Filterability of Distillate Fuels

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THE STABILITY of distillate fuels has been studied by evaluating the changes in many factors such as color, light transmission, soluble gum, and insoluble residue after the fuels have been aged for a suitable length of time. 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 (*3-6, 8*). Many different procedures and apparatus have been devised and are used for laboratory evaluation of filterability (*1-3, 5-7*). 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 test method for assaying fuel filterability was needed before this study could be started. In general, small-scale methods have shown poor reproducibility. Therefore, the primary purpose of this study was to explore the influence of each factor on the filterability of fuels.

The apparatus used is a modification of one developed for jet fuels by ASTM (*1*). The authors had learned in preliminary work that a relatively simple gravity-flow method may be substituted satisfactorily for a differential pressure method which had been devised to simulate a diesel engine fuel filtration system. Both methods rated a series of aged fuels in essentially the same relative order. Therefore, the gravity-flow method was chosen because of its simiplicity and relative ease of operation.

Aside from differences in the properties of the fuels themselves and the sediments dispersed in them, filter paper porosity proved to be a major factor. By correcting for variations due to filter paper differences, it was now possible to determine that the most important physical property of fuels affecting filterability is viscosity. In all these studies the variations due to possible differences in natural sediments were avoided by using carbon black dispersed in fuels to determine the relative contributions of other properties on filter plugging.

APPARATUS AND PROCEDURES

An ASTM method (*1*) 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 Figure 1. With the modified filter paper holder (Figure 2), the effective filtering area of the paper is 1 square cm. A 12-inch head of fuel was used above the filter paper in all runs except for a few made with an 18-inch head.

The filter paper (Precision Scientific Co., Catalog No. 74698) was a stock of 10-micron paper specially selected for uniformity and set aside for correlation studies by Research Division V, Section B, ASTM Committee D-2.

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. Plugging volume is defined as the total volume of fuel passing through the filter before the flow rate decreases to 10 ml. per minute.

The relative porosity of each individual filter paper was determined by calibration with iso-octane (*1*). The fuel reservoir of the apparatus was charged with 500 ml. of iso-octane, 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 filter papers used in this work, the calibration times ranged from 23.5 to 30.0 seconds per 100 ml. Duplicate calibrations fell within ±0.2 second per 100 ml. The fuel filtration was run immediately after each calibration, to avoid disturbing the paper or otherwise changing the measured porosity.

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.

The filtrations were made in a constant-temperature room at 72° F. to avoid variations in results due to uncontrolled temperature changes. The fuel was conditioned at this temperature for at least 24 hours before use.

