PREPARATION OF 50 PERCENT BORON-HYDROCARBON SLURRIES
USING COMBINATIONS OF GLYCEROL SORBITAN LAURATE
WITH VARIOUS THICKENERS

By Irving A. Goodman and Virginia O. Fenn

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON
July 25, 1955
PREPARATION OF 50 PERCENT BORON-HYDROCARBON SLURRIES USING COMBINATIONS OF GLYCEROL SORBITAN LAURATE WITH VARIOUS THICKENERS

By Irving A. Goodman and Virginia O. Fenn

SUMMARY

Fluid slurries, containing 50 percent by weight of boron powder (1-micron average particle size) in JP-5 fuel, were prepared with the aid of small concentrations of glycerol sorbitan laurate (G-672) as a wetting or fluidizing agent. Seven commercial products were tested for their ability to thicken or stabilize the slurries containing glycerol sorbitan laurate.

The commercial thickening products tested were aluminum octoate, acetylene black, silica aerogel, a fine synthetic silica, a hydrated magnesium aluminum silicate, phenolic resin Microballoons, and dimethyldioctadecyl ammonium bentonite.

Brookfield apparent viscosity data were plotted against slurry age for varying concentrations of the two additive components of the slurry. The various additive formulations were evaluated on the basis of their effect on the viscosity, settling characteristics, and general physical appearance of the slurries.

The aluminum octoate - glycerol sorbitan laurate combination was studied in the greatest detail. Fluid, rather stable slurries could be prepared with this pair of additives, and minimum viscosities were obtained at glycerol sorbitan laurate concentrations of 0.7 to 0.9 percent with aluminum octoate concentrations of 0.3 to 0.4 percent.

The other six thickeners were tested in an exploratory way. All, with the possible exception of the fine silica and the phenolic resin Microballoons, could be used to produce slurries with satisfactory viscosity, stability, and physical appearance. None, however, appeared to show any distinct advantage over aluminum octoate in this respect.

INTRODUCTION

Elemental boron is of interest as a fuel for long-range ram-jet application because of its relatively high heating value, both on a weight
and volume basis. A stable, fluid, concentrated suspension of the very finely divided powder in jet fuel offers promise as a convenient physical form for utilizing boron as a ram-jet fuel.

Small and full-scale tests of the performance of boron slurry fuels in ram-jet burners have been reported (refs. 1 to 5). Reference 6 described a boron slurry formulation containing two additives, glycerol sorbitan laurate, a wetting agent (hereinafter to be designated by its trade name, G-672) and aluminum octoate, a thickening agent. Since viscosity data sometimes showed substantial changes for small increments of additive concentration, a more detailed study of these effects over a range of concentrations was undertaken.

As part of a continuing effort to improve the physical properties of a boron slurry, other additives were sought as possible substitutes for aluminum octoate. The other six commercial products selected for study included acetylene black, a silica aerogel (Santocel C), a fine synthetic silica (PL-171), a hydrated magnesium aluminum silicate (Parmagel), phenolic resin Microballoons, and dimethyldioctadecyl ammonium bentonite (Bentone-34).

The quantitative data presented herein have been restricted to apparent viscosities as determined on the Brookfield viscometer. Although such data may appear very erratic at times, they nevertheless do indicate gross trends. When accompanied by qualitative descriptions of the general appearance of the slurry and its stability or resistance to settling, the viscosity data may be used to screen the most promising formulations for further study. Until a better understanding of the rheology or flow characteristics of such systems is acquired, this type of data provides the main basis of comparison among the many slurry formulations studied. This report may be considered to supplement the information in reference 6.

EXPERIMENTAL

Materials

Boron, hydrocarbon, aluminum octoate, and G-672. - Among the materials used in this investigation, the boron, hydrocarbon, aluminum octoate, and G-672 were supplied from the same sources described in reference 6.

