

for 5000, 5500, 6000 and 6500A, obtain the data which show very small but definite differences, the values of B for the shorter wave-lengths being larger than those for longer wave-lengths. The order of magnitude of this difference at $\Delta L = 10$ cm can be expressed as $B_{4500} - B_{6500} = 0.001$. Measurements on width and thickness indicated that during the stretching they decrease proportionally. Width was not measured for the strip in the constant temperature chamber, but it was assumed that the cross-sectional area would be proportional to d^2 . With this assumption the data show that if there is a volume change under the conditions of stretching, it is certainly less than one percent. This of course means a Poisson's ratio of 0.50, which has been found to hold for rubber.

A further test was made to include both the increase in length and the subsequent decrease. A fresh strip was extended nearly 200 percent by one-millimeter steps every two minutes and then shortened the same way. The curves for this

experiment are Figs. 5 and 6. It is obvious that the return differs decidedly from the stretching. The strip finally became slack before the nut had reached the zero position, in other words the two-minute interval was too short for the strip to keep up with. In all of these experiments the stretching was in the direction of calendering.

Birefringence measurements on rubber have generally been made on elastic rather than plastic rubber and have followed a somewhat different procedure,⁴ yet they seem to indicate a similar behavior in many respects. The Vinylite resin, like rubber, is raised in temperature by stretching, and when under constant load shortens when heated. When heated, either with constant load or constant length, the birefringence decreases. When stretched and left standing at constant temperature the birefringence decreases. Measurements on these changes are in progress.

⁴ W. E. Thibodeau and A. T. McPherson, Nat. Bur. Standards J. Research **13**, 887 (1934).

The Viscosity of Pennsylvania Oils at High Pressure

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(Received October 15, 1938)

Viscosity-pressure-temperature data are presented for six Pennsylvania oils which differ in chemical and physical properties at atmospheric pressure. This study is a continuation of one reported previously and employs the same apparatus and experimental method. While the pressure coefficient of viscosity increases in general with molecular weight, the relationship seems to be significant only for fractions of a narrow boiling range from a single oil. The mean temperature coefficient of viscosity, between 100° and 210°F, however, increases with molecular weight at all pressures for all the oil samples.

A PREVIOUS paper¹ presented viscosity-pressure-temperature data for three mineral oils refined from California, Oklahoma, and Pennsylvania crudes. This paper is the result of a similar study made on six Pennsylvania oils, an investigation undertaken to study the characteristics of such oils in more detail than has been made hitherto. Particularly, the viscosity at several pressures and temperatures has been studied in relation to the boiling point, tempera-

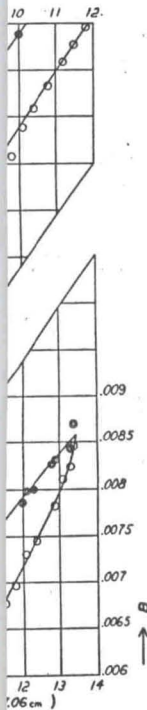
ture coefficient of viscosity, and molecular weight.

Of the six oils, numbers 1, 2 and 4 were commercial Pennsylvania products. No. 1 was a "bright stock" of high molecular weight, No. 2 a "neutral" of low molecular weight, and No. 4 a highly refined oil, solvent extracted with Chlorex. Oils 3, 5 and 6 were narrow boiling cuts fractionated from oil No. 4 in the Petroleum Refining Laboratory of this school. Table I is a summary of the characteristics of the oils at atmospheric pressure.

¹ R. B. Dow, J. App. Phys. **8**, 367 (1937).

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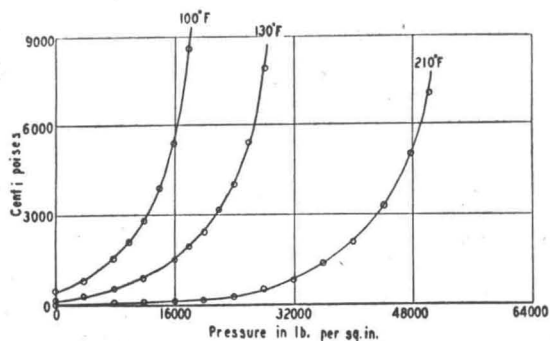


Fig. 1. Absolute Viscosity vs. Pressure - Oil No. 1.

