Study on the Potential of Boilover for Used Engine Oil and the Prediction of the Boilover Onset Time

by

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14368

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Chemical)

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Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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Approved by:

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DR AZIZUL BUANG

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or person.

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HANI TIARA FAIHANA BINTI HIFNI

ABSTRACT

Boilover phenomena has getting numerous attention throughout the industries due to the extreme consequences and impacts. Based on past researcher, boilover hazard accident commonly happen for crude oil or fuel oil. Many studies has been made to investigate the potential of boilover for both fuel. However, as of today, none had study the potential of boilover for used engine oil. In this project, it is proposed to study the potential of boilover of used engine oil fire and the prediction of the boilover onset time. The method that will be used for this experiment is basically simple combustion with different parameters. The experimental parameters for this study are the type of fuel used, depth of the fuel in the tank and size of the container.

In order to achieve the objectives for this project, experiments were conducted using two different size of containers. Used engine oil, the main parameter, was collected from a car workshop located at Seri Iskandar, Perak. For each container, five run of experiments will be conducted with different depth of fuel. Boilover onset time and the volume of fuel left after boilover were recorded. The experiment was repeated to demonstrate consistency of the result. The fire behavior was observed and recorded throughout the experiment.

For comparative study with the experimental result recorded, theoretical calculation on the boilover onset time was obtained using heat transfer correlation. Both result were being compared and analyses. The differences between both results can be relate to the heat loss from the flame to the surrounding. Consequently, this project is capable of predicting the boilover onset time for used engine oil and the quantity of burning fuel being ejected during the boilover phenomena.

ACKNOWLEDGEMENT

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Thank you.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

According to Macmillan Dictionary, boilover is defined as "*if a liquid boils over, it rises so much when it boils that it flows over the top of the container that it is in*". In another dictionary, boilover is defined as "*to boil to such an extent as to overflow its container*". When these definitions are linked to industrial fires that boilover, it relates to an extremely hazardous situation at which burning hot fuel are ejected vigorously after prolonged burning of hydrocarbon fuels.

Boilover resulted due to the difference in density between fuel and water. Below figure are the example for boilover phenomena.

FIGURE 1 Boilover phenomena

As stated earlier, the key condition for this condition to happen is due to the difference in density between two liquid. As water is poured onto or presence within the fuel, it will quickly sinks to the bottom of the container, due to the water density is much higher than the fuel.

During fire burning, oil on the surface will heat up the solution and simultaneously the heat move downwards within the oil until the heat reaches the bottom of the container. The water at the bottom is heated and rapidly vaporizes into steams - provided the temperature reach water boiling point, causing it to expand, pushes and expels the oil above upward. This will resulting in the expulsion of the oil onto large and unrestrained area outside the container.

1.2 Problem Statement

There were many cases where boilover accident happen in the industry. Some cases resulting in death, some are not. In 1976, one boilover incident happened in Milford Haven, United Kingdom, where an incandescent hydrocarbon particles from a nearby flare, ignited a spill fire on the roof of a 250ft diameter tank that had experienced some small quantities of crude oil leakage. In this incident, the flames were ejected several feet into the air and 1000 tons of burning crude oil landed in the bund, sparking fires up to four acres away.

Other case, in 1971, when a lightning hit a 33m diameter tank at Czechowice-Dziedzice Refinery, Poland that contained crude oil, causing its cone roof to collapse and causing a full surface fire. Five hours after the fire started a rapid boilover occurred, throwing burning fuel in all directions up to 250m away. This incident causing 33 people died as the consequences of the boilover. In 1982, similar incident was reported at a power plant in Tacoa, Venezuela. A huge explosion occurred and ripped off a tank roof in the plant. After 8 hours the fire started, there was a violent boilover. This incident killed over 150 people because the ejected burning fuel raced down the hillside toward the plant and local population. (Azizul, 2014)

On 4th November 2013, ten firefighters were injured in a firefighting operation of an abandoned tire factory in Kota Bharu, Kelantan. The accident happen when a horizontal cylinder oil tank that were located at the back of the factory was suddenly explode causing fire strikes to the firefighters. The exact type of fuel in the cylinder was unknown, but the investigator believe it was used engine oil that had been left for the tire manufacturing operation.

The manager from *Jabatan Bomba dan Penyelamat* Kelantan stated that the fire was under control for a period of time before the explosion suddenly happened. The explosion of fire from the oil tank shoot fireballs at least 30 meter in air. Based on boilover theories, it is believed that boilover phenomena had happened in the cylinder oil tank.

FIGURE 2 Fire explosion from the incident in Kota Bharu, Kelantan

In Malaysia, special firefighter team that has knowledge on how to control a boilover fire accident only located in a huge plant own by big enterprises. However, in small medium enterprises, fire accident will be control by the local fire department. The problem that can be seen here was that most of the local fire department has lack of knowledge on boilover phenomena and ways to control them. As accident like this were rarely happen, most safety department in companies and the fire department themselves are lack of awareness on this accident that may occur. Boilover phenomena incident can cause fatal accidents.

