MECH2670: Thermofluids 2

REAL INTERNAL AND EXTERNAL FLOW:
Viscosity of Oils

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1   Introduction

1.1   Aims

Oils come in many different forms, most filled with a wide variety of hydrocarbons and other chemicals. This results in different oils to have different viscosities. The aim of this experiment was to determine the viscosity of two different oil mixtures both created from the same base oils. From this we can see what effect adding different concentrations of these oils with known viscosity to the viscosity of a mixture. Secondly, the viscosity of oils also changes with temperature which allows us to see the effect that this change will have on the viscosity of the oils as well as the concentration of the two base oils. To measure the relationship between temperature and viscosity Vogel's Equation (Equation 2) is used. This will be later used in calculations to determine the accuracy of this equation and the results. [2]

1.2   Theory

Extra high viscosity index (XHVI) oils are used in this experiment, specifically XHVI4.0 and XHVI8.2. These oils are highly refined, mineral based oils. Fluids like these are produced from crude oils in oil refineries and then are mixed with other compounds to form the final oil used in the experiment [2]. This is good because it means that the properties of the oil once processed are known and as such can be used for theoretical calculations for experiments. On oils such as these we can apply the relationship in Equations 1 [3]& 2 in order to find the theoretical relationship between the viscosity and temperature of particular oils. The equation is known as Vogel's Equation (or more specifically the Vogel–Fulcher–Tammann–Hesse Equation).

$$ln(\eta) = k + \frac{b}{T + \theta} \tag{1}$$

Or,

$$\eta = ke^{\frac{b}{T+\theta}} \tag{2}$$

Where,

η = dynamic viscosity (mPa.s)
k,b = constants for a particular oil
θ = constant (assumed to be 95) [2]
T = temperature (°C)

2   Methodology

2.1   Experiment

2.1.1   Apparatus

This experiment requires very little apparatus. The main requirements are the two known oils and then the two different oil mixtures that are being tested. The other piece of equipment is the viscometer which measures the viscosity of the oil, and a water bath to set the temperature of the oil. Finally with a thermometer to measure the temperature that the oil is at. The viscometer has a known conversion factor some of which are shown in Table 1 from which the recorded data can be converted into the viscosity.

2.1.2   Set-up

Simply to set up the experiment the oil is placed in the viscometer as shown in Figure 1. The water bath is set to temperature. As can be seen in the image the starting temperature is $40°C$. Then when ready switch on the viscometer and begin taking readings.

2.1.3   Procedure

To complete this experiment the viscometer is switched on and the motor begins to spin the spindle and the torque is measured by the machine. To get an accurate result it is best to allow for a few rotations of
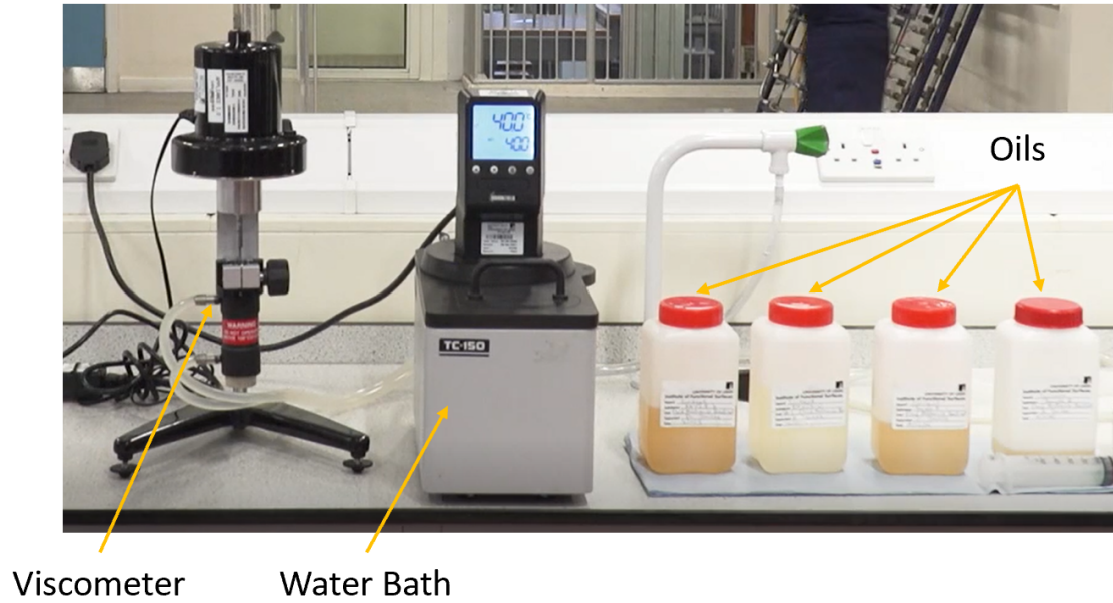
Figure 1: Shows the viscometer with the oil inside ready to begin testing.

