Predicting the next oil change for automotive engine oil

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Abstract. The main purpose of the engine lubrication system is to supply lubricating oil to all moving parts in the engines to reduce friction rates. The failure of this can cause damage to the engine system. The aim for this project is to develop a user-friendly device to predict as accurately as possible the next oil change for an automobile. The device consisted of four main parts, the electronic part, the heating element, the main body and the cover. A 12V DC motor is used to measure the current as the shaft connected to the motor immersed in fluid which temperature is controlled at 40 Celsius. The experiment was conducted using waste oil lubricant (WLO) collected from an automobile servicing centre. The behaviour of a given fluid was analysed using data generated. A measure of viscosity was calculated. The upper limit of viscosity change is set to +15% change and -10% for lower limit. The result shows the deterioration of WLO in term of viscosity. From the sample tested with the device, all the WLO were overused as the oil was over the allowable limit of viscosity changes which could present a danger of possible damage to the engine. Therefore, this device can function as a preventive maintenance device of car as the user can predict when is the best time to change their automobile oil lubricant.

1. Introduction

The main purpose of the engine lubrication system is to supply lubricating oil to all moving parts in the engines to reduce friction rates [1]. The lubricating oil is known as the engine oil. The failure of the lubrication system can cause damage to the engine system [2]. Thus, continuous monitoring of the engine oil viscosity is a priority in extending the lifespan of the engine. However, the oil’s useful life varies considerably depending on the operation conditions, the fuel quality and operating parameters. Every increment of temperature will cause the viscosity of the fluid especially oil lubricant to decrease due to the particles dispersed in the fluid will increases their oscillatory speed and atomic bonds become weaker. During operation, oil lubricant will deteriorate and lost its protective properties. Nowadays, there is no specific ways or system that uses any automatic device to predict the next oil change for an automobile. Lubricating oil can only be measured and detected manually [3, 4] are developed. Most of the sensor and resonator used are costly as the setup of the sensor and resonator are expensive. The aim for this project is to develop a user-friendly device to predict as accurately as possible the next oil change for an automobile. The project intends to solve the problem faced by the motorist such as environment problems that come from any unnecessary oil change of an automobile.
2. Viscosity of oil lubrication
Oil lubrication main purpose in car engine is to reduce the friction made by moving metal parts in the engine such as, piston head and engine block wall. Lubrication serves to these four purposes, reduction of resistance by relative motion, reduction rate of wear, preventing seizure and carry away heat generated by the friction [5]. This means lubrication will produce a protective film to protect the engine. Viscosity is the main property that is considered when reviewing oil lubricant properties. Viscosity relates to the film thickness and internal resistance of the lubricant [6]. As the viscosity varies, film thickness and internal resistance of the oil lubricant also varies.

Since the 19th century, no-slip boundary condition had been used in fluid mechanic and lubrication study [7] and linear slip length model proposed by Navier also been adopted due to its simplicity. By using both, the study of film thickness due to viscosity shows there is a significant effect on lubrication. As the viscosity decreased, the film thickness increased and moving closer towards theoretically full condition calculated by using Navier-Stokes’s equation.

In car engine, the viscosity will change due to two factors, wear level of the oil lubrication (resulting increasing in viscosity) and contamination of fuel (resulting decreasing in viscosity) in the oil lubrication reservoir [8]. These changes of viscosity will affect the film thickness of the oil lubrication.

2.1 Viscosity vs. temperature of oil lubricant
Oil lubricants were designed to change their viscosity as the temperature change. This was due to the nature of the engine operation itself, as the piston moving faster the needs of low viscosity lubricant is required otherwise the oil lubricant will bring resistance rather than helping the piston slide in the block. There are thousands of oil lubricants brand in the market and each of the oil lubricant is classified to their viscosity index (VI) and each engine have their recommended VI of oil lubricant provided for manufacturer.

