Article presented in “TEST” Vol.26 (January 15, 2013,
issued by Japan Testing Machinery Association

Title

Vibration Rheometer RV-10000

Sub-title

Making the shear rate of the tuning-fork vibration viscometer adjustable to develop a new rheometer for liquids

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Summary

By making the shear rate of the tuning-fork vibration viscometer adjustable, we have developed the RV-10000 vibration rheometer. Using this rheometer it is possible to analyze the nature of non-Newtonian fluids. Further, continuous viscosity measurements across the wide range of 0.3 to 10000 mPa·s is possible with this rheometer, and the user can also measure a rapid change in viscosity caused by changes to the shear rate. This paper will introduce the RV-10000 and the properties of the various non-Newtonian fluids that can be measured with it.

1.Introduction

One of the ways to measure the state of a liquid is by its viscous property, and the viscosity coefficient is used to express this. The reference substance of viscosity is water, and at a temperature of 20°C the viscosity of water (deionized) is defined as 1.002 mPa·s (millipascal second). The necessity of viscosity measurement is obvious when we see that, for example, the viscosity of engine oils for automobiles has a large influence on engine performance, or in industrial plants or along crude oil pipelines it is essential to ensure the flow of liquids by controlling their viscosity.

Recently, areas where it is necessary to evaluate the viscosity of liquids are increasing. For example, in relation to the human body, there are areas such as measuring the viscosity of blood or bile; that of soft drinks to create a more enjoyable drinking sensation; or measurements related to the treatment of dysphagia, where people lose control of their swallowing functions leading to liquids entering the lungs, which can cause pneumonia, the leading cause of death among senior citizens.

Particularly in regard to mis-swallowing, this problem quite obviously has a relation to the viscosity of consumable liquids, and in this aging society viscosity management is becoming an increasingly relevant issue, whether in the production of thickeners sold to treat this problem or controlling it directly onsite in elderly care facilities.*1

2.Background to development

A&D Company, Limited is the only instrument maker in the world with a long history of producing tuning-fork vibration viscometers. Notably, we have been selling a highly-versatile tuning-fork vibration viscometer for the last 9 years. This viscometer has the special feature of being able to measure liquids with a viscosity even below water (as low as 0.3 mPa·s) to liquids with a viscosity as high as a thick honey (around 10000 mPa·s) in quick succession over a short period.

Previously, sales of rheometers have been almost exclusively rotational types. Rotational rheometers measure the liquid's viscosity from the torque detected by the rotational axis of the device. Measurement by rotational torque is geared towards measurement of the viscoelasticity of liquids with a high range of viscosity. However, it does not have sufficient sensitivity to measure liquids with a low range of viscosity, has poor repeatability, and is hard to handle, among other problems. In order to solve these problems, we developed the RV-10000 rheometer, with the shear rate adjustable by changing the amplitude of the oscillators.

A structural diagram of the sensor section and a photograph of the exterior of the RV-10000 can be seen in Figures 1 & 2 below. Figure 1 is a diagrammatic illustration of the section for detecting viscosity. The oscillators, arranged side-by-side in order to resonate at a set amplitude, have their amplitude detected by displacement sensors. In order to keep displacement constant, the electrical current of the electromagnetic drive section is controlled. At this time, the proportional electrical current necessary to power the electromagnetic drive section is used to measure the viscosity resistance of the liquid being measured, which is represented by the [viscosity x density] of the liquid.

Figure 2 shows the RV-10000 placed on the anti-vibration table designed for the rheometer, set up with the constant-temperature circulatory liquid cistern for regulating the temperature of the sample liquid, which is placed in the attached water jacket.

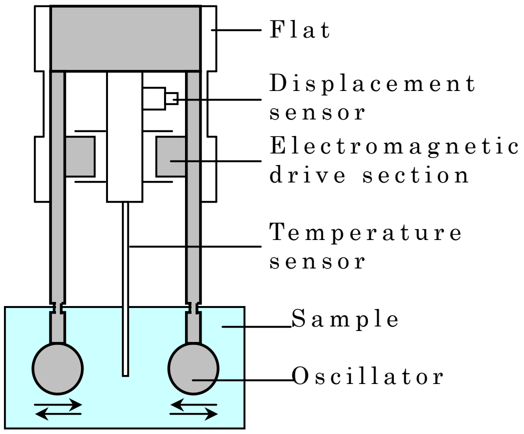

Figure 1　Structure of viscosity detection section

Figure 2　Exterior of RV-10000

3.RV-10000 specifications

The RV-10000's vibration frequency is set at its natural frequency of 30Hz and only its vibration amplitude can be adjusted. The oscillators move in a back and forth motion, so even if amplitude is set at a fixed rate, the oscillators speed would repeatedly move between zero and its top speed in a cyclical fashion. Therefore the numerical value of the shear rate is an effective (root-mean-square) value to record. Also, with a vibration viscometer, the viscous resistance calculated from the motion equation is expressed by [viscosity x density]. Further, in order to distinguish between "kinematic viscosity", found by dividing viscosity by density, and the "dynamic viscosity", we are proposing a new method of notating [viscosity x density] as "static viscosity".*2

