How Does Temperature (283 K,293 K,303 K,318 K and 333 K) Affect Honey's Viscosity?

Introduction

Honey is commonly used in life. Apart from being a kind of tasty sauce, honey can also be used as medicine. According to Mayo Clinic, antioxidants in honey are helpful to reduce cardiovascular disease. Besides, honey can also act a cough suppressant for people with upper respiratory infections and acute nighttime cough.

We are often warned to pour honey out carefully, since honey is very viscous. I often notice that it is easier to pour honey out in hot summer during cold winter because the honey is less viscous during summer. This is intriguing for me because different values of viscosity involved in different level of difficulty of extracting and processing of the liquid, which also leads to different cost of production for factories. I decided to investigate this topic because I would like to use this research to educate people the viscosity of honey at various temperatures and help factories to select the right time of utilizing honey. The density of honey is 1420 kg·m^{-3} (Practical Investigation -Density), which I will be used in the calculation part.

There are multiple factors affecting the viscosity of the liquid (Temperature, Flow Conditions, Pressure, Multiphase flow and Suspended Particles) (Dey). I choose the temperature to investigate because temperature can be controlled easier and temperature is more related to my personal experience of using honey.

Background Information

This research investigates the relationship between temperature and the viscosity of honey. The viscosity of the fluid can be seen as the inverse of fluidity (how easily a fluid may flow). The viscosity is the internal friction between the molecules comprising the fluid. (Dey). As a result, a fluid with a high viscosity has more internal friction to prevent flow, whereas a fluid with a low viscosity has little friction. (Dey).

As temperature increases, the kinetic energy increases and the molecules in the liquid move faster and become more mobile. The attractive binding energy is reduced and therefore the viscosity is reduced. ("How Does Temperature Change Viscosity in Liquids and Gases?").

To measure the value of viscosity, Stokes law should be introduced. Stokes law measure the drag force F_d on a spherical object in a viscous fluid. ("Stokes' Law | Wikiwand")

As I show in figure 1, the red spherical ball in the liquid is experiencing an upward drag force F_d as well as a downward gravitational force F_g.

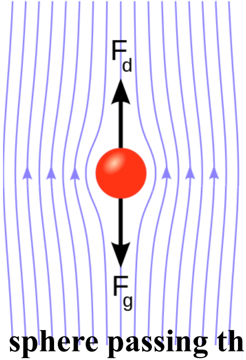


Figure 1: Free body diagram of a sphere passing through a liquid from Wikiwand.

According to Stokes law, the velocity can be calculated as:

$$v = \frac{2}{9}\frac{(\rho_p - \rho_f)}{\mu} gR^2$$

where
g is the gravitational field strength ($\mathrm{m{\cdot}s^{-2}}$)
R is the radius of the spherical particle (m)
ρ_p is the mass density of the particle ($\mathrm{kg{\cdot}m^{-3}}$)
ρ_f is the mass density of the fluid ($\mathrm{kg{\cdot}m^{-3}}$)
μ is the dynamic viscosity ($\mathrm{kg{\cdot}m^{-1}{\cdot}s^{-1}}$). (Wikiwand).
This formula can be transferred to be

$$\mu = \frac{2}{9}\frac{(\rho_p - \rho_f)}{v} gR^2$$

The formula above can help me to calculate the dynamic viscosity directly.
My aim is to measure how temperature affects viscosity of honey, so I will draw a curve about value of viscosity of honey at 283 K,293 K,303 K,318 K and 333 K.
The formula which relates temperatures and viscosity of fluid:

$$\mu = A \cdot e^{B/T} \text{(Banerji)}$$

where A and B are constants.

Research question

How does temperature (283 K,293 K,303 K,318 K and 333 K) affect honey's viscosity?

Hypothesis

I am predicting that as temperature increases, the viscosity of honey decreases exponentially. Due to the formula given by Banerji, $\mu = A \cdot e^{B/T}$, indicating the exponential relationship between temperature and viscosity.

Variables

Table 1: Independent and dependent variables in the experiment.

Independent Variable	Method of manipulation
Temperature (283 K,293 K,30 3K,318 K and 333 K).	Conduct the experiment through different temperatures (283 K,293 K,303 K,318 K and 333 K). For temperature 303K,318K and 333K, I used the hot plate and water bath to heat the honey. For 283K and 293K, I placed some ice into a 500 cm^3 beaker and mix the water to control the temperature below the 298K. I used a temperature probe to monitor all of the temperatures above. I use a glass rod to stir the honey to make sure that heat is transferred evenly.

