THE WELLS-BROOKFIELD CONE/PLATE DIGITAL VISCOMETER

Operating Instructions

Principle of Operation	3
Cone/Plate Theory	3
Introduction	3
Initial Setup	4
Calibration	4
Initialization	5
Operation	6
Accuracy	7
Fault Diagnosis	7
Specifications	7
Repairs and Service	8
Warranty	8
Appendix	9

BROOKFIELD ENGINEERING LABORATORIES, INC.

240 Cushing Street, Stoughton, MA 02072 USA
Telephone: (617) 344-4310 Telex: 924-497

M/82-040-A

Principle of Operation

The Wells-Brookfield Cone/Plate Digital Viscometer rotates a conical spindle at a precise speed and measures the torque necessary to overcome the viscous resistance to the induced movement caused by the presence of sample fluid between the spindle and a stationary flat plate. This is accomplished by driving the spindle through a calibrated beryllium copper spring. The degree to which the spring is wound, detected by a rotational transducer, is proportional to the viscosity of the fluid.

Continuous readout of viscosity can be accomplished in two ways: by means of the integral three-digit LED display, or by the 0-10 mv analog output signal which can be fed into a variety of indicating or recording devices.

The Viscometer is able to measure over a number of ranges since, for a given spring deflection, the actual viscosity is proportional to the spindle speed and is related to the spindle's angle and diameter. For a material of given viscosity, the spring deflection will be greater as the spindle diameter and/or rotational speed increase, or the spindle angle decreases.

Measurements made using the same spindle at different speeds are used to detect and evaluate the rheological properties of the test material. Our booklet, "Solutions to Sticky Problems" discusses the Viscometer's use in this respect.

Cone/Plate Theory

If the axis of a nearly flat conical surface is perpendicular to a flat plate with the cone's apex lying in the plane of the plate, and if either the cone or the plate is rotated with respect to the other about the axis, fluid in the space between the two will be subjected to uniform shear rate.

This, except for small edge effects, follows from the fact that the rate of movement of any point on either surface is proportional to its distance from the axis and that the separation of the surfaces at that point is equivalently proportional to the same radius. The ratio of the rate of movement of the surface (at any point) to the distance of separation is fixed for any speed of rotation, and constant over the entire surface. Since rate of shear is by definition this ratio, it is therefore constant.

By using small angles between cone and plate (less than 4^{o}), substantial rates of shear and hence, shearing stresses, can be achieved with comparatively low rotational speeds, low viscosities and small samples.

Introduction

The Wells-Brookfield Cone/Plate Digital Viscometer is powered by a precision synchronous motor. Exact speeds of rotation are assured as the motor will turn erratically and spasmodically if synchronism cannot be maintained.

Speed changes are effected by a transmission having eight speeds. The square speed control knob has two numbers on each face; by moving the knob through two complete turns the eight speeds may be selected in sequence.

To ensure rotation at the indicated speed it is important that the face of the knob upon which this speed is shown be closely parallel to the Viscometer's base. Although not absolutely necessary, it is advisable to change speeds while the motor is running.

Calibration of this Viscometer is accomplished by a simple mechanical procedure. Both the cone spindle and the sample cup have small pins projecting from their surfaces. These pins provide a reference point from which the separation of the spindle and the plate can be set with an accuracy of .0001" or better.

Initial Setup

1. Mount Viscometer securely on laboratory stand. Level the Viscometer, referring to the bubble level on the back of the instrument.

2. Verify that the Viscometer's (and recorder's, if used) power requirements match your power source before connecting it to power.

3. If using recorder: connect output cable to recorder terminals. Connect the red wire to the "+" terminal and the black wire to "-". Insert the plug on the other end of the cable into the Viscometer's output receptacle. Set the recorder's input selector (if so equipped) to 10 mv full scale.

   NOTE: DO NOT CONNECT OUTPUT CABLE TO POWER!

4. Connect fittings on Viscometer sample cup to temperature bath with flexible hose. The lower fitting on the sample cup should be connected to the bath's pump outlet; the upper fitting to the return. All connections should be clamped.

   It is not recommended to operate the Viscometer at sample temperatures in excess of 100 degrees C.

Calibration

1. Turn on temperature bath and allow sufficient time for sample cup to reach the desired temperature. Calibration should always be performed at operating temperature.

2. Swing sample cup clip to one side and remove sample cup. Using wrench supplied, hold Viscometer lower shaft and screw on cone spindle, lifting lower shaft slightly at the same time (note left-hand thread). Avoid putting side thrust on the shaft.

