# Building and Validating a Rotational Viscometer

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Mechanical Engineering

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**Abstract**

This project was an effort to redesign an initial prototype rotational viscometer to experimentally test whether or not viscosity values vary significantly when the geometry of the viscometer is changed. The scope of the project involved designing and building a viscometer that could vary the gap between the inner and outer cylinders, variation of the testing fluid's temperature, and control of the device's RPM. After weeks of planning, designing, and fabrication the new viscometer was complete. In order to control the device, monitor the sensor readings, and calculate the testing fluid's viscosity a LabVIEW program was created. Testing on medium to high viscous fluids was completed to determine if the viscosity values and the geometry of the viscometer are dependent or independent of each other. The results did show a correlation between measured viscosity and variations in the geometry of the viscometer. More testing is required to further verify the results and properly calibrate the device.

**Introduction**

Viscosity is often referred to as a fluid's *thickness* or how much it resists deformation due to an applied force. Rotational viscometers measure the amount of torque needed to rotate an object moving through fluid at a known RPM. Using the measured torque, RPM, and dimensions of the device, the viscosity can be calculated using equation 1.

$$v = \frac{(Tg)}{(15\pi^2 r^3)(RPM)(h)} \qquad \text{Equation 1}$$

The variables represented in Equation 1 are as follows: T is torque (Nm), g is the gap size (m), r is the radius of the inner cylinder (m), and h is the height of the fluid being tested (m).

This project was developed to expand on an initial prototype viscometer developed in the fall of 2014 (Figure 1). This was a relatively simple proof of concept model.

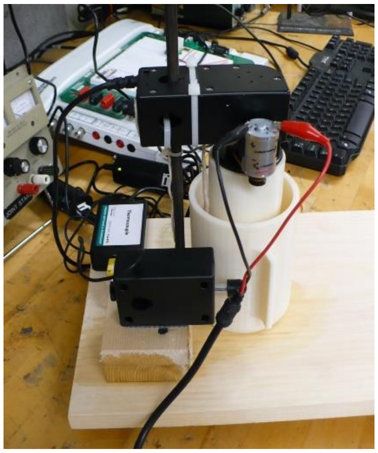

Figure 1. 2014 Prototype utilizing 3D printed components

For this project a new design was conceptualized, fabricated, and tested. This new design met several criteria including,

- Designed for future use in ME labs;
- Designed to be durable, sustainable, and easy to dissemble and clean;
- Multiple inner cylinders for varying gap sizes;
- Rotational system able to handle very high viscosity fluids;
- Fluid heating capabilities; and
- Motor control and sensor monitoring all achieved using LabVIEW.

In addition to these criteria the project was also designed to experimentally address whether the measured viscosity varies significantly when the geometry of the viscometer is altered.

**Materials and Methods**

In order to achieve the goals of the project the majority of the aspects of the design for the initial prototype were completely overhauled. Aluminum was selected as the primary material for the components as it would meet several of the design criteria including temperature variation, durability, and could be cleaned easily. While aluminum could act as an excellent material for heating and cooling, the overall weight will likely affect the viscometer's testing ability. To compensate for this a supported and rigid design was created (Figure 2.).

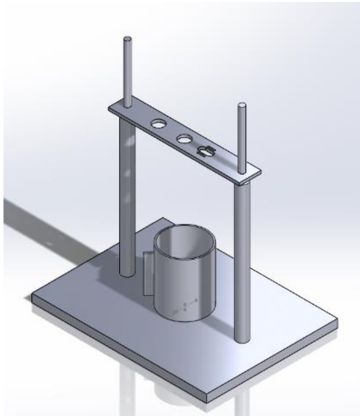

Figure 2. Basic SolidWorks Design (inner cylinder(s) not shown)

The new design required a much larger motor in order to rotate the heavier cylinders as well as create enough torque for high viscosity fluids. In order to have the motor spin the outer cylinder, a gear drive system was incorporated using a smaller pinion gear on the motor mated up to a larger gear which is affixed to the inner cylinder and the rotary encoder (Figure 4 Center). This allows the motor to drive the inner cylinder as well as obtaining the known RPM value of the rotating cylinder.

With the design settled on, materials were ordered and the fabrication phase began. This was one of the longest phases in the project and many hours were spent machining the components (Figure 3).