With the standard in the field of viscosity measurement, the capillary tube viscometer, it is possible to measure the kinematic viscosity of a liquid. With this type of measurement, the measured value of kinematic viscosity is equal to the viscosity divided by the density, so it is necessary to multiply the measured value by the density in order to reveal the dynamic viscosity.

On the other hand, the vibration viscometer is designed to measure the static viscosity. With this type of measurement it is necessary to divide the measured value by the density to get the value for dynamic viscosity.*3

In Figure 3, the oscillator amplitude and the measurable range of viscosity of the RV-10000, as well as the shear rate obtained from these variables, are displayed. While it depends on the viscosity value, one can see that measurement is performed with the shear rate ranging from 5 to 1000s^{-1}. With a high viscosity value, a strong electromagnetic force is required and only a small shear rate can be measured. Even if the vibration amplitude is the same, it can be presumed that the decrease in shear rate in relation to a high viscosity is a result of the extent of the "shear stress" increasing in relation to a high viscosity, where, due to the limited size of the measurement container, the shear rate decreases in a relative manner.

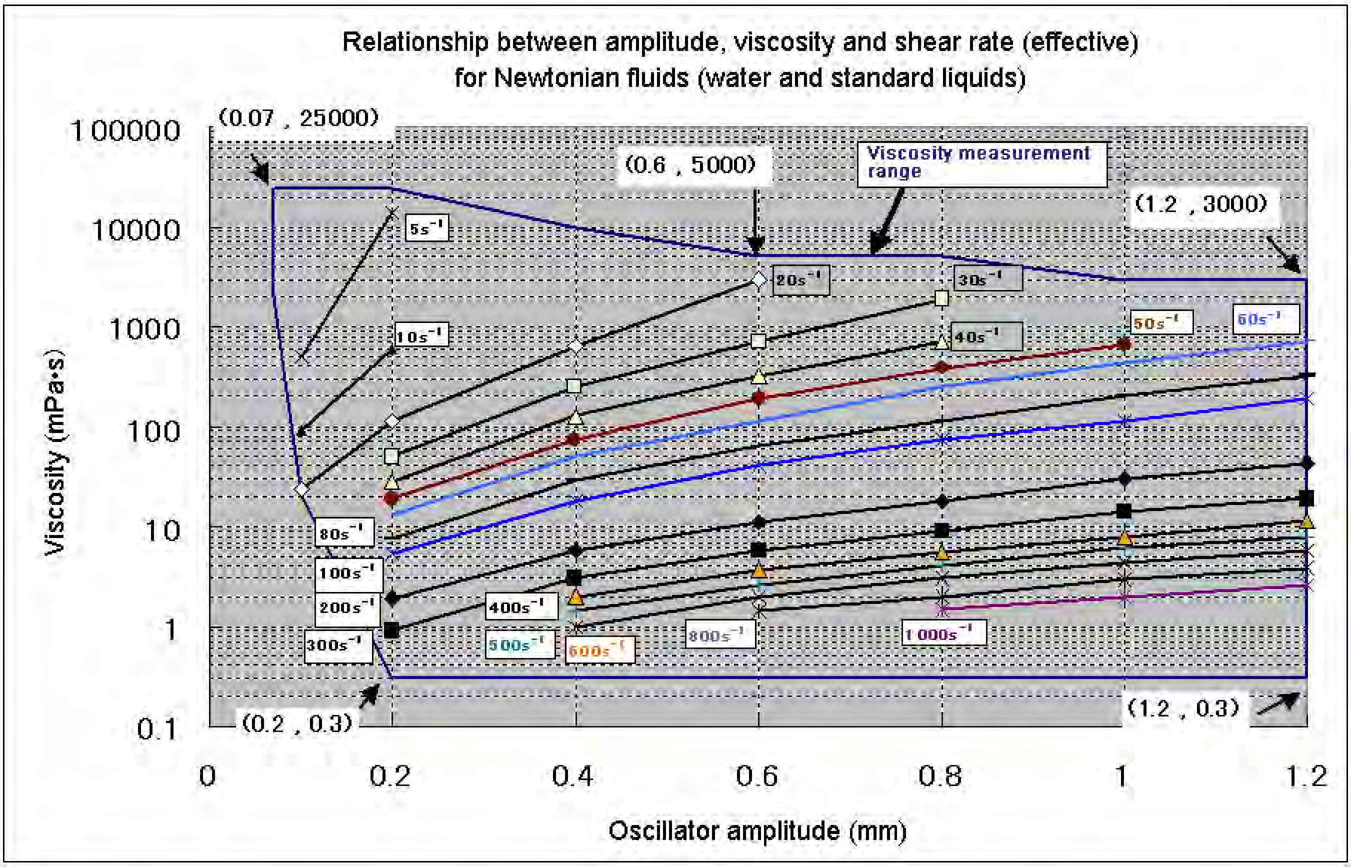

Figure 3 The relationship of vibration amplitude, viscosity and shear rate of Newtonian fluids

4.Results of measurements using the RV-10000

