Designation: D 3236 – 88 (Reapproved 1999)

An American National Standard

Standard Test Method for Apparent Viscosity of Hot Melt Adhesives and Coating Materials[1]

This standard is issued under the fixed designation D 3236; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the apparent viscosity of hot melt adhesives and coating materials compounded with additives and having apparent viscosities up to 200 000 millipascal second (mPa·s) (Note 3) at temperatures up to 175°C (347°F).

NOTE 1—Although precision has not been studied, this procedure may be adaptable to viscosities higher than the present 200 000-mPa·s limit and temperatures above 175°C (347°F). Equipment described in this procedure permits testing of materials having viscosities as high as 16×10^6 mPa·s and provides temperatures up to 260°C (500°F).

NOTE 2—For petroleum waxes and their blends having apparent viscosities below 15 mPa·s, Test Method D 445 is especially applicable.

NOTE 3—One pascal second (Pa·s) = 1000 centipoise (CP); one millipascal second (mPa·s) = one centipoise.

1.2 The values stated in acceptable metric units are to be regarded as the standard. The values in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (the Calculation of Dynamic Viscosity)[2]

3. Terminology

3.1 *Definitions:*

3.1.1 *viscosity*—the ratio of shear stress to shear rate. The viscosity of a liquid is a measure of the internal friction of the liquid in motion. The unit of dynamic viscosity is the pascal second. For a Newtonian liquid, the viscosity is constant at all shear rates. For a non-Newtonian liquid, viscosity will vary depending on shear rate.

3.1.2 *apparent viscosity*—the viscosity determined by this test method and expressed in millipascal seconds. Its value may vary with the spindle and rotational speed selected because many hot melts are non-Newtonian.

4. Summary of Test Method

4.1 A representative sample of the molten material to be tested is maintained in a thermally controlled sample chamber. Apparent viscosity is determined under temperature equilibrium conditions using a precision rotating spindle type viscometer. Data obtained at several temperatures can be plotted on appropriate semi-logarithmic graph paper and apparent viscosity at intermediate temperatures can be estimated.

5. Significance and Use

5.1 This test method distinguishes between hot melts having different apparent viscosities. It is believed that apparent viscosity determined by this procedure is related to flow performance in application machinery operating under conditions of low shear rate. Apparent viscosity as determined by this test method may not correlate well with end use applications where high shear rates are encountered.

5.2 Materials of the type described in this procedure may be quite non-Newtonian and as such the apparent viscosity will be a function of shear rate under the conditions of test. Although the viscometer described in this test method generally operates under conditions of relatively low shear rate, differences in shear effect can exist depending upon the spindle and rotational speed conditions selected for the test program. Maximum correlation between laboratories, therefore, depends upon testing under conditions of equivalent shear.

5.3 Approximate shear rates using various spindles are shown in Table A1.1 in the Annex to this procedure.

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[1] This test method is under the jurisdiction of ASTM Committee D-2 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.10.0A on Physical and Chemical Properties.

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[2] *Annual Book of ASTM Standards*, Vol 05.01.

TABLE 1 Suitable ASTM Thermometers

Temperature Range	Immersion, mm	Scale Error, max	ASTM Thermometer Number
90°C to 170°C	51	0.2°C	35C-62
194°F to 338°F	51	0.5°F	35F-62
145°C to 205°C	76	0.4°C	100C-68

6. Apparatus

6.1 *Viscometer*, rotating spindle type with leveling stand.[3]

6.2 *Viscometer Spindles*, stainless steel.[3]

6.3 *Sample Chamber*, with precision proportional temperature controller[3,4] that provides control accuracy of ±1.0°C (1.8°F) or better through the range from 100 to 200°C (212 to 392°F).

6.4 *Graph Paper*, semi-logarithmic.

7. Calibration

7.1 The viscometer is precalibrated using Newtonian fluids by the manufacturer. No zero adjustment is provided since experience has shown that the zero point will not vary due to changes in the spring. The viscometer and spindles are precision equipment and should be kept from undue shock and mishandling. Physical damage to the instrument will often reveal itself as erratic or no oscillation of the pointer when the instrument, with or without the spindle in place, is operated in air. When operating normally, the pointer will be stable and have free oscillation about the zero point in air.

