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# RESEARCH MEMORANDUM

EFFECT OF TEMPERATURE ON VISCOSITY OF SLURRIES OF  
BORON AND MAGNESIUM IN JP-5 FUEL

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## NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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RESEARCH MEMORANDUMEFFECT OF TEMPERATURE ON VISCOSITY OF SLURRIES OF BORON  
AND MAGNESIUM IN JP-5 FUEL

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## SUMMARY

The viscosities of slurries containing 50 to 65 percent by weight of boron in JP-5 fuel were determined at temperatures from 30° to 80° C (86° to 176° F), and of slurries containing 50 percent by weight of magnesium in JP-5 fuel from -40° to 80° C (-40° to 176° F).

Plastic viscosities of the boron slurries as calculated from Severs Rheometer and Stormer viscometer data decreased consistently with an increase in temperature. Apparent viscosity of boron slurries did not change regularly with temperature.

An exponential curve of the form  $\log y = aT + b$  fits the viscosity-temperature relation for the magnesium slurries from about 0° to 80° C, but does not fit the data below 0° C. The plastic viscosity and yield value of these slurries decreased with increasing temperature. The magnesium slurries can probably be used as aircraft fuels to temperatures as low as -30° C.

## INTRODUCTION

The use of hydrocarbon suspensions of magnesium and boron particles for jet fuels is being studied at the NACA Lewis laboratory. Potentially, such fuels have decided advantages over hydrocarbon fuels either in added range (boron slurries) or in greater thrust (magnesium slurries). A summary of the work through 1954 on the preparation and properties of slurries is given in reference 1.

Control of the physical properties of these slurries is necessary in order to ensure consistent results in their application as aircraft fuels. Of these properties, viscosity is of primary importance because of its relation to stability, pumping, and spraying.



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Most of the viscosity data reported previously (ref. 1) have been measured at or near 30° C (86° F). However, in practice, slurries must be stored and used over wide ranges of temperature. Therefore, data showing variations of slurry viscosity with temperature are needed.

An investigation of the effect of temperature on the viscosity of several slurries is described herein. The viscosities of the slurries containing 50, 60, and 65 percent by weight of boron were measured at 30°, 50°, and 80° C (86°, 122°, and 176° F). The viscosities of 50 percent by weight of magnesium (vapor-process magnesium, ref. 2) slurries were measured from -40° to 80° C (-40° to 176° F).

## EXPERIMENTAL DETAILS

### Materials

Boron powder. - The boron powder was prepared commercially by the thermal reduction of boric oxide with magnesium (ref. 3); the average particle size was approximately 1 micron as determined by the air-permeability method with the Fisher Sub-Sieve Sizer. The purity was about 90 percent free boron and was quite similar to the low-acidity boron described in reference 4.

Magnesium. - The magnesium was prepared at the Lewis laboratory by shock-chilling magnesium vapor with liquid hydrocarbon fuel as described in reference 2. This magnesium is referred to as vapor-process magnesium throughout the report. The two batches used had a purity of 92 percent free magnesium. Sedimentation analysis indicated that 50 percent by weight of the magnesium powder was smaller than 4 microns.

Hydrocarbon medium. - Throughout the investigation MIL-F-7914, grade JP-5, fuel with the properties listed in table I was used.

Additives. - Aluminum octoate ("fast gelling"), produced by the Witco Chemical Company, was used to gel the boron slurries.

The surface-active agent was glycerol sorbitan laurate, manufactured by the Atlas Powder Company and designated by the trade name G-672. Both additives are described more fully in reference 4.

### Preparation of Slurries

Boron. - The boron slurries were made by adding the boron powder to a suspension of aluminum octoate (if used) and G-672 in JP-5 fuel. The partially dry mixture was mixed by shaking with a commercial paint conditioner followed by intensive mixing until the slurry was smooth and free from lumps. The high-speed dispersing unit described in reference 4 was used in this final mixing operation.

Magnesium. - Two batches of magnesium slurry were prepared by diluting the concentrated (60 to 75 percent solid) vapor-process magnesium to 50 percent with the required JP-5 fuel and G-672 and shaking with the paint conditioner. The concentration of G-672 in each batch was about 0.5 percent.

#### Viscosity Measurements

Since the viscosities of the gelled boron slurries change with time (ref. 4), most of the measurements were made 1 day after preparation. In addition, one sample was aged until the Stormer viscosity remained constant at 30° C (8 days after preparation) before the Stormer measurements were made at elevated temperatures.

Viscosities of the magnesium slurries were measured only with the Stormer viscometer, and temperature studies were made when the viscosity at 30° C had reached a constant value with time.

Brookfield. - The Brookfield apparent viscosity was a one-point measurement at a low rate of shear, made with a model LVF Brookfield Synchro-lectric viscometer. The instrument and its method of operation and precision are fully described in reference 5. The number 3 spindle at 12 rpm (rate of shear, approximately 10 sec<sup>-1</sup>) was used for viscosities below 10,000 centipoises, and the number 4 spindle at 6 rpm (rate of shear, approximately 0.5 sec<sup>-1</sup>) was used for higher viscosities. The measurements were made in 1-pint paint cans immersed in a bath at the desired temperature.

Severs. - Severs flow curves were plotted from data obtained with a Severs Extrusion Rheometer. The operation and constants of this instrument are discussed in reference 5. The construction was modified by the addition of a concentric jacket around the slurry chamber and orifice. Temperature was controlled by circulating mineral oil from a constant-temperature bath through the jacket. The orifice tube was 0.2011 centimeter in diameter and 5.00 centimeters long. Plastic viscosity was calculated from the slope of the shear rate - shearing stress curve (sec<sup>-1</sup> against psi).

Stormer. - Stormer flow curves were plotted from data obtained on a commercial Stormer viscometer modified as described in reference 4. Plastic viscosity was calculated from the straight-line portion of the plot of rate of rotation against applied load according to the following equation:

$$U = \frac{0.040}{\text{Slope of line}}$$

where  $U$  is the plastic viscosity in poises and 0.040 is the instrumental constant. When the "up" curve and "down" curve did not coincide, the down curve was used for the calculation. In order to calculate the yield value in dynes per square centimeter, the linear portion of the down curve was extrapolated to the load axis and the intercept was multiplied by 2.3. Yield values were calculated only for the magnesium slurries.

The bath, supplied with the instrument, was heated with a thermostated heater for temperature above room temperature and cooled with dry ice for temperatures below room temperature. An atmosphere of dry nitrogen was provided above the sample to prevent condensation of moisture during the low-temperature determinations.

