Rheology Solutions for the Surface Coatings Industries

How To Measure Thixotropy For Surface Coatings Industries

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Company Profile

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Rheology Solutions

Tim's Top Tips – Rheology Solutions for the Surface Coatings Industries.

How To Measure Thixotropy For Surface Coatings Industries

Key Words: *Rheology, rotational, liquid, viscosity, thixotropy, yield stress.*

About The Author

Tim has a background in engineering and specifically in rheology, with a B.Eng and Ph.D. in Chemical Engineering and has held postdoctoral research positions in engineering rheology. Tim's research has continued for the last seven years and recent interests and publications include the application of rheology and rheometry to mineral, food, polymer and surface coatings systems. His current position encompasses the managment of customer contract testing and also includes customer focussed education and training. Additionally he is available to provide technical input for existing or proposed materials characterisation systems for both laboratory and production.

Table Of Contents

Introduction

Often the surface coatings industries must overcome problems related to (and often dictated by) the flow properties of their product, though the relationships between these properties and production related issues are not always immediately apparent. It is the purpose of this series of articles, "Rheology Solutions for the Surface Coatings Industries", to help illuminate the issues faced by the industry, how they relate to the flow properties of problem materials and how they can be successfully measured and controlled with a view to better processing.

Definitions

Thixotropy is a form of time dependent behaviour describing a material whose viscosity decreases over time while it is subjected to shearing forces. After some time the material recovers completely to its original state.

Thixotropy should not be confused with rheopexy, a rare phenomenon, (rheopexy is also time dependent, but the viscosity increases with time). The following techniques and discussions for measuring thixotropy apply for rheopectic measurements also.

Rheodestruction is also a time related phenomenon, but rheodestroyed materials do not recover their initial state. The following techniques and discussions for measuring thixotropy apply for rheodestructive measurements also.

Background and Discussion

Thixotropy is a relative measurement and as such depends on the experimental conditions and technique used to measure it. There are several such techniques, the simplest being modified flow curves, or constant shear rate or shear stress measurements. A more complicated, but perhaps more

intuitively understood method is the shear and recovery method.

In order to attain repeatability the most appropriate technique should be selected and the sample handling and experimental procedures defined fully. These should be unchanged for all tests, so that thixotropy for different materials can be properly compared.

Thixotropy is a relative measure of the extent and speed of recovery of the internal structure of a material during and after shear. It is useful because it allows an estimate of the effects of agitation, pumping etc for prolonged periods, and also the effects of ceasing the agitation etc (i.e. how quickly the structure will rebuild, and how difficult it will be to restart the process as a result).

Note: Working definitions are provided at the end of the paper.

Measurement Techniques and Pitfalls

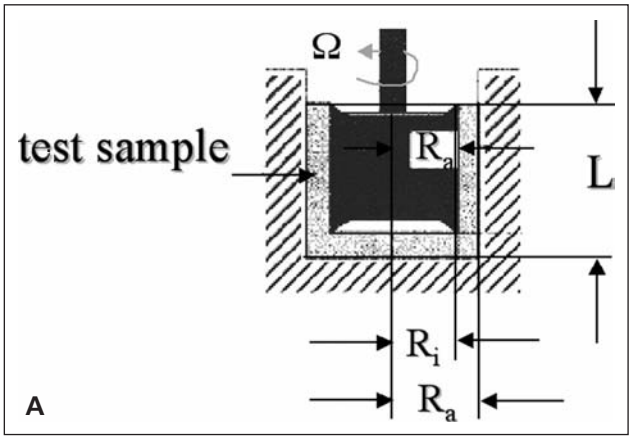
CS or CR?

Thixotropy can be collected either in Controlled Rate, CR, (impose a shear rate and measure the shear stress) or in Controlled Stress, CS, (impose a shear stress and measure the resultant shear rate). In theory, for materials with no time dependent properties both CS and CR flow curves should yield identical results. For thixotropic materials one should choose a technique and stick to it, so that results will be comparable from one test to the next. The main difference lies in the sensitivity of the instrument at low shear rates. CS instruments generally combine an air bearing with a high-end motor to provide good control and measurement of very small deflections, and also of high rpm measurements. CR instruments generally do not have the same level of control and detection at low rpm.

To make a CR or CS measurement you will need:

- **A viscometer or rheometer**
  In general a viscometer can make only CR measurements – in other words flow and viscosity curves are the main purpose of the instruments. As a result thixotropy loops, and steady shear measurements can also be made with these instruments. A rheometer is capable of much more, including viscoelastic measurements, creep and recovery measurements and so on. CS instruments have an air bearing so that these extra measurements can be made. The air bearing also allows shear and recovery measurements to be made because they can probe the structure of the material without influencing the rate at which it rebuilds.

- **A suitable sensor system**
  Viscometric geometries should be used to make measurements to generate flow and viscosity curves. Viscometric geometries include cone and plate, cup and bob, plate and plate (all for rotational instruments) and capillaries (for a flow-through device such as a capillary viscometer). Typically rotational devices are used and the viscometric geometries that apply are shown in Figure 1.



