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1. Introduction

In order to know the state (properties of matter) or the fluidity of a liquid or a gas, measuring its viscosity is an effective way. For example, the viscosity of a liquid is an important parameter for designing the piping in a plant, or transporting crude oil or chemical agent through a pipeline. Measuring viscosity has been playing an important role in, to say nothing of the petrochemistry industry, a wide range of industries such as the food, printing (ink), medical drug, or cosmetics industries, as well as in the quality control during a production process or in various research and development stages for the improvements of quality and performance. Recently, in the electronic engineering industry it has become recognized that controlling viscosity of photoresist fluid, which is used in the production processes of the print circuit board, the cathode-ray tube and the flat liquid crystal display, is a crucial factor to determine the qualities, performances and yields of finished products. Among those industries, it has also been recognized that controlling optimum viscosity reduces production costs.　Furthermore, in the biology and medical fields, viscidity of blood for instance affects hemodynamics and microcirculation, and viscosity is also an important parameter for the research on colloidal solution such as biopolymer solution.

Generally speaking, viscosity is associated only with liquid. Because gas is relatively inviscid fluid, it is considered that no major errors will be produced if ignoring a force towards the direction of the gas flow that exerts on a plane against the gas (tangential stress), unless it is not involving a fast-moving object such as a rocket or aircraft. This kind of ideal fluid in which no tangential stress generates when it is in motion (fluid state) is called a **perfect fluid** or an **inviscid fluid**.　Almost all liquid are **viscous fluid** having viscidity. For example, when rotating a drum container filled with water on its vertical central axis, the water that was at rest in the beginning starts moving as being dragged by the container's inside wall and then whirls completely together with the container as if it were a single rigid body. This is caused by the force (tangential stress) having generated in the direction of the flow (movement) on the surfaces of water and the container's inside wall. A fluid that generates this kind of force is regarded as having **viscosity**. Viscous fluid is further divided broadly into two categories; **Newtonian fluid** that is subject to Newton's law of viscosity, and **non-Newtonian fluid** that is not subject to Newton's law of viscosity.

As described above, fluid can be broadly categorized as shown in Figure 1 below:

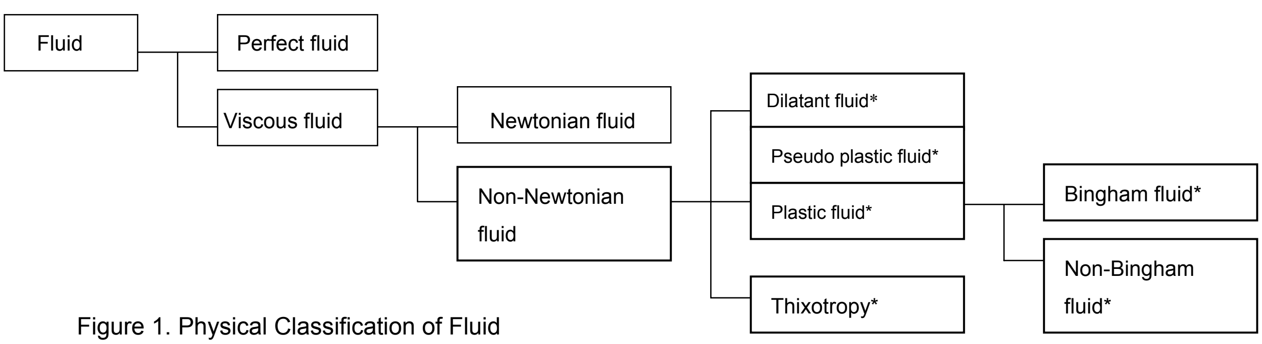
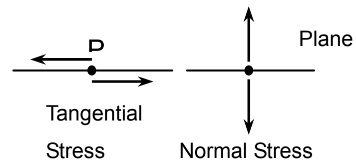


Figure 1. Physical Classification of Fluid

* Please refer to "2. Viscosity".

*Tangential Stress

* Where a plane passes through a given point P in a fluid, every part of the fluid on the both sides of the plane exerts a force on each other. The force (stress) per unit area of the plane is resolved into a tangential component and a normal component; they are called a tangential stress and a normal stress respectively. For example, when it is a resting fluid, the tangential stress is zero and the normal stress exerts a pressure.



2. Viscosity

Viscosity, which is also called a viscosity coefficient, is the substance constant indicating the magnitude of the "fluidity" of a fluid. Let's look at viscosity from a physics point of view in order to understand and define it properly.

As shown in Figure 2, the two plates, board A and board B, are placed in parallel filled with a liquid (fluid). The distance between board A and board B is y_0. Where board A is fixed and board B is being moved parallel to board A at a constant speed of V_0, if the fluid between board A and board B is also in motion parallel to board A and has produced a steady flow, this is called the **Couette flow**.

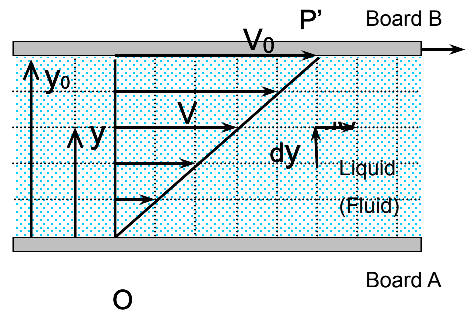


Figure 2. Couette Flow (Newtonian Fluid)

Where the velocity at a given distance y between board A and board B is V, they are in proportion as shown in Figure 2. Where the slope of the straight line connecting O and P' is D,

$$\mathbf{D = V/y}$$

Since it equals to the increased quantity of the velocity per unit distance, i.e. the velocity gradient,

$$\mathbf{D = dV/dy} \qquad (1)$$

D is called a **shearing rate**.

In Figure 2, the liquid layers at distance y and at distance y+dy flow in parallel at speed V and at speed V+dV respectively. Because of the difference in the velocities, an internal frictional force will develop between them. The frictional force applying to the unit area of the plane parallel to the flow direction between board A and board B is called a **tangential stress**. This is also known as a **shearing stress**.

Where τ stands for a tangential stress, it is proportionate to shearing stress D. Where η stands for the proportional constant,

$$\tau = \eta D \text{ (Newton's law of viscosity)} \qquad (2)$$

The equation (2) represents the law known as **Newton's law of viscosity**. Proportional constant η is called a **viscosity** or a **viscosity coefficient**.

$$\eta = \tau/D \qquad (3)$$

The fluid subject to this law, whose viscosity η at specific temperature is constant in spite of shearing rate D or shearing stress τ, is called a **Newtonian fluid**. If shearing rate D and shearing stress τ are not proportionate, i.e. if viscosity η of the fluid is variable with the quantities of shearing rate D or shearing stress τ, it is called **non-Newtonian fluid**. A liquid such as water, alcohol, etc. which is composed of a single substance (molecule) is a Newtonian fluid. On the other hand, a polymer solution, a colloidal solution, etc. generally belongs to non-Newtonian fluid.

Figure 3 shows the relationship between shearing rate D and shearing stress τ. As straight line ① shows, where they are in proportion indicating a constant slope of the line, it is a Newtonian fluid. Where θ stands for the slope, viscosity η is written by the following equation (4);

$$\eta = \tan\theta \qquad (4)$$

The fluids with fluidities such as shown by lines ② - ⑤ are non-Newtonian fluids. Viscosity τ/D varies in response to the quantity of shearing rate, and the viscosity will not be constant.

Curved line ② shows what is called the **dilatant fluid**, and the viscosity increases as the shearing rate increases. Curved line ③ shows what is called the **pseudo plastic fluid**, and the viscosity decreases as the shearing rate increases.

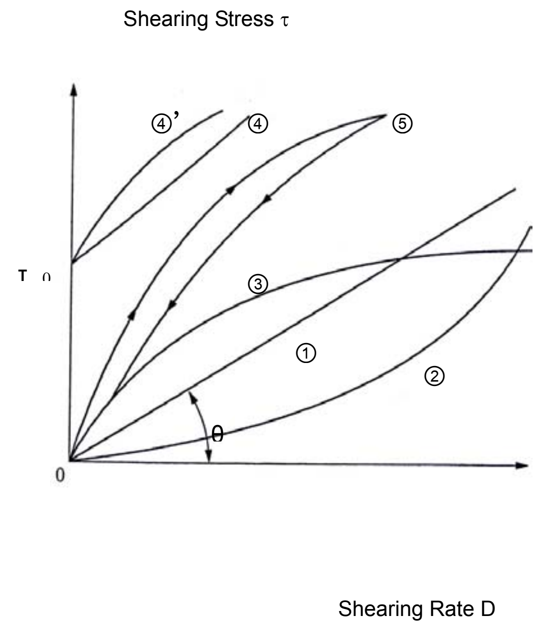


Figure 3. Newtonian Fluid and Non-Newtonian Fluid (Yutaka Matsuyama, Jitsuyo Kogyo Bunseki, 61, The Energy Conservation Center, 2001)

Straight line ④ and curved line ④' show what is called the **plastic fluid,** which will not flow until the quantity of the shearing rate becomes equal to or over shearing stress τ_0 (yield stress) of specific criticality after increased from zero. After reaching the yield stress, if the relationship between τ and D shows a straight line as line ④, it is called the **Bingham fluid**. If it shows a non-straight line as curved line ④'', it is called the **non-Bingham fluid**.

Curved line ⑤ shows what is called **thixotropy**. Hysteresis occurs during the increasing and decreasing processes of the shearing rate. This shows when a liquid at rest becomes a sol state (colloidal solution) at flow, and then returns to a gel again at rest.

Table 1 below shows typical examples of each type of fluid:

Type of fluid	Typical example
①Newtonian fluid	Water, sugar solution, salt solution, alcohol, solvent, glycerin, silicon oil, oil-based (water-based) cosmetics, mercury
②Dilatant fluid	Starch solution, moist sand (quick sand), suspension (high concentration), clay slurry, paint, chocolate (buttermilk)
③Pseudo plastic fluid	Colloidal solution, polymer solution, emulsion, lacquer varnish, paint/dye, mayonnaise, sauces, juice, evaporated milk
④Plastic fluid (Bingham fluid)	Margarine, tomato ketchup, egg white (foam), toothpaste, cream (cosmetics), various slurries (cloudy liquid with solid particle)
(Non-Bingham fluid)	Print ink, paint, coating, mayonnaise, refined flour of alimentary yam paste , asphalt, blood
⑤Thixotropy	Solder paste, grease, print ink, clay suspension, tomato ketchup, cocoa, cream (cosmetics)

3. Units of Viscosity

According to the equation (3) aforementioned, viscosity is $\eta = \tau/D$. This is represented by SI units based on MKS system of units as follows:

(i) Shearing stress τ is a force per unit area. The unit of force is newton (N). Then the unit of τ is N/m^2 and this is represented by pascal [Pa] that is the unit of stress (pressure).

