THE DRAINAGE ERROR IN THE BINGHAM VISCOMETER¹

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1. INTRODUCTION

For the accurate determination of absolute viscosity it is usual to employ instruments with glass capillaries, more or less modified from the original form of Ostwald. These instruments differ in the arrangement of the bulbs in which the liquid is measured, and in the manner of filling with a definite working volume. In the instruments of Ostwald, and of Traube² there is a drainage error due to the variation, with the viscosity, of the volume discharged from the bulb. This error is avoided in the apparatus of Lidstone³ by the use of mercury which does not wet the bulb, while in the Ubbelohde form of instrument the flow is into a dry bulb, and the measured volume is independent of the viscosity of the liquid tested.

The Bingham viscometer⁴ shown in Fig. 1, is similar to the Ubbelohde in having two bulbs so arranged as nearly to eliminate the effect of variations in the density of the liquid, and in the use of a constant air pressure to cause the flow. The working volume is contained between the mark H and the overflow into the trap at A. When the temperature is raised, the volume is again adjusted by causing the surplus to run into the trap.

The volume of flow is contained in the bulb C, between the marks B and D. This bulb is alternately emptied and filled, if check tests are run, but it should be noted that from the method

¹ Published by Permission of the Director, U. S. Bureau of Standards.

² Holde-Mueller, *Examination of Hydrocarbon Oils*, p. 117; 1915.

³ F. M. Lidstone, *Jour. Soc. Chem. Ind.*, 36, p. 270, 317; 1917.

⁴ E. C. Bingham and R. E. Jackson, *B. S. Scientific Paper No. 298*, p. 64; 1917. E. C. Bingham, *Proc. A.S.T.M.*, 18, part 2, p. 373; 1918. The word viscometer is used by Bingham and will be used throughout this paper to avoid confusion, even for instruments usually called viscosimeters.

FIG. 1. The Bingham viscometer

of adjusting the working volume, the bulb is already wet before the first run can be made, so that a comparison can not be made between the capacity of the bulb to deliver, and of a dry bulb to receive.

Since the Bingham viscometer is used only where great accuracy is required, and since it is claimed that it is "accurate to a tenth of one per cent,"⁵ an error which might be of no importance in another type of instrument can not be considered as negligible. It is evident that the drainage error will increase with the viscosity, or with the amount of liquid which clings to the walls of the bulb, and the error might be considerable when the instrument is used for testing lubricating oils, with viscosities up to 20 poises and over. Thorpe and Rodger⁶ who used a similar instrument, concluded that for the comparatively fluid liquids with which they had to deal, with a maximum viscosity of 0.14 poise, a cylindrical form of the bulbs was preferable, in order that the contained liquid might the more readily acquire the temperature of the bath, although with spherical bulbs, as used by Ubbelohde, less liquid adheres to the walls. In the Thorpe and Rodger instrument there is a trap on both sides and each bulb is graduated, so that the working volume may be adjusted after the first run to allow for possible evaporation.

Barr⁷ used an Ostwald viscometer for testing glycerin, with a viscosity of 1.26 poise, and remarks,

The viscometer was filled by a pipette, the time of drainage of the pipette necessary for the accuracy sought being determined by experiment.

He does not appear to have considered whether the time of flow of his viscometer was sufficient or not to eliminate drainage error.

The object of this paper is to consider evidence of drainage error in the Bingham viscometer, and to estimate the magnitude of this error, or the time of flow necessary to render it negligible, with a bulb of 4 cubic centimeters capacity. While Bingham

⁵ Proc. A. S. T. M., loc. cit. The effect of the uncertainty in regard to end effects, upon the demonstrable accuracy of the instrument, is considered in the discussion of this paper.

⁶ T. E. Thorpe and J. W. Rodger, *Phil. Trans. R. S.*, 185, part 2, p. 423; 1894.