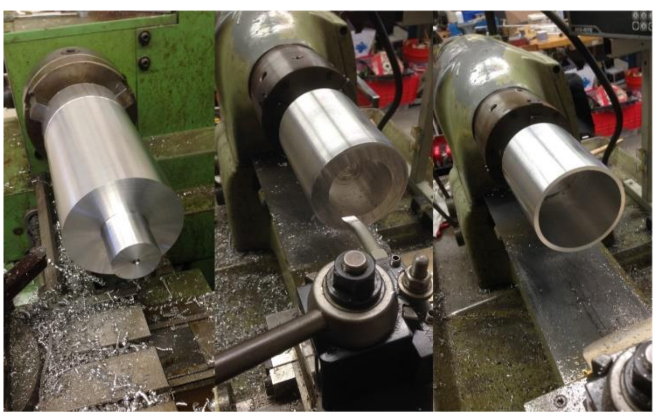

Figure 3. Outer Cylinder construction on lathe

After several weeks in the machine shop the fabrication was finished and the fitting of all the sensors and components could take place.

Figure 4. Left: Finished cylinders, Center: gear drive attached to one of the inner cylinders, Right: bearing mounted on outer cylinder

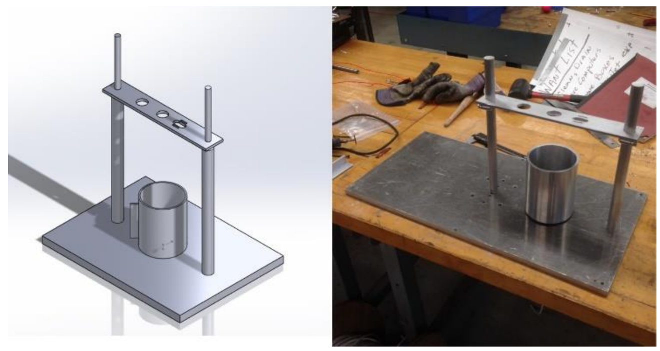

Figure 5. SolidWorks Concept and End Product

For the viscometer to be able to collect all the necessary data to calculate viscosity, a program, an interface, and sensors were selected. The NI LabVIEW program with NI myRIO as the interface was chosen. LabVIEW is a graphical program used for instrumentation purposes. The NI myRIO was selected as the interface because the myRIO met the requirements needed and the university is in the process of switching out older interfaces for the myRIO. It was decided that for the rotational viscometer to be used in the future by professors and students, it needed to be programmed using the myRIO as the interface.

Sensors were chosen such that they would work with the NI program and interface. Revolutions per minute, temperature, and force had to be measured and monitored by the sensors. A rotary motion encoder, a thermocouple, and a dual range force sensor were the sensors incorporated into the rotational viscometer. The rotary motion encoder uses a built in encoder to measure the amount of clicks it takes the shaft to travel $360^o$. In LabVIEW an encoder block can collect the amount of clicks the rotary motion encoder monitors. Then, by multiplying the amount of clicks by the total clicks in one revolution, divided by the run time in seconds, and multiplied by 60 seconds in a minute the RPM of the inner cylinder is calculated by LabVIEW. The temperature of the fluid can be measured using a thermocouple that sends a signal to LabVIEW. LabVIEW reads the incoming signal as a voltage signal and uses a calibration equation for the thermocouple to convert the voltage signal to temperature. The dual range force sensor can measure force readings between ±10 N or

±50 N. Like the thermocouple the force sensor sends LabVIEW a voltage signal so a calibration equation is used to convert the voltage signal to a force. In the LabVIEW program we can multiply the measured force by the distance from the axis of rotation to where the force sensor hits the tab on the outer cylinder to get the torque generated by the fluid.

For the ability to control the motor's speed, an electronic motor controller is used to relay a pulse width signal from the LabVIEW program to the motor. A frequency is input into the LabVIEW panel which sends the signal to the motor controller telling it how fast it should spin.

The LabVIEW program takes in all the signals from the rotary motion encoder, the thermocouple, and the dual range force sensor (Figure 6). This allows the user to monitor and collect the measured torque, force, temperature, and RPM from the fluid and the rotational viscometer.