(ii) Shearing rate D is defined as dV/dy by the equation (1), and is represented by the unit [s^{-1}], which was given by dividing the unit [m/s] of speed V by the unit [m] of distance y. Therefore, according to (i) and (ii), the unit of viscosity η is [Pa]/ [s^{-1}]=[Pa·s]. [Pa·s] reads “Pascal·second”.

(SI unit system) **Unit of viscosity η is [Pa·s]** (5)

On the other hand, according to CGS system of units, the unit of force is dyne, and the unit of τ is [$dyne/cm^2$]. Since the unit of shearing rate D is [s^{-1}] above, the unit of viscosity η is represented by [$dyne/cm^2$]/ [s^{-1}]= [$dyne\cdot s/cm^2$], which is called poise [P].

(CGS unit system) **Unit of viscosity η is [P]** (6)

The relationship (conversion) between SI and CGS units of viscosity η is represented by the equation 1[Pa·s] = 10 [P] because 1 newton is 1×10^5 dyne, and $1m^2$ is $1\times10^4 cm^2$. Therefore,

1[m Pa·s]=1[cP] (7)

[m Pa·s] and [cP] read “mili-pascal-second” and “centi-poise” respectively.

The result given by dividing viscosity η by density$\rho$of the liquid is called **kinematic viscosity**, or **kinetic viscosity**, or **dynamic viscosity**.

Where a symbol v stands for the kinetic viscosity;

Kinetic viscosity $v=\eta/\rho$ (8)

SI unit of kinetic viscosity is represented by $[m^2/s]$, which was given by dividing the equation (5) by the unit of density $[kg/m^3]$. $[m^2/s]$ reads "square-meter-per-second".
On the other hand, with CGS unit, it is represented by $[cm^2/s]$, and this unit is called stokes [St].
Therefore, the units of kinetic viscosity are as follows:

SI unit: $\mathbf{[m^2/s]}$ (9)
CGS unit: $\mathbf{[cm^2/s]=[St]}$ (10)

Relationship (conversion): $\mathbf{1\times10^{-4}[\ m^2/s\ ] = 1[\ cm^2/s\ ] = 1[\ St\ ]}$ (11)

Or; $\mathbf{1\times10^{-6}\ [\ m^2/s\ ] = 1\ [\ mm^2/s\ ] = 1\times10^{-2}\ [\ St\ ] = 1\ [\ cSt\ ]}$

(12)
[cSt] reads centi stokes.

Briefly Explained – Viscosity
As shown in Figure 4, where stress τ exerted on board B (inside) of unit area 1 cm^2 is 1$[dyne/cm^2]$ when the distance between board A and board B is 1cm and it is filled with liquid, and only board B is being moved parallel at speed of 1cm/second (shearing rate D = 1$[s^{-1}]$), according to the equation (3) $\eta = \tau / D$, viscosity η of this liquid is given as 1 poise [P], or according to the equation (7), as 0.1 pascal second [Pa·s].

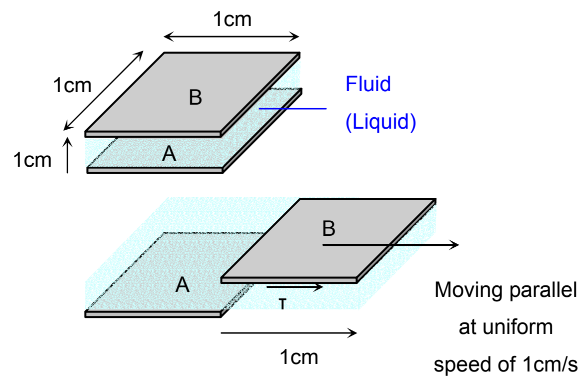


Figure 4. Geometric Definition of Viscosity

1. Vibro Viscometer

Measuring viscosity coefficient is useful for evaluating viscidity. Several types of viscometer have been developed for research and development, or various industries. Viscometers are classified into the following types by the measurement principle. As of today, viscometers 2) to 4) below are standardized as the JIS viscosity measurement method.

1) Vibro viscometer: Measures viscosity by controlling the amplitude of the sensor plates immersed in a sample and measuring the electric current to drive the sensor plates.

2) Rotational viscometer: Measures viscosity by measuring the running torque of the cylindrical rotors immersed in a sample.

3) Capillary viscometer: Obtains viscosity by letting a sample flow inside the capillary and measuring the difference in pressures between the both ends of the capillary.

4) Falling-ball viscometer: Obtains viscosity by measuring the time of a cylindrical or spherical object falling through a sample over a specific distance.

5) Cup-type viscometer: Obtains viscosity by measuring the time of a sample filled in the container flowing out of the orifice.

As shown in Figure 5, we immerse the thin sensor plates into a sample. When the spring plates are vibrated with a uniform frequency, the amplitude varies in response to the quantity of the frictional force produced by the viscidity between the sensor plates and the sample. The vibro viscometer controls the driving electric current to vibrate the spring plates in order to make uniform amplitude.

Since the frictional force of viscidity is directly proportional to the viscosity, the driving electric current (driving power) for vibrating the spring plates with a constant frequency to make uniform amplitude is also directly proportional to the viscosity of each sample.

The vibro viscometer measures the driving electric current to vibrate the sensor plates with a uniform frequency and amplitude, and then the viscosity is given by the positive correlation between the driving electric current and the viscosity.

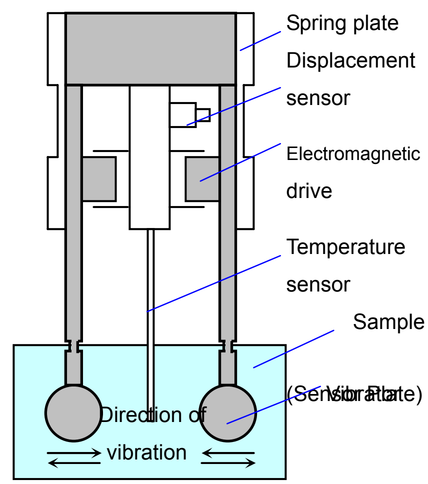


Figure 5. Vibro Viscometer (Detection System)

A&D's vibro viscometer SV Series is designed for sensitive measurement of viscosity providing a wide dynamic range and high resolution by vibrating with a frequency of about 30 Hz equivalent to the eigenfrequency (resonance) of the detection system.
As a result, SV-10 materializes the dynamic range as wide as from 0.3 mPa·s to 10,000 mPa·s, and is capable of continuously measuring in this measurement range with repeatability (accuracy) and stability. This wide dynamic range enables to measure viscosity changes in processes of thixotropy liquid during turning into gel from sol (colloidal solution), or in processes of curing of resin, adhesive or paint, which can not be continuously measured with a conventional rotational viscometer.

2. Rotational Viscometer

As shown in Figure 6, we insert a cylindrical rotor in a sample and rotate it with a motor at a constant speed. The rotational viscometer employs the measurement method applying the fact that viscosity is directly proportional to a running torque required to make steady rotating motion. As shown in Figure 6, when the rotation has become steady, the running torques caused by the viscosity and the twist of the spring will be balanced, the twist angle of the spring will be proportional to the viscosity of a sample, and an index of this will be displayed on the scale. Some devices display the digital value of viscosity coefficient converted from running torque.

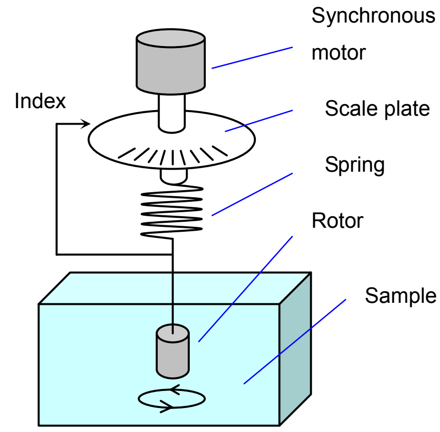


Figure 6. Principle of Rotational Viscometer

The one such as shown in Figure 6 is called the **single cylindrical rotational viscometer** whose method is the simplest. There is another method called the **coaxial double cylindrical viscometer**, which has outer and inner cylinders with a central axis. This measures viscosity by filling between the both cylinders with a sample fluid and rotating either of them to make a laminar flow.

There is also another called the **torque type viscometer**, which measures viscosity by controlling uniform running torque.

The rotational viscometer is, in principle, a fine measurement method. However, it requires a several kinds of rotors in order to cover a wide range of measurement. The measurement range of a single rotor is narrow, and, as a result, the continuity of a measurement will be disturbed and lost when exchanging rotors.

In addition, the measurement accuracy is guaranteed only for the full scale, and then errors in measurement are inevitable in the lower viscosity range.

In worse cases, accurate viscosity may not be obtained because viscosity varies accompanied by the gradually rising temperature of a sample after starting the measurement in both lower and higher viscosity ranges. This happens because, in lower viscosity range, a larger rotor is required to detect torque more than a certain level, and, in higher viscosity range, a great quantity of kinetic energy caused by a great frictional force exerts on the rotor.

3. Capillary Viscometer

When the laminar flow of liquid flows through a cylindrical capillary tube, as shown in Figure 7, where symbol Q stands for the volume of flow per unit time (flow rate), 2r for the diameter, L for the length of the capillary tube, P_1 and P_2 for the pressures at the both ends of the capillary tube, and the pressure differential P_1 - P_2 is

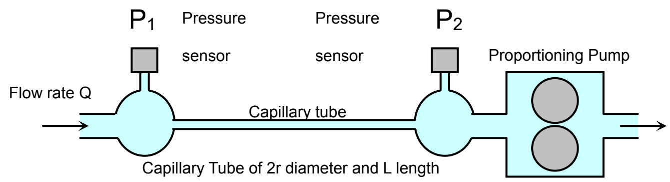


Figure 7. Principle of Capillary Viscometer

ΔP, the flow rate Q is directly proportional to the pressure gradient ΔP/L. This phenomenon is called **Poiseuille's law** and written by the equation (13).
From the equation (13), viscosityηis given by the equation (14) as follows:
Therefore, with a capillary viscometer that has a structure shown in Figure 7, the viscosityηcan be

$$Q = \frac{\pi r^4}{8\eta} \frac{\Delta P}{L} \qquad (13)$$

obtained by measuring the flow rate Q of the fluid flowing through the capillary tube and the pressure differential ΔP between the both ends of the capillary tube. This measurement method is based on the

$$\eta = \frac{\pi r^4}{8L} \frac{\Delta P}{Q} \qquad (14)$$

laws of physics; therefore, the viscosity according to the definition of viscosity can be obtained. This is called the absolute measurement method of viscosity.