⁷ Guy Barr, *Reports and Memoranda*, No. 755; Aeronautical Research Com., p. 4; London; 1921.

apparently paid most attention to correctness of average pressure and of working volume, he recognized⁸ the danger of imperfect drainage, for he says:

Our theoretical investigation proves therefore that the bulbs of the viscometer should be as short as convenient, but with a large radius. The constricted portions should be both narrow and short. These objects may be best achieved without sacrificing good drainage, by having each bulb like two filtering funnels placed with their ends together.

2. CALIBRATION OF THE BINGHAM VISCOMETER

In the Bingham viscometer flow is caused by air pressure applied first to one side and then to the other when a check determination is desired. In an ideal instrument the time of flow would be the same in each direction, and there would be no hydrostatic head correction, but this is rarely attained in practice.

The calibration of the instrument has been fully described in B. S. Scientific Paper No. 298, to which the reader is referred for further details than can be given here. The usual assumptions are made that there is no turbulence and that the capillary is very long in proportion to its diameter. Then the coefficient of the kinetic energy correction is equal to

$$C' = \frac{1.12 Q}{8 \pi l} \quad (1)$$

where Q is the volume of the bulb in cubic centimeters, and l is the length of capillary in centimeters.

In the equation

$$h' = \frac{\mu}{2 C \gamma} \left(\frac{1}{t_1} - \frac{1}{t_2} \right) + \frac{C'}{2 C} \left(\frac{1}{t_1^2} - \frac{1}{t_2^2} \right) \quad (2)$$

h' is a constant of the instrument used in correcting for hydrostatic head. t_1 and t_2 are the times of flow in the two directions, and could only be equal if the bulbs were absolutely alike. μ is the viscosity in poises, and γ is the density in grams per cubic centimeter of the calibrating liquid.

Before using equation (2) it is necessary to calculate an approximate value of C from the equation

$$C = \frac{\mu + \frac{C' \gamma}{t}}{\rho t} \quad (3)$$

⁸ E. C. Bingham, H. I. Schlesinger and A. B. Coleman, Jour. Am. Chem. Soc., 38, p. 32; 1916.

where p is the pressure causing flow, in grams per square centimeter. For this purpose only, p may be taken equal to h = average manometer reading reduced to grams per square centimeter, or centimeters of water column, and then, after h' has been obtained, p and C may be corrected and h' recalculated if necessary.

The absolute viscosity in poises, is calculated from equation (3) in the form

$$\mu = C p t - C' \gamma / t$$

where p is the corrected manometric pressure, and is equal to

$$p = h \pm h' \gamma - K \pm L \quad (5)$$

where h' has the plus sign when t has the lower value, and the minus sign when the flow is in the opposite direction and t is greater. K is a correction due to change in density of water with the temperature and to weight of air in the manometer, and its value depends upon the manometric head and the room temperature, while L is a minor correction due to difference in elevation of the center of the manometer and of the viscometer. Tables for K and L are given in *Scientific Paper* No. 298.⁹

For the instrument used in this work, C' was calculated to be 0.01229 by equation (1) with the approximate values, $Q = 4\text{cc}$ and $l = 14.5\text{ cm}$. The diameter of capillary was approximately 0.07 cm. The two other instrumental constants, C and h' , were found as shown in Table 1.

The capillary was almost too large to calibrate with water, so that it was necessary to use very low manometric pressures. In some cases the manometer reading of only 11 centimeters was not large in comparison with h' whereas Bingham¹⁰ implies that for the most accurate work the manometer reading should be at least 30 h' . The value of .00000898 was obtained for C four times out of the fifteen tests, and as it agrees fairly well with the average, it was taken as the most probable value. In calculating Table 1, p was found and C calculated separately for each direction of flow, and the values given are the averages of the two values thus obtained.

⁹ For similar tables for use with a mercury manometer, see paper by E. C. Bingham and Henry Green, *Proc. Am. Soc. Test. Mat.*, 19, II, p. 651; 1919.

