Development of a Simple and Objective Evaluation Method for Thickened Liquids Using Funnels

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**Keywords:**

Dysphagia; viscosity; thickened liquids; swallowing

**Abstract**

Some patients with dysphagia are prone to aspiration of low-viscosity liquids. Thickened liquids are often used in attempts to prevent aspiration. The patients should be given thickened liquids with suitable thickness, and the thickness should be constant at all time. While rotational and cone-and-plate viscometers are used for the evaluation of thickened liquids, they are high-precision and expensive equipment. To control the thickness of liquids, a simple and objective evaluation method is thus necessary. We developed a method to evaluate thickened liquids using funnels, and verified the appropriateness of this method. We measured the outflow times of five thickened liquids through funnels. One of the thickened liquids was a commercially available nutritional supplement, another was made with a thickening agent that contained guar gum, and all others were made with a thickening agent that contained xanthan gum. Four funnels with different stem sizes were tested. We found that the outflow time of thickened liquids through a funnel depended on their viscosities at a shear rate between 10 and 50 $s^{-1}$, when the average inner diameter of the stem was in the range of 5.3–9.0 mm, and the volume of the liquid poured into the funnel was 30 mL. The correlation coefficient between the value of the sensory evaluation and the outflow time of the funnel with an average stem ID of 5.3 mm was 0.946. Therefore, this method may be useful in hospital and nursing home kitchens for evaluating thickened liquids.

## Practical Applications

The findings of this study will help develop a new method for the evaluation of thickened liquids. Funnels made from polypropylene, which are inexpensive and light, were used in this method. The process for measuring the outflow time of thickened liquids through a funnel is simple, and we can obtain quantitative data that are objective. Even though line spread test (LST) is well known as a simple measurement method, nutritional supplements and liquids thickened using a thickening agent containing guar gum have not been evaluated accurately. The funnel method was found to have a stronger correlation with sensory evaluation compared to LST. This method is useful in hospital and nursing home kitchens for evaluating thickened liquids.

## Introduction

Dysphagia is associated with stroke, neuromuscular disorders, sarcopenia, and structural failure due to malignant tumors (Yamashita 2012; Sonoda 2012). Some patients with dysphagia are prone to aspiration of low-viscosity liquids, such as water or tea. Thickened liquids are often used in attempts to prevent aspiration (Leonard *et al*. 2014).

Staff members of hospitals and nursing homes are required to prepare thickened liquids according to the swallowing capability of the patients. To control the thickness of these liquids, it is necessary to measure their viscosity. Rotational and cone-and-plate viscometers are typically used for the quantitative evaluation of the viscosity of thickened liquids (Nicosia and Robbins 2007; Saint-Aubert *et al*. 2014); however, it is difficult to have such high-precision and expensive equipment in hospitals and nursing homes. Mann and Wong (1996) suggested the line spread test (LST) as an easy way to evaluate thickened liquids, and Nicosia and Robbins (2007) showed its usefulness. The LST was developed in the 1940s to measure the consistency of fruit sauces and cream fillings (Grawemeyer and Pfund 1943; Adams and Birdsall 1946). For this test, a cylinder filled with a thickened liquid is placed on the center of a flat plate with concentric circles. When the cylinder is lifted, the liquid flows on the plate. The limit of flow of the liquid indicates the thickness.

Shear rates during swallowing have been studied for approximately 50 years globally. Wood (1968) reported a swallowing shear rate for Newtonian glucose syrup and non-Newtonian sauces to be 50 $s^{-1}$ according to sensory evaluation. Following that study, the National Dysphagia Diet (NDD) adopted the shear rate of 50 $s^{-1}$ to classify thickened liquids (National Dysphagia Diet Task Force 2002). Shama and Sherman (1973) estimated the oral shear rate from about 10 $s^{-1}$ to over 1000 $s^{-1}$, and it depends on the flow characteristics of the food.

In Japan, many commercially available thickening agents have been used in hospitals and nursing homes. In the past, the staff members prepared thickened liquids using their own judgment, which caused problems since there was no common standard for controlling the thickness of liquids. To overcome this issue, the dysphagia diet committee of the Japanese Society of Dysphagia Rehabilitation (JSDR) introduced the Japanese Dysphagia Diet 2013 for Thickened Liquid (JDDTL). This classification system was based on water thickened with thickening agents containing xanthan gum with sensory evaluation, and showed the viscosity ranges at a shear rate of 50 $s^{-1}$ and the ranges of LST values. Yamagata and Kayashita (2015) reported that LST values of some types of liquids such as nutrient liquids and water, thickened with guar gum and xanthan gum, had no correlation with the sensory evaluation of thickness. The shear rate estimated using the LST was 1 $s^{-1}$, indicating that the thickness of thickened liquids determined by sensory evaluation and LST were different (Yamagata and Kayashita 2015). To control the thickness of different types of thickened liquids, a simple and objective method of evaluating thickness, with a high correlation with the sensory evaluation of thickness, is necessary.