## RESULTS AND DISCUSSION

Viscosities of slurries consisting of 50, 60, and 65 percent boron in JP-5 fuel were measured at 30°, 50°, and 80° C with the Brookfield, Severs, and Stormer viscometers. The Brookfield apparent viscosities are presented in table II. Flow curves and plastic viscosities obtained with Severs and Stormer viscometers are plotted in figures 1 to 4.

Flow curves and plastic viscosities of 50 percent slurries of vapor-process magnesium in JP-5 fuel were obtained over the range of -40° to 80° C with a Stormer viscometer. The data along with yield values are presented in figures 5 to 7.

A discussion of the different flow curves and the methods of determining viscosity and yield value are given in the appendix.

### Boron Slurries

Brookfield apparent viscosity. - Brookfield viscosities of several boron slurries at 30°, 50°, and 80° C (86°, 122°, and 176° F) are shown in table II. Brookfield viscosities are apparent viscosities at low rates of shear and did not change consistently with temperature in most of the data shown. A possible explanation is given in the appendix.

Severs viscosity. - Severs Rheometer flow curves are shown in figure 1. Figure 1(a) is typical of the data obtained from slurries of 50 to 60 percent boron. At any one temperature, the plastic viscosity did not change with an increased rate of shear. The plastic viscosity as measured by the reciprocal of the slope of the rate of shear - shearing stress curve decreases consistently from 30° to 80° C.

The effect of increasing the boron concentration to 65 percent by weight and omitting the aluminum octoate is shown in figure 1(b). The

viscosities at 30° and 50° increase with an increased rate of shear and therefore are typical of dilatant systems (see appendix). At 30°, for example, the plastic viscosity was 4.5 poises up to a rate of shear of about 600 reciprocal seconds and 7.0 poises above 600 reciprocal seconds. The scatter of data at 80° C makes it difficult to determine whether or not dilatancy was present.

3738 Stormer viscosity. - Figure 2 shows Stormer flow curves for a 50-percent-boron slurry at various temperatures. The curves are representative of the 50- and 60-percent-boron slurries with aluminum octoate as an additive. The plastic viscosity decreases progressively with an increase in temperature. The size of the loop (see appendix) also decreases with an increase in temperature. The flow curves for a 65-percent slurry with no aluminum octoate were similar but had a much smaller loop. The curves indicated a slight degree of dilatancy at the higher rates of shear comparable with the data obtained with the Severs Rheometer.

Effect of temperature. - Plastic viscosities obtained on the Stormer viscometer for several boron slurries are presented in figure 3. At 80° C the plastic viscosities of the thinner slurries were one-fourth to one-half the viscosity at 30° C, while the viscosity of the thickest slurry was only about one-eighth of the value at 30°.

Figure 4 is a comparison of the plastic viscosities determined on the Stormer viscometer with those obtained on the Severs Rheometer. The values used for the 65-percent slurry were from the lower part of the curves obtained on the Severs viscometer (see fig. 1(b)), since those rates of shear are comparable with the rates of shear obtainable on the Stormer viscometer. The trends of the viscosities with temperature on the two instruments are very similar, despite the differences in absolute values of the viscosities. The difference in values may be due in part to the fact that the Severs Rheometer measures flow of material that has experienced no thixotropic breakdown; whereas, the sample in the Stormer viscometer was sheared continuously from the start to the end of the determination.

#### Magnesium Slurries

Stormer viscosity. - Stormer flow curves at five temperatures for a 50-percent-magnesium slurry are shown in figure 5. The up and down portions of the curve coincide, indicating no thixotropy. The curves are quite similar to ones obtained from Bingham plastics with rotational viscometers (ref. 6).

Effect of temperature. - The change of plastic viscosity with temperature for two magnesium slurries is shown in figure 6. The change of viscosity of JP-5 fuel is plotted on figure 6 for comparison. An

exponential curve of the form  $\log y = aT + b$  fits the viscosity-temperature relation for magnesium slurries from about 0° to 80° C but does not fit the data below 0° C. The plastic viscosity decreased with increasing temperature. For sample 1 at 80° C, the plastic viscosity was about one-half of the value at 30° C, and at 30° C the plastic viscosity was about one-fifth of that at -30° C. The plastic viscosities of these slurries apparently remain low enough for use as aircraft fuels to about -30° C (approximately -20° F).

Figure 7 is a plot of the change of yield values of the 50-percent-magnesium slurries with temperature. The curves have the same general shape as the viscosity-temperature curves. At 50° C, the yield values were about one-third of those at -30° C. The higher values for sample 2 could limit its use to temperatures above about 0° C. The cause for the higher values is unknown at this time.

## SUMMARY OF RESULTS

### Boron

A study of the effect of temperature on the viscosity of boron-slurry fuels consisting of 50, 60, or 65 percent by weight of boron, JP-5 fuel, and various concentrations of G-672 and aluminum octoate gave the following results 1 day after preparation of the slurries:

1. At 30° C, the plastic viscosities of the slurries containing 50 and 60 percent boron (with aluminum octoate) and 65 percent boron (without aluminum octoate) were 2.5, 17, and 4 poises, respectively, as determined with the Stormer viscometer, or about 150 to 1000 times the viscosity of JP-5 fuel. Similar plastic viscosities were obtained with the Severs Rheometer.

2. Raising the temperature from 30° to 80° C (a) decreased the plastic viscosity of the slurries by about 50 to 80 percent (the viscosity of JP-5 fuel decreases by about 50 percent over this temperature range); (b) decreased the degree of thixotropy of the slurries; (c) did not affect the Brookfield apparent viscosity of the slurries in a consistent manner.

### Magnesium

A study of the effect of temperature on a slurry consisting of 50 percent by weight of vapor-process magnesium, JP-5 fuel, and approximately 0.5 percent G-672 gave the following results:

1. The plastic viscosity as determined with the Stormer viscometer was 0.5 poise at 30° C, or about 30 times the viscosity of JP-5 fuel.

2. Raising the temperature from 30° to 80° C (a) decreased the plastic viscosity by about 50 percent; (b) decreased the yield value by about 20 percent.

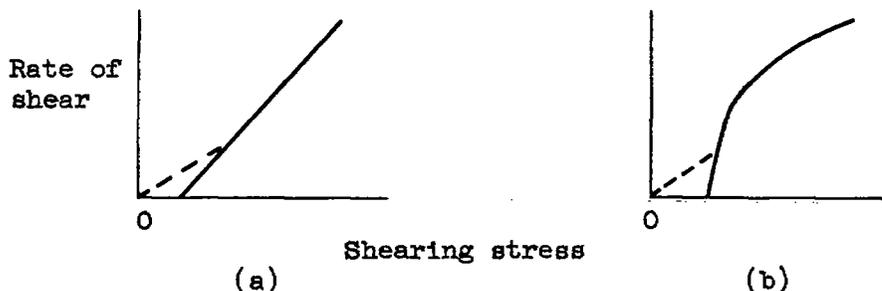
3. In the temperature range 0° to 80° C, the equation of the form  $\log y = aT + b$  fitted the viscosity-temperature curve. This equation did not fit the curve at temperatures below 0° C.