7.2 The instrument may be further calibrated using standard reference fluids. Suitable fluids are available in nominal viscosities up to 15 000 mPa·s at 149°C (300°F).[5] The procedure for instrument calibration using standard reference fluids is that encompassed by this test method. Results obtained using standard reference fluids should not deviate from the nominal viscosity by more than 2 %.

7.3 The temperature controller of the type recommended for this procedure is factory calibrated and has control capability of ±0.5 % of the control point (±1.0°C at 175°C). To further check the controller and further establish controller settings, use the following procedure: Place a sufficient quantity of low viscosity (500 mPa·s or less) hot melt in the sample container to permit immersion of the appropriate ASTM thermometer to the proper depth. Do not permit the thermometer bulb to rest on the bottom of the sample container. Suitable thermometers are shown in Table 1.

NOTE 4—Particular care must be taken not to overflow the sample chamber when using the 100°C, 76-mm immersion thermometer.

7.3.1 Insert the thermometer through the insulating cover of the sample container and hold it in place at the point required for proper immersion depth. Adjust the thermal controller to provide the desired test temperature. Rotate the thermometer during temperature reading to minimize the effect of thermal gradients in the sample. Continue temperature readings and controller adjustment until minimum deviation from test temperature is obtained. Minimum deviation may vary between laboratories, depending upon the controller, but should in no case exceed ±0.5°C (0.9°F). Repeat this procedure for any test temperature desired within the scope of this procedure.

8. Procedure

8.1 *Selection of Spindle*—From the estimated viscosity of the sample and Table A1.1 in the Annex, select a viscometer and spindle combination that will produce readings in the desired range.

NOTE 5—Use only the spindle shown to be appropriate for the viscometer to be used.

8.1.1 Where more than one spindle is available for the range selected, choose the spindle that produces results nearest the midpoint of the measurable viscosity range. Viscometer scale readings must be within the 10 to 95 range.

NOTE 6—Care must be taken in the storage and handling of spindles and assemblies. Protect them from dust, corrosive deposits, and mechanical abuse. Avoid touching the calibrated section of the spindle with the hands. Clean the spindle and sample chamber thoroughly after each use. A recommended cleaning procedure is included in Annex A2.

8.2 *Preparation of Sample*—Place the required amount of representative sample (see Table 2) measured to the nearest 0.005 g (or 0.05 mL if handled in the molten state) in the sample chamber. Melt the sample in an oven set at the desired test temperature or in the thermo-container preheated to the desired test temperature. Avoid excessive or prolonged heating of the sample to minimize thermal and oxidative effects. Use a fresh sample for each temperature for which a determination is to be made.

8.3 *System Alignment and Spindle Insertion*—After the sample is completely melted, lower the properly aligned and leveled viscometer until the tips of the alignment bracket just touch the top of the thermo-container, making contact directly behind the locating ring. Raise the viscometer, positioning the tips of the alignment bracket 2 mm (1⁄16 in.) above the top of the thermo-container. Using both hands, gently slide the thermo-container base until the tips of the alignment bracket *just touch* the locating ring. *Do not* forcibly displace the alignment bracket (see Fig. 1). Screw the link coupling nut onto the viscometer coupling nut (note left-hand thread).

TABLE 2 Sample Size Requirement

Spindle	Approximate Volume, mL	Approximate Sample Weight, g[A]
SC 4-18	8.00	6.40
SC 4-21	8.00	6.40
SC 4-27	10.50	8.40
SC 4-28	11.50	9.20
SC 4-29	13.00	10.40
SC 4-31	10.00	8.00
SC 4-34	9.50	7.60

[A] Based on typical molten specific gravity of 0.800. If the specific gravity of the material to be tested varies greatly from this value, sample size must be adjusted to ensure proper liquid level on the spindle shaft.

[3] Suitable viscometers and accessories can be obtained from Brookfield Engineering Laboratories, Inc., Stoughton, MA 02072.

[4] A suitable temperature controller can be obtained from Athena Controls, Inc., 2 Union Road, West Conshohocken, PA 19428.