A method for measuring the viscosity of a more viscous liquid such as paint uses a special cup called the “Ford cup” with a shape similar to that of a funnel. The outflow time of the paint from the hole at the bottom of the cup reflects the viscosity of the paint. Another, the Posthumus funnel composed of an upper large cylinder, a lower small cylinder and a connecting conical part is used for evaluating viscosity of yoghurt (Salazar *et al*. 2009, Kutter *et al*. 2011). However, the Ford cup is expensive and costs more than $200. Furthermore it is difficult to obtain the Posthumus funnel in Japan. Therefore, we focused on commercially available plastic funnels that are inexpensive and practical in kitchens.

Recently, International Dysphagia Diet Standardisation Initiative (IDDSI) introduced a flow test using 10 mL syringes (2016). This method uses the same measurement principle of the Ford cup and the Posthumus funnel. However, the value measured using this method has not been discussed about its appropriateness.

In this study, we developed a new method to evaluate thickened liquids using funnels. Then, we verified the appropriateness of this method and applied it to classify liquids according to JDDTL.

## Materials and Methods

### Materials

Five samples were used in the study (Table 1): one was a commercially available nutritional supplement (Resource® PemPal thickened with strawberry flavor, Nestlé Japan, Japan); another was made with a thickening agent that contained guar gum (Hightoromeal, Food-care, Japan); and all others were made with a thickening agent that contained xanthan gum (Tsuruinko-Quickly, Clinico, Japan). The thickening agents were dissolved in 100 g of water (Natural Mineral Water, Suntory, Japan) by stirring with a spatula for 1 min. All samples were kept at 20°C for 30 min. In JDDTL, a three–level categorization system of thickness (mildly thick, moderately thick, and extremely thick) was designed. The viscosity at the shear rate of 50 $s^{-1}$ of mildly, moderately, and extremely thick were 50–150 mPa・s, 150–300 mPa・s, and 300–500 mPa・s, respectively. Therefore, the viscosities of the samples were decided to be 150 mPa・s, 300 mPa・s, and 500 mPa・s in this study.

[Table 1 here]

### Evaluation method for thickened liquids using funnels

A stopwatch was used to measure the time between the initiation of pouring 30 mL of thickened liquid into a funnel and the end of the outflow from the funnel. The maximum volume of funnel a) that was the smallest in four funnels was about 50mL. To pour thickened liquid at once without spilling, the volume of liquid was fixed 30mL. When the volume was 10 or 20 mL, the outflow times of the thickened liquids were too short to evaluate the differences between samples. The thickened liquid was poured to the funnel quickly, and the time at which no drop was observed after waiting for

2 s was considered as the end of the measurement period. Since we would like to develop a practical evaluation method of thickened liquid, we decided to finish the measurement of outflow time by 180 s. The dimensions of the funnels are shown in Figure 1, and their values are given in Table 2. Funnel c) was the only one with a rounded shape [Figure 1(ii)]. This four funnels made from polypropylene were typical and commercially available (As One, Japan), and their prices ranged from $1 to $10.

[Figure 1 here]

[Table 2 here]

**Analyzing the flow in the funnel stem**

Hagen-Poiseuille's law is applied to Newtonian flow in a pipe:

$$Q = \frac{\pi R^4 P}{8L\eta} \quad (1)$$

where Q is the flow rate, R the radius, P the difference of both ends' pressure, L the length and η the viscosity. Here this law was used to estimate non-Newtonian flow. The shear rate at the wall of a pipe was derived from Eq. 1:

$$\gamma(R) = \frac{RP}{2L\eta} = \frac{4Q}{\pi R^3} \quad (2)$$

This equation was used to discuss the shear rate in the funnel stem.

**Measurement of Viscosity**

The viscosity of each thickened liquid was measured with a rheometer (Rheo Stress 6000; Thermo Scientific HAAKE, Germany). The mode of a cone–and–plate viscometer was used. The diameter and the angle of the cone were 35 mm and 1° respectively, and the truncation gap was 47 µm. We measured the viscosity at shear rates of 1, 5, 10, 50, 100, 500, and 1,000 $s^{-1}$. The viscosity at each shear rate was recorded after keeping the shear rate for 60 s.