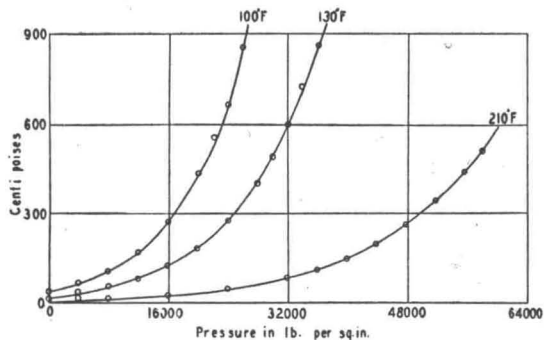


Fig. 2. Absolute Viscosity vs. Pressure - Oil No. 2.

The pressure effects were studied in the High Pressure Laboratory of the Department of Physics and the apparatus was similar to that used in the previous study.¹ A rolling-ball viscometer, the temperature of which was regulated by a thermostated bath, was used in measuring viscosity over a pressure range of

TABLE I. Data on Pennsylvania oils at atmospheric pressure.

OIL No.	CHARACTERISTICS	BOILING-POINT RANGE		MOLECULAR WEIGHT	VISCOSITY INDEX	DENSITY (g/cm ³)		
		IN DEGREES F	10 mm Hg ABSOLUTE PRESSURE			100°F	130°F	210°F
1.	Commercial "Bright Stock"	583-604	706	102	0.879	0.869	0.841	
2.	Commercial "Neutral"	459-588	368	100	.860	.849	.821	
3.	High Boiling Point Fraction From Oil 4	517-534	370	117	.841	.830	.801	
4.	Solvent Refined "Neutral"	450-507	352	116	.838	.827	.798	
5.	Medium Boiling Point Fraction From Oil 4	482-504	342	122	.836	.825	.796	
6.	Low Boiling Point Fraction From Oil 4	453-478	310	127	.832	.821	.792	

58,000 lb./in.² at temperatures of 100°, 130° and 210°F. A new calibration curve was necessary since the angle of tilt was less than that used in the previous study. Consequently, for long roll times the absolute coefficient of viscosity, μ , is given by (See Eq. (3) of previous paper):¹

$$\mu(7.36 - \rho)/155.5T.$$

As before, ρ is the density of the oil in absolute units and T is the corrected roll time in seconds. The characteristics of the calibration curve were so similar to the one used previously that it is unnecessary to reproduce it here.

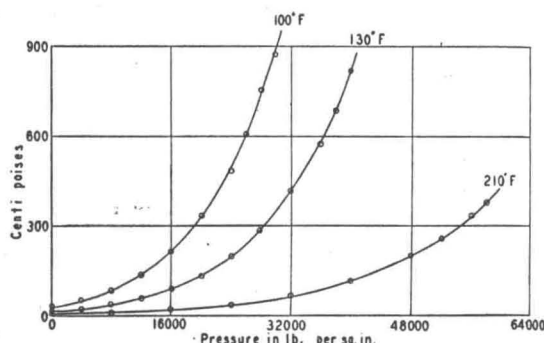


Fig. 3. Absolute Viscosity vs. Pressure - Oil No. 3.

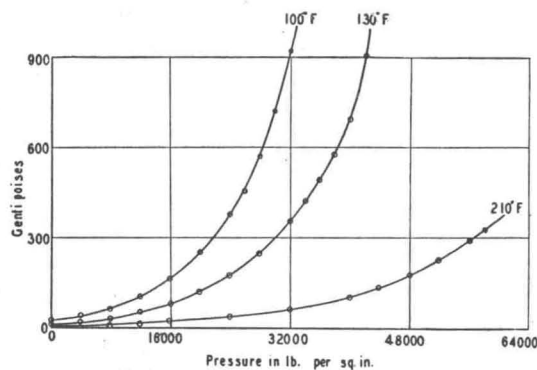


Fig. 4. Absolute Viscosity vs. Pressure - Oil No. 4.

DATA AND DISCUSSION

The viscosities, measured independently by the capillary pipette and rolling-ball methods, are given in Table II. The results by both methods agree closely, the worst disagreement being about eight percent at 210°F for a viscosity of about four centipoises.

The viscosities at higher pressures are recorded in Figs. 1-6.

On examining the data shown on curves in Figs. 1-6, it will be observed that the oil having

the higher coefficient of viscosity at any pressure at any temperature, the greater the increase in the viscosities with pressure. The viscosities increased uniformly with pressure, those of the oil having the higher coefficient of viscosity and more pronouncedly when fractional viscosities are used.

Table III compares the results of the two methods over the range of pressures studied.

While the pressure of the oil is related to the

TABLE II. Viscosities.