2.2 Viscous torque and current
Viscous torque is the resistance that fluid offer to rotational motion. The idea of viscous torque comes from the common way to measure kinematic viscosity; relates the gravitational force to a falling sphere, but translating that motion to linear motion of rotating spindle and calculating the torque [9].

\[ \tau = -k \omega \]  

Where \( \tau = \text{torque} \), \( k = \text{viscous coefficient} \), \( \omega = \text{angular velocity} \)

Since the spindle is rotated by a direct current (DC) motor, the torque can be measured since torque of DC motor is proportional to the current.

2.3 Relation between current and torque of DC motor
As the motor spins the current consumption varies with torque. As the torque goes higher the current consumption will become lower and the lower the torque the higher the current consumption. According to Ohm’s law the value of torque can be calculated by:

\[ I = \frac{V}{R} \]  
\[ P_{in} = I \times V \]  
\[ P_{out} = \tau \times \omega \]  
\[ E = \frac{P_{out}}{P_{in}} \]

where \( I = \text{current} \), \( V = \text{voltage} \), \( R = \text{resistance} \), \( P = \text{power} \), \( \tau = \text{torque} \), \( \omega = \text{angular velocity} \)
Those are the most basic equation in Ohm’s law. To go further, the angular velocity of DC motor can be calculated by:

$$\omega = \text{rpm} \times \frac{2\pi}{60}$$  \hspace{1cm} (6)

By arranging the efficiency equation:

$$P_{\text{out}} = P_{\text{in}} \times E$$  \hspace{1cm} (7)

Substituting the equation:

$$I \times V \times E = t \times \text{rpm} \times \frac{2\pi}{60}$$  \hspace{1cm} (8)

And rearrange the equation:

$$t = \frac{I \times V \times E}{\text{rpm} \times \frac{2\pi}{60}}$$  \hspace{1cm} (9)

Blade will be attached to the motor spindle and immersed in lubricant oil to create resistance. By providing the DC motor with constant PMW signal, the speed is maintained to be constant. For this condition as the resistance varies, the power also will vary accordingly. Therefore, Power $\alpha$ Torque

As difference viscosity creates difference resistance, the current consumption also will be different as the torque needed to spin the blade at constant speed. Therefore, Torque $\alpha$ Current

This also relates to the viscosity, as the oil lubricant viscosity gives difference measure to the resistance. Therefore, Current $\alpha$ Viscosity

Another relation that also important to the device is that viscosity of lubricant oil will vary with temperature where the viscosity will be lower at higher temperature and higher at lower temperature.

### 2.4 Industrial method to measure viscosity

There are lots of ways to measure viscosity and all of them have different advantages and limitation. There are no best all-purpose ways to measure all type of fluid and different method must use to get an accurate reading. Rotational viscometer is one of the ways to measure viscosity of liquid. Liquid is poured into a container, preferably a beaker and the place under the rotational viscometer. A spindle which attached to metal ball or disc type then immersed into the liquid. As the machine operates, the spindle will spin, and the torque is measured and calculated in term of viscosity.

The quartz viscometer is an exceptional sort of vibrational viscometer. Here, a swaying quartz precious stone is submerged into a liquid and the particular effect on the wavering conduct characterizes the consistency \[10\]. The rule of quartz viscosimeter depends on the possibility of W.P. Artisan. The fundamental idea is the use of a piezoelectric gem for the assurance of thickness. The high-vist electrical field that is connected to the oscillator causes a development of the sensor and results in the shearing of the liquid. The development of the sensor is then impacted by the outside powers of the liquid which influences the electrical reaction of the sensor. The adjustment technique as a pre-state of thickness assurance by methods for a quartz precious stone backpedals to B. Bode who encouraged the point by point investigation of the electrical and mechanical transmission conduct of the swaying framework. Based on this adjustment, the quartz viscometer was produced which permits ceaseless consistency assurance in resting and streaming fluids.
2.5 Previous developed devices using Arduino microcontroller

A measuring device developed by previous researchers using the idea of the device is by using a microcontroller (Arduino) to control a 12v DC motor and measure the viscosity [11]. The device then used in an experiment to measure viscosity of used fresh oil lubricant and WLO; by measuring the current, and the experiment was a success. The device didn’t work as expected in the preliminary design as the current sensors was not sensitive enough and then replaced by a multimeter to take the current reading from the 12V DC motor. Also, to operate this device, two power sources were used, 12V DC battery and 5V USB cable, this makes the device heavy and not ergonomic.