¹⁰ Bingham, Schlesinger and Coleman, *loc. cit.*, p. 32.

TABLE 1. *Calibration of Bingham viscometer*

Calibrating liquid	Temperature	$C \times 10^8$	h'
	$^{\circ}C$		
Distilled water.....	5	886	.95
Distilled water.....	5	920	.88
Distilled water.....	10	889	.93
Distilled water.....	10	919	.87
Distilled water.....	15	898	.94
Distilled water.....	20	899	.93
Distilled water.....	25	898	.94
Distilled water.....	25	898	.83
Distilled water.....	25	909	.87
Distilled water.....	25	904	.87
40% sucrose solution.	25	913	.85
60% sucrose solution.	20	868	.86
60% sucrose solution.	25	896	.87
60% sucrose solution.	30	898	.85
60% sucrose solution.	30	901	.88
Average.....		900	.89

3. USE OF THE BINGHAM VISCOMETER

After h' has been determined, it is not necessary to refer again to equation (2), but p has to be determined for every test, by equation (5), since it varies slightly with the room temperature even if the manometer reading is not changed. The viscosity is then determined from equation (4).

A series of blends were made for use in calibrating technical viscometers, and their viscosities are shown in Table 2.

TABLE 2. *Viscosities of calibrating liquids*

Sample No.	Temperature $^{\circ}C$	Density g/cc	Viscosity Poises
1	20	.854	.1847
	40	.840	.0873
	55	.830	.0559
2	20	.894	.3927
	40	.881	.1573
	55	.871	.0928

TABLE 2 (continued)

Sample No.	Temperature ° C	Density g/cc	Viscosity Poises
3	20	.884	.4702
	40	.871	.1854
	55	.861	.1072
4	20	.874	.603
	40	.860	.2315
	55	.850	.1313
5	20	.909	1.680
	35	.899	.664
	40	.896	.511
	50	.889	.320
	55	.886	.2592
6	20	.875	.872
	40	.861	.3198
	55	.851	.1787
7	10	.970	25.06*
	15	.967	15.89*
	20	.963	10.21*
	23	.961	8.00*
	25	.960	6.84
	30	.956	4.795
	35	.953	3.312
	40	.950	2.338
8	20	.875	1.232
	40	.861	.440
	55	.851	.2395
9	20	.819	.02878
	40	.805	.01860
	55	.794	.01571
10	20	.849	.1232
	40	.835	.0620
	55	.825	.04147
11	20	.859	.2307
	40	.845	.1023
	55	.835	.0638

TABLE 2 (continued)

Sample No.	Temperature ° C	Density g/cc	Viscosity Poises
12	20	.882	.531
	40	.869	.1851
	55	.859	.1064
13	20	.876	.714
	40	.856	.2638
	55	.846	.1466
14	20	.872	1.038
	40	.858	.3691
	55	.848	.2009
	90	.832	.0690
15	20	.887	1.563
	40	.874	.4491
	55	.864	.2211
16	20	.901	1.333
	40	.888	.4175
	55	.878	.2141
17	20	.873	1.266
	40	.859	.4435
	55	.849	.2387
18	20	.911	1.686
	40	.898	.634
	55	.888	.3557
19	20	.911	2.361
	40	.898	.829
	55	.888	.445
	90	.870	.1611
20	20	.882	1.429
	40	.869	.502
	55	.859	.2701
21	20	.926	2.599
	40	.913	.935
	55	.903	.514

TABLE 2 (continued)

Sample No.	Temperature ° C	Density g/cc	Viscosity Poises
22	20	.892	3.20
	40	.879	.951
	55	.869	.4856
23	40	.873	1.325
	55	.863	.639
24	40	.873	1.446
	55	.863	.692
25	40	.873	1.546
	55	.863	.728
	90	.842	.1982
26	40	.878	2.250
	55	.868	1.014
27	40	.881	3.221
	55	.871	1.415
	90	.848	.3360
28	20	.930	6.725
	25	.927	4.215
	30	.923	2.764
	37.8	.918	1.508
	45	.914	.933
	50	.910	.712
	54.4	.907	.554
	60	.904	.4143
	70	.897	.2714
	80	.890	.1790
	90	.884	.1236

