CAP 2000+ Viscometer

Manual
Dear customer,

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- Technical Sales Force
- Technical & Application Support
- Application and Technical Seminars
- Repair & Certification Service

BYK-Gardner is part of the Additives and Instrument Division of ALTANA AG, a leading supplier of additives for coatings and plastics. Together, we offer complete and unique solutions for you our customer. Thank you for your trust and confidence. If there is anything we can do better to serve your needs, do not hesitate to let us know.

Your BYK-Gardner Team
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## Appendix E - Warranty Repair and Service
I. INTRODUCTION

The CAP Series Viscometers utilize Cone and Plate geometry with integrated temperature control of the test sample material. The CAP 2000+ is a variable speed viscometer over the range of 5-1000 RPM. The instrument operates by digital setting and display; rotational speed can be automatically timed to stop. Viscosity measurements are made over various viscosity ranges depending upon the cone spindle and the rotational speed (shear rate). Viscosity is selectively displayed in units of centipoise (cP), poise (P), milliPascal seconds (mPa•s) or Pascal seconds (Pa•s). Temperature control of sample is possible between either 5°C (or 15°C below ambient, whichever is higher) and 75°C, or 50°C and 235°C depending on viscometer model.

The CAP 2000+ Viscometer selectively displays in either the CGS or SI units (see page 8):

<table>
<thead>
<tr>
<th>CGS</th>
<th>SI</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity: P or CP</td>
<td>Pa•s or mPa•s</td>
<td>0.1 Pa•s = 1 P (= 100 cP)</td>
</tr>
<tr>
<td>Shear Rate: SEC-1</td>
<td>SEC-1</td>
<td></td>
</tr>
<tr>
<td>Speed: RPM</td>
<td>RPM</td>
<td></td>
</tr>
<tr>
<td>Temperature: °C</td>
<td>°C</td>
<td></td>
</tr>
</tbody>
</table>

The CAP 2000+ Viscometer output data to a parallel printer in the CGS and SI units:

<table>
<thead>
<tr>
<th>CGS</th>
<th>SI</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity: P or cP</td>
<td>Pa•s or mPa•s</td>
<td>0.1 Pa•s = 1 P (= 100 cP)</td>
</tr>
<tr>
<td>Full Scale Range (F.S.R.): %</td>
<td>%</td>
<td>0.1 Pa•s = 1 P (= 100 cP)</td>
</tr>
<tr>
<td>Shear Stress: Dynes/cm²</td>
<td>N/m²</td>
<td>1.0 N•m = 10’ dyne•cm</td>
</tr>
<tr>
<td>Shear Rate: SEC⁻¹</td>
<td>SEC⁻¹</td>
<td></td>
</tr>
<tr>
<td>Speed: RPM</td>
<td>RPM</td>
<td></td>
</tr>
<tr>
<td>Run Time: Seconds</td>
<td>Seconds</td>
<td></td>
</tr>
<tr>
<td>Temperature: °C</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>Cone Spindle Number: No.</td>
<td>No.</td>
<td></td>
</tr>
</tbody>
</table>
I.1 COMPONENTS

The following items are included:

1. CAP 2000+ Viscometer
2. Cone Spindle(s)
3. Spindle Case
4. Solvent Trap
5. Power Cord: 115V 220V UK Germany
6. Operating Instructions Manual

The following optional items may have been included:

7. Viscosity Standard Fluid for calibration
8. CAPCALC Software

Please check to be sure that you have received all components, and that there is no damage. If you are missing any parts, please notify BYK-Gardner or your local BYK-Gardner representative immediately. Any shipping damage must be reported to the carrier. Save the packing container, if possible, for future use when returning the viscometer to BYK-Gardner or an authorized dealer for service.
I.2 UTILITIES

Input Voltage: 115 VAC or 230 VAC
Input Frequency: 50/60 Hz
Power Consumption: Less than 345 WATTS
Fuses: (2) 5x20mm, 3A, 250V, Fast Acting for 125VAC
(2) 5x20mm, 1.6A, 250V. Fast Acting for 250VAC

Power Cord Color Code:

<table>
<thead>
<tr>
<th></th>
<th>United States</th>
<th>Outside United States</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot (live)</td>
<td>Black</td>
<td>Brown</td>
</tr>
<tr>
<td>Neutral</td>
<td>White</td>
<td>Blue</td>
</tr>
<tr>
<td>Ground (earth)</td>
<td>Green</td>
<td>Green/Yellow</td>
</tr>
</tbody>
</table>

I.3 SPECIFICATIONS

Torque Ranges: 1x = 181,000 dyne•cm
22.7x = 7,970 dyne•cm

Speeds: 5-1000 RPM (in increments of 1 RPM)

Temperatures:
- CAP 2000+L 5°C (or 15°C below ambient, whichever is higher) to 75°C
- CAP 2000+H 50°C to 235°C All models provide 0.1°C increments

Weight:
- Gross Weight 36 lb 16.3 kg
- Net Weight 27 lb 12.3 kg
- Carton Volume 4.9 cu ft 0.15 m³
- Carton Dimensions 18 in. L x 18 in. W x 26 in. H
  48 cm. L x 48 cm. W x 66 cm. H

Materials: CAP cone spindles and temperature plates are made of tungsten carbide.
Solvent Trap is made of Teflon.

Operating Environment:
- CAP 2000+ Viscometers must be operated within the following ambient temperatures: +5°C (41°F) to 40°C (149°F)
- and humidity: 20% to 80% R.H. (non-condensing atmosphere)

Electrical Certifications / Conforms to CE Standards:
- BSEN 61326: Electrical equipment for measurement, control and laboratory use - EMC requirements.

NOTICE TO CUSTOMERS:
This symbol indicates that this product is to be recycled at an appropriate collection center.

Users within the European Union:
Please contact your dealer or the local authorities in charge of waste management on how to dispose of this product properly. All BYK-Gardner offices and our network of representatives and dealers can be found on our website: www.byk.com

Users outside of the European Union:
Please dispose of this product according to your local laws.
I.4 INSTALLATION

**NOTE:** DO NOT lift the viscometer by the handle or display panel!
LIFT by the base console or column!

1) Set the viscometer on a clean level bench surface.

2) Remove shipping spindle blank and foam packing from CAP Viscometer. Store the spindle blank in the spindle case. Use again only when transporting CAP Viscometer.

3) Verify that the viscometer’s power requirements match your power source BEFORE connecting it to power.

*The AC input voltage and frequency must be within the appropriate range as shown on the name plate of the viscometer.*

**NOTE:** The CAP Viscometer must be earth grounded.
Use the three (3) wire power cord! Do not alter!

4) Connect the power cord to the viscometer and to the power supply (source).

5) If using a printer, connect the printer cable to the printer port and printer.

6) If using a computer, connect the RS-232 cable (supplied with CAPCALC software) to the serial port and the computer.

**NOTE:** Ensure that both the printer and the CAP-2000+ are off when connecting cables.
I.5 SAFETY SYMBOLS AND PRECAUTIONS

SAFETY SYMBOLS
The following explains safety symbols which may be found in this operating manual.

⚠️ Indicates hazardous voltages may be present.

⚠️ Caution: HOT surface.