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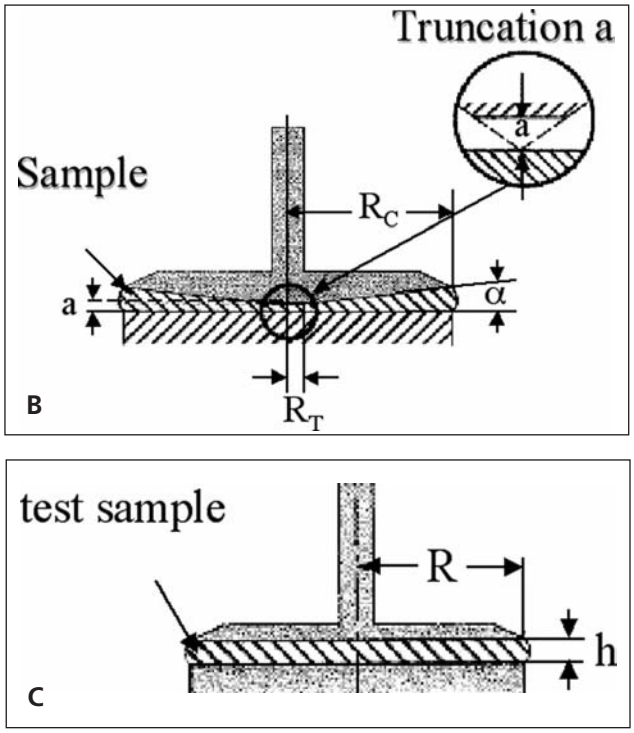

Figure 1: Standard viscometric geometries (L to R) Cup & Bob, Cone & Plate, Plate & Plate

- **Theory**
  The theory for this type of measurement is that the flow behaviour is defined for a range of shear rates and shear stresses so that its reaction to different processing conditions (pumping, mixing, storage etc) can be predicted. The range of shear rates or shear stresses tested is usually defined by those present in the process. The viscosity of a material is calculated as follows:

$$\eta = \frac{\tau}{\dot{\gamma}} \qquad (1)$$

η = viscosity, mPa.s or cP (1mPa.s = 1cP)
τ = shear stress, Pa or mPa
γ = shear rate, s^{-1}

1.0 The thixotropy loop test

The following discussion is based on a CR ramp test, but the arguments hold equally for CS ramp tests. Similarly, step tests could be used rather than ramp tests (see "How to measure flow and viscosity curves for the surface coatings industries" for further discussion on these subjects). As mentioned before, once a technique is settled upon, it should be used for every test.

This thixotropy loop technique involves a transition from zero shear rate to a maximum designated shear rate (called the up-curve), holding the shear rate constant for a time (this step is sometimes left out), and then ramping smoothly from the maximum shear rate back to zero shear again (called the down-curve). The rate of change of shear rate for the up- and down-curves and the time at maximum shear rate are user defined and the number of data points is usually high so that a continuous curve is generated. Plotting the results as shear rate vs. shear stress or viscosity (Figure 3), if the up-curve lies above the down-curve and the measurement can be repeated after some rest time, then the material is thixotropic.

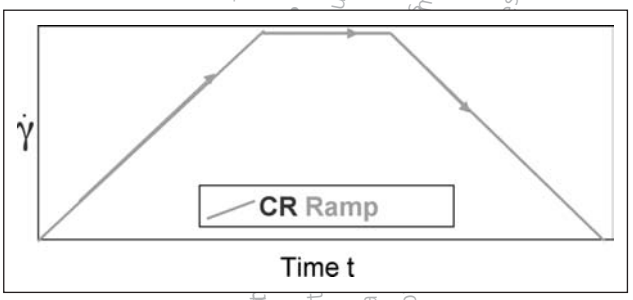

Figure 2: Input for ramp test

1.1 Experimental procedure

The experimental layout can be one shown in Figure 1.

- The material is loaded and the measuring geometry closed.
- A lower and an upper shear rate (CR) or shear stress (CS) is chosen, as is the number of measurement points between them.
- The material is subjected to a shear rate profile, like in Figure 2.

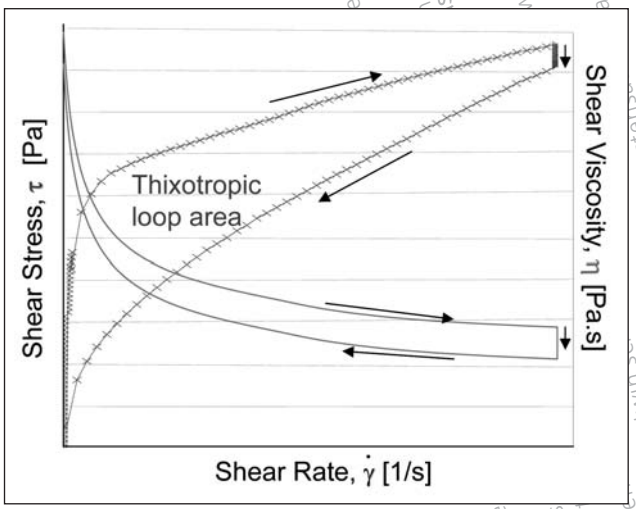

Figure 3: Thixotropy loop.