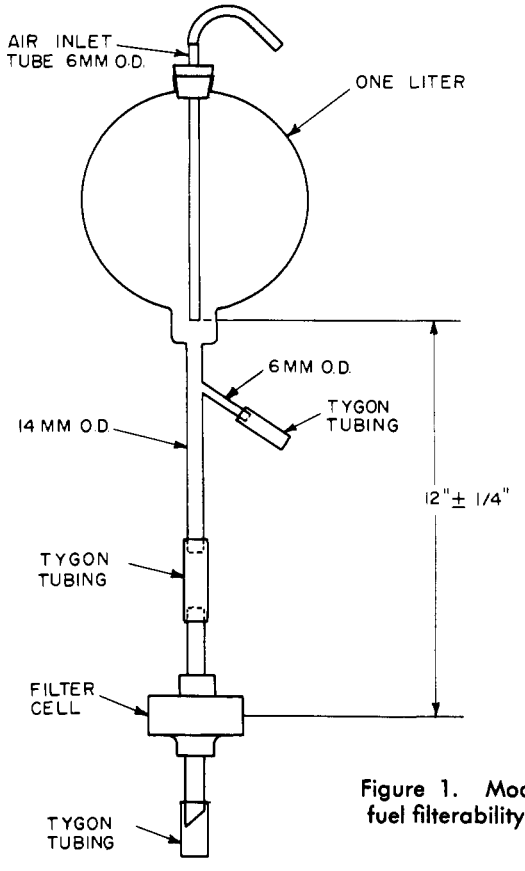

Figure 1. Modified ASTM fuel filterability apparatus

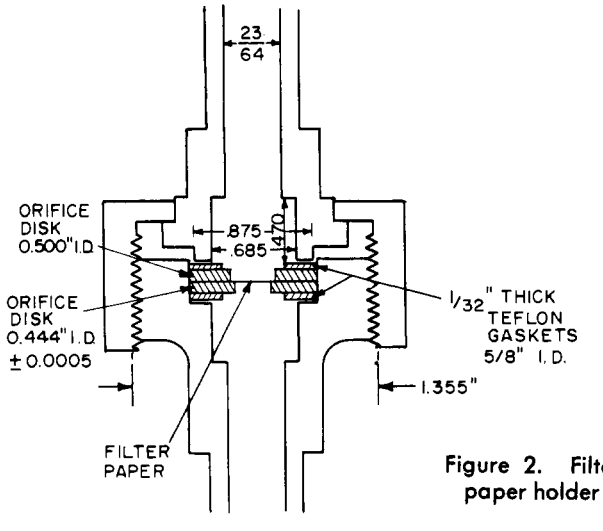

Figure 2. Filter paper holder

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. The fuel was filtered through an 0.8-micron cellulose ester filter (Millipore Filter Corp., Watertown, Mass.). A weighed quantity of carbon contained in an open piece of aluminum foil was introduced into the filtered fuel. The mixture was agitated by hand and then for 30 minutes on a shaker. Normally, the reservoir was charged with 875 ml. of fuel for each test.

RESULTS AND DISCUSSION

Effect of Filter Paper Porosity. Carbon dispersions in each fuel were prepared in a batch large enough to allow four repetitive filtration runs to be made. A fresh filter paper was used for each run, the paper having just been calibrated with iso-octane.

In Figure 3, filterability data are plotted for four different fuels, each contaminated with carbon at a level of 2.0 mg. per 100 ml. In this graph the paper calibration time is posted as the abscissa and fuel plugging volume (milliliters of fuel filtered before the flow rate drops to 10 ml. per minute) is the ordinate. It is significant that in all cases the plots show a decided decrease in fuel plugging volume with increase in calibration time. Using fuel D67 as an example, the plugging volume dropped from 285 ml. with a 24-second paper to 175 ml. with a 28-second paper.

Figure 4 presents the results obtained with five fuels contaminated with carbon at a level of 1.0 mg. per 100 ml. In this series where the carbon contamination was halved, the same trend was established: that as paper porosity decreased, significantly less fuel could be filtered before plugging.

To get some idea of the magnitude of the effect of porosity, if in Figures 3 and 4 the individual plugging volumes for each fuel at calibration times of 24 and 30 seconds are compared, it is seen that there is a decrease of 30 to 60% in filtration volume over this 6-second range. These calibration times essentially bracket those of the papers used in these studies and are approximately the same as the acceptable calibration range specified by the ASTM (*1*). These large changes are directly traceable to differences in filter porosity.

Effect of Fuel Viscosity on Filterability. It is apparent that filter paper porosity is not the only significant factor in the filterability of contaminated fuels. If it were, the curves in Figures 3 and 4 would be approximately superimposed. On the contrary, there are large differences in the filterability curves from fuel to fuel. Consequently, another important factor is involved, as the filter paper variations for each fuel are accounted for by the data in Figures 3 and 4. Furthermore, the sediment was standardized by using a single batch of carbon. Hence, the relatively large displacements in the filterability curves must be due to intrinsic differences in the fuels themselves.

To investigate this latter possibility, the filterability of each carbon-contaminated fuel was compared to the flow time of the same fuel in a clean, filtered condition. A further series of experiments and correlations was made to accomplish this.

First, the flow time of a series of clean fuels was measured using calibrated filter papers. The flow time of each fuel versus calibration time is plotted in Figure 5. The data labeled "ASTM, 18-inch head" were obtained in the apparatus described in (*2*). The head of fuel, not the geometry of the apparatus, is the important factor. A difference in the head of fuel is reflected as a change in calibration time. If, in Figure 5, these data curves are cut by drawing a vertical line at a paper calibration time of 25 seconds, the fuel flow varies from 80 seconds per 100 ml. for fuel D139 to 190 seconds for D62. The flow times of the filtered fuels so obtained may be compared with the plugging volumes of these same fuels. The plugging volumes are taken from Figure 4, also at 25-second calibration. To check these values, several runs were made in which the clean fuel was followed by a run through the same paper with the same fuel containing 1.0 mg. of carbon per 100 ml. Both sets of values are plotted in Figure 6. The flow-time of each clean fuel is plotted against the plugging volume of the carbon-contaminated fuel. 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 or properties of the fuel and that this property is closely related to the flow time of clean fuel through filter paper of constant calibration.