It is important for the fire department to gain knowledge and at least know how to control this type of fire hazard. Based on this recently accident happen in Kelantan, the student will conduct an experiment to study on the potential of boilover for used engine oil. If the potential is high, the student will continue the study on the prediction of the boilover onset time and the boilover behavior for used engine oil.

1.3 Objective

As of today, many studies had been conducted on the potential of boilover in crude oil and fuel oil. However, none had study on the potential of boilover in used engine oil. Therefore, the main objective for this project is to study on the potential of boilover for used engine oil and to predict the boilover onset time. This project study must be capable of estimating:

i. The potential of used engine oil to boilover
ii. The time for used engine oil to boilover upon fuel surface ignition
iii. The amount of fuel remaining in the tank prior to boilover and hence the quantity of fuel that would be ejected during boilover.

The main criterion of the study is that they should produce reliable result to guide the emergency response personnel on handling the boilover phenomenon. At the end of the study, all objectives should be achieved.

1.4 Scope of Study

The study will involve in studying whether used engine oil can create a boilover phenomenon or vice versa. If it is possible, further study will be conducted on the prediction of the boilover onset time for used engine oil. The parametric study will focus on:

i. **Type of fuel – used engine oil**

   The student will conduct the experiment to study the potential of boilover in this type of fuel. The student will relate the characteristic for a fuel to boilover with the said type of fuel.

ii. **Depth of fuel**

   The student will study the effect of the depth of fuel to the boilover onset time. Detail data analysis should be obtain.

iii. **Volume of fuel**

   The student will study the effect of the volume of fuel to the boilover onset time and the fire enlargement / ejection behavior. Detail data analysis should be obtain.

iv. **Size (diameter) of container**

   The student will study the effect of the diameter of the tank to the boilover onset time.

CHAPTER 2
LITERATURE REVIEW

According to a research study by Broeckmann and Schecker (1995), there were three categories of fuel ejection from burning oil tanks.

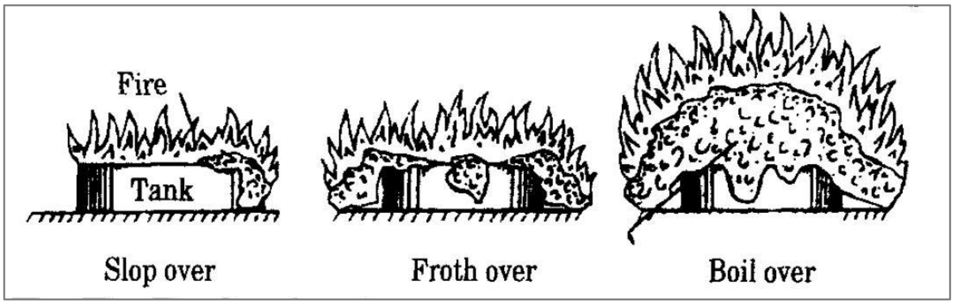

FIGURE 3 The three categories of fuel ejection from burning oil tanks

A slop over is a discontinuous frothing over of the fuel on one side of the tank. A froth over is a continuous frothing of burning material with low intensity. The most dangerous fire ejection was the boilover, where in this cases, there will be a violent fuel ejections, frothing over of the whole tank content, flame enlargements and the formation of fireballs. This represent enormous danger to the surrounding.

Broeckmann and Schecker stated that two conditions needed for occurrence of boilover. The conditions are:

1) A zone of uniform temperature and increasing extent under the fuel surface – the **hot zone** has to be formed during the fire.
2) The oil has to be in "viscous nature".

The formation of hot zone is related to the distillation of the burning oil during the fire, which the boiling points of fuel have to vary over a wide range. This usually due to the variety of component in the fuel itself. Boilover phenomena lead to a burning product spreading over an area of several tank diameters away. There is a "rule of thumb" that stated boilover fall out can extend 5 – 10 times diameters in each direction from a tank. However, actual diameters depend on the quantity of fuel involved, amount of vaporized liquid and wind direction. Other general accepted "rule of thumb" is that the hot zone will travel downwards at a speed of approximately 1 – 2 meter every hour. Nevertheless, this can only be used as a very rough estimate as actual speed will depend on fuel type and constituents. (Mirdrikvand, Roshan, Mahmoudi)

In Broeckmann and Schecker research study, the objective was to study the heat transfer mechanisms in different type of fuels. They conducted the study by heating the oil in an upright cylindrical open vessels made of normal steel with vary diameters and capacity. Temperatures in the fuels were measured using thermocouples and data were stored by a data-logging system. Effects of water vaporization were recorded by a video camera.

From the experiment conducted, they have proved that heat is transferred into the bulk of burning distillates with vary boiling ranges by heat conduction, convection or radiation. They also concluded that ejection of burning material could be prevented by the addition of ceramic particles. Addition of ceramic particles smoothed the vaporization process and considerably decreased the severity of the consequences.