- The reaction of the material to the imposed shear rate (reaction = shear stress) or shear stress (reaction = shear rate) is measured and the viscosity calculated according to equation (1).

- The result of the experiment is a thixotropy loop, as illustrated in Figure 3.

- The thixotropy of different materials can be compared by comparing the area bounded by the thixotropy loop, as illustrated in Figure 3.

1.2 Benefits of the thixotropy loop test

- **The complete picture**
  A ramp test can provide a complete picture of how the material will behave between the set experimental limits.

- **Simple measurement and simple analysis**
  The measurement is quite simple to execute and the data is straightforward to process.

- **Other data**
  Since viscosity data can also be generated when viscometric geometries are used, other interesting and useful data is available to the user.

1.3 Potential problems with the thixotropy loop test

- **Understanding the meaning of the data**
  Sometimes, the real physical meaning of the changes in the thixotropy loop area, are not apparent. The areas do however offer a good comparison technique for different materials, or to gauge the effects of different rheology modifiers on the system.

- **Relative data**
  The results generated are relative only, and not absolute. Changing experimental procedure or handling could change the results significantly. A single loop does not fully describe whether or not the sample is thixotropic, or if rheodestruction has taken place. Consecutive curves after fixed rest times are necessary to assess the recovery of the material.

- **Solid fraction size**
  For multiphase systems, often there is a solid fraction, which has particles of considerable size. If this size is close to the size of the measuring gap, then one or more particles may 'bridge' the gap and cause an artificially high shear stress. The problem can be solved by using particles no more than 1/3 of the gap size (1/10 for concentrated pastes). Also, often larger particles contribute little to the overall flow behaviour of the material and can be removed without large penalties for the applicability of the measurement.

- **Sensor inertia**
  Sensors, in particular concentric cylinders and large diameter cones or plates may be quite heavy. As the rate of rotation changes through the ramp test, this weight causes the sensors to accelerate to a higher speed than expected by the control software in the viscometer or rheometer and so the shear rate experienced by the material is higher than that 'imposed' by the controller. This results in a shift in shear stresses and viscosities for the flow curve from the actual ones. This effect can be reduced or removed by allowing sufficient time for the ramp. A general rule of thumb is to allow at least 1s of test time for every $1s^{-1}$ of shear rate in the ramp. So, a ramp from 0-$100s^{-1}$ should take at least 100s to complete.

- **Time**
  Because of the potential problems with inertia, ramp tests covering very wide ranges of shear rate can take considerable time to complete. On the other hand, because the test is a relative one, the maximum shear rate can be defined to shorten the duration of all tests if necessary.

- **Temperature control**
  At high shear rates, shear heating can be an issue. Shear heating is caused by internal frictional heat generated as the lamina of fluid move over each other. When the measuring gap is small this can usually be successfully controlled, but prolonged exposure to high shear rates can still be a problem.

- **Settling materials**
  If a material tends to settle, long test times tend to reduce the likelihood of successful test outcomes. The longer the test takes, the more likely the solid fraction is to have settled out of the measurement space, or at least created a concentration gradient through it. Sometimes it is possible to ramp from high to low shear rates first, rather than the other way around, allowing the material to be kept in suspension longer, and if possible to reduce ramp times as much as practicable. Alternatively using a modified step test with high shear steps to resuspend materials between descending 'measurement' steps can also be successful. The key is to keep the technique consistent once it has been decided upon, so that all data is comparable. Often settling materials will appear to be thixotropic as the shear stress generally drops while the material settles.

- **Chaotic flow**
  One of the key assumptions for rheological measurements is that the flow in the measuring gap is laminar. Too high shear rates can cause the flow regime to become turbulent and the measurements are unreliable. The onset of chaotic flow can be overcome or delayed by changing the measuring geometry or the measurement gap.

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- **Slip**
  Multi-phase systems tend to slip at the boundary of the measuring geometry. A major assumption for rheological measurements is that the first layer of material 'sticks' to the walls of the measuring geometry. Plate & plate or concentric cylinder geometry walls can be roughened or serrated to reduce or remove the slip phenomenon.

- **Time dependent materials**
  Sample handling and experimental technique can be crucial for repeatably measuring time dependent (eg thixotropic) materials. The same handling procedure (pouring, mixing, resting, loading into the test equipment etc) and experimental procedure (rest time, ramp time and upper and lower limits) is critical for repeatable measurements, and it must be remembered that for time dependent materials the results are relative only – they depend on the technique used to generate them.

2.0 The constant shear test

The following discussion is based on a CR test, but the arguments hold equally for CS tests, where the shear rate is monitored as a function of time.

