THE CHANGE OF DYNAMIC FRICTION IN ALUMINIUM SURFACES THROUGH HEATING THE ENGINE OIL LAYER BETWEEN THEM

Introduction

Friction is a force that significantly affects the motion of moving objects in everyday life. Friction's presence is often an unfavorable phenomenon due to the shifts in force and energy parameters it causes. This has led to investigations that aim to find methods to reduce it. One of the places where we notice the importance of reducing friction is combustion engines in the automobile industry. Most gasoline combustion engines have an average of around 20% energy efficiency[1]. Meaning that out of 45MJ energy[2] produced from the burned diesel, only 9MJ is useful energy. However, due to the presence of friction in the engine parts, the useful energy concludes to be less than 9MJ. Therefore, to increase an engine's efficiency, it is intended to reduce the value of the coefficient of dynamic friction. One approach to reducing friction is the use of lubrification.[3] Lubricants form layers between two objects' surfaces, hence making a partial or entire separation between them. However, lubricants maintain their own disadvantages to the system; they change phase into solid at 3°C[4] and into gas at 300°C[5]. This investigation experiment will help test how the lubricant layer's temperature between two aluminum surfaces affects the change in dynamic friction coefficient?

Background

Friction is the resistance force that one surface or object encounters when moving over another. In this investigation, friction is symbolized with the symbol (F_f). In nature, we meet two types of friction, static friction, and dynamic friction. Static friction occurs when the object and the surface encounter a force of friction that is more significant than the force being exerted, therefore leaving no relative movement between the surfaces. Dynamic friction occurs when the force of friction is smaller than the force being exerted, thus causing the object to move. In this investigation, I will focus only on the dynamic friction. That comes from the fact that static friction in this investigation would be involved only when the engine is turned off, which wouldn't give us the opportunity to evaluate the efficiency of the engine. In comparison, dynamic friction occurs only when the engine parts are in motion, which would indeed allow us to gain an outcome for the efficiency of the engine. Dynamic Friction (F_f) is calculated using the coefficient of friction (μ_d) and the normal to the surface force (R) through the formula.[6]

$$F_{\mathrm{f}} = \mu_{\mathrm{d}} R \quad [1]$$

(F_f)- Force of friction

(μ_d)- Coefficient of dynamic friction

(R)- Normal to the surface force

[1] "Toyota Gasoline Engine Achieves Thermal Efficiency Of 38 Percent." 14 Apr. 2014, https://www.greencarreports.com/news/1091436_toyota-gasoline-engine-achieves-thermal-efficiency-of-38-percent. Accessed 17 Feb. 2021.

[2] "Case Study: The effect of an amorphous carbon coated gear-wheel ...." https://www.researchgate.net/publication/316669347_Case_Study_The_effect_of_an_amorphous_carbon_coated_gear-wheel_on_a_hydraulic_orbital_motor's_efficiency_over_time. Accessed 17 Feb. 2021.

[3] "How Does Lubrication Reduce Friction | Shield Lubricants." 24 Oct. 2018, https://shieldoils.com/how-does-lubrication-reduce-friction/. Accessed 10 Mar. 2021.

[4] "What's the Freezing Point of Motor Oil? - bikerscafeblog.com." 16 Jun. 2020, https://bikerscafeblog.com/whats-the-freezing-point-of-motor-oil/. Accessed 18 Feb. 2021.

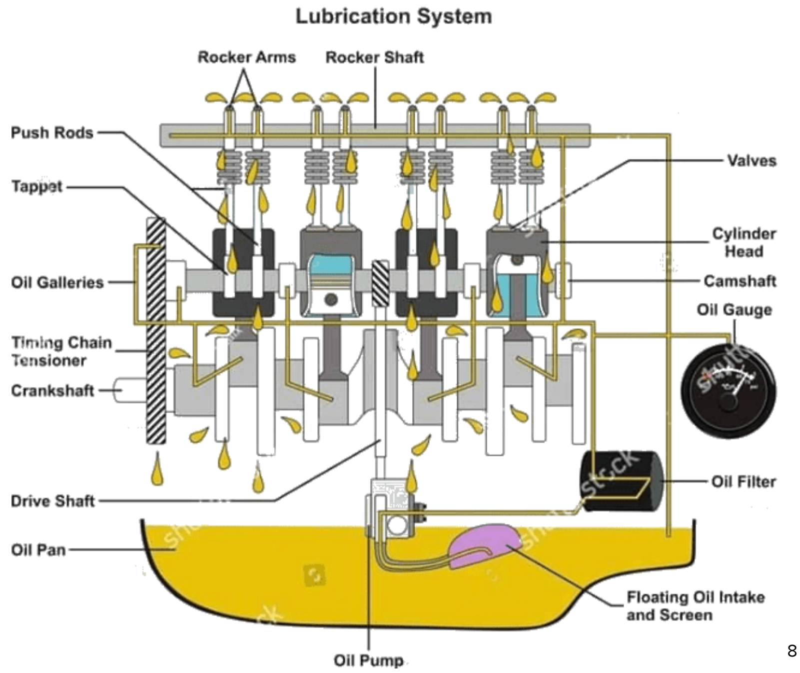
[5] "Chemistry - Oil as a Lubricant - Petroleum." http://www.petroleum.co.uk/oil-as-a-lubricant. Accessed 23 Aug. 2020.

