

Guide to Viscosity Measurement

Abstract

Viscosity is an important property of liquids to determine how they flow, spread, or level under certain conditions. It can be defined as a liquid's internal resistance to flow. Being able to measure the viscosity will allow to predict the behavior in a process or an application. When applying a paint by roll application the paint viscosity will strongly influence the amount of paint applied per surface area, thereby determining both yield and hiding power. It is crucial for liquid products to undergo a viscosity measurement in incoming and outgoing QC.

Table of Contents

1	Viscosity Defined	2
1.1	What is the viscosity of my product?	2
1.2	Is the measure of the defined viscosity relevant?	2
2	Viscosity Measurement	3
2.1	Which parameter is important to do one right viscosity measurement?	3
2.2	Viscometer choice, which technology to choose?	3
2.3	How to validate measured values in front of application needs?	3
3	Rheology – How Fluids Behave	4
3.1	What is the link/difference between Rheology and Viscosity?	4
3.2	Which instrument to choose to analyze rheology of my product?	5
4	Accurate Measurements with a Rotational Viscometer.....	5
5	Choose the Correct Viscometer Range and Spindle	6
6	Evaluation of Viscosity Flow Curves.....	8
7	Viscosity methods and influence of shear rate	9
7.1	Rheometer	9
7.2	Rotational Viscometer	9
7.3	Flow Cups.....	10
8	Viscometers for special applications	10
8.1	Cone and Plate Viscometer	10
8.2	Krebs Stormer Viscometer	11
8.3	Measurement of Creams, Gels and Ointments	11
9	Verification & Calibration of Viscometers with 17025 Certified Viscosity Standard	12
10	Viscosity terms – Viscosity related standards	13
10.1	Viscosity terms and definitions	13
10.2	Viscosity related ASTM standards for rotational viscometry	16
11	Literature and Standards	18

1 Viscosity Defined

1.1 What is the viscosity of my product?

This frequently asked question deserves clarification as there are several viscosity values to qualify a product:

- Kinematic viscosity ν (nu), resulting from a flow time measurement, takes account of gravity and concerns rather less viscous fluids and simple rheological behavior: Newtonian fluids. It is expressed in Stokes, cStokes or cm^2/s .
- Dynamic viscosity η (Eta) qualifies most formulated products; it is free from the effect of density and is most measured with rotary instruments. It can consider the rheological behavior of the product, which gives it an absolute character. Its units are Pa. s and mPa. s ($1 \text{ mPa.s} = 20^\circ\text{C}$ water viscosity) or Poise or cPoise.
- In the field of polymers, there are other viscosity values such as specific viscosity, intrinsic viscosity, and relative viscosity, which make it possible to calculate the average viscous molar mass of these polymers in solution.

It is therefore important to clearly define what information you want to collect before embarking on a measure of “viscosity” that could prove difficult or unnecessary to better qualify your product.

1.2 Is the measure of the defined viscosity relevant?

The answer to this question raises other questions:

- Why do I need the viscosity value? Meet a standard, check the stability of the product quality, validate an industrial process, innovate, provide a specification to a customer.
- Defining the purpose of this measure is the first step.
- Does the temperature at which I am measuring reflect the time I want characterize? it is very important to be as close as possible to what the product undergoes in its life cycle.
- Do the quantified results of this measure allow me to identify discrepancies that I judge between two products? The precision of a measurement is not enough to make it relevant.
- What information should I communicate around this viscosity value? Specify the standard used where measurement conditions will help to dialogue between services, with your customers and your suppliers.
- Why don't I find the same viscosity value as my supplier?
This very frequent and quite legitimate question has its source in the notion of rheological behavior, which we will deal with in the second chapter. This requires a precise and clear dialogue on the measures established by each other. The more information that accompanies the viscosity value provided, the more it is easy to refer to it to make a measurement in the closest conditions with its own means.

Of course, some standards in place or product constraints – available volume, test temperature, product type – will require the use of identical or use versatile instruments that will adapt to most of the stated conditions.

2 Viscosity Measurement

2.1 Which parameter is important to do one right viscosity measurement?

As viscosity is not a constant physical value to measure, therefore it is important to know the varying parameters which could influence this value during a quality measurement.

The most important factors to know or control are the following:

- Temperature, because according to the chemical formulation of sample, the temperature could affect the viscosity value. Even the increasing of temperature will give lower viscosity values, it is recommended to compare samples' viscosities or to be in accordance with standard values.
- Speed or shear rate is the major parameter which influence the viscosity of formulated products, that are non-Newtonian fluids. This induces to use defined or standard geometry where this parameter is well-known; like cone-plate, coaxial cylinder systems.
- Time is the third variable to control for several types of products, because viscosity has tendency to decrease when the shearing is longer than if it is short. This thixotropic effect is rare, but it could affect drastically process and trouble also accuracy of viscosity control.

2.2 Viscometer choice, which technology to choose?

Due to historical standard methods or easy to use justification, many types of viscometers were developed and used to control viscosity measurement. If the possibility of choice is given, you must know a few things to find the best one in function of your sample or needs:

- Glass kinematic tubes viscometers are made to obtain a very accurate kinematic viscosity, essentially on very liquid samples, without complex rheological behavior. Those are standard into petroleum industry or useful to analyze solvent diluted polymer solutions.
- Falling Ball Höppler viscometer, standardized into pharmacopeia viscosity controls, is ideal for Newtonian clear syrup and lotions; a set of different size balls enable to measure the range of viscosity and it is possible to control the sample temperature through an external water circulating to connect to a bath.
- Standard flow cups, with defined volume and calibrated hole diameter, so present into coating and paints area, easy to use and perfectly adapted to solvent paints.
- Rotational viscometer with standard spindle, to answer to ASTM/ISO standard; most popular system to measure relative dynamic viscosity of all type of products; the only one precaution to take is to consider all parameters for an accurate measurement: speed, spindle, volume of sample, time, etc.
- Rotational viscometer with shear rate defined geometries (cone-plate, coaxial systems), DIN/ISO standards compatible, recommended for non-Newtonian products into all activity domains. most defined and absolute viscosity values are obtained with those configurations.