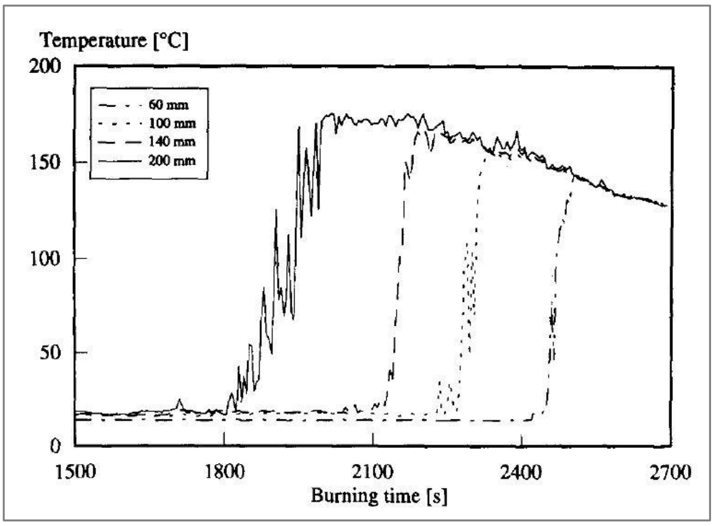

FIGURE 4 Temperature development at different heights in Forties crude oil. (Broeckmann and Schecker, 1995)

In another study by Koseki, Natsume, Iwata, Takahashi and Hirano (2006), a study has been conducted on large scale boilover experiment using crude oil. In this study, the objective was to study the mechanisms of boilover in a large scale storage tank. In this experiment, 5m diameter and 0.9m high pan filled with crude oil was used. The fuel thickness was 450mm in depth and water layer thickness was 100mm.

Burning rate was measured by a level meter connected to the bottom of the pan wall and radiation intensity was measured using radiometers placed around the burning pan at a height about 1.2m from ground level. Temperature profiles was measured by using K-type thermocouples of 0.32mm. The experiment had shown increased rate of the isothermal layer (hot zone) thickness that being evaluated on the basis of measured temperature profiles changes in the fuel. Hot zone growth rate, temperature and thickness changed with time. Koseki et al. had agreed that their result are in good agreement with those evaluated by an empirical method proposed by Burgoyne and Katan (1947).

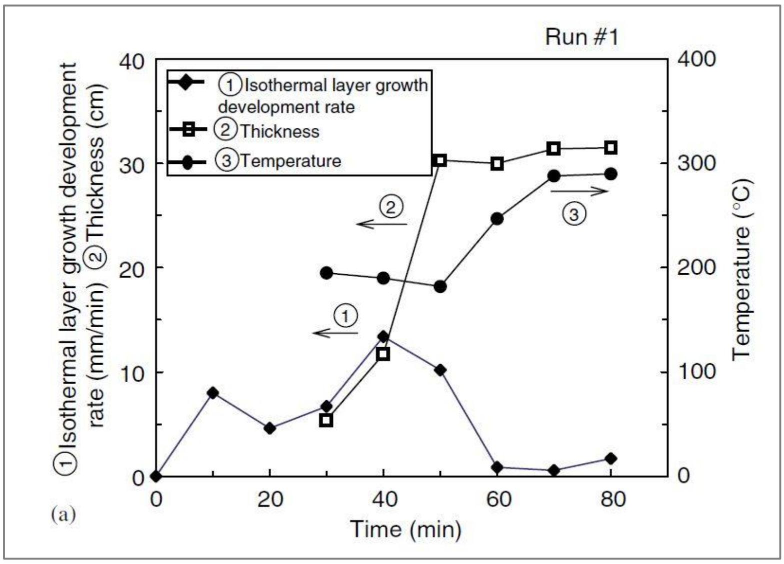

FIGURE 5 Time histories of isothermal layer growth rate, thickness and temperature of the isothermal layer (Run #1). (Koseki, Natsume, Iwata, Takahashi & Hirano 2006)

In a study conducted at Jebal Dhanna (JD) terminal area for Abu Dhabi Company for Onshore Oil Operation (ADCO) (Shaluf and Abdullah, 2011) the following methods are used for the experiment:

a) Two steel pans with 2.4m and 4.5m diameters were used for the burning crude oil.
b) Level meter was used to measure the burning rate.
c) Thermocouples was used to measure the temperature profile inside the liquid fuel and connected to the data control room.
d) Fire behavior, hazards and boilover development were recorded using a video camera.

The experiment objective was to gain more knowledge of the boilover phenomenon of crude oil. They also would like to verify if the crude oil stored by ADCO would boilover. Next, they want to estimate the rate of hot zone growth and the period needed from ignition to boilover. Lastly, the objective was to estimate the radian heat and consequences of boilover.

