Determining the Activation Energy of Corn Syrup using the Arrhenius Equation

The viscosity of corn syrup at varying temperatures was determined by measuring the terminal velocity of a ball bearing falling through the fluid.

QUEENSLAND ACADEMIES
Science Mathematics & Technology Campus

Utkarsh Sharma
QASMT
Toowong, Queensland, Australia
June/July 2018

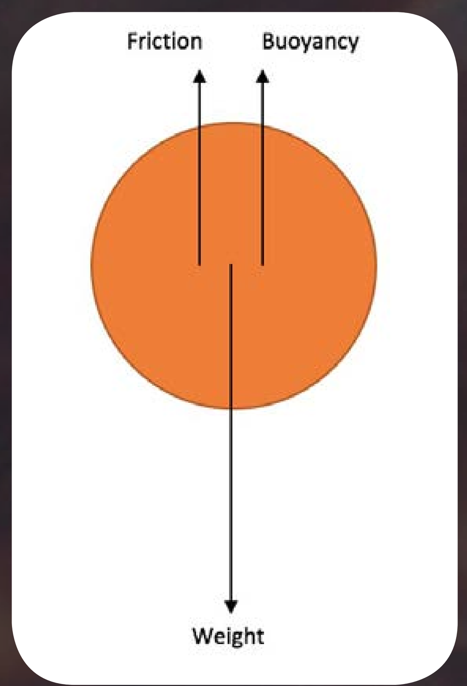
Research Question:

What is the activation energy of Corn Syrup using the Arrhenius Equation?

Background:

This investigation measured the dynamic viscosity of corn syrup by examining the forces on a ball bearing falling through the liquid. The Corn syrup was heated to various temperatures and the change in viscosity recorded.

All bodies in a liquid will, at first, accelerate due to gravity and then slow down, due to the frictional forces acting on the body. The magnitude of this frictional force on a sphere radius r travelling at terminal velocity v_T with dynamic viscosity η is given by Stokes' Law, which states:



$$F_{viscosity} = 6\pi r\eta v_T$$

Weight Force = Frictional Force + Bouyant Force

$$mg = 6\pi r\eta v_T + \frac{4}{3}\rho_l g\pi r^3$$

$$\eta = \frac{2r^2 g(\rho_b - \rho_l)}{9v_T}$$

This formula gives the value of the dynamic viscosity of a substance density ρ_l from a falling sphere (density ρ_b and radius r) at terminal velocity v_T.

When molecules flow from one position to another, they have to overcome an energy barrier. In a liquid this is called the activation energy (E_α). The relationship between viscosity and activation energy given by the Arrhenius-Type equation:

$$\eta = Ae^{\frac{E_\alpha}{RT}}$$

R is the universal gas constant and T is the temperature of the liquid. The constant A is a entropy factor specific to the viscous fluid.