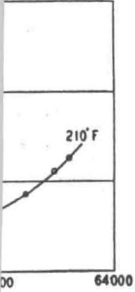
OIL NUMBER	CAPILLARY PIPE
1.	406.
2.	34.
3.	26.
4.	23.
5.	20.
6.	14.

TABLE III. Comparison of Methods.

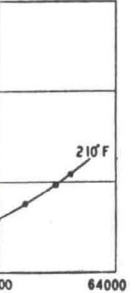
OIL No.	14.2 lb./in. ²	10.0 lb./in. ²
1.	0.00850	0.008
2.	.00778	.008
3.	.00762	.008
4.	.00757	.007
5.	.00745	.007
6.	.00730	.007

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Oil No. 4

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the higher coefficient of viscosity at atmospheric pressure at any temperature will likewise have the greater coefficient under pressure. While the viscosities of the fractions, oils 3, 5 and 6 increased uniformly with the molecular weights, those of the commercial oils did not, a result that indicated that the relation between viscosity and molecular weight is of significance only when fractions of a narrow boiling range are used.

Table III contains computations of the mean temperature coefficient of viscosity, calculated over the range 100° to 210°F from the pressure data.

While the viscosity index at atmospheric pressure of these oils did not seem to be directly related to the viscosity at various pressures and

TABLE II. Viscosities at atmospheric pressure (centipoises).

OIL NUMBER	100°F		210°F	
	CAPILLARY PIPETTE	ROLLING BALL	CAPILLARY PIPETTE	ROLLING BALL
1.	406.00	415.00	25.90	26.05
2.	34.40	34.05	4.82	4.90
3.	26.20	26.90	4.01	4.33
4.	23.40	23.00	3.75	3.87
5.	20.00	19.65	3.62	3.54
6.	14.20	14.45	2.70	2.87

TABLE III. Mean temperature coefficient of viscosity 100°-210°F.

OIL No.	14.2 lb./in. ²	10,000 lb./in. ²	18,000 lb./in. ²	30,000 lb./in. ²	MOLECULAR WEIGHT	VISCOSITY (CENTI-POISES)	
						100°F	210°F
1.	0.00850	0.00870	0.00890		706	415	26
2.	.00778	.00812	.00835		368	34	5
3.	.00762	.00810	.00829	0.00852	370	27	4
4.	.00757	.00796	.00803	.00844	352	23	4
5.	.00745	.00777	.00796	.00848	342	20	4
6.	.00730	.00764	.00794	.00828	310	14	3

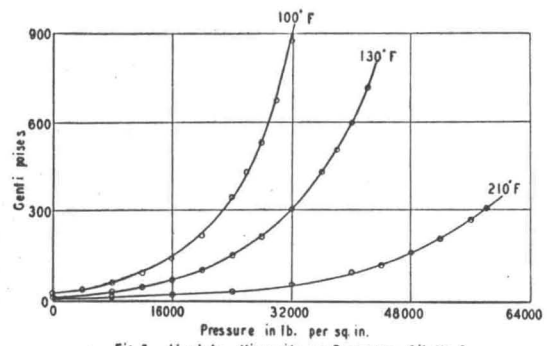


Fig. 5 Absolute Viscosity vs. Pressure - Oil No. 5

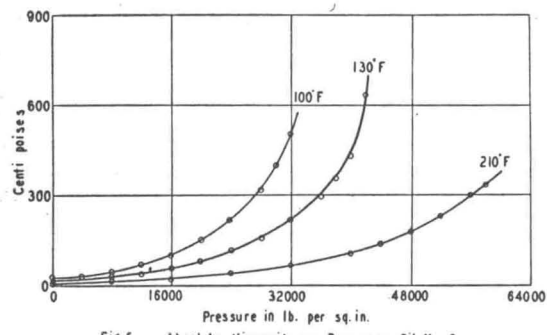


Fig. 6. Absolute Viscosity vs. Pressure - Oil No. 6

temperatures, the mean temperature coefficient of viscosity did seem to be related to the molecular weight, both increasing together with increase of pressure. For each oil, it was found that the temperature coefficient of viscosity increased with pressure as shown in Table III, a result which is normal for pure liquids.

These studies are being continued at present with the intention of mapping in greater detail the viscosity characteristics of lubricating oils over a wide range of experimental conditions. In conclusion, the authors acknowledge the interest and cooperation of Dr. M. R. Fenske. They are indebted to the Pennsylvania Grade Crude Oil Association for partial support of this program.