2.3 How to validate measured values in front of application needs?

Except to answer to a standard, a good question before to create a viscosity measurement method, is to think about utility of this value regarding the application information you need.

If you want to know, if the sample is right to be used by a customer, it is recommended to control their viscosity at the shear rate zone, applied into application.

Another case should be to evaluate the capability of a product to have a good stability over time or to be adapted to a new packaging or process line. Dependent on the application, it could be interesting to create specific viscosity measurement methods to be optimized for the quality of the products.

Some easy-to-use shear rate calculation formulae and simply knowledge about conditions of processing, storage or packaging should be helpful to consider the results of measurement in correlation with application.

3 Rheology – How Fluids Behave

3.1 What is the link/difference between Rheology and Viscosity?

These two terms are not to be opposed but they are well related to each other:

- Viscosity is the unit element that will be used in rheological studies conducted on a product. It is therefore preponderant and intrinsically linked to the behavior of product rheology.
- Rheology, or science of flow, makes it possible to know and understand, how a fluid will behave under the influence of parameters during its manufacture, its packaging, its storage, its transport, and of course its use by a whole each.

Key parameters that affect viscosity and translate into rheological studies are temperature, deformation, or shear as well as time.

Newtonian products will be used for all fluid or viscous products where viscosity varies only with temperature. Water, oils, solvents, honey, varnishes and other glycerophthalic paints fall into this category. A simple measure of viscosity to a defined temperature is sufficient to characterize them.

Formulated products, for the most part, tend to become more fluid than at rest when deformed or sheared, they are called visco-fluidifying or rheo-fluidifying products.

We'll distinguish between pseudoplastic fluids, visco-fluidifying substances that flow by gravity such as shampoos, emulsions, etc.

Plastic products for which it is necessary to cross a threshold constraint to begin to flow are for example:

- Ketchup
- Toothpaste
- Paintings
- Chocolate

Other information such as visco-elasticity may be interesting to analyze, when problems of stability, holding or even adhesivity in some cases.

As mentioned above, time can also affect the viscosity of the thixotropy, a drop in viscosity as a function of the shear time. This reversible phenomenon adds to the visco-fluidifying behavior. It is often difficult to control and can lead to product quality errors and even process problems.

3.2 Which instrument to choose to analyze rheology of my product?

As stated, tests used to measure the different rheological behaviors require suitable instruments and software. Often sophisticated, complex, and expensive solutions are recommended, but are in practice not always the best solution.

Therefore, we recommend taking a pragmatical approach according to the product to analyze:

- What volume?
- What order of viscosity?
- What is its nature?
- Product loaded or not?
- What level of expertise is desired (quality control, R&D, basic research)?
- What is my budget?
- Do I have the in-house skills to properly use such equipment and interpret the data?

The answers to these questions will guide you towards the most convenient choice in terms of material, accessories, and methods according to your needs.

Example:

The OICCC standard, established for chocolate since the 1970s, when the computer did not exist, made it possible to define the measure of viscosity of the chocolate at 40°C, with determination of the flow limit according to CASSON, to obtain both parameters that still today qualify the structure of a chocolate, coming from its cocoa butter content, and its shear viscosity once it passes the LE [2].

This simple and comprehensive method of rheological control proves that rheology is present in all your products, that it can provide solutions to your problems of quality, pumping, stability, application, more results in a simple viscosity value and without being too complex to use and analyze.

4 Accurate Measurements with a Rotational Viscometer

A Step-By-Step Process:

Rotational viscometers provide a cost efficient yet reliable and reproducible way to measure the viscosity of liquid samples. They can measure absolute viscosity when used e.g., with a small sample adaptor. Such an accessory provides a defined shear rate so absolute viscosity values can be calculated. However, in many cases the measurement of the relative viscosity is sufficient. For this kind of measurement, the spindle is just inserted into a beaker or can, resulting in a relative value that can be compared with QC specs defined for these conditions or other batches ensuring a consistent quality of the product.

Ensure that your viscometer is calibrated properly by testing it with an ISO 17025 certified calibration oil.