**Line Spread Test**

The LST was performed using a flat plate with concentric circles and six axes showing the radius of each circle. A cylinder with a diameter of 30 mm, filled with a 20 mL of thickened liquid, was placed on the center of circles. The cylinder was lifted and the liquid was allowed to spread for 30 s. The flow limits of the liquid along the six axes were read and averaged. This test was performed three times to obtain the average.

**Measurement of dispersion between individuals**

Four students and two staff members of the Doshisha Women's College (all women with a mean age = 26.2 ± 8.9 y) were selected as panelists for this measurement. They were interested volunteers and were informed that they would be evaluating thickened liquids using funnels. Panelists were given a paper with directions, type-a funnels, 30 mL polypropylene cups, a stopwatch, a funnel stand, and five samples (NS, X150, X300, X500, and G300) and were asked to perform the evaluation method for thickened liquids using funnels.

### Data analysis

The sum of the sensory evaluation rankings for the same samples (Yamagata and Kayashita 2015) were compared with the values obtained using the funnel method and LST. Pearson's correlation coefficient between the outflow time through a funnel or LST and the sum of the sensory evaluation rankings was calculated using the IBM SPSS Statistics v24.

## Results and Discussion

### Outflow time through funnels

Table 3 gives the means and standard deviations of the outflow times for the 30 mL samples through the four funnels that were measured three times.

[Table 3 here]

According to Hagen-Poiseuille's law (Eq. 1), the flow rate of a liquid through a funnel depends on the viscosity of the liquid, the pressure relating to the volume of the liquid remaining in the funnel and gravity, the inner diameters and the length of the stem. When the viscosity of the liquid is low, the flow rate is high. When the volume of liquid remaining in the funnel is larger, the flow rate is higher. As the volume decreases, the flow rate also decreases. Therefore, for one measurement, the flow rate is high initially, and decreases as the liquid flows out of the funnel. The flow rate is higher when the inner diameters of the stem (A and B in Figure 1) are larger. Of the funnels used in this study, funnel a) had the smallest inner diameter, and thus the longest outflow time. For funnel d), the outflow times of the thickened liquids were too short to evaluate the differences between samples. Comparing funnel a) to b), even though the stem length (C in Figure 1) of funnel a) was shorter than that of funnel b), the outflow time of funnel a) was longer than that of funnel b). In the case of the funnels used in this study, the inner diameter of the stem has a larger contribution to the outflow time than the stem length. This is also explained by Hagen-Poiseuille's law: flow rate is proportional to radius to the 4th power and inversely proportional to length.

Consequently, when the stem size of the funnel and the volume of the thickened liquid poured into the funnel are fixed, the outflow time depended on the viscosity of the thickened liquid.

**Shear rate of outflowing**

According to Eq. 2, the outflow time is decreased when the flow rate of the thickened liquid is higher, and the shear rate is higher. When the inner diameters of the funnel stem are large, the shear rate of the thickened liquid flowing through the stem increases, and when they are small, the shear rate decreases. The shear rate of the beginning of the outflow process is larger, and the end is smaller. Moreover the shear rate of the center in a pipe is lower, and near the wall is higher. For estimating the shear rate in the stem, it is necessary to analyzing the flow like Kutter's study (2011). In this study, we estimated shear rate of the outflow process from funnels by comparing with viscosities measured by a cone-and-plate viscometer, as shown in Figure 2. The shear rates of the funnels given here are the mean values estimated between the beginning and end of the outflow process of whole stem.

[Figure 2 here]

The descending order (i.e., longest to shortest) of the thickened liquids with respect to the outflow time through funnel a), b), and c) was (1) X500, (2) NS, (3) X300, (4) G300, and (5) X150. Although the order of the viscosity was not the same as the outflow time, as seen in Figure 2, we assumed that the order would be the same between 10 and 50 $s^{-1}$, which was shown as a dotted line in Figure 2. Consequently, it is assumed that average shear rate of funnel a), b) and c), with average stem inner diameters in the range of 5.3–9.0 mm, corresponds to between 10 and 50 $s^{-1}$.

**Comparing with sensory evaluation**

Yamagata and Kayashita (2015) reported sensory evaluation results of thickened liquids. In the sensory evaluation, panelists who were clinical staff, 77% of them registered dietitians, placed the thickened liquid into their mouth and ranked the viscosity on a scale from low to high. The sum of the sensory evaluation ranking numbers was calculated for each sample, and its lower value meant lower viscosity in this case (Yamagata and Kayashita 2015). They are shown in Table 3. We used this sensory evaluation result to verify appropriateness of the evaluation method of thickened liquids using funnels.