[6] Homer, David, and Michael Bowen Jones. "Forces." *Physics*, Oxford, 2014, pp. 54–58.

How does engine lubrication work

Piston is a moving plate embedded in a cylinder which is made gas-tight by piston rings[7]

Fig. 1: Annotated Lubrication System in an engine



[8]

In a combustion engine, oxygen and fuel combine to start the combustion process and produce power to begin the piston's reciprocating motion (up and down linear motion)[9]. The reaction produces high-pressure gas that applies a force on the piston and pushes it downwards. The piston is further attached to the crankshaft through a rod, which provides the transmission of the power generated.

The lubrication system is responsible for circulating oil to the moving parts of an engine that are acting relative to each other and reduce friction between their surfaces.

The pump receives power from the engine due to its connection to the drive belt. Oil is then sucked into the pump from the oil span, and crosses through the oil pressure regulator and an oil filter which ensures to clean oil dust particles. The oil then passes through oil lines and holes drilled inside the crankshaft to lubricate them. The oil lines are also connected to oil sprouts that spread oil upwards to lubricate the piston. The oil, which excesses, drains back to the sump, which gathers up the used oil and returns the oil into the pump to be circulated again in the engine.[10] [11]

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[7] "Piston - Energy Education." 4 Jun. 2018, https://energyeducation.ca/encyclopedia/Piston. Accessed 24 Aug. 2020.
[8] "Engine Lubrication System: definition, parts, types ... - Studentlesson." 21 Jul. 2020, https://studentlesson.com/engine-lubrication-system-definition-parts-types/. Accessed 10 Mar. 2021.
[9] "What does reciprocating motion mean? - Definitions.net." https://www.definitions.net/definition/reciprocating+motion. Accessed 12 Mar. 2021.
[10] "Engine Lubrication System." https://www.grc.nasa.gov/www/k-12/airplane/lubesys.html. Accessed 10 Mar. 2021.
[11] "How Engine Lubrication System Works - YouTube." 18 Jul. 2012, https://www.youtube.com/watch?v=mmmcj53TNic. Accessed 10 Mar. 2021.

Engine oils and their relationship to temperature

Engine oils are any of the numerous substances that consist of base oils enhanced with various additives. They are used for the lubrication of internal combustion engines. The main function of engine oil is the reduction of friction[12] and the protection of the surfaces from degradation[13]. Engine oils improve mechanical efficiency, the load-carrying performance of engine test rings, and engine vehicles' driving performance.[14] However, lubricants have practical limitations when it comes to operating temperatures.

When the engine oil is at high temperatures, the fluid will become too thin, and its viscosity (lubricants resistance to flow) will be very low. When the lubricant is too thin, it does not form a sufficient layer to separate the moving parts, causing the engine to be less efficient while operating. Once they've exceeded their base activation temperature, lubricants will start to oxidize twice as fast per every 10°C you heat them.[15]

During an engine startup in low temperatures, such as those experienced in cold weathers, the fluid will start to congeal and restrict the engine oil flow. The lubricant's viscosity is going to be very high, and the oil structure will thicken up. Gears will start to push congealed "pieces" of engine oil out of the way and won't be able to pass lubricant to the other components that need it as well. This will eventually require higher energy to start the engine since friction between the components has been increased. Components in the engine will starve of lubricant, which would lead to the metal to metal contact. [16]

Experimental Variables

The **independent variable** is the temperature of the engine oil in the experiment. The temperature is measured in °C and is increased every trial by 5°C.

The **dependent variable** is the dynamic coefficient of friction or the surface slip resistance coefficient of the object.

The **controlled variables** are, the mass of the aluminium cuboid affecting the Normal to the surface (R), the mass of the weights affecting the net force of the system (F_{net}) and the distance (s) that the aluminium cuboid crosses.