There is another type of capillary viscometer made of glass as shown in Figure 8.

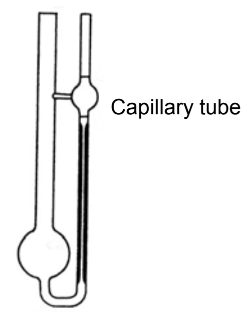


Figure 8. Capillary Viscometer (Free-fall)

Although processing of this capillary tube is not easy, it has rather simple principles and a structure. Due to the simplicity of the principles, it has been used since early times and greatly improved. This capillary viscometer can obtain kinetic viscosity vby measuring time t taking a certain amount of sample to flow by free-fall through the capillary tube.

Each viscometer is given the viscosity constant C, which was valued by calibrating with Viscosity Standard Fluid.
The measurement of kinetic viscosity with this capillary viscometer is presented by the equation (15) below;

$$v = C\ t \qquad (15)$$

The correlation between kinetic viscosity and viscosity is presented by the equation (8) above, so viscosity η is presented by the equation (16) measuring density ρ of a sample;

$$\eta = \rho\ v = \rho\ C\ t \qquad (16)$$

The principles and the structure of the capillary viscometer is simple, however, you need to pay a lot of attention to the measuring operation, which requires quite troublesome processes, in order to make accurate measurement. For instance, cleaning of the inside of the capillary viscometer needs special care for the capillary tube; before measurement you need to do a couple of ultrasonic cleansing using a cleaning liquid such as benzene and then dry, followed by another ultrasonic cleansing now with acetone and then dry, and finally rinse out using purified water and then dry. Temperature control is also essential because glass is susceptible to thermal expansion/contraction under the influence of temperature, especially in lower viscosity range, and it may bring grave errors to the measurement. In this way, the measurement requires a lot of care and troublesome processes to make. Besides that, you must measure the density of the measuring sample beforehand because the viscosity will be given by calculating from the measured result acquired as kinetic viscosity.

4. Falling-ball Viscometer

As shown in Figure 9, the falling-ball viscometer measures viscosity by dropping by free fall a column- or sphere-shaped rigid body, whose dimensions and density are known, into a sample, and measuring time taken for it to fall a specific distance. Figure 9 illustrates its principle for the viscosity measurement under the law of free-fall of a rigid body in the gravity field. There is another type of device, which measures traveling time when horizontally transporting a rigid body, such as a piston, in a sample fluid at a constant speed by the force applied by the electromagnetic field.

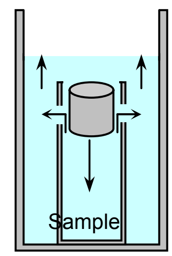


Figure 9. Principle of Falling-ball Viscometer

Unlike the vibro viscometer or the rotational viscometer, the capillary viscometer or the falling-ball viscometer shown in Figures 8 and 9 cannot continuously measure viscosity. It is also impossible to continuously output digital signals of viscosity coefficient or to control data.

5. Cup Type Viscometer

When measuring the viscosity of paint or ink, sometimes the cup type viscometer as shown in Figure 10 may be used. The same method is also employed for adjusting viscosity of coating applied to the exterior of automobile using an electrostatic atomization machine.

As shown in the figure, the cup type viscometer measures time taking a sample fluid, such as paint or ink, filled in a cup of a specific capacity to outflow from the orifice of the cup.

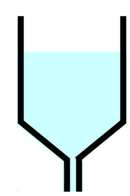


Figure 10. Cup-type Viscometer

The Ford Cup Viscometer is a typical cup type viscometer and Cup No. 3 for relatively lower viscosity and Cup No. 4 for relatively higher viscosity are often used.

Normally, you will measure time taking the sample to outflow from the orifice using a stopwatch. On the other hand, there is the digital Ford Cup Viscometer, which detects the outflow of the sample with the optical sensor, automatically calculates time necessary to finish continuous outflow, and digitally indicates it by 0.01 second.

As well as capillary viscometer and falling-ball viscometer, the cup type viscometer is not suited for a continuous measurement of viscosity because data as electric signal is difficult to obtain in the measurement.

B． Viscosity Standard

1． Viscosity Standard

We know the viscosity of distilled water measured precisely; the viscosity of distilled water is 1.002 mPa•s (kinetic viscosity 1.0038 mm^2/s) at 20.00 ℃ at 1 atm, and this is the primary viscosity standard in Japan.
There are Viscosity Standard Fluids for calibration of viscometer, which are standardized by Japanese Industrial Standard, JIS Z8809, as shown in the following.

2. Viscosity Standard Fluid

As shown in Table 2, based on the coefficient of kinetic viscosity at 20 ℃ as the reference value, the Japanese Industrial Standard, JIS Z8809, standardizes thirteen types of Viscosity Standard Fluids. Please note that local suppliers may supply Viscosity Standard Fluids for each country.

Table 2. Viscosity Standard Fluid in Japan

Type	Kinetic Viscosity [mm^2/s]				Viscosity [mPa•s]			
	Ref.	Approximate Value			Approximate Value			
	20°C	25°C	30°C	40°C	20°C	25°C	30°C	40°C
JS 2.5	2.5	-	2.1	1.8	2	-	1.6	1.4
JS 5	5	-	3.9	3.2	4.1	-	3.2	2.5
JS 10	10	-	7.4	5.7	8.4	-	6.1	4.6
JS 20	20	-	14	10	17	-	11	8.2
JS 50	50	-	32	21	43	-	27	18
JS 100	100	-	59	38	86	-	51	32
JS 200	200	-	110	66	170	-	95	56
JS 500	500	-	260	150	440	-	230	130
JS 1000	1000	-	500	270	890	-	430	230
JS 2000	2000	-	940	480	1800	-	820	420
JS 14000	14000	-	5500	2400	12000	-	4800	2100
JS 52000	52000	-	20000	8500	46000	-	18000	7500
JS 160000	160000	100000	-	-	140000	90000	-	-

These Viscosity Standard Fluids have traceability to the national standard. Some of them are registered with COMAR, the database for certified reference materials, which is associated with the international standards. Those are easy to come by here in Japan; Nippon Grease Co., Ltd., one of the major vendors of Viscosity Standard Fluids, supplies Viscometer Standard Fluids with traceability to the national standard, which are calibrated by the National Institute of Advanced Industrial Science and Technology.
We need to be careful about handling of Viscosity Standard Fluid. As shown in Table 2, viscosity depends greatly on temperature. If the temperature has changed 1 ℃, the viscosity will change about 2%-7%. Therefore, when calibrating a viscometer, we need to precisely control the temperature. There are the other handling cautions given by JIS Z8809 as follows;

(1) Seal the container of Viscosity Standard Fluid and keep it at room temperature avoiding heat and light.
(2) Never put back used Viscosity Standard Fluid into the original container.
(3) Avoid reusing used Viscosity Standard Fluid. It is desirable to use it up as soon as possible once opened.

3. Viscosity of Water

Water (distilled water) is a substance easy to come by or handle, and also internationally recognized as standard. Water can be used as a convenient standard fluid in lower viscosity. When using water as a standard fluid, we need to purify the water to include no impurity in it, and generally use purified water or distilled water. Purified water is also used when we do a couple of conjugating cleanings after thoroughly cleansing the inside of the sample container using cleaning agent to remove any impurity remaining in it. Before measuring, we need to clean the sensor unit to be immersed into a sample in case there is any residue on them.

As shown in Table 3 and Figure 11, the viscosity of water greatly varies in response to temperature changes. It holds true to every liquid and gas; in case of water, the viscosity of 1.002 mPa•s will change to 1.792 mPa•s at 0℃, or to 0.282 mPa•s at 100℃. It produces a difference of 2% – 3% in viscosity when the temperature changes 1℃. Even if we carefully manage to keep the temperature of the sample (water) within ±1℃, in the end error of ±5% in the measured value may be brought about due to complex of error factors such as water's properties, operator's operational mistake, or viscometer's congenital error.

Table 3. Viscosity and Kinetic Viscosity (1 atm)

Temp. t (℃)	Visco. η (mPa•s)	Kine. Visco. v(mm^2/s)	Temp. t (℃)	Visco. η (mPa•s)	Kine. Visco. v(mm^2/s)
0	1.792	1.792	40	0.653	0.658
5	1.520	1.520	50	0.548	0.554
10	1.307	1.307	60	0.467	0.475
15	1.138	1.139	70	0.404	0.413
20	1.002	1.0038	80	0.355	0.365
25	0.890	0.893	90	0.315	0.326
30	0.797	0.801	100	0.282	0.295

JIS Z8803

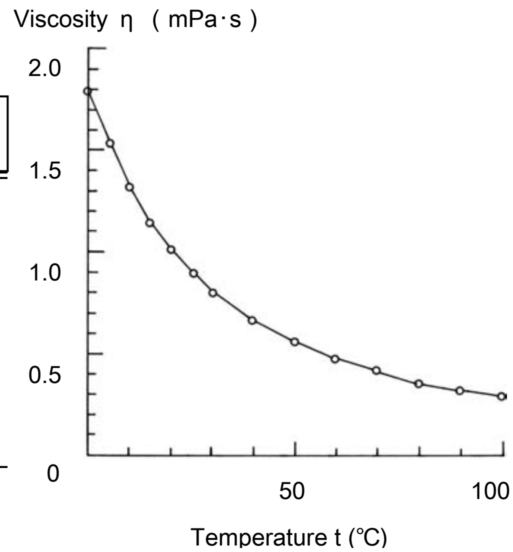


Figure 11. Correlation between Viscosity and Temperature of Water (1 atm)

C. Calibration

No.	Question	Answer
1	Can a user do viscosity coefficient calibration?	Yes. Users can calibrate SV Series using Viscosity Standard Fluids (aforementioned) or a liquid whose viscosity is under your control. When calibrating your viscometer, since the viscosity of Viscosity Standard Fluid depends on the temperature, before inputting a calibration value, you need to make a temperature correction of the viscosity coefficient of the standard fluid in response to the temperature displayed while measuring a sample. As to Viscosity Standard Fluids, temperature correction values are listed on Certificate or Certificate of Measurement. If they were not attached, please ask the manufacturer of Viscosity Standard Fluid. *Vibro Viscometer SV-10 requires no exchange of sensor plates for the viscosity range as wide as from 0.3 mPa• s to 10,000 mPa• s. For calibration, just prepare several kinds of Viscosity Standard Fluids so that you can do it by yourself. This will save you more time and money for calibration/control of viscosity, comparing to rotational viscometer. * Viscosity Standard Fluid standardized by JIS is composed of hydrocarbon mineral oil, which is susceptible to temperature changes or other environmental factors. You are recommended to use a chemical-synthesized Viscosity Standard Fluid, such as silicon oil, which is more stable in environmental changes.
2	Which is adopted for viscosity calibration, one-point calibration or two-point calibration?	Both one-point and two-point calibrations are available for A&D's vibro viscometer SV series. You can choose either of the one-point input (span correction) or the two-point input (zero/span corrections) of calibration values. We recommend the two-point calibration if measuring range is wide.
3	Are Traceability System Diagram and Certificate available?	Yes. Traceability System Diagram and Certificate on viscosity and temperature can be issued. SV Series on delivery is all calibrated for viscosity with Viscosity Standard Fluid. On issuance of Certificate, inspections using JS 2.5 and JS 1000 Viscosity Standard Fluids standardized by JIS will be given. Temperature inspection is given at a fixed temperature around room temperature. Please ask for Certificate on the placement of order. (Issuance of Certificate will be charged.) If you need Certificate for the product after purchase, please send us the whole unit of the SV model.