the liquid in order for everything to have reached a steady state point. Once results have been recorded at this speed and temperature, the speed is changed. Beginning at 3RPM for each oil and the raised to 6. Next the temperature is changed (increased beginning from $40°C$ to $70°C$ in $5°C$ increments. Results are recorded for two speeds at each temperature. Repeat this process for each of the oil mixtures in the machine.

2.2 Viscosity Conversion

Table 1: Snapshot of Correction factors table

	Speed (RPM)	Shear rate $(\sec^{-1})$	Factor
[2]	12	14.68	0.5
	6	7.34	1.0
	3	3.67	2.0
	1.5	1.83	4.0

After recording the data, the torque must be multiplied by a conversion factor to find the dynamic viscosity of the fluid. The values for this factor are as shown in Table 1 [2].

2.3 Vogel's Equation

Using Vogel's equation (Equation 2) and the experimental values at $40°$C and $70°$C two equations can be created:

$$16.45 = ke^{\frac{b}{40+95}} \quad 7.55 = ke^{\frac{b}{70+95}}$$

Solving the two equations simultaneously provides solutions to the values of k and b.

2.4 Mixture Percentages

A similar approach can be taken to find the ratio of XHVI 4.0 oil and XHVI 8.2 oil in each of the different mixtures.

$$\eta_{mixture} = \eta_{4.0}x_1 + \eta_{8.2}x_2 \tag{3}$$

Where,

η = dynamic viscosity (mPa.s)

x = percentage of fluid in the mixture (/100)

Equation 3 is Arrhenius method for finding the viscosity of a mixture of two different fluids that both have known viscosities. [1]

$$1 = x_1 + x_2 \tag{4}$$

Equation 4 can be derived from the fact that the concentration of both of the oils must add to 100%. The last step again is the solve the two equations simultaneously using the known viscosity values of the oils which have been found in doing this experiment.

3   Results

Tables 2 to 5 display the raw data obtained in this experiment and the then processed data. The initial raw data was the torque measured by the viscometer. By use of conversion factor this data has been converted into the viscosity data of each oil. Labelled under the viscosity section in the table. Finally the last two rows show the average viscosity at each temperature across the two speeds and the theorectical values worked out ising Vogel's Equation.

Table 2: XHIV 4.0

Torque (RPM)	Temperature (°C)						
	40	45	50	55	60	65	70
Raw	**Torque**						
3	8.4	7.3	6.5	5.6	5	4.4	3.9
6	16.1	14	12	10.4	9.1	8.1	7.3
Processed	**Viscosity**						
3	16.8	14.6	13	11.2	10	8.8	7.8
6	16.1	14	12	10.4	9.1	8.1	7.3
Average	16.45	14.3	12.5	10.8	9.55	8.45	7.55
Theoretical	16.45	14.12	12.24	10.72	9.47	8.42	7.55

Table 3: XHIV 8.2

Torque (RPM)	Temperature (°C)						
	40	45	50	55	60	65	70
Raw	**Torque**						
3	20	16.5	14	11.5	10	8.5	7
6	40	33	27.5	23	19.5	17	14.5
Processed	**Viscosity**						
3	40	33	28	23	20	17	14
6	40	33	27.5	23	19.5	17	14.5
Average	40	33	27.75	23	19.75	17	14.25
Theoretical	40	32.66	27.04	22.67	19.23	16.48	14.25