⚠️ Refer to the manual for specific warning or caution information to avoid personal injury or damage to the instrument.

SAFETY OVERVIEW

⚠️ If this instrument is used in a manner not specified by the manufacturer, the protection provided by the instrument may be impaired.

⚠️ This instrument is not intended for use in a potentially hazardous environment.

⚠️ In case of emergency, turn off the instrument and then disconnect the electrical cord from the wall outlet.
I.6 KEY FUNCTIONS

Figure I-1 shows the control keys on the face of the viscometer display panel:

**NUMERIC 0-9**  
Used for data entry

**ENTER**  
Accepts entered data

**STOP/ESCAPE**  
Stops cone spindle rotation at any time / Exits data entry field

**DELETE**  
Overwrites entered data

**PRINT**  
Sends data to the parallel port

**RUN**  
Starts spindle rotation and measurement

**RUN TIME**  
Selects time entry mode (time of spindle rotation)

**HOLD TIME**  
Selects time entry mode (wait time before spindle rotates)

**SPINDLE**  
Selects the cone spindle entry mode

**TEMP**  
Selects the temperature entry mode
I.7 VISCOSITY AND TEMPERATURE DISPLAY

Viscosity is displayed in either $P=$Poise or $cP=$Centipoise (CGS system) or $Pa\cdot s=$Pascal seconds or $mPa\cdot s=$milliPascal seconds (SI system). If the viscosity measurement is over range, “EEEE” will be displayed. BYK-Gardner recommends a minimum reading of 10%. If the display value is between 0 and 10%, the unit display will flash to indicate an out of range condition. If the viscometer settles out with a final reading below zero, negative values will be displayed.

Temperature is displayed in °C=degrees centigrade.

I.8 Cleaning

Instrument, Keypad & Painted Surfaces:
Clean with dry, non-abrasive cloth. Do not use solvents or cleaners.

Immersed Components (spindles/cones) and temperature controlled plate:

NOTE: Sample plate and spindle may be hot. Use care when using solvents.

All immersed components are made of carbide steel. Clean with non-abrasive cloth and solvent appropriate for sample material that is not aggressive to immersed components.

Do not use metal objects to clean the plate surface, as scratching of the plate may occur and compromise cone calibrations.

Solvent Trap:
Solvent Trap (P/N C1K-63) is made of Teflon. Clean with non-abrasive cloth and solvent appropriate for sample material that is not aggressive to Teflon.

Do not use metal objects to clean the plate surface, as scratching of the plate may occur and compromise cone calibrations.

Immersed components (cone spindle) may be at an elevated temperature. Use caution when cleaning hot surfaces. Use caution when applying solvents to hot surfaces. Refer to the MSDS for the specific solvent for proper handling techniques.

NOTE: When cleaning, take care not to apply excessive force which may bend the spindle shaft or otherwise damage the instrument.
II. GETTING STARTED

II.1 POWER ON

Turn the power ON using the switch located on the rear of the base console. The start-up screen will be displayed for four seconds and will indicate the viscometer model, version number and torque range.

After four (4) seconds, the main screen will be displayed (Figure II-2).

**Default Temperatures**

- CAP L Series Viscometer 25.0°C
- CAP H Series Viscometer 50.0°C

**Special Functions**

Units of measure and speed control may be selected through the special functions screen. This screen is accessed by pressing the STOP key during instrument power up.

The CAP-2000+ can be configured to control speed by either rotations per minute (RPM) or shear rate (1/SEC). This selection is set by choosing 1=SPEED CONTROL in the special functions screen, then selecting 1=RPM or 2=1/SEC and pressing ENTER.

The CAP-2000+ can be configured to display viscosity in one of four units: Poise (P), Centipoise (cP), Pascal Seconds (Pa•s) or milliPascal seconds (mPa•s). This selection is set by choosing 2=Units of Measure in the special functions screen, selecting 1=P, 2=cP, 3=Pa•s or 4=mPa•s and then pressing ENTER.

Once the CAP-2000+ has been configured, the instrument must be turned OFF. The configuration will be stored in memory.

II.2 CONE SPINDLE SELECTION AND SETTING

Raise the viscometer handle to its highest position.

The CAP cones have viscosity ranges as shown in Appendix A. After selecting the appropriate cone for the viscosity range to be utilized, carefully attach the cone to the viscometer as shown (Figure II-2).

**NOTE:** Spindles 7-10 should only be used in the speed range of 5-400 RPM. At speeds greater than 400 RPM, the test sample will not remain in the gap and measurement results will be unreliable.

Be sure to align the flats on the spindle shaft with the thumb screw.
When using the solvent trap, connect it to the cone adapter by sliding it up, passing the slot by the thumb screw and turning the trap clockwise onto the thumbscrew. Slide the cone up into the adapter as far as it will go and hand lock it in place with the thumb screw. Tighten the thumb screw firmly and securely.

Press the SPINDLE key. The display will change to the spindle entry screen. Using the number keys, type in the required spindle number.

Two digits must be entered for the cone number. For cone 01 through 09, the first number remains as “0”.

**NOTE:** The default cone setting on power-up will be the last cone entry prior to shutting off the viscometer.

After the correct two (2) digits have been entered, press the ENTER key and the cone will be accepted for viscometer calculations. The screen will display the following message:

```
Spindle 04
CALIBRATE? YES/NO
```

Normally there is no requirement to perform a cone calibration. Cones supplied at the time of order are calibrated to the viscometer prior to shipment.

**NOTE:** 1. CAP Viscometers allow for only one cone at a time of the same cone number to be calibrated to the viscometer. Multiple cones of the same cone number must each be calibrated to the viscometer before operation (refer to Appendix B).
   2. Cones entered as 11 through 20 must be first calibrated following the directions in Appendix B.

If you are not going to calibrate the cone, continue by pressing the NO key then ENTER. The viscometer will display the MAIN SCREEN (Figure II-1). If you are going to calibrate the cone, press the YES key, refer to Appendix B, and follow the calibration instructions under Cone Calibration.
II.3 SPEED SETTING

The CAP2000+ is a variable speed viscometer. The speed of rotation is shown in the lower right corner of the display. To change the speed of rotation, enter the new speed using the number keys. The new speed will be shown in the lower right hand corner of the display. To accept the new speed, press ENTER.

The new speed may be cancelled by pressing ESCAPE before pressing ENTER. To begin spindle rotation, press the RUN key.

NOTE: The speed cannot be changed while the motor is running.

Speed control may be configured to either shear rate or rotations per minute (see Special Functions in section II.1). Data entry for speed selection is the same in either configuration.

Data entry must be in whole numbers.

II.4 TEMPERATURE CONTROL SETTING

Press the TEMP key and the current temperature setting will blink. The default temperature on start-up is 25.0°C on low temperature models and 50°C on high temperature models.

The temperature ranges are:
Low temperature: 5°C (or 15°C below ambient, whichever is higher) to 75°C
High temperature: 50°C to 235°C

NOTE: The temperature can be set in increments of 0.1°C.

Use the number keys to type in the required set point.

Use the ENTER key to accept the new set point.