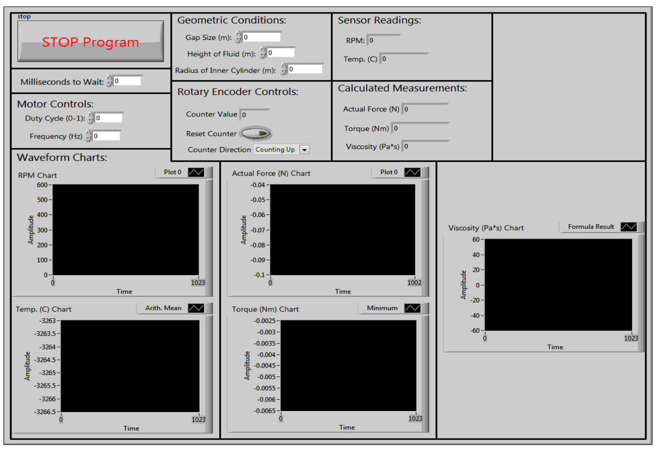


Figure 6: LabVIEW control panel with device controls, inputs, and graphical readouts

To calculate the viscosity of the fluid in the viscometer a formula block uses the torque and RPM that was measured and the specific geometric conditions of the experiment. The geometric conditions that can be varied are the gap size between the inner and outer cylinders, the height of the fluid, and the radius of the inner cylinder. The values of force, torque, temperature, RPM, and viscosity all can be exported into excel after each test.

A few programming problems that arose were that the Vernier myDAQ adaptor that was used to wire the interface was not completely compatible for the myRIO. This caused data from the rotary motion encoder to be collected in the wrong direction. To resolve that, a digital input was added to the breadboard interface connected to the myRIO that could read the signal from the rotary encoder in the direction that was needed. In addition, a calibration equation was added to the program to convert incoming voltage signal from the rotary encoder into units of force, such as Newtons. Another major problem that was encountered was the ability to control the speed of the motor. The problem was due to several factors but the major factor was the complexity of servo motors. In order to address this, the servo motor was swapped for a similar sized DC motor. Fortunately, the motor controller was compatible with a variety of different motors which made this switch relatively easy.

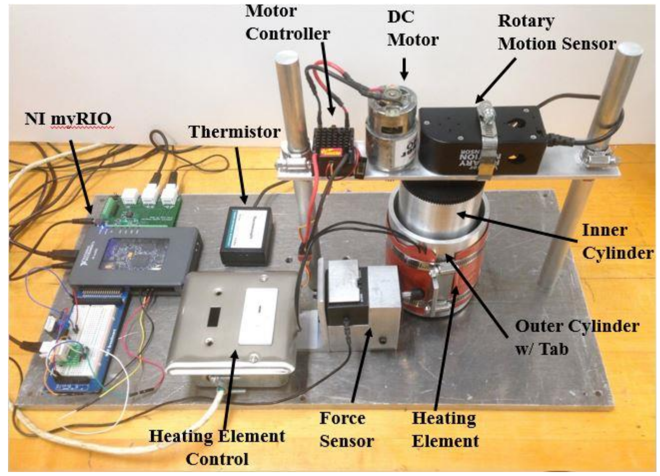


Figure 7. Completed Viscometer with all sensors and components

## Results

Once the programming and the fabrication was complete, testing the viscometer's capabilities was started. A Reynold's number was calculated to determine what RPM values would be appropriate for maintaining laminar flow throughout testing. Most of the data collected had laminar flow so the data could be analyzed. Water was the first fluid tested in order to gage the accuracy of the viscometer. However, water proved to be unusable due to its low viscosity and thus not generating a readable torque. For this application to get any usable data, medium to high viscosity fluids have to be used. Vacuum pump oil, SAE 30 motor oil, and glycerin were among the first fluids used. Initial tests yielded data that could not be reconciled with existing known values. As previously mentioned the force sensor turned out to be the source of the problem in the data that was being recorded. With the force sensor issue resolved, usable data was taken on glycerin, SAE 30 motor oil, and the vacuum pump oil. Testing was done while varying the gap size, the temperature of the fluid, and the speed of the inner cylinder. Reliable data was taken with the medium and large cylinder but the small cylinder could not produce a torque large enough to be picked up by the force sensor currently in place.

The most interesting results were seen when the viscosity of glycerin was graphed against the inverse absolute temperature. Figure 7 shows the known viscosity values of glycerin (blue) falling in between the experimental data of the medium cylinder (orange) and the large cylinder in (grey) [2]. The graph depicts variance in the data collected for the medium and large cylinder compared to the known data. This shows that the ability of the current setup to measure values of viscosity is affected by the alterations in geometry in the viscometer.