Dependent Variable	**How measurements are taken**
Viscosity of honey	The time of falling of the ball and the distance the ball falls are two variables which need to be measured. Other values need for calculation have already been known by the data provided (from data booklet or from producers). The terminal velocity of the ball falling can be calculated as $\frac{\text{distance the ball falls}}{\text{Time of falling of the ball}}$. The terminal velocity is calculated when the ball is falling to the line of 50 ml in 100 ml measuring cylinder, which can help me to ensure that the ball is close to terminal velocity.

Table 2: Controlled variables in the experiment.

Controlled Variables	**Why it needs to be controlled**	**Method of manipulation**
Multiphase flow	The volume of each phase influences the viscosity of multiphase flow. (Dey). Therefore, controlling the phase of honey eliminates the possibility of another factor changing dynamic viscosity.	Always use liquid phase of honey.
Pressure of the honey	The intermolecular distance reduces as pressure increases, and hence the intermolecular force increases. As a result, the relative velocity between two adjacent layers decreases, resulting in an increase in the viscosity. ("Effect of Pressure on Viscosity - QS Study"). Therefore, controlling the pressure eliminates the possibility of another factor changing dynamic viscosity.	Conduct the experiment under normal pressure (100 kPa).
Flow Conditions	The viscosity of liquid remains constant in laminar flow but changes in turbulent flow. (Dey). Therefore, controlling the flow conditions eliminates the possibility of another factor changing dynamic viscosity.	Conduct the experiment in the same environment, keeping liquid still.
Suspended Particles	High solid content adds viscosity to the system, which must be taken into account while determining the proper rate of settling. Therefore, it is vital to make sure that the honey I used is very pure. ("Stoke's Law")	Use pure honey solution in the experiment.

Material List

Table 3: Material and equipment list.

Material List	Equipment List	
Honey 100ml	Sphere 2,500 kg·m^{-3} ×1 with radius R 0.014 m	100 ml Measuring Cylinder ± 1 cm^3 ×1
	Water bath ×1	Temperature probe ×1
	Hot plate ×1	Glass rod ×1
	500 ml beaker ×1	iPhone timer ×1

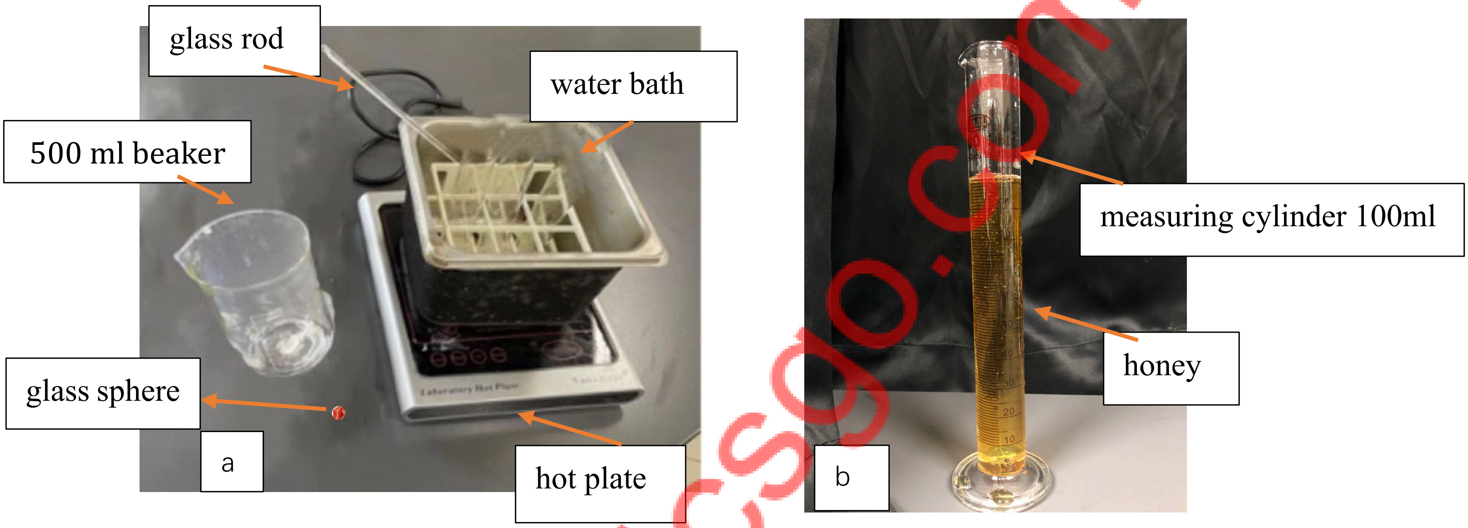


Figure 2: Setup for the experiment.