From this experiment, Shaluf and Abdullah had concluded below points as their result taken:

1. Multiple boilover occurred after steady burning of the crude oil.
2. The hot zone growth rate is estimated to be **2.2 m/h**.
3. The boilover occurred at about 10h which is longer than the typical time of boilover – 8h.
4. **Massive increases in thermal radiation**; in excess of 20kW/m^2 on initial boilover approx. 47kW/m^2 on final boilover.
5. Boilover did not result in high “rain out”. Only minor area outside the bund.
6. Additional of methanol shows that it is possible to delay boilover onset.

In another study, a small scale experiment were conducted to determine the effect of the fuel boiling point on the onset characteristic of the boilover burning of a fuel spilled on water (Garo and Vantelon, 1996). In the experiment, the fuel layer thickness and pan diameter was kept constant (fuel layer thickness: 13 mm, pan diameter: 150 mm). Using heating oil, crude oil and five single-component fuels, the boiling points temperature range was 383K to 560 K. The pans were placed on a load cell to measure the fuel consumption rate.

Before the test, the water was poured into the pan first and then the fuel until it reached 1 mm below the pan lip. Fuel and water temperatures were measured with an array of Chromel-Alumel thermocouples, 0.5 mm in diameter, inserted horizontally through the side wall. A laser sheet, passing through the center of the pan was used to enhance the illumination of the fuel layer. A simultaneous video recording of the bubble nucleation and dynamics at the fuel / water interface, and of the plume above the pool had been done.

Garo and Vantelon had concluded that the disruptive burning of liquid fuels spilled on water (boilover) is due to the heterogeneous nucleation of the water at the fuel-water interface. According to the study, for boilover to occur, the boiling point of the fuel must be at least above the saturation temperature of the water. Boilover intensity will increase as the boiling point of the fuel increase, primarily because the thickness of the fuel and superheated water layers is larger at the onset of boilover. Thicker fuel and superheated water layers result in a stronger and faster ejection of the fuel, created more explosive and hazardous boilover event.

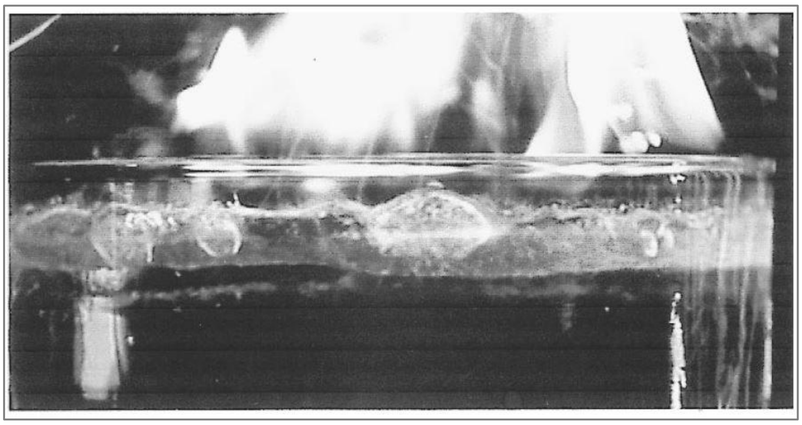

FIGURE 6 Increasing bubble nucleation intensity (Garo & Vantelon, 1996)

Another research conducted by Laboureur, Aprin, Osmont, Buchlin and Rambaud (2013) contributes further to the understanding and the modeling of boilover apparition and consequences. Small scale experiments have been performed with glass and metal reservoirs filled with a diesel-oil mixture.

In this research, two types of experiments have been conducted. First, field tests have been carried out with reservoirs of large dimensions, but experienced a strong dependence on environmental conditions such as wind. Next, laboratory experiments have been performed to guarantee a calm and uniform environment. The effect of the fuel and water thickness, of the lip height were investigated.

From this research study, it can be conclude that the mass boilover intensity depends on both the fuel thickness and the reservoir diameter. It is also indicates that, when the burnt mass ratio increases, more fuel is likely to be expelled from the reservoir and lead to a strong flame increase and / or to several boilover.

