Choosing the Correct CAP Instrument for Automotive Paints and Coatings

Introduction

When it comes to viscosity testing and characterization, automotive paints and coatings have always posed a challenge. The numerous formulations and their complex structures do not lend themselves easily to testing using a single method. For many years, the CAP type of viscometer (originally known as the ICI Cone Plate) has been used to test automotive paints for viscosity at high shear rates. These high shear instruments provide the necessary information on viscosity to qualify flow behavior, which in turn ensures that each batch will have proper performance.

But where to begin on selecting the correct CAP? There are high and low torque CAP instruments with a choice of fixed or variable speed, numerous cone selections and different temperature control ranges. From these many possibilities, how does one choose the best instrument and cone for testing? Thankfully, there are some guidelines.

Established Test Methods

Automotive paints and coatings are applied by spraying, which typically involves shear rates in the range of 10,000 to 12,000 1/sec. The high torque CAP using spindle CAP-01, -02 or -03 has traditionally been used to make this measurement on oil based formulations. A relatively new test method designed by the automotive paint suppliers in the USA (DuPont, PPG, BASF) calls for a shear rate of 500 1/sec. This method addresses the growing population of water based formulations and requires the low torque CAP with CAP-10 spindle running at 100rpm. For the higher shear testing at 10,000 1/sec, ASTM D4287 is the common standard test method in North America, for the lower shear testing at 500 1/sec, ASTMD7395-07 applies. In Europe the comparable standard test methods are ISO 2884 and ISO 3900.

When the above guidelines apply, you can easily choose an instrument. However, there are a few other things to consider. Will you be formulating a new material or testing against known good samples? If you are formulating, you will need greater flexibility in your instrument, that is, variable speed capability; therefore, the CAP 2000+ is your choice. For established test methods requiring a single viscosity data point, a fixed speed instrument such as the CAP 1000+ is the more logical choice.

Brookfield offers single and multiple speed instruments. The CAP-1000+ has a fixed standard speed of either 750 or 900 rpm; an alternative custom speed such as 100 rpm, is available and should be requested at time of order. For variable speed capability, the CAP-2000+ offers selectable speeds of 5-1000 rpm in single speed increments. This choice offers greater flexibility for dealing with changing formulations and for performing flow curve testing.

Temperature

The CAP instruments also have choices for temperature control capability. There is a Peltier plate built into the CAP instruments to control temperature; two options are available. The high temp instrument, designated by "H", allows temperatures to be set from 50°C to 235°C and is good for testing resins. The low temp instrument, designated by "L", is the most popular and allows temperature to be set from 5°C to 75°C. The "L" or low temperature instrument is more commonly ordered when running in accordance with the ASTM methods listed above.

High Torque or Low Torque?

The CAP-1000+ and 2000+ instruments are available in high and low torque configurations. A CAP instrument in a low torque configuration is approximately equivalent to an RV torque on a standard viscometer. An RV has a spring torque of 7187 dyne-cm; a low torque CAP instrument has a spring torque of 7970 dyne-cm.

A high torque CAP instrument has a spring torque approximately 23 times that of a low torque CAP (181,000 dyne-cm). That is why you see a low torque CAP instrument designated as a "1/23".

Choosing either a low or high torque CAP requires a similar decision making process to standard Brookfield viscometers; it depends on the viscosity range of the material. When following an ASTM standard the decision is easy as the standard defines the speed, torque and shear rate that must be used.

How to Choose

So far, we can sum up the instrument choices as low torque or high torque, fixed speed or variable speed, high temp or low temp. So which instrument /spindle combination do you choose? This is dependent on a few factors.