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 at

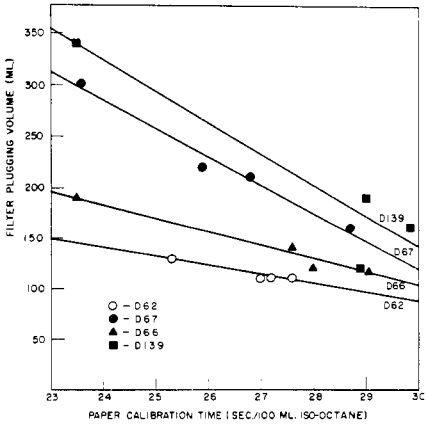

Figure 3. Effect on filter paper porosity on filterability of fuels contaminated with 2.0 mg. of carbon black per 100 ml.

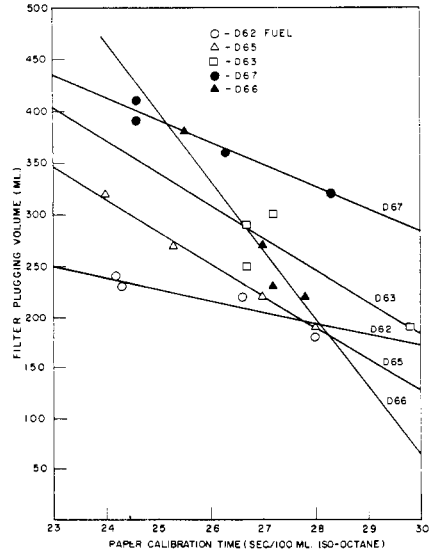

Figure 4. Effect on filter paper porosity on filterability of fuels contaminated with 1.0 mg. of carbon black per 100 ml.

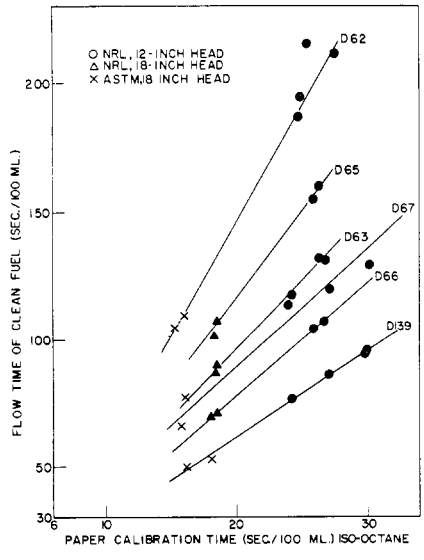

Figure 5. Effect on filter paper porosity on fuel flow, using two heads of fuel

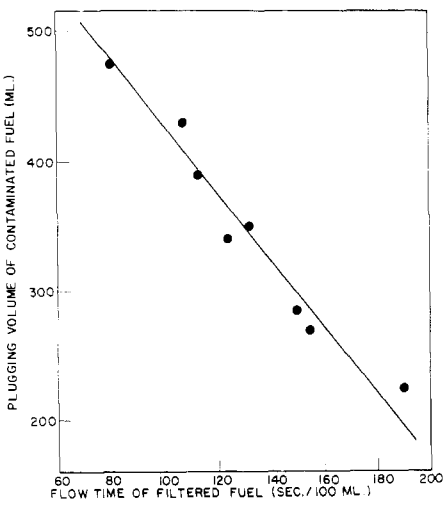

Figure 6. Flow of filtered fuel compared to filterability of fuel containing 1.0 mg. per 100 ml. of carbon at 72° F.

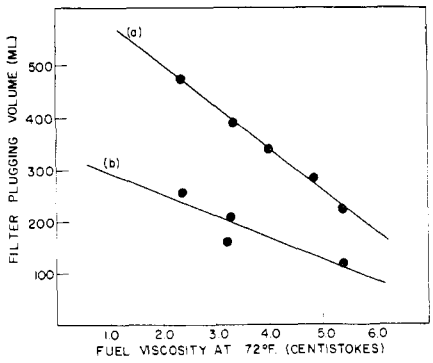

Figure 7. Effect of fuel viscosity on filtration of fuel contaminated with
a. 1.0 mg. carbon per 100 ml.
b. 2.0 mg. carbon per 100 ml.