NOTE: Thermal equilibrium of the sample and of the spindle must be considered for best measurement results. Upon powering up the Viscometer or after changing the temperature set point, allow sufficient time for the plate to reach the desired temperature. It is recommended to have the spindle in contact with the plate prior to introducing the sample material to ensure that the spindle is also at the temperature of test. BYK-Gardner recommends using the solvent trap at all times to enhance the temperature control of the sample material. After inserting the sample material onto the plate, lower the spindle and solvent trap and allow sufficient time for thermal equilibrium prior to starting the test.
II.5 HOLD TIME SETTINGS

Hold time sets the time period between when the **RUN** key is pressed and when the spindle begins to rotate. This time period is normally used to ensure thermal equilibrium of the sample and spindle. The hold time range is 0 to 999 seconds.

Press the **HOLD TIME** key and the current hold time will blink on the default screen. Use the number keys to type in the required hold time and press the **ENTER** key.

**NOTE:** When the hold time is set to zero, it is not displayed on the default screen.

II.6 RUN TIME

Run time sets the time period of spindle rotation. The run time range is 0 to 999 seconds.

Press the **RUN TIME** key and the current run time will blink on the default screen. Use the number keys to type in the required run time and press the **ENTER** key.

**NOTE:** Run time will be shown on the default screen only when hold time is set to zero.

A run time of zero sets the viscometer to infinite run mode. In this mode, the spindle will rotate at the set speed for as long as the **RUN** button is pressed. When the **RUN** key is released, the spindle will stop rotating.

**NOTE:** With a run time of zero, the hold time will not be used.

The time required for reading stabilization will depend on the speed of rotation and the nature of the test sample. Longer runs times are recommended at lower speeds.

<table>
<thead>
<tr>
<th>Speed of Rotation</th>
<th>Run Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-1000 RPM</td>
<td>12 seconds</td>
</tr>
<tr>
<td>20-50 RPM</td>
<td>20 seconds</td>
</tr>
<tr>
<td>5-20 RPM</td>
<td>30 seconds</td>
</tr>
</tbody>
</table>
II.7 PRINTING

Pressing the PRINT key at any time sends information on test parameters to the printer port. However, viscosity, full scale range and shear stress data will only be printed after it is first displayed during a test run.

At the end of a timed speed execution, data will automatically be sent to the printer port. To print a heading, press and hold the STOP/ESCAPE key and press the PRINT key.

<table>
<thead>
<tr>
<th>VISCOSITY (POISE)</th>
<th>F.S.R. (%)</th>
<th>TEMP (Deg C)</th>
<th>S.STRESS (D/CM2)</th>
<th>S RATE (1/sec)</th>
<th>SPEED (RPM)</th>
<th>TIMER (SEC)</th>
<th>CONE No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>-</td>
<td>25.0</td>
<td>-</td>
<td>10000</td>
<td>0750</td>
<td>20</td>
<td>02</td>
</tr>
</tbody>
</table>

A maximum of 999 seconds can be printed when running in manual TIMER mode (00). Over 999 seconds will print EEE.

NOTE: The TIMER (SEC) column will indicate the accumulated time of running at the moment the print key is pressed while the cone is rotating. This time value will not include the hold time.

II.8 RUN AND STOP KEYS

The RUN key has three functions:
1. Press RUN to execute a timed measurement.
2. Press and hold the RUN key for continuous rotation when 00 is the timer setting.
3. Used in executing a cone calibration.

The STOP key has three functions:
1. Stops the cone rotation at any time.
2. Pressing and holding the STOP/ESCAPE key during power up selects the viscosity display units and speed of rotation.
3. Pressing and holding the STOP and PRINT keys simultaneously executes the printing of a new heading (Section II.7).

II.9 PARAMETER DISPLAY

The parameter display will appear, as shown in Figure II-1, immediately after the RUN key is pressed. All relevant measurement parameters will be shown for 5 seconds including speed, shear rate, run time, hold time and spindle. The display will return to the default screen after five seconds.

NOTE: The viscometer will be operating according to the selected parameters while the parameter display screen is shown.
III. OPERATION

The CAP 2000+ Viscometer rotates a precisely machined cone spindle over a temperature controlled plate shearing the test sample over a range of speeds from 5 to 1000 RPM. This provides a comprehensive capability to analyze materials for viscosity behavior as a function of both shear rate and temperature. Tests can be run in standalone mode or under PC control. This chapter explains how to use the CAP2000+ toward these objectives.

III.1 MAKING VISCOSITY MEASUREMENTS

The following procedure is recommended for making a single point viscosity measurement in standalone mode.

With the viscometer on a clean level surface, connect it to the proper power supply (Section I.4).

1. Turn the power switch **ON** (Section II.1).
   
   The procedure assumes that the following list has been done:

   a) If the viscometer has been “off” for an extended period (i.e., overnight) a “warm up” period of 30 minutes is suggested. The default temperature (25°C) is used for low temperature instruments (CAP2000+L). The default setting for high temperature instruments is 50°C (CAP2000+H). If a cone calibration is to be done immediately after the warm up period, temperature should be set to 60°C right away (calibration temperature for high temperature instruments) to save some time.

   b) The cone calibration procedure (Appendix B) will be done at the factory for all cones which are supplied with the instrument. Cone calibration is required when a new cone (i.e., replacement for lost/damaged cone) is used, or when calibration check fails.

   c) When making measurements with low temperature instruments (CAP2000+L), the solvent trap may not be required (for the containment of solvents and/or prevention of sample “drying”). The trap should be used for all measurements with high temperature instruments (CAP2000+H).

   d) The CAP2000+ will print automatically when a reading is taken if a parallel printer is connected and “on line.”

   e) Select and attach the cone (Section II.2).

   **NOTES:**

   1. Lock the cone tightly into the adapter.

   2. When measuring volatile samples such as paints and coatings, and when using either a high temperature CAP 2000+H or CAP 2000+H, the solvent trap must be put in place over the cone to prevent the test sample from drying out during the rotation of the cone.

   f) Set the temperature control (Section II.5).
2. Set the cone number.
3. Set the speed of rotation.
4. Lower the handle placing the cone onto the plate. Lock the handle into its lowest position. Drop the solvent trap over the cone.

**NOTE:** Allow ten (10) minutes for the cone to come to equilibrium temperature with the plate.

5. Raise the handle. Place the sample to be measured onto the plate below the cone and solvent trap. Refer to Appendix A for recommended sample sizes. Lower the cone and solvent trap.

**NOTES:**

1. Lower the handle *gently*. **DO NOT FORCE THE CONE ONTO THE PLATE.**

2. The sample must completely cover the face of the cone and extend beyond the edge of the cone about 1.0 mm (see table A-1 for sample size).

3. Release the solvent trap placing it onto the plate over the cone so it does not touch the cone shaft.

The user should ensure that the substances placed under test do not release poisonous, toxic or flammable gases at the temperatures to which they are subjected to during the testing.

6. Allow the cone, plate and sample to equilibrate to the temperature control setting.

**NOTE:** A minimum of one (1) to three (3) minutes equilibrium time is recommended, depending upon the sample.

7. Set the **Run Time** for rotating the cone (Section II.6) and the **Hold Time**.

**NOTE:** The time required for reading stabilization will depend on the speed of rotation and the nature of the test sample. Longer runs times are recommended at lower speeds.