[5] Suitable calibration fluids may be obtained from Brookfield Engineering Laboratories, Inc., Stoughton, MA 02072 or Cannon Instrument Co., P. O. Box 16, State College, PA 16801.

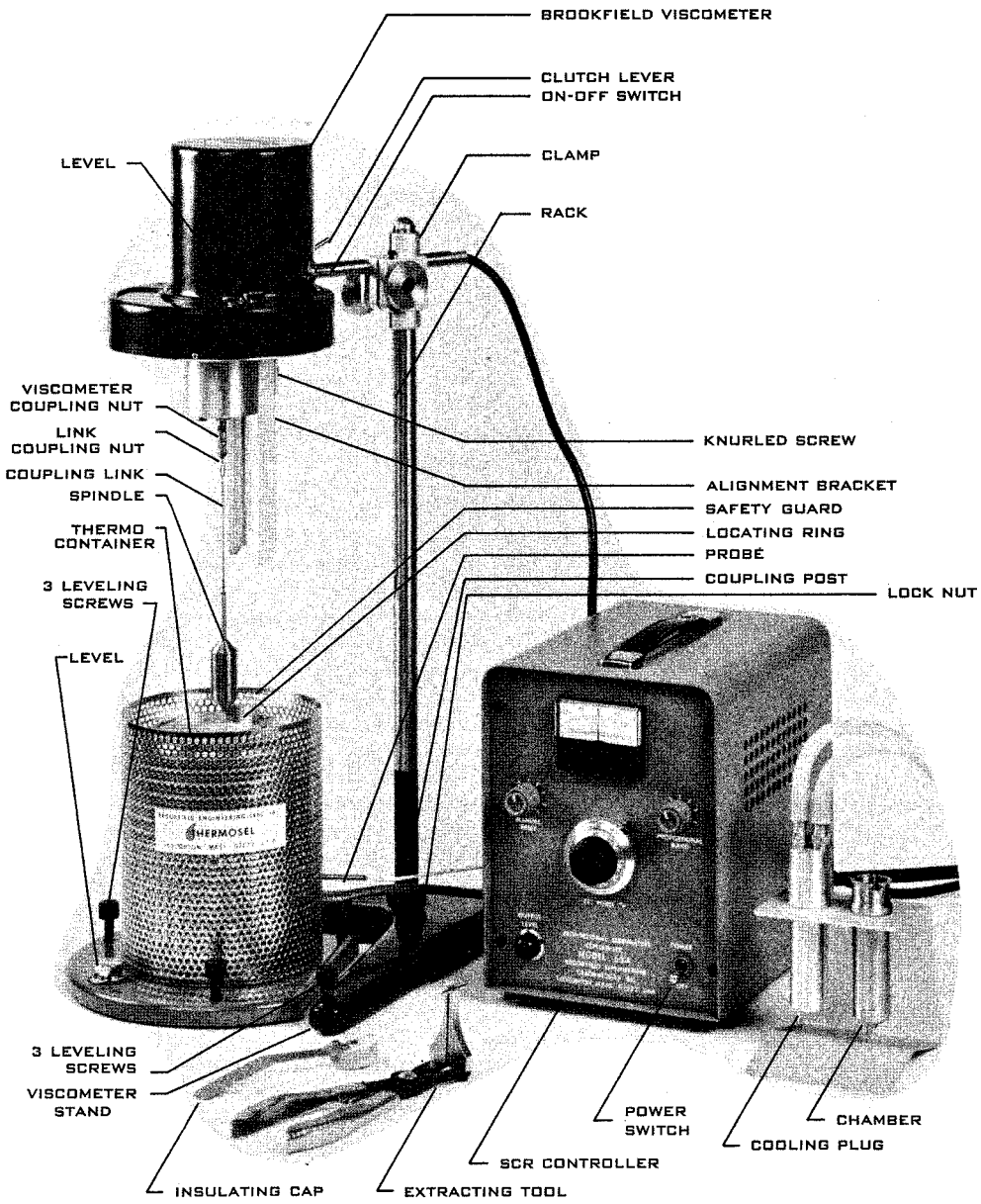

FIG. 1 Apparatus for Viscosity Determination

Connect the coupling link to the spindle (and the coupling nut). Lower the spindle into the sample chamber and connect the link coupling nut to the viscometer coupling nut, noting the left-hand thread. Pick up the insulating cap and place it over the sample chamber (see Fig. 1).