What follows explains results of viscosity measurements performed by varying the amplitude of the oscillators, and thereby the shear rate.

The result of measurement of water is shown in Figure 4. The horizontal axis shows the amplitude of the oscillators and the vertical axis shows the viscosity. Water is a Newtonian fluid, so in response to a change in amplitude the viscosity stays constant. Figure 5 shows the result of a mixture of 62% cornstarch and 38% water (by weight). The figure shows that from amplitudes of 0.8 mm upwards, the viscosity value rises dramatically. Further, with a slight change to the mixture ratio to 60%+40%, that sudden rise in viscosity is not apparent.

This phenomenon can be seen on the internet presently, with popular footage of people able to run over a non-Newtonian fluid, while sinking if they walk across. In scientific terms, when a strong shear rate (pressure) is applied in this case, the viscosity increases suddenly and shows behavior similar to a solid. When weak pressure is applied to it, it performs like a liquid. Liquids that behave in this manner are known as dilatant fluids.

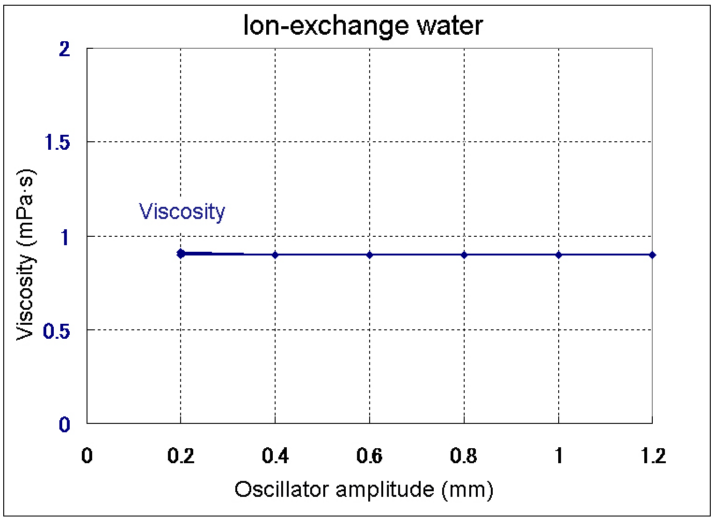

Figure 4 Ion-exchanged water: vibration amplitude and viscosity values

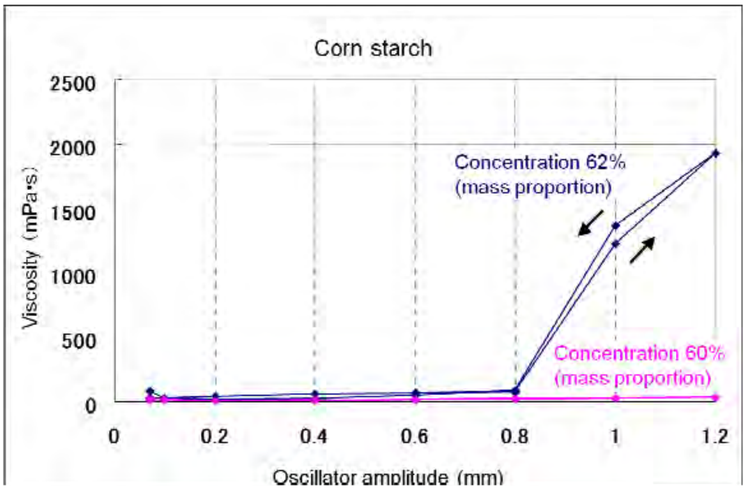

Figure 5 Cornstarch: vibration amplitude and viscosity values

The results of tests on skin moisturizing cream and tomato ketchup are shown in Figures 6 & 7. The tests demonstrate that both fluids display the characteristics of Bingham fluids, with the viscosity decreasing in response to an increase in shear rate.