<table>
<thead>
<tr>
<th>Speed of Rotation</th>
<th>Run Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-1000 RPM</td>
<td>12 seconds</td>
</tr>
<tr>
<td>20-50 RPM</td>
<td>20 seconds</td>
</tr>
<tr>
<td>5-20 RPM</td>
<td>30 seconds</td>
</tr>
</tbody>
</table>

8. Put the printer on-line (optional, Section II.7).

9. Press the **RUN** key and execute the viscosity measurement.
NOTE: Due to the dynamics of shearing a fluid in the CAP “H” series Viscometers, the temperature display may indicate a deviation from the equilibrium temperature setting as the cone begins rotating at high shear rates. The temperature display may indicate the temperature of the plate and the momentary changes show the cycling of the temperature control at high temperature. The accuracy of the viscosity measurement is maintained within the limits specified in Table 3.1.

NOTE: The parameter display will be shown for 5 seconds.

10. Read the results of the sample test on the printer or write down the test conditions and viscosity results from the viscometer display.

11. Relocate the solvent trap onto the cone adapter and raise the handle.

12. It is recommended to remove the cone for cleaning. However, with care, the cone can be cleaned in place.

13. Clean the viscometer plate (refer to Section I.8).

II.2 COMPUTER CONTROL

The CAP2000+ Viscometer can be operated remotely under PC control when using the CAPCALC application software.

When advanced sample analysis is required, CAPCALC application software can control the CAP2000+ Viscometer from a PC. CAPCALC for Windows requires Windows NT or higher CAPCALC application software displays, prints and stores tabulated data files (Excel).

CAPCALC software has automatic data capture (up to 200 data points per test) and graphical data display (rheograms) to facilitate analysis of test samples. The software also allows temperature control of the sample plate for integrated viscosity/temperature tests between 5°C and 75°C (CAP 2000+L) or 50°C and 200°C (CAP 2000+H) depending on viscometer model. CAPCALC features include on-screen and printed plots of % F.S.R.; viscosity or shear stress vs. cone speed, shear rate, time or temperature. Also available are automatic calculation of Yield Stress (Bingham Plastic or Casson) and Power Law Consistency Index.

Additional information on the communications protocol for CAP2000+ is contained in Appendix D.

Contact BYK-Gardner or our authorized agent to obtain the CAPCALC software.
### III.3 ACCURACY OF MEASUREMENT

Table III.1 indicates the accuracy of the viscosity measurement with CAP spindles 01-06. This accuracy depends on both the rotational speed of the cone and the percent of full scale range at which viscosity is measured. The accuracy for viscosity data provided by CAP Viscometers is the indicated percentage of the full scale range. See Appendix A for information on how to determine Full Scale Viscosity Range (FSR).

**Table III-1 Accuracy of Viscosity Measurement**

<table>
<thead>
<tr>
<th>Cone</th>
<th>FULLSCALE VISCOSITY RANGE ACCURACY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>400 RPM</td>
</tr>
<tr>
<td>01</td>
<td>—</td>
</tr>
<tr>
<td>02</td>
<td>—</td>
</tr>
<tr>
<td>03</td>
<td>—</td>
</tr>
<tr>
<td>04</td>
<td>—</td>
</tr>
<tr>
<td>05</td>
<td>—</td>
</tr>
<tr>
<td>06</td>
<td>± 2.0%</td>
</tr>
<tr>
<td>07</td>
<td>—</td>
</tr>
<tr>
<td>08</td>
<td>—</td>
</tr>
<tr>
<td>09</td>
<td>—</td>
</tr>
<tr>
<td>10</td>
<td>—</td>
</tr>
</tbody>
</table>

Cones 07-10 are not recommended for use at these speeds.

**CAP 2000+H VISCOMETERS**

<table>
<thead>
<tr>
<th>Cone</th>
<th>FULLSCALE VISCOSITY RANGE ACCURACY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>400 RPM</td>
</tr>
<tr>
<td></td>
<td>10 to 100%*</td>
</tr>
<tr>
<td>01</td>
<td>—</td>
</tr>
<tr>
<td>02</td>
<td>—</td>
</tr>
<tr>
<td>03</td>
<td>—</td>
</tr>
<tr>
<td>04</td>
<td>—</td>
</tr>
<tr>
<td>05</td>
<td>—</td>
</tr>
<tr>
<td>06</td>
<td>—</td>
</tr>
<tr>
<td>07</td>
<td>2%</td>
</tr>
<tr>
<td>08</td>
<td>2%</td>
</tr>
<tr>
<td>09</td>
<td>2%</td>
</tr>
<tr>
<td>10</td>
<td>2%</td>
</tr>
</tbody>
</table>

Cones 07-10 are not recommended for use at these speeds.

**Viscometer Temperature Control Accuracy**

<table>
<thead>
<tr>
<th>Viscometer</th>
<th>Temperature Control Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAP1000L &amp; H</td>
<td>± 0.2°C</td>
</tr>
</tbody>
</table>

* = Full Scale Range
III.4 REPEATABILITY

The CAP 2000+ Viscometer is repeatable to ±0.5% of the full scale viscosity range (FSR). Due to shear heating considerations which occur at higher shear rates, the measurement of NIST Viscosity Standard Fluids at rotational speeds above 900 RPM may show a decrease in viscosity with an increase in rotational speed (shear rate).

Normal forces due to the shearing of a viscoelastic fluid (such as paint) are accounted for in the CAP Series Viscometers by weight on the spindle column: 3.6 Newtons (360,000 dynes) on a 1xCAP, 1.2 Newtons (120,000 dynes) on a 22.7xCAP total force. This is done to avoid having the cone lift off the plate, thereby changing the cone plate geometry and producing incorrect viscosity readings. For normal forces greater than 3.4 Newtons (340,000 Dynes) total force, additional externally mounted weights are required. However, more weight means more wear on the cone and plate. Additional weights should only be considered when definitely required and removed when not required.

Contact BYK-Gardner or your local BYK-Gardner Dealer/Distributor/Representative for details on the above information.
## APPENDIX A - CONE NUMBERS, SAMPLE SIZES, VISCOSITY RANGES