Pearson's correlation coefficient ($r$) and $p$-value between the outflow time and the sum of the sensory evaluation ranking numbers are shown in Table 3. Because the outflow time through funnel a) and b) for X500 was >180, $r$ of all funnels were calculated without the values of X500 to equalize the number of values. Since $r$ of funnel a) was 0.946, we could use it to evaluate viscosities of thickened liquids as with sensory evaluation. However, we found out that it cannot be used to evaluate X500. Even though $r$ of funnel c) was lower than that of funnel a), the outflow time of X500 for funnel c) was 52 s, which is the highest value of the five thickened liquids; therefore, funnel c) is useful to evaluate the thickness of X500. To evaluate a thickened liquid, we measure outflow time through funnel a) firstly. If outflowing time is more than 180 s, outflow time of funnel c) should be measured.

**Measurement of dispersion between individuals**

In our evaluation method, the end point is when no additional drops from the funnel are observed for 2 s. Considering that it is difficult to measure 2 s while observing the end of the funnel stem, it is possible that the outflow times resulted in different outcomes when the outflows were measured by multiple people. Six panelists performed this process using funnel a), and Table 4 shows the mean values and standard deviations of the outflow times calculated on the basis of the results from panelists. The standard deviations for G300, X150, and X300 were $< 4$ because the difference between the panelists was considerably small. The standard deviation of the outflow time of NS was larger than those of other samples. This sample had difficulty in draining from the funnel, making it difficult to find the end point of the measurement. Forming and dropping a droplet is concerned with surface tension, viscosity, yield stress and shear thinning nature. This is a problem of the funnel method in case of evaluating different types of thickened liquids. However, the order of the thickened liquids with respect to outflow times was the same for all six panelists. Thus, this funnel evaluation method can yield the same results with different evaluators.

[Table 4 here]

**Practical evaluation method for thickened liquid**

The LST is an easy way to evaluate the degree of thickness of a thickened liquid. The LST values, $r$ and $p$-value between the LST value, and the sum of the sensory evaluation ranking numbers are shown in Table 3. The results for the xanthan gum-based samples imply that the LST value decreases as the sensory evaluation ranking increases. This correlation decreases once the other two thickened liquids are included. The LST can be used to evaluate the degree of thickness of liquids thickened with xanthan gum type of thickening agent (Saint-Aubert *et al*. 2014). The change in viscosity with respect to the shear rate depends on the type of thickening agent used, therefore, the LST is not suitable for evaluating the viscosity of liquids thickened with different agents.

The new method needs funnels, a stopwatch, and a stand to hold the funnel. Funnels made from polypropylene are light, inexpensive, and suitable to kitchens in hospitals and nursing homes. Measuring the outflow time of thickened liquids through a funnel is simple, and we can obtain quantitative data which are objective. A study by Adeleye and Rachal (2007) reported the outflow times of thickened liquids that passed through a funnel, but they showed only results and did not study about sizes of stems and shear rates. In this study, we showed it is possible to evaluate thickened liquids using funnels by studying stem sizes and comparing these to the viscosity and sensory evaluation.

The syringe method introduced by IDDSI (2016) is also a simple evaluation method for thickened liquids. The procedure is as follows: remove the plunger from a syringe and discard, cover the nozzle of the syringe with a finger, fill the syringe up to the 10 mL line with thickened liquid, remove the finger from the nozzle at the same time as starting the stopwatch, replace the finger over the nozzle at 10 s, read the scale of the remaining liquid, and classify the level of thickened liquid. Both measurement of liquid volume and test of thickness can be performed at the same time with a syringe. Furthermore there is no dripping problem. It is necessary to evaluate appropriateness of the syringe method.

**Applying to the classification system for thickened liquids**

Although the sensory evaluation by Yamagata and Kayashita (2015) exhibited a high correlation with viscosity at 10 $s^{-1}$, other sensory evaluations correlated with viscosities in the range of 50–130 $s^{-1}$ (Yamagata *et al*. 2012). In the evaluation in 2015, samples with viscosities in the range of 150–500 mPa･s at a shear rate of 50 $s^{-1}$ were used, and in the evaluation in 2012, samples with viscosities in the range of 100–200 mPa･s at a shear rate of 50 $s^{-1}$ were used. Swallowing shear rates have been studied several times, and estimated from about 10 $s^{-1}$ to over 1000 $s^{-1}$, and it depends on the flow characteristics of the food (Shama and Sherman 1973).