There is also one similar project that used PID torque control, in which can be relate to this project [12]. A technical paper had been released on PID control using only LN293 motor driver. They had developed a grip mechanism control that being controlled by a motor driver. The motor driver has the capabilities to detect current on its own without using any extra current sensing module. This feature was never used by the manufacturer of the motor driver, so to use this feature, one must create a motor driver from scratchs or altering the motor driver IC. Group of researchers from UNITEN managed to create their own motor driver from scratchs and their experiment was a success. This experiment is relevant to this project as the current can be detected solely by motor driver. This could save money on using other current sensing method and save the utilized pin on the microcontroller.

3. Fabrication of components

The device consisted of four main parts, the electronic part, the heating element, the main body and the cover as shown in Figure 1. Majority of the enclosure were made from acrylic material and 3D printed components. Ease of use and reliability were the main concerns during design stage. A simple controller, Arduino controlled two main devices, which are current sensing module and temperature control system. A 12V DC motor is used to measure the current as the shaft connected to the motor immersed in fluid. Fluid’s temperature is also being controlled at 40º Celsius. The device basic was only to measure the current drawn by the DC motor at a controlled temperature.

![Figure 1. Illustration on how the device works.](image)

3.1 Experiment set up

In the preliminary experiment the device was used on water, cooking oil, detergent and no-load test to test device reliability. The second experiment was for waste oil lubricant (WLO) collected from an automobile servicing centre. All data generated were exported to Excel spreadsheet to analyse the behaviour of a given fluid. A measure of viscosity was calculated. The upper limit of viscosity change is set to +15.0% change and -10.0% for lower limit. The result will show the deterioration of WLO in
term of viscosity. At these points of changes, the oil already doesn’t provide the protective properties and wear to the engine will be at a faster rate.

4. Results and discussion

Variables controlled during preliminary experiment were: 1. the temperature was set to 28º Celsius, 2. the speed was at 200 PWM, and 3. the data was taken from interval 100ms for 85 reading. The data collected was in voltage and to convert to current, using the Ohm’s Law is sufficed. Preliminary experiment showed that the device has the capabilities to differentiate the value of viscosity of a given fluid. Table 1 shows the comparison between those samples.

| Type of fluids | No load | Water | Oil | Detergent |
|----------------|---------|-------|-----|-----------|
| Trend line equation | $y = 0.0056x +$ | $y = -0.0006x +$ | $y = 0.0032x +$ | $y = 0.0006x +$ |
| $x = 1$ | 3.3943 | 3.4910 | 3.5226 | 3.5452 |
| Rank | 1 | 2 | 3 | 4 |

Table 1. Comparison between samples for preliminary experiment.

| No | Type of oil | Type of car | Current mileage (km) | Recommended change mileage (km) |
|----|-------------|-------------|----------------------|---------------------------------|
| 1  | WLO- 5W30 (Petronas Fully synthetic) | Persona 1.6 | 40787 | 39780 |
| 2  | SLO – 5W30 | - | - | - |
| 3  | WLO – 10W40 (Petronas Semi synthetic) | Preve 1.6 | 84088 | 84031 |
| 4  | WLO – 5W40 (Shell Ultra Fully synthetic) | Exora 1.6 (turbo) | 72281 | 71119 |
| 5  | SLO – 10W40 | - | - | - |
| 6  | WLO – 10W40 (Petronas semi-synthetic) | Iriz 1.6 | 31510 | 32068 |
| 7  | SLO – 5W40 | - | - | - |

Table 2. List of samples collected.

For actual experiment, oil samples were collected at Proton servicing centre (Mentakab). The process only took one day and there were four samples of WLO and three sample of stock lubricant oil (SLO) collected as shown in Table 2. The samples were collected during automobile servicing operation, when the plug at the bottom of the engine was removed. The moment the oil lubricant exits the engine, the oil lubricants already categorized as WLO and need to be disposed of properly. Experiment was done according to their type of oil and the brand. This was necessary to ensure the oil lubricants are comparable. SOL was set as a benchmark to other WOL. The data was exported to excel and a graph of viscosity over speed had been plotted.

