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Fabrication of a Rheometer for Yield Stress Fluids

Roya Davaripour[a], Nahid Maleki-Jirsaraei[a]*, Somayeh Azizi[a] and Shahin Rouhani[b]

[a]Physics Department, Alzahra University, Tehran, Iran, 199389117
[b]Physics Department, Sharif University of Technology, Tehran, Iran, 11365-11155

Abstract We fabricated a simple and cheap rheometer to measure rheological properties of yield stress fluids, specially yield stress and yield valium. Since we used a non-rotating drill for measurements in this method, effect of phenomena (such as wall slip, edge fracture and disruption of sample), that cause disturbance in measurement of yield stress for these fluids, is omitted or reduced. Fabrication of this rheometer is inspired by the work of [Semniok et al.] on suspensions in 2014, with some changes to make it suitable for viscoelastic fluids. Validity conditions and independency of measurements to the instrument's parameters is determined by studying effect of the diameter of the vessel containing fluid, and also the length of the drill. We compared measurements of this instrument with the measurements of the rheometer of Anton Paar Company, aside from a constant value that can be calibration constant, the results are in good agreement. Our study suggests that this constant difference of the two methods can be reduced to zero by choosing a longer drill. Also, this rheometer makes the studying of the nature of yield stress and yield valium- possible-which are now the important questions in yield stress fluids.

Keywords: Rheometer, yield stress, yield stress fluids, shear rate.

1. Introduction

The science of rheology is the study of the deformation and flow of matter, first known in the United States in 1929, examines a wide range of materials, such as asphalt, oils, paints, plastics, etc. [1]. There are fluids which the most important of their characteristics having the yield points. These fluids with qualified reason can be classified for both liquids and solids. The network collapses only when external forces are large enough to overcome network forces (that is, bigger than the threshold of shear stress which is called the "yield point"). These types of fluids have a flow curve that does not cut the axis of the width at the origin and disconnects at the yield point $\tau 0$. All these disordered materials show a nonlinear response to an external mechanical force, which is due to the existence of a limited threshold force for the motion of stream in the fluid [2-4].

These types of fluids can be isolated from solid state by applying a suitable stress, and can be find the behavior of liquids, that's kind of stress called yield stress and thus these fluids are called yield stress fluids. Fluids with yield stress are available in a wide range of applications such as toothpastes, cements, mortars, floorings, drilling mud, mayonnaise, etc[1]. Accordingly, easy and inexpensive measurements of this quantity are important for all of these industries, while rheometers are usually expensive devices and it is not necessarily easy to work with them. Particularly, the industries usually involved with a particular fluid and doesn't require a complete expensive system, and prefer to have a cheaper but appropriate device for their fluids properties.

Recently, from a fundamental perspective the nature of the stress has been discussed, whether the yield stress is a transition from solid to liquid, or from more fugacious to lesser, or basically whether the yield stress of each fluid is a characteristic quantity for stress fluid, and finally, the validity of the Herschel-Balkil equation has been questioned in some papers. [5-9].

In other way, since in order to measure the yield stress in most methods, the fluid should be removed from its rest, and this itself can disrupt the accurate measurement of yield stress, the challenges to accurately measure the amount of yield tension is remaining [10].

Hitherto, various rheometers have been used to find yield stress value. But each of their types has limitations. The main limitation of using torque rheometers is the timing of this method and the probability of decreasing the particle size distribution during the measurement. The main problem of using a webbing rheometer (blade) is that to apply for some specific concentrations, since the blade cannot be attached to the sample without compromising the sample, it does not provide a satisfactory result. Recently, papers using a parallel geometry rheometer have been highlighted. But this tool is only suitable for fluids that have not very large particles and Suspensions that are not very concentrated, since it is possible to observe complex phenomena such as wall sliding and edges 2, 3 for higher concentrations.

Semniuk et al. [4] presented a new rheometer for Suspensions with yield stress. They have shown that this method can be used for many of these suspensions, and their results are consistent with the measurements obtained from the Vien rheometer.

