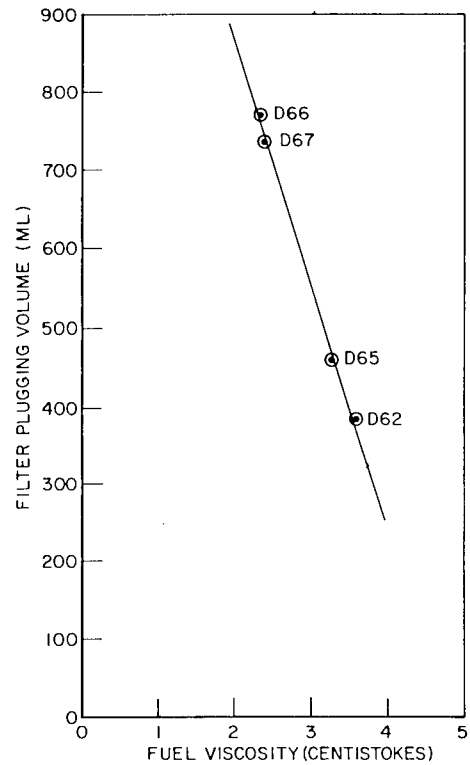

Fig. 8 – Comparison of fuel viscosity with filtration of fuel contaminated with 1 mg carbon/100 ml (100°F)

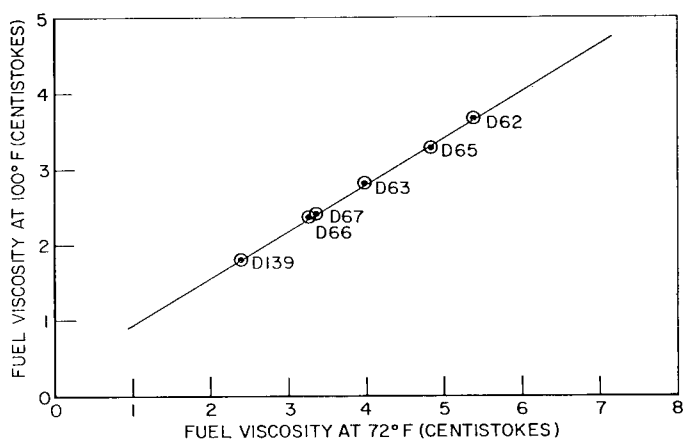

Fig. 9 – Comparison of fuel viscosity (72° and 100°F)

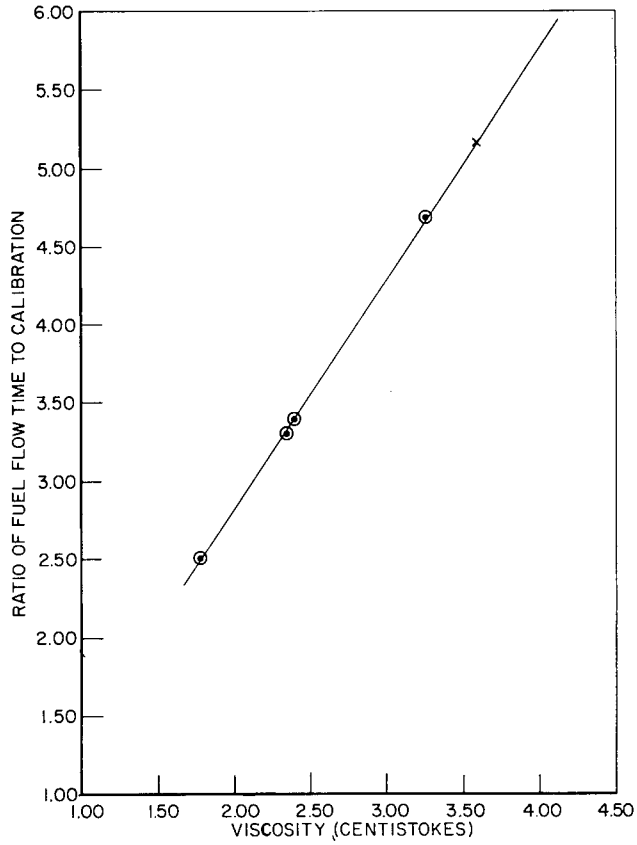

Fig. 10 – Comparison of fuel viscosity to the ratio of fuel flow time to calibration (100°F)