The constant shear technique involves imposing a single, constant shear rate (of shear stress) on the material and monitoring the response. The results are usually compared by an assessment of the time taken to reach a certain predetermined shear stress or viscosity, or to achieve a predetermined % of the initial or final value, or by the time taken to achieve an equilibrium value.

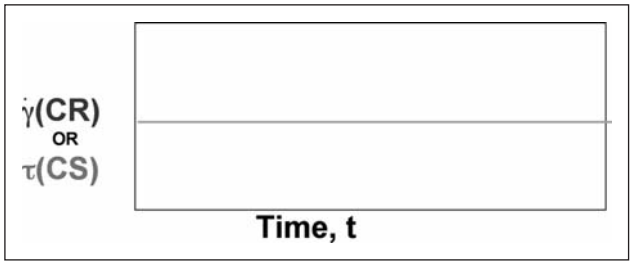

Figure 4: Input for constant shear test

2.1 Experimental procedure

The experimental layout can be one shown in Figure 1.

- The material is loaded and the measuring geometry closed.
- A constant shear rate (CR) or shear stress (CS) is chosen, as is the number of measurement points.
- The material is subjected to a shear rate profile, like in Figure 4.
- The reaction of the material to the imposed shear rate (reaction = shear stress) or shear stress (reaction = shear rate) is measured and the viscosity calculated according to equation (1).
- The results of the steady shear rate experiment are viscosity and shear stress curves, as illustrated in Figure 5.

The thixotropy of different materials can be compared by comparing the times taken to reach a certain % of the initial shear stress, or some fixed value of the shear stress, or an equilibrium value (see Figure 5).

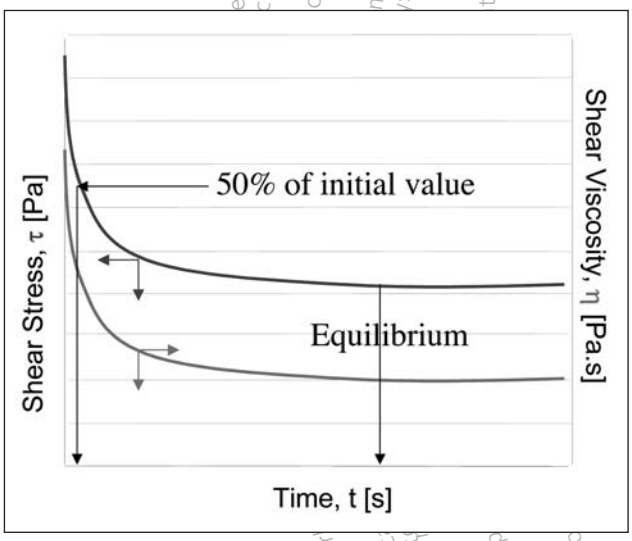

Figure 5: Results from a constant shear test

2.2 Benefits of the constant shear test

- **Steady shear rates**
  Tests can be chosen to cope better with shear heating.
- **Sensor inertia**
  Because the shear rate is unchanged for the duration of the test, the controller has time to adjust the speed of rotation of the sensor so that it is exactly as specified.
- **Intuitive interpretation of the data**
  The meaning of the data is easily understood and applied once the appropriate process shear rates or shear stresses are known.
- **Time**
  Appropriate shear rates and % of original values can be chosen to enable the testing to be relatively quick.
- **Simple measurement and simple analysis**
  The measurement is quite simple to execute and the data is straightforward to process.

2.3 Potential problems with the constant shear test

A single test does not fully describe whether or not the sample is thixotropic, or if rheodestruction has taken place. Consecutive curves after fixed rest times are necessary to assess the recovery of the material.

- **Solid fraction size**
  For multiphase systems, often there is a solid fraction, which has particles of considerable size. If this size is close to the size of the measuring gap, then one or more particles may 'bridge' the gap and cause an artificially high shear stress. The problem can be solved by choosing a measurement geometry so that maximum particle size is no more than 1/3 of the gap size (1/10 for concentrated pastes). Sometimes larger particles contribute little to the overall flow behaviour of the material and can be removed without large penalties for the applicability of the measurement.

- **Early warning of problems with technique or measurement**
  Having data for the complete range of shear rates allows the user to investigate the possibility of settling, chaotic flow in the measuring gap and slip at the measurement geometry walls. Data from a single shear rate test may not reveal this information readily, especially if only a few data points are taken. Often in these cases settling material will appear to be thixotropic as the shear stress generally drops while the material settles.

- **Temperature control**
  At high shear rates, shear heating can be an issue. Shear heating is caused by internal frictional heat generated as the lamina of fluid move over each other. When the measuring gap is small this can usually be successfully controlled, but prolonged exposure to high shear rates can still be a problem. To reduce this, the steady shear chosen for the test can be reduced to reduce or remove the likelihood of shear heating.