Hypothesis

In an engine, a combustion reaction occurs to the fuel, producing heat and counterforce for the piston, forcing it to move. This counterforce is the useful energy generated from the combustion reaction. Nevertheless, more energy is lost due to the friction of the components in the engine. Engine oil is used to lower friction between the surfaces within the engine block to raise efficiency. However, engine oil shows limitations as it starts to lose its purpose of providing more frictionless contact between components. The engine oil's temperature boundaries where it starts to lose its purpose are at boundaries: lower than 3°C; higher than 300°C. When engine oil temperature rises towards 300°C, it starts to lose its properties, such as becoming thinner and its viscosity drops. Whereas when it drops towards 3°C the liquid starts to thicken and delays the engine components' movements. These will hamper the movement of the piston, leading to less energy generated. Considering this, **I hypothesise that the increase in engine oil's temperature from the normal (room) temperature, will increase the dynamic friction between the components.**

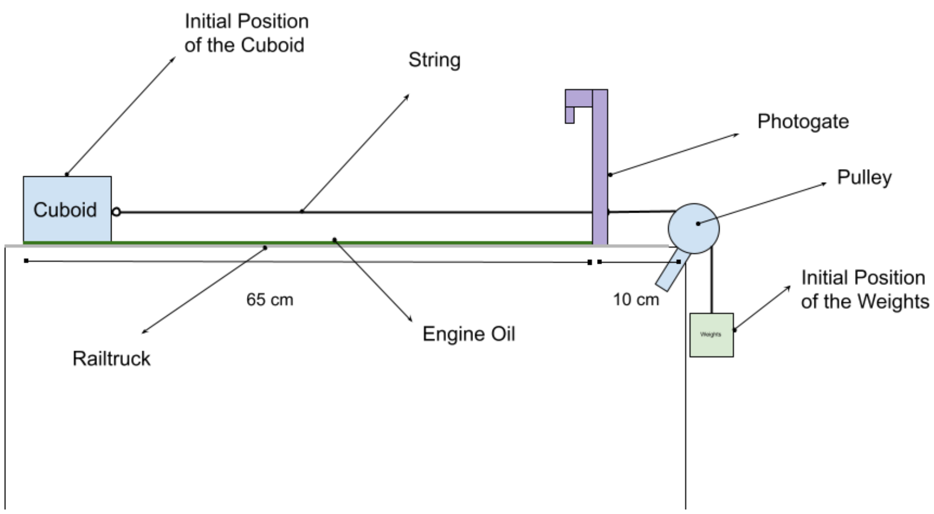
[12] "What is Motor Oil? | Pennzoil." https://www.pennzoil.com/en_us/education/know-your-oil/what-is-motor-oil.html. Accessed 9 Jan. 2021.
[13] Durak, Ertuğrul & Kurbanoglu, Cahit & Tunay, Recai. (2006). Experimental study of effects of oil additives into coefficient of friction in journal bearings at different temperatures. Industrial Lubrication and Tribology. 58. 288-294. 10.1108/00368790610691365.
[14] Durak, Ertuğrul & Kurbanoglu, Cahit & Bıyıklıoğlu, Aydın & Kaleli, Hakan. (2003). Measurement of friction force and effects of oil fortifier in engine journal bearings under dynamic loading conditions. Tribology International. 36. 599-607. 10.1016/S0301-679X(02)00263-3.
[15] "The Effect of Temperature on Lubricant Viscosity | Shell United States." https://www.shell.us/business-customers/lubricants-for-business/shell-expertise/our-experts/robert-profilet/effect-of-temperature-on-viscosity.html. Accessed 20 Feb. 2021.
[16] "How Cold Temperatures Affect Your Lubricants." https://www.machinerylubrication.com/Read/30093/cold-temperatures-lubricants. Accessed 20 Feb. 2021.

Experiment Equipments:

1. An **Aluminium Cuboid** with 4x8x1 cm (0.1kg ± 0.005kg)
The aluminium Cuboid takes the role of the piston. The reason for choosing aluminium is due to the fact that most of the vehicles use aluminium for their pistons. This is because they are lighter, and have the necessary metal strength needed for the engine.[17] I will limit my investigation into using one type of the cuboid aluminium.
2. An **Aluminium Rail Track** (0.80m ± 0.005m)
The aluminium Rail Track will cover the role of the inner surface of the engine.
3. A **Fixed Pulley**
A pulley will be used to change the direction of the force exerted without changing the magnitude of the force
4. 1x **Photogate**
"**Photogates** are a timing device that measures times of the changes in state of an infrared beam that is blocked by a flag of known length, as well as the times the beam is unblocked. Using the flag length, and the blocked time, students can calculate speed."[18]
5. 1 liter 15W-40 **Engine Oil**
The engine oil will be used in order to measure the various velocities of the aluminium objects when it passes through various engine oil temperatures.
6. 200ml **Beaker**
A beaker will be used in order to hold up the engine oil at the heater
7. **Laboratory hot Plate**
A heater will be used to heat up the engine oil into different temperatures
8. **Mercury Lab Thermometer** (± 0.05°C)
A thermometer that measures a maximum of 100°C will be used in order to measure the exact temperature of engine oil
9. **String** (0.70m ± 0.005m)
A non elastic string will be used in order to connect the weights with the aluminium cuboid
10. **Weights** (0.1kg ± 0.005kg)
Weights will be used as a pull force for the aluminium cuboid. Weights need to weigh more than the aluminium cuboid.