### CAP 1000 AND 2000 VISCOMETERS

<table>
<thead>
<tr>
<th>Cone Number(^1)</th>
<th>Shear Rate (sec(^{-1}))</th>
<th>Sample Size (micro liters)</th>
<th>Calibrating Fluid Low Temp Cap at 25°C</th>
<th>Calibrating Fluid High Temp Cap at 60°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>13.33N</td>
<td>67</td>
<td>CAP1L 89 cP</td>
<td>CAP1H 89 cP</td>
</tr>
<tr>
<td>02</td>
<td>13.33N</td>
<td>38</td>
<td>CAP2L 177 cP</td>
<td>CAP2H 177 cP</td>
</tr>
<tr>
<td>03</td>
<td>13.33N</td>
<td>24</td>
<td>CAP3L 354 cP</td>
<td>CAP3H 354 cP</td>
</tr>
<tr>
<td>04</td>
<td>3.33N</td>
<td>124</td>
<td>CAP4L 708 cP</td>
<td>CAP4H 708 cP</td>
</tr>
<tr>
<td>05</td>
<td>3.33N</td>
<td>67</td>
<td>CAP5L 1417 cP</td>
<td>CAP5H 1417 cP</td>
</tr>
<tr>
<td>06</td>
<td>3.33N</td>
<td>32</td>
<td>CAP6L 3542 cP</td>
<td>CAP6H 3542 cP</td>
</tr>
<tr>
<td>07</td>
<td>2N</td>
<td>1700</td>
<td>CAP7L 1328 cP</td>
<td>CAP7H 1328 cP</td>
</tr>
<tr>
<td>08</td>
<td>2N</td>
<td>400</td>
<td>CAP8L 5313 cP</td>
<td>CAP8H 5313 cP</td>
</tr>
<tr>
<td>09</td>
<td>2N</td>
<td>100</td>
<td>CAP9L 21,250 cP</td>
<td>CAP9H 21,250 cP</td>
</tr>
<tr>
<td>10</td>
<td>5N</td>
<td>170</td>
<td>CAP10L 236 cP</td>
<td>CAP10H 236 cP</td>
</tr>
<tr>
<td>(N = \text{RPM})(^*)</td>
<td></td>
<td></td>
<td></td>
<td>*Approximate Value</td>
</tr>
</tbody>
</table>

\(^*\)Number marked on the cone shaft

### Table A-1

### CAP 1000 VISCOSITY RANGES (POISE)

<table>
<thead>
<tr>
<th>Cone Number(^1)</th>
<th>400 RPM</th>
<th>750 RPM</th>
<th>900 RPM</th>
<th>Cone Range Coefficient</th>
<th>Cone Angle (degrees)</th>
<th>Cone Radius (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>0.46 - 4.6</td>
<td>0.25 - 2.5</td>
<td>0.21 - 2.08</td>
<td>1.875</td>
<td>0.45</td>
<td>1.511</td>
</tr>
<tr>
<td>02</td>
<td>0.93 - 9.3</td>
<td>0.5 - 5.0</td>
<td>0.42 - 4.17</td>
<td>3.75</td>
<td>0.45</td>
<td>1.200</td>
</tr>
<tr>
<td>03</td>
<td>1.87 - 18.7</td>
<td>1.0 - 10.0</td>
<td>0.83 - 8.33</td>
<td>7.5</td>
<td>0.45</td>
<td>0.953</td>
</tr>
<tr>
<td>04</td>
<td>3.75 - 37.5</td>
<td>2.0 - 20.0</td>
<td>1.67 - 16.67</td>
<td>15</td>
<td>1.8</td>
<td>1.200</td>
</tr>
<tr>
<td>05</td>
<td>07.05.75</td>
<td>4.0 - 40.0</td>
<td>3.33 - 33.33</td>
<td>30</td>
<td>1.8</td>
<td>0.953</td>
</tr>
<tr>
<td>06</td>
<td>18.7 - 187</td>
<td>10.0 - 100.0</td>
<td>8.33 - 83.33</td>
<td>75</td>
<td>1.8</td>
<td>0.702</td>
</tr>
<tr>
<td>07</td>
<td>0.78 - 7.8</td>
<td>Not recommended</td>
<td></td>
<td>3.15</td>
<td>3</td>
<td>2.399</td>
</tr>
<tr>
<td>08</td>
<td>3.12 - 31.2</td>
<td></td>
<td></td>
<td>12.5</td>
<td>3</td>
<td>1.511</td>
</tr>
<tr>
<td>09</td>
<td>12.5 - 125.0</td>
<td></td>
<td></td>
<td>50</td>
<td>3</td>
<td>0.953</td>
</tr>
<tr>
<td>10</td>
<td>1.25 - 12.5</td>
<td></td>
<td></td>
<td>5</td>
<td>1.2</td>
<td>1.511</td>
</tr>
</tbody>
</table>

\(^1\)Number marked on the cone shaft

**NOTE:** Spindles 7-10 should only be used in the speed range of 5-400 RPM. At speeds greater than 400 RPM, the test sample will not remain in the gap and measurement results will be unreliable.
SAMPLE SIZE

It is necessary that sufficient sample is placed between the cone and plate to completely cover the surface of the cone when the cone is locked in the RUN position. With sufficient sample, an excess of about 1 mm in width will be seen around the periphery of the cone edge.

For calibration and best reproducibility of results, the sample sizes shown in Table A1 should be used.

CAP 2000+ RANGES FOR CONES 01 THROUGH 10

To determine the full scale viscosity range (FSR) for any cone/speed, divide the Cone Range Coefficient (refer to Table A2) by the rotational speed (RPM).

Full Scale Viscosity Range (Poise) = \( \frac{\text{Cone Range Coefficient}}{\text{RPM}} \)  
Equation A1

CAP 2000+ RANGES FOR CONES 11 THROUGH 20

Spindle Multiplier Constant (SMC):  
\( \text{SMC} = (\text{supplied by the manufacturer}) \)

Shear Rate Constant (SRC):  
\( \text{SRC} = (\text{supplied by the manufacturer}) \)

Viscosity (poise) = \( \frac{\text{Shear Stress (dynes/cm}^2\text{)}}{\text{Shear Rate (sec}^{-1}\text{)}} \)  
Equation A2

Shear Stress (dynes/cm\(^2\)) = Viscosity (poise) \times \text{Shear Rate (sec}^{-1}\text{)}  
Equation A3

Shear Rate = \( \frac{\omega}{\sin \theta} \)  
Equation A4

\( \omega = \text{Cone Speed (rad/sec)} = \left( \frac{2\pi}{60} \right) \times N \)

\( N = \text{RPM} \)

\( \theta = \text{Cone Angle (degrees)} \)

\( r = \text{radius of cone spindle} \)

Viscosity (poise) = \( \frac{\text{Full Scale Viscosity Range} \times (\% \text{ FSR})}{100} \)  
Equation A5
EXAMPLE: CAP 2000+L Viscometer; Cone (02); running at 750 RPM; temperature 25.0°C; % FSR = 73.8. Determine the viscosity (poise), shear stress (dynes/cm2), shear rate (sec⁻¹).

Using **Equation A2**, determine the full scale viscosity range at 750 RPM:

\[
\text{Full Scale Viscosity Range (poise)} = \frac{3,750}{750} = 5.00 \text{ poise}
\]

Using **Equation A5**, determine the viscosity at 73.8% of full scale range:

\[
\text{Viscosity (poise)} = 5.00 \text{ (poise)} \times \frac{73.8}{100} = 3.69 \text{ poise}
\]

Using **Equation A4**, determine the shear rate:

\[
\text{Shear Rate (sec}^{-1}) = \frac{2(3.1416)(750)}{(60)(\sin 0.45)} = 10,000 \text{ sec}^{-1}
\]

Using **Equation A2**, determine the shear stress:

\[
\text{Shear Stress (dynes/cm2)} = (3.69)(10,000) = 36,900 \text{ dynes/cm2}
\]
APPENDIX B - CALIBRATION PROCEDURES

Normally there is no requirement to perform a cone calibration. Cones supplied at the time of order are calibrated to the viscometer prior to shipment.

VERIFICATION OF CALIBRATION

At selected intervals, depending upon usage and number of operators, the CAP Viscometer calibration should be verified using NIST Fluids. Referring to Appendix A (Table A-1), find the appropriate NIST Fluid(s) for the cone(s) being used.