The purpose of thickening a beverage for dysphagia patients is to control the flow rate during swallowing and to prevent aspiration. NDD made its own classification system for thickened liquids that uses a viscosity of 50 $s^{-1}$ based on Wood's report (Wood 1968; National Dysphagia Diet Task Force 2002). Australia and Canada also have their own classification system based on the viscosity at a shear rate of 50 $s^{-1}$ (Cichero *et al.* 2013). Even though it was difficult to decide a shear rate at swallowing, it was necessary to decide a shear rate evaluation for making a classification system of thickened liquids.

[Table 5 here]

The dysphagia diet committee of JSDR made JDDTL that was based on liquids thickened by thickening agents using xanthan gum (The dysphagia diet committee of the Japanese Society of Dysphagia Rehabilitation, 2013). The shear rate of the viscosity for its criterion was 50 $s^{-1}$ like NDD. Table 5 shows a part of the JDDTL. We tried to make a classification system of thickened liquids using funnels, and we used the outflow times of 30 mL of X150, X300, and X500 through funnel a). When the outflow time is less than 10 s, the liquid is classified as mildly thick. When the outflow time is between 10 s to 50 s, the liquid is classified as moderately thick. The case when the outflow time is more than 50 s is measured through funnel c). When the outflow time is between 12 s to 52 s, the liquid is classified as extremely thick. Using this method, G300 was classified as moderately thick, and NS was classified as extremely thick (Table 6). Classified levels using other methods have also been shown in Table 6. Levels classified by the method using funnels, agreed very well with the results obtained from viscosity (50 $s^{-1}$) and sensory evaluation. However levels classified by the LST were different from others. This result suggests that the method using funnels is useful to classify thickened liquids.

[Table 6 here]

The Japanese classification system is based on viscosity values ranging from 50 to 500 mPa･s, while the American and the Canadian classification systems are for the viscosity range of 50–1750 mPa･s; the Australian system is 150–900 mPa･s (Cichero *et al.* 2013). Thickening agents using starch is mainly used in America, Canada and Australia. In this study, we investigated a simple objective evaluation method for thickened liquids using xanthan gum or guar gum and nutritional supplement based on the Japanese classification, the results of which exhibited a high correlation with sensory evaluation. For this method to have widespread use, thickened liquids using starch with viscosities of 1750 mPa･s at a shear rate of 50 $s^{-1}$ need to be studied. With this in mind, we plan to continue to evaluate the use of the funnel method.

## Conclusions

In this study, we tried to develop a simple and objective evaluation method for thickened liquids using funnels that are inexpensive and practical. We found out that the outflow time of thickened liquids through a funnel depended on the viscosity at a shear rate between 10 and 50 $s^{-1}$ of the liquid, when the average stem inner diameter was in the range of 5.3–9.0 mm, and the volume of the liquid poured into the funnel was 30 mL. This method was found to have a stronger correlation to sensory evaluation compared to LST, and we classified thickened liquids using this method according to JDDTL. The LST is not most suitable for thickness assessment of thickened liquids. We are convinced that the new method of using funnels is useful for evaluating the viscosity of thickened liquids in the kitchens of hospitals and nursing homes.

## Ethical Statements

Conflict of Interest: The authors declare that they do not have any conflict of interest.

Ethical Review: This study does not involve any human or animal testing except evaluating thickened liquids using funnels.

Informed Consent: Written informed consent was obtained from all study participants.

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**Table 1**. Concentration of thickened liquids and viscosity of dissolved samples

| Sample name | Abbreviation | Trade name of thickening agent | Concentration (%) | Viscosity at 50 $s^{-1}$ (mPa·s) |
|---|---|---|---|---|
| Nutritional Supplement | NS | – | – | 516.5 |
| Guar Gum 300 | G300 | Hightoromeal | 1.50 | 296.5 |
| Xanthan Gum 150 | X150 | Tsururinko-Quickly | 1.35 | 155.1 |
| Xanthan Gum 300 | X300 | Tsururinko-Quickly | 2.10 | 298.5 |
| Xanthan Gum 500 | X500 | Tsururinko-Quickly | 3.10 | 506.6 |

**Table 2.** Size of funnels

| Funnel name | Fig. 1 | A (mm) | B (mm) | ave.ID[1)] (mm) | C (mm) | D (mm) | E (mm) |
|---|---|---|---|---|---|---|---|
| a | i | 6.0 | 4.5 | 5.3 | 61 | 60 | 45 |
| b | i | 7.2 | 5.3 | 6.3 | 80 | 85 | 63 |
| c | ii | 10.5 | 7.5 | 9.0 | 34 | 80 | 42 |
| d | i | 11.5 | 11.5 | 11.5 | 24 | 75 | 54 |

1) ave.ID is mean of A and B.