Experimental Procedure

Fig 2: Diagram of the apparatus for the investigation



[17] MAHLE GmbH. "Piston Materials." *SpringerLink*, 2012, link.springer.com/chapter/10.1007%2F978-3-8348-8662-0_4.

[18] "Photogates, Fences, and Timers - Product Guides | PASCO." https://www.pasco.com/products/guides/photogates. Accessed 23 Aug. 2020.

Follow the sketch of Fig.2

1. Position the aluminium rail track on one side end of a desk.
2. Hook up the pulley on the side of the rail track that is close to the end of the desk
3. Hook up the photogate in the rail track, 10 cm away from the pulley
4. Position the aluminium object 65cm away from the photogate.
5. Attach the aluminium object to the string, and attach the other end of the string to the weights.
6. Wrap the string around the pulley
7. Suspend the weights in mid-air while the aluminium object is on the rail track
8. Pour 30ml of room temperature engine oil in the beaker and then pour in in the rail track.
9. Set the photogate on before starting to take the measurements.
10. Release the weights to fall downward under the influence of gravity, in order to accelerate the aluminium object
11. Measure the velocity of the aluminium object while passing through the photogate.
12. Repeat the experiment 4 times per value of temperature taken
13. Clean up the rail track before the next engine oil temperature is poured.
14. Pour another 30ml of engine oil in the beaker.
15. Increase the temperature of the engine oil by 5°C more than the previous temperature
16. Repeat the steps 8-14 until the final temperature to measure is 55 °C

Risk Management

While conducting an experiment is important to take into consideration the risks that an experiment might hold. The risks of the experiment held for this experiment are going to be considered according to the three main criterias: Safety Issues; Ethical Issues; and Environmental Issues:

Safety Issues

To prevent getting burned from the engine oil droplets, the temperatures investigated were ranging from 20 °C to 55 °C. Make sure to use heat gloves every time you use the heater. Consider using a N95 mask in order to prevent breathing the pollutants that the engine oil might produce while heating up.

Ethical Issues

The engine oil used will be poured back into its bottle so that it can be recycled for other investigations.

Environmental Issues

Another reason for not having the engine oil reach high temperatures is due to its capability to pollute the environment. When engine oils heat up, they can produce airborne pollutants that can reach into people's lungs and affect their health. If engine oil reaches water surfaces as oceans and seas, it floats on the surface of the water. That blocks the sunlight and the oxygen that the ocean requires for its creatures to live, thus killing fish and shellfish.[19]

[19] "Why we should recycle used motor oil - Fact sheet." https://www.environment.gov.au/protection/publications/factsheet-why-we-should-recycle-used-motor-oil. Accessed 23 Aug. 2020.

Gathering Raw Data

TABLE 1: Velocity values taken every try that the engine oil temperature was increased

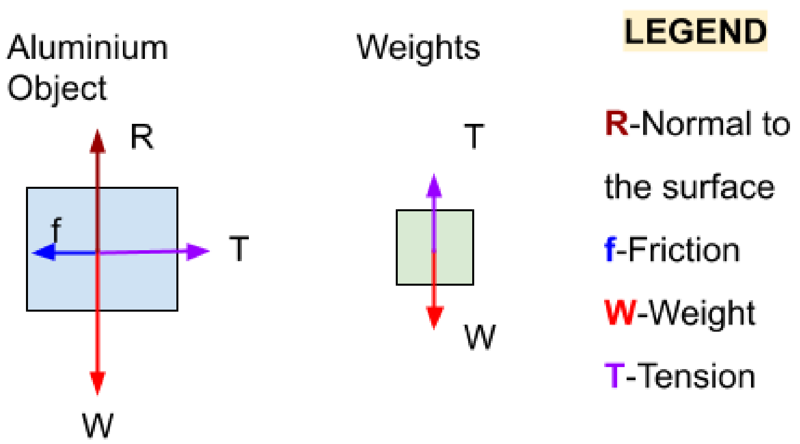
Final Velocity v ± 0.005 m/s					
Temperature ±0.5°C / Number of tries	Trial 1 m/s	Trial 2 m/s	Trial 3 m/s	Trial 4 m/s	Average m/s
20 (°C)	1,67	1,80	1,75	1,69	1,73
25 (°C)	1,81	1,80	1,79	1,80	1,80
30 (°C)	1,89	1,85	1,85	1,85	1,86
35 (°C)	1,96	1,97	1,90	1,87	1,93
40 (°C)	1,99	2,00	1,99	1,99	2,00
45 (°C)	2,02	2,01	2,00	2,01	2,01
50 (°C)	2,03	2,01	2,02	2,02	2,02
55 (°C)	2,11	2,07	2,10	2,08	2,09

After the different velocities values were gathered in the experiment, the average of each velocity for each temperature change was calculated. This way, instead of taking into concern all four values of velocities of each trial, a generalization of these values could be taken into consideration for the analysis. Without getting into a deeper explanation, it becomes noticeable that the object's average velocity has increased for every increase in temperature to the engine oil. This has proved that temperature of lubricant does affect the velocity of the cuboid.