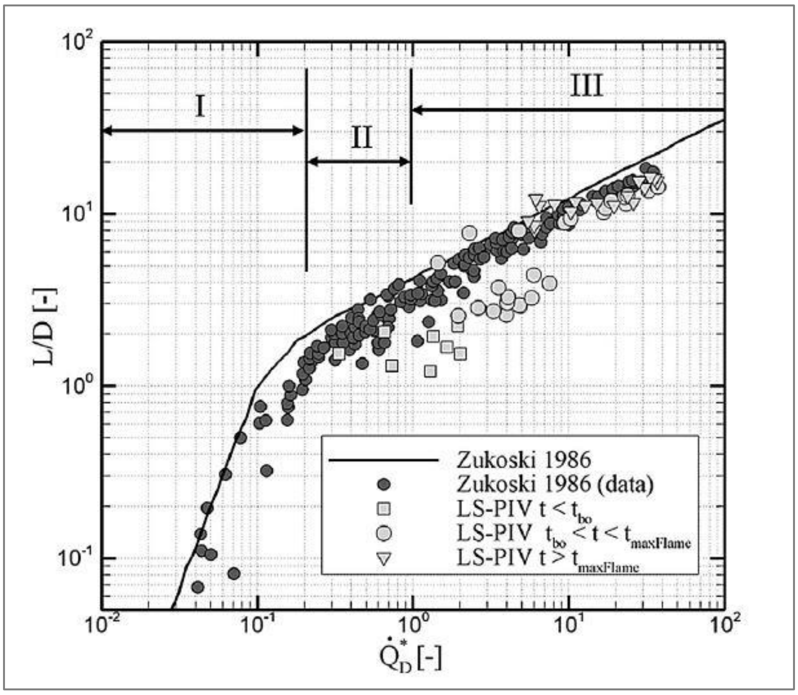

FIGURE 7 Flame height correlated with a non-dimensiol heat release rate.
(Laboureur, Aprin, Osmont, Buchlin, & Rambaud, 2013)

CHAPTER 3

METHODOLOGY

3.1 Project Flow Chart

Below is the project flow chart for this study project that must be followed in order to achieve the objective of this study.

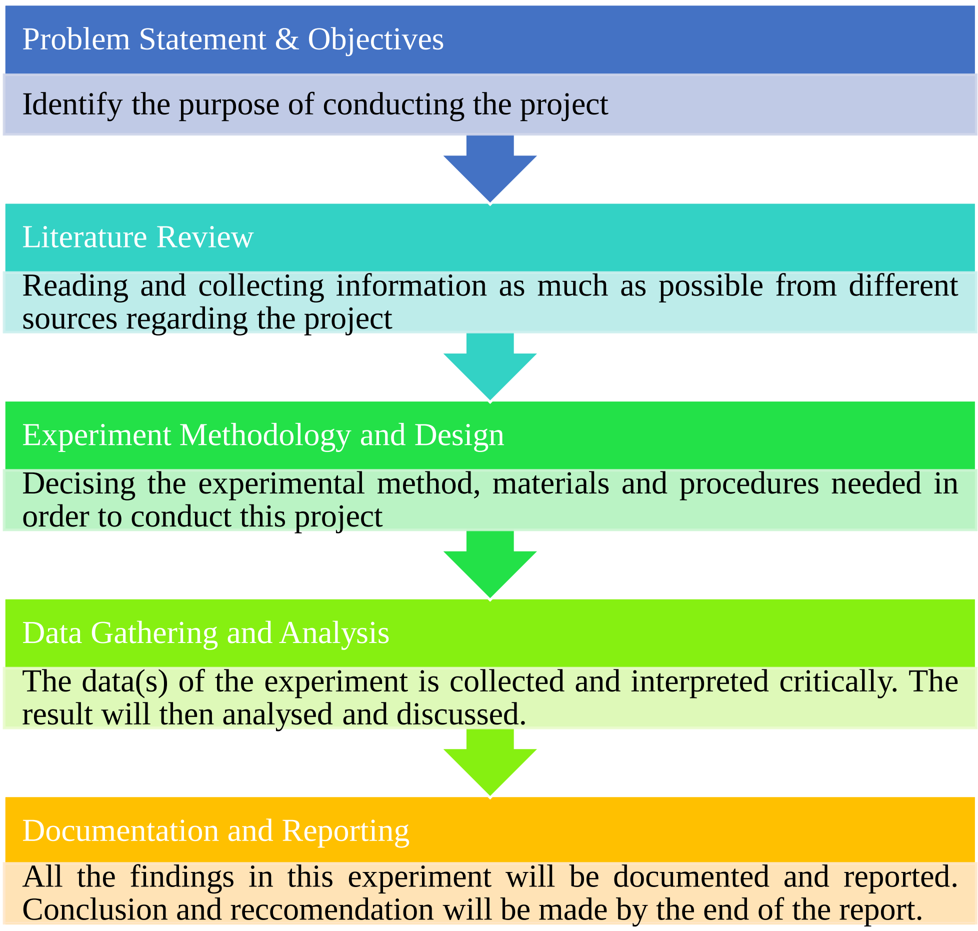

FIGURE 8 Project Flow Chart

3.2 Gantt chart and Key Milestone

FYP I

TABLE 1 Final Year Project I Gantt chart and Key Milestone

No	Detail	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Title														
2	Preliminary Research Work and Proposal Preparation														
3	Submission of Extended Proposal														
4	Proposal Defense Presentation														
5	Project work continues – to improve on all necessary elements														
6	Submission of Interim Draft Report														
7	Submission of Interim Report														

Process	Key Milestone

FYP II

TABLE 2 Final Year Project II Gantt chart and Key Milestone

No	**Detail**	**Week**													
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Materials and equipment preparation														
2	Experiment conducted – Progress Report preparation														
3	Submission of Progress Report														
4	Experiment continues														
5	Pre-SEDEX														
6	Submission of Draft Final Report														
7	Submission of Dissertation (soft bound) & Technical Paper														
8	Viva														
9	Submission of Project Dissertation (hard bound)														

Process	**Key Milestone**

3.3 Experiment Methodology

3.3.1 Materials and Equipment

1. **Used engine oil**

   This material will be obtain from the local car workshops around Sri Iskandar and Tronoh. An official memorandum endorse by the project supervisor will be given to the shop owners. In the memo, it will be stated that the used of the engine oil are for research purpose.