Table 4: Mixture A

Torque (RPM)	Temperature (°C)						
	40	45	50	55	60	65	70
Raw	**Torque**						
3	17.5	15	13	11	9.5	8	7
6	34.5	29	24.5	21	18	15.5	13.5
Processed	**Viscosity**						
3	35	30	26	22	19	16	14
6	34.5	29	24.5	21	18	15.5	13.5
Average	34.75	29.5	25.25	21.5	18.5	15.75	13.75
Theoretical	34.75	28.96	24.45	20.87	18.0	15.66	13.75

Table 5: Mixture B

Torque (RPM)	Temperature (°C)						
	40	45	50	55	60	65	70
Raw	**Torque**						
3	16.5	13.5	11	10	8.5	7.5	7
6	31	25.5	21.5	18	16	14	13
Processed	**Viscosity**						
3	33	27	22	20	17	15	14
6	31	25.5	21.5	18	16	14	13
Average	32	26.25	21.75	19	16.5	14.5	13.5
Theoretical	32	27.01	23.07	19.91	17.34	15.24	13.5

Figure 2 below is a plot of the viscosity from the two constituent oils (XHVI4.0 and XHVI8.2) and the speed that the viscometer was running at.
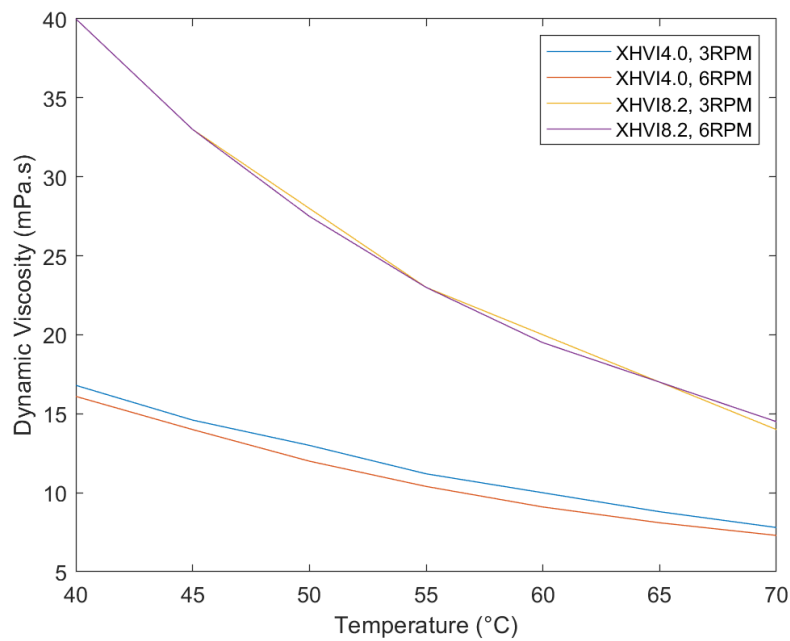

Figure 2: This graph shows the change in the dynamic viscosity of the oils over the temperature range. It also displays the effect that using a different speed can have on the viscosity measurement.

The values of k and b obtained are summarised in Table 5 and obtained using the method shown previously in section 2.2 using Vogel's Equation. The final outcome using these values is then expressed in the theoretical section of Tables 2 to 5

Table 6: k & b values

Oil	k	b
XHVI4.0	0.227	251.12
XHVI8.2	0.137	332.82
Mixture A	0.212	298.96
Mixture B	0.278	278.30

Finally Tables 7 and 8 show the concentration of each of the oils in both of the mixtures.

Table 7: Percentage concentration of oils in Mixture A

Temperature[°C]	XHVI 4.0	XHVI 8.2
40	0.223	0.777
45	0.199	0.801
50	0.175	0.825
55	0.151	0.849
60	0.126	0.874
65	0.101	0.899
70	0.075	0.925
Average	0.150	0.850

Table 8: Percentage concentration of oils in Mixture B

Temperature[°C]	XHVI 4.0	XHVI 8.2
40	0.340	0.660
45	0.305	0.695
50	0.269	0.731
55	0.231	0.769
60	0.193	0.807
65	0.153	0.847
70	0.112	0.888
Average	0.229	0.771