In the present work, inspired by Semniuk et al. [10], we designed a suitable device for measuring the yield stress and elastic deflection of fluids. In this process, a spiral drill was transferred to the sample. According to the tested material (fluids) as well as by creating conditions for measuring the volume of yield, in addition to the yield stress, contrary to the work of the Semiuk, in which different doors were used for the sample vessel in order to examine its effect on the measurements, we used containers of different diameters.

2. Materials and Methods

Design and construction of the machine

In figure 1, the rheometer is shown. The drill is made of bronze, the total length is 150 mm, the main axis diameter is 4.5 mm, has a spiral groove with a length of 81/18 mm, a diameter of the grooves of 12.9 mm, the number of steps 6 and the distance of inside to inside of the grooves is 12/9 mm, the thickness of each groove is 1.5 mm. The drill is connected through a chuck to a single load cell (single-base, maximum measured power of 50 N, a precision of 0.01 N and with an aluminum frame) connected by a carrier and just goes up and down and does not turns. The data is stored on an Usb2 cable using Code Vision AVR Standard

Edition 2.05.3 in a notepad file. The carrier is powered by a 200-degree step motor, 24 V DC, 0.26 Amp of the TS3103B344 model, manufactured by Japan's Tamagawa company, which is move by a grooved bar coupled by an expansion. The electronic part is designed to allow measurement through the program. The electronic box can be used to move the motor (up or down), speed in rpm (from 5 to 200 rpm or from 0.1 to 3 mm per second), as well as the number of rotational frequencies. This device does not have oscillating sections.

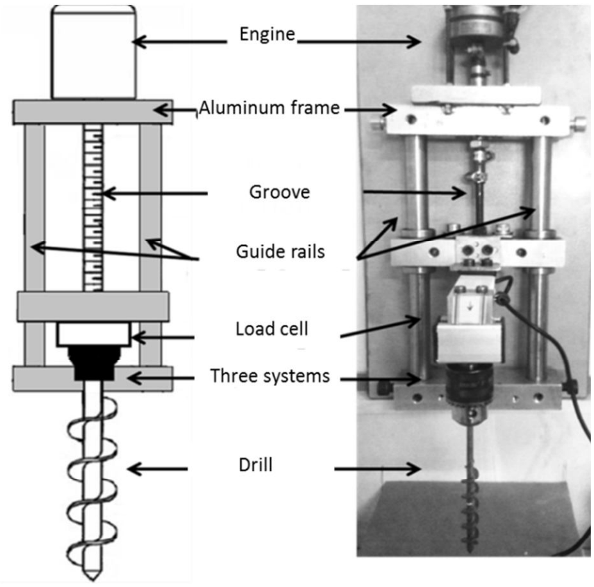

Figure 1: Rheometer schematic (left), rheometer image (right).

3. Measurement process

vessels with at least 100 mm high were selected for carrying the fluid, after pouring the sample into the containers for all tests, the drill which previously connected to the load cell through chuck using a manual mode of the machine having a constant speed of 100 rpm are taken to the desired height without rotation and stopping into the sample (Figure. 2).

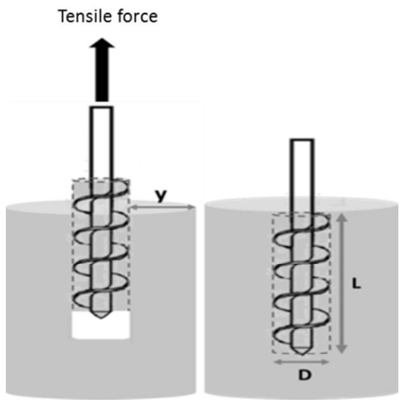

Figure 2: Design of drill (right) after insertion into sample material and also before turning on the engine, (left) drill

after moving on the engine during measurement.