Lewis Flight Propulsion Laboratory  
National Advisory Committee for Aeronautics  
Cleveland, Ohio, May 27, 1955

## APPENDIX - FLOW CURVES AND VISCOSITY OF SLURRIES

## Boron Slurries

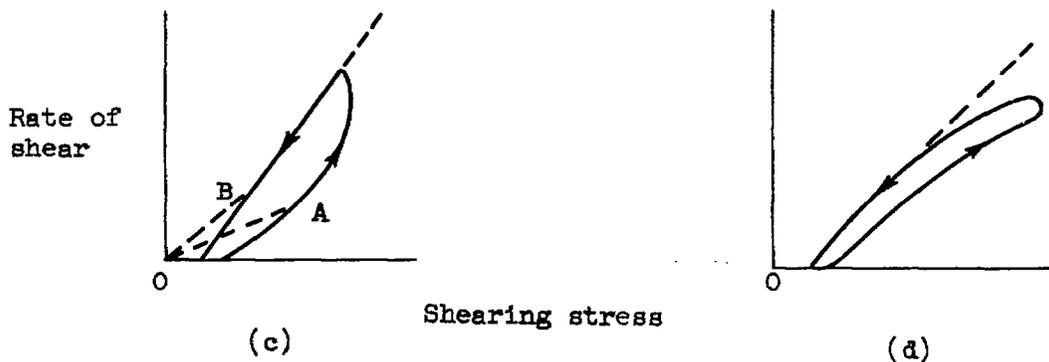
Severs Rheometer. - The plots of data obtained from a Severs Rheometer with boron slurries were of the general shape shown in the following sketches:



Plastic viscosity in poises is given by the reciprocal of the slope of the straight line when the rate of shear is expressed in reciprocal seconds and the shearing stress in dynes per square centimeters. Thus, the viscosity of sketch (a) remains constant over a range of shear rate, while the viscosity of sketch (b) decreases with an increased rate of shear. By definition, a dilatant material is one whose viscosity increases with an increased rate of shear.

The apparent viscosity is given by the reciprocal of the slope of a line from the origin of the plot to a point on the flow curve as shown by the dotted lines.

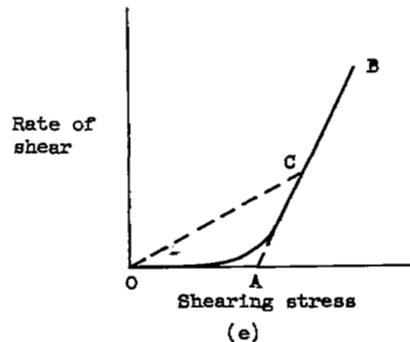
Stormer viscometer. - Plots of the Stormer viscometer data for the boron slurries are shown in the following sketches:



The data are obtained by increasing the shearing stress stepwise and measuring the rate of shear at each increase until the upper limit of the instrument is reached (approx.  $1000 \text{ sec}^{-1}$ ). The shearing stress is then decreased stepwise until the lower limit is reached (approx.  $2 \text{ sec}^{-1}$ ). The two portions of the curve thus obtained are designated by the arrows and by the terms "up" and "down" portions of the curve. Separation of the up and down portions to form a loop is an indication of thixotropy, and the size of the loop is a measure of the thixotropy. The slope of the down portion is a function of the plastic viscosity of the slurry after the thixotropic structure has been broken down and is the one used for the calculations in this report. Apparent viscosities are measured by the reciprocal of the slope of a line from the origin of the plot to the flow curve; OA is a measure of the apparent viscosity before thixotropic breakdown and OB after thixotropic breakdown.

#### Magnesium Slurries

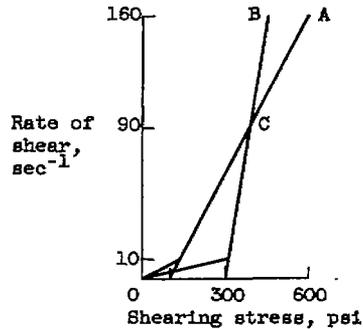
A plot of Stormer viscometer data for a 50-percent-magnesium slurry is shown in sketch (e):



The plastic viscosity is measured by the reciprocal of the slope of the straight-line portion AB of the curve. The yield value is defined as the shearing stress at the intercept A of the straight line with the shearing stress axis (zero rate of shear). The apparent viscosity at any point C is measured by the slope of the line from the origin of the plot to that point.

### Comparison of Apparent Viscosity with Plastic Viscosity

(f) Assume a slurry gives a Stormer flow curve as in curve A, sketch (f):



(f)

Curve B represents a different slurry or the same slurry at a higher temperature. The apparent viscosity at a given rate of shear is the reciprocal of the slope of a line drawn from the origin of the plot to the curve at that rate of shear. In this case, assume that the desired rate of shear is 10 reciprocal seconds. Calculation gives the following values:

Line	Plastic viscosity, poises	Apparent viscosity, poises
A	3.1	13.5
B	.9	31.0

It is evident from these values that caution should be used in predicting flow behavior from apparent viscosities.

The value of 10 reciprocal seconds was chosen for the example because it is the approximate rate of shear of the Brookfield viscometer with the number 3 spindle at 12 rpm.

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## REFERENCES

1. Olson, Walter T., and Breitwieser, Roland: NACA Research on Slurry Fuels through 1954. NACA RM E55E14, 1955.
2. Witzke, Walter R., Prok, George M., and Walsh, Thomas J.: A Preliminary Study of the Preparation of Slurry Fuels from Vaporized Magnesium. NACA RM E53K23, 1954.
3. Mazza, Harold, and Sawyer, Dwight L.: Status of Research on the Large Scale Production of Elemental Boron. Fourth Quarterly Tech. Prog. Rep., Dec. 1, 1953-Mar. 1, 1954, American Potash and Chem. Corp., Mar. 15, 1954. (Contract AF 33(616)-488.)
4. Goodman, Irving A., and Fenn, Virginia O.: Preparation and Properties of Concentrated Boron-Hydrocarbon Slurry Fuels. NACA RM E54F18a, 1954.
5. Pinns, Murray L., and Goodman, Irving A.: Study of the Physical Properties of Petrolatum-Stabilized Magnesium-Hydrocarbon Slurry Fuels. NACA RM E53J16, 1954.
6. Green, Henry: Industrial Rheology and Rheological Structures. John Wiley & Sons, Inc., 1949, p. 37.