Wherever possible, a single drum of boron powder was used to complete the study of a given additive in order that trends might be definitely established. Analyses of samples from the five drums used in the investigation show average particle diameters (based on Sub-Sieve Sizer readings) of about 1 micron, moisture content (based on weight loss after
2-hr heating at 105° C) of zero to 0.8 percent, a free boron content of about 90 percent, and a water extract acidity (see ref. 6) of pH 5.3 to 5.9.

The hydrocarbon was a MIL-F-7914 (AER), grade JP-5 fuel, which, prior to use, had been percolated through a column packed with activated alumina.

Other additives. - The additives used are all very specific commercial products and were not modified or altered prior to use. The commercial designation and a brief description of each product, as provided by the supplier, is included. Typical physical properties, taken from descriptive literature, are listed in table I for those additives not previously described.

The acetylene black is a 99.5 percent pure carbon black made by the thermal decomposition of acetylene and supplied by Shawinigan Chemicals, Ltd.

Two types of finely divided silica were tested. One was a silica aerogel produced by the Monsanto Chemical Co. and marketed as Santocel C. It is described as an extremely porous, light, chemically inert material. The other was a synthetic experimental product supplied by the du Pont Chemical Co. and designated as PL-171. This material is described as consisting of "ultimate spherical particles" having pronounced hydrophobic, organophilic properties derived from a surface coating.

The hydrated magnesium aluminum silicate was a product marketed as Permagel by the Attapulgus Minerals and Chemical Corp. It is described as a highly colloidal, purified form of the mineral attapulgite. The particles are said to be small and needle-like with a length-to-diameter ratio of about 60.

The phenolic resin Microballoons are supplied by the Standard Oil Co. (Ohio). The product consists of small spherical hollow particles made from a phenolic resin and containing nitrogen sealed in at about atmospheric pressure.

The material chemically designated as dimethyldioctadecyl ammonium bentonite is better known by its trade name Bentone-34. It is produced by the National Lead Co. The product results from a cation exchange reaction between the appropriate quaternary ammonium salt and bentonite or its clay mineral component, montmorillonite. Under proper conditions, it has the property of gelling many organic liquid systems.

Slurry Preparation

The boron concentration was held at 50 percent by weight for all slurries studied in this investigation.
The method of preparation of slurries containing G-672 and aluminum octoate as additives was identical to that described in reference 6. Essentially the same procedure was also followed in the preparation of slurries containing the phenolic resin Microballoons in place of aluminum octoate.

A slight modification in the procedure was made for the other thickeners studied. For each of these, mixtures of boron, G-672, and JP-5 fuel were prepared in sufficient quantity to make up the number of samples needed. For example, 2000 grams of a mixture would be prepared containing 50 percent boron, 1 percent G-672, and 49 percent by weight of JP-5 fuel. This mixture would then be divided up into 400-gram batches and the desired concentration of thickener added to each. For a 0.5 percent thickener concentration, for example, 2 grams would be added. The resulting very slight deviation from the exact concentrations reported could not significantly affect the gross trends which were of prime interest.

All the additives were simply stirred in with the aid of a high-speed mixing unit. No special techniques were used in the application of any particular additive, since a comparison of the relative merit of the additives was desirable on the basis of a standard method of slurry preparation.

Measurement of Slurry Viscosities

All the viscosity data reported were obtained on the Brookfield rotational viscometer, previously described in reference 7, according to the procedure described in references 7 and 8. The procedure may be summarized as follows:

Viscosities were determined on all samples at 30°C (86°F). In general, the number 3 spindle was used at 12 rpm for slurries with apparent viscosities of less than 10,000 centipoises, while the number 4 spindle at 6 rpm was used for slurries of higher viscosity. Each sample, prior to viscosity measurement, was thoroughly stirred with a spatula until it appeared homogeneous. An arbitrarily chosen 30-second interval of spindle rotation was adopted as standard, and no spindle guard was used.