With the viscometer set up, perform viscosity measurements following the outline of Section III. Prior to pressing the RUN key to initiate a cone calibration, we recommend a period of thermal equilibrium of approximately 30 minutes for the fluid, cone and plate. This period should begin immediately after entering the calibration temperature and associated viscosity value (in cP). Execute viscosity measurement and record results.

Verify the result to have an accuracy according to the information in Section III (Table III-1). If the calibration is outside the accuracy limits, proceed with the following Cone Calibration.

INTERPRETATION OF CALIBRATION TEST RESULTS:

When verifying the calibration of the CAP 2000+, the instrument and viscosity standard fluid error must be combined to calculate the total allowable error.

The CAP 2000+ accuracy is defined in Section III.1 as a function of spindle number 03.

BYK-Gardner Viscosity Standards Fluids are accurate to (+/-) 1% of their stated value.

EXAMPLE: Calculate the acceptable range of viscosity using CAP 2000+ with Spindle 03 at 900 RPM; Standard Fluid CAP-3L with a viscosity of 350 cP at 25°C:

1) Calculate full scale viscosity range using the equation:

Full Scale Viscosity Range [P] = \frac{\text{Range Coefficient}}{\text{RPM}}

Where: Range Coefficient = 7500 from Table A2

\[
\text{Full Scale Viscosity Range} = \frac{7500}{900} = 8.33 \text{ P} (833 \text{ cP})
\]

The viscometer is accurate to (+/-) 16.7 cP. (which is 2% of 833)

2) The viscosity standard fluid is 350 cP. Its accuracy is (+/-) 1% of 350 or (+/-) 3.5 cP.
3) Total allowable error is (16.7 + 3.5) cP. = (+/-) 20.2 cP. (0.2 P).
4) Therefore, any viscosity reading between 329.8 and 370.2 cP. indicates that the viscometer is operating correctly. Any reading outside these limits may indicate a viscometer problem. If the reading falls outside the acceptable range, perform a cone calibration (Appendix B). If the calibration is outside the accuracy limits, proceed with the following Cone Calibration.
Appendix B

CONE CALIBRATION

A special feature of the CAP Series Viscometers allows the user to perform a cone calibration using Viscosity Standard Fluids. This field calibration will accommodate any wear on the tip of the cone which may result from contact with the plate.

**NOTE:** A cone calibration should be performed when: 1) using a new cone for the first time, 2) switching between two cones of the same number and 3) verification of calibration provides data outside of the acceptable range.

Refer to Appendix A (Table A1) and choose the calibration fluid for the spindle being calibrated. These fluids are for the recommended calibration speed (900 RPM for cones 1-6, 100 RPM for cones 7-10). You may choose a different speed of calibration. The calibration fluid should be selected to be approximately 42% of full scale range (see Equation A1).

**EXAMPLE:** If you choose to calibrate Cone 01 at a speed of 500 RPM:

- Calculate full scale viscosity range at 500 RPM:
  
  \[
  \text{A1: } \text{FSR} = \frac{1,850}{500 \times 1} = 3.75 \text{ poise}
  \]

- Determine 42% of FSR (full scale range)
  
  \[
  3.75 \text{P} \times 0.42 = 1.575 \text{ Poise}
  \]

- Select a calibration fluid in the range of 1.575 Poise

1. Turn on the CAP 2000+ Viscometer.
2. Attach solvent trap to coupling shaft.
3. Attach spindle.
4. Place appropriate amount of sample (Refer to Appendix A (Table A1)) onto the center of the Viscometer plate directly below the spindle.
5. Pull down the handle, locking it into the lowest position, placing the spindle in contact with the plate.
6. Lower the solvent trap.

**NOTE:** The solvent trap must be utilized when calibrating to ensure proper temperature control.

7. Select the spindle to be calibrated by using the SPINDLE key.
8. Select YES for CALIBRATE and press ENTER.
9. Enter the appropriate values for temperature (°C) and viscosity (cP) prompted by the screen.

**NOTE:** Viscosity values are always entered in units of CENTIPOISE (cP) no matter what units have been selected as unit of measure for normal operation.

\[
100 \text{ cP} = 1\text{P}; \quad 1\text{cP} = 1\text{mPa}\cdot\text{s}; \quad 1000 \text{ cP} = 1\text{Pa}\cdot\text{s}
\]
NOTE: The Viscometer temperature control must be identical to the specified temperature for the viscosity standard when executing the calibration. Normally calibration will be at 25°C for “L” Series CAP Viscometers and 60°C for “H” Series CAP Viscometers.

10. Allow at least 30 minutes for thermal equilibrium of the plate, calibration fluid and spindle.

11. Press the RUN key to start the calibration.

NOTE: The calibration process may be cancelled at any time prior to pressing RUN to calibrate, by pressing the ESCAPE key.

When calibration is complete, spindle rotation will stop and the “CALIBRATION COMPLETE” screen is displayed. Press ENTER to continue.

CUSTOM SPINDLES

The CAP Series Viscometer allows for the use of custom spindles. Please contact BYK-Gardner’s Technical Sales Department for more information.

Custom spindles are calibrated using spindle entry codes 11-20. The calibration of a custom spindle requires the entry of two parameters: SMC and SRC. The SMC and SRC are required for proper calculation of viscosity.

The SMC and SRC must be entered after entering the spindle number (11-20) and selecting YES (1) for calibration. Follow the screen prompts.

Once SMC and SRC are entered, follow the procedure described above for spindles 01-10.

NOTE: SMC and SRC need to be entered only once for any spindle number 11-20. The CAP Series Viscometer will store these values. SMC and SRC can be overwritten by executing a spindle calibration.

<table>
<thead>
<tr>
<th>VISCOSITY</th>
<th>FSR</th>
<th>TEMP</th>
<th>S.STRESS</th>
<th>S.RATE</th>
<th>SPEED</th>
<th>TIMER</th>
<th>CONE</th>
<th>SAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>(POISE)</td>
<td>(%)</td>
<td>(Deg C)</td>
<td>(D/CM2)</td>
<td>(1/sec)</td>
<td>(RPM)</td>
<td>(SEC)</td>
<td>No.</td>
<td>No.</td>
</tr>
</tbody>
</table>

Operator: ______________________________________________________
Date: ____________________________
Model/Serial#: ____________________________
Fluid: ____________________________

Figure B-1
APPENDIX C - VARIABLES IN VISCOITY MEASUREMENTS

As with any instrument measurement, there are variables that can affect a Viscometer measurement. These variables may be related to the instrument (Viscometer), or the test fluid. Variables related to the test fluid deal with the rheological properties of the fluid, while instrument variables would include the Viscometer design and the spindle geometry system utilized.

RHEOLOGICAL PROPERTIES

Fluids have different rheological characteristics that can be described by Viscometer measurements. We can then work with these fluids to suit our lab or process conditions.

There are two categories of fluids:

**Newtonian**
- These fluids have the same viscosity at different Shear Rates (different RPMs) and are called Newtonian over the Shear Rate range they are measured.