   The mating surfaces of the spindle and lower shaft must be clean to prevent eccentric rotation of the spindle.

3. Turn power switch on (up), energizing Viscometer display. The power switch is on the left side of the front panel.

4. Check bubble level to be sure Viscometer is level. Turn motor switch on (up) and set speed selector knob to 10 or 12 rpm (depending on model). The motor switch is on the right side of the front panel.

   Allow Viscometer to run until display reading stabilizes (or fluctuates by no more than 0.1). Turn zero adjustment knob until the display reads 00.0.

5. Turn motor switch off, placing Viscometer in standby mode.

6. Place sample cup against adjusting ring, being sure to position the notch on the side of the cup around the sample cup clip. Swing clip under cup to secure it in place.

Avoid hitting the spindle when installing the sample cup. If the display doesn't return to zero after installing the sample cup, unscrew the adjusting ring (turn it to the left) until the display reading returns to zero.

7. Run the Viscometer at 10 or 12 rpm.

   If the display reading regularly jumps to 0.3 or higher, or will not settle to zero (indicating that the pins in the spindle and the sample cup are contacting), screw the adjustment ring to the left until the reading stabilizes at or near zero.

   If the display reading remains at or near zero, continue to the next step.

8. Turn the adjusting ring to the right in small increments (one or two minor divisions on the ring) while watching the digital display. Turn the adjusting ring until fluctuation of the display reading indicates that the pins have made contact.

   Once contact has been made, back off the adjusting ring (turn it to the left) in small increments until stablization of the display reading indicates that the pins are not contacting.

   Turn the adjusting ring to the right in very small increments (about 1/64") until the display reading fluctuates regularly by a small amount. This determines the point at which the pins are just making contact.

9. Make a pencil mark on the adjusting ring directly under the index mark on the pivot housing. Turn the adjusting ring to the left exactly the width of one minor division. This will separate the pins by exactly .0005".

   The Viscometer is now calibrated and is ready for operation.

   It is recommended that this calibration procedure be performed every time the spindle is removed from the Viscometer and replaced. The Viscometer's calibration can be checked by the use of Brookfield Viscosity Standards (under controlled temperature conditions only).

Initialization

1. After the Viscometer is calibrated, it should be zeroed before running sample tests. The following procedure can be performed with the spindle installed and the sample cup on or off.

2. Turn power switch on, energizing Viscometer display.

3. Check bubble level to be sure Viscometer is level. Turn motor switch on and set speed selector knob to 10 or 12 rpm (depending on model).

4. Allow Viscometer to run until display reading stabilizes (or fluctuates by no more than 0.1). Turn zero adjustment knob until the display reads 00.0. This also zeros the output signal.

5. If a recorder is used, it should be zeroed after the Viscometer has been zeroed. The recorder input must be in the "run" mode. After the recorder is zeroed, switch it to the "standby" mode.

6. Turn motor switch off, placing Viscometer in standby mode.

Operation

1. Calibrate and zero the Viscometer (and recorder, if used) according to the procedures described previously.

2. Remove the sample cup. Place sample fluid in cup according to the table below, being sure that the sample is bubble-free and spread evenly over the surface of the cup. Sample volume must be sufficient to wet the entire face of the spindle and approximately 1.0mm up the spindle's outside edge.

Spindle	Angle (degrees)	Sample Volume (ml)
CP-40	0.8	0.5
CP-41	3.0	2.0
CP-42	1.565	1.0
CP-50	0.8	0.2
CP-51	1.565	0.5
CP-52	3.0	0.5

   Replace the sample cup, being careful not to hit the spindle.

3. Allow sufficient time for the sample fluid to reach the desired temperature.

4. To make a viscosity measurement, turn the motor switch on, which energizes the Viscometer drive motor. Allow time for the display reading to stabilize. The time required for stabilization will depend on the speed at which the Viscometer is running and the characteristics of the sample fluid.

   The digital display on this Viscometer reads from 0-99.9. When making a viscosity measurement, the display reading should be noted and multiplied by a factor which is obtained by consulting the range table for the Viscometer model and spindle in use. The factor is calculated by dividing the viscosity range for the speed in use by 100. For maximum accuracy, display readings below 10.0 should be avoided.

   Range tables for most Viscometer models are provided in the Appendix. For models not shown in the tables, supplementary range sheets are supplied with the instrument.