Drills with lengths of 81.18, 44.64 and 27.1 mm were used. The data is starts to be save immediately after the engine is started and after the connected of the load cell to the computer by using the software mentioned. Each test is repeated 3 times and errors are measured based on the absolute error.

Assuming that the contribution of the force measurement to the complex deformation of the material near the end of the drill is negligible, it can be neglected. Also, the specimen deformation occurs when the connection as a cutting surface is in the form of a cylindrical surface that is determined by the depth of the drill and the diameter of the drill (Figure. 2). In this case, the shear stress will appear:

$$\tau_{app} = \frac{F}{\pi DL} \quad (1)$$

Where F is the measured force during deformation, D is the drill diameter and L is the length of the drill that enters the sample. The denominator of the shear stress fraction is the same as the cylinder side area. The apparent stress depends on the deformation and deformation rate. The apparent strain γ_{app}, the displacement of the drill axis divided by y, is the radius of the container, as defined in Figure. 2 (on the left), and the apparent strain rate is defined as the displacement rate of the drill axis divided by y. Initially, in order to measure stress growth, the apparent shear stress is plotted as a function of time, as shown in Figure. 3.

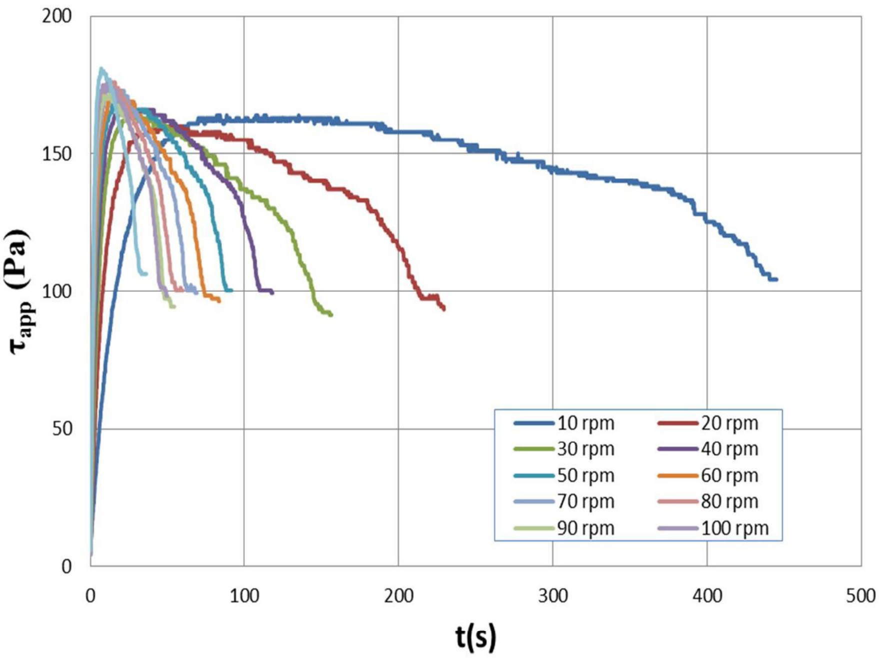

Figure. 3: An example of the mean apparent shear stress in terms of time with three repetitions at engine speeds: 10, 20, 30, 40, 50, 60, 70, 80, 90, 100 and

150 rpm, length of 81.18 mm drill, for Hair gel at 23 ± 1 ° C.

The apparent shear stress in this case has a maximum, which is represented by $\tau_{app\ max}$. After adjusting the device, according to the definition of relation (2) for the yield stress, we seek to obtain apparent maximum shear stress in sufficiently low cutting rates.

$$\tau_0 \equiv \lim_{\dot{\gamma}_{app}\to 0} \tau_{app,max} \quad (2)$$

4. Materials used and preparation

This device can be used to calculate the yield stress and yield volume of fluids. Our test fluid is a Carbopol Mousse Gel, whose yield stress and its rheological data were previously obtained with the Anton Par MCR302 rheometer (Figure. 4). In the measurements, the sample temperature has been attempted at 23 ± 1 ° C. Before each test, the sample was mixed with a mechanical stirrer Heidolph, RZR 2041, for 3 minutes at a rate of about 930 rpm, after being immersed in a sample container.