Procedure

1) Prepare 100 ml honey through a 100 ml measuring cylinder. Pour it into a 500 ml beaker.
2) Place the 500 ml beaker with 100 ml honey into water bath. Pour a proper amount of water into the water bath. Heat the honey by a hot plate at 303 K.
3) Transfer the heated solution to a 100 ml measuring cylinder. Place the spherical glass ball into the honey and record it falls.
4) Repeat steps 2 to 3 five times.
5) Repeat steps 2 to 4 at 283 K,293 K,303 K,318 K and 333 K respectively. At 283 K and 293K, placing ice and water into a water bath to decrease the temperature because room temperature is higher than 283 K and 293 K.

Environmental, Ethical and Safety Concern.

When I increase the temperature of hot plate to 303 K,318 K and 333 K, it would be very dangerous to touch the hot plate due to the high temperature.
There are no environmental or ethical or safety concern when conducting this experiment.

Table 4: The time of falling at different temperatures (283 K, 293 K, 303 K, 318 K and 333 K).

For observation convenience, average data is marked into brown color, and the outlier is marker red.

Temperature (±0.5℃)	Time of Reaction (s) ±0.5s					
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
283.0 K	138	140	120	133	135	133
293.0 K	80	79	80	80	79	79.6
303.0 K	28	31	27	31	30	29.6
318.0 K	6	8	9	4	12	7.8
333.0 K	3	3	3	7	3	3.8

Calculation process of average time of falling, take the example at 333K:

Average time of falling $= \frac{3.0+3.0+3.0+7.0+3.0}{5} = 3.8\text{s}$

Data Analysis and Error Propagation

In the following process, I will only show one data process (at 333 K). The rest of the data result will be shown in the summary table. The following calculation process is assumed in an ideal condition in which I ignore the small errors in fluctuations of temperature and pressure, which might affect the result of experiment. I also ignore the evaporation rate of honey solution. If the evaporation rate of honey solution is high, then the height of the solution might be lower than expected, so the reaction time might be higher, vice versa. This error will be further discussed in the evaluation part.

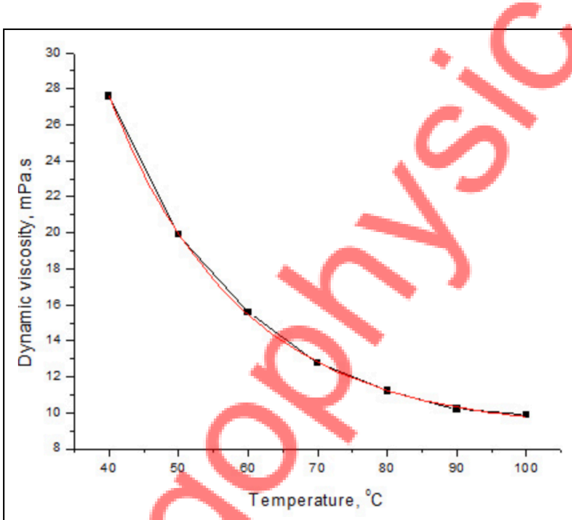
Table 5: Calculation and error propagation.

Determine the difference between density	Error Propagation
$\rho_p - \rho_f$=2500$kg \cdot m^{-3}$ −1420$kg \cdot m^{-3}$ = 1080 $kg \cdot m^{-3}$	There is no error propagation here because the data of density of honey and the particle come from theory.
Determine the velocity of falling	Error Propagation
$v = \frac{0.25}{3.8} = 0.066\ \text{m} \cdot \text{s}^{-1}$	Percentage uncertainty of Falling time $= \frac{0.5}{3.8} = 13\%$ Percentage uncertainty of Height of measuring cylinder is 0 because the data comes from theory. Percentage uncertainty of terminal velocity= 13%

Determine the difference between density	Error Propagation
$\mu = \frac{2}{9}\frac{(\rho_p - \rho_f)}{v}gR^2$ $= \frac{2}{9} \times \frac{1080}{0.06578} \times 9.81 \times 0.014^2$ $= 7.0142 Pa \cdot s$	Percentage uncertainty of $\mu = \%v + 2\%R + \%g$ $= 13\% + 0\% + 0\%$ $= 13\%$ There is no percentage uncertainty for R and g because their values are from theory. Absolute uncertainty for μ $= 13\% \times 7.0142$ $= \pm 0.9$
$\mu(333\ K) = 7.0 \pm 0.9\ Pa \cdot s$	

Table 2: Value of dynamic viscosity at (283 K,293 K,303 K,318 K and 333 K).

