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Viscosity of Propylene Glycol Solutions

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Viscosity of Propylene Glycol Solutions

Overview

Goal: The goal of this experiment is to test the relationship of viscosity and composition by using the viscosity of the unknown substance to find its composition. Measuring viscosity of a substance is important to processing it efficiently, specifically for pumping through a system or determining the best process for treatment.

Comparable Technology: A variety of viscometers exist in order to obtain the most accurate readings of experimental materials. The standard method of measuring viscosity is through a glass tube viscometer, which estimates viscosity by measuring the amount of time it takes fluid to flow through a capillary tube made of glass[1]. Rotational viscometers operate my measuring the time it takes a flowing fluid to turn an object in a fluid[1]. These viscometers make use of the flowing force of the fluid, and they can use either a spring system or a digital encoder system[1]. Different measuring systems exist as well, with the standard being a cone and plate system, where fluid flows under the cone shape and over the plate, in order to minimize shear stress[1]. Parallel plate systems use two parallel plates and is ideal for measuring across temperature gradients, allowing a smooth transition[1]. Couette systems use a cup and filling material, and the fluid flows in between the two[1]. These systems are best for materials with low viscosity, since this system minimizes shear stress, but the system is also harder to operate routinely due to issues with cleaning and needing larger volumes of fluid[1].

Procedure: An unknown concentration of propylene glycol solution and seven known concentrations of propylene glycol solution were used for this experiment. A Cannon-Fenske Routine Viscometer was used to measure the viscosities of the known and unknown solutions. Solutions that were less viscous used size 50 capillary glassware, size 100 was used for the unknown solution, and solutions with higher viscosity used size 150 capillary glassware. The mass of water and propylene glycol were weighed to make each solution to be used in the calibration curve. Time was measured when measuring viscosity at a constant temperature of 40^{0}C.

Principles

Kinematic viscosity is the ratio of dynamic viscosity to density. The ratio of shear stress to the shear rate is the dynamic viscosity of a fluid, which gives a measurement of resistance to deformation in laminar flow for a Newtonian fluid. This ratio is unique to kinematic viscosity, which will allow the experiment to only consider two variables (kinematic viscosity and concentration) in order to interpolate for an unknown variable.

Temperature, density, and composition can create changes in the deformation of the flow. Pressure is negligible on liquid-phase fluids, so it does not factor into this experiment.

Kinematic viscosity can be measured using the viscometer because of a relationship between the Hagen-Poiseuille law, pressure drop because of gravity, dynamic viscosity, and kinematic viscosity. Kinematic viscosity can also be related to time using a viscometer constant specific to each capillary glass.

Commented [HK1]: What exactly is the K constant? If it is specific to each capillary, where do you get the values from?

Commented [MC2R1]: Should be C constant, and it is a manufacturer provided quantity.

$$\mu = Ct\rho$$

Where μ is the dynamic viscosity, C is the viscometer constant, t is time, and p is the density. Viscometer constants are generally measured and provided by the manufacturer of the viscometer. The above equation is used to calculate dynamic viscosity, which can be converted to kinematic by dividing by density.

$$v = \mu/p$$

Where v is the kinematic viscosity, μ is the dynamic viscosity, and p is the density. This information will be used to graphically relate concentration of solute and dynamic viscosity.

The Cannon-Fenske Routine Viscometer is a large water bath with a coil for temperature control and a fin to keep constant thermoequilibrium. It is used to measure the viscosity of various solutions. Capillary glasses are placed in the bath as a vessel for the liquid to measure viscosity. The glassware constricts downward flow of the liquid, where time multiplied by viscometer constant equals the kinematic viscosity. Larger capillary glassware is used to measure solutions with higher viscosities. More viscous solutions will take longer to pass through a capillary glass. In this experiment, propylene glycol solutions will become more viscous with increasing concentration of propylene glycol. This information can be used to compare the unknown to known concentrations.

Procedure

Experimental Procedure

1. The experimenter will be given a number of solutions with known concentrations of propylene glycol in water and one unknown solution. These can be any concentration between 0% and 100% propylene glycol, with variation between the solution concentrations.
2. Measure the viscosity of each solution using the viscometer procedure and record the findings.
3. For the unknown solution, measure its viscosity as well.
4. To find the concentration of the unknown solution, use the concentrations and viscosities of the known solutions and the viscosity of the unknown solution with linear interpolation or a linear-fit program to find the unknown concentration.

Viscometer Procedure

1. Clean the viscometer using water, and by passing clean, dry, filtered air through the instrument to remove the final traces of solvents.

2. If there is a possibility of lint, dust, or other solid material in the liquid sample, filter the sample through a sintered glass filter or fine mesh screen.

3. To charge the sample into the viscometer, invert the instrument and apply suction, immerse the arm in the liquid sample, and draw liquid in up to the marked starting point. Wipe the arm clean, and turn the instrument to its upright position.

4. Place the viscometer into the holder and insert it into the constant temperature bath. Align it vertically by means of a small plump bob in the large tube or use a self-aligning holder.