1. Prepare your sample in accordance with a standard test method, such as ASTM D2196-10 Standard Test Methods for Rheological Properties of Non-Newtonian Materials by Rotational Viscometer, or ISO 2555, ISO 1652 [1].
2. To achieve repeatable, reliable, and accurate results use the same viscometer, spindle, rotational speed(s), test time, container shape, size and placement, and sample size for repetitive and QC testing. Always use the spindle guard leg.
3. Viscosity is temperature dependent. Control the ambient temperature as well as the temperature of your sample, spindle, and spindle guard to ensure accurate and repeatable results. This can be achieved with a circulating water bath and various accessories. Allow everything to equilibrate for at least one hour before measuring. Use an accessory sample temperature probe with your instrument during measurement to ensure that you maintain a constant sample temperature.
4. Ensure that your spindle is clean, shaft is not bent and has not any dings or dents.
5. Ensure that you do not introduce air bubbles into your sample during preparation.
6. Be careful not to shear the sample while preparing through shaking, stirring or mixing as some materials (shear thinning / shear thickening) take time to recover to their resting viscosity. Always slowly lower the spindle into the sample. If you do introduce shear, ensure to allow sufficient time for recovery before measuring.
7. Ensure that your sample container is clean without any residue from prior tests.
8. Ensure that the spindle is immersed in the sample up to the middle of the line on the shaft. Overfilling or underfilling can result in erroneous results.
9. Avoid turbulence, normally caused by higher speeds, which can alter results. This is especially important with lower viscosity samples.
10. Ensure to use the same test time as many fluids change viscosity over time. E.g. shear thinning fluids decrease in viscosity as shear is applied, and in some liquids this reduction in viscosity is time dependent.
11. In most cases ensure that the spindle rotates at least 5 times before you record a value. This may need to be adjusted with some non-Newtonian fluids. But ensure that measurement time is not too long, especially with highly viscous samples, as this can cause higher friction and resultant sample shear heating and changes in viscosity. A rule of thumb is to allow the displayed viscosity to stabilize before measurement. If it does not stabilize, the fluid likely exhibits time dependent viscosity. In this case you should define a time or times for measurement(s).
12. Prevent the sample from drying or evaporating, as it will lead to higher viscosity.

5 Choose the Correct Viscometer Range and Spindle

Rotational viscometers are manufactured in three different viscosity ranges to enable a broad range of viscosity measurement. The first step is to determine the viscosity range that is close to the viscosity of the products that you will be measuring – either low, medium, or high viscosity.

Low Viscosity

Adhesives (solvent base)

Biological Fluids

Medium Viscosity

Adhesives (hot melt)

Ceramic Slurries

High Viscosity

Asphalt

Caulking Compounds

Chemicals	Creams	Chocolate
Coatings, Water-Based	Dairy Products	Epoxies
Edible Oils	Detergents	Gels
Inks, Water-Based	Dressings & Sauces	Grease
Juices	Gums	Inks (ballpoint, offset)
Liquid Soap	Inks (screen printing)	Mayonnaise
Liquid Wax	Lotions & Cremes	Molasses
Mouthwash	Paints	Ointments
Paints, Latex	Paints & Coatings	Pastes
Photo Resist	Paper Coatings and Pulp	Peanut Butter
Soda	Plastisols	Putty
Solvents	Shampoo & Conditioner	Roofing Compounds

Once you choose the viscometer range that approximates your product, the second step is to select a spindle and rotational speed. Spindle sets are supplied with each viscometer that enable you to measure within the full viscosity range of your instrument. In the end, most of the time choosing the correct spindle and rotational speed requires trial and error.

There are several factors that you should consider before selecting a spindle and rotational speed:

- If you are trying to duplicate a method or result, use the same spindle, rotational speed, container, and sample size used in the method to be duplicated.
- If you need to approximate a particular shear rate, for example the shear that will be created when your product is applied, you should choose a rotational speed that will approximate that shear rate.
- If you know the viscosity of the sample to be tested, use the appropriate setting on your viscometer. Simply input the spindle code and RPM setting, the instrument will display the viscosity range of that combination. Try different combinations to select the appropriate spindle.
- If you do not know the viscosity of the fluid to be tested, your goal is to find a speed and spindle combination that will give you a torque reading between 20% and 90%. Try to find a combination that gives you a torque near 50%, this is the optimal area to be testing for the best accuracy. Simply measure your sample with the chosen spindle at various speeds. If you can't obtain a reading between 20% and 90% by varying the speed, then you need to try a different spindle. If your reading is above 90% at the slowest speed, choose the next smallest spindle. If your reading is below 20% at the highest speed, choose the next largest spindle.
- If you need to test at multiple speeds, choose a spindle that will yield readings between 20% and 90% for at least three speed settings.
- In general, the lowest viscosity range can be measured with the biggest spindle at maximum speed. The highest viscosity range can be measured with the smallest spindle at the lowest speed.

6 Evaluation of Viscosity Flow Curves

Steady-shear flow curves for suspensions and solutions measured under the same conditions may exhibit a different behavior over a range of shear rates. Also, some materials may exhibit more than one distinct behavior over different shear rate regions of the same flow curve. Several types of behavior can be classified according to their characteristic shape. Figure 1 below illustrates the most frequently encountered.

- 1. Newtonian** Differential viscosity and viscosity coefficient are constant with shear rate.
- 2. Shear-thickening** Differential viscosity and coefficient of viscosity increase continuously with shear rate.
- 3. Shear-thinning (pseudoplastic)** Differential viscosity and coefficient of viscosity decrease continuously with shear rate. No yield value.
- 4. Shear thinning (pseudoplastic) with yield response** Differential viscosity and coefficient of viscosity decrease continuously with shear rate once the apparent yield stress has been exceeded.
- 5. Bingham plastic (ideal)** Obeys the Bingham relation ideally. Above the Bingham yield stress, the differential viscosity is constant and is called the plastic viscosity, while the coefficient of viscosity decreases continuously to some limiting value at infinite shear rate.
- 6. Bingham plastic (non-ideal)** Above the apparent yield stress the coefficient of viscosity decreases continuously, while the differential viscosity approaches a constant value with increasing shear rate. Extrapolation of the flow curve from the linear, high shear rate region (plastic region) to the stress axis gives the apparent Bingham yield stress. The differential viscosity in the linear region is termed the plastic viscosity.