Temperature(K)	Dynamic Viscosity $Pa \cdot s$
283.0±0.5	245.9±0.9
293.0±0.5	146.9±0.9
303.0±0.5	54.6±0.9
318.0±0.5	14.4±0.9
333.0±0.5	7.0±0.9



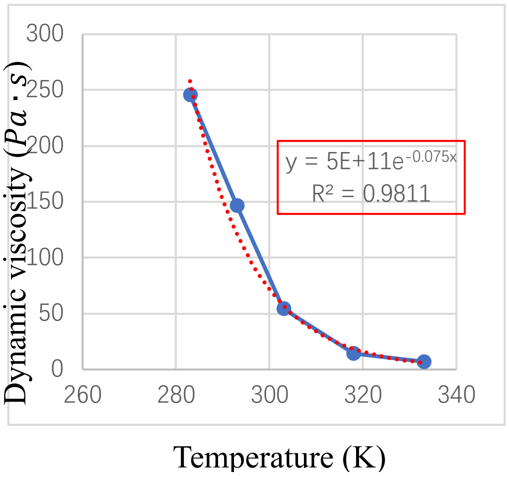


Figure 3: Relationship between temperature and dynamic viscosity of oil. (Stanciu)

Figure 4: Relationship between temperature and dynamic viscosity of honey.

From figure 3, it is shown that as temperature increases, the dynamic viscosity decreases exponentially. In figure 4, the value of R^2 (correlation index)= 0.9811, highlighting correlation between temperature (K) and is very strong and examines the reliability of my data collected. The error bar is added in figure 4, however, the error bar is too small to be indicated on the graph, highlighting the relative accuracy of the data collected.

Although the exponential relationship between temperature and viscosity is commonly proved, Banerji has pointed out some limitations. Therefore, an empirical relationship between viscosity and temperature was proposed:

$$\log(log\mu)=\mathrm{A}-BT. \text{ (Banerji)}$$

where A and B are constants.

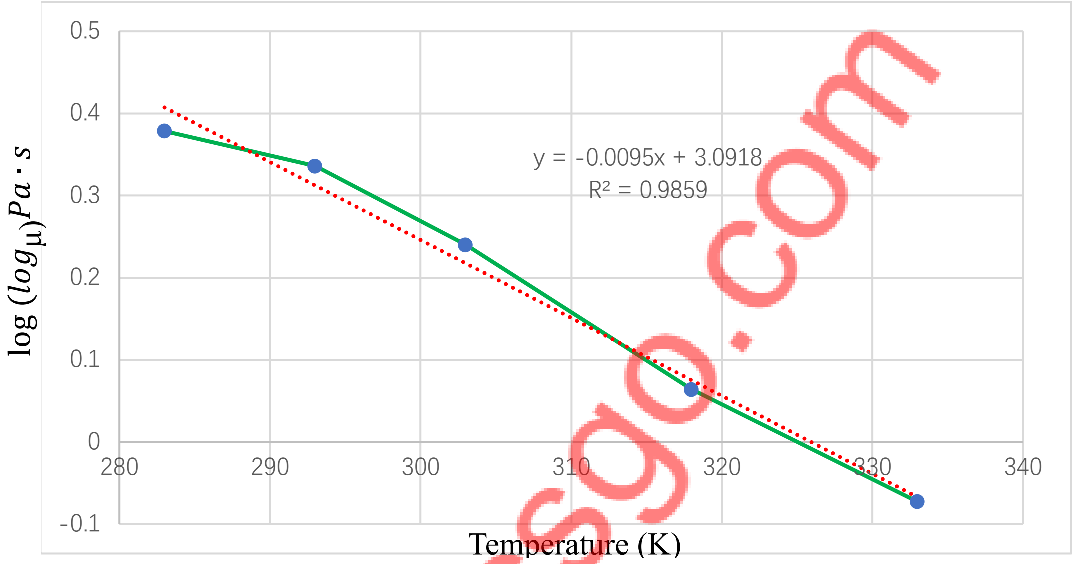


Figure 5: The relationship between temperature and viscosity of honey in logarithm.