4.1 Semi synthetic oil lubricant (Petronas)

The changes in measurement in term of viscosity are shown in Figure 2 and Figure 3. There are significant changes of viscosity up until 100 PWM for both samples (Iriz and Preve samples). It happened due to steady flow of the oil lubricant, thus, was making the resistance towards the motor less. Another approach was made; where from all the data (at every speed) were combined to get a single value of viscosity to represent the oil lubricants. By representing the viscosity as a single value, this made the process to judge the deterioration easier compared to visual aid.
Figure 2. Graph for semi synthetic oil lubricant for Iriz’s sample.

Figure 3. Graph for semi synthetic oil lubricant for Preve’s sample.

The result in Table 3 shows all the oil lubricants were past the point of 15.0% changes. Iriz’s sample was already at 30.7% changes and Preve’s sample at 44.5% changes. Even though the level of oil lubricants is still within limit (for all sample), the oil no longer protects the engine. As the viscosity changes, the oil deposition at the wall will reduce. The current way to change oil lubricant is by looking at the mileage. From the Iriz’s sample the driver exceeded the mileage by 558km and as expected, the oil was no longer within the viscosity limit. For Preve’s sample, the oil change was done earlier than recommended but the oil viscosity was severely overused by 44.5% viscosity changes. This was evidence that neglected factors play a significant role in oil lubrication. Neglected factors include car idling time, type of terrain, engine capacity and style of driving.

Table 3. Comparison of viscosity for semi synthetic oil lubricant.

| Sample | Viscosity (cP) | Current Mileage (km) | Last Oil Change | Mileage Remaining |
|--------|----------------|----------------------|-----------------|------------------|
| Stock  | 12.86416       | -                    | -               | -                |
| Iriz   | 16.81353(+30.7%) | 31510               | 27068           | -558             |
| Preve  | 18.59172(+44.5%) | 84088               | 79031           | 57               |
4.2 Fully synthetic oil lubricant (Petronas)
Figure 4 shows the trend of changes of oil lubricant were the same as Semi Synthetic oil lubricant where a change of 26.3% in viscosity. The arguments for discussion are the same as in section 4.1, but it is important to note here is that this type of oil lubricants gives the lowest changes in viscosity. Even though the sample was over the limit of allowable changes, it still has the lowest changes in viscosity for this collection of Persona samples as shown in Table 4.

![Figure 4](image)

**Figure 4.** Graph for fully synthetic oil lubricant (Persona’s sample).

| Sample      | Viscosity* (cP) | Current Mileage (km) | Last Oil Change | Mileage Remaining |
|-------------|-----------------|----------------------|-----------------|------------------|
| Stock       | 13.39486        | -                    | -               | -                |
| Persona     | 16.91618(+26.3%)| 40787                | 29780           | -1007            |

4.3 Fully synthetic (Shell Ultra)
Among all the oil lubricants, sample from Exora have the highest change in viscosity by 71.9% as shown in Figure 5 and Table 5. The high change could be the result from the turbo charger installed to the engine. Since installation of turbo in any vehicle was due to increasing the peak performance, and not to be more economical. The result was expected. Forcing the engine to work harder surely has a significant effect on the lubrication.

![Figure 5](image)

**Figure 5.** Graph for fully synthetic oil lubricant (Exora’s sample).
Table 5. Comparison of viscosity for fully synthetic oil lubricant.

| Sample | Viscosity* (cP) | Current Mileage (km) | Last Oil Change | Mileage Remaining |
|--------|-----------------|----------------------|-----------------|------------------|
| Stock  | 11.57811        | -                    | -               | -                |
| Exora  | 19.89833(+71.9%)| 72281               | 61119           | -1162            |

5. Conclusion

From the sample tested with the device, all the WLO were overused as they exceeded the allowable limit of viscosity changes. If this condition continues without any action taken, it could present a danger of possible damage to the engine. Therefore, this device can function as a preventive maintenance device of car as the user can check when is the best time to change their automobile oil lubricant.

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