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TABLE I. - PHYSICAL PROPERTIES OF MIL-F-7914, GRADE JP-5 FUEL

Distillation range, °F	
Initial boiling point	370
Percent evaporated	
5	388
10	397
20	406
30	414
40	424
50	433
60	441
70	452
80	465
90	487
95	506
Final boiling point	534
Residue, percent	1.2
Aromatics, Silica gel, percent by volume 10.4	
Specific gravity, 60/60° F	0.816
Density <sup>a</sup> at 68° F, g/ml	0.8115
Hydrogen-carbon ratio	0.162
Heat of combustion <sup>b</sup> , Btu/lb	18,625
Aniline point, °F	153.1

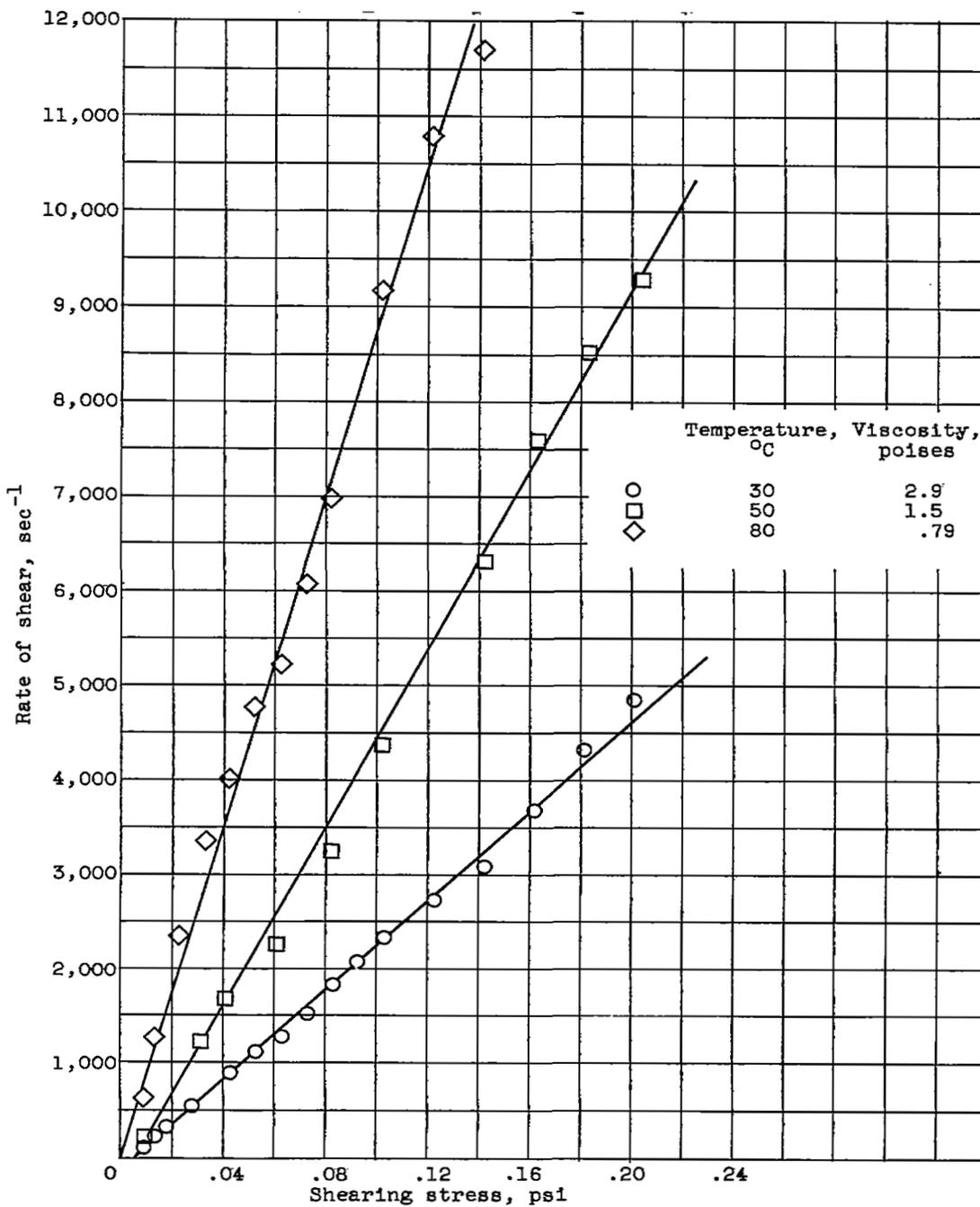
<sup>a</sup>Obtained on material passed through activated alumina.

<sup>b</sup>Calculated from aniline-point gravity correlation.