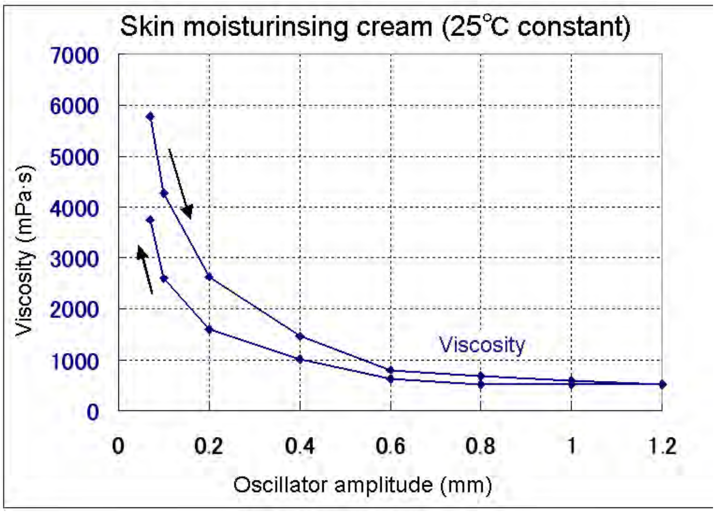

Figure 6 Moisturizing cream: vibration amplitude and viscosity values

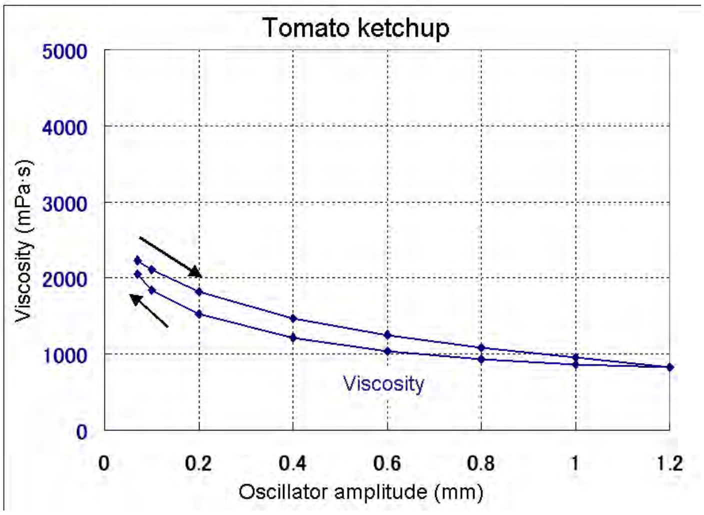

Figure 7 Tomato ketchup: Vibration amplitude and viscosity values

Thickening agents that are used in care facilities were tested and the results are displayed in Figures 8 & 9. They can be very important additives to meals to prevent pneumonia caused by mis-swallowing, but the figures show that even when the same quantity is added to water the viscosity obtained varies greatly depending on the brand. Further, as the thickening agent was added, the temperature coefficient of the viscosity was decreased to approximately 2/3 of that of the water base.