First, what is the material? How thick is it? If you are formulating, you may need a few spindles. Here is a chart that shows viscosity ranges (in Poise) and a shear rate coefficient (in reciprocal seconds as sec-1)

CAP Cone Viscosity Ranges (Poise)

MODEL High Torque	Cone Spindle CAP-01 Sample Volume 67µL Shear Rate (sec^{-1}) 13.3N	Cone Spindle CAP-02 Sample Volume 38µL Shear Rate (sec^{-1}) 13.3N	Cone Spindle CAP-03 Sample Volume 24µL Shear Rate (sec^{-1}) 13.3N	Cone Spindle CAP-04 Sample Volume 134µL Shear Rate (sec^{-1}) 3.3N	Cone Spindle CAP-05 Sample Volume 67µL Shear Rate (sec^{-1}) 3.3N	Cone Spindle CAP-06 Sample Volume 30µL Shear Rate (sec^{-1}) 3.3N	Cone Spindle CAP-07 Sample Volume 1700µL Shear Rate (sec^{-1}) 2.0N	Cone Spindle CAP-08 Sample Volume 400µL Shear Rate (sec^{-1}) 2.0N	Cone Spindle CAP-09 Sample Volume 100µL Shear Rate (sec^{-1}) 2.0N	Cone Spindle CAP-10 Sample Volume 170µL Shear Rate (sec^{-1}) 5.0N
1000+ @750rpm	.25-2.5	.5-5	1-10	2-20	4-40	10-100	N/A	N/A	N/A	N/A
1000+ @900rpm	.2-2	.4-4	.8-8	1-16	3-33	8-83	N/A	N/A	N/A	N/A
1000+ @400rpm	.375-4.6	.75-9.3	1.5-18.7	3-37.5	6-75	15-187	.78-7.81*	3.13-31.3*	12.5-125*	1-10*
2000+ @5-1000rpm	.2-375	.4-750	.8-1.5K	1-3K	3-6K	8-15K	.78-625*	3.13-2.5K*	12.5-10K*	1-1K*
Low Torque (for applications requiring low shear rates for low/medium viscosity fluids, an optional low torque 797-7,970 dyne-cm instrument can be ordered)										
1000+ @100rpm†	.2-.81	.2-1.6	.33-3.3	.65-6.5	1.3-13	3.3-33	.13-1.3	.54-5.4	2.2-22	.22-2.2
2000+ @5-1000rpm	.2-16	.2-32	.2-66	.2-130	.2-260	.2-660	.2-26	.2-108	.2-440	.2-44

µL = microLiter K = 1 thousand P = poise 1 Pa·s = 10 poise N = RPM e.g. Cone CAP-01 13.3 x 10 (rpm) = 133 sec-1
*Maximum speed recommended with this spindle is 400 rpm. Viscosity range indicated is for operation at 400 rpm. †Special speed instrument.
Note: Viscosity ranges shown above are for illustration. The exact range will depend upon instrument configuration.

for each spindle. The viscosity ranges are given for the standard fixed speeds of a CAP-1000+ at 750 and 900 rpm, examples of custom speeds for the CAP-1000+ at 100 and 400 rpm, and the variable 5-1000 Rpm speeds
of a CAP-2000+. Multiply the ranges given in Poise by 100 to get centipoise. To get an idea of the viscosity range your material, refer to some common Newtonian materials to judge the material you wish to test. For example, an SAE 30 motor oil is 150 to 200cP; honey can range to 10,000cP.

Do you need to test at a certain shear rate? If so, you will need to choose the appropriate spindle. Each spindle has a Shear Rate coefficient. This is the "N" parameter in the above chart and refers to rpm. For example, a CAP-01 spindle has a shear rate coefficient of 13.3N. Thus, using a fixed speed 750 rpm CAP instrument and a shear rate coefficient of 13.3, the shear rate would be 10,000 sec-1. This is the standard test method set forth in ASTM 4287, ISO 2884 and BS 3900 and is a very common test in the paints and coatings industry.

With an idea of the viscosity range of your material and what shear rate you need to test, you can choose the appropriate spindle. CAP-2000+ units will give you a variety of speeds and thus shear rates. CAP-1000+ units are fixed speed, thus you would need to change the spindle for different viscosity ranges.
The attached applications provide examples of tests that were run on different automotive paints to illustrate use of high torque and low torque CAP Viscometers.