Sample No. 5 is a French oil used in standardizing the Barbey viscometer. Sample No. 7 is castor oil, the viscosities marked with an asterisk having been estimated by comparison with another sample. No. 28 is the U oil referred to by Bingham.¹¹ A blown vegetable oil was used in mixing some of the more viscous samples, and the change of viscosity with the temperature is thereby decreased.

¹¹ E. C. Bingham, Bureau of Standards, Tech. Paper No. 204, p. 58; 1922.

4. THE SCOTT VISCOMETER

In previous work of calibrating viscometers¹² use was made of water and ethyl alcohol solutions which are not suitable for instruments with outlet tubes of large diameter, such as are used for determining the viscosity of varnishes or fuel oils. The Scott viscometer was the first of these large tube instruments to be calibrated with liquids whose viscosity had been determined by the Bingham viscometer, and a difficulty experienced in the calibration was ascribed to the drainage error of the Bingham instrument.

The Scott viscometer¹³ is not essentially different from other technical efflux instruments, such as the Saybolt, Engler, and Redwood.

Table 3 gives dimensions of the Scott viscometer, according to the designer, and also gives dimensions of two particular instruments, one as measured by the Bureau of Standards, and the other as reported by the Ordnance Department.

TABLE 3. *Dimensions of Scott viscometers*

Dimension	B. S.	Ord. Dept.	Scott	
	Cm.	cm.	inch	cm.
Diameter of oil container, at top.		8.66		
Av. diameter of oil container.	8.738	8.74	3½	8.90
Diameter of outlet tube.	.275	.267	.108	.274
Diam. of conical valve seat, at top.	.956	.864		
Length of outlet tube and lower conical flare.	.628	.686	¾	.953
Length of lower conical flare.	.05			
Length along axis of conical valve seat. ...	.567			
Depth of upper end of conical valve seat below surface of water with 200 cc of water in container.	3.47			
Mean diam. of widest part of flare at lower end of outlet tube.	.385			

¹² Bureau of Standards, Tech. Papers Nos. 100, 112, and 125.

¹³ Proc. Am. Soc. Test. Mat., Vol. 10, p. 117-146, 1910: A. H. Gill, Oil Analysis, p. 164; 1913: Wm. M. Davis, Friction and Lubrication, p. 42; 1904: W. G. Scott, Drugs, Oils and Paints, Vol. 13, p. 50; 1897-8.

According to Scott the outlet tube must be made by using a new No. 35 twist drill, and the time of discharge for 50 cc of water at 60°F (15°.6C) is between 10 and 11 seconds.

There is no filling mark so 200 cc of the liquid to be tested is measured in a graduated cylinder and poured into the container, the cylinder being left 10 or 15 minutes to drain if necessary. The data of table 4 were obtained with oils selected from table 2.

Fig. 2 shows a Higgins diagram¹⁴ calculated from data of Table 4. The graph represents the equation

$$\text{kinematic viscosity} = \frac{\mu}{\gamma} = 0.0178 t - \frac{2.74}{t} \quad (6)$$

but since the outlet tube has a flare at both ends, it is not to be

FIG. 2. Higgins diagram for Scott viscometer

expected that two instruments will have exactly the same time of flow or that equation (6) would be of general application. On account of the impossibility of accurately estimating the average

¹⁴ W. F. Higgins, Jour. Soc. Chem. Ind., 32, p. 568, 1913.

diameter of outlet tube, no attempt was made to check equation (6) by a Herschel diagram similar to Fig. 5.