Usually, viscosity determinations were made within 1 or 2 hours after slurry preparation, then about every other day for 2 weeks, and finally about weekly thereafter until the sample was discarded. The sample was discarded when, in the operator's judgment, the settled portion of the slurry became so hard and difficult to redisperse that further data would be of little value. In all the figures showing viscosity-age histories, the symbol // signifies the age at which the slurry was discarded.
The physical appearance of the slurry was qualitatively noted prior to and after each remixing. These observations were useful aids in evaluating the slurry, since the Brookfield apparent viscosity in itself is not an adequate criterion for this purpose. Actually, in many cases, the apparent viscosities were recorded over a longer period of time than would appear justified on the basis of physical appearance.

RESULTS AND DISCUSSION

In order to provide a reasonable basis for comparing various slurries, the results obtained for each combination of additives are discussed in two ways. First, the effect of additive type and concentration as well as slurry age on Brookfield apparent viscosity is considered. Secondly, it is also necessary to discuss the appearance of the slurry prior to remixing for viscosity measurement. These two criteria, evaluated in the light of each other, may then be used to judge the merits of a given additive concentration.

G-672 and Aluminum Octoate

Viscosity. - Figure 1 shows the effect of variation of G-672 concentration on the apparent viscosity-age history of slurries containing zero, 0.2, 0.3, and 0.4 percent aluminum octoate. As might be expected, slurries prepared without aluminum octoate (fig. 1(a)) decreased in apparent viscosity as the G-672 concentration was increased from 0.9 to 2.1 percent by weight. Slurries containing less than 0.9 percent G-672 were so viscous that they exceeded the capacity of the viscometer throughout the period of observation. The 0.9 percent slurry showed extremely erratic behavior throughout, although the scatter of the viscosity readings seemed to lessen as the slurry aged. Slurries containing 1.2 and 1.5 percent followed each other rather closely in viscosity-age history, as did the 1.8 and 2.1 percent slurries.

The combination of G-672 and aluminum octoate in certain proportions resulted in some rather unexpected effects on the apparent viscosity-age history of the slurries (figs. 1(b) to (d)). Although aluminum octoate itself is generally considered to be a gelling or thickening agent, the observed viscosity decrease due to additive was more pronounced in the presence of aluminum octoate than without it. For example, 0.7 percent G-672 with no aluminum octoate gave a slurry too viscous to measure on the viscometer. On the other hand, 0.6 percent G-672 and 0.2 percent aluminum octoate lowered the viscosity to 4000 to 7000 centipoises. A slurry containing 0.75 percent G-672 with 0.2 percent aluminum octoate leveled off at an apparent viscosity of about 5000 centipoises; 0.6 percent G-672 and 0.3 percent aluminum octoate had about the same effect; whereas, with 0.7 percent G-672 and 0.4 percent aluminum octoate, the
viscosity dropped to about 500 to 1000 centipoises. It is also of interest to note that higher concentrations of G-672, namely 1.3 and 1.6 percent, in the presence of 0.4 percent aluminum octoate gave slurries of higher viscosity than that containing only 0.7 percent G-672. Apparently, for a given aluminum octoate concentration, a minimum apparent viscosity occurs in a specific G-672 concentration range.

In figure 2, the viscosity data are plotted against G-672 concentration for slurries which had aged 1 hour, 1 day, and 3 or 4 days. It is particularly evident in figures 2(c) and (d) that the greatest change in viscosity with slurry age occurs at G-672 concentrations of 0.7 to 0.9 percent and aluminum octoate concentrations of 0.3 to 0.4 percent. This effect is not as distinct in figures 2(a) and (b), where aluminum octoate is either absent or in low concentration.

The phenomenon of a minimum viscosity exhibited in this type of system may be compared with that reported in reference 9, in which benzene solutions of sodium phenyl stearate and the effect of small additions of water, acid, alcohol, phenol, glycol, amine, and ketone on the viscosity were studied. It was observed that the addition of a small amount of water (about 0.5 mole per equivalent of dissolved soap) resulted in a sharp drop in viscosity to a minimum, followed by increases in viscosity with further small additions of water. In the present work, the amount of water dissolved in the G-672 could conceivably be sufficient to produce the effect; or the G-672 itself, because of its polar character, could be exerting this influence on the JP-5 solution of aluminum octoate.