- **Settling materials**
  If a material tends to settle, long test times tend to reduce the likelihood of successful test outcomes. The longer the test takes, the more likely the solid fraction is to have settled out of the measurement space, or at least created a concentration gradient through it. Sometimes it is possible to step from high to low shear rates, rather than the other way around, allowing the material to be kept in suspension longer, and if possible to reduce step times as much as practicable. Alternatively using a modified step test with high shear steps to resuspend materials between descending 'measurement' steps can also be successful. A settling material will appear to be thixotropic as the shear stress generally drops while the material settles.

- **Chaotic flow**
  One of the key assumptions for rheological measurements is that the flow in the measuring gap is laminar. Too high shear rates can cause the flow regime to become turbulent and the measurements are unreliable. The onset of chaotic flow can be overcome or delayed by changing the measuring geometry or the measurement gap.

- **Slip**
  Multi-phase systems tend to slip at the boundary of the measuring geometry. A major assumption for rheological measurements is that the first layer of material 'sticks' to the walls of the measuring geometry. Plate & plate or concentric cylinder geometry walls can be roughened or serrated to reduce or remove the slip phenomenon.

- **Time dependent materials**
  Sample handling and experimental technique can be crucial for repeatably measuring time dependent (eg thixotropic) materials. The same handling procedure (pouring, mixing, resting, loading into the test equipment etc) and experimental procedure (rest time, ramp time and upper and lower limits) is critical for repeatable measurements, and it must be remembered that for time dependent materials the results are relative only – they depend on the technique used to generate them.

3.0 The shear and recovery test

The following discussion is based on a CS/CR/CS test, but the arguments hold equally for CS/CS/CS tests, where the viscosity of the middle segment is dictated by the imposition of a high shear stress for a short time.

The shear and recover technique involves non-destructive evaluation of the initial structure, using an oscillatory measurement, followed by a highly destructive rotation segment at high shear rate or shear stress. These two are immediately followed by a non-destructive oscillatory measurement identical in its settings to the first segment, observing structure rebuild. The results are usually compared by an assessment of the time taken to finally regain a certain predetermined viscosity, or to achieve a predetermined % of the initial value, or by the time taken to achieve an equilibrium value.

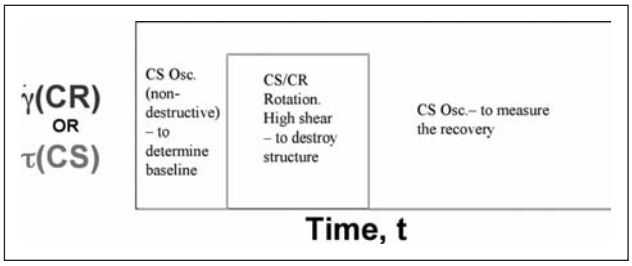

Figure 6: Input for shear and recovery test

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3.1 Experimental procedure

The experimental layout can be one shown in Figure 1.

- The material is loaded and the measuring geometry closed.
- The parameters (determined before) for the oscillatory and high shear segments are chosen.
- The material is subjected to a shear rate profile, like in Figure 6.
- The reaction of the material to the imposed deformation (for oscillatory measurements it is convenient to use the complex viscosity), shear rate (reaction = shear stress) or shear stress (reaction = shear rate) is measured and the viscosity calculated according to equation (1).
- The results of the steady shear rate experiment are viscosity vs. time curves, as illustrated in Figure 7.

The thixotropy of different materials can be compared by comparing the times taken to reach a certain % of the initial shear stress, or some fixed value of the shear stress, or an equilibrium value (see Figure 5).

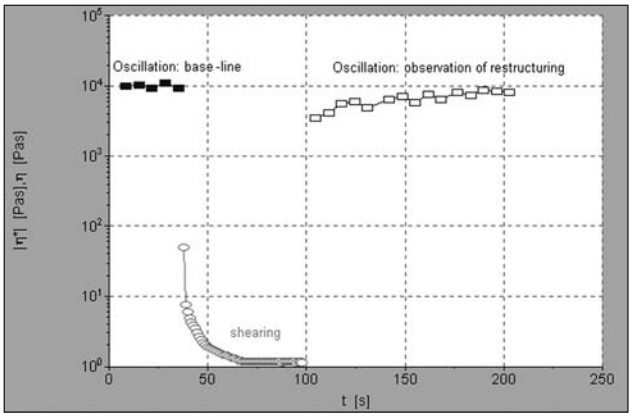

Figure 7: Results from a shear and recovery test

3.2 Benefits of the shear and recovery test

- **Monitors recovery**
  Of the tests mentioned this is the only one that immediately informs about recovery.
- **Intuitive interpretation of the data**
  The meaning of the data is easily understood and applied once the appropriate process shear rates or shear stresses are known.
- **Time**
  Appropriate shear rates and % of original values can be chosen to enable the testing to be relatively quick.
- **Shear heating**
  These tests, including the high shear segment can be set up to reduce the likelihood of shear heating.
- **Simple analysis**
  The data is straightforward to process.