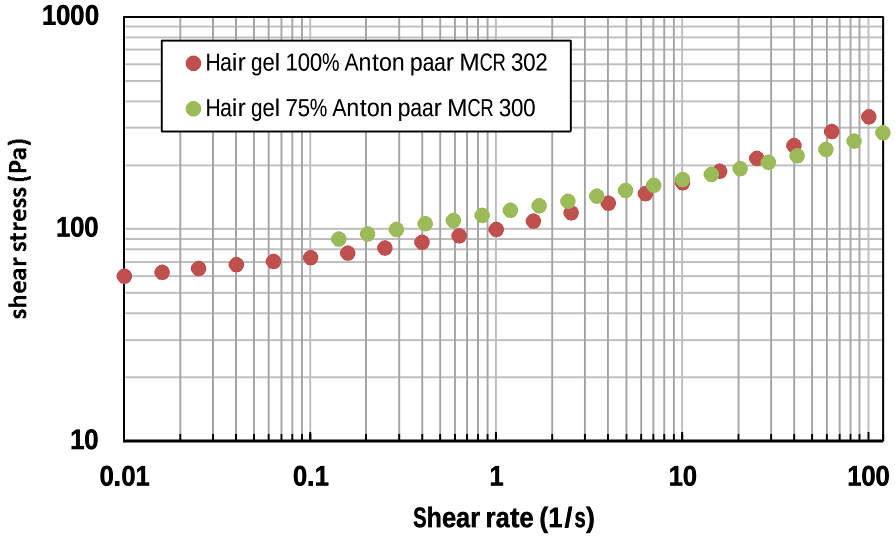

Figure 4: Stress pattern in terms of shear rate of Anton data for Hair gel of 100% and 75%

5. Results and discussions

Effect of diameter of sample container and determination of y_c

In this section, we used 7 vessels with diameter of: 104/62, 62.8, 47.4, 40.4, 32.1, and 27.8, 22.3 mm, respectively, in order to examine the effect of the diameter of the carrier vessel. From the examination of the data obtained for different vessels at two engine speeds of 10 and 150 rpm (Figure. 4), it was found that the container diameter affects to the tensile measurements, through increasing the container diameter, the amount of stress measured decreases. For containers larger than the diameter of 4/47 (4 times the drill diameter), which is called a critical diameter, this effect disappears

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and threshold stress measurement becomes independent of the container diameter (Figure. 5).

The continuity dependence of the measurements to the container diameter brings some results, since for vessels with diameters larger than the critical diameter, the measurements are not dependent on the diameter, it can be concluded that the effective volume affected by the drill movement, or the volume of yield, can be measured with this critical diameter and this is a positive achievement of this device.