5. Allow approximately 10 minutes for the sample to come to the bath temperature at 40^0C and 15 minutes at 100^0C.

6. Apply suction to the arm and draw the liquid into the tube.

7. To measure the efflux time, allow the sample to flow freely down the tube measuring time for the sample to leave the marked endpoint.

8. Repeat steps 6 and 7 for check runs.

Commented [HK3]: Is the viscometer the different size capillary glassware?

Commented [MC4R3]: No, the viscometer is the device used for measurement, while the glasses are separate from it until the experiment is performed.

Representative Results

The viscosity of different concentrations of propylene glycol were measured. Viscosity was found to increase with propylene glycol concentration, as expected. Times were recorded to be used to find kinematic viscosity by multiplying by the C constant that corresponded to the glassware size. Many measurements were made to account for random error.

Time as measured by the experimenter, viscometer constant, and density can be inserted into:

$$\mu = Ct\rho$$

To solve for dynamic viscosity. To convert to kinematic viscosity, divide dynamic by density:

$$v = \mu/p$$

The unknown concentration was also calculated and was compared to these sample concentration solutions. Linear interpolation was used to estimate the concentration, and the relationship was best fit to a linear function (Figure 1).

$$y = y_1 + \frac{x - x_1}{x_2 - x_1}\,(y_2 - y_1)$$

For the above equation for linear interpolation, use any two data points of kinematic viscosity and known concentration from the known solutions, then set x as the measured viscosity of the unknown solution, to find the unknown concentration (y).

This linear graph shows that viscosity and composition follow a linear relationship. As solute composition increases in a solution, viscosity will increase with it. Knowing this relationship, the concentration of the unknown solution could be found easily by measuring the viscosity and relating it to the known relationship between concentration and viscosity. Our experiment could have been more accurate with more known concentrations tested or a more precise thermometer.

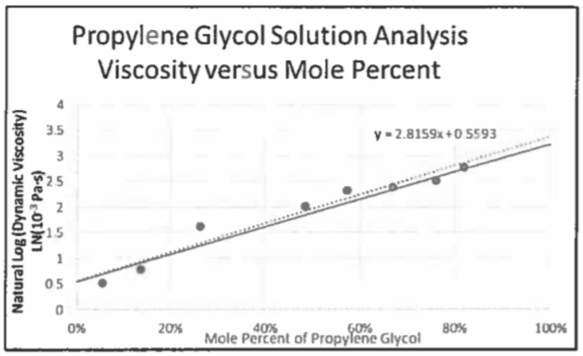

Figure 1: The relationship between concentration of solution and viscosity demonstrated a linear fit.

Summary

The goal of this experiment was to test the relationship of viscosity and composition by using the viscosity of the unknown substance to find its composition. A number of known concentration solutions of propylene glycol and one unknown concentration solution were tested. Relationships between density, dynamic viscosity, and kinematic viscosity were used to compare the solutions. Since solutions become more viscous as they became more concentrated, we were able to narrow the concentration of the unknown solution down to a small range. Linear interpolation was used to estimate the concentration, and the relationship was best fit to a linear function. For this experiment, increasing the accuracy of the thermometer could have decreased our uncertainty significantly, since it is the main source of error. More concentrations could also have been tested to increase the precision.

Applications

Accurate viscosity testing is important to a variety of fields. In the food processing industry, food must be tested for viscosity throughout its creation as it is transported throughout a facility[2]. These measurements are used to maximize the efficiency of the process and to establish standards for production[2]. The viscosity is important to the food industry because it will determine how long transport of food through a pipe or processor will take, how long it will take food to dry, and the time it will take to dispense food into packaging for transportation and retail[2]. Engineers will use the viscosity to maximize flow of the product through piping in order to save energy and maximize the product, without diminishing the quality of the finished product[2]. Viscosity is also important to establish safe standards for the force that can be applied to materials and product without damaging it[2].

In the petroleum industry, viscosity is an important control for quality assessment[3]. When purchasing or processing crude oil, companies must measure the viscosity to determine the appropriate treatment[3]. The viscosity gives important information about the composition of the crude oil[3]. Oil of different compositions will then be used to create different products[3]. Some refineries can only process oils of a certain viscosity, so accurate testing is important to determine which materials they can use for refining[3]. Further, in oil refining, the viscosity of the oil is used to plan the most efficient methods for extraction, transportation, and refining[3]. Temperature can also have an impact on the viscosity of oil, so controls must be put in place to have the oil at an appropriate temperature for its viscosity[3]. Additionally, the viscosity of an oil will determine the way it is cleaned up in the case of a leak[3].

Sources

1. "A Basic Introduction to Viscometry." *A Basic Introduction to Viscometry*. N.p., n.d. Web. 7 Jan. 2017.

2. CSC Scientific. "What is Viscosity, and Why is Measuring Viscosity Important?" *What is Viscosity, and Why is Measuring Viscosity Important?* N.p., n.d. Web. 7 Jan. 2017.

3. "Applications." *Anton Paar*. N.p., n.d. Web. 13 Jan. 2017.