Analysis and Processing of Data

The first approach towards the analysis of raw data, is to find an equation that allows us the possibility to find μ_d (dynamic coefficient of friction) as an output and the velocity of the cuboid as an input. After that the uncertainties need to be calculated as well so that the graphing a data becomes possible

Figure 3: Sketch of the full body diagram of the aluminium object and the weights



In order to determine the **coefficient of friction,** a free-body diagram of the weights and the aluminium object was made.

The forces acting on the aluminium object are:

- Weight (W) acting downard
- Normal Force (R) acting upwards to prevent the two solids from passing through each other
- Friction (f) between the rail track and the object resisting the motion of the object
- Tension (T) on the rope accelerating the object

The normal to the surface force is canceled out with the weight of the object. That applies because there was no change in angle between the rail track and the horizontal surface (thus, both vectors have the same magnitude) and because both vectors have opposite directions with each other. This outlasts only the force of tension (T) and friction (f) to be further considered in the analysis. Since the object is in motion, it is said that T>f, since a greater force than friction, needs to be applied to set the body in motion.

The forces acting on the weights are:

- Weight (W) of the weights
- Tension (T) on the rope

In the situation of the weights, the resistance of the dowards pull of gravity is going to be experienced through the upward tension force. Since the weights are in motion, it is said that W>T, since a greater force than Tension needs to be applied in order to set the body in motion downwards.

Newton's 2nd law equation will be used for the two free-body diagrams in order to write two equations that will allow us to determine two expressions to find the value of tension. The Fnet will be expressed as the force in the direction of the motion minus the force that opposes it. This will lead us to the equations [2] and [3].

Mass of the aluminium cuboid is (m_1)= 0.1kg ± 0.005kg
Length of the distance covered from the cuboid = 0.65m ± 0.005m
Mass of the weights is (m_2) = 0.1kg ± 0.005kg

1. Finding the value of Tension for The Aluminium Object (F_{net}-Net Force (sum of vectors acting on a body[20]) ; (g-Gravitational force, that is equal to 9.81 m/s^2)

$F_{net} = T - f$

$m_1 \times a = T - (R \times \mu_d)$

$m_1 \times a = T - (m_1 \times g \times \mu_d)$

$T = m_1 \times a + (m_1 \times g \times \mu_d)$ [2]

2. Finding the value of Tension for the Weights

$F_{net} = W - T$

$m_2 \times a = m_2 \times a - T$

$T = m_2 \times g - m_2 \times a$ [3]

The values will be rearranged so that the equation allows the value of the dynamic coefficient of friction as an output. This created a proper equation that contained as an output the coefficient of friction and as an input the velocity of the aluminium object.

[20] "Determining the Net Force - The Physics Classroom." https://www.physicsclassroom.com/class/newtlaws/Lesson-2/Determining-the-Net-Force. Accessed 19 Feb. 2021.

3. Set the two tension formulas [2] ; [3] equal to each other and solve for μ_d

$m_1 \times a + (m_1 \times g \times \mu_d) = m_2 \times g - m_2 \times a$

$(m_1 \times g \times \mu_d) = m_2 \times g - m_2 \times a - m_1 \times a$

$$\frac{m_2 \times g - m_2 \times a - m_2 \times a}{(m_1 \times g)} = \mu_d$$

$$\frac{m_2 \times g - a(m_1 + m_2)}{(m_1 \times g)} = \mu_d$$

4. Use the kinematic equations (it is assumed the cuboid slides in a perfect straight line) in order to substitute the value of acceleration with the velocity of the aluminium object.[21]

* Kinematic equation:

$v^2 = u^2 + 2a \times \Delta s$

Where: v-final velocity; u-initial velocity which is equal to 0 since the object starts at rest; Δs- change of the distance that the object has covered;

$a = \frac{v^2}{2\Delta s}$ [4]

$$\frac{m_2 \times g - \left(\frac{v^2}{2\Delta s}\right)(m_1 + m_2)}{(m_1 \times g)} = \mu_d \quad [5]$$

Example:

$$\frac{0.1 \times 9.81 - \left(\frac{1.73^2}{2 \times 0.65}\right)(0.1 + 0.1)}{(0.1 \times 9.81)} = \mu_d$$

$$\frac{0.981 - (2.302) \times (0.2)}{(0.981)} = \mu_d$$

$$\frac{0.981 - (2.302) \times (0.2)}{(0.981)} = \mu_d$$

$0.53068 = \mu_d$

$\mu_d = 0.53068$

Using the values of average velocities from Table 1, the formula [5] was used to generate the values of dynamic friction per each temperature value.