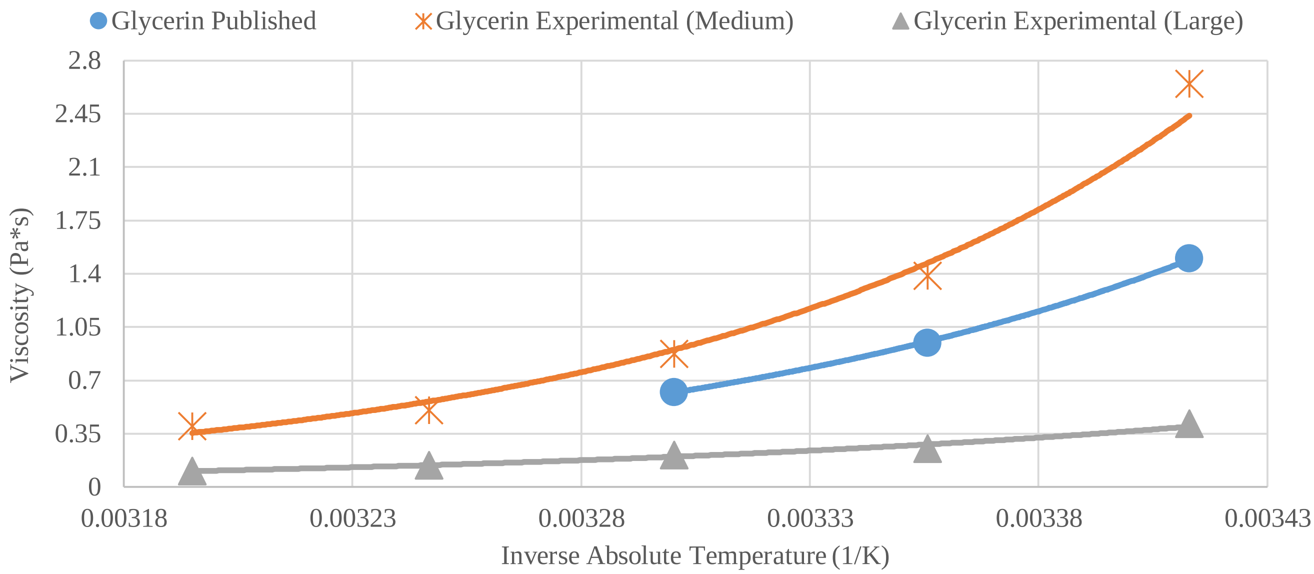


Figure 8. Graph of the Viscosity of Glycerin vs. Inverse Absolute Temperature [2]

**Discussion**

The initial results of the project are promising. The viscosity data obtained from the variety of fluids that were used suggest that the device is capable of obtaining reliable viscosity values over a range of temperatures. This is most prevalent in the data for glycerin but was also present in some of the other fluids tested. It was also determined that varying the geometry, specifically changing the gap size between the inner and outer cylinder does indeed have an effect on the accuracy and reliability of the data values for viscosity. On average the data values from one gap size to another differed by some constant value. However, the amount of consistent data points throughout a trial fluctuated dramatically depending on which gap size was being used. This is mostly due the change in the amount of torque created from one size cylinder to the next. The smaller cylinder generated very little torque which made for very inconsistent and largely unusable data. The medium and large cylinder both produced ample torque for good data acquisition but the medium cylinder with a gap size of 17.5 mm proved to yield the most reliable and consistent data. Perhaps the large cylinder which creates a 5 mm gap size does not create enough fluid volumetric space for the inner cylinder to move through. This would suggest that there is an ideal gap size for generating the most reliable and accurate viscosity values.

**Conclusion**

The majority of the project's goals were accomplished and the capabilities of the device verified. A rotational viscometer was designed and built meeting most or all of the criteria and requirements laid out in planning. The viscometer has been built to be durable and can be cleaned rather quickly. The LabVIEW program is working properly, and is collecting the required data from the sensors on the viscometer.

Based upon the data gathered for glycerin, the viscosity data collected varies with changes in the geometry of the viscometer. In order to address this further calibration using multiple fluids should be investigated.

Going forward with the design, there are a number of additional things that need to be addressed before the device can be implemented into laboratory use. A more permanent and tamper resistant housing for the myRIO interface and wiring needs to be constructed, as well as a clear safety shield over the device when operating. A better solution for monitoring temperature is needed as the current thermocouple gets caught on the rotating cylinder when placed in the fluid. A manual and procedure will need to be created for the device and device operation. It would be helpful if the program could calculate the Reynold's number during tests to ensure the fluid's flow is laminar. Lastly, the viscometer needs to be properly calibrated to guarantee consistent and accurate data values. With these tasks completed the device should produce viscosity values within the acceptable level of accuracy and be entirely ready for lab use.

**References**

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**Acknowledgments**

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**Biographies**

**Brian Cherrington** is a senior in the Mechanical Engineering Department of Tagliatela College of Engineering. His hopes are to move onto a field of work were he can apply his innate talents and interests in hands on applications and learning.

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