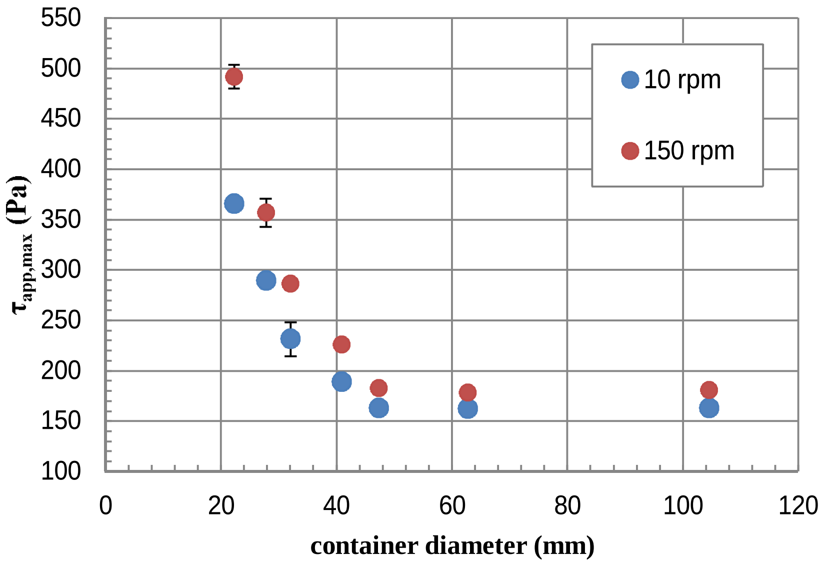

Figure 5: Diagram of the effect of the diameter of the fluid carrier container on the maximum apparent shear stress in terms of the diameter of 7 dishes at two engine speeds of 10 and 150 rpm. As can be seen, for diameters larger than 4/47 measurements gets independent of the diameter

6. The effect of drill length

To investigate the effect of the length of the drill, we used three different drill lengths in the specimen, as we have seen, with the decrease in the length of the insertion the maximum apparent shear stress increased (Figure. 6). To find out the reason of this phenomenon, it can be said that in the calculations, the surface is considered as a cylindrical and since it has a screw structure and it is more complex and differs from the cylinder and also this difference is more pronounced in smaller drill lengths, but in larger lengths the drill is converted to a better approximation, therefore, the length of the drill is longer and the measured value will be closer to the calculated value. To solve this problem, we have to choose the drill long enough such that it does not change for drills higher than the measured value of stress, or calibration should be used, which will be explained in the next section.

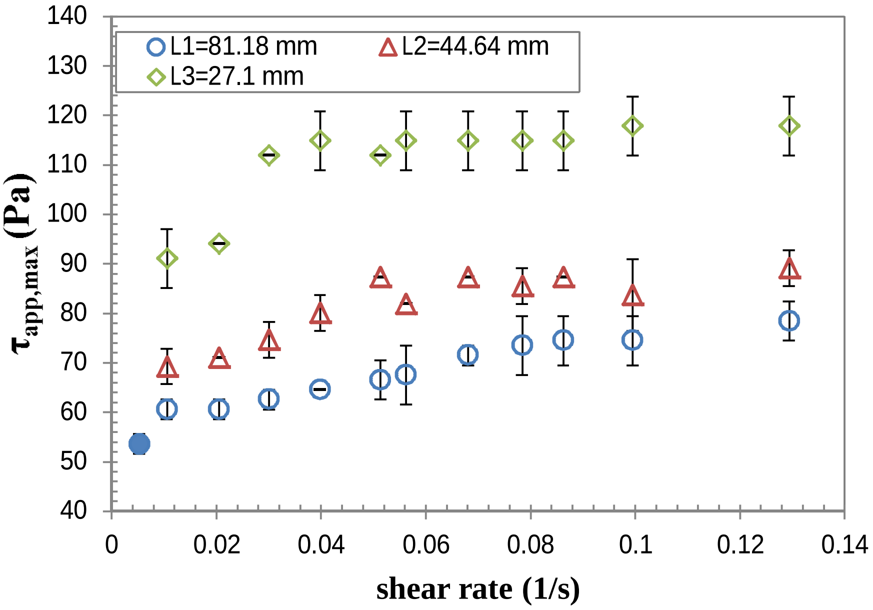

Figure 6: Comparison diagram for maximum shear stresses in terms of shear rate, taking into account y_c for different lengths L1, L2 and L3, and engine speeds 10, 20, 30, 40, 50, 60, 70, 80, 90, 100 And 150 rpm. The yield stress is the solid blue circle point for the speed of the 5 rpm and L1 length. (Data values are after calibration at shear rates)