TABLE II. - BROOKFIELD APPARENT VISCOSITIES  
OF VARIOUS BORON SLURRIES

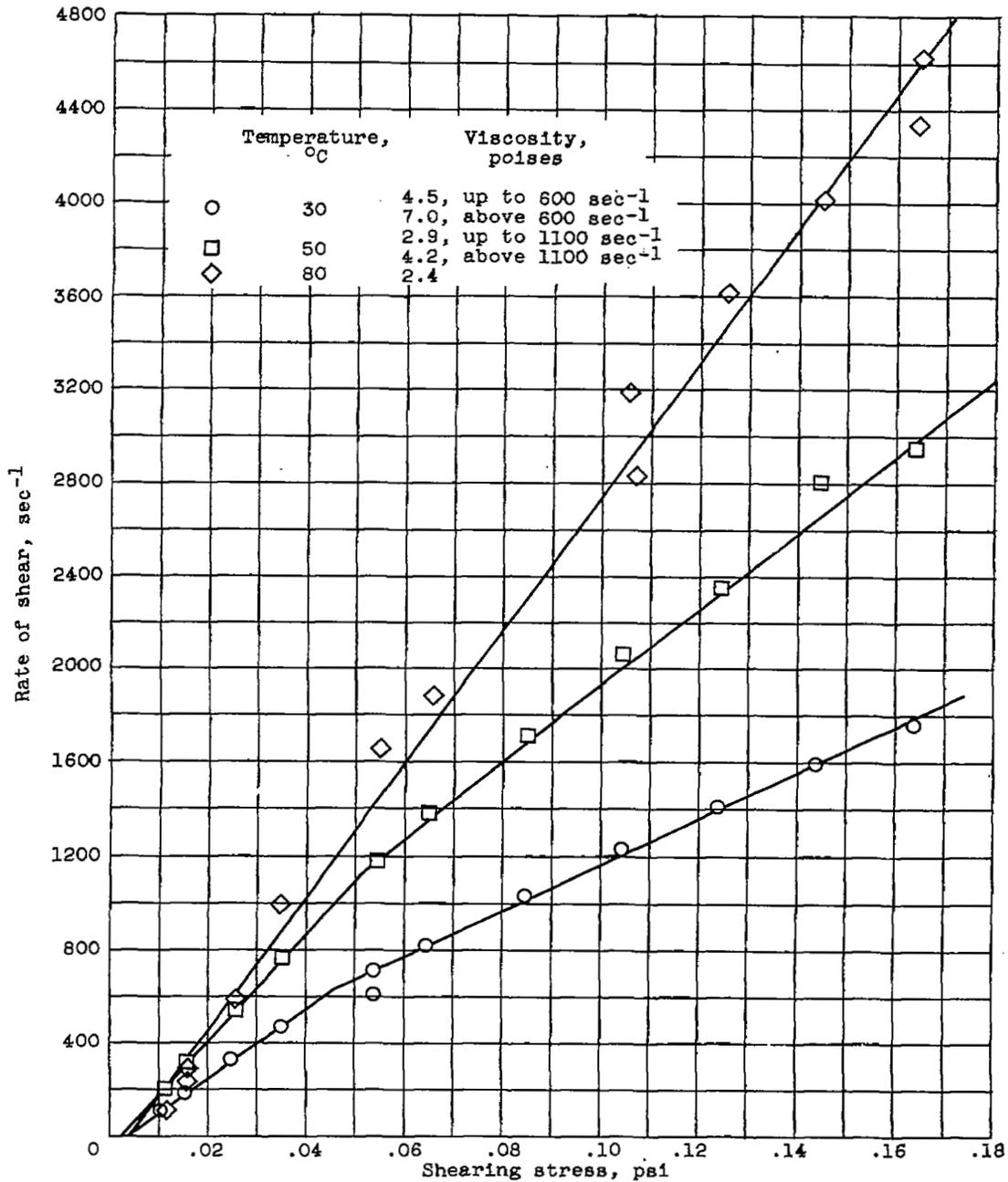
Sample	Composition, percent <sup>a</sup>			Brookfield apparent viscosity, centipoises, at		
	Boron	G-672	Aluminum octoate	30° C	50° C	80° C
1	50	1.6	0.3	6,020	3,420	6,200
2	65	2.0	0	6,860	5,240	8,320
3	60	1.6	.25	22,200	20,600	11,600
4	50	1.6	.5	1,690	1,680	2,660

<sup>a</sup>Remainder of sample is JP-5 fuel.



(a) Boron, 50 percent; G-672, 1.6 percent; aluminum octoate, 0.3 percent.

Figure 1. - Effect of temperature on Severs flow curves for two boron - JP-5 slurries. Aging, 1 day.



(b) Boron, 65 percent; G-672, 2.0 percent; aluminum octoate, 0.

Figure 1. - Concluded. Effect of temperature on Severs flow curves for two boron - JP-5 slurries. Aging, 1 day.

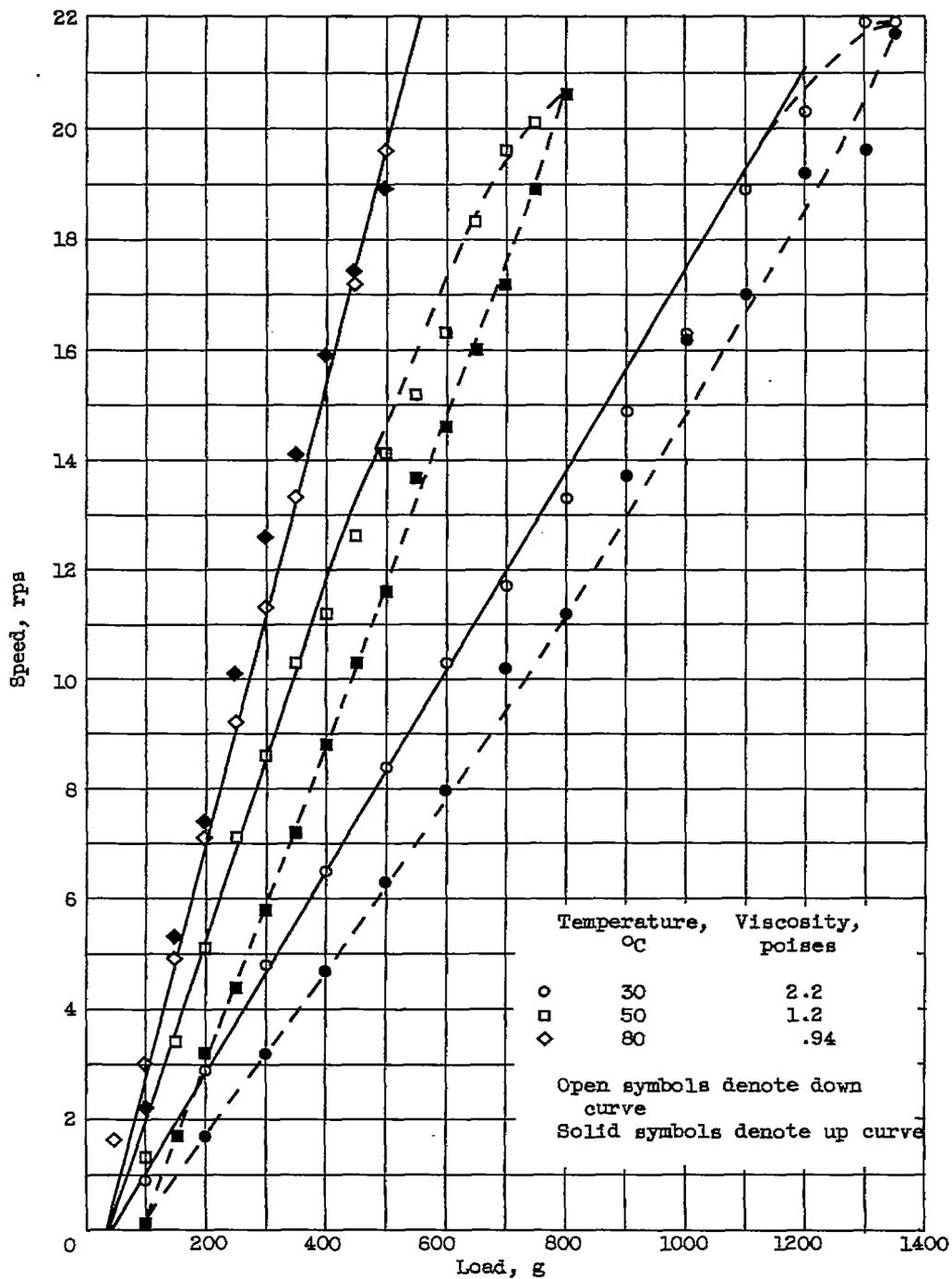


Figure 2. - Effect of temperature on Stormer flow curves for 50-percent-boron - JP-5 slurry. G-672, 1.6 percent; aluminum octoate, 0.3 percent; aging, 1 day.