From figure 5, it is indicated that there is a negative proportional relationship between temperature and $\log(log\mu)$. The R^2 is 0.9859, highlighting temperature has a strong correlation with the viscosity of honey. The error bar is too small to be shown in my graph. This result aligns with the theory indicated by Banerji, stating that there is a linear regression between temperature and $\log(log\mu)$.

I could not calculate the percentage error in this experiment because my investigation focuses on the trend of viscosity of honey and it is extremely difficult to find others' work same as mine. Besides, different brands of honey may have different value of viscosity due to natural variations in composition (sugar, colloid materials, and water content).

However, according to Banerji, the relationship between viscosity of water in logarithm and temperature is also linear, which is the same as my findings of the relationship between temperature and honey in logarithm.

Evaluation and Improvements:

(1) Strengths and practice

a. Although there exist random errors when I was recording the time of reaction by iPhone timer, referring to data marked red in table 1, which may affect the reaction time. However, five experiments for each temperature were averaged to reduce random errors, contributing the value of $R^2 = 0.9859$. This practice thus increases the precision of the value of dynamic viscosity of honey.

b. My stirring of honey can make the temperature in the honey solution more consistent. In the preliminary trial, I found that the temperature at the top of the honey was different from the temperature at the bottom, which would definitely affect the speed of the sphere. Therefore, in the actual experiment, I increase the amount of water in the water bath and continued to stir the honey to make the temperature even.

(2) Systematic Errors

a. I measured the value of viscosity by using Stoke's Law. However, there are some limitations with Stoke's Law. The precision of Stokes' equation results might be impacted by Brownian movement, which is a spontaneous (zigzag) movement of particles in a fluid induced by collisions with high-speed atoms or molecules in the gas or liquid. Brownian migration will reduce sedimentation to some extent. As a result, the true rate of sedimentation differs from the rate estimated using Stokes' equation.

b. When I used a water bath and a hot plate to heat the honey to a specific temperature, the temperature may not have been maintained as required during the process of pouring the honey from beaker to measuring cylinder. As a result, at temperatures ranging from 303K to 318K and 333K, the actual temperature may be lower than projected. Regarding the temperatures of 283K and 293K, the actual temperature during the pouring operation may be greater than 283K due to the ambient temperature of 298K. This may impair the accuracy of the outcome.
Improvement: Next time, I'll conduct the experiment in a water bath to keep the temperature steady.

c. According to Moisture in Honey Test, raw honey has a moisture content of around 18%. Water will evaporate at high temperatures, causing the structure of the honey to vary Therefore, the viscosity may change accordingly.

(3) Random Errors

From data propagation, the total percentage uncertainty is 26.31578%, this error is considered random error, which can be reduced with more trials. Since I have repeated five trials for each temperature, the random error is diminished small enough to have a significant impact on the results of experiments.

a. When I finished one trial, I needed to pour the honey out to take the sphere. Every time I poured the honey out, I needed to supplement the honey to 100ml. During this process, the distance of the sphere falling may become longer or shorter, which causes the random error.

b. The time of falling is counted by an iPhone timer manually. Due to the fact that there is no apparent change to indicate the sphere has fallen to the bottom of the measuring cylinder, the judgment of the sphere falling to the bottom may not be accurate.

Conclusion

This investigation aims to investigate the relationship between temperature and viscosity of honey. After interpretating figure 4 and figure 5, my hypothesis is verified, which is as temperature increases, the dynamic viscosity decreases exponentially. Although the data does not fit perfectly with the exponential trend, the value of $R^2 = 0.9859$ is high enough to prove my hypothesis.

Future Work

In the future, I would like to further investigate how different brands of honey have various values of viscosity at different temperatures. This can lead me to know how honey varies in their compositions for different brands. Besides, I am also intrigued by how different pressures change the viscosity of honey. In this research, I have already figured out how different temperatures affect the value of viscosity of honey, so it is reasonable for me to have an investigation on the effect of pressure. It is very common for factories to adjust the pressure to increase the productivity, so this further investigation would be very useful to society.

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