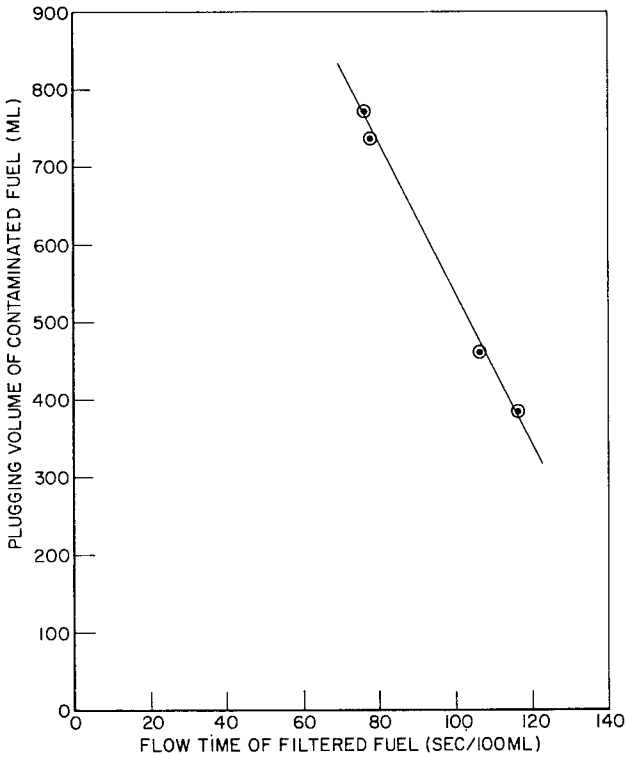

Fig. 11 – Flow of filtered fuel compared to filterability of fuel containing 1.0 mg carbon/100 ml (100°F)

Table 2
Effect of Head on Calibration-,-Flow of Filtered Fuel, and Filterability of Fuel Contaminated with 1.0 mg Carbon/100 ml (72°F)

Fuels*	Density (d)†	Viscosity (n)‡ (centistokes)	n/d	A $\left(\frac{n_F/d_F}{n_i/d_i}\right)$	Filter Cell	t_i§ (sec/100 ml)	t_F¶ (sec/100 ml)	B (t_F/t_i)	B/A	Plugging Volume (ml)	Filter Cell	t_i§ (sec/100 ml)	t_F¶ (sec/100 ml)	B (t_F/t_i)	B/A	Plugging Volume (ml)
					12-inch Head						18-inch Head					
D65	0.863	4.83	5.60	5.46	1	26.3	160.1	6.08	1.09	-	1	18.5	107.7	5.82	1.07	350
					2	25.9	155.0	5.98	1.10	270	2	18.3	101.6	5.55	1.02	-
D63	0.844	3.99	4.73	4.61	1	26.8	131.4	4.90	1.04	-	1	18.6	90.2	4.85	1.05	420
					2	26.3	132.0	5.02	1.09	350	2	18.4	86.7	4.71	1.02	-
D66	0.835	3.22	3.86	3.76	1	25.9	105.6	4.08	1.06	-	1	18.1	69.6	3.85	1.02	770
					2	26.7	107.5	4.03	1.07	430	2	18.5	70.9	3.83	1.02	-
Isooctane	0.690	0.708	1.026	1.000												

*Fuels were contaminated with 1 mg carbon/100 ml.
†The densities of the fuels were measured at 60°F and corrected at 72°F using the factor 0.0008 g/ml per degree. The density of isooctane was calculated from literature data.
‡Viscosities of the fuels were determined at 72°F by ASTM Method D-445 (14). The viscosity of isooctane was calculated from literature data.
§Isooctane calibration of the filter.
¶Fuel flow time through the filter.

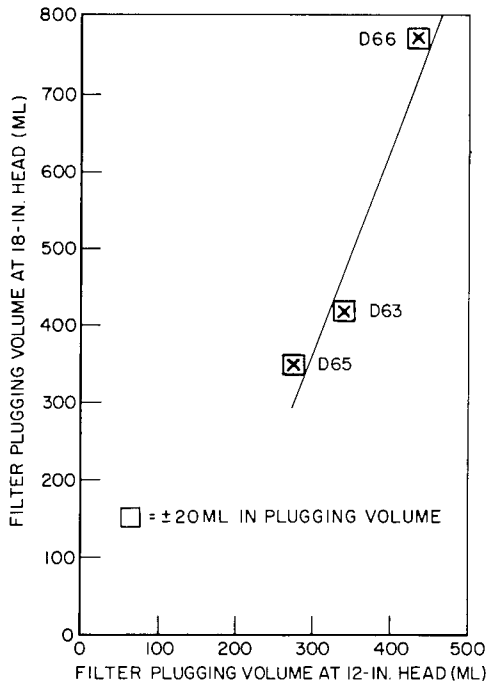

Fig. 12 - Effect of 12-inch and 18-inch heads on the filterability of fuel contaminated with 1.0 mg carbon (72° F)