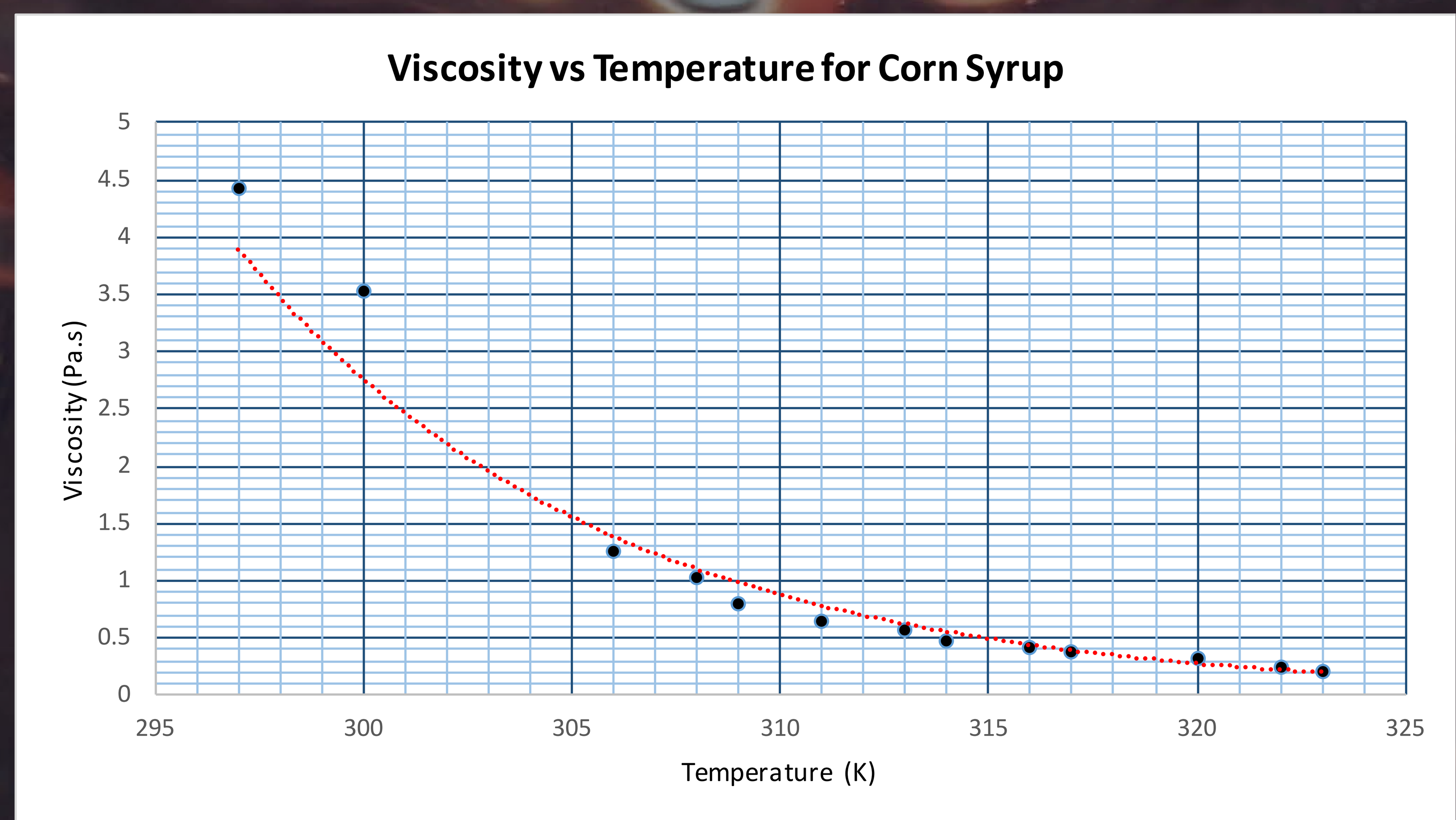
Methodology:

1. Measure the diameter and mass of the ball bearing and determine its density.
2. Determine the density of 800mL of corn syrup by measuring its mass.
3. Pour all the corn syrup into a beaker that can fit within a microwave.
4. Put the beaker into the microwave and heat it up in 30 seconds increments.
5. Measure the temperature after every 30 seconds and raise the temperature of the liquid to approximately 50°C.
6. Pour all the liquid back into the measuring cylinder and record its temperature. Before dropping the ball each time, record the temperature of the liquid.
6. Drop the ball bearing into the liquid and record its motion on a digital camera.
7. Repeat step 5 and 6 multiple times for a varying range of temperature values.
8. Import all videos into Tracker and plot a displacement time graph. By finding the slope of the graph, we can find the terminal velocity of the ball bearing.

Figure 1. Apparatus setup

Data:

Temperature ($\pm 0.5\ K$)	Terminal Velocity ($\pm 0.001\ s$)	Viscosity ($Pa.s$)	Error in Viscosity ($Pa.s$)
323	6.032	0.221	0.0438
322	5.176	0.257	0.0511
320	4.142	0.321	0.0638
317	3.495	0.381	0.0757
316	3.061	0.435	0.0864
314	2.763	0.482	0.0958
313	2.323	0.573	0.1140
311	2.035	0.654	0.1301
309	1.645	0.809	0.1611
308	1.293	1.029	0.2050
306	1.045	1.274	0.2540
300	0.377	3.530	0.7100
297	0.300	4.433	0.8946



Graph 1. Viscosity of corn syrup for varying temperature.

Analysis:

The graph of viscosity vs temperature shown in graph 1 shows an exponential relationship consistent with the Arrhenius-Type equation:

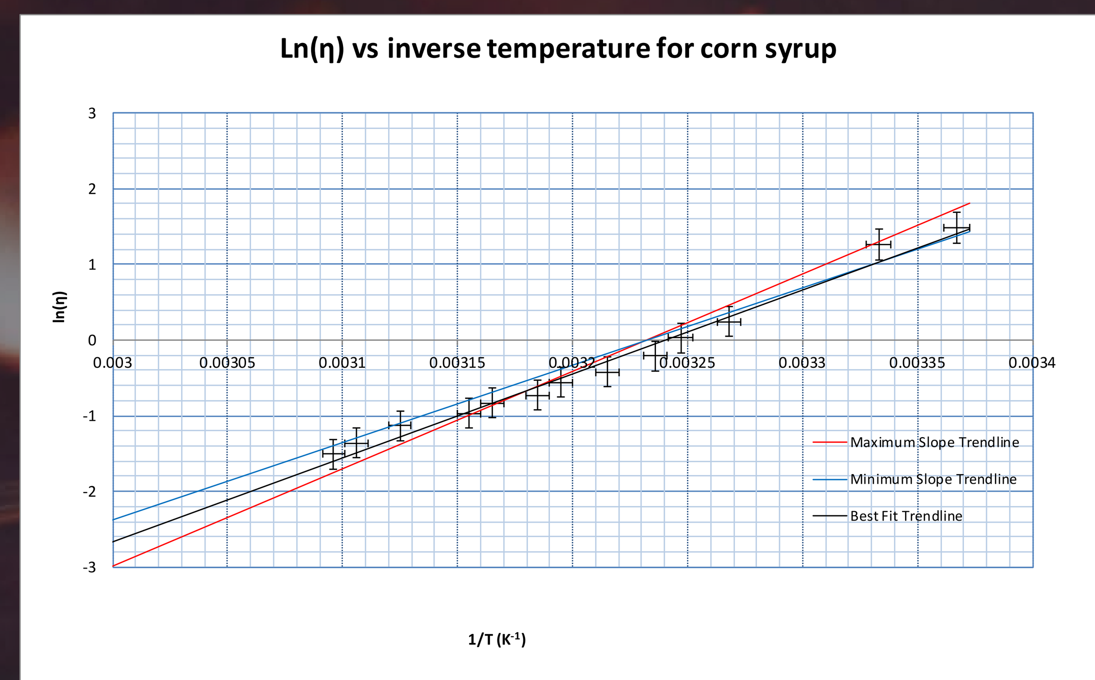
$$\eta = Ae^{\frac{E_\alpha}{RT}}$$

This equation can then be linearized by taking the natural log of both sides.

$$\ln\eta = \ln A + \frac{E_\alpha}{R}\cdot\frac{1}{T}$$

Thus, by plotting a graph of the natural log of viscosity vs the reciprocal of temperature, the gradient can be used to find the activation energy.

Natural log Viscosity (ln(η))	Uncertainty in ln(η) (Δln(η))	Inverse Temperature (1/T) K^{-1}	Uncertainty in 1/T (Δ1/T) K^{-1}
-1.511	0.1986	3.096×10^{-3}	4.79×10^{-6}
-1.358	0.1987	3.106×10^{-3}	4.82×10^{-6}
-1.135	0.1987	3.125×10^{-3}	4.88×10^{-6}
-0.966	0.1988	3.155×10^{-3}	4.97×10^{-6}
-0.833	0.1988	3.165×10^{-3}	5.00×10^{-6}
-0.730	0.1988	3.185×10^{-3}	5.07×10^{-6}
-0.557	0.1989	3.195×10^{-3}	5.10×10^{-6}
-0.424	0.1990	3.215×10^{-3}	5.17×10^{-6}
-0.212	0.1991	3.236×10^{-3}	5.24×10^{-6}
0.029	0.1992	3.247×10^{-3}	5.27×10^{-6}
0.242	0.1994	3.268×10^{-3}	5.34×10^{-6}
1.261	0.2011	3.333×10^{-3}	5.56×10^{-6}
1.489	0.2018	3.367×10^{-3}	5.67×10^{-6}



Graph 2. Linearised data.

Evaluation:

Using the gradient of the Graph 2 the activation energy (E_α) was calculated to be 92.1 kJ/mole with an uncertainty of 1.1 kJ/mole. The uncertainty was determined from the maximum and minimum slope lines. The intercept ln (A) is 35.9 ± 4.3 the entropic factor of corn syrup.

The experimental values obtained in this study are in reasonable agreement with literature values. Quoted literature values for fructose solution activation energy range from 20-100 kJ/mole depending on the syrup concentration. The Karo brand corn syrup used is a concentrated solution of fructose and glucose sugars.

A potential source of error in this investigation is the evaporation of the water from the corn syrup during heating changes the concentration and therefore viscosity. The corn syrup was heated only to a maximum of 50°C to minimise the evaporation effect.

Conclusion:

The viscosity of the corn syrup at various temperatures was successfully determined using a terminal velocity technique. By application of the Arrhenius Equation model the activation energy of corn syrup was 92.1 ±1.1 kJ/mole.