**Table 3.** Outflow time, LST and Pearson's correlation coefficient between outflow time and sum of sensory evaluation

| Sample Name | | NS | G300 | X150 | X300 | X500 | *r* | *p* |
|---|---|---|---|---|---|---|---|---|
| Outflow time mean±SD (s) | a | 61.5±1.6 | 19.1±0.9 | 9.1±1.0 | 49.8±2.6 | >180 | 0.946 | 0.054 |
| | b | 34.3±1.2 | 11.4±0.1 | 5.0±0.3 | 14.0±1.0 | >180 | 0.734 | 0.266 |
| | c | 20.1±2.9 | 12.1±1.6 | 6.7±1.2 | 12.7±0.6 | 51.8±2.7 | 0.822 | 0.178 |
| | d | 9.8±1.9 | 6.7±2.0 | 5.3±0.4 | 4.2±0.1 | 5.1±0.7 | 0.293 | 0.707 |
| LST (mm) | | 45.8±2.6 | 42.1±2.0 | 39.9±2.3 | 34.7±1.9 | 30.3±3.5 | -0.027 | 0.973 |
| Sensory Evaluation[1)] | | 663[2)] | 439 | 228 | 674[2)] | 948 | - | - |

1) YAMAGATA, Y. and KAYASHITA, J. 2015. Evaluation of the Japanese Dysphagia Diet 2013 by the JSDR dysphagia diet committee (Thickened Liquid) by using several types of thickened liquids. Jpn. J. Dysphagia Rehabil. 19, 109–116.

2) There is no significant difference between the sensory evaluation values of NS and X300.

**Table 4.** Mean and SD of outflow time measured by 6 panelists

| Sample name | mean±SD (s) |
|---|---|
| Nutritional Supplement | 70.2±10.6 |
| Guar Gum 300 | 19.9±3.1 |
| Xanthan Gum 150 | 11.4±3.2 |
| Xanthan Gum 300 | 42.2±3.6 |
| Xanthan Gum 500 | >180 |

**Table 5.** Japanese Dysphagia Diet 2013 (Thickened Liquid) (excerpt)

| | Level 1<br>Mildly thick | Level 2<br>Moderately thick | Level 3<br>Extremely thick |
|---|---|---|---|
| Viscosity (mPa·s)[1)] | 50–150 | 150–300 | 300–500 |
| LST (mm) | 36–43 | 32–36 | 30–32 |