7. Set up the device and determine of the yield stress

To adjust the device such that its measurements are independent of its parameters, we first need to use a container for carrying the fluid with a diameter higher than 4.47 mm (Figure. 4). Second, we must be sure that we have selected the correct length (to a large enough size) of the drill. By comparing the measured data with the device and via the full length of the drill and also by the Anton parameter rheometer data for the shear rates of approximately 0.01 to 0.2 (1 / s) we found that the data of the built-in device has a positive constant of about 102 psi relative to the rheometer's antenna par; That means, our drill is not long enough, but long drill in addition to the buildup problems requires a long container for the carrier fluid and consequently the need for more fluid for each test. since the difference in timing Our built-in machine with the results of the Anton Parameter's rheometer is only a constant value (Figure. 7) therefore, we calibrated our device for length L1 (full length drill), which for other examples this issue has been validated. Then, according to equation (2), we tried to use the lowest engine speed to be monitored in the digital system of the machine, which is 5 rpm for our system, which is equivalent to a shear rate of 0.005 (1 / s) In this condition, the device obtained the yield stress ($\tau 0$) of the carbopol hair gel by about 53 pc (Figure. 5), which is slightly less than the yield stress measured with Anton Pare at a shear rate of 0.01 (1 / s), 60 Pascal, which is first fully expected, and the second shows that if the engine and the processing system are more appropriate, the device can also test smaller quantities and help to answer this important question in yield stress which yield stress essentially is a characteristic value or depends on related conditions.

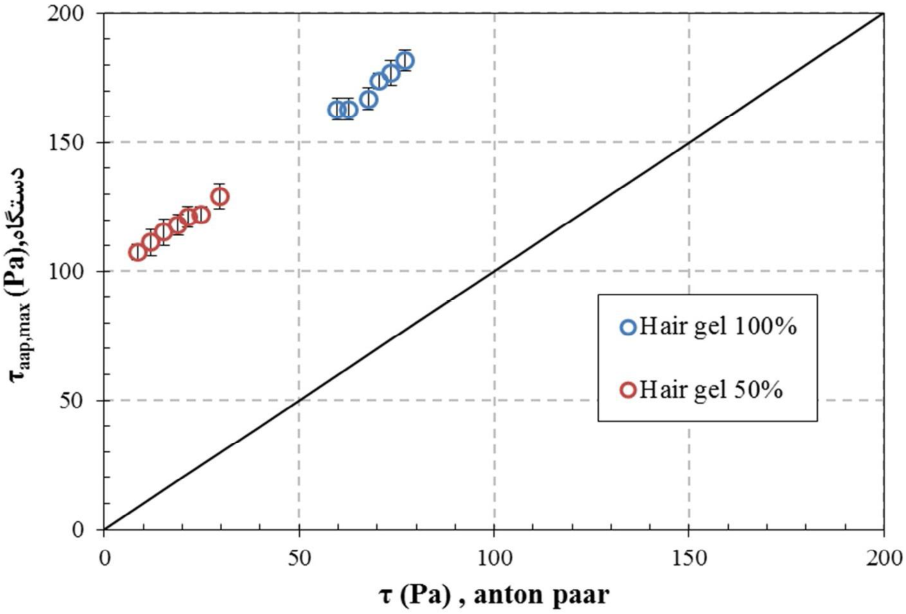

Figure 7 shows the comparison of the maximum shear stresses obtained during the L1 with the device and the Anton Parameter rheometer for a concentrated gel (hollow blue circle) and 50% volumetric gel (hollow red circle). As the figure shows, they have good consistency with a constant calibration value.

8. Conclusion

We provide a simple and inexpensive method to measure the yield stress and the yield volume and construct the corresponding device and determine the independence and validity of the measurements this method does not have the limitations and stiffness of the previous methods, and can be applied to a wide range of yield fluids that are used in the industry. The effects of shear rates, vessel diameter, and drill length are investigated in this paper. If the engine and the processing system are used more appropriately, it can also test the probability of measuring the lower yield stresses for the fluid and also help to answer to the important question of the yield stress fluid, whether; the yield stress is characteristic value for one fluid stress or depends on the conditions.

This device can also be used for the complete rheometer and the determination of the dynamical quantities and fluids time-dependent properties by embedding a more distant motor and creating an oscillatory state.

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