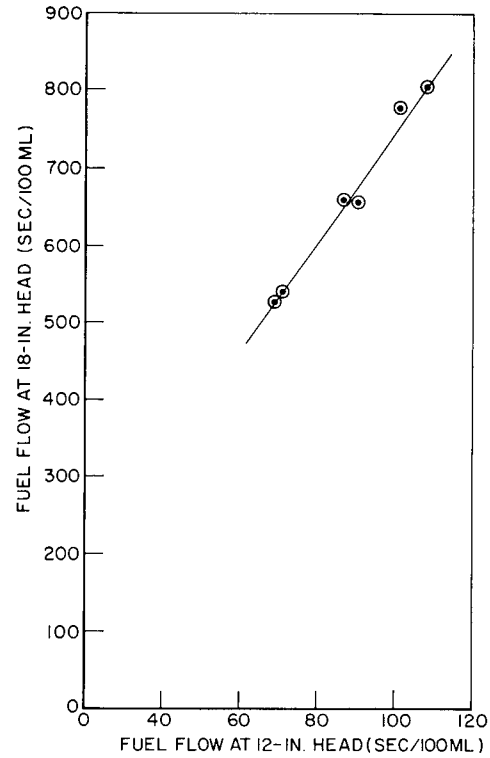

Fig. 13 - Comparison of flow of filtered fuel at 12-inch and 18-inch heads (72° F)

In addition, consideration of the viscosity of the fuels and the isooctane standard in Table 2 also adds credence to the validity of the data. The viscosity of fluids may be compared by the equation

$$\frac{n_F}{n_i} = \frac{t_F d_F}{t_i d_i} \tag{1}$$

in which n is the viscosity, t is the flow time, d is the density, and the subscripts F and i refer to fuel and isooctane respectively. Then

$$\frac{n_F d_i}{n_i d_F} = \frac{t_F}{t_i} \tag{2}$$

derived from Eq. (1) compares the relative flow times of fuel and isooctane. If

$$\frac{n_F d_i}{n_i d_F}$$

is set equal to A (as in Table 2) and t_F/t_i equal to B, the ratio

$$\frac{B}{A} = 1 \ . \tag{3}$$

If unity is obtained from the experimental data, then the system conforms to theory. In Table 2, all the values of this ratio derived from the data are slightly greater than unity. Nevertheless, these calculated ratios are close enough to unity to show that the system at both heads of fuel conforms to theory.

Relation of Change in Head to Change in Calibration

When all other things are equal, plugging volumes of fuels vary inversely with the calibration times of the filter papers as shown by the data in Fig. 2. In order to compare two fuels accurately, they should be filtered through filters having the same calibration. Considering the range of calibrations of present filters (Fig. 7 in Ref. 12), it is not feasible to select a sufficient number of filters having the same calibrations to permit comparison of even a small number of fuels. A method for correcting calibration times to a standard value would be very useful.

In the present method, changing the head caused the calibration and the fuel flow to change in a regular manner as shown in Table 2 and Figs. 3 and 13. These results suggested that it might be possible to bring calibrations of filters to a standard value by suitably adjusting the head of fuel. It was first necessary to learn if the corrections could be obtained and applied in a simple manner. Therefore a brief preliminary probe of the relation between calibration (C) and head (H) was made.

In these experiments isooctane was used as the calibrating liquid because it is commonly employed as a standard of reference in filtration work. The calibration procedure described earlier was followed. To allow variation of the head, a 6-inch extension of pyrex tube was inserted between the lower end of the glass apparatus and the filter cell. Air inlet tubes of different lengths were used to establish the head of liquid between the limits of 10 to 18 inches as desired. The flow rate (F) of the liquid through the filter is proportional to the head. Calibration (sec/100 ml) is inversely proportional to the flow rate (ml/sec). The results of calibrating two filters at various heads are reported in Table 3. Each filter was first calibrated at a 12-inch head and then the flow time of each filter was measured in the order given in Table 3. The observed flow rate is the reciprocal of the calibration time. The calculated flow rate equations are derived from the observed values by the method of least squares. From these equations it was calculated that an error of ±0.25 inch in adjusting the head would lead to errors of ±0.07 and 0.06 ml/sec in flow rates of filters 1 and 2 respectively. The plot of flow rate versus head for filter 2 is given in Fig. 14, in which the points represent the observed data, the line represents the equation obtained by the method of least squares, and the rectangles represent the limits of error.