   When using a recorder, switch recorder to "run" mode to record the Viscometer reading. Note that the paper used in the recorder has a 0-100 scale. The reading on the chart is utilized in the same fashion as the Viscometer display reading.

5. Turn the Viscometer motor switch off when changing or cleaning a spindle, changing samples, etc. This is a standby mode in which the electronic circuits of the Viscometer remain energized. It is advisable to leave the power switch on between tests to minimize drifting of the Viscometer reading.

   It is recommended, when operating the Viscometer for a lengthy period, that zero be checked occasionally as described previously.

6. The interpretation of results and the instrument's use with non-Newtonian and thixotropic materials is discussed in the booklet, "Solutions to Sticky Problems."

Accuracy

All models of the Wells-Brookfield Cone/Plate Digital Viscometer are guaranteed to be accurate to within 1% of whatever full scale range is employed when used in the specified manner. Readings should be reproducible to within 0.2% of full scale subject to variations in fluid temperature, etc.

Fault Diagnosis

Problem	Cause	Action
Spindle doesn't rotate	Drive motor not energized	Turn power switch on
Display reads "---"	Underrange (Spindle jammed)	Consult factory
Display reads "EEE"	Overrange	Change speed and/or spindle
Recorder pen moves in wrong direction	Output polarity reversed	Exchange output leads
No recorder response	Viscometer is at zero reading	Check for output at upscale reading
	Recorder off	Check recorder power and power switch
	Output shorted	Check output connections

Specifications

Power Supply:	115V/60 Hz or 230V/50 Hz
Output Signal:	0-10 mv DC
Output Impedence:	1 k ohms

Repairs and Service

Any Brookfield Digital Viscometer used in the United States requiring repair or service should be returned to:

Brookfield Engineering Laboratories, Inc.
240 Cushing Street
Stoughton, Massachusetts 02072

The Viscometer should be shipped in its carrying case together with all the spindles originally provided with the instrument.

For service on Viscometers located outside the United States, consult the dealer from whom you purchased the instrument.

Warranty

Brookfield Viscometers are guaranteed for one year from date of purchase against defects in materials and workmanship.

APPENDIX

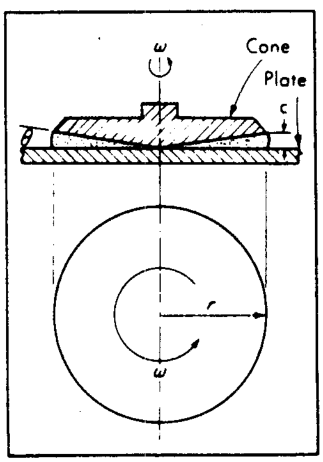
Cone/Plate Mathematics

Range Tables

Cone/Plate Mathematics

Cone and Plate geometry, as illustrated, is the fixation of a conical vertex perpendicular to and in point contact with a flat plate. When the cone is made very obtuse (θ less than 4°) and rotated at constant speed (ω), precise viscosity measurements are obtained at absolute and uniform values of shearing rate and stress.

Viscosity (poise) is the ratio of shear stress to shear rate. Shear stress is related to the summation of torque (T) over the conical surface. Shear rate is related to the cone rotational speed (ω), and gap width (c) at any radial distance (r) from the center of the rotating cone.



The ratio of (ω r) and (c) is a constant for any value of (r). Since (c) is a maximum at cone radius (r), the shear rate is related to (ω) and sin (θ).

For the Wells-Brookfield Cone/Plate Viscometer, the mathematical relationships are:

$$\text{Shear Stress (dynes/cm}^2) = \frac{T}{\frac{2}{3}\pi r^3}$$

$$\text{Shear Rate (Sec}^{-1}) = \frac{\omega}{\sin\theta}$$

$$\underset{\text{(mPa·s)}}{\text{Viscosity (Centipoise)}} = \frac{\text{Shear Stress} \times 100}{\text{Shear Rate}}$$

Where:

T = % Full Scale Torque (dyne-cm)

r = Cone Radius (cm)

ω = Cone Speed (rad/sec)

θ = Cone Angle (degrees)

Cone Radius:
CP 40, CP 41, CP 42 — 2.4 cm
CP 50, CP 51, CP 52 — 1.2 cm

Range Tables

All ranges are in centipoise.
(1 cps = 1 mPa•s)