TABLE 4. *Tests of Scott viscometer, B. S. 6452*

Sample No.	Temperature	Time	Sample	Temperature	Time
	° C	Seconds		° C	Seconds
water	15.6	11.2	12	40	19.9
				55	16.3
1	20	20.6	13	40	24.1
	40	15.0		55	18.5
	55	13.8			
2	20	32.2	14	40	29.1
	40	19.2		55	20.6
	55	15.9			
5	20	129.8	15	20	118.1
	35	46.9		40	34.5
	40	36.3		55	21.0
	50	26.9			
	55	22.6			
6	20	51.0	16	40	23.1
	40	25.2		55	21.3
	55	18.4			
7	10	1865.7	17	20	95.4
	15	1139.7		40	35.5
	20	707.8		55	22.7
	23	546.3			
	25	464.8			
	30	320.9			
	35	227.5			
	40	166.3			
11	40	16.0	18	40	46.8
	55	14.3		55	28.0

It will be noted that very viscous oils, giving points at the extreme left of Fig. 2, show too low a value of the ordinate $\frac{\mu}{\gamma t}$.

As there was a possibility that this was due to some peculiarity of the laws of flow through so short a tube of variable diameter,

it seemed that this should not be accepted as an indication of drainage error in the Bingham instrument without confirmation.

5. OTHER POSSIBLE CAUSES OF THE LOW VALUES OF $\frac{\mu}{\gamma t}$

Various possible causes for the low values of the ordinates of Fig. 2, at very high viscosities, seemed worthy of consideration. The error could not be due to the contraction of the oil after leaving the outlet tube of the Scott viscometer, because the error is most marked when tests are run at temperatures lower than room temperature. A drainage error in the Scott viscometer would lower the average head, increase t and thus decrease the ordinate, but it seemed unlikely that the error would be appreciable in an instrument having such a large, shallow container. The tests for drainage error were therefore made on a Saybolt Universal viscometer tube.

After making a run in the usual way, vacuum was quickly applied to the bottom of the outlet tube to draw out all the oil except that clinging to the walls. The maximum film thickness, calculated from the difference in weight of the dry and wet container, was 0.011 centimeter, with an oil of 5000 seconds viscosity. Further tests were made by filling the container to the level reached at the end of a normal run, 8.8 cm below the overflow rim, and applying a vacuum as before. The results showed that only 8 per cent of the oil which adhered to the walls in the first series of tests, was above the 8.8 centimeter level, so that the average film thickness on the walls exposed during a normal run would be only 0.0009 centimeter. Although this value does not strictly apply to the Scott viscometer, it seems safe to regard the film thickness as inappreciable in comparison with the 9 centimeter diameter of this instrument.

6. INDICATIONS OF DRAINAGE ERROR OF BINGHAM INSTRUMENT BY COMPARISON WITH SAYBOLT AND REDWOOD VISCOMETERS

Figs. 3 and 4 show calibration diagrams for Saybolt Universal viscometer No. 109. Fig. 3, like Fig. 2, shows too low an ordinate at high viscosities, while in Fig. 4 values of the abscissas near the

bottom of the graph are too large. Figs. 5 to 7 show Higgins diagrams for the Redwood No. 1, Redwood Admiralty, and Saybolt Furol viscometers, respectively. It will be noted that they all show the same signs of drainage error in the Bingham instrument, or some cause producing the same effect, so that it may be concluded that the evidence noted in Fig. 2 is not due to any peculiarity of the Scott viscometer.

FIG. 3. Higgins diagram for Saybolt Universal viscometer No. 109

Fig. 8 shows another method of indicating the drainage error and was suggested by a diagram of Higgins.¹⁵ The upper graph, from the work of Higgins, shows the relation between the time of flow of the Redwood viscometer and the kinematic viscosities obtained with a viscometer similar to that used by Thorpe and Rodger. The lower graph shows results obtained in calibrating

¹⁵ W. F. Higgins, Collected Researches, National Physical Laboratory, 11, p. 12; 1914.