8.4 *Viscosity Determination*—Ensure that the material in the sample chamber is completely molten and that temperature controller settings are proper. Turn on the viscometer and allow the spindle to rotate at the lowest spindle speed available to minimize temperature gradients in the sample as well as possible shear effects. When temperature equilibrium is indicated, turn off the viscometer, remove the insulating cap, raise the viscometer and spindle, and inspect the liquid level on the spindle shaft. It should extend about 3 mm (⅛ in.) up the spindle shaft beyond the upper, tapered portion of the spindle. If the liquid level varies significantly from this, add or remove sample to provide this level. Replace the insulating cap, and allow the unit to reestablish temperature equilibrium with the spindle rotating at the lowest available speed. Continue spindle rotation for 15 min after apparent equilibrium. Increase the spindle speed to that required to produce a scale reading nearest the midpoint of the scale, but in no case outside the 10 to 95 unit range. Engage the pointer clutch and stop the viscometer motor when the pointer is in view. Record the scale reading. Restart the viscometer motor, and allow at least five additional revolutions of the spindle. Engage the pointer clutch and stop the viscometer motor with the pointer in view. Record the second dial reading. Repeat the above operation until three consecutive scale readings are obtained which differ by no more than 0.5 unit.

9. Calculation

9.1 Determine the average of the three consecutive scale readings which differ by no more than 0.5 scale unit. To

convert to millipascal seconds, multiply this value by the appropriate factor taken from either the instrument instruction manual or Table A1.2 in the Annex. Repeat this for each temperature.

NOTE 7—If it is necessary to interpolate for viscosity values at intermediate temperatures, plot a series of observed apparent viscosity values on the logarithmic scale and the corresponding test temperatures on the linear scale of appropriate semi-logarithmic paper, using a series of at least three different temperatures. From the plot, determine the apparent viscosity at any temperature requested, within the range of test temperatures.

10. Report

10.1 Report the apparent viscosity at a given temperature along with the particulars of the instrument model, the spindle number and rotational speed. *Example:* Apparent viscosity at 125°C (RVT, SC 4-28, 20 rpm)—20 000 mPa·s.

NOTE 8—If it is desired to report the shear rate corresponding to the instrument/spindle/speed combination, refer to Table A1.1 for the appropriate calculation.

11. Precision and Bias

11.1 The precision of this test method as determined by statistical examination of interlaboratory results is as follows:

11.1.1 *Repeatability*— The difference between two test results, obtained by the same operator with the same apparataus under constant operating conditions on identical test material would, in the normal and correct operation of the test method, exceed the following values in one case in twenty:

8.8 % of the mean of the two results. (1)

11.1.2 *Reproducibility*—The difference between two single and independent results obtained by different operators working in different laboratories in identical test material would, in the long run, exceed the following value only in one case in twenty:

25.4 % of the mean of the two results. (2)

NOTE 9—The precision of this test method is based on a round-robin conducted using six wax-based hot melt materials that are believed to be representative of the class. Tests were conducted at three temperatures by seven to eleven laboratories using the Brookfield viscometer model and spindle combination available to that laboratory. This encompassed a total of four viscometer models (Models LVF, LVT, RVT, and HBT) and seven different spindles, each appropriately tailored to the viscometer used. The effect of shear rate was disregarded.

11.1.3 A review of that portion of the data which can be considered comparable at equal shear rates indicates that those laboratories capable of comparing data at equal shear rates can expect improvement in reproducibility. It is estimated that under conditions of equal shear rate reproducibility the values would in the long run, exceed the following in one case in twenty:

15 % of the mean of the two results. (3)

11.1.4 A summary of data generated in this round-robin program is shown in Table 3 and Table 4.

11.2 *Bias*—The procedure in this test has no bias because the value of apparent viscosity can be defined only in terms of a test method.