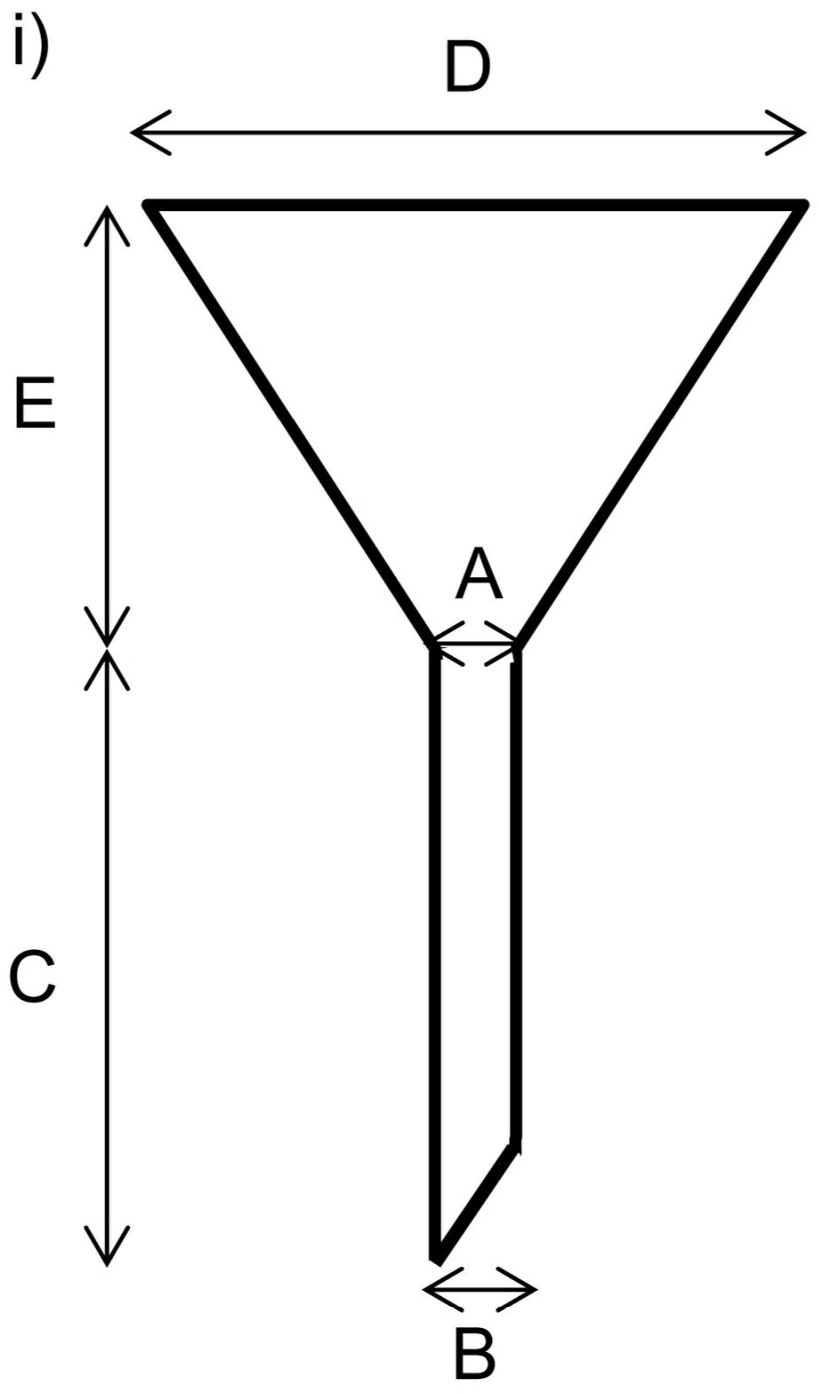
1) At a shear rate of $50 s^{-1}$

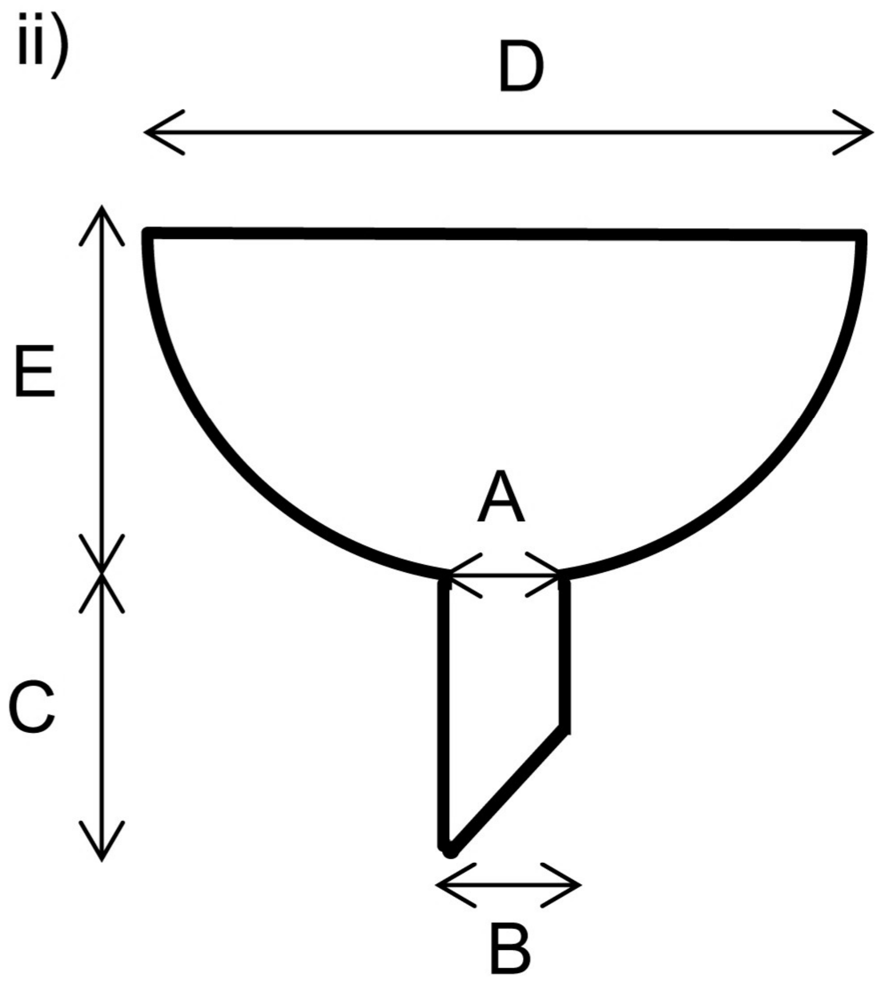
**Table 6.** Comparison of classified levels using funnel method, viscosity, sensory evaluation and LST