Since the flow rate (F) and head (H) data approximated a straight line relation so closely, it is possible to calculate the change

$$\left(\frac{dC}{dH}\right)$$

in calibration (C) caused by altering the head, as follows:

$$C = \frac{1}{F} \tag{4}$$

$$F = mH + b. \tag{5}$$

Table 3
Effect of Head on Calibration and Flow Rate of Isooctane (72° F)

Order	Head (H) (inches)	Calibration (C) (sec/100 ml)	Flow Rate (F) obs (ml/sec)	Flow Rate (F) calcd (ml/sec)	Deviation (ml/sec)
Filter 1					
1	12	24.2 , 24.2	4.13	4.09*	-0.04
2	18	17.5 , 17.4	5.71	5.68*	-0.03
3	16	19.4 , 19.4	5.15	5.15*	0.00
4	14	21.6 , 21.7	4.61	4.62*	+0.01
5	12	24.8 , 24.7	4.03	4.09*	+0.06
6	10	27.8 , -	3.60	3.56*	-0.04
					±0.03 avg
Filter 2					
1	12	23.8 , 23.7	4.20	4.21†	+0.01
2	10	26.7 , 26.8	3.75	3.73†	-0.02
3	12	23.8 , 23.8	4.20	4.21†	+0.01
4	14	21.2 , 21.2	4.69	4.72†	+0.03
5	16	19.4 , 19.3	5.15	5.18†	+0.03
6	18	17.6 , 17.6	5.68	5.66†	-0.02
					±0.02 avg

*Calculated flow rate by least squares F = 0.265H + 0.91.
†Calculated flow rate by least squares F = 0.241H + 1.32.

Differentiating Eqs. (4) and (5) give Eqs. (6) and (7) respectively

$$\frac{dC}{dF} = \frac{-1}{F^2} \tag{6}$$

$$\frac{dF}{dH} = m \cdot \tag{7}$$

Combining Eqs. (6) and (7) gives

$$\frac{dC}{dH} = \frac{dC}{dF} \cdot \frac{dF}{dH} = -\frac{m}{F^2} \cdot \tag{8}$$

Substituting Eq. (5) for F in Eq. (8) gives

$$\frac{dC}{dH} = -\frac{m}{(mH + b)^2} \cdot \tag{9}$$

Equation (9) shows that the relationship is not linear and that the calibration varies inversely with the head. Table 4 presents a comparison of the change in calibration with the change in head using the experimental data and values derived from Eq. (9).

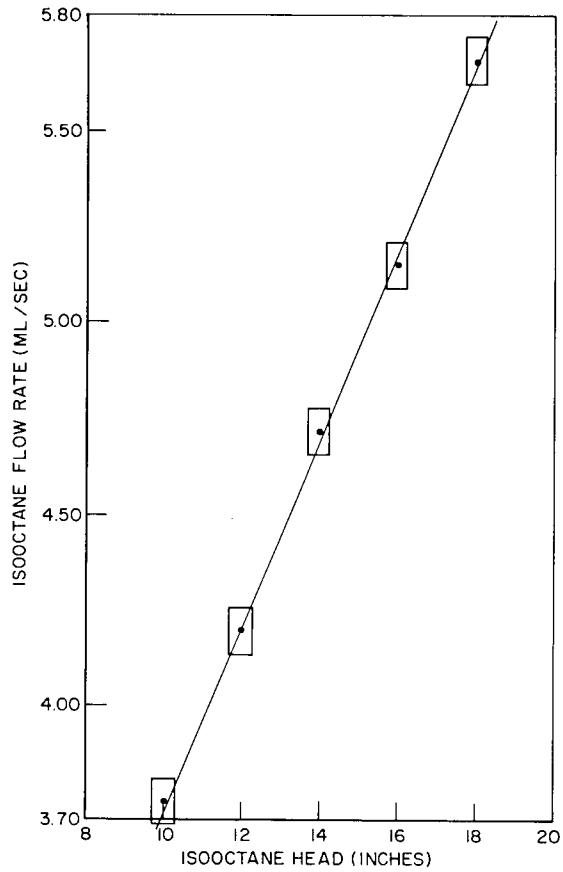

Fig. 14 – Effect of head on the flow rate of isooctane through the filter (72°F)