The viscosities of all of the slurries containing G-672, with and without aluminum octoate, sooner or later dropped into what is usually considered a desirable range, that is, below 7000 to 8000 centipoises. Many of these slurries initially showed very high viscosities and required aging for as long as 3 weeks before the viscosity dropped to the desired level.

General appearance and evaluation. - None of the slurries in this group could be considered perfectly stable. When their viscosities had dropped sufficiently, the samples would invariably show a supernatant liquid up to 1/2 inch in depth. The main body of the slurry might be soft and smooth throughout, but generally had a thin layer of gummy sediment after a few days. All the slurries in the group had these characteristics to a greater or lesser degree. The anticipated slurry storage time, and the specific application for which the slurry is considered, will determine the desired viscosity. This viscosity, in turn, dictates the selection of a particular additive formulation.
Acetylene Black and G-672

Viscosity. - The effect of acetylene black concentration on the viscosity-age history of boron slurries with concentrations of 1.0 and 1.5 percent G-672 is shown in figure 3.

Figure 3(a) shows that, for slurries containing 1.0 percent G-672, the apparent viscosity increases from about 3500 to about 15,000 centipoises as the acetylene black concentration is increased from zero to 1.0 percent. On the basis of these viscosity data, probably no more than 0.5 percent acetylene black could be tolerated for a practical slurry fuel. As a matter of fact, the slurry containing no acetylene black indicated a very desirable viscosity level. All four of the slurries in this group show relatively constant viscosity over the entire period of study.

Figure 3(b) is a similar plot for slurries containing 1.5 percent G-672 and acetylene black concentrations up to 1.5 percent. Because of the increased G-672 concentration, generally lower apparent viscosities were observed for given acetylene black concentrations. Relatively constant viscosities were again noted except during the first week or two of aging. The expected trend of increased viscosity with increased acetylene black concentration was also observed.

General appearance and evaluation. - All the slurries containing 1.0 percent G-672 were relatively stable, as implied by the long period of viscosity measurement (fig. 3(a)). Except for the usual supernatant liquid up to 1/2 inch deep, these slurries had a generally soft, smooth consistency with little or no sediment. The two slurries of higher viscosity (0.5 and 1.0 percent acetylene black) did not flow readily as liquids but rather resembled the consistency of mayonnaise.

The slurries containing 1.5 percent G-672 were less promising. Those containing 1.0 and 1.5 percent acetylene black were the most stable, but had excessively high apparent viscosities. The other three slurries, while in the desirable viscosity range, had poor physical characteristics. For example, after about 2 weeks, appreciable amounts of hard sediment were noted in these, and although viscosity measurements were continued for some time after that, the condition of the slurries probably did not warrant it.

On the basis of limited experimental data, acetylene black appeared to have acceptable stabilizing characteristics. Some of the samples, containing only very low concentrations of acetylene black, displayed relatively constant viscosity and good stability. Although the slurry containing 1.0 percent G-672 and no acetylene black also had desirable properties, a small percentage of acetylene black, perhaps 0.25 to 0.5 percent, is probably advisable in order to minimize settling. There is
apparently no reason for using G-672 concentrations greater than 1.0 per-
cent, since correspondingly greater acetylene black concentrations are
then required for stabilization.

Silica Aerogel (Santocel C) and G-672

**Viscosity.** - Viscosity-age data for slurries containing 1.0 and 1.5 percent G-672 and Santocel C concentrations up to 1.0 and 2.0 percent, respectively, are presented in figure 4.

Santocel C increased the viscosity of the slurries containing 1.0 percent G-672 to almost the same extent as acetylene black for a given concentration. There was more difference in effect of the two thickeners in the slurries containing 1.5 percent G-672. The slurry containing 1.5 percent acetylene black, for example, had a viscosity of about 20,000 centipoises, as compared with only about 4000 centipoises for the corres-
ponding Santocel C slurry.

**General appearance and evaluation.** - Slurries prepared with Santocel C are also very similar to the acetylene black slurries in physical appearance and stability. The noncombustibility of the Santocel is perhaps its only relative disadvantage, and this could hardly be considered a serious factor at such low concentrations.