D. Accuracy (Repeatability)

No.	*Question*	*Answer*
4	What is the measurement accuracy of viscometer? What does 1% repeatability mean?	It is the variation in measurement results when repeating measurements of the same sample under the same conditions. In statistics, this is called the standard deviation. For SV Series, it means when measuring the same sample under the same conditions the variation (repeatability) in measurement results (measured values) does not surpass 1% as the standard deviation. *Example of 1% standard deviation: When repeating measurement of a liquid of 100mPa• s viscosity, values between 99mPa• s and 101mPa• s will be indicated 67 times out of 100.

Briefly Explained Symbols

Table 4. Greek Characters.

A α	alpha	H η	eta	N ν	nu	T τ	tau
B β	beta	Θ θ, ϑ	theta	Ξ ξ	xi	Υ υ	upsilon
Γ γ	gamma	I ι	iota	O o	omicron	Φ φ, ϕ	phi
Δ δ	delta	K κ	keppa	Π π	pi	X χ	chi
E ε	epsilon	Λ λ	lambda	P ρ	rho	Ψ ψ	psi
Z ζ	zeta	M μ	mu	Σ σ, ς	sigma	Ω ω	omega

■ Product

A . Mechanism and Features of Sine-wave Vibro Viscometer SV

Sine-wave Vibro Viscometer SV Series has a unit to detect viscosity of a sample, which is composed of two thin sensor plates as shown in Figure 12. It drives the sensor plates to vibrate at uniform sine-wave vibration in reverse phase like a tuning fork.

The sensor plates are driven with the electromagnetic force of the same frequency as eigenfrequency (resonance), which is characteristic of each structure, in order to resonate the measuring system. This usage of resonance is the most prominent feature of this viscometer. When the detection unit vibrates, it produces sizable magnitude of reaction force on the supporting unit of the sensor plates via the spring plates. However, since each sensor plate is driven in reverse phase against each other at the same vibration frequency/amplitude in order to cancel the reaction force, it enables to obtain stable sine-wave vibration.

The electromagnetic drive unit controls the vibration of the sensor plates in a sample at uniform amplitude, utilizing the resonance of the detection unit. The driving electric current as an exciting force will be detected as the magnitude of the viscidity, which is present between the sensor plates and the sample. The viscosity coefficient is given by the correlation (Figure 13) between the driving electric current and the magnitude of viscidity (viscosity coefficient).

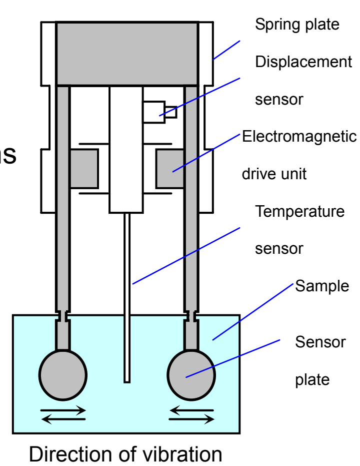


Figure 12. Viscosity Detection Unit (Vibration System)

The advantages of resonating the measuring and detection systems are as follows;

1) Resonance of the detection unit allows viscosity detection with high sensitivity in lower viscosity range and also to effectively acquire a driving force with just a small amount of electric current. Thus, it is possible to measure viscosity while maintaining wide dynamic range and high resolution.

2) The inertial force and restitutive force of the sensitive plates are cancelled by each other to be in proportion, thus the exciting force (driving electric current) is influenced only by the magnitude of viscidity (viscosity). (The parameter of viscosity alone can be extracted.)

3) The vibration system of the sensor plates is not affected by the inertial and restitutive forces, thus it is possible to measure rapid changes in viscosity of a sample while quickly tracking it.

Furthermore, since the surface areas of the detection unit and sensor plates of SV Series are small, and they are driven with much lower frequency (30Hz) comparing to that of a conventional vibro viscometer (several kHz), SV Series boasts the following features:

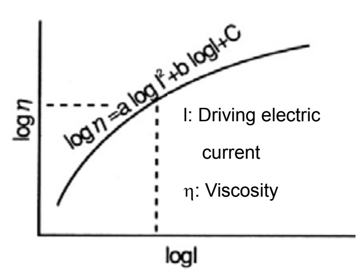


Figure 13. Correlation between Electromagnetic Drive Unit and Driving Electric Current

1. Measures viscosity in real time in response to changes in viscosity of a sample, while measuring simultaneously the temperature of the sample in real time. Thus correlation between the temperature change and the viscosity can be measured.
2. The newly developed SV method (tuning-fork type) achieves accuracy with repeatability of as high as 1% in viscosity measurement.
3. No need to exchange sensor plates during continuous measurement in the wide range of viscosity from as low as 0.3mPa•s to as high as 10,000mPa•s. (In case of the rotational viscometer, several kinds of rotors are required, and continuity of viscosity measurement is disturbed and lost when exchanging them.)
4. Since the surface area/thermal capacity of the viscosity detection unit (sensor plates) is small, the temperatures of a sample and the sensor plates will reach the thermal equilibrium in a very short time to make accurate temperature measurement. (In case of the rotational viscometer, since the surface area/thermal capacity of the rotors is large, it takes several minutes to achieve this.)
5. Continuous measurement of viscosity is possible for a long period because the small thermal capacity of the sensor plates causes relatively minor interference to temperature of a measuring sample.
6. The thin sensor plates are employed to avoid deforming a sample's structure in order to measure viscosity changes of the sample in a stable condition. Even viscosity of a non-Newtonian fluid can be measured with high repeatability by utilizing eigenfrequency (resonance).
7. A gel sample with bubbles also can be measured in a stable condition. The frequency of the sensor plates at as low as 30Hz does not break fine bubbles in a sample, and does not affect large bubbles dispersed in a sample.
8. The two sensor plates interact to make it possible to measure the viscosity of a stirring or flowing sample. (The rotational viscometer cannot measure such sample because of interferences of the rotating direction and current direction.)
9. Since a sample in flowing state can be measured, viscosity measurement on the production line is practicable by installing a bypass overflow tank. The laboratory and production line can share the identical data management.
10. Changes in properties of a sample can be continuously measured. Since it has high resolution and no inertia instability of sensor plates, changes in interfacial properties such as cloud point or wettability can be observed from changes in viscosity.
11. WinCT-Viscosity, Windows Communication Tools Software, will be equipped with SV Series. You can create real time graphs of data on viscosity and temperature as shown in Figure 14 with this software.

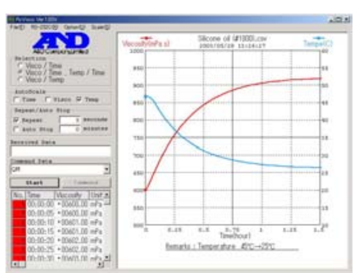


Figure 14. Real Time Display
of Measured Data
(WinCT-Viscosity)

B. Measurement Method

No.	*Question*	*Answer*
5	What method is employed for SV Series?	It's the SV method (the Sine-wave Vibro Viscometer). Please see "Product A. Mechanism and Features of Sine-wave Vibro Viscometer SV Series" for the details.
6	Why are there two pieces of sensor plates?	This is to stabilize the vibration properties of the detection unit. They are vibrated with the sine-wave frequency of 30 Hz, which is equal to the eigenfrequency (resonance) characteristic of each structure. It allows making accurate measurement by resonating the whole measurement system. A single piece of sensor plate is having a sizable reaction force produced on its supporting unit via the spring plate. In order to cancel this force, another single piece of sensor plate is vibrated in reversal phase at the same frequency/amplitude. The reaction force of the sensor plate is cancelled against each other; therefore, very stable vibration measurement system can be constructed. Please see "Product A. Mechanism and Features of Sine-wave Vibro Viscometer SV Series" for the details.
7	Is its data compatible with that of the rotational viscometer (B type)?	As to a Newtonian fluid, yes. In case of a non-Newtonian fluid, sometimes it is not compatible due to the difference in the shearing rate particular to each measurement device. If it is not compatible, obtained data of each device needs to be managed individually or the coefficient needs to be taken into account. Generally, it is effective to adopt a method, which enables to secure accurate measurement values in a short measurement time, for improvements of quality and productivity in the future.
8	If the obtained values are different from that of the rotational viscometer (B type), how should we interpret?	As to a non-Newtonian fluid, data that has compatibility with a cone plate rotational viscometer could be obtained. As to viscometer in general, it is recognized that, if the measurement method or measurement conditions were different, the measured results will be different. To compare several measurement methods, the repeatability of measured results is the key evaluation criteria. It is guaranteed that the SV-10 achieves 1% repeatability through the wide range from 0.3mPa• s to 10,000mPa• s, which a conventional viscometer has never achieved.

No.	Question	Answer
9	What magnitude of shearing rate does SV-10 have?	As to a non-Newtonian fluid, the shearing rate is not proportional to the shearing stress, and then the evaluation of viscosity cannot be made without determining the value of the shearing rate or the shearing stress. The SV-10 measures viscosity at constant shearing rate. The velocity (shearing rate) of the sensor plates keeps periodically circulating from zero to peak because sine-wave vibration is utilized. The shearing rates obtained from the driving force of the sensor plates in response to the viscosity value of a Newtonian fluid measured with Viscosity Standard Fluid are as follows;

Viscosity coefficient [mPa・ s]	Shearing rate (max.) [1/s]	Shearing rate (effective value) [1/s]
1	590	420
10	130	92
100	42	30
1000	17	12
10000	10	7

C. Measuring Viscosity

No.	Question	Answer
10	How long does it take to measure?	In 15 seconds after starting measurement, the initial viscosity coefficient will be indicated. Measured values will be displayed in real time in response to the changes in viscosity after that. With SV Series, the viscosity changes of a sample can be very quickly tracked in a stable condition by virtue of its compact measurement system; the sensor unit (sensor plates), whose surface area and the mass are small, makes only small shifts and thus reaches thermal equilibrium with the temperature of a sample in just seconds.
11	What amount of sample is necessary for a measurement?	35 ml to 45 ml. Compared to the rotational viscometer (B type), it can measure with a lesser amount.