Table 4
Comparison of Estimated and Calculated Change in Calibration with Change in Head

Head (inches)	Calibration (sec/100 ml)	Estimated* $\Delta C/\Delta H$ (sec/inch)	Calculated† dC/dH (sec/inch)	Deviation
10	26.7		-1.73	
11		-1.45	-1.53	+0.08
12	23.8	(-1.35)‡	-1.37	+0.02
13		-1.25	-1.22	-0.03
14	21.3	(-1.10)‡	-1.10	0.00
15		-0.95	-0.99	+0.04
16	19.4	(-0.93)‡	-0.90	-0.03
17		-0.90	-0.82	-0.08
18	17.6		-0.75	

*Estimated from calibration data for heads one inch above and below.
†Calculated from Eq. 4.
‡Estimated from calibration data for heads two inches above and below.

These probing experiments show the feasibility of preparing a set of corrections so that the head may be varied to obtain a standard calibration. In order to demonstrate the principle, the data in Table 4 were collected over a wide range of heads and calibrations. Variations of a much narrower range would yield a sufficient number of useable filters for practical purposes (see Fig. 7 in Ref. 12). Furthermore, plugging volume is defined as the total volume of fuel which has passed through the filter by the time the fuel flow rate through the filter has decreased to 10 ml/min. Both the calibration and the fuel flow time change linearly in the same direction when the head is varied. Therefore adjusting the isooctane calibration of the filters to a standard calibration by varying the head over a suitable range should yield an acceptably accurate plugging volume.

Effect of Fuel Aging and of Soluble Gum on Viscosity

As shown earlier (Fig. 5), viscosity has a major influence on the plugging volumes of fuels. It is conceivable that the viscosity of a fuel could change with aging and/or an increase in soluble gum, thus affecting the comparative filterability of fuels. Table 5 contains viscosity and soluble gum data for the fuels used in these experiments. With the exception of fuel D139 which was almost fresh, the fuels were about three years old when the first viscosities were determined. Since the data show no appreciable changes in viscosity during the next fourteen months at ambient temperature, it is evident that the results of the filterability studies were not affected by interim viscosity changes. The data also show that neither the soluble gum content nor the viscosity is significantly changed by the addition of the carbon and subsequent filtration.

Table 5
Effect of Ambient Storage of Fuels on Viscosity and Soluble Gum

Fuels	Storage Time of Fuel (Months)					
	0	24	36	42	42*	50*
	Viscosity (centistokes)†					
D62	-	-	3.60	3.60	3.60	-
D65	-	-	3.26	3.26	-	3.31
D63	-	-	2.78	2.81	-	2.82
D67	-	-	2.40	2.42	2.41	2.41
D66	-	-	2.35	2.35	2.35	2.35
D139‡	-	-	1.76	1.77	1.79	1.78
	Soluble Gum (mg/100ml)§					
D62	2.1¶	2.4¶	-	10.8	9.4	-
D65	4.0¶	31.8**	-	75.3	-	-
D63	4.2¶	18.9¶	-	31.7	-	-
D67	4.6¶	7.9¶	-	11.3	13.4	-
D66	2.8¶	7.2**	-	15.6	17.2	-
D139‡	-	-	-	1.0	1.8	-

*After filterability studies with 1.0 mg carbon/100 ml.
†Viscosity at 100°F by ASTM Method D-445 (14).
‡Fuel D139 was almost fresh when the other fuels were 36 months old.
§Soluble Gum – ASTM Method D381-56T, by steam jet at 500°F (15).
¶Average values for soluble gum from Navy-CRC Barge Storage Program Preliminary Report – Draft No. 2 (July 1957).
**Average of four determinations.