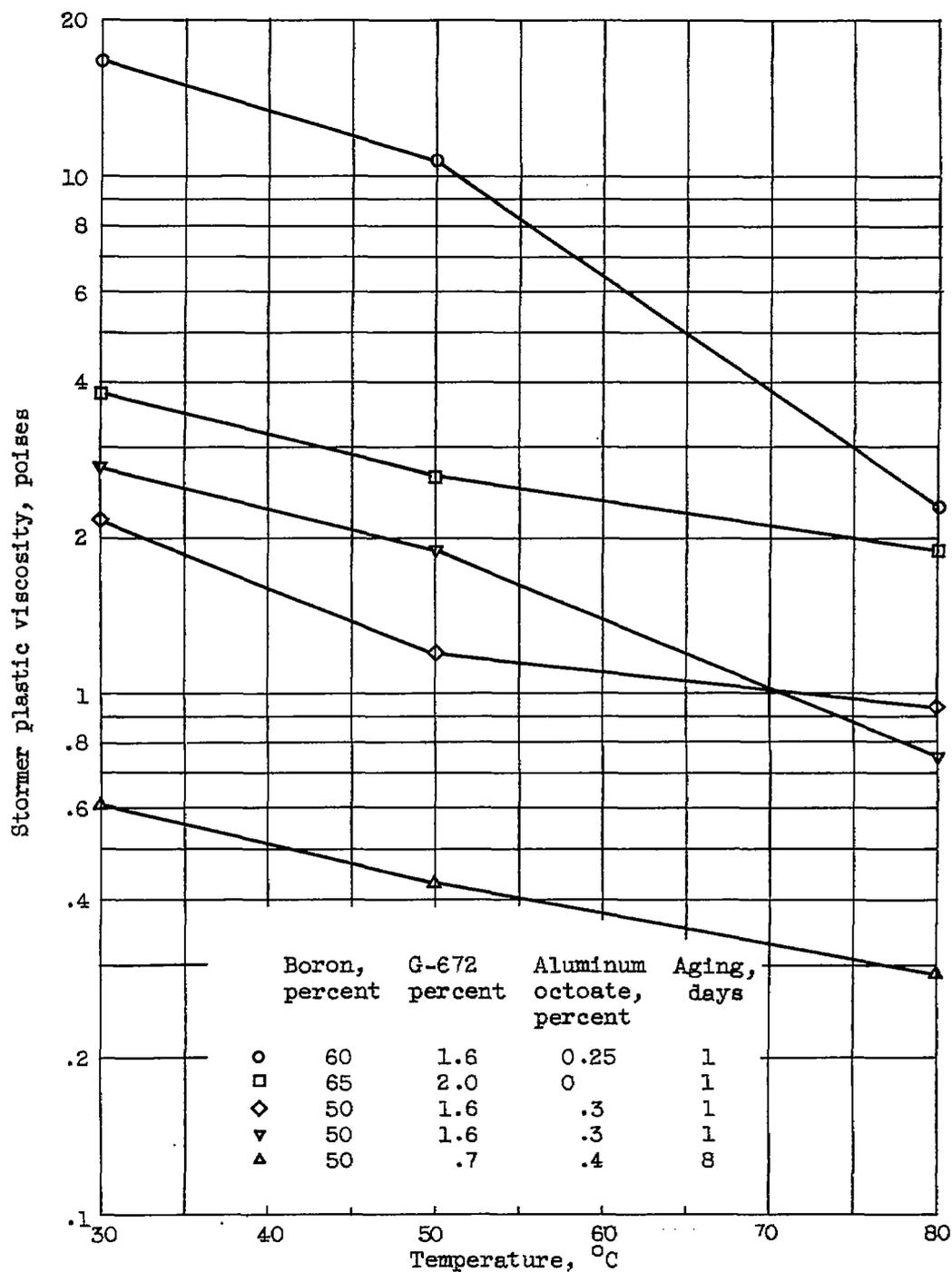


Figure 3. - Effect of temperature on plastic viscosity of boron slurries as determined by Stormer viscometer.