3.3 Potential problems with the shear and recovery test

- **More complicated measurement**
  The measurement is not as straightforward to set up, as some preliminary work needs to be done to find the Linear Viscoelastic Envelope (LVE) for the oscillatory segments. Experienced operators can quickly achieve this.
- **Instrument**
  A CS instrument is required for this type of measurement, which is usually more costly, and also involves the need for a supply of clean, oil-free compressed air.
- **Solid fraction size**
  For multiphase systems, often there is a solid fraction, which has particles of considerable size. If this size is close to the size of the measuring gap, then one or more particles may 'bridge' the gap and cause an artificially high shear stress. The problem can be solved by choosing a measuring geometry so that maximum particle size is no more than 1/3 of the gap size (1/10 for concentrated pastes). Sometimes larger particles contribute little to the overall flow behaviour of the material and can be removed without large penalties for the applicability of the measurement.
- **Early warning of problems with technique or measurement**
  Having data for the complete range of shear rates allows the user to investigate the possibility of settling, chaotic flow in the measuring gap and slip at the measurement geometry walls. Data from a single shear rate test may not reveal this information readily. Often in these cases settling material will appear to be thixotropic as the shear stress generally drops while the material settles.
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  One of the key assumptions for rheological measurements is that the flow in the measuring gap is laminar. Too high shear rates can cause the flow regime to become turbulent and the measurements are unreliable. The onset of chaotic flow can be overcome or delayed by changing the measuring geometry or the measurement gap.

- **Slip**
  Multi-phase systems tend to slip at the boundary of the measuring geometry. A major assumption for rheological measurements is that the first layer of material 'sticks' to the walls of the measuring geometry. Plate & plate or concentric cylinder geometry walls can be roughened or serrated to reduce or remove the slip phenomenon.

- **Time dependent materials**
  Sample handling and experimental technique can be crucial for repeatably measuring time dependent (eg thixotropic) materials. The same handling procedure (pouring, mixing, resting, loading into the test equipment etc) and experimental procedure is critical for repeatable measurements, and it must be remembered that for time dependent materials the results are relative only – they depend on the technique used to generate them.

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Summary

Table 1 summarises the possibilities for measuring a flow or viscosity curve using the techniques discussed. Each of the techniques is ranked between 0 and 5 for each of the potential issues and solutions, where:

5 = Excellent 4 = Good 3 = Adequate
2 = Possible 1 = Difficult 0 = Not Possible

Determining the most suitable type of measurement or instrument is not simply a matter of adding up the ranking for each. Rather, identify which measurement technique, variable etc is most relevant and appropriate for your application/product. Often, more than one technique is required to ensure consistency, reproducibility and accuracy is achieved.

Table 1: Assessment of strengths/weaknesses for each technique

Technique:	Thixotropy Loop	Constant Shear	Shear & Recovery
Measurement			
Rapid	3	4	4
Easy	4	4	3
Accurate	4	4	5
Small sample volume	4	4	4
Temperature control	4	5	5
Measuring system			
Rheometer or viscometer	Both	Both	Rheometer
Large variety of sensors	5	5	5
Structural disruption on loading avoidable	2	2	2
Slip avoidable	4	4	4
Number of Participants			
Single operator	5	5	5
Experimental			
Measures materials with large particles & agglomerates	1	1	1
Settling suspension measurements	2	2	1
Direct determination of recovery from measurement	No	No	Yes
Shear heating reduced	5	4	5
Detection of slip, turbulence, shear heating etc	4	5	1
Inertia avoidable	4	4	4
Results			
Intuitively comprehended	4	5	5

* *Depending on the test, these parameters may be viewed alternatively as either a strength or as a weakness*

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Other Notes Available in the Tim's Tips - Rheology Solutions for the Surface Coatings Industries Series are:

- How To Measure Yield Stress (Rheo372)
- How to Measure Flow and Viscosity Curves (Rheo370)

Other Information Available for the Surface Coatings Industries include:

- Rheology Solutions for Surface Coatings Industries Information Kit
- Applications Laboratory and Contract Testing Capabilities Statement for Surface Coatings Industries
- Technical Literature for Surface Coatings Industries

Focused on providing our **customers** with materials characterisation **solutions** through knowledge, experience and support.

Surface Coatings Dictionary

Industry Term: **Capillary Rheometer.**
Definition: A rheometer which measures flow properties through a capillary.
Governing Properties: The pressure on the liquid and the pressure drop of the liquid through the capillary. The capillary geometry dictates the shear forces experienced by the liquid as if flows.
Rheology Solutions Instrument: HAAKE RheoCap.

Industry Term: **Complex Viscosity.**
Definition: The viscosity measured by dynamic rheometry, related to both the viscous and elastic portions of flow for a viscoelastic fluid.
Governing Properties: This is a property governed by the viscoelastic properties of the material - elastic and viscous moduli (G' and G''). It is measured on a CS rheometer using a frequency sweep.
Rheology Solutions Instrument: HAAKE RheoStress, HAAKE MARS.