No.	Question	Answer
12	What repeatability can it achieve?	Repeatability of 1% is achievable when repeating measurements of the same sample under the same condition. High repeatability is realized for the whole measuring range to obtain stable measured values. Moreover, since its operation is easier than other methods, it allows one who is not a specialist to repeat a number of times of measurement and obtain stable measured result each time. A sequence of changes in temperature of a heterogeneous substance such as a composite can be measured as well as changes in the properties of matter and the viscosity properties of a non-Newtonian fluid.
13	Is the measurement unit convertible to another?	1. The unit of viscosity coefficient can be switched between mPa•s/Pa•s and cP/P. 2. The unit of temperature can be switched between ℃ and °F.
14	What is the minimum display (resolution)?	See below.

• When the unit mPa•s or Pa•s is selected (set at mPa•s on delivery)

Visco. (mPa•s)	Measurement unit selected							
	mPa•s				Pa•s			
	Display	Min. unit	Unit	Remarks	Display	Min. unit	Unit	Remarks
1	0.30 ↓ 9.99	0.01			0.0003 ↓ 0.0099	0.0001		0.01 mPa•s not displayed
10	10.0 ↓ 99.9	0.1	mPa•s		0.0100 ↓ 0.0999	0.0001	Pa•s	
100	100 ↓ 999	1			0.100 ↓ 0.999	0.001		
1000 10000	1.00 ↓ 10.00	0.01	Pa•s	Switches to Pa•s	1.00 ↓ 10.00	0.01		

• When cP or P is selected;

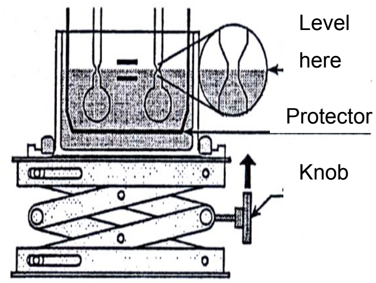
Visco. (mPa•s)	Measurement unit selected							
	cP				P			
	Display	Min. unit	Unit	Remarks	Display	Min. unit	Unit	Remarks
1	0.30 ↓ 9.99	0.01			0.0030 ↓ 0.0999	0.0001		
10	10.0 ↓ 99.9	0.1	cP		0.100 ↓ 0.999	0.001	P	
100	100 ↓ 999	1			1.00 ↓ 9.99	0.01		
1000 10000	10.0 ↓ 100.0	0.1	P	Switches to P	10.0 ↓ 100.0	0.1		

No.	*Question*	*Answer*
15	If a solvent sample is measured, the accessory sample cup will not melt?	The sample cup is made of polycarbonate, so it may be disfigured or melted with a solvent. In such case, please use a glass beaker, etc. instead that is available on the market. Please make sure to remove the protector from the sensor unit when a 100 ml beaker is used. (A 100 ml or larger beaker can be used).
16	What materials are the sensor plates, the temperature sensor, and the protector, which come in contact with a sample, made of?	Stainless steel (SUS304) is used. It will not be corroded with a normal organic solvent, or not easily corroded with an acid or basic (alkaline) solution sample either. In order to make it withstand prolonged use and prevent the occurrence of errors, cleanse (wipe off) with a counteractive solution to neutralize.
17	Is it necessary to exchange sensors or parts for each measuring range?	No. SV-10 has a measuring range as wide as from 0.3mPa•s to 10000mPa•s, so there will be no need to exchange sensors for the full range. Therefore, even a process of violent changes in viscosity, such as where a sol turns into a gel, can be continuously measured without losing sequence of data thanks to the lack of the necessity of exchanging sensors. With the rotational viscometer, it is difficult tracking the changes of properties of matter in a wide range like above, because a single rotor can only measure viscosity for a narrow range. Wide range and continuous measurement with SV Series will help develop new materials or functional materials in research field.
18	To what temperature of a sample is measurable?	The measuring range is from 0℃ to 100℃. The heat resistance temperature of the accessory sample cup (plastic) is about 120℃, and so it is usable for the measurement of a sample at 100℃ or lower.

No.	Question	Answer
19	Is the temperature change of a sample measurable simultaneously with the viscosity change?	SV Series is equipped with a temperature sensor in the detection unit (immersed in a sample) enabling simultaneous measurement of temperature of a sample during measuring viscosity. You need not prepare for a thermometer by yourself. Values of viscosity and temperature will be simultaneously indicated on the display unit of SV Series, so the temperature of a sample can be monitored in real-time during the measurement. The correlation between changes in temperature and viscosity can be tracked in real-time as well. SV Series can detect accurate temperature immediately because the temperatures of a sample and the detection unit (sensor plates) with small surface area/thermal capacity can reach the thermal equilibrium in a short time. SV Series can be connected to a PC. The accessory software "*WinCT-Viscosity*" enables you to monitor the progress of changes in viscosity and temperature in real-time during measurement with graphs and numerical values. Measured values can be saved in a file (CSV format), and then you can convert it into an Excel format and obtain data or graphs to suit your purpose.
20	How can I measure the viscosity change while changing the temperature of a sample?	1. The easiest way is to measure the cooling process of a preheated sample by leaving it in the sample cup. You can also use a heater to heat the sample cup, but please make sure that the temperature of the heater's surface does not exceed 120℃. We recommend using a beaker when it exceeds 100℃. 2. The data of viscosity/temperature can be transmitted during measurement to a PC using the standard accessory software "*WinCT-Viscosity*". As a result, obtaining viscosity/temperature data in numerical values is possible while simultaneously displaying a graph in real time. "*WinCT-Viscosity*" has a function to create a graph representing the temperature placed along the x-axis and the viscosity along the y-axis, thus temperature coefficient of viscosity can be checked visually.
21	Is it possible to measure the viscosity of a non-Newtonian fluid?	Yes. Since the thin sensor plates of the detection unit scarcely deform the structure of a sample, it is possible to make a stable measurement of a non-Newtonian fluid with high repeatability quickly responding to the change in viscosity of the sample.

No.	*Question*	*Answer*
22	Can I obtain accurate results even from a sample of low viscosity?	1. Yes. SV Series offers you stable measurement results from a sample of low viscosity. You can measure viscosity as low as 0.3 mPa•s and above with no need for exchanging sensors or installing a special adapter/accessories for low viscosity measurement. Accurate evaluation of the correlation between temperature and viscosity is also made possible by immediately measuring the temperature of a sample. Applying this feature, SV-10 is expected to offer an objective evaluation method in order to evaluate "smoothness and pleasantness to throat" of low viscosity liquid such as soft drinks, wines, sakes, beers, or sparkling liquor by representing it in numerical values that were difficult to make before. 2. In other methods, measuring viscosity in the range as low as 50 mPa•s or lower has caused many difficulties due to the interferences caused by energy in the measurement systems, the sensitivities, or measurement principles. On the other hand, SV-10 can easily measure a sample of low viscosity while tracking the temperature of the sample.
23	Is it possible to measure viscosity of a sample in flow state?	Yes. It is the greatly unique feature of Sine-wave Vibro Viscometer SV-10 to continuously measure viscosity of a flowing sample. It is possible to measure a flowing sample of viscosity in the range of 300 mPa•s or lower if it can be stirred with a stirrer. However, please note that if the surface of a sample fluid is waving in flowing motion, the surface level varies and a stable measurement cannot be made. In case of a non-Newtonian fluid, its viscosity changes as its flow state changes, so please make sure to measure at constant flowing rate. A flowing sample in production line can be continuously measured in production line by installing a bypass overflow tank in order to keep a level surface of the fluid.

No.	Question	Answer
24	How can I obtain rigorous absolute values of viscosity?	Vibro Viscometer SV Series is set (adjusted) on delivery to indicate the viscosity coefficient of a fluid assuming its density is 1. The viscosity coefficient on the display represents a product of multiplication of a viscosity and a density based on the measurement principles. In order to obtain the absolute value of viscosity, please divide the measured viscosity value of a sample by its density at that time. Example: where a sample was measured at temperature T, the absolute value will be obtained as follows; 1) Viscosity is displayed as 73.6 (mPa•s). 2) Specific gravity of the sample at temperature T is 0.856. 3) The absolute value of viscosity η_M is 73.6/0.856=85.98 (mPa•s). If the density of a sample is uncertain, please measure the density (specific gravity) of the sample beforehand with an electronic balance and density measuring kit. It can be easily obtained with A&D's analytical electric balance GR Series or general electronic balance GX/GF Series and density measuring kit. *In this case, measure the viscosity under the same temperature condition as the density (specific gravity) was measured.
25	Is it possible to measure a kinetic viscosity?	1. No. The Vibro Viscometer cannot directly measure it. You can calculate it by obtaining the absolute value η_M as in Q&A24 and dividing it once again with the density of a sample.

No.	*Question*	*Answer*
26	To what level should the surface of a sample fluid come? What's the affect on the measuring value if the level of the surface varies?	1. As you can see in the figure on the right, there is a narrowed place just above the round-shaped part of the sensor plate. Adjust to level these most narrowed places of the sensor plates with the surface of the fluid sample. If either of the right or left sensor plates cannot be leveled with the surface of the fluid, please adjust the two leveling feet at the rear of the main body in order to eliminate body tilt.  2. If the surface of a fluid changes by 1 mm, the viscosity coefficient will change about 5%. After repeating initial several measurements, one will be able to manage to level the surface of the fluid sample. In due course, error occurrence in leveling of the surface will fall below ±1%, when repeating measurements of the same sample under the same conditions. The higher the viscosity, the harder the leveling of the surface of a sample fluid becomes, due to its adhesion to the sensor plates. For viscometers in general, it is required to establish and practice operational procedures to secure repeatability in measurement of a high viscosity sample.