FIG. 4. Herschel diagram for Saybolt Universal viscometer No. 109

the Redwood viscometer at the Bureau of Standards,¹⁶ the kinematic viscosities being obtained by an instrument of the Bingham type. The curve at the lower end of the graph is due to kinetic energy, but the rest of the graph should be straight, since the equa-

FIG. 5. Higgins diagram for Redwood viscometer

tion for the Redwood viscometer is of the same form as equation (6). The upper part of the line from Higgins tests is straight, but the lower line bends downward at the upper end. This difference in the two lines shows that the drainage error of Higgins's instrument with cylindrical bulbs, is less than the drainage error due to the specially shaped bulb in the Bingham instrument.

7. CALIBRATION OF BULB OF BINGHAM INSTRUMENT BY OILS OF VARIOUS VISCOSITIES

In order to get a more direct and accurate measurement of the drainage error, a special jacketed pipette was built with a bulb of the same size and shape as in the Bingham viscometer used in the work above recorded. There was no capillary and the rate of dis-

¹⁶ Winslow H. Herschel, B. S. Technologic Paper No. 210; 1922.

charge could be regulated by a stop cock. The volume discharged could be readily determined from the density of the oil and the weight discharged.

Since the viscosity, by equation (4), is proportional to C , or inversely proportional to the volume discharged, the true viscosity will be to the apparent viscosity (as calculated from a value of C

FIG. 6. Higgins diagram for Redwood viscometer, Admiralty type

determined by calibration with water) as the volume of water discharged from the bulb is to the volume of oil. The capacity of the bulb when calibrated with water was 4.232 cubic centimeters.

Table 5 gives results of calibration of the bulb with oils of various viscosities, the correction factor being the ratio of capacity of the bulb to discharge water and oil.

Fig. 9, from data of table 5, may be used in estimating the drainage error in a given test, or in selecting a time of flow so that the error will be negligible. The numbers on points indicate the correction factors, and lines of equal factors have been drawn. Data has been added from the work of Bingham and Young¹⁷

¹⁷ E. C. Bingham and H. L. Young, paper presented before the Birmingham, Ala., meeting, A. C. S.; April, 1922.

TABLE 5. Factors to correct for drainage error of Bingham viscometer

Corrected viscosity	Time	Fac-tor	Time	Fac-tor	Time	Fac-tor	Time	Fac-tor	Time	Fac-tor
Poises	Sec.		Sec.		Sec.		Sec.		Sec.	
.1278	463	1.000								
.242	58	1.003	255	1.000						
.430	80	1.005	312	1.001	900	1.000				
.722	87	1.007	400	1.000						
1.247	103	1.012	240	1.007	420	1.000				
2.140	150	1.015	212	1.010	585	1.007	1524	1.003		
3.642	296	1.012	600	1.011	1280	1.007	1070	1.009	2332	1.005
6.473	300	1.013	420	1.012	1181	1.007				
9.560	343	1.018	846	1.010	1491	1.008				
12.160	744	1.015	1168	1.011	1680	1.010	2862	1.006		
17.960	728	1.019	1351	1.012	2700	1.010				

showing a somewhat smaller drainage error, due it is believed to the use of a larger bulb.

FIG. 7. Higgins diagram for Saybolt Furol viscometer

8. METHODS OF AVOIDING DRAINAGE ERROR

Drainage error may be avoided by using torsional viscometers, but these instruments are outside the scope of this paper. In the Lidstone viscometer, previously referred to, the liquid to be tested rests upon mercury, and the separation of the two liquids would

FIG. 8. Relation of kinematic viscosity to time of flow of Redwood viscometer

apparently offer considerable difficulty. In technical instruments for oil, of which the Saybolt Universal and Furol may be taken as examples, there is no drainage error, but there is another error, due to the contraction of the oil after it leaves the outlet tube, which may be called the cooling error. Barbey avoids both the drainage and the cooling errors by using a constant hydrostatic head, and running a test for the constant time of ten minutes. The receiving flask is heated in the bath to the nominal temperature of test, before reading of the volume discharged is taken, and results are expressed as "fluidity" or the rate of discharge in cubic centimeters per hour.