4 Discussion

First, as expected as temperature increased the viscosity of all of the oil decreases. This can be seen from all of the tables. As an example reading from Table 2 at 40°C the average viscosity across both speeds was 16.45mPa.s and it goes on to decrease the viscosity at every temperature increase. Finally at 70°C the viscosity reached 7.55mPa.s. This is also very clear from the graph in Figure 2. The graph also shows that the effect of the speed of the viscometer on the viscosity of the oil. For the higher viscosity oil (XHVI8.2) speed had very little effect on the accuracy of the results. That is clear as the lines of best fit are almost identical for each temperature interval. However, for the lower viscosity oil (XHVI4.0) the reading for viscosity were more varied. This could be due to the fact that there is a higher resistance to motion in the XHVI8.2 oil and so a change in speed is more controlling giving a more accurate reading. One other reason could be that there was a slight systematic error in the viscometer used to measure the torque of the oil. This could lead to a constant error, which could describe the graph as all of the values are a similar distance apart.
The tables also show the comparison with the theoretical and experimental calculations, the data reveals that the accuracy of the theoretical calculation is quite high. Although the theoretical calculation is not

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entirely theoretical as it uses some of the experimental data to find the k and b values shown in Table 6. This would mean that a high level of accuracy would be expected. Specifically the theoretical calculation uses data from the minimum temperature and the maximum temperature average viscosity, hence why they first and final values in the tables are identical. For all the oils, all of the theoretical values were very close to the values measured in the experiment which shows the high accuracy of the viscometer and the results obtained.

From Tables 7 and 8 the results for the concentration of the oils can be seen at both temperatures. The final results for the concentration of each was 15% XHVI4.0 and 85% XHVI8.2 for mixture A, and 22.9% XHVI4.0 and 77.1% XHVI8.2 for Mixture B. Every result shows that there was more of the higher viscosity oil in each mixture. It also shows that mixture A had a higher amount of the XHVI8.2 compared to XHVI4.0. This data is worked out completely using theoretical calculations and so there is no way of comparing this data to test the accuracy. However, by comparing the viscosities of these oils from the table this is as the concentrations make sense as the viscosity of the mixtures were closer to the viscosity of the XHVI8.2 oil. Mixture A has the higher viscosity, throughout the temperature range, this again follows the trend with the concentrations; the concentration of the XHVI8.2 oil is lower. One thing that came as a surprise from these results is that as the temperature increased the concentration of the higher viscosity oil seemingly increased. However, the viscosity of the mixture decreased so it would be expected that the concentration of the lower viscosity index would increase.

To improve this experiment clearly more results could have been taken. There were no repetitions in this experiment and as such there may be errors in the data. For example the error between the theoretical calculations and the results could have been reduced. Another way of improvement would be to only use one viscometer. In each viscometer there may be a small systematic error that is undetectable on inspection and by using the same one for all of the results this error could have been seen and removed for all of the data. However, done in this way in varied viscometers it is difficult to find a common error to correct the data to fit with the theoretical calculations. One other improvement for this experiment would be to try more speeds of the viscometer to see what effect that this also has on the viscosity and see if there is a trend there. Whilst also providing more values to find the average viscosity from. A final suggestion would be to use smaller temperature intervals to check that the trend of viscosity increasing happens over the full temperature range and there are no spikes or effects that may unexpectedly happen at certain temperatures.

5   Conclusion

In conclusion mixture A had a lower viscosity than mixture B. Therefore the fact that mixture A had a higher concentration of XHVI4.0 compared to mixture B was expected. Also as predicted with the temperature increase, there was a viscosity decrease. This occurred in every sample, across the whole temperature range, thus showing that this assumption is correct for a large temperature gap. For example a 30°C temperature range gave a good idea of how the viscosity acts over a considerable range. By using smaller gaps this trend could be confirmed to an even greater level of degree. Also by increasing the whole temperature range for example going from 0°C to 100°C would allow us to see if the trend continues up into the larger temperatures and in the lower temperatures. Overall the experiment was highly accurate as seen by the comparison between the theoretical and experimental results.

References

[1] L R Baykova, N A Garris, and G I Karimova. Multiple regression model for determining and predicting the viscosity of crude oils mixture. *IOP Conference Series: Earth and Environmental Science*, 272(2):022154, jun 2019.

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[3] Marcio Luis Ferreira Nascimento and Cristina Aparicio. Data classification with the vogel–fulcher–tammann–hesse viscosity equation using correspondence analysis. *Physica B: Condensed Matter*, 398(1):71–77, 2007.