D. Collection and Output of Data

No.	*Question*	*Answer*
27	Is printing of measured result output available? Is it possible to collect and save measured data?	Yes. Output printing and data collection are possible. 1. Via RS-232C equipped as standard, by connecting it to the compact printer AD-8121 (optional), measured results can be printed. With the functions of AD-8121, statistical calculation of the viscosity measurement results or change in viscosity (numerical values) per length of time can be printed. Please use the accessory cable of AD-8121 for connection. 2. Connecting to a PC, the standard accessory software Windows Communication Tools "*WinCT-Viscosity*" enables to monitor the progress of changes in viscosity and temperature in real time during measurement with graphs and numerical values. The measured data can be saved in a file (CSV format) and convert it in a Excel file in order to use graphing functions to obtain data and graphs suited your purpose. * Please see "Application A. Data Analysis" for the details on the features of the software and examples of display of "*WinCT-Viscosity*".

Application

A. Data Analysis

1. Windows Communication Tools

1. Windows Communication Tools "*WinCT-Viscosity*"

Via RS232C, this software enables A&D's Sine-wave Vibro Viscometer SV Series to display the progress of measurement in real time on a PC or easily transmit the measured results (data) to save or analyze. The CD-ROM of *WinCT-Viscometer* is equipped as a standard accessory of Viscometer SV Series.

Windows Communication Tools *WinCT-Viscosity* includes three software functions as follows;
-RsVisco: Graphing software to create graphs of the measured results and the progress of viscosity measurement.
-RsCom: Data transmission/reception software
-ReKey: Data transfer software

Software	Content
• RsVisco	1. Creates the real-time graph of data received from A&D's Sine-wave Vibro Viscometer SV Series via RS-232C. Progress of change in viscosity during measurement can be monitored in a graph. Temperature data also can be simultaneously displayed, and the graph of temperature and viscosity can be monitored in real time. 2. The following three types of graphs are provided to choose from; ①Viscosity (Y axis) – Time (X axis) ②Viscosity/Temperature (Y axis) – Time (X axis) ③Viscosity (Y axis) – Temperature (X axis) 3. Graphs can be overlaid in repeating measurements. (in 10 colors) 4. Measured data can be saved in a CSV format file. 5. Displayed graph can be printed with a printer via a PC.
• RsCom	Send and receive data with a PC via RS-232C. This software is capable of controlling the Viscometer SV Series. 1) Recorded data can be saved in a text file. 2) Received data can be printed with a printer via a PC. 3) Simultaneous communication with multiple viscometers connected to ports of a PC is practicable. (Multiprocessing)
• RsKey	1. Data output from SV Series can be imported to general application software (Microsoft Excel, etc.) via RS-232C. It is useful to process data with the other application software. 2. Data output from Viscometer SV Series can be automatically input to application software as it were input with a keyboard. Transmits to spreadsheet software (Excel), word processing software (Word, memo pad), or the other various kinds of application software.

(1) Example of RsVisco Display

RsVisco is software to read the measured results (CSV file) and create a graph representing the measuring viscosity in real-time as shown in the figures below. Figures 15 and 16 show the graphs representing viscosity changes of silicon oil (Newtonian fluid) measured at room temperature while leaving it cooling down from about 45℃ to 25℃. In Figure 15, the graph shows the elapsed time plotted along the x-axis and the viscosity (left) and the temperature (right) plotted along the y-axis. In Figure 16, the same data is represented by plotting the temperature along the x-axis and the viscosity along the y-axis. The linearity of the correlation between the changes in viscosity in response to the changes in temperature is well presented.

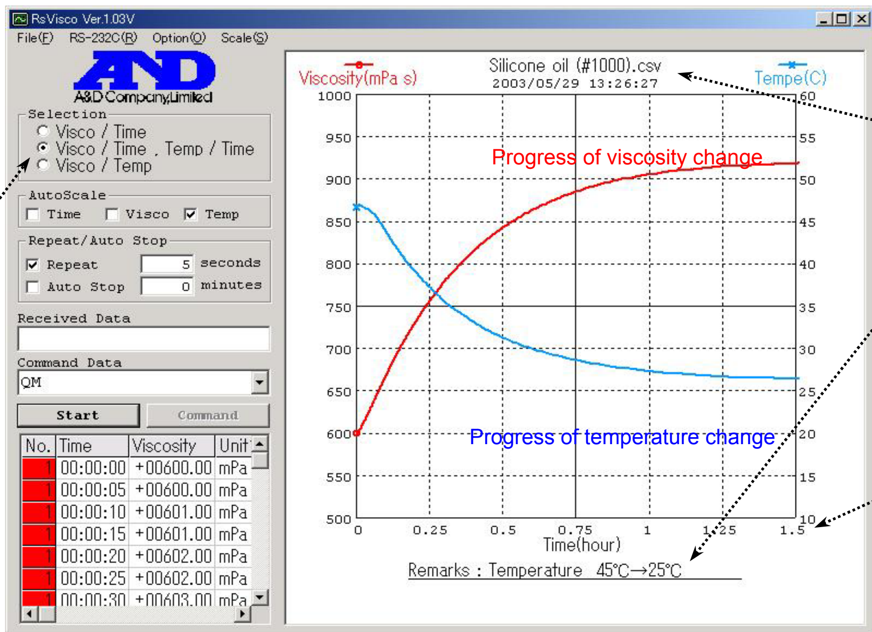


Figure 15. Example of Measurement Display of Silicon Oil

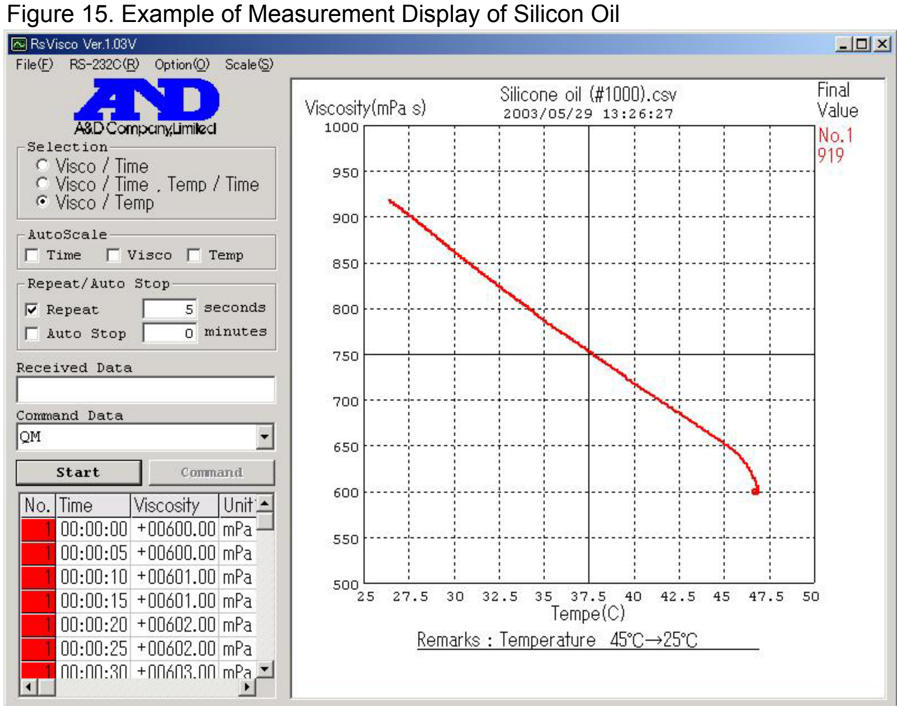


Figure 16. Correlation between Viscosity Change in Response to Temperature Change of Silicon Oil

(2) Example of Viscosity Measurement of Water-based Paint

Figure 17 shows the graph representing the measured result of a water-based varnish at room temperature under the fixed condition. This sample shows a stable viscosity despite the elapsed time.

Figure 18 represents the measured result of a water-based paint (black) at room temperature under the fixed condition.

After starting the measurement, this sample shows a tendency of gradually decreasing (thixotropy). To evaluate the viscosity of a sample as this, for instance, we will find the time when the decreasing tendency becomes slow experimentally. We can evaluate the viscosity value from the time.

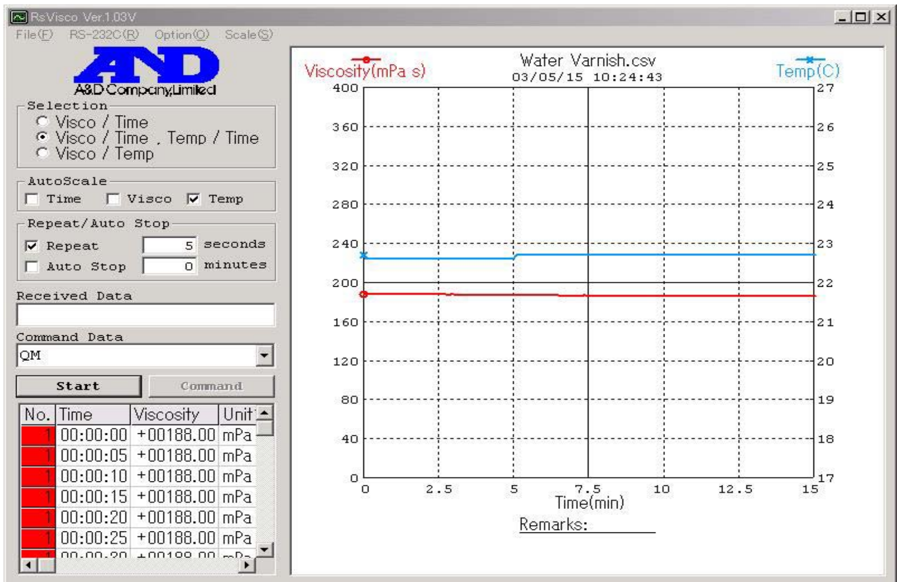


Figure 17. Example of Viscosity Measurement of Water-based Varnish

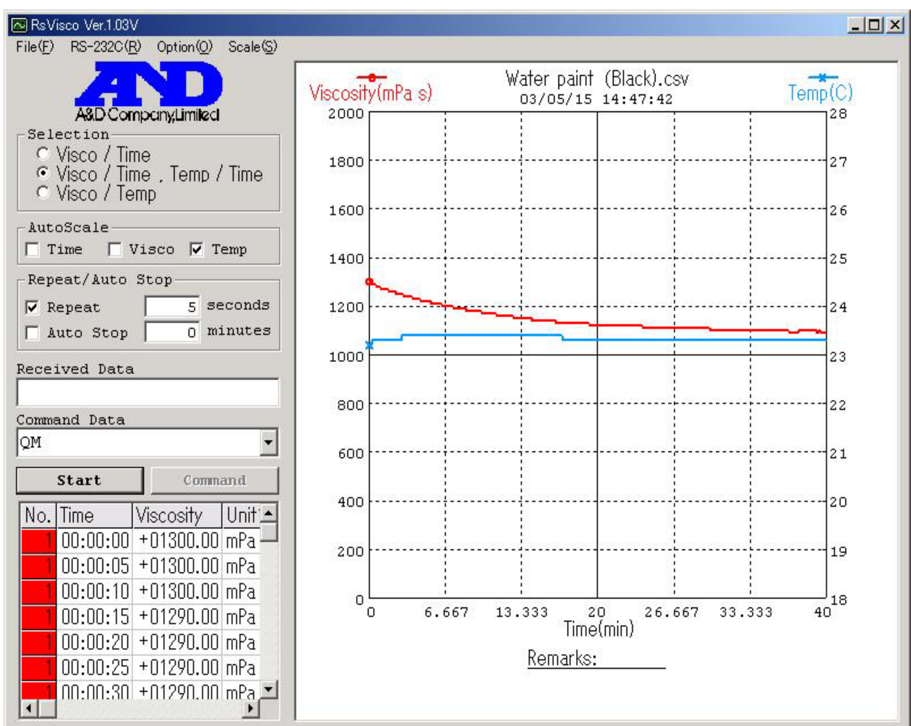


Figure 18. Example of Viscosity Measurement of Water-based Paint (Black)

(3) Viscosity Measurement of Food

Figures 19 and 20 show the graphs representing the measured results of the viscosity of egg white while heating it with a heater from room temperature to about 80℃. The behavior of egg white rapidly coagulating over 60℃ is measured well. The graphs precisely show the properties of protein (albumin), which is the main component (composition) of egg white.