12. Keywords

12.1 adhesives; apparent viscosity; coating materials; hot melt adhesives; viscosity

TABLE 3 Summary of Precision Estimates, Total Round-Robin Data

Sample No.	Average Viscosity, mPa·s	Sa	deg freedom	Sa + b	deg freedom	Sa %	Sa + b %
MI69-28							
100°C	65.2	2.02	11	3.64	10	3.10	5.58
125°C	38.7	1.07	10	2.39	9	2.76	6.18
150°C	25.2	0.27	10	2.20	9	1.07	8.73
MI69-29							
100°C	170.2	4.39	10	19.7	9	2.58	11.58
125°C	93.4	2.54	9	9.10	8	2.72	9.74
150°C	55.8	1.00	9	4.23	8	1.79	7.59
MI69-30							
125°C	232,100	8540	6	9040	5	3.68	3.88
150°C	128,167	4280	6	7380	5	3.34	5.76
175°C	74,021	1840	7	5310	6	2.49	7.17
MI69-31							
125°C	3416	117	11	207	10	3.43	6.06
150°C	1456	43.2	11	70.0	10	2.96	4.81
175°C	756	16.7	11	46.2	10	2.21	6.11
MI69-32							
125°C	66,560	2850	9	7410	8	4.28	11.13
150°C	26,800	1130	9	2750	8	4.22	10.26
175°C	11,850	449	9	1030	8	3.79	8.69
MI69-33							
125°C	165,300	3730	7	7320	6	2.26	4.43
150°C	74,590	1880	8	2650	7	2.52	3.78
175°C	35,840	1820	9	2420	8	5.07	6.75

Pooled Data:

Sa (overall) = 3.14 % at 162 deg freedom
3.14 × 2.80 = 8.8 % relative

Sa + b (overall) = 7.60 % at 7 deg freedom
7.60× 3.34 = 25.4 % relative

TABLE 4 Summary of Precision Estimates, Selected Shear Equalized Data

Sample No.	Average Viscosity, mPa·s	Sa	deg freedom	Sa + b	deg freedom	Sa %	Sa + b %
MI69-28							
100°C	64.4	1.33	7	2.15	6	2.07	3.34
125°C	38.0	0.56	5	0.75	4	1.47	1.97
150°C	24.1	0.51	6	0.47	5	2.12	1.95
MI69-29							
100°C	163.2	0.63	6	4.09	5	0.38	2.51
125°C	90.3	0.75	5	1.90	4	0.90	2.11
150°C	53.7	0.83	5	1.30	4	1.55	2.42
MI69-30							
125°C	229,900	10,240	4	15,700	3	4.59	7.04
150°C	130,900	5200	5	5200	4	3.97	3.97
175°C	74,640	830	5	4750	4	1.11	6.36
MI69-31							
125°C	3429	40	6	77.6	5	1.17	2.26
150°C	1474	12.3	6	28.3	5	0.83	1.92
175°C	770	15.6	5	21.0	4	2.03	2.73
MI69-32							
125°C	68,680	1450	5	3440	4	2.11	5.00
150°C	28,000	255	6	1670	5	0.91	5.96
175°C	12,350	361	6	911	5	2.92	7.38
MI69-33							
125°C	167,700	1730	5	5000	4	1.03	2.98
150°C	75,700	756	7	1645	6	1.00	2.17
175°C	37,350	685	5	1070	4	1.83	2.86

Pooled Data:
Sa (overall) = 1.83 % at 99 deg freedom Sa + b (overall) = 3.81 % at 4 deg freedom
1.83 × 2.82 = 5.16 % relative 3.81 × 3.92 = 14.93 % relative

ANNEXES

(Mandatory Information)

A1. APPARATUS AND EQUIPMENT SET-UP

A1.1 *Viscometer and Stand*—Set up the viscometer stand on a firm, level surface convenient to a 15-A, 115-V, 60-Hz a-c electrical service and a cooling water supply and drain. Connect the coupling post to the rack, and screw both posts into the V-shaped base, leaving the lock nut loose. Place the three leveling screws in position in the base. Attach the viscometer to the stand, inserting it into the clamp on the rack. The viscometer must be leveled and centered on the viscometer base. Lock the posts tightly to the stand with the lock nut on the coupling post. Raise the viscometer to the highest position on the stand. Making certain that the power switch is off, plug in the viscometer power cord.