UNCERTAINTIES

We will calculate the error of μ_d using the method of propagation of errorsl as shown in the following:

- $m_1 = m_1 \pm \Delta m$
- $m_2 = m_2 \pm \Delta m$
- $a = a \pm \Delta a$
- $v = v \pm \Delta v$
- $s = s \pm \Delta s$

$$a = \frac{v^2}{2s}$$

[21] Homer, David, and Michael Bowen Jones. “Forces.” *Physics*, Oxford, 2014, pp. 36–37.

$$\Delta a = \frac{d}{dv}\left(\frac{v^2}{2s}\right)\Delta v + \frac{d}{ds}\left(\frac{v^2}{2s}\right)\Delta s$$

$$\Delta a = \frac{d}{dv}\left(\frac{v^2}{2s}\right)\Delta v + \frac{d}{ds}\left(\frac{v^2}{2s}\right)\Delta s$$

$$\Delta a = \left(\frac{v}{s}\right)\Delta v + \left(\frac{v^2}{2s^2}\right)\Delta s$$

$$\mu_d = \frac{m_2 \times g - (a)(m_1 + m_2)}{(m_1 \times g)}$$

$$\mu_d = \frac{d}{da}\left(\frac{m_2 \times g - (a)(m_1 + m_2)}{(m_1 \times g)}\right)\Delta a + \frac{d}{dm_1}\left(\frac{m_2 \times g - (a)(m_1 + m_2)}{(m_1 \times g)}\right)\Delta m_1 + \frac{d}{dm_2}\left(\frac{m_2 \times g - (a)(m_1 + m_2)}{(m_1 \times g)}\right)\Delta m_2$$

$$\mu_d = \left(\frac{(m_1 + m_2)}{(m_1 \times g)}\right)\Delta a + \left(\frac{g - a}{(m_1 \times g)}\right)\Delta m_2 + \left(\frac{a \times m_1}{(m_1^2 \times g)}\right)\Delta m_1$$

Example:

For the value of v = 1.73 m/s

$$a = \frac{v^2}{2s} = \frac{1.73^2}{2 \times 0.65} = 2.30$$

$$\Delta a = \left(\frac{v}{s}\right)\Delta v + \left(\frac{v^2}{2s^2}\right)\Delta s$$

$$\Delta a = \left(\frac{1.73}{0.65}\right) \times 0.005 + \left(\frac{1.73^2}{2 \times 0.65^2}\right) \times 0.005$$

$$\Delta a = \left(\frac{1.73}{0.65}\right) \times 0.005 + \left(\frac{1.73^2}{2 \times 0.65^2}\right) \times 0.005$$

$$\Delta a = 0.01330 + 0.017709$$

$$\Delta a = 0.03101$$

$$\Delta\mu_d = \left(\frac{(m_1 + m_2)}{(m_1 \times g)}\right)\Delta a + \left(\frac{g - a}{(m_1 \times g)}\right)\Delta m_2 + \left(\frac{a \times m_1}{(m_1^2 \times g)}\right)\Delta m_1$$

$$\Delta\mu_d = \left(\frac{(0.1 + 0.1)}{(0.1 \times 9.81)}\right)0.03101 + \left(\frac{9.81 - 2.30}{(0.1 \times 9.81)}\right)0.005 + \left(\frac{2.30 \times 0.1}{(0.1^2 \times 9.81)}\right)0.005$$

$$\Delta\mu_d = \left(\frac{(0.1 + 0.1)}{(0.1 \times 9.81)}\right)0.03101 + \left(\frac{9.81 - 2.30}{(0.1 \times 9.81)}\right)0.005 + \left(\frac{2.30 \times 0.1}{(0.1^2 \times 9.81)}\right)0.005$$

$$\Delta\mu_d = 0.00632 + 0.03826 + 0.011734$$

$$\Delta\mu_d = 0.056314$$

$$\Delta\mu_d = \pm\ 0.056$$

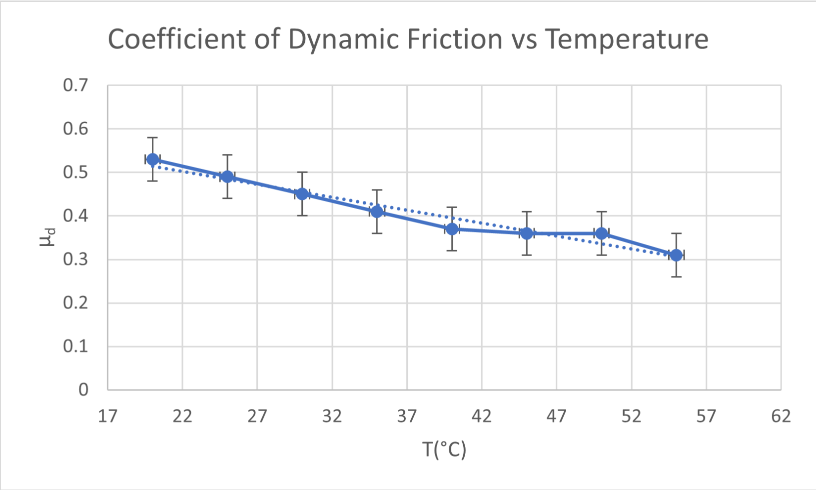
TABLE 2: The dynamic friction coefficient per different values of the temperature