**Non-Newtonian**
- These fluids have different viscosities at different shear rates (different RPMs). They fall into two groups:
  1) Time Independent non-Newtonian
  2) Time Dependent non-Newtonian

The time dependency is the time they are held at a given Shear Rate (RPM). They are non-Newtonian, and when you change the Viscometer spindle speed, you get a different viscosity.

**Time Independent**

**Pseudoplastic**
- A pseudoplastic material displays a decrease in viscosity with an increase in shear rate, and is also known as “shear thinning”. If you take Viscometer readings from a low to a high RPM and then back to the low RPM, and the readings fall upon themselves, the material is time independent pseudoplastic and shear thinning.

**Time Dependent**

**Thixotropic**
- A thixotropic material has decreasing viscosity under constant shear rate. If you set a Viscometer at a constant speed, recording P values over time, and find that the P values decrease with time, the material is thixotropic.
VISCOMETER RELATED VARIABLES

- Most fluid viscosities are found to be non-Newtonian. They are dependent on Shear Rate and the spindle geometry conditions. The specifications of the Viscometer cone and plate geometry will affect the viscosity readings. If one reading is taken at 400 rpm, and a second at 1,000 rpm, the two viscosity values produced may be different because the readings were made at different shear rates. The faster the spindle speed, the higher the shear rate.

- The shear rate of a given measurement is determined by the rotational speed and the cone angle.

- A repeatable viscosity test should control or specify the following:
  1. Viscometer model
  2. Cone used
  3. Test temperature
  4. Test speed(s) [or the shear rate(s)]
  5. Length of time to record viscosity
  6. Sample volume sufficient to cover the face of the cone
PRINTER OUTPUT - CAP 2000+

The cable connection on the CAP2000+ Viscometer is a standard 25 pin parallel printer cable connector.

PRINTER OUTPUT - CAP 2000+

When connecting the CAP 2000+ to a computer, use BYK-Gardner Computer Cable (Part No. DVP-80). If you are not using the BYK-Gardner computer cable, jump (connect) pins 4 and 9 (refer to Figure E1) on the CAP 2000 end of the serial cable. The cable connections are:

- Com Port RxD (pin 2 (9 pin) or pin 3 (25 pin) to CAP Txd (pin 3)
- Com Port TxD (pin 3 (9 pin) or pin 2 (25 pin) to CAP RxD (pin 2)
- Com Port ground (pin 7) to CAP Serial Ground (pin 5)

The RS232 protocol is implemented as follows:

- Baud rate: 9600
- Parity: None
- Data bits: 8
- Stop bits: 1

The following pages review the transmit/receive commands between the CAP 2000+ and a computer (Table D2), the byte status interpretation (Table D1) and a sample program for external control of the CAP 2000+ Viscometer.

![Figure D-1](image-url)
# Appendix D

## CAP 2000+ TRANSMIT/RECEIVE COMMANDS FOR COMPUTER COMMUNICATION

<table>
<thead>
<tr>
<th>COMMAND RECEIVED</th>
<th>CAP 2000 RESPONSE</th>
<th>FUNCTION</th>
</tr>
</thead>
</table>
| Vyyy<CR>         | V<ss><CR>          | • Sets current speed and starts motor.  
                    • 000H <= yyy <= 3E8H (5 to 1000 RPM).  
                    • Anything between 001H and 005H is interpreted as 5 RPM.  
                    • Anything over 3E8H is interpreted as 1000 RPM.  
                    • All yyy values shall be padded to 3 characters with leading zeros.  
                    • A speed of 000 will stop the motor.  
                    • Sets clear the motor on bit (bit 1) in the status byte accordingly.  
                    • Sets illegal value bit in status byte if yyy is outside limits (See Table D2). |
| Tttt<CR>         | T<ss><CR>          | • Sets current temperature and controls to it.  
                    • 032H <= ttt <= 2EEH; CAPLO (5°C to 75 °C).  
                    • 000H <= ttt <= 92EH; CAPHI (0°C to 235°C).  
                    • Any temperature under the lower limit is interpreted as the lower limit.  
                    • Any temperature over the upper limit is interpreted as the upper limit.  
                    • The CAP 2000+ must divide all ttt values received by 10 before use.  
                    • All ttt values shall be padded to 3 characters with leading zeros.  
                    • Sets illegal value bit in status byte if ttt is outside limits (See Table D2). |
| R<CR>            | R<vvvvvffffrrrrrrttttcc> <ss><CR> | • Returns a data packet to the host.  
                    • vvvvvv : viscosity ,P , (multiplied by 1000 by the CAP 2000+). All vvvvvv values shall be padded to 6 characters with leading zeros.  
                    • ffff : FSR ,% , (multiplied by 100 by the CAP 2000+). All ffff values shall be padded to 4 characters with leading zeros.  
                    • rrrrrr : shear rate ,1/seconds , (multiplied by 100 by the CAP 2000+). All rrrrrr values shall be padded to 6 characters with leading zeros.  
                    • ttt : temperature ,°C , (multiplied by 10 by the CAP 2000+). All ttt values shall be padded to 3 characters with leading zeros.  
                    • cc : cone. All cc values shall be padded to 2 characters with leading zeros. |
| I<CR>            | ICAP+<bbxxxxddddd> <ss><CR> | • Identify the viscometer and firmware in use.  
                    • bb: HI or LO : temperature range.  
                    • xxx : firmware version (decimal format) multiplied by 100.  
                    • ddddd : spring constant, (multiplied by 10,000 by the CAP 2000+). All ddddd values shall be padded to 5 characters with leading zeros. |
| Scc<CR>          | Saaaaaaeeeeecc <ss><CR> | • Selects cone to be used.  
                    • cc : cone #: All cc values shall be padded to 2 characters with leading zeros.  
                    • 01H<=cc<=14H; Any S command sent with a cone number outside these limits will be ignored.  
                    • Cone # outside limits: response values represent the cone the instrument is staying with.  
                    • aaaaaa : cone multiplier constant. All aaaaaa values shall be padded to 6 characters with leading zeros.  
                    • eeeeee : shear rate constant of cone (multiplied by 10000). All eeeeee values shall be padded to 6 characters with leading zeros.  
                    • Sets illegal value bit in status byte if cc is outside limits (See Table D2). |
| Kccvvvvvveeeeee aaaaaayyy<CR> | Kccvvvvvveeeeee aaaaaayyy<ss><CR> | • Calibrate a new cone.  
                    • The response will not be returned to the host until the calibration is complete.  
                    • cc : cone #: All cc values shall be padded to 2 characters with leading zeros.  
                    • vvvvvv : viscosity of calibration fluid (centipoise). All vvvvvv values shall be padded to 6 characters with leading zeros.  
                    • eeeeee : shear rate constant of cone. The CAP 2000+ divides all eeeeee values by 10000 upon receiving them and multiplies by 10000 before sending them. All eeeeee values shall be padded to 6 characters with leading zeros.  
                    • aaaaaa : cone multiplier constant. All aaaaaa values shall be padded to 6 characters with leading zeros.  
                    • yyy: calibration speed. Subject to same limitations as in V command.  
                    • If there is an error, bit 7 of the status byte is set. |
| Invalid Command  | ???<CR>           | • Invalid command received |
Appendix D

**NOTE:** All multiplication and division operations performed on any of the command values should be done while the values in question are in their decimal (base 10) form (i.e. before any conversion to hexadecimal).