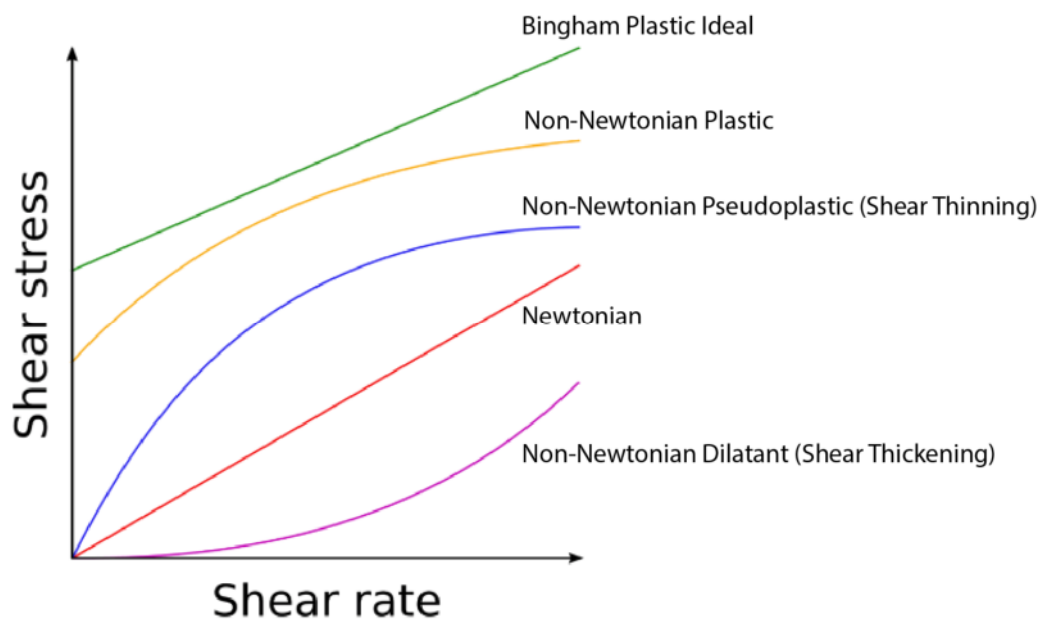


Figure 1: Shear flow curves classification

7 Viscosity methods and influence of shear rate

Most paints are non-Newtonian liquids, which means their viscosity depends on the applied shear rate, which is a measure for how the paint is sheared or worked during a flow. Many paints have a lower viscosity when high shear rates are applied, for example while stirring or spraying, compared to their storage viscosity.

Different viscosity measuring methods apply different shear rates during measurement. This can result in different values for the measured viscosity of non-Newtonian paints for different methods. In some cases, also the time dependence of viscosity after shearing must be considered. The measured viscosity of so-called thixotropic paints will depend on how the paint is sheared for example during handling before the measurement, as the paint will “remember” the shear treatment for some time.

For the above reasons it is important to choose a method that provides a reproducible shear rate when checking the quality of paint. Figure 2 gives an overview over shear rates applied at certain applications as well as measuring methods.

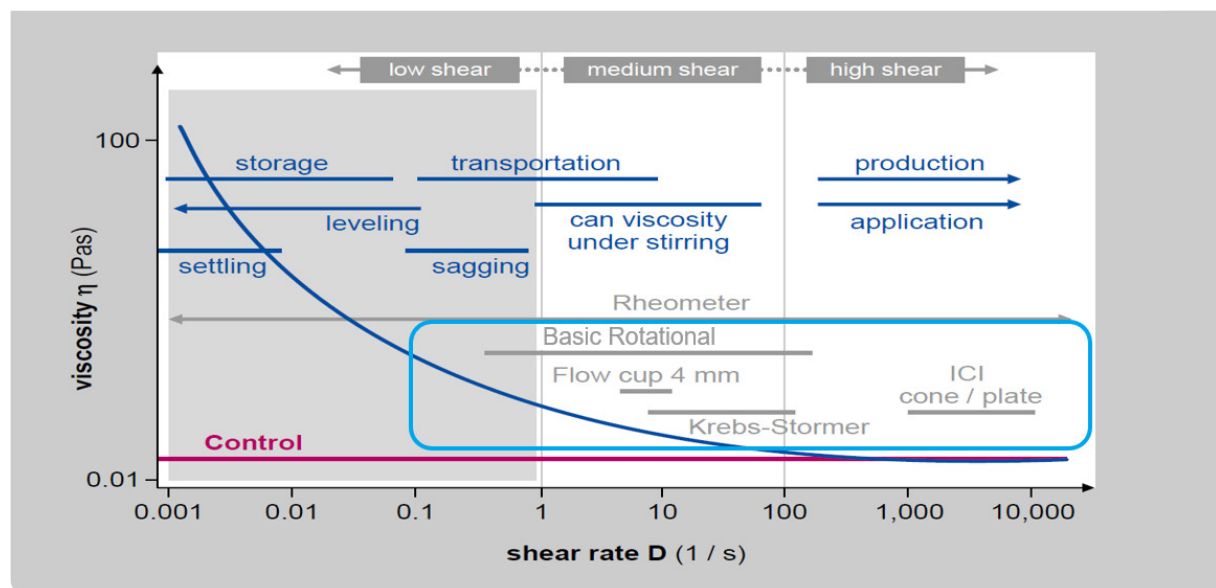


Figure 2: Shear rates at different applications

7.1 Rheometer

Rheometers are the instruments of choice to study the entire rheological behavior. While these instruments will give you the full picture, they are complicated in usage and data interpretation requiring highly trained personnel and are most expensive.