Bingham¹⁸ suggests that the drainage error may be avoided in his instrument if the flow begins in the neighborhood of the trap

¹⁸ E. C. Bingham, *Fluidity and Plasticity*, p. 66; 1922.

opening, for then a certain amount of liquid may flow into the measuring bulb after the record of time has begun, and this will tend to offset the effect of any liquid left in the bulb at the end of the time of flow.

The Ubbelohde form of Ostwald instrument has, as ordinarily used, the disadvantage that it is necessary to refill it before running a check test, but there is no drainage error. This advantage and that of ease in running a retest may both be retained by the

FIG. 9. Correction factors for Bingham viscometer

following slight changes. Referring to Fig. 1, graduate bulb K with marks similar to B and D. Fill from A to H, keeping the bulb K dry, and empty the trap. Apply air pressure on the left limb and make the first run into the dry bulb. Apply air pressure on the right limb and make the second run into bulb C which will be wet, and the third run will be into bulb K which will also be wet. The difference in the time for the first and third runs will be due to drainage error.

It should be noted that there is normally a difference in time between a run from left to right and one from right to left, so that

the difference in time between the first and second runs would not usually be due entirely to the drainage error. The drainage error could however be calculated as the per cent difference between the viscosities as calculated from the first and second runs, the instrumental constant h' allowing for the difference in time of flow in the two directions when the volume is measured both times in a wet bulb.

9. CONCLUSIONS

1. The drainage error is negligible only for comparatively light oils when a sufficiently long time is taken for the discharge. A diagram is given to show the relation between viscosity, time of flow and per cent drainage error.

2. The drainage error may be avoided by having the trap on the opposite limb from the bulb which measures the volume discharged.

APPENDIX. COMPARISON OF VISCOSITIES AS OBTAINED BY THE SCOTT VISCOMETER, AND BY THE PLUMMET METHOD OF BASSECHES¹⁹

The investigation to be described was undertaken in the hope of explaining the difficulty in calibrating the Scott viscometer, afterwards shown to be due to drainage error of the Bingham instrument used in determining the viscosity of the calibrating liquids. While the results are somewhat discordant, this may be attributed largely to the rapid change of viscosity with the temperature in the case of such highly viscous substances. Even with lubricating oils, an error of one per cent in viscosity, will be caused by an error of 0.2 to 0.1°C, depending upon the viscosity and upon the source of the crude oil.

While the tests were inconclusive as far as proving or disproving that there was a serious drainage error in the Bingham instrument, it is believed that a description of the Basseches method will be of interest since this method seems to be unsurpassed as a very rapid though approximate method of measuring the consistency of very viscous or plastic substances.

Basseches method is as follows. The liquid or soft plastic substance to be tested is placed in a shallow dish on a stand under a

¹⁹ Based upon unpublished manuscript of J. L. Basseches, formerly of the Bureau of Standards.

plummet hung from the arm of a chemical balance the beam of which can be lifted. The plummet is of cylindrical shape with a conical base, the juncture of cylinder and cone forming the line to which the plummet is immersed by raising the stand. The beam is then lifted and if necessary the stand is readjusted so that the pointer comes to the first division on the right end of the scale. A weight is placed on the pan of the balance, causing the plummet to be pulled out of the material under test, and the time required for the pointer to traverse five scale divisions is taken by means of a stop watch. The pan also contains the counter-poise for the plummet. As will appear later, this operation must be repeated with a different weight on the pan, in order to find both of the numerical values determined by the test.