2. **Water**

   Water will be used as a material that has a higher density than the used engine oil. It can be obtain anywhere around the campus. In this experiment, depth of the water will be fixed at 1 cm for each run.

3. **Oil tank**

   In this experiment, different tank with different diameter will be used. The tanks will be refer as Tank A and Tank B. Below are the illustrations and measurements for each tank.

   <u>Tank A</u>

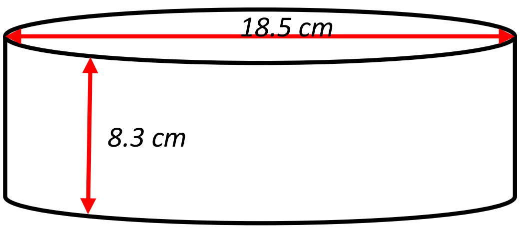

FIGURE 9 Measurement for Tank A

Tank B

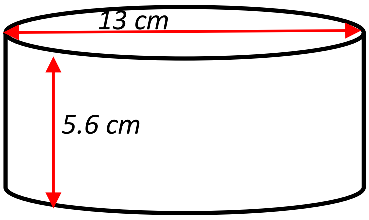

FIGURE 10 Measurement for Tank B

4. **Gas lighter**

Gas lighter for starting up the fire. It can be obtain from the chemical engineering laboratory.

5. **Digital camera**

This equipment purpose is to record the fire behavior during the ongoing experiment, and the indication of the fire spreading after the boilover.

3.3.2 Experiment Procedure

Below is the standard procedures for this experiment. However, the procedure will changes slightly for every run based on the parameters; depth of fuel, volume of fuel and size of tank.

1. Based on the depth of the fuel needed, the volume of the fuel was calculated based on below equation:

$$\boldsymbol{V = \pi r^2 h}$$

   Where,

   V = volume of the fuel, r = radius of the tank, h = depth of fuel.

2. The volume of water was calculated using the same equation as above, with fixed depth of 1 cm. Therefore, the volume of water for tank A and tank B are shown by the equations below:

$$\boldsymbol{V_A = \pi(9.25^2)(1) \quad V_B = \pi(6.5^2)(1)}$$

$$\boldsymbol{V_A = 269ml \quad V_B = 133ml}$$

   Where V_A and V_B is the volume of water needed for tank A and tank B.

3. Water and fuel was measured according to the volume needed.
4. Water was poured into the tank followed by the fuel.
5. The tank being left for five minutes as to let the water settle down to the bottom below the fuel.
6. The surface of the fuel was being ignited by the lighter.
7. The fire behavior was recorded using a digital camera.
8. Onset time until the boilover happen was being recorded.
9. Procedures was repeated using different volume of fuel and different tank.

3.3.3 Series of Experiment

For this current project, each tank will have five run of experiment, with different depth of used engine oil. Different depth will give different volume of fuel inside the tank. For each run the onset time to boilover and the fuel left after the boilover will be recorded. After calculating the volume of water and fuel needed for each depth, below is the table for recording purpose.

<u>Tank A</u>

TABLE 3 Tank A data table

No. of run	**Initial depth of water (cm)**	**Initial depth of fuel (cm)**	**Volume (ml)**	**Boilover onset time (s)**	**Fuel left after boilover (ml)**
1	1	2	538		
2	1	3	806		
3	1	4	1075		
4	1	5	1344		
5	1	6	1613		

<u>Tank B</u>

TABLE 4 Tank B data table

No. of run	**Initial depth of water (cm)**	**Initial depth of fuel (cm)**	**Volume (ml)**	**Boilover onset time (s)**	**Fuel left after boilover (ml)**
1	1	2	265		
2	1	2.5	332		
3	1	3	398		
4	1	3.5	465		
5	1	4	531		

3.3.4 Prediction of Boilover Onset Time based on Thermodynamic Law

The heat apply by flame to the oil surface will vaporize the light end and also increase the temperature of the bulk liquid in the tank. Such concept can mathematically represent by below formula:

$$\boldsymbol{Q = \dot{m}C_{p,st}(T_{bo} - T_{st}) + \dot{m}h_v}$$

Where, Q = heat flux (W)

$\dot{m}$ = burning rate in (m/s)

$C_{p,st}$ = specific heat constant at storage temperature (J/kg.K)

T_{bo} = boilover temperature (K)

T_{st} = storage temperature (K)

H_v = heat vaporization in (J/kg)

Since, $\dot{m} = \frac{\rho.A.h}{t}$

Then, $Q = \frac{\rho_l.A.h_l}{t} C_p(T_{bo} - T_{st}) + \frac{\rho_v.A.h_v}{t} H_v$