Fine Silica (PL-171) and G-672

**Viscosity.** - Viscosity-age data for slurries containing 1.0 percent G-672 and concentrations of PL-171 up to 1.5 percent are plotted in figure 5. Differences introduced by the particular batch of boron powder used are evidenced by the low viscosity of the sample containing no PL-171. Samples containing 1.5 percent G-672 were not studied with this additive, because, for the particular drum of boron used in this study, the amount of PL-171 required for adequate thickening was deemed excessive.

**General appearance and evaluation.** - For this particular boron powder, the samples had generally poor physical qualities. Even the most stable of the samples prepared, which contained 1.5 percent PL-171, was not very satisfactory in appearance. Its viscosity leveled off at about 7000 to 7500 centipoises, but after less than 2 months, it had a rather hard, lumpy consistency.
Hydrated Magnesium Aluminum Silicate (Permagel) and G-672

Viscosity. - The effect of Permagel additions on the viscosity-age history of boron slurries containing 1.5 percent G-672 is shown in figure 6. Slurries containing 1.0 percent G-672 were not studied with Permagel. Since the sample containing no Permagel had a viscosity similar to the corresponding control samples (no thickener) of figures 3(b) and 4(b), the boron powder used here may be assumed to be similar. It then appears that Permagel is in general not nearly so effective a thickener as acetylene black, but somewhat comparable to Santocel C for 1.5 percent G-672 (see figs. 3(b) and 4(b)). For example, a slurry containing 1.5 percent G-672 and 1.5 percent Permagel had an apparent viscosity of about 3000 to 4000 centipoises. A slurry of similar composition, containing 1.5 percent acetylene black, had a viscosity of 10,000 to 12,000 centipoises, while the viscosity of the corresponding Santocel C slurry was about 4000 centipoises.

General appearance and evaluation. - The properties of the Permagel slurries in the higher viscosity range were acceptable. Although the 1.5 and 2.0 percent Permagel slurries showed somewhat erratic viscosity behavior at times, the main body of the slurry remained in a generally satisfactory condition throughout the period of viscosity measurement. However, since higher concentrations of Permagel were necessary for a given viscosity and for good stability, it offers less promise of application as a slurry stabilizer than most of the other materials tested.

Phenolic Resin Microballoons and G-672

Viscosity. - The effect of Microballoon concentration on the apparent viscosity-age history of boron slurries containing 1.5 percent G-672 is shown in figure 7. Because these Microballoons are hollow particles, they would naturally tend to lower the density of the slurry. A 50 percent boron slurry containing 5 percent by weight of the Microballoons actually has a density about 10 percent lower than that of the same slurry without additive. Greater concentrations than this were therefore not considered.

As the Microballoon concentration is increased from zero to 4 percent, a gradual increase in apparent viscosity from 1700 to about 3000 centipoises occurred. This is a very small increase for the relatively large increase in additive concentration.

General appearance and evaluation. - The sediment in these slurries was generally very gummy, and the stability appeared to be no better than that of the sample containing no Microballoons. The apparent exception to this observation, indicated in figure 7 for the 3.0 percent additive, is
not considered significant, since the physical appearance of all of these slurries was poor. The longer period of apparent viscosity measurements in this case was not justified. It is apparent that little can be gained from the use of this material as an additive in the acceptable range of concentrations.

Dimethyldioctadecyl Ammonium Bentonite (Bentone-34) and G-672

Viscosity. - Figure 8 shows the apparent viscosity-age data obtained for boron slurries containing 1.0 or 1.5 percent G-672 and Bentone-34 concentrations up to 1.5 percent by weight. The apparent viscosity increases as the Bentone-34 concentration is increased.