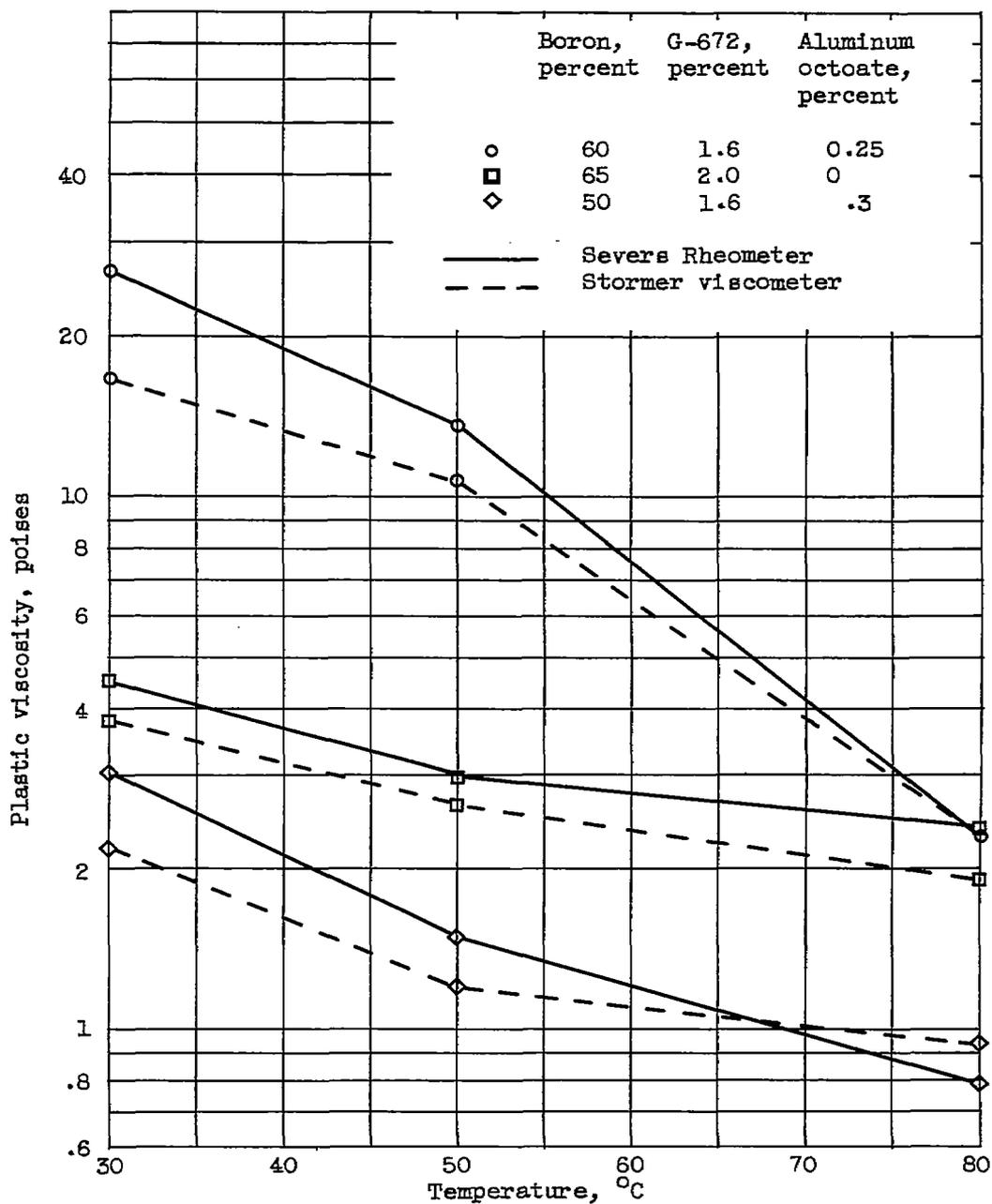


Figure 4. - Comparison of plastic viscosities of boron slurries as determined from flow curves obtained from Severs Rheometer and Stormer viscometer at various temperatures. Aging, 1 day.

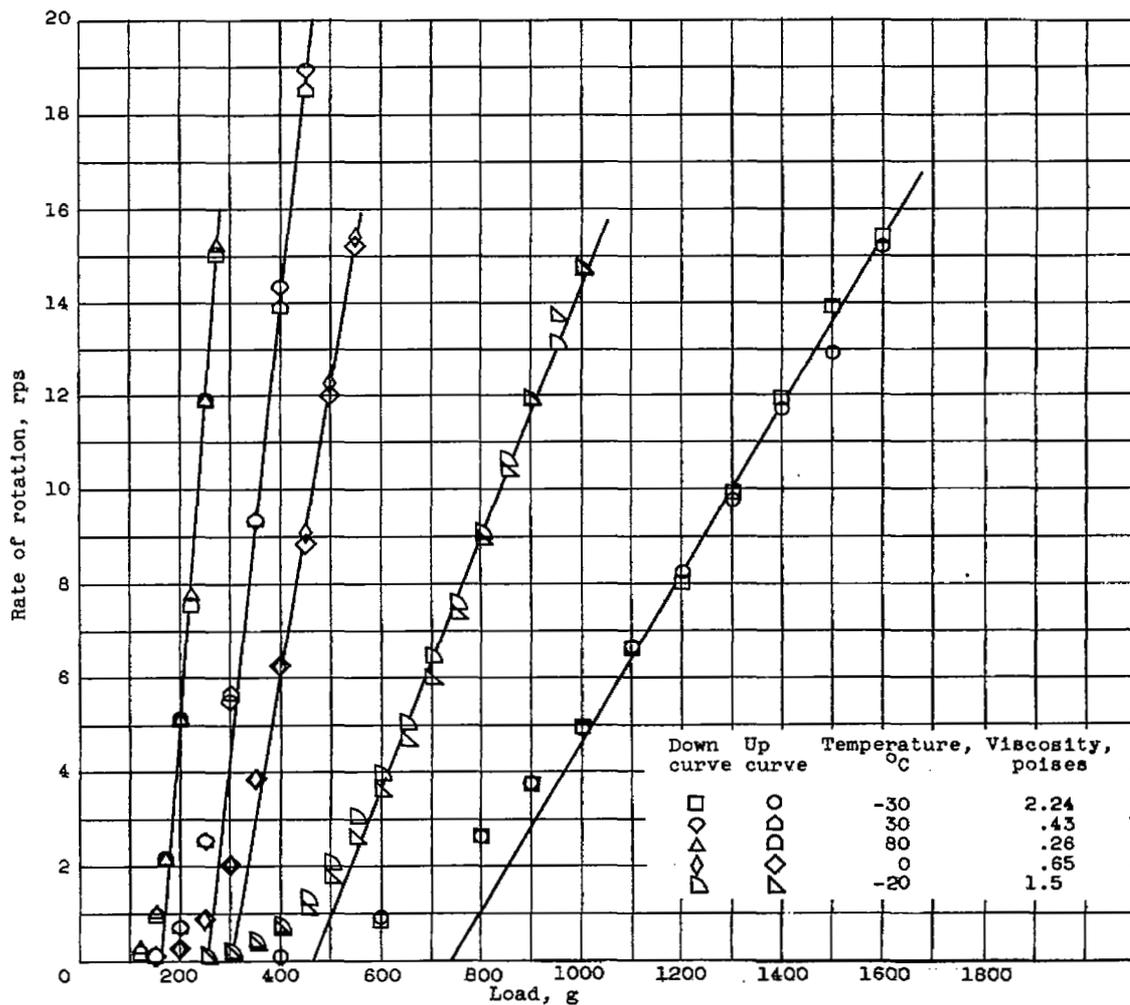


Figure 5. - Effect of temperature on flow curves of 50-percent magnesium - JP-5 slurry as determined with Stormer viscometer. G-672, 0.5 percent.