$\frac{Q}{A} = \frac{\rho_l.h_l}{t} C_p(T_{bo} - T_{st}) + \frac{\rho_v.h_v}{t} H_v$

Where, $\frac{Q}{A}$ = heat flux from the flame (W/m^2)

ρ_v = density of the vaporized fraction (at boiling point) (kg/m^3)

ρ_l = density of liquid (at storage temperature) (kg/m^3)

h_v = height of the vaporized fraction (m)

h_l = height of remaining liquid (m)

t = time to boilover (s)

The height of the remaining liquid is determined by,

$$h_l = h_0 - h_v$$

Where, h_0 = initial height of oil

The height of vaporized fraction correlates to the burning of the lighter ends, hence,

$$h_v = \dot{m}_v . t$$

Therefore, $h_l = h_0 - \dot{m}_v . t$

Rearranged the heat balance to give the correlation to determine the time to boilover as shown:

$$\frac{\dot{Q}}{A} t = \rho_v . \dot{m}_v . t . H_v + \rho_l . (h_0 - \dot{m}_v . t) . C_{p,st}(T_{bo} - T_{st})$$

$$\frac{\dot{Q}}{A} t - \rho_v . \dot{m}_v . t . H_v + \rho_l . \dot{m}_v . t . C_{p,st}(T_{bo} - T_{st}) = \rho_l . h_0 . C_{p,st}(T_{bo} - T_{st})$$

$$t = \frac{\rho_l . h_0 . C_{p,st}(T_{bo} - T_{st})}{\frac{Q}{A} - \dot{m}_v . [\rho_v . H_v - \rho_l . C_{p,st}(T_{bo} - T_{st})}$$

Therefore, based on the above equation, to calculate the predicted boilover onset time, it is requires to know the specific gravity, density and boiling point of the fuel. Thus, the information can be used to predict other physical properties such as heat of combustion, heat of vaporization and specific heat capacity.

The density of vaporized fraction, ρ_v and remaining liquid, ρ_l can be estimated through the following equation:

$$\rho = \rho_r - \alpha(T - T_r) + \beta(T - T_r)^2$$

where ρ_r is the density at the reference temperature T_r.

$$\alpha = (66 \pm 5) \times 10^{-5} for\ SG \in (0.61, 0.84)$$

$$\alpha = \left((189 - 146.5SG) \pm 5\right) \times 10^{-5} for\ SG \in (0.84, 1.07)$$

$$\beta = [(-15.4 + 19SG) \pm 2 \times 10^{-7}$$

The specific heat, C_p at temperature, T is predicted using equation as shown below:

$$C_p = \frac{1.685 + 3.4\times10^{-3}T}{SG}$$

While the heat vaporization, H_v could be estimated by,

$$H_v = \frac{251.47 - 377.136\times10^{-3}T_{bp}}{SG}$$

The correlation below could estimate the heat of combustion, H_c.

$$H_c = 46513 - 8800SG^2 + 3142SG$$

The heat flux from the flame to burning oil surface could be quantified based on the measured experimental flame temperature. However, for a generic correlation where the experimental data is not available (or not required), the heat flux is predicted by the following equation (Committee for the Prevention of Disasters, 1992):

$$\frac{\dot{Q}}{A} = x_r . r_{comb} . H_c$$

Where, x_r = faction of radiative heat feedback to fuel surface

r_{comb} = mass burning rate (kg/m^2.s)

r_{comb} = $\dot{m} . \rho_l$

The burning rate of surface regression rate of unit m/s is estimated as below (Committee for the Prevention of Disasters, 1992):

$$\dot{m}_v = \frac{1.0\times10^{-3} . H_c}{\rho_v . [H_v + C_{p,T_{bp}}(T_{bp} - T_{st})}$$

3.3.5 Safety Precautions

For this project experiment, some safety precautions have been taken due to the fire hazard during the experiment. Firstly, the experiment will not be done in the laboratory. Instead, it will be done at a field to avoid fire hazard emergency to happen. This experiment also limited to a small scale tank and small volume of used engine oil. This small scale tank will only create a slight boilover, hence does not bring any harm to the surrounding. Apart from that, a fire extinguisher will be provided at all time during the experiment in case of emergency.

CHAPTER 4

RESULT & DISCUSSION

4.1 Boilover Potential for Used Engine Oil

After conducting the experiment, it is observed and proven that boilover can occur in used engine oil. Due to various component in the used engine oil, it offer a wide range of boiling point during the combustion period. Below figures are the observations of fire behavior and boilover for the experiment conducted in Tank A.

FIGURE 11 Steady State

FIGURE 12 Initial boilover

FIGURE 13 First major boilover

FIGURE 14 Second major boilover

FIGURE 15 Post boilover

FIGURE 16 After boilover

Figure 11 – Figure 16 shown the boilover phenomena of used engine oil. In Figure 11, it can be observed that the flame burning rate started to become steady and stable. However, boilover potential cannot be seen in this period of burning. Based on previous study, the potential ‘indicators’ for boilover include boiling, fuel and steam ejection and audible indication. In many literatures, it has been mentioned that the start of the boilover event is normally accompanied by a noise characteristic (a crackling sound) which relates to the explosion of vapour bubbles that carry the fuel into the flame.