Industry Term: **Controlled Rate.**
Definition: Mode of operation for a rheometer or viscometer. Controls the shear rate imposed on the sample.
Governing Properties: CR mode is usually available using a CS rheometer or a CR viscometer.
Rheology Solutions Instrument: HAAKE ViscoTester 550, HAAKE RotoVisco, HAAKE RheoStress, HAAKE MARS.

Industry Term: **Controlled Stress.**
Definition: Mode of operation for a rheometer or viscometer. Controls the shear stress imposed on the sample.
Governing Properties: CS mode is usually available using a CS rheometer but not on a CR viscometer.
Rheology Solutions Instrument: HAAKE RheoStress, HAAKE MARS.

Industry Term: **Flow Curve.**
Definition: A flow curve is a plot showing the relationship between shear rate and shear stress.
Governing Properties: It can be measured using a CS rheometer or a CR viscometer.
Rheology Solutions Instrument: HAAKE ViscoTester 550, HAAKE RotoVisco, HAAKE RheoStress, HAAKE MARS.

Industry Term: **Linear Viscoelastic Envelope (LVE).**
Definition: The LVE is the region in which the internal structure of a material remains unchanged as the imposed stress or deformation is gradually increased.
Governing Properties: Measured on a CS rheometer using a stress sweep or a strain sweep.
Rheology Solutions Instrument: HAAKE RheoStress, HAAKE MARS.

Industry Term:	**Rheodestruction.**
Definition:	The irrecoverable changes in the structure of a material due to the action of shearing forces.
Governing Properties:	It can be measured using a thixotropy loop on a CS rheometer or a CR viscometer.
Rheology Solutions Instrument:	HAAKE ViscoTester 550, HAAKE RotoVisco, HAAKE RheoStress, HAAKE MARS.

Industry Term:	**Rheology.**
Definition:	The flow and deformation of matter.
Governing Properties:	N/A
Rheology Solutions Instrument:	HAAKE ViscoTester 550, HAAKE RotoVisco, HAAKE RheoStress, HAAKE MARS.

Industry Term:	**Rheometer (Controlled Stress).**
Definition:	An instrument designed for the measurement of viscous and viscoelastic flow properties at specified temperature and atmospheric conditions, by measuring the force required to move one layer over another without turbulence.
Governing Properties:	Rheometers often have air bearings, making them highly sensitive to small variations in load or displacement and can operate in rotation or oscillation for Controlled Rate or Controlled Stress modes. Some rheometers have mechanical bearings, but in general they do not have the required sensitivity to make good use of CS mode in these cases and can not run oscillatory measurements well (or at all).
Rheology Solutions Instrument:	HAAKE RheoStress, HAAKE MARS.

Industry Term:	**Rheometer.**
Definition:	An instrument designed for the measurement of viscous and viscoelastic flow properties at specified temperature and atmospheric conditions, by measuring the force required to move one layer over another without turbulence.
Governing Properties:	Rheometers often have air bearings, making them highly sensitive to small variations in load or displacement and can operate in rotation or oscillation for Controlled Rate or Controlled Stress modes. Some rheometers have mechanical bearings, but in general they do not have the required sensitivity to make good use of CS mode in these cases and can not run oscillatory measurements well (or at all).
Rheology Solutions Instrument:	HAAKE RheoStress, HAAKE MARS.

Industry Term:	**Rheopexy.**
Definition:	Rheopectic fluids show shear thinning behaviour combined with a time dependency. The viscosity of a rheopectic fluid increases when subjected to a constant shear rate for a period of time. The viscosity of rheopectic fluids often recovers substantially over a period of time after the shearing forces have been removed.
Governing Properties:	Rheopexy depends on the rate of structural recovery in the material. It can be measured using a flow curve on a CR or CS instrument, or by measuring the recovery of the moduli after shearing on a CS rheometer.
Rheology Solutions Instrument:	HAAKE ViscoTester 550, HAAKE RotoVisco, HAAKE RheoStress, HAAKE MARS.

Industry Term: **Shear Rate.**
Definition: The rate of change of displacement resulting from an imposed shear stress.
Governing Properties: N/A
Rheology Solutions Instrument: HAAKE ViscoTester 550, HAAKE RotoVisco, HAAKE RheoStress, HAAKE MARS.

Industry Term: **Shear Stress.**
Definition: This is the force per unit area imposed on an element of fluid.
Governing Properties: The shear stress is dependent on the geometry of the fluid element and can be measured by a CR viscometer and may be imposed by a CS rheometer.
Rheology Solutions Instrument: HAAKE ViscoTester 550, HAAKE RotoVisco, HAAKE RheoStress, HAAKE MARS.

Industry Term: **Slip.**
Definition: The liquid does not adhere to the wall of the measuring geometry.
Governing Properties: N/A
Rheology Solutions Instrument: HAAKE ViscoTester 550, HAAKE RotoVisco, HAAKE RheoStress, HAAKE MARS. (Serrated sensors should be used.)