It will be assumed that two properties or groups of properties are to be measured, one of which, viscosity, causes a resistance in proportion to the velocity, or inversely as the time, while the second group of properties causes a resistance which is independent of the velocity. Let W_v be that portion of the weight required to overcome viscosity, and W_s the portion required to overcome the constant resistance. Then

$$W = W_v + W_s \quad (7)$$

Basseches regarded W_s as a measure of surface tension only, believing that the "yield value" of plastic materials is only a form of surface tension manifested in the adsorbed liquid films on the surfaces of the solid particles. Without attempting to decide this matter, W_s will be considered here as a measure of all other resistances than viscosity, which may include surface tension, yield value and friction of the balance. Part of the weight must also be expended in lifting the film which adheres to the plummet.

If all the weight were exerted in overcoming viscosity, t would be inversely proportional to W , or for two trials,

$$W_1 t_1 = W_2 t_2 = \text{constant} = V \quad (8)$$

where W_1 and W_2 are the weights used in the two trials, and t_1 and t_2 are the corresponding times, the units employed being grams and seconds. But since surface tension, or some similar resistance must also be overcome, the net weight expended in overcoming

viscosity, and which must be inserted in equation (8) is $W - W_s$, so that the equation becomes

$$(W_1 - W_s) t_1 = (W_2 - W_s) t_2 = V \quad (9)$$

from which

$$W_s = \frac{W_2 t_2 - W_1 t_1}{t_2 - t_1} \quad (10)$$

After W_s has been found from equation (10), V may be found from equation (9).

Two terms which are used to indicate the consistency of printing inks are "tack" or "tackiness" and "length" and Basseches proposed that VW_s should be used as a measure of the former, and $\frac{V}{W_s}$ as a measure of the latter.

Since V is proportional to the viscosity in poises, if the liquid is truly viscous, this method may be used to determine viscosity if the plummet is calibrated with a liquid of known viscosity. If μ is the viscosity of the calibrating liquid in poises, then

$$\mu = KV \quad (11)$$

where K is an instrumental constant.

For example a sample of sodium silicate gave the following results at 22°C (71.6°F) using the 3 centimeter plummet.

W in grams	t in seconds
1.874	6.0
1.904	5.0

Then $W_s = \frac{11.244 - 9.520}{1.0} = 1.724$ and by equation (9), $V = 0.90$.

Since under the same conditions castor oil gave $W_s = 0.88$ and $V = 0.78$, and since the viscosity of castor oil at 22°C is about 8.34 poises, from equation (11), $K = \frac{8.34}{0.78} = 10.7$

In a comparison of the plummet method using another sized plummet, with the Scott viscometer, and with the falling ball method,²⁰ the results were obtained as shown in Table 6 and Fig. 10.

²⁰ S. E. Sheppard, Jour. Ind. and Eng. Chem., 9, p. 523; 1917; W. H. Gibson and L. M. Jacobs, Jour. Chem. Soc. London, p. 473; May, 1920.

The viscosity by plummet was calculated from equation (11) using a value of 65.7 for K as obtained with blown rape seed oil at 30°C.

FIG. 10. Comparison of different methods of measuring viscosity

TABLE 6. Comparison of different methods of measuring viscosity

Liquid		Basseches					Herschel
	Temp.	V	Absolute viscosity, poises.				Viscosity in poises by equation (6)
			Plummet	Dropping ball of diameter in cm.			
				.3175	.3970	.137	
	° C	Sec/g					
Castor oil.....	23	.128	8.4	6.7	6.9	6.3	9.3
Burnt litho No. 1...	30	.270	17.7	13.5	13.8	12.3	14.4
Burnt litho No. 1...	23	.408	26.8	17.9	18.1	16.5	22.7
Rosin oil.....	30	.487	31.9	22.2	22.3	21.8	23.3
Blown rape.....	30	.698	45.8	39.6	39.9	39.6	45.8
Rosin oil.....	23	.817	53.6	38.4	37.9	40.3	56.6
Blown rape.....	23	1.15	75.5	54.2	54.6	51.4	78.9
Half tone varnish...	23	5.00	328.0				