Shortly before the boilover happens, as shown in Figure 12, a loud crackling sound can be heard as far as 100m from the tank. The crackling sound can be heard for around 3 to 5 second before the boilover happened. It can be observed that during the initial boilover, the flame enlargement and fuel injection for the used engine oil has occurred. In a study, Azizul (2014) stated that boilover is also seen through fuel ejection due to the violent boiling of water and frothing over the tank contents which resulted in an increase in the flame height two or three times larger than during steady burning period.

In Figure 13 and Figure 14, major boilover had occurred for the used engine oil, in which the interval time between those two are only split seconds away. Both major boilover showed the same characteristic; flame enlargement and fuel ejection. However, it can be observed that flame enlargement for these two major boilover is larger than the flame enlargement during initial boilover. Moreover, the flames during the initial and major boilover were observed to be approximately 2 to 5 times the diameter of the tanks and hot burning fuel was thrown out from the tank which landed several meters away.

In Figure 15, post boilover occurred for used engine oil. During this period, the flame on the surface of the fuel started to extinguished. However, fuel injection still occurred throughout this period but with minimum amount of injection. In Figure 16, after the boilover had occurred, flame started to extinguished and no flame enlargement or fuel ejection can be observed. It can be assumed that when the water at the bottom of the tank being ejected during the boilover, it tends to suppressed the fire on the surface of the fuel. In summary, to identify the potential of boilover, physical observation such as the presence of higher sound levels and flame enlargement can be observed.

4.2 Boilover Onset Time for Used Engine Oil

4.2.1 Data Table

TABLE 5 Result data table for tank A

No. of run	**Initial depth of water (cm)**	**Initial depth of fuel (m)**	**Volume (ml)**	**Boilover onset time (s)**
1	1	0.02	538	982
2	1	0.03	806	1660
3	1	0.04	1075	2771
4	1	0.05	1344	3030
5	1	0.06	1613	4119
*6	1	0.03	806	1647
*7	1	0.04	1075	2651

*Repeated experiment

TABLE 6 Result data table for tank B

No. of run	**Initial depth of water (cm)**	**Initial depth of fuel (m)**	**Volume (ml)**	**Boilover onset time (s)**
1	1	0.02	265	965
2	1	0.025	332	1262
3	1	0.03	398	1640
4	1	0.035	465	2185
5	1	0.04	531	2563

4.2.2 Effect of Depth of Fuel on Boilover Onset Time

Based on the data table, graph of boilover onset time vs depth of the fuel has been plotted for both tank A and tank B. The graphs are shown below.

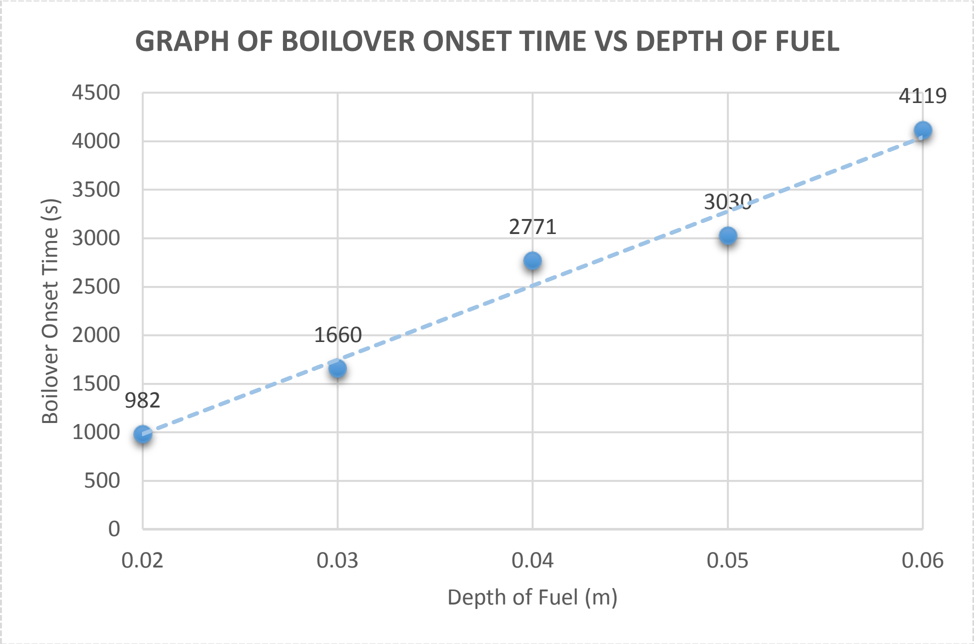

FIGURE 17 Graph of boilover onset time vs depth of fuel for tank A