Table 6
Effect of Accelerated Storage of Fuels for 16 Hours at 210°F on Viscosity and Soluble Gum

Aging Conditions	Run No.	D140 Fuel		D141 Fuel		D142 Fuel		D148 Fuel	
		Viscosity (Centistokes)	Soluble Gum (mg/100 ml)	Viscosity (Centistokes)	Soluble Gum (mg/100 ml)	Viscosity (Centistokes)	Soluble Gum (mg/100 ml)	Viscosity (Centistokes)	Soluble Gum (mg/100 ml)
Original		3.21	8.7	2.65	5.6	2.69	2.4	2.34	12.4
In Pyrex Glass	1	3.21	17.5	2.66	22.4	2.70	4.8	2.35	9.1
	2	3.21	19.9	2.66	21.2	2.70	4.1	2.34	9.8
In Soft Glass	1	3.21	17.7	2.66	-	2.70	2.9	2.36	9.7
	2	3.21	13.2	2.66	10.0	2.70	3.2	2.36	9.1

*Viscosity at 100°F – ASTM Method D-445 (Ref.14).
†Soluble gum by steam jet at 500°F – ASTM Method D381-56T (Ref. 15).

Table 6 presents viscosity and soluble gum data for fuels stored at 210°F for 16 hours in accelerated stability studies. These fuels had degraded considerably in other respects (2). However, neither the heat treatment nor the increase in soluble gum content produced noticeable effects on the viscosity. It can be presumed therefore that filterability should also be a valid measurement in accelerated predictive stability studies of fuels. In other words, it is likely that changes in measured filterability must be due to the formation of insoluble suspended matter in the fuel during aging, and not due to changes in viscosity.

SUMMARY AND CONCLUSIONS

1. The filterability of distillate fuels which contain a given amount of sediment is directly proportional to the viscosities of the fuels.

2. The effect of temperature on filterability was demonstrated to be pronounced and due to the change of fuel viscosity with temperature.

3. The filterability of a given fuel is directly proportional to the height of the column (head) of fuel maintained above the filter.

4. A quantitative relationship of filter calibration to head of fuel was established. It was shown that variations in calibration could be corrected by adjustment in the height of the fuel column over the filter.

5. Data obtained during fuel aging show that there is no significant change in fuel viscosity due to aging at ambient temperature for as long as 14 months or at 210°F for 16 hours. This implies that changes in fuel filterability must be due to the formation of insoluble suspended matter in the fuel.

6. The good repeatability of plugging volume data emphasizes the suitability of the simple gravity-flow method for rating filterability.

REFERENCES

1. Johnson, J.E., Chiantella, A.J., and Carhart, H.W., Ind. Eng. Chem. 47:1226-30 (1955)

2. Christian, J.G., Chiantella, A.J., Johnson, J.E., and Carhart, H.W., Ind. Eng. Chem. 50:1153-56 (1958)

3. Goodrich, J.E., Stayner, R.A., and Dimpfl, L.H., Preprints, Division of Petroleum Chemistry, ACS, New York, N. Y., Sept. 1957

4. Hunt, R.A., Jr., Tom, T.B., and Bolt, J.A., Ind. Eng. Chem. 48:1899 (1956)

5. Konrad, W.A., Tutwiler, T.S., and Shipley, N.L., Petrol. Process. 11:145 (1956)

6. Nelson, F.L., Osterhout, D.P., and Schwindeman, W.R., Ind. Eng. Chem. 48:1892 (1956)

7. Walker, A.O., and Stanton, J.P., Petrol. Refiner 33:187 (1954)

8. Nixon, A.C., and Minor, H.B., Ind. Eng. Chem. 48:1909 (1956)

9. Nixon, A.C., and Steckler, B.M., Preprints, Division of Petroleum Chemistry, ACS, Chicago, Illinois, Sept. 1958

10. American Society for Testing Materials, "Proposed Method of Test for Filterability of Jet Fuels," Appendix I in "ASTM Standards on Petroleum Products and Lubricants," Nov. 1954

11. American Society for Testing Materials, "Proposed Method of Test for Filterability of Aviation Turbine Fuels," Appendix III in " ASTM Standards on Petroleum Products and Lubricants," Dec. 1958

12. Chiantella, A.J., and Johnson, J.E.,"Filterability of Distillate Fuels. Part 1 – Development of Methods and Effect of Filter Porosity," NRL Report 5565, Nov. 3, 1960

13. Chiantella, A.J., and Johnson, J.E., J. Chem. and Eng. Data 5:387-389 (1960)

14. American Society for Testing Materials "Test for Kinematic Viscosity," ASTM Standards, Method D-445-53T, 1957

15. American Society for Testing Materials, "Existent Gum in Fuels by Jet Evaporation," ASTM Standards, Method D-381-56T, 1956

* * *