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;aaaaaa&gt;</td>
<td>Cone multiplier constant (hexadecimal). All cone multiplier constant values are six characters padded with leading zeroes.</td>
</tr>
<tr>
<td>&lt;bb&gt;</td>
<td>{HI / LO} Indicates whether the instrument operates in the high (0°C to 235°C) temperature range or the low (5°C to 75 °C) temperature range.</td>
</tr>
<tr>
<td>&lt;cc&gt;</td>
<td>Cone number (hexadecimal); all cone numbers are two characters padded with leading zeroes. All cone values are two characters padded with leading zeroes.</td>
</tr>
<tr>
<td>&lt;CR&gt;</td>
<td>Carriage return</td>
</tr>
<tr>
<td>&lt;ddddd&gt;</td>
<td>Spring Constant (hexadecimal). The Spring Constant must be multiplied by 10,000 before transmission by the CAP 2000+. Use the base Spring Constant for the model, not an adjusted constant after calibration.</td>
</tr>
<tr>
<td>&lt;eeeeee&gt;</td>
<td>Shear rate constant of a cone to be calibrated (hexadecimal). The CAP 2000+ must divide shear rate constants by 10000 after they are received, and multiply shear rate constants by 10000 before sending them out. All shear rate constant values are six characters padded with leading zeroes.</td>
</tr>
<tr>
<td>&lt;ffft&gt;</td>
<td>% FSR (hexadecimal). % FSR values are multiplied by 100 before transmission from the CAP 2000+. All FSR values are four characters padded with leading zeroes.</td>
</tr>
<tr>
<td>&lt;rrrr&gt;</td>
<td>Shear rate (1/seconds) values (hexadecimal). Shear rate values are multiplied by 100 before transmission by the CAP 2000+. All shear rate values are six characters padded with leading zeroes.</td>
</tr>
<tr>
<td>&lt;ss&gt;</td>
<td>Status byte, returned in hexadecimal format, see Table 2 for complete description. All status bytes are two characters padded with leading zeroes.</td>
</tr>
<tr>
<td>&lt;ttt&gt;</td>
<td>Temperature (°C) sent to or from the CAP 2000+ (hexadecimal). The CAP 2000+ must divide all temperature values received by 10, and multiply all temperature values sent by 10. All temperature inputs are three characters padded with leading zeroes.</td>
</tr>
<tr>
<td>&lt;wwww&gt;</td>
<td>Viscosity (P) sent to or from the CAP 2000+ (hexadecimal). The CAP 2000+ must divide all viscosity values received by 1000, and multiply all viscosity values sent by 1000; all viscosity values are six characters padded with leading zeroes.</td>
</tr>
<tr>
<td>&lt;xxx&gt;</td>
<td>Firmware version number, in decimal format, multiplied by 100 by CAP 2000+ before transmission (i.e. for firmware version 2.15, xxx would be 215).</td>
</tr>
<tr>
<td>&lt;yyy&gt;</td>
<td>Speed (RPM) input (hexadecimal). All speeds are three characters padded with leading zeroes.</td>
</tr>
</tbody>
</table>
INTERPRETATION OF BYTE STATUS

BYK-Gardner Viscometers are guaranteed for one year from the date of purchase against defects in materials and workmanship. They are certified against primary viscosity standards traceable to the National Institute of Standards and Technology (NIST). The Viscometer must be returned to BYK-Gardner USA or the BYK-Gardner dealer from whom it was purchased for warranty service. Transportation is at the purchaser’s expense. Remove the spindle from the viscometer and attach the shipping cap to the pivot cup to prevent shipping damage. The Viscometer should be shipped in its carrying case together with all spindles originally provided with the instrument.

<table>
<thead>
<tr>
<th></th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor Off</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>0</td>
</tr>
<tr>
<td>Motor On</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>1</td>
</tr>
<tr>
<td>Over FSR (&gt;=115.0%)1</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>1</td>
<td>X</td>
</tr>
<tr>
<td>Valid FSR (&lt;115.0%)</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>0</td>
<td>x</td>
</tr>
<tr>
<td>Value Outside Limits2</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>1</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Value Within Limits</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>0</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Calibration Error</td>
<td>13</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>0</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

1 Bit 2 is set in response to an R command (request for information) only.

2 If an input is received that is outside the allowable limits for a command, Bit 3 shall be set for the response to that command only. Once the response to the command has been sent to the host, Bit 3 shall be cleared again.

3 This bit is set in response to a calibration command if an error occurred in the respective operation.
EXAMPLE:
1. The CAP 2000+ has been turned on with the proper cable inserted in the serial portal placing the unit in its external mode.

2. The host computer sends an I. The CAP2000+ responds with an ICAPHI22010000000, indicating a high temperature CAP2000+ with Version 2.20 firmware, a spring constant of 1.00, and a status byte of 0.

3. The host sends a T190. The CAP 2000+ begins controlling to 40.0°C and responds with T100.

4. The host sends V1F4. The CAP 2000+ ramps to 500 rpm and responds with V02 indicating the motor is running.

5. The host sends a T9C4. The request to control temperature to 250.0°C is illegal. The CAP 2000+ responds with T0A indicating a temperature request outside the limits of the instrument.

6. The host sends an R. The CAP 2000+ responds with R002B1115950A25A83E80102 indicating a viscosity reading of 11.025 Poise, a FSR reading of 55.25%, a shear rate of 6650 1/sec, a sensed temperature of 100.0°C, and a number one cone. Note that Bit 3 of the status byte has been cleared. It is set only in response to the offending command (T9C4) and is cleared as soon as the response is issued.
APPENDIX E – WARRANTY REPAIR AND SERVICE

WARRANTY

BYK-Gardner Viscometers are guaranteed for one year from the date of purchase against defects in materials and workmanship. They are certified against primary viscosity standards traceable to the National Institute of Standards and Technology (NIST). The Viscometer must be returned to BYK-Gardner USA or the BYK-Gardner dealer from whom it was purchased for warranty service. Transportation is at the purchaser’s expense. Remove the spindle from the viscometer and attach the shipping cap to the pivot cup to prevent shipping damage. The Viscometer should be shipped in its carrying case together with all spindles originally provided with the instrument.

For repair or service return to one of the locations listed below, or consult BYK-Gardner or the dealer from whom you purchased the instrument.

GERMANY
BYK-Gardner GmbH
Lausitzer Strasse 8
82538 Geretsried
Germany
Phone: +49-8171-3493-0
Fax: +49-8171-3493-166

USA
BYK-Gardner USA
9104 Guilford Road
Columbia, MD 21046
USA
Phone: +1-301-483-6500
Fax: +1-301-483-6555

CHINA
BYK-Gardner Shanghai Office
Room 1407, SIPAI PLAZA
103, Cao Bao Road
Shanghai 200233
P.R. China
Phone: +86-21-6475-8570
Fax: +86-21-6475-7284

BRAZIL
BYK-Gardner Latin America
Rua das Aroeiras, 771
Bairro Jardim-Santo André-SP
CEP 09090-000
Brazil
Phone: +55-11-2147-1199
Fax: +55-11-2147-1168