7.2 Rotational Viscometer

Rotational viscometers are easy to operate and most often used for QC applications. Like rheometers they give repeatable and reliable results and operate at shear rates most suited for the respective application:

- Basic rotational viscometers are very versatile and cover a broad range of shear rates and viscosities. They are used as a reliable and reproducible way to measure the relative viscosity in cans and beakers as a simple QC check and can also determine absolute viscosities in a wide range by using a so-called small sample adaptor.
- Krebs or Stormer viscometers are best used with paints that will be spread with a paint brush or roller, that is paints that will be applied at a medium shear rate from 10 to 100 s⁻¹. A typical application is architectural paints, but this viscometer type is also used in other applications where a fast, reliable, and highly standardized method is required.
- Cone and plate viscometers are often used at high shear rates and therefore allow control over the paint's viscosity during application but can measure also at shear rates down to 20 s⁻¹ as well. Samples are tested in a defined geometry and the instruments can measure absolute viscosities up to 15,000 poise.
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7.3 Flow Cups

Flow cups are available at a low cost and offer a quick way to check a viscosity. Their primary result is the efflux time that can be calculated into kinematic viscosity. They should only be used for Newtonian liquids as they are error prone for the measurement of e.g., thixotropic paints, as the measured value for these paints can depend on the handling before the measurement, like stirring and filling the paint into the cup. See the [Insta Visc Viscosity Calculator app](#) to help to calculate the viscosity from measurements with flow cups [3].

8 Viscometers for special applications

8.1 Cone and Plate Viscometer

To evaluate dynamic viscosity measurement a cone and plate viscometer is used as described in DIN ISO 2884-1 and ASTM D4287 [4].

Cone & plate viscometers are a practical tool for any QC or R&D lab requiring quick and easy testing of materials, regardless of application. They are suitable for Newtonian or non-Newtonian materials with viscosities up to 15,000 poise and shear rates from as low as 25 s⁻¹ up to 13000 s⁻¹. Instruments are available with either fixed speeds that meet industry standards, or variable speeds that allow for varying shear rates. Most also have built in heating and cooling to allow testing from 5°C to 235°C.

Below are the advantages and disadvantages of using a cone and plate viscometer versus a standard rotational viscometer.

Advantages:

- Subjects the sample to uniform shear rates, unlike a typical viscometer where shear rates vary across the sample container
- Results are not dependent on sample container size and shape
- Easier to fill & clean
- Less sample needed
- Faster and easier temperature ramp up and stabilization

- Quickly handles measuring 2-point QC tests where the specified shear rates are far apart e.g., 20 sec⁻¹ and 9000 sec⁻¹
- Fast cycle time = decreased time and labor costs to run tests
- Shear rate range broad enough to show shear thinning behavior of pseudoplastic materials

Disadvantages

- Need very homogenous samples due to the small sample volume
- Materials that contain large particles may yield inconsistent results
- More expensive than a standard rotational viscometer
- Needs correct fill volume under the cone, otherwise large variations in viscosity values can result
- Faster drying of samples due to small sample size
- Limited shear rates compared to standard rotational viscometers

8.2 Krebs Stormer Viscometer

The most popular method to determine viscosity of architectural paint uses a Krebs Stormer viscometer as described in ASTM D562 [5]. The Stormer viscometer uses a paddle that rotates through the paint at 200 rpms in a standardized container. The resistance created by the paint is measured and expressed in Krebs units, or KUs. The higher the KU number, the more viscous the paint. Modern Krebs Stormer viscometers such as the BYK byko-visc DS also simultaneously display viscosity in centipoise (cP) and grams (gm). The BYK unit is useable with viscosities in the 40-141 KU range, which is equivalent to 27-5274 centipoise (cP) per ASTM D562 [5]. They are simple, easy to use, and yield operator independent results with no calculations needed.

Krebs Stormer viscometers are typically used in QC applications to ensure that paints meet production specifications, and in R&D to develop new coatings. They are best used with paints that will be spread with a paint brush or roller, that is paints that will be applied at a medium shear rate from 10 to 100 s⁻¹, depending on speed of brushing and depth of coating applied. They can also be used in other applications, such as raw material, slurries, and some food applications within the specified viscosity range. Measurement of creams, gels, and ointments.

8.3 Measurement of Creams, Gels and Ointments

Using a cosmetic product on skin is a typical sensorial experience, where the flow characteristics of creams, gels or ointments are determinant. At the same time, those physical properties are essential to producing a product properly packaged and easy to use. All these cosmetics samples have a shear-thinning behavior meaning the viscosity decreases when the shear strain we impose on it increases. Moreover creams, ointments and gels have a plastic behavior, that means they don't flow only on gravity effects. Sometimes they also add some visco-elastic properties meaning they can range from solid-like products to liquid-like products.

Due to all those flow properties, it becomes important to define the best the viscosity measurement to obtain values which identify quality and aspect of application. With a rotational viscometer we could apply a defined speed of rotation (ISO 2555) or obviously a

shear rate or shear rates ramp to a sample (ISO 3219). This helps formulators understand what force is required to enable the products to start flowing (pump dimension, packaging pressure to exit sample from it). The amount of force required to start the cream or gel to flow is called the yield stress. When the sample starts to flow it takes on a shear-thinning behavior. Shear thinning - is the non-Newtonian behavior whose viscosity decreases under shear strain. Using the rotational viscometer allows formulators to define the shear thinning curve based on defined shear rates (ISO 3219). Thus, a better understanding of how the product will flow or be easy to apply to the skin, is achieved. [6]

As the shear-thinning characteristics is the researched behavior of these products, environmental features influence the measured values. As temperature, this induces to measure the temperature of sample during measurement or to use thermostatic chamber to maintain it. Another important parameter which could influence the viscosity of such fluids is time; when viscosity decrease during shearing time, this is a thixotropic effect. This factor is important to consider about the stability of product.