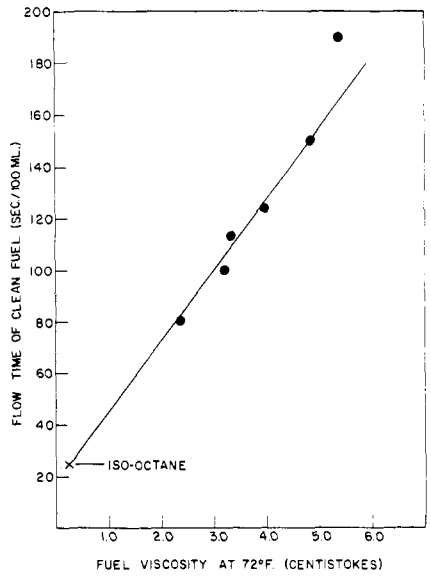

Figure 8. Effect of fuel viscosity on fuel flow through filter paper of 25-second iso-octane calibration

a constant calibration value of 25 seconds are plotted against fuel viscosity in Figure 7. The values for 1.0 and 2.0 mg. of carbon per 100 ml. of fuel are represented by curves *a* and *b*, respectively. An excellent correlation was obtained, showing that fuel viscosity is undoubtedly the fuel property having a major influence on filterability.

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, because the latter fuel has a lower viscosity. The curves in Figure 7 show that a fuel of viscosity of 5.5 centistokes containing 1.0 mg. of carbon per 100 ml. did plug sooner than a fuel with 2 mg. of carbon which had a viscosity of 2.5 centistokes.

A plot of viscosity *vs.* flow time of clean, filtered fuels is given in Figure 8. This corroborates the close relationship of fuel flow and fuel viscosity. Similar data for iso-octane fit neatly on the curve extrapolated from the fuel data.

General Considerations. The data obtained in the present studies show that some provision must be made to minimize or correct for the differences in filter paper, if a small-scale filterability method is to be useful. The selection of filter papers having calibration times in a range narrow enough to overcome the porosity effect would be awkward and is not proposed. The nonuniformity in filter paper is certainly magnified by the small filtering area used. However, an increase in filtering area to get better uniformity would increase the volume of fuel required for each test and this is undesirable and should be avoided if possible. It would be much better either to develop a filter medium of uniform porosity that would be suitable for assaying filterability or to adopt a means of compensating for differences in porosity of the paper-type filters now used. A limited number of calibrations with iso-octane of a cellulose ester (Millipore) filter showed it to have a fairly narrow porosity range. However, this range was still too broad for general use. In addition, the flow rate was considerably lower and the fragility of this material made handling difficult. Consequently, the practical expedient is to make corrections based on paper calibrations.

Several other fuel properties have been examined for effect on filterability. Such properties as specific gravity and soluble gum have been found to have negligible effect.

The original decision to operate at a constant temperature was well founded. It is consistent that because the viscosity of a fuel changes fairly markedly with temperature, and filterability is greatly dependent on viscosity, filtrations run at different temperatures may give widely varying results. For example, an average iso-octane calibration time of 25.0 seconds at 72° F. was found to decrease to 22.6 seconds at 100° F. Consequently, it is important to calibrate all papers at a constant temperature. Also, whereas fuel D62 plugged at 225 ml. at 72° F., the plugging volume increased to 385 ml. at 100° F. This illustrates the importance of temperature control to obtain reproducible results.

The relationship between the behavior of carbon contamination and natural sediment which develops on aging of a fuel has not yet been established. The reasons for choosing a fixed and controllable contaminant for these early studies are obvious, and the behavior of carbon relative to natural sediments remains to be determined. However, the marked effects of porosity on filterability found in this study are general in nature and therefore should also apply to natural sediments. Comparison of carbon contamination and natural sediment indicates that, in some cases at least, the nature and magnitude of the filter-plugging effect are similar. In addition, the effect of fuel viscosity is undoubtedly a general phenomenon.

To obtain meaningful results in fuel filterability, it is necessary to take proper consideration of filter porosity, fuel viscosity, and temperature.

ACKNOWLEDGMENT

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