Although the slurry containing 1.0 percent G-672 and 1.0 percent Bentone-34 (fig. 8(a)) had a fairly constant apparent viscosity of about 10,000 centipoises, it was actually almost the same in appearance and viscosity as the slurry containing 1.5 percent of each additive (fig. 8(b)). The numerical differences in the viscosity data result from the fact that two different viscometer spindles were used in measuring the viscosities. All the data for the first slurry (fig. 8(a)) were obtained by use of the number 4 spindle. In figure 8(b), the indicated viscosities of 10,000 centipoises or greater were obtained with the number 4 spindle, whereas the others, averaging about 7500 centipoises, were obtained with the number 3 spindle.

General appearance and evaluation. - Slurry stability was relatively poor except for the two higher viscosity samples, which contained 1.0 and 1.5 percent of each additive. The slurry that contained 1 percent of each additive appeared particularly good. The body of the slurry remained soft and smooth almost throughout the period of viscosity measurement, although the usual supernatant liquid layer was observed. While the slurry containing 1.5 percent of each additive had the same apparent viscosity as that containing 1.0 percent, it did not have the same physical appearance. After about 1 month of aging, a sticky settled portion began to appear in it, and with further aging, the slurry assumed a grainy, somewhat lumpy appearance. The consistency of the more stable of these slurries is similar to that of mayonnaise. It appears, then, that Bentone-34, in certain concentrations, may possibly be useful as a slurry stabilizing agent.

GENERAL REMARKS

The apparently erratic viscosity data observed in many cases may be due to several causes. In the case of very high viscosities, the
viscometer spindle sometimes cuts a channel in the slurry, causing slip-
page and thus indicating erroneously low values. Below about 10,000
centipoises spindle number 4 was replaced by number 3 for reasons of
added instrument sensitivity. This change in viscometer spindle was
shown to cause discontinuities in the apparent viscosity-age curves due
to the accompanying change in rate of shear.

Another possible cause of erratic results may be attributed to non-
uniform remixing prior to viscosity measurement. Although stirring was
continued in each case until the sample appeared homogeneous, this treat-
ment may have been inadequate in some difficult cases.

The surface effects associated with the types of additives studied
are not instantaneous. This may account for the irregularities observed
during the first 2 or 3 weeks of the slurry's life. The viscosity read-
ings generally become more uniform as the slurry ages.

It should be emphasized again that the results reported herein can-
not be completely generalized. They are specific for the particular
batches of additive used. Because of the nature of many of these addi-
tives, the results could vary considerably with different lots of ma-
terial. In spite of its limitations, however, the information does in-
dicate trends and can be used as a guide in choosing approximate additive
concentrations for desired properties. As was pointed out in reference
6, the boron powder itself may have a profound influence on slurry prop-
erties. This factor must also be considered in evaluating these results.

CONCLUDING REMARKS

This experimental investigation has demonstrated some unusual con-
centration effects involving aluminum octoate and G-672 in 50 percent
boron slurries. Certain combinations of the two additives, for example,
will result in a much lower apparent viscosity, with good stability, than
could be obtained without the aluminum octoate, which by itself generally
functions as a thickening or gelling agent. As a result, it appears pos-
sible that the total additive concentration required for satisfactory vis-
cosity and stability may be appreciably reduced if desired.

The second part of this investigation consisted of a preliminary
study of six prospective substitutes for aluminum octoate. The data are
limited in kind and in quantity, and no special techniques were developed
for the use of each individual additive. It appears, however, that acety-
ylene black, Santocel C, Permagel, or Bentone-34 could be used in con-
junction with G-672 to prepare a satisfactorily fluid and stable boron
slurry. The fine silica (PL-171) and phenolic resin Microballoons were
not deemed promising for this application. None of the additives showed
any marked advantage over the currently used aluminum octoate. It may
be, however, that some of them are less sensitive than aluminum octoate to chemical reaction or the presence of moisture and other polar materials. If so, greater reproducibility might be insured by their use. More work on these materials would be necessary, however, to establish definitely whether this is true.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, May 18, 1955