A1.2 *Alignment Bracket*—With the viscometer raised to the highest position on the stand and the dial directly in front, attach the alignment bracket to the back of the viscometer pivot cup, securing it tightly with the knurled screw.

A1.3 *Thermo-container, Sample Chamber, and Safety Guard* —Level the red thermo-container base using the three leveling screws in the base. Slide the perforated safety guard over the top of the thermo-container, sliding it past the power cord flush against the red base. Using the extracting tool, insert the sample chamber into the thermo-container. Rotate the sample chamber until it drops and locks in place preventing further rotation.

A1.4 *Controller and Probe*—Place the controller on the level surface adjacent to the thermo-container. Insert the three-pronged male plug from the thermo-container braided cord into the socket on the controller. **Caution:** This plug must be connected to the controller only. Insert the 4-in. stainless steel probe into the hole in the thermo-container located directly above the braided cord. Plug the other end of the probe into the connector on the controller. Making certain that the controller power switch is in the OFF position, plug the controller power cord "into" a 115-V, 60-Hz, grounded a-c power source.

A1.5 *System Alignment and Spindle Insertion*—Level the viscometer stand base and the thermo-container and base. Lower the viscometer until the tips of the alignment bracket *just touch* the top of the thermo-container, making contact directly behind the locating ring. Raise the viscometer, positioning the tips of the alignment bracket about 2 mm (1⁄16 in.) above the top of the thermo-container. Using both hands, gently slide the thermo-container base until the tips of the alignment bracket *just touch* the locating ring. *Do not* forcibly displace the alignment bracket. Screw the link coupling nut onto the viscometer coupling nut, noting the left-hand thread. Connect the coupling link to the spindle. Lower the spindle into the sample chamber and connect the spindle and link to the link coupling nut on the viscometer. Place the insulating cap over the sample chamber inlet, thus capping the system.

TABLE A1.1 Viscometer-Spindle Data

LV Series Viscometers						
Spindle	Viscosity Range, mPa·s			Shear Rate, s^{-1}	Sample Volume, mL	Approximate Sample Weight, g
	LVT	LVF	5 x LVT			
SC 4-18	5–10 000	5–500	25–50 000	1.32 (N)[A]	8.0	6.4
SC 4-31	50–100 000	50–5 000	250–500 000	0.34 (N)	10.0	8.0
SC 4-34	100–200 000	100–10 000	500–1 000 000	0.28 (N)	9.5	7.6

RV Series Viscometers						
Spindle	Viscosity Range, mPa·s			Shear Rate, s^{-1}	Sample Volume, mL	Approximate Sample Weight, g
	RVT	RVF	RVF–100			
SC 4-21	50–100 000	250–25 000	50–5 000	0.93 (N)	8.0	6.4
SC 4-27	250–500 000	1 250–125 000	250–25 000	0.34 (N)	10.5	8.4
SC 4-28	5001 000 000	2 500–250 000	500–50 000	0.28 (N)	11.5	9.2
SC 4-29	1 000–2 000 000	5 000–500 000	1 000–100 000	0.25 (N)	13.0	10.4

HA Series Viscometers					
Spindle	Viscosity Range, mPa·s		Shear Rate, s^{-1}	Sample Volume, mL	Approximate Sample Weight, g
	HAT	HAF			
SC 4-21	100–200 000	1 000–100 000	0.93 (N)	8.0	6.4
SC 4-27	500–1 000 000	5 000–500 000	0.34 (N)	10.5	8.4
SC 4-28	1 000–2 000 000	10 000–1 000 000	0.28 (N)	11.5	9.2
SC 4-29	2 000–4 000 000	20 000–2 000 000	0.25 (N)	13.0	10.4

HB Series Viscometers					
Spindle	Viscosity Range, mPa·s		Shear Rate, s^{-1}	Sample Volume, mL	Approximate Sample Weight, g
	HBT	HBF			
SC 4-21	400–800 000	4 000–400 000	0.93 (N)	8.0	6.4
SC 4-27	2 000–4 000 000	20 000–2 000 000	0.34 (N)	10.5	8.4
SC 4-28	4 000–8 000 000	40 000–4 000 000	0.28 (N)	11.5	9.2
SC 4-29	8 000–16 000 000	80 000–8 000 000	0.25 (N)	13.0	10.4