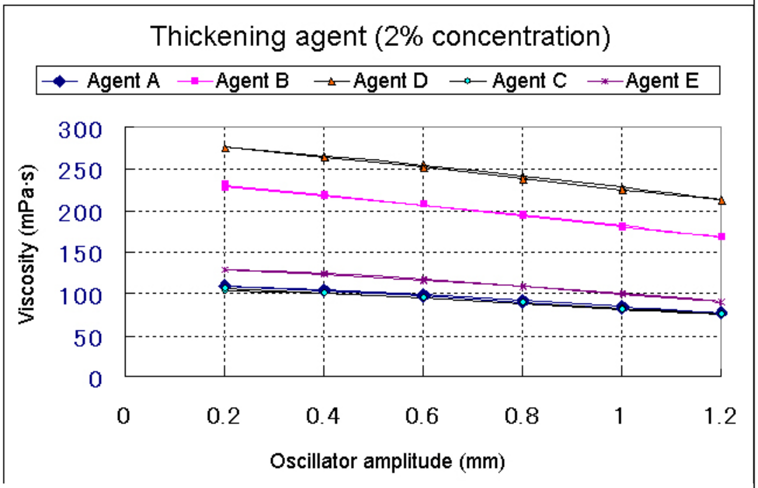

Figure 8 Thickening agent: vibration amplitude and viscosity

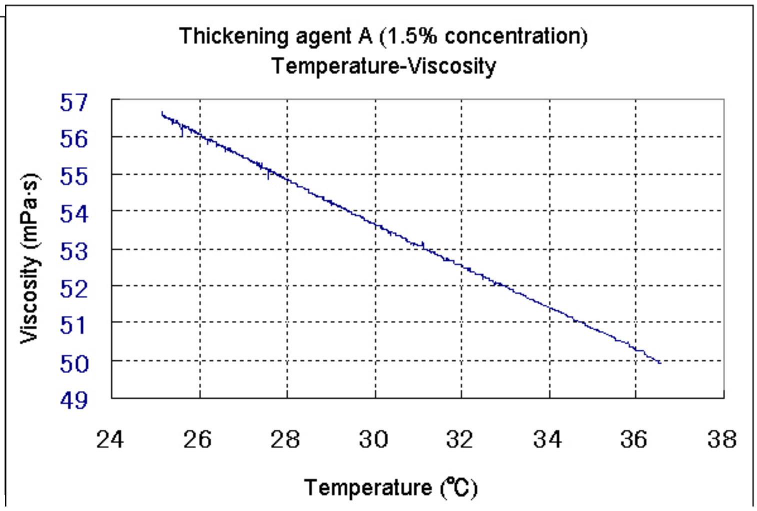

Figure 9 Thickening agent: temperature coefficient (temperature-viscosity)

Finally, the results of tests on gelatin, which can easily be structurally damaged as a food product, using differences in concentration and temperature as parameters for changes in viscosity, as well as tests on the cloud point of surface active agents, can be seen in Figures 10 & 11. A large change in viscosity is shown from just a small difference in concentration. An extreme change in physical properties can also be observed, which is identified as a change in viscosity. Also, the cloud point of the surface active agent can be detected as a turning point (35.4°C) in the viscosity, which increases with temperature until it suddenly drops at that point. We were able to record very interesting phenomena with our experiments.

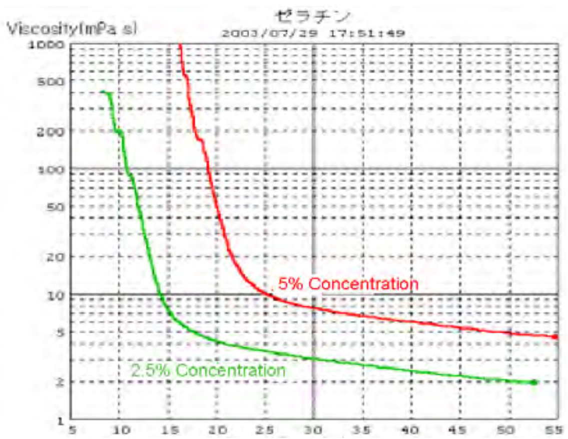

Figure 10 Gelatin: temperature - viscosity

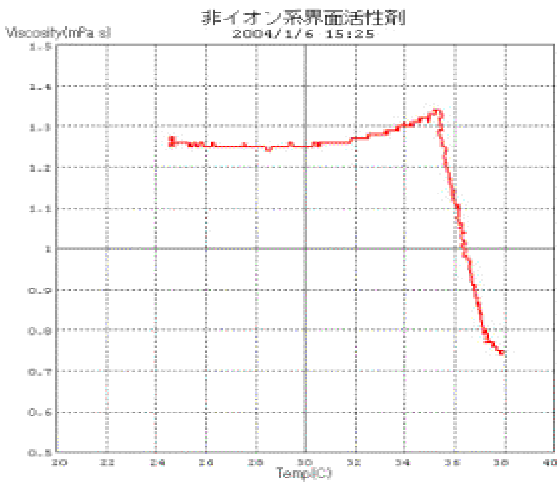

Figure 11 Deionized surface active agent (concentration 1%): temperature - viscosity

5. Conclusion and future development

A new vibration rheometer has now been commercialized. Using this rheometer RV-10000 it is possible to exert energy on a liquid at the barest minimum limit, measure viscosity quickly, while at the same time capturing data in relation to the change in the shear rate.

From the change in shear rate it is possible to grasp the non-linear behavior of the liquids, measure the change in viscosity over a period of time or change in temperature, as well as measure the viscosity of gelatinous liquids, which can easily be structurally damaged.

In the future, we would like to improve the RV-10000 and develop it into a device also able to measure the dynamic viscoelasticity of a liquid. Further, we would like to offer new influential methods for the measurement of physical properties of low viscosity fluids in research laboratories all around the world with the use of these rheometers, such as clearly demonstrating the previously hard to grasp relationship between the cloud point of surface active agents and shear rate.

References

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A&D Company Website