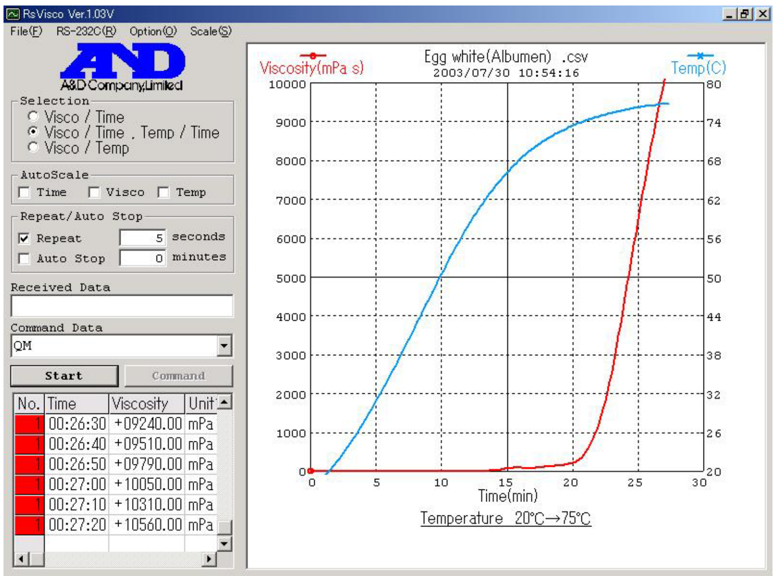


Figure 19. Example of Viscosity Measurement of Egg White

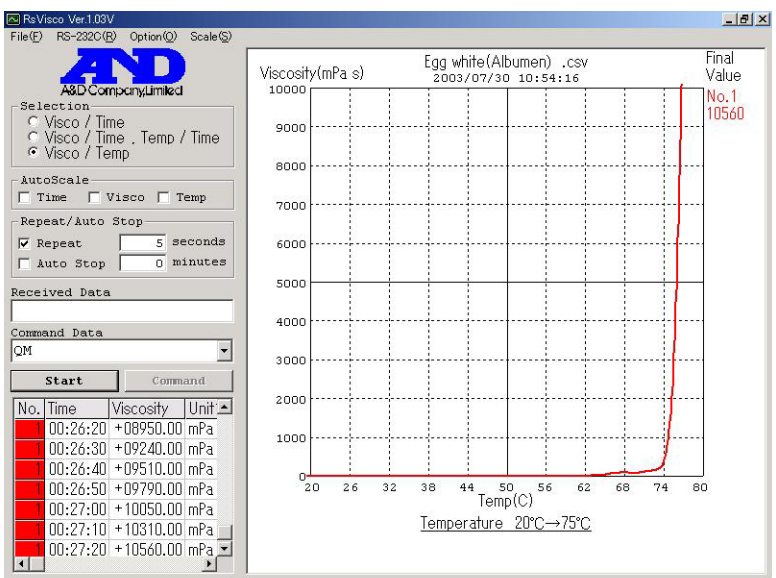


Figure 20. Increasing Process of Viscosity of Egg White with Temperature Increase

Figures 21 and 22 show the graphs representing the measured results of the viscosity of egg white, shown in Figures 19 and 20, by indicating with logarithmic scale on the y-axes (viscosity). We can observe, especially in Figure 22, that when the temperature was 60℃ or lower the viscosity of egg white decreased as the temperature increased, like a common liquid does, but once it surpassed 60℃, the viscosity increased rapidly as its protein coagulated. The vibro viscometer SV Series can capture precise dynamic changes in viscosity as well as small changes peculiar to a sample (matter).
As you can see below, *WinCT-Viscosity (RsVisco)* can indicate a logarithmic axis on the viscosity axis so as to clearly present the changes in viscosity of a wide range or of non-linearity.

Indicates a logarithmic axis as viscosity axis.

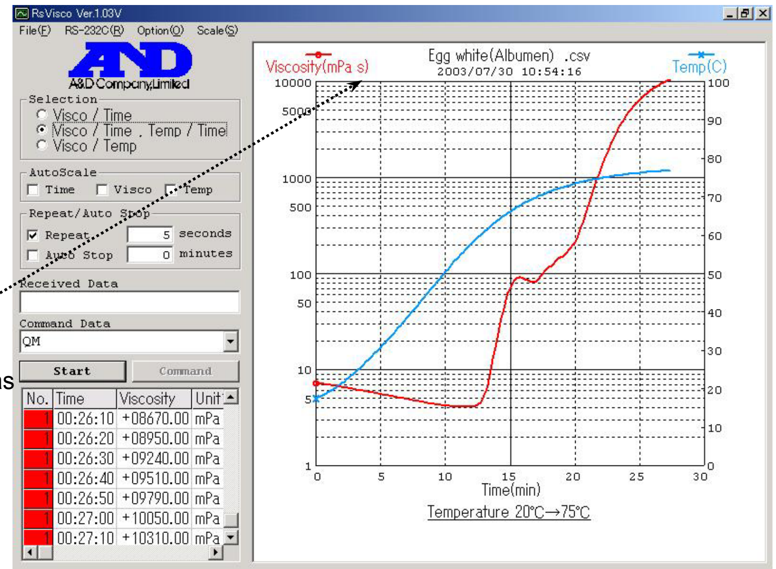


Figure 21. Example of Viscosity Measurement of Egg White (Log scale on the viscosity axis)

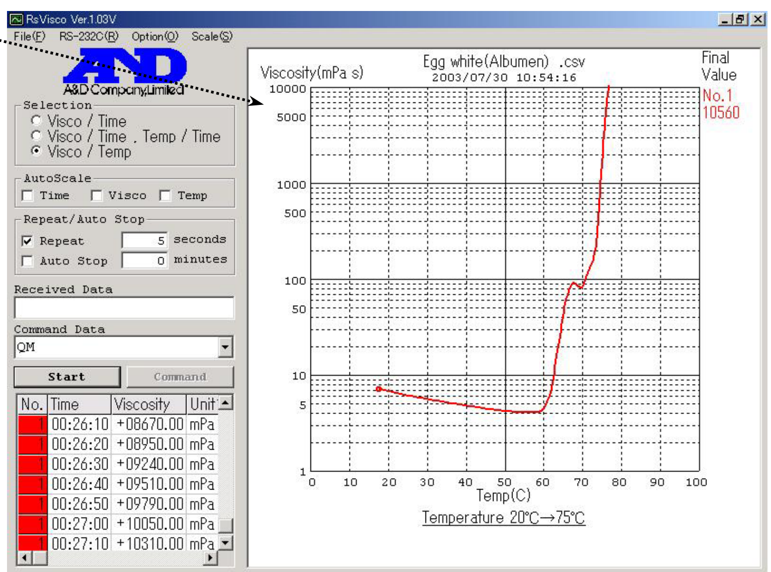
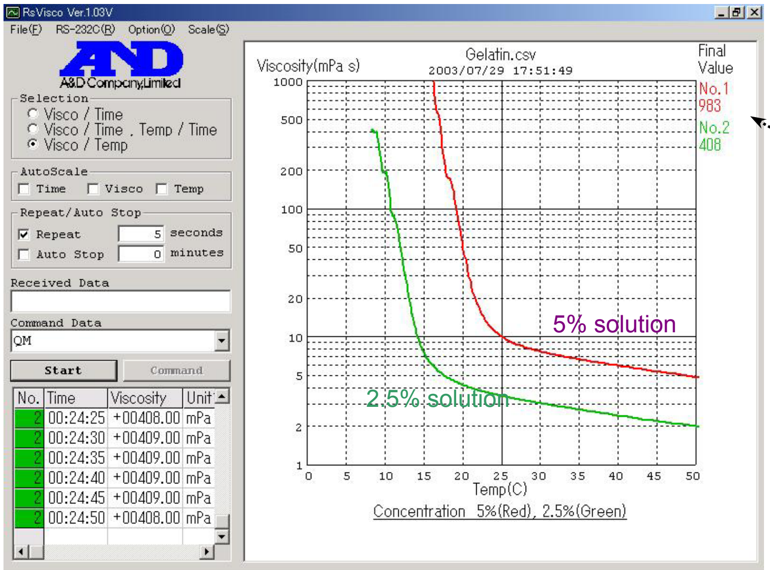


Figure 22. Progress of Viscosity Increase in Response to Temperature Increase of Egg White (Log scale on the viscosity axis)

Figure 23 shows an example of viscosity measurement of 2.5% and 5% gelatin solutions while varying the temperatures. The temperature is plotted along the x-axis and the viscosity along y-axis (log). We can observe that the coagulation point depends on the concentration of the solution.



Multiple measurements can be overlaid in a graph. (10 colors available)

Figure 23. Example of Viscosity Measurement of Gelatin of Different Concentration (Viscosity Axis Log Scale)

Figure 24 is the graph representing the measured result of custard pudding at approx. 20℃. Four samples (3 good samples and 1 failure sample) were measured. The upper three lines (red, light blue and light green) are of good samples and the lower line (purple) is of the sample, which was evaluated as a failure. As we can see, the evaluation made based on one's experience is now possible to present with values by measuring the viscosity with SV-10.