Factor = Range/100

Viscosity = Display Reading x Factor

LVTDCP

3.0° Cone			
SPEED (RPM)	SHEAR RATE (SEC^{-1})	CONE # CP-41 2 ml SAMPLE	CONE # CP-52 0.5 ml SAMPLE
60	120.0	19.2	155.33
30	60.0	38.4	310.66
12	24.0	96.0	776.64
6	12.0	192.0	1,553.3
3	6.0	384.0	3,106.6
1.5	3.0	768.0	6,213.1
0.6	1.2	1,920.0	15,532.8
0.3	0.6	3,840.0	31,065.6

1.565° Cone			
SPEED (RPM)	SHEAR RATE (SEC^{-1})	CONE # CP-42 1 ml SAMPLE	CONE # CP-51 0.5 ml SAMPLE
60	230.0	10.00	80.90
30	115.0	20.00	161.80
12	46.0	50.00	404.50
6	23.0	100.00	809.00
3	11.50	200.00	1,618.00
1.5	5.75	400.00	3,236.0
0.6	2.30	1,000.0	8,090.0
0.3	1.15	2,000.0	16,180.0

0.8° Cone			
SPEED (RPM)	SHEAR RATE (SEC^{-1})	CONE # CP-40 0.5 ml SAMPLE	CONE # CP-50 0.2 ml SAMPLE
60	450.0	5.14	41.36
30	225.0	10.28	82.72
12	90.0	25.70	206.80
6	45.0	51.40	413.60
3	22.5	102.80	827.20
1.5	11.25	205.60	1,654.4
0.6	4.50	514.00	4,136.0
0.3	2.25	1,028.0	8,272.0

RVTDCP

3.0° Cone			
SPEED (RPM)	SHEAR RATE (SEC^{-1})	CONE # CP-41 2 ml SAMPLE	CONE # CP-52 0.5 ml SAMPLE
100	200	122.88	983
50	100	245.76	1,966
20	40	614.40	4,915
10	20	1,228.8	9,830
5	10	2,457.6	19,660
2.5	5	4,915.2	39,320
1.0	2	12,288.0	98,300
0.5	1	24,576.0	196,600

1.565° Cone			
SPEED (RPM)	SHEAR RATE (SEC^{-1})	CONE # CP-42 1 ml SAMPLE	CONE # CP-51 0.5 ml SAMPLE
100	384.0	64	512
50	192.0	128	1,024
20	76.8	320	2,560
10	38.4	640	5,120
5	19.20	1,280	10,240
2.5	9.60	2,560	20,480
1.0	3.84	6,400	51,200
0.5	1.92	12,800	102,400

0.8° Cone			
SPEED (RPM)	SHEAR RATE (SEC^{-1})	CONE # CP-40 0.5 ml SAMPLE	CONE # CP-50 0.2 ml SAMPLE
100	750.0	32.70	262
50	375.0	65.40	524
20	150.0	163.50	1,310
10	75.0	327.00	2,620
5	37.5	654.00	5,240
2.5	18.75	1,308.0	10,480
1.0	7.50	3,270.0	26,200
0.5	3.75	6,540.0	52,400

HBTDCP

3.0° Cone			
SPEED (RPM)	SHEAR RATE (SEC^{-1})	CONE # CP-41 2 ml SAMPLE	CONE # CP-52 0.5 ml SAMPLE
100	200	983	7,864
50	100	1,966	15,728
20	40	4,915	39,321
10	20	9,830	78,643
5	10	19,660	157,286
2.5	5	39,320	314,572
1.0	2	98,300	786,430
0.5	1	196,600	1,572,860

1.565° Cone			
SPEED (RPM)	SHEAR RATE (SEC^{-1})	CONE # CP-42 1 ml SAMPLE	CONE # CP-51 0.5 ml SAMPLE
100	384.0	512	4,096
50	192.0	1,024	8,192
20	76.8	2,560	20,480
10	38.4	5,120	40,960
5	19.2	10,240	81,920
2.5	9.6	20,480	163,840
1.0	3.84	51,200	409,600
0.5	1.92	102,400	819,200

0.8° Cone			
SPEED (RPM)	SHEAR RATE (SEC^{-1})	CONE # CP-40 0.5 ml SAMPLE	CONE # CP-50 0.2 ml SAMPLE
100	750.0	262	2,096
50	375.0	524	4,192
20	150.0	1,310	10,480
10	75.0	2,620	20,960
5	37.5	5,240	41,920
2.5	18.75	10,480	83,840
1.0	7.50	26,200	209,600
0.5	3.75	52,400	419,200