The following outlines the two referred to methods according to ASTM or ISO standard:

ASTM/ISO2555 is used to measure apparent viscosity of material by measuring torque with the spindle rotating at a constant speed into one defined Becher with 500 ml of sample. Apparent viscosity in centipoises (equal to mPa.s) is calculated by multiplication of scale reading of viscometer by a scale factor, which depends on spindle number and rotation speed. When materials are non-Newtonian, this method gives limited information, but which could be enough for comparative controls, at the conditions to respect all same conditions and test like time to stop procedure.

ISO3219 Shear rate is well known in this standard, because using completely defined shear rates geometries. On premium model like the byko-visc RT offers the ability to increase and decrease speeds of rotation (then shear rates). The samples will be sheared under different shear rates, this will induce to analyze the flow behavior, determine yield stress or thixotropic effect. With these possibilities, all application areas should be observed to give right and useful values of viscosity for R&D, quality control or process personnel.

9 Verification & Calibration of Viscometers with 17025

Certified Viscosity Standard

Cosmetics, food, paint, pharma, personal care, and a host of other product manufacturers all run viscosity tests daily on a large variety of their products. Viscosity is measured in R&D, during production, and in final product QC. The products measured can vary in viscosity. For example, a food manufacturer might need to test thin, low viscosity salad dressing, as well as higher viscosity ketchup with shear thinning flow behavior.

When using a viscometer to test substances of varying viscosities it is important to ensure that your viscometer is calibrated in the viscosity range of the products that you are testing. Modern rotational viscometers like the BYK byko-visc RT series enable the user to verify the calibration, as well as to calibrate their instrument on site using ISO 17025 [Reference 5] certified standard oils.

Because viscosity varies with temperature, calibration oils are certified at specific temperatures that are listed on the certificate. Most oils are certified at 25°C, but higher temperature oils are also available. Some oils are certified at multiple temperatures as well. It is important to note that the temperature of the calibration oil as well as the spindle should be maintained at the certification temperature when calibrating. This can be accomplished by using a circulating water bath or other accessory that allows temperature stability. To ensure accurate calibration, the use of two or three oils with differing viscosity values is suggested. Ideally one should be below the viscosity of your products, and one should be above. BYK standard oils do not change viscosity with time or shear.

Calibration oils relevant to the viscosity of the products to be measured should be purchased with every viscometer to ensure accurate readings, as well as to comply with ISO 17025 [Reference 5] and other quality systems, standards, and requirements.

10 Viscosity terms – Viscosity related standards

10.1 Viscosity terms and definitions

Absolute Viscosity

The force needed for a liquid to overcome its internal friction and start to flow. Also known as dynamic viscosity.

Centipoise

A unit of measurement for dynamic viscosity equivalent to 1/100 of a poise. It is abbreviated cP, cps, cp and cPs.

Dilatant

Also described as shear thickening fluids, they are characterized by increased viscosity with increases in shear rate. In other words, the more you mix or stir these fluids, the thicker they become. Fluids containing suspended solids, such as some candies and sand/water mixtures are typical dilatant fluids.

Dynamic Viscosity

Also known as shear viscosity, defined as the resistance of one layer of a fluid to move over another layer. In other words, the amount of force needed to make a fluid flow at a certain rate.

dyne-cm

A unit of measurement traditionally used to measure surface tension. May also refer to torque in viscosity measurements.

Fluid

A fluid is a substance which deforms continuously under the application of a shear stress and can be either a liquid or gas.

Kinematic Viscosity

A measure of a fluid's internal resistance to flow under gravitational forces. It is measured by determining the time in seconds required for a fixed volume of fluid to flow a known distance under gravity through an orifice of a calibrated viscometer at a controlled temperature. Typical instruments used are Zahn cups & Ford Cups of distinct types, as well as capillary viscometers.

KREBS Unit (KU)

One Krebs unit (KU) is the weight in grams that will turn a paddle type rotor, that is submerged in the sample, 100 revolutions in 30 seconds. It is typically measured using a Krebs Stormer type viscometer with a paddle spindle rotating at 200 RPM. It is commonly used in the paint and coatings industry. Krebs units can be converted to centipoise using ASTM D 562. These viscometers typically measure from 40-141 KU which is equivalent to 27-5274 centipoise.

milliPascal Seconds

A dynamic viscosity unit of measure for viscosity; abbreviated as mPa-s. 1 pascal second is equal to 1000 milliPascal-second (mPa-s).

Newtonian

Sir Isaac Newton assumed that all fluids at a given temperature exhibited the same viscosity, independent of the shear rate. In other words, twice the force would move a fluid twice as fast. We have since found this not to be the case – many fluids do change viscosity based on shear rate. But the viscosity of many fluids, such as water, remain constant regardless of shear rate. Hence, we refer to these fluids as Newtonian. Measuring Newtonian fluids is simple, as measured viscosity will be the same regardless of which spindle, speed, or viscometer is used.

Non-Newtonian

These fluids are those where viscosity changes as shear rate changes. When their shear rate is varied, their shear stress does not vary in the same proportion, and their viscosity changes, either higher or lower. In other words, when more force is applied to the fluid it will then thin or thicken, and flow slower or faster. This is sometimes referred to as shear thinning and shear thickening. There are many types of non-Newtonian behavior, including Pseudoplastic, Dilatant, Plastic, Thixotropic, and Rheopectic. See these terms for further explanations.