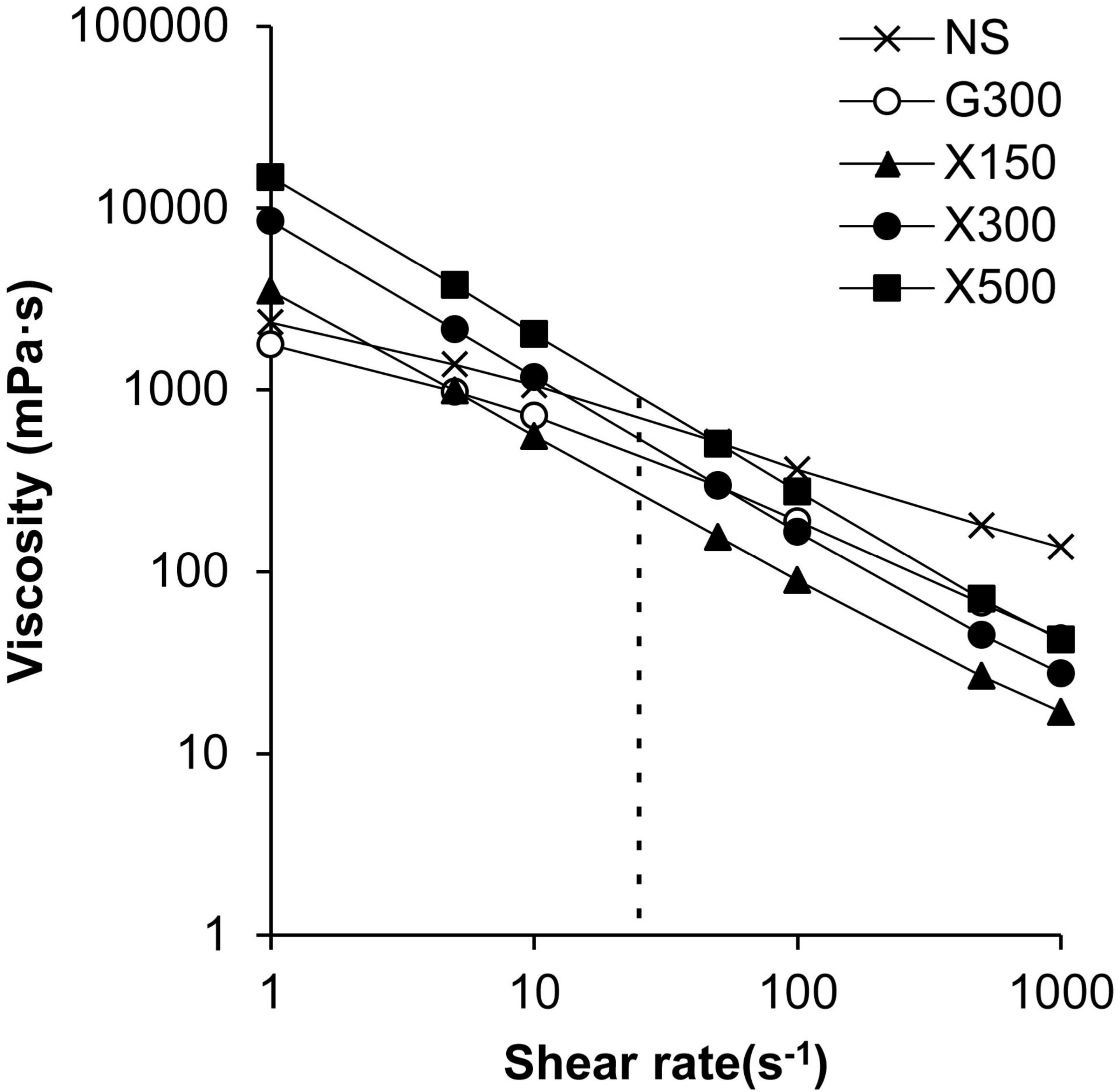
| Classifying method | G300 | NS |
|---|---|---|
| Funnel method | Moderately thick | Extremely thick |
| Viscosity ($50s^{-1}$) | Moderately thick | More than extremely thick |
| Sensory evaluation | Moderately thick | Moderately or extremely thick |
| LST | Mildly thick | Less than mildly thick |

**Figure 1.** Schematic diagrams of funnels used in this study

**Figure 2.** Viscosity plotted against shear rate


i)
D
E
A
C
B


ii)
D
E
A
C
B



NS
G300
X150
X300
X500
Viscosity (mPa·s)
100000
10000
1000
100
10
1
1
10
100
1000
Shear rate(s-1)