Processed Data Table

Dynamic Coefficient μ_d		
Temperature ± 0.5°C	**Dynamic Coefficient per average velocity**	**Uncertainty of the dynamic coefficient**
20 (°C)	0.53	±0.05
25 (°C)	0.49	±0.05
30 (°C)	0.45	±0.05
35 (°C)	0.41	±0.05
40 (°C)	0.37	±0.05
45 (°C)	0.36	±0.05
50 (°C)	0.36	±0.05
55 (°C)	0.31	±0.05

Table 2 reveals that the dynamic coefficient between two dry aluminum surfaces (1.4[22]) would drop to 0.85 when engine oil is applied between the surfaces. This proves that lubrificantes do make the movement easier in an engine.

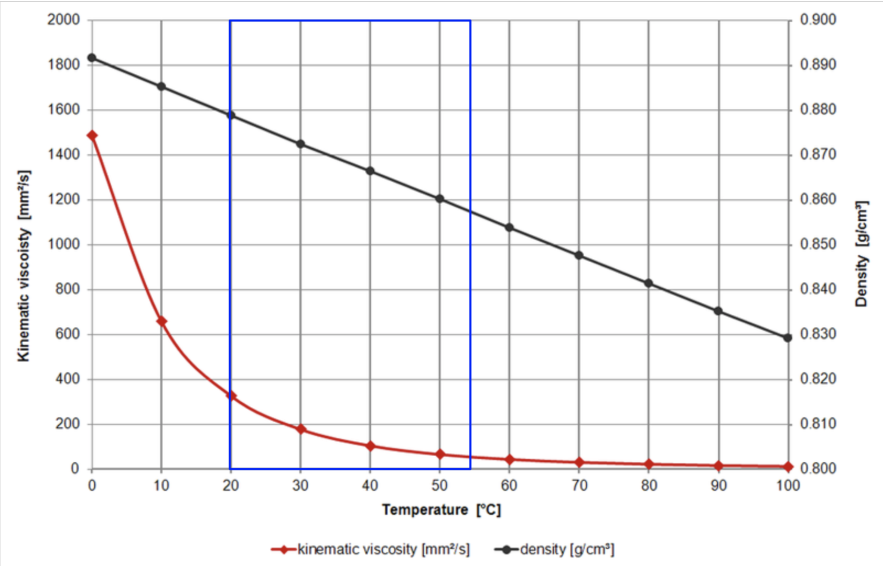
Graph 1: The Variation of The Coefficient of Friction of the Aluminium object with the change in the Temperature of Oil



Graph 1 shows the relationship between the experimental values of Temperature and and the calculated coefficient of dynamic friction. According to the graph, the dynamic coefficient of friction between the surfaces is affected by the Temperature of the lubricant and this relationship is linear. As the temperature of the engine oil increases the dynamic coefficient of friction decreases.

In this graph, the regression coefficient is R^2=0.962, which suggests that the correlation of data with the trendline is very strong. Taking into account the values presented in the graph, **the hypothesis states proved to be wrong.**

[22] "Friction and Friction Coefficients - Engineering ToolBox." https://www.engineeringtoolbox.com/friction-coefficients-d_778.html. Accessed 24 Aug. 2020.



[23]

The plot above visualizes engine oil characteristics that belong to the category 15W-40(the same as the lubricant used in this experiment). By studying the range of this plot in which the experiment will occur (visualized by the blue square), specifically the range from 20°C to 55°C, a few conclusions can be made. The kinematic viscosity is seen to drop sharply as the temperature increases, whereas the density of the oil falls linearly with the increase in temperature. This means that although the density does not decrease by a great margin, the property of kinematic viscosity is affected significantly. As expected, with the increase in temperature and the fall of the kinematic viscosity, the dynamic friction coefficient will also rise. The experiment aims to gather measurements of the dynamic coefficient of friction in increasing temperatures and observe an increasing trend, which would be consistent with the fall of the kinematic viscosity.

The reason why this phenomenon occurred in the experiment focuses on the fact that the low values of temperatures have been taken into consideration. Even though the engine oil has been heated up and has started to get thinner and lose its viscosity, it won't reach a significant level to affect the dynamic coefficient of friction to increase. Due to that, the engine oil is still thick and viscous enough to stay in between the two aluminum surfaces leading to the cuboid aluminum to slide faster each time the temperature is increased and thus leading to the dynamic coefficient to decrease. The engine oil features are still available to the system; however, it is clear that the moment the engine oil starts to exceed a specific temperature, the properties of the lubricant will lose up ;and the results of the research made earlier, will begin to show up. Moreover, this investigation's temperature values and the insignificant lowering of viscosity would improve the system by allowing the engine oil to cover up the surface in greater detail. The internal friction between the engine oil molecules will get lower and allow the dynamic friction to decrease.