Plastic

Under static conditions this type of fluid behaves as a solid. Stress must be applied to the fluid for it to start flowing. This stress is the yield stress. An example of this type of fluid is ketchup, it will not normally pour from the bottle unless the bottle is shaken or hit with your palm. The amount of energy needed to start this flow is called the Static Yield. These fluids may also have Newtonian, pseudoplastic, or dilatant flow characteristics.

Poise

A dynamic viscosity unit of measure in the centimeter-gram-second system of units. 10 Poise (10 P) = 1 Pascal Second (Pa-s). Abbreviated as P.

Pseudoplastic

These fluids decrease in viscosity as force is applied. In other words, the more you stir these fluids the thinner they will become. Paint, nail polish, whipped cream, blood, milk, and quicksand are all examples of pseudoplastic fluids. Also known as shear thinning fluids. These are the most common non-Newtonian fluids.

Relative Viscosity

The viscosity value of a non-Newtonian material at a defined shear rate.

Rheology

The study of the deformation and flow of materials, especially non-Newtonian fluids.

Rheometer

A type of viscometer, rheometers measure the way in which liquids flow in response to

varying applied forces. It is typically used with fluids that have complex viscosity characteristics that cannot be defined by a single viscosity value.

Rheopexy

A rare non-Newtonian liquid behavior where viscosity increases over time under a constant shear force. In other words, the longer a fluid is mixed or stirred the higher its viscosity becomes. Many rheopectic fluids will thicken or even solidify when shaken. Gypsum paste, as well as some lubricants, are examples of rheopectic fluids.

Reciprocal Seconds

Unit of measurement of shear rate. Also written as seconds⁻¹.

Shear (liquid)

The relative motion between adjacent layers of a moving liquid. Shear forces act tangentially to a surface causing deformation.

Shear Rate

This is the rate at which a fluid is sheared during flow, also defined as the rate of change of velocity at which fluid layers move past each other. Shear rate is normally expressed in reciprocal seconds (1/s) or seconds⁻¹. It is calculated with a viscometer by considering the spindle shape and rotational speed as it rotates in a sample container of fluid.

Shear Stress

Primarily caused by the friction between fluid particles, due to fluid viscosity. Defined as the force per unit area used to move a material. A shear stress is an example of a tangential stress, i.e., it acts along the surface, parallel to the surface. Friction due to fluid viscosity is the primary source of shear stresses in a fluid. When shear stress is applied to a fluid at rest fluid, the fluid cannot remain at rest but will move because of the shear stress.

Static Yield

The amount of force/torque needed to initiate flow of a material at rest. For example, the amount of force needed on a bottle of ketchup to start it flowing from the bottle.

Stormer Viscometer

Defined in ASTM D562, a Stormer type viscometer uses a paddle type spindle rotating at 200 rpms. They are the most widely used viscometer type for paints and coatings viscosity testing.

Stoke

A Kinematic unit of measure that can be expressed in terms of centistokes (cS or cSt); 1 stokes = 100 centistokes = 1 cm² s⁻¹ = 0.0001 m² s⁻¹. One stoke is equivalent to one poise divided by the density of the fluid in g/cm³.

Thixotropy

These fluids decrease in viscosity when subjected to constant shear. For example, some gels become fluid when shaken or stirred, but revert to a gel state when shaking or stirring is stopped. This is a non-Newtonian shear thinning behavior that is highly time dependent, both for the shear thinning and to begin, as well as for the liquid to return to its previous state. Thixotropic behavior is time dependent and can occur in conjunction with other flow behaviors. It can also be observed with only with certain shear forces.

Thixotropy is rare, but this behavior can be found in gelatins, shortening, greases, heavy printing inks, colloidal solutions, etc.

Torque

The rotational equivalent of linear force. In a viscometer this is measured as the amount of energy that the spindle needs to rotate a certain distance while immersed in a sample. Force (F) times Distance (r) = Torque. Distance is measured from the pivot point to the point where the force will act. The SI unit of torque is a in Newton-meter (N-m).

Viscometer or Viscosimeter

The first use of the word viscometer is said to have been in 1883, and its definition is an instrument with which to measure viscosity, typically liquids. In other words, it measures a fluid's resistance to deformation under shear stress. In a typical Rotational Viscometer, a spindle moves through the sample fluid to measure the viscosity. Zahn cups and Ford cups are examples of viscometers where the sample flows through an orifice under the force of gravity, and viscosity is measured by determining the time in seconds necessary for a fixed amount of liquid to flow through a defined orifice size. Another type of viscometer is a bubble tube viscometer, which measures viscosity by measuring the time it takes for an air bubble to pass through a liquid in a tube.

Viscosity

A simple definition is that it is a measure of thickness, for example grease is thicker than water, and therefore has a higher viscosity. In a scientific sense, the viscosity of a fluid is a measure of its resistance to deformation at a given rate, or the resistance of a material to flow. Viscosity equals shear stress divided by shear rate.

Yield Stress

This is defined as the amount of force required for a material to start to flow. A practical example is a tube of toothpaste – the yield stress is the amount of energy required to start the flow of the toothpaste from the tube. Another example is squeeze bottles of mustard, mayonnaise, or ketchup – the yield stress is the amount of force needed to get them to flow from the bottle. This is a key factor to control when developing new foods and other consumer goods such as personal care products that will be packaged in a squeeze bottle. If the yield stress is too high the consumer will find it difficult to dispense the products, and if too low the material will flow from the packaging too fast.