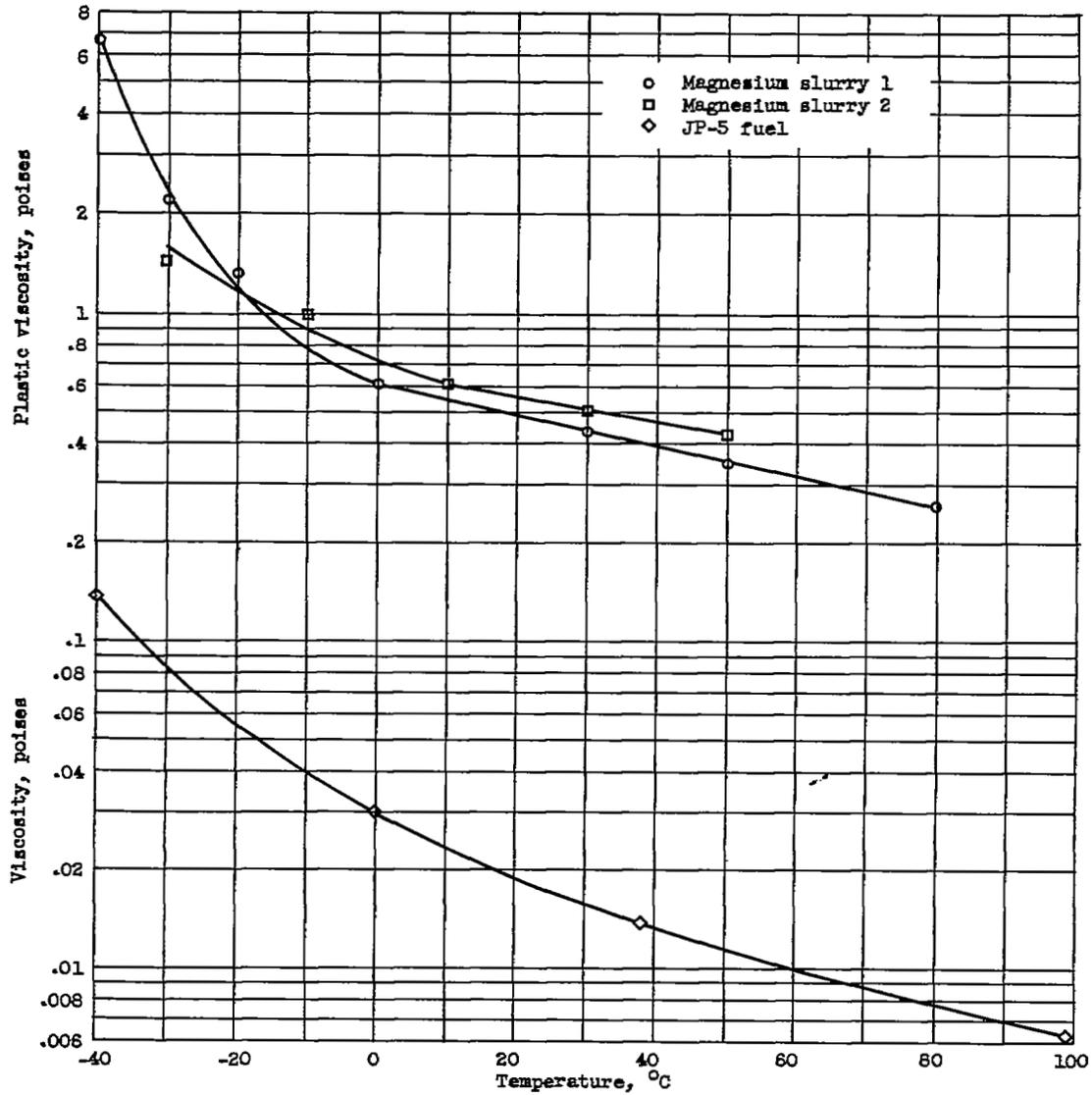


Figure 6. - Change of viscosity with temperature of 50-percent-magnesium - JP-5 slurries. JP-5 fuel data shown for comparison.

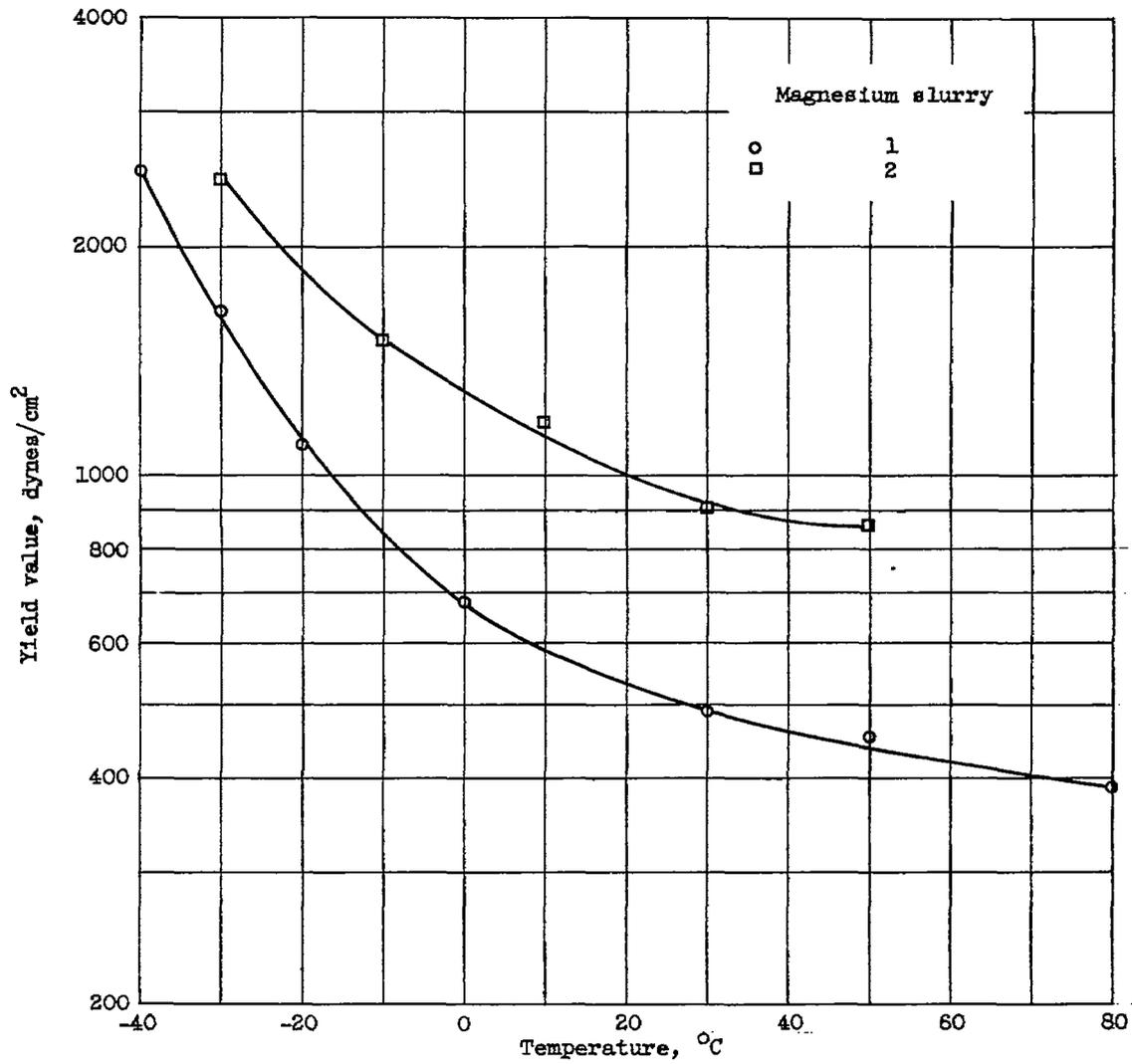


Figure 7. - Effect of temperature on yield value of 50-percent-magnesium - JP-5 slurries.

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