[A] *N* = rpm at which dial readings are taken

Example: Model RVT Viscometer/SC 4-28 spindle at 20 rpm

Shear Rate Factor × Spindle Speed in rpm = Shear Rate in s^{-1}

0.28 × 20 = 5.6 s^{-1}

TABLE A1.2 Viscometer-Spindle Factor Data

NOTE 1—To calculate viscosity in millipascal seconds (mPa·s) multiply the dial reading by the factor, corresponding to the viscometer, spindle, and speed combination utilized.

Speed, rpm	LV Series Viscometer Spindle Factors								
	LVT			LVF			5 × LVT		
	SC4-18	SC4-31	SC4-34	SC4-18	SC4-31	SC4-34	SC4-18	SC4-31	SC4-34
60	0.5	5	10	0.5	5	10	2.5	25	50
30	1.0	10	20	1.0	10	20	5	50	100
12	2.5	25	50	2.5	25	50	12.5	125	250
6	5	50	100	5	50	100	25	250	500
3	10	100	200				50	500	1M
1.5	20	200	400				100	1M	2M
0.6	50	500	1M				250	2.5M	5M
0.3	100	1M	2M				500	5M	10M

Speed, rpm	RV Series Viscometer Spindle Factors											
	RVT				RVF				RVF-100			
	SC4-21	SC4-27	SC4-28	SC4-29	SC4-21	SC4-27	SC4-28	SC4-29	SC4-21	SC4-27	SC4-28	SC4-29
00	5	25	50	100	...	...	...	...	5	25	50	100
50	10	50	100	200	...	...	...	...	10	50	100	200
20	25	125	250	500	25	125	250	500	25	125	250	500
10	50	250	500	1M	50	250	500	1M	50	250	500	1M
5	100	500	1M	2M	...	...	...	...				
4	...	...	...	...	125	625	1.25M	2.5M				
2.5	200	1M	2M	4M	...	...	...	...				
2	...	...	...	...	250	1.25M	2.5M	5M				
1	500	2.5M	5M	10M	...	...	...	...				
0.5	1M	5M	10M	20M	...	...	...	...				

Speed, rpm	HA Series Viscometer Spindle Factors							
	HAT				HAF			
	SC4-21	SC4-27	SC4-28	SC4-29	SC4-21	SC4-27	SC4-28	SC4-29
100	10	50	100	200	...	...	...	...
50	20	100	200	400	...	...	...	...
20	50	250	500	1M	...	...	...	...
10	100	500	1M	2M	100	500	1M	2M
5	200	1M	2M	4M	200	1M	2M	4M
2.5	400	2M	4M	8M	...	...	...	...
2	...	...	...	...	500	2.5M	5M	10M
1	1M	5M	10M	20M	1M	5M	10M	20M
0.5	2M	10M	20M	40M	...	...	...	...

Speed, rpm	HB Series Viscometer Spindle Factors							
	HBT				HBF			
	SC4-21	SC4-27	SC4-28	SC4-29	SC4-21	SC4-27	SC4-28	SC4-29
100	40	200	400	800	...	...	...	...
50	80	400	800	1.6M	...	...	...	...
20	200	1M	2M	4M	...	...	...	...
10	400	2M	4M	8M	400	2M	4M	8M
5	800	4M	8M	16M	800	4M	8M	16M
2.5	1.6M	8M	16M	32M	...	...	...	...
2	...	...	...	...	2M	10M	20M	40M
1	4M	20M	40M	80M	4M	20M	40M	80M
0.5	8M	40M	80M	160M	...	...	...	...

A2. CLEANING OF EQUIPMENT

A2.1 The spindle and sample chambers are made from stainless steel and may be cleaned with most commercial chlorinated or hydrocarbon solvents. If the solvents are heated, adequate precautions must be taken to avoid toxicity, flammability, or explosive hazards. Spindles and cham-bers must not come in contact with sulfuric acid, hydrofluoric acid, hydrochloric acid, and ferric chloride. Care must also be exercised to avoid scratching or deforming the spindles.