Industry Term: **Thixotropy Loop.**
Definition: Thixotropy loop is a technique to measure the thixotropy of a liquid and consists of two consecutive flow curves. The difference in the areas below the flow curve is a measure of the thixotropy fluid and the loop is called a thixotropy loop.
Governing Properties: Measuring using flow curves on a CS rheometer or CR viscometer.
Rheology Solutions Instrument: HAAKE ViscoTester VT550, HAAKE RotoVisco, HAAKE RheoStress, HAAKE MARS.

Industry Term: **Thixotropy.**
Definition: Thixotropic fluids show shear thinning behaviour combined with a time dependency. The viscosity of a thixotropic fluid drops when subjected to a constant shear rate for a period of time. The viscosity of thixotropic fluids often recovers substantially over a period of time after the shearing forces have been removed.
Governing Properties: Thixotropy depends on the rate of structural recovery in the material. It can be measured using a flow curve on a CR or CS instrument, or by measuring the recovery of the moduli after shearing on a CS rheometer.
Rheology Solutions Instrument: HAAKE ViscoTester 550, HAAKE RotoVisco, HAAKE RheoStress, HAAKE MARS.

Industry Term: **Viscoelastic Measurements.**
Definition: Materials, which are partly elastic (i.e. solid) and partly viscous (i.e. fluid). When they are deformed some of the energy is stored (solid) while the remainder is lost through flow (fluid).
Governing Properties: N/A.
Rheology Solutions Instrument: N/A.

Industry Term:	**Viscometer.**
Definition:	An instrument for measuring the viscosity of a liquid at specified temperature and atmospheric conditions, by measuring the force required to move one layer over another without turbulence; also referred to as viscometer.
Governing Properties:	Viscometers usually have mechanical bearings in their motor and generally operate in rotational mode only.
Rheology Solutions Instrument:	HAAKE ViscoTester 550, HAAKE RotoVisco.

Industry Term:	**Viscosity Curve.**
Definition:	A viscosity curve is the (usually non-linear) relationship between viscosity and shear rate derived from a flow curve on a CS rheometer or CR viscometer.
Governing Properties:	Viscosity is the shear stress divided by the shear rate. These are measured on a CR viscometer or CS rheometer using a flow curve.
Rheology Solutions Instrument:	HAAKE ViscoTester VT550, HAAKE RotoVisco, HAAKE RheoStress, HAAKE MARS.

Industry Term:	**Viscosity.**
Definition:	The resistance to flow of a fluid.
Governing Properties:	Viscosity is the shear stress divided by the shear rate. These are measured on a CR viscometer or CS rheometer using a flow curve.
Rheology Solutions Instrument:	HAAKE ViscoTester VT550, HAAKE RotoVisco, HAAKE RheoStress, HAAKE MARS.

Industry Term:	**Yield Stress.**
Definition:	The minimum shear stress required to initiate flow in a fluid.
Governing Properties:	Governed by the structural properties of the material at rest, measured by extrapolation using a flow curve, or using the vane technique, both on a CR or CS instrument. It can also be measured using a CS rheometer by a stress ramp.
Rheology Solutions Instrument:	HAAKE ViscoTester 550, HAAKE RotoVisco, HAAKE RheoStress, HAAKE MARS.

Notes:

- ViscoTester 550 and RotoVisco are controlled rate viscometers, RheoStress is a controlled stress rheometer, MARS is a modular R&D Controlled Stress Rheometer, all of which are HAAKE brand names of Thermo Fisher Scientific (Karlsruhe, Germany) GmbH.

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Information Request Form

Tim's Top Tips – Rheology Solutions for the Surface Coatings Industries

How To Measure Thixotropy For Surface Coatings Industries

To ensure a speedy response to your enquiry, please take the time to ensure you complete accurately all the relevant sections below.

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▶ Please provide me more information on the following:

- ☐ HAAKE VT550 - Controlled Rate Viscometer
- ☐ HAAKE RotoVisco - Controlled Rate Viscometer
- ☐ HAAKE RheoStress - Controlled Stress Rheometer
- ☐ HAAKE RheoCap - Capillary Rheometer
- ☐ Contract Testing
- ☐ Technical Literature for Surface Coatings Industries
- ☐ Training & Seminars *(Please specify)*

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- ☐ HAAKE Temperature Control Range - Refrigerated Circulators
- ☐ HAAKE Temperature Control Range - Heating Circulators
- ☐ HAAKE RheoStress RS600 - Modular Controlled Stress Rheometer
- ☐ HAAKE MARS - Modular R&D Controlled Stress Rheometer
- ☐ Rheology Solutions for Surface Coatings Industries Kit
- ☐ Other *(Please specify)*

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Comments: .....

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Please return your completed form to Rheology Solutions Pty Ltd by fax to 03 5367 6477 or post to Rheology Solutions Pty Ltd. PO Box 754 Bacchus Marsh, Victoria 3340 or send an email to info@rheologysolutions.com

Focused on providing our customers with materials characterisation solutions through knowledge, experience and support.

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