Calibration

After you have chosen the CAP viscometer for your customer, the unit will need to be calibrated by your customer as a matter of good lab practice. Make sure to acquire the correct mineral oil fluid to calibrate your instrument based on the torque, temperature and cone spindle you have chosen. This chart supplies the correct calibration fluid based on these parameters:

CAP Viscometer Oil Fluids

For calibrating CAP Series cones each spindle has its own fluid

HOW TO SELECT A CAP FLUID

- Determine which viscometer is being used: High Torque or Low Torque.
- Determine which temperature model is being used:
  Low Temperature (5°C-75°C) or High Temperature (50°C-235°C)
- Determine which cone is being used.

	HIGH TORQUE CAP				LOW TORQUE CAP			
	Low Temp 25°C		High Temp 60°C		Low Temp 25°C		High Temp 60°C	
Cone Spindle	Brookfield Part #	Viscosity cP (mPa•s)	Brookfield Part #	Viscosity cP (mPa•s)	Brookfield Part #	Viscosity cP (mPa•s)	Brookfield Part #	Viscosity cP (mPa•s)
1	CAP1L	89	CAP1H	89	CAP0L	57	CAP0H	57
2	CAP2L	177	CAP2H	177	CAP1L	89	CAP1H	89
3	CAP3L	354	CAP3H	354	CAP2L	177	CAP2H	177
4	CAP4L	708	CAP4H	708	CAP3L	354	CAP3H	354
5	CAP5L	1,417	CAP5H	1,417	CAP4L	708	CAP4H	708
6	CAP6L	3,542	CAP6H	3,542	CAP5L	1,417	CAP5H	1,417
7	CAP7L	1,328	CAP7H	1,328	CAP1L	89	CAP1H	89
8	CAP8L	5,313	CAP8H	5,313	CAP3L	354	CAP3H	354
9	CAP9L	21,250	CAP9H	21,250	CAP5L	1,417	CAP5H	1,417
10	CAP10L	236	CAP10H	236	CAP2L	177	CAP2H	177

Note that this is the only instrument offered by Brookfield where the customer can recalibrate and not need to return the unit to an authorized dealer.

Customers Who Use the KU-2 (or Stormer) Viscometer

Krebs viscosity is another issue that comes up frequently in regards to paints and coatings. Customers, who measure in Krebs units, but have not used the CAP-type viscometer before, will ask how to choose the correct CAP for their paint/coating.

Krebs viscometers rotate a paddle spindle at 200 rpm and give viscosity readings on the material in Krebs units. What is this equivalent to in centipoise? There are charts that can supply an approximation. Or if you have a Brookfield KU-2 Viscometer, the Krebs reading can be converted into a cP reading by rotating the knob, which controls choice of measurement units.

The best approach, however, if your customer only has a Krebs Viscometer, is to run some flow curve tests in your lab on the customer's material(s). This guarantees that the recommendation you make for choice of CAP viscometer will work.

Data Gathering

Once an instrument and spindle combination has been chosen, testing can begin. If single point testing is all you need, then the CAP1000+ Instrument can be used as a standalone test station. For plotting rheological curves to determine flow behavior, performing math modeling, exporting data to Excel, and producing graphs and data charts, a software product called CAPCALC has been designed for use with the CAP2000+ Instruments. For data gathering, CAPCALC is indispensable for formulators and manufacturers alike.

Easy to use and comprehensive, CAPCALC allows for software control of the CAP2000+ Instrument. This feature allows formulators to establish multiple step programs for testing. Data graphs can be analyzed for viscosity versus time and shear stress versus shear rate. Math modeling for analyzing the data includes Herschel-Bulkley, Bingham and Power Law models. Data can easily be exported to Excel, time stamped and stored.

Summary

This discussion is intended to give you a better understanding of how the CAP Viscometer is used by customers who work with paints and coatings, especially in the automotive industry. When in doubt about the best choice of instrument, ask the customer for a sample and run an evaluation test. If still in doubt, send me an email so that I can offer further guidance.

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