Conclusion and Evaluate

In conclusion, this investigation has proven my initial hypothesis to be wrong. The gathered measurements show the dynamic coefficient of friction to be decreasing, thus the increase in temperature of this oil would lead to a machine running more efficiently. However, although the measurements portray this behavior in the oil, it is important to note that my hypothesis was motivated by research, which studies the change of the dynamic friction coefficient at much higher temperatures. In higher temperatures, the viscosity of the oil falls to the extent that the oil is not capable of effectively coating the surfaces, thus leading to contact and not only higher friction, but also deterioration of mechanical parts. As a result, I am inclined to believe that my investigation did not support my hypothesis, because it is not possible for me to recreate high oil temperatures in my experiment, and add those measurements to my data. Regardless, the use of this lubricant did in fact lead to significantly decreased friction between aluminum parts.

[23] "Viscosity of Engine Oil – viscosity table and …." https://wiki.anton-paar.com/en/engine-oil/. Accessed 12 Mar. 2021.

Experimental Assumptions which then translate into the investigation's limitations have been taken in consideration as well such as:

1. While it is sliding in the rail track, the trajectory of the cuboid is in a straight line without deviations. Deviations curve the cuboid's trajectory, meaning that the kinematic equations would result in being ineffective. Thus, the cuboid trajectory was a factor that was taken into consideration while holding the experiment. Every time that significant deviations of the cuboid were noticed, the data was dropped. The experiment was repeated for the same conditions.
2. The engine oil poured over the rail track is equally distributed across the track. If the engine oil was distributed incorrectly, it would lead the cuboid to experience less friction in the lubricated areas and high friction in unlubricated areas. This would further affect the final velocity of the object, which would direct to an unreliable result.
3. The contact between the heated engine oil and the rail track's temperature, doesn't affect the lubricant temperature. In a scenario where the assumption would be considered, it would result in the engine oil's calculated temperatures being inaccurate. That results because the lubricant's internal energy will pass to the rail track by conduction, until both temperatures achieve thermal equilibrium.
4. The lubricant's temperature values from 20°C to 55°C are significant enough to provide a conclusion. The research found out that engine oil starts to lose its properties at high temperatures (300°C). This would lead the experiment to be incapable of determining a lubricant's limitations in terms of the dynamic coefficient of friction. This would further lead the conclusion to be inaccurate due to the lack of similar conditions as in a real engine.
5. The velocity of the cuboid is the same as the velocity of a piston. A piston's velocity might vary around 25m/s. This has shown a weakness in data representation since they were not so realistic about the situation they were being investigated.

This experiment has some ways of **improving** such as :

One method of improving my investigation would be the rail track's heating up to the same temperature as the lubricant temperature that is being tested. This would reduce the error of values of temperature of the lubricant. That results because both materials' temperature would be similar; thus, no significant energy transfer between the two materials would occur. A second improvement to the experiment would be to consider the dynamic friction of all the types of engine oils. When examining an engine oil, it is essential to consider the location in which the lubricant is used. Lubricants that are thin and less likely to thicken in low temperatures allow for a quick start of your engine in cold weather. Lubricants that are thick and less likely to thin in hot temperatures allow for the oil to last longer, and perform better at higher temperatures. 0W-20 and 5W-30 lubricants are used for colder climates, and; 15W-40 and 20W-50 lubricants are used for hotter climates.[24] Taking this into account, different lubricants would experience different changes in viscosity as a response to the temperature changes. Thus it is essential to mention that the results for one lubricant do not necessarily apply to all lubricants.

Further studies or an **extension** to this, would be to determine the dynamic coefficient of friction in pistons with other material such as steel, and also in different types of engine oils. Every type of engine oil tends to have a different effect on the coefficient compared to the other ones (as mentioned in the analysis). This might lead to the evaluation of one of the most efficient engine oils. A further extension would be if the experiment would be conducted in engine oil surfaces with higher temperature than 55 °C. This would prove the information gathered from the articles that the engine oil loses its properties in high temperatures because it gets thinner and less viscous, proving the stated hypothesis to be true.

Overall, I was amazed that I could clearly demonstrate the relationship of temperature of the oil and the dynamic coefficient of friction with all the limitations occurring during the eksperiment. This is just one more fascinating example found in the world that could be applied in the Motion unit of physics.

[24] "Oil viscosity and oil grades | Lubricants - Total Lubricants." https://www.lubricants.total.com/consumers/maintenancetips/Oil-viscosity-and-oil-grades. Accessed 12 Mar. 2021.