REFERENCES


### TABLE I. - TYPICAL PROPERTIES OF ADDITIVES (AS REPORTED BY SUPPLIER)

<table>
<thead>
<tr>
<th>Name and source</th>
<th>Chemical composition</th>
<th>Mean particle size, micron</th>
<th>Specific surface, sq m/g</th>
<th>Bulk density, lb/cu ft</th>
<th>Particle density, g/cc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetylene black</td>
<td>99.5 Percent carbon</td>
<td>0.04</td>
<td>70</td>
<td>6.25</td>
<td>1.95</td>
</tr>
<tr>
<td>(Shawinigan Chemicals, Ltd.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Santocel C</td>
<td>90 Percent SiO₂</td>
<td>4.00</td>
<td>600</td>
<td>6.00</td>
<td>2.05</td>
</tr>
<tr>
<td>(Monsanto Chemical Co.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PL-171</td>
<td>89 Percent SiO₂</td>
<td>.01</td>
<td>300</td>
<td>20.0</td>
<td>----</td>
</tr>
<tr>
<td>(du Pont Chemical Co.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permagel</td>
<td>Hydrated magnesium</td>
<td>----</td>
<td>---</td>
<td>40.0</td>
<td>2.45</td>
</tr>
<tr>
<td>(Attapulgus Minerals and Chemical Corp.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microballoons</td>
<td>Phenolic resin</td>
<td>33.00</td>
<td>---</td>
<td>8.7</td>
<td>.33</td>
</tr>
<tr>
<td>(Standard Oil Co. (Ohio))</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bentone-34</td>
<td>Dimethyldioctadecyl</td>
<td>1.00</td>
<td>---</td>
<td>110.0</td>
<td>1.80</td>
</tr>
<tr>
<td>(National Lead Co.)</td>
<td>ammonium bentonite</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 1. - Continued. Brookfield apparent viscosity against age for 50 percent boron slurries in JP-5 fuel containing various concentrations of G-672 and aluminum octoate.
Figure 1. - Continued. Brookfield apparent viscosity against age for 50 percent boron slurries in JP-8 fuel containing various concentrations of 0-672 and aluminum octoate.
Figure 1. - Concluded. Brookfield apparent viscosity against age for 50 percent boron slurries in JP-5 fuel containing various concentrations of G-372 and aluminum octoate.
Figure 2. - Brookfield apparent viscosity against G-672 concentration for 50 percent boron slurries in JP-5 fuel containing various concentrations of aluminum octoate.

(a) No aluminum octoate.
Figure 2. - Continued. Brookfield apparent viscosity against G-672 concentration for 50 percent boron slurries in JP-5 fuel containing various concentrations of aluminum octoate.
0.3 Percent aluminum octoate.

Figure 2. - Continued. Brookfield apparent viscosity against 0-672 concentration for 50 percent boron slurries in JP-5 fuel containing various concentrations of aluminum octoate.
Figure 2. - Concluded. Brookfield apparent viscosity against G-672 concentration for 50 percent boron slurries in JP-5 fuel containing various concentrations of aluminum octoate.

(d) 0.4 Percent aluminum octoate.
Figure 3. - Brookfield apparent viscosity against age for 50 percent boron slurries in JP-5 fuel containing G-672 and various concentrations of acetylene black.
Figure 5. - Brookfield apparent viscosity against age for 50 percent boron slurries in JP-5 fuel containing G-672 and various concentrations of fine silica (PL-171).
Figure 6. - Brookfield apparent viscosity against age for 50 percent boron slurries in JP-5 fuel containing 1.5 percent G-672 and various concentrations of hydrated magnesium aluminum silicate (Permagel).
Figure 7. - Brookfield apparent viscosity against age for 50 percent boron slurries in JP-5 fuel containing 1.5 percent G-672 and various concentrations of phenolic resin Microballoons.
Figure 8. Brookfield apparent viscosity of slurry for 50 percent boron slurries in JP-5 fuel containing 0.472 and various concentrations of dimethyl dihydrocarboxylate amourium bentonite.
Figure 8.- Concluded. Brookfield apparent viscosity against age for 50 percent boron slurries in JP-5 fuel containing 0.6 percent sodium borate (bentone-34).