10.2 Viscosity related ASTM standards for rotational viscometry

Viscosity measurement is also a topic of numerous international standards. These standards ensure that there is a mutual understanding of test methods and quality between suppliers and buyers. The following list gives an overview of the test methods specified by ASTM for viscosity measurement:

- C474 Standard Test Methods for Joint Treatment Materials for Gypsum Board Construction
- C965 Practices for Measuring Viscosity of Glass Above the Softening Point
- C1276 Standard Test Method for Measuring the Viscosity of Mold Powders Above their Melting Point Using a Rotational Viscometer
- D115 Methods of Testing Varnishes Used for Electrical Insulation
- D562 Standard Test Method for Consistency of Paints Using the Stormer Viscometer
- D789 Test Methods for Determination of Relative Viscosity, Melting Point, and Moisture Content of Polyamide (PA)
- D803 Standard Test Methods for Testing Tall Oil
- D1074 Test Method for Compressive Strength of Bituminous Mixtures

- D1076 Specification for Rubber-Concentrated, Ammonia Preserved, Creamed and Centrifuged Natural Latex
- D1084 Test Methods for Viscosity of Adhesives
- D1337 Test Method for Storage Life of Adhesives by Viscosity and Bond Strength
- D1338 Practice for Working Life of Liquid or Paste Adhesives by Viscosity and Bond Strength
- D1417 Methods of Testing Rubber Latexes-Synthetic
- D1439 Methods of Testing Sodium Carboxymethyl-cellulose
- D1824 Test Method for Apparent Viscosity of Plastics and Organosols at Low Shear Rates by Brookfield Viscometer
- D1986 Test Method for Determining the Apparent Viscosity of Polyethylene Wax Brookfield Viscometer
- D2196 Standard Test Methods for Rheological Properties on Non-Newtonian Materials by Rotational Viscometer
- D2243 Test Method for Freeze-Thaw Resistance of Waterborne Coatings
- D2364 Standard Methods of Testing Hydroxyethyl-cellulose
- D2556 Test Method for Apparent Viscosity of Adhesives Having Shear Rate Dependent Flow Properties
- D2669 Test Method for Apparent Viscosity of Petroleum Waxes Compounded with Additives (Hot Melts)
- D2983 Standard Test Method for Low-Temperature Viscosity of Automotive Fluid Lubricants Measured
- D3236 Standard Test Method for Apparent Viscosity of Hot Melt Adhesives and Coating Materials
- D3468 Standard Specification for Liquid-Applied Neoprene and Chlorosulfonated Polyethylene Used in Roofing and Waterproofing
- D3716 Standard Test Methods for Use of Emulsion Polymers in Floor Polishes
- D3730 Standard Guide for Testing High-Performance Interior Architectural Wall Coatings
- D3791 Standard Practice for Evaluating the Effects of Heat on Asphalts
- D3794 Guide for Testing Coil Coatings
- D3806 Standard Test Method for Small-Scale Evaluation of Fire-Retardant Paints
- D4016 Standard Test Method for Viscosity of Chemical Grouts by the Brookfield Viscometer
- D4143 Standard Guide for Testing Latex Vehicles
- D4212 Standard Test Method for Viscosity by Dip- Type Viscosity Cups
- D4280 Standard Specification for Extended Life Type, Raised, Retroreflective Pavement Markers
- D4402 Standard Test Method for Viscosity Determinations of Asphalts Using a Rotational Viscometer
- D4712 Guide for Testing of Industrial Water- Reducible Coatings (withdrawn 2017)
- D4800 Standard Guide for Classifying and Specifying Adhesives
- D4878 Standard Test Methods for Polyurethane Raw Materials: Determination of Viscosity of Polyols
- D4889 Standard Test Methods for Polyurethane Raw Materials: Determination of Viscosity of Crude or Modified Isocyanates
- D5018 Standard Test Method for Shear Viscosity of Coal-Tar and Petroleum Pitches
- D5133 Standard Test Method for Low Temperature, Low Shear Rate, Viscosity/Temperature Dependence of Lubricating Oils Using a Temperature-Scanning Technique

- D5146 Standard Guide to Testing Solvent-Borne Architectural Coatings
- D5324 Standard Guide for Testing Water-Borne Architectural Coatings
- D5400 Standard Test Methods for Hydroxypropyl cellulose
- D6080 Standard Practice for Defining the Viscosity Characteristics of Hydraulic Fluids
- D6083 Specification for Liquid Applied Acrylic Coating Used in Roofing (withdrawn 2014, no replacement)
- D6267 Standard Test Method for Apparent Viscosity of Hydrocarbon Resins at Elevated Temperatures
- D6373 Standard Specification for Performance Graded Asphalt Binder
- D6577 Standard Guide for Testing Industrial Protective Coatings
- D6895 Standard Test Method for Rotational Viscosity of Heavy-Duty Diesel Drain Oils at 100°C

11 Literature and Standards

- [1] ASTM D2196-20: Standard Test Methods for Rheological Properties on Non-Newtonian Materials by Rotational Viscometer
ISO 2555: International Office of Cocoa, Chocolate and Confectionery
ISO 1652: Rubber latex – Determination of apparent viscosity by the Brookfield test method
- [2] OICCC: International Office of Cocoa, Chocolate and Sugar Confectionery
- [3] Insta Visc Viscosity Calculator app
- [4] ISO 2884-1: Paints and varnishes – Determination of viscosity using rotary viscometers – Part 1: Cone-and-plate viscometer operated at a high rate of shear
ASTM D4287: Standard Test Method for High-Shear Viscosity Using a Cone/Plate Viscometer
- [5] ASTM D562: Standard Test Method for Consistency of Paints Using the Stormer Viscometer
- [6] ISO 3219: Standard Test Methods for Rheological Properties of Non-Newtonian Materials by Rotational Viscometer.
- [7] ISO 17025: Testing and Calibration Laboratories