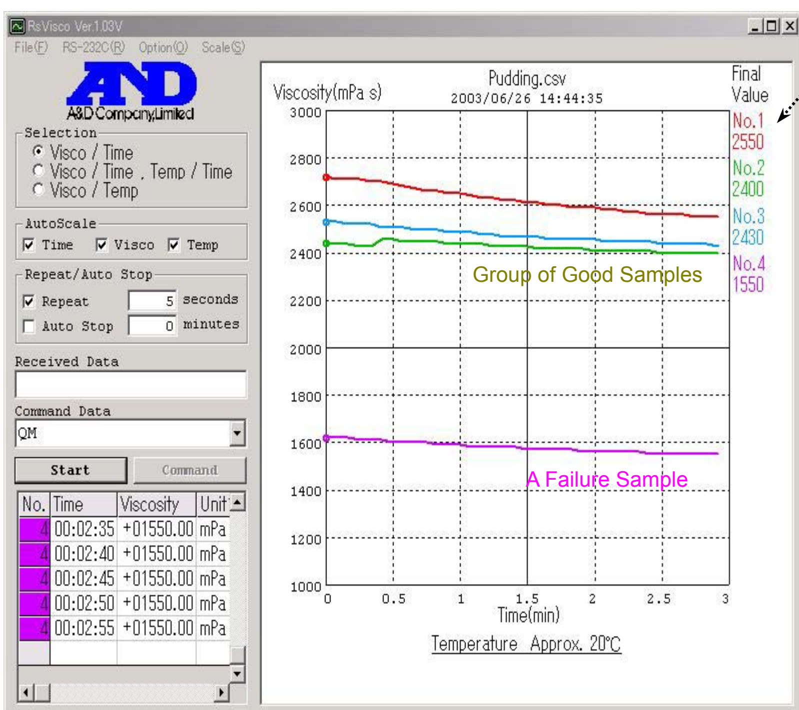


Figure 24. Example of Viscosity Measurement of Custard Pudding

Figure 25 shows the graph representing the measured result of Worcester sauce under the fixed condition (room temperature).
We can see the SV-10 measurement presents that Worcester sauce shows a stable viscosity in response to the elapsed time.

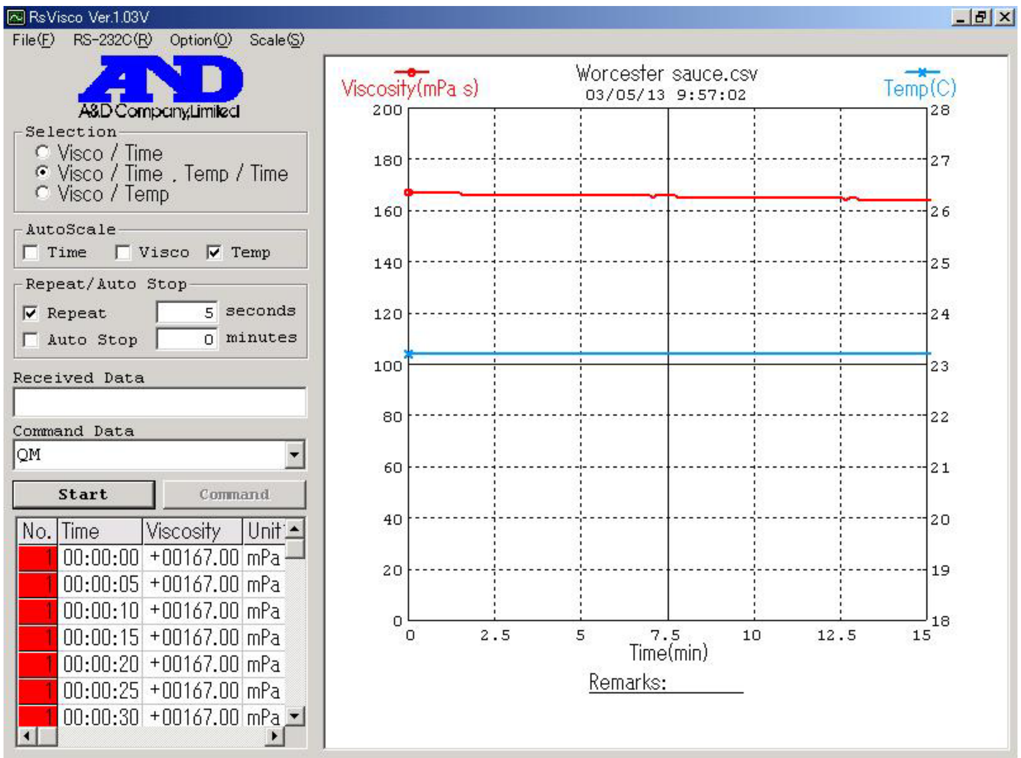


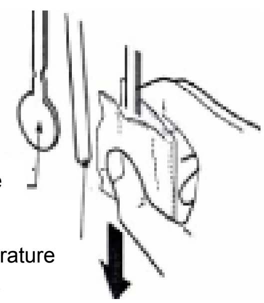
Figure 25. Example of Viscosity Measurement of Worcester Sauce

Maintenance

A. Sensor Plate

No.	*Question*	*Answer*
28	Can a user exchange the sensor plates?	No. If the sensor plate should be damaged or you cannot get rid of any residue of a congealed sample from the sensor plate, please send us the measurement unit together with the display unit for exchanging and adjustment.

B. Cleaning

No.	*Question*	*Answer*
29	How should I clean the measurement unit?	After measurement, please clean the sensor plates, temperature sensor, and protector with a cleaning agent or solvent to remove residue of a sample attached to them. Especially if it is a curing sample, clean it as soon as possible after the measurement. Clean the sample cup as well. If the cleaning agent is not volatile, wipe it off with purified water, so as not to affect on the next measurement of a sample.  How to clean: As shown in the figure above, hold the sensor plate or temperature sensor lightly with a tissue between your fingers and wipe off any attached sample with the tissue by sliding it up and down. After that, soak a tissue with a cleaning agent or solvent and then clean in the same way using the tissue. Clean with purified water if necessary. Normally, being pressed lightly between your fingers will not damage the sensor plates, temperature sensor, or protector. However, do not add any unnatural force more than necessary to them.

Specifications of the Sine-wave Vibro Viscometer SV-10

Measurement Method Tuning-fork Vibration Method

Viscosity Measurement Range 0.3 mPa･s - 10000mPa･s (cP)

Viscosity Measurement Repeatability 1%

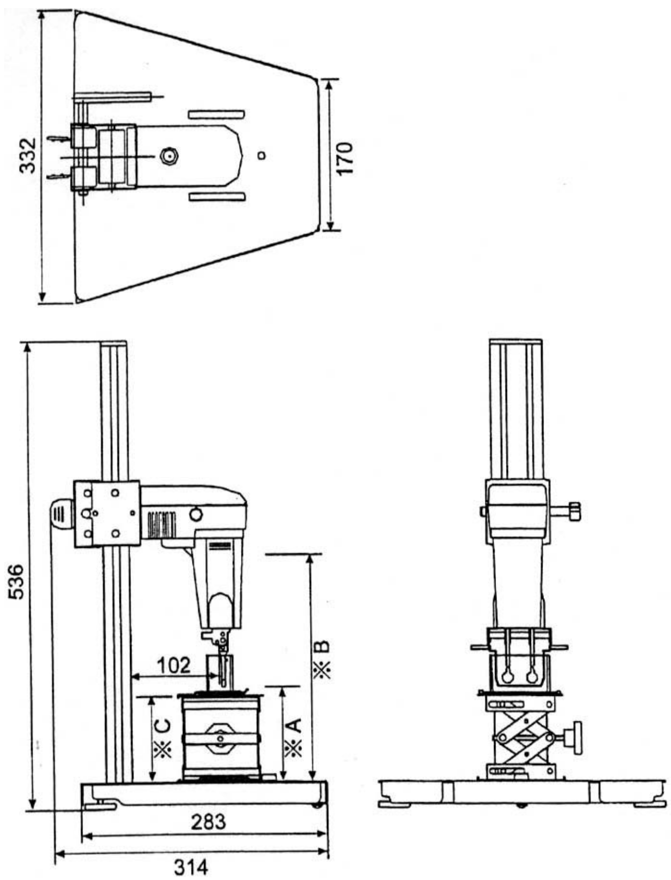
Minimum Display

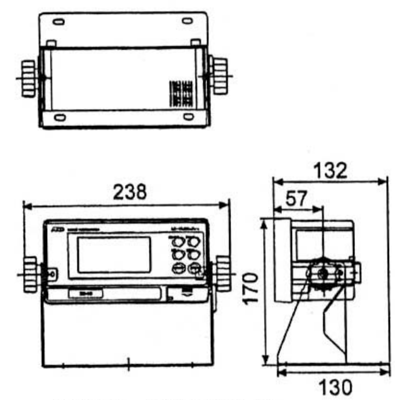
Viscosity Range (mPa･s)	Minimum Display (mPa･s)	Minimum Display (Pa･s)
0.3 ~ 10	0.01	0.0001
10 ~ 100	0.1	0.0001
100 ~ 1000	1	0.001
1000 ~ 10000	※10	0.01

*Unit is Pa•s.

Viscosity Indication Units	mPa･s, Pa･s, cP, P
Operational Temperature Range	10 ~ 40℃ (50-104°F)
Sample Quantity	35ml or more
Sample Temperature Measurement Unit	0 ~ 100℃/0.1℃ (32-212°F/0.1°F)
Temperature Measurement Error Limit	±0.5℃ (20 ~ 30℃) ±1℃ (0 ~ 20℃) ±2℃ (30 ~ 100℃)
Display Unit	Vacuum Fluorescent Display (VFD)
Length of Connection Cable	Approx. 1.5m (measurement unit – display unit)
Communication Function	RS-232C
Power Supply	AC adapter
Consumption of Electricity	Approx. 14VA (AC adapter included)
Dimension/Weight	Measurement unit 332W×314D×536H (mm) / Approx. 5.0kg Display unit 238W×132D×170H (mm) / Approx. 1.3kg
Standard Accessories	1 AC adapter Data communication tools software WinCT-Viscosity (1 CD-ROM) 4 polycarbonate sample cups 1 RS-232C cable (25P - 9P) 1 connection cable between the measurement unit and display unit (approx. 1.5m) 1 Instruction manual
Option	Compact printer AD-8121

Dimensions





(1.5m length connection cable)

*A=Lowest level of the sensor plates 3.5mm
(protector in use, table excluded)

Units: mm

*B=Highest level of the sensor plates 268mm

*C=Level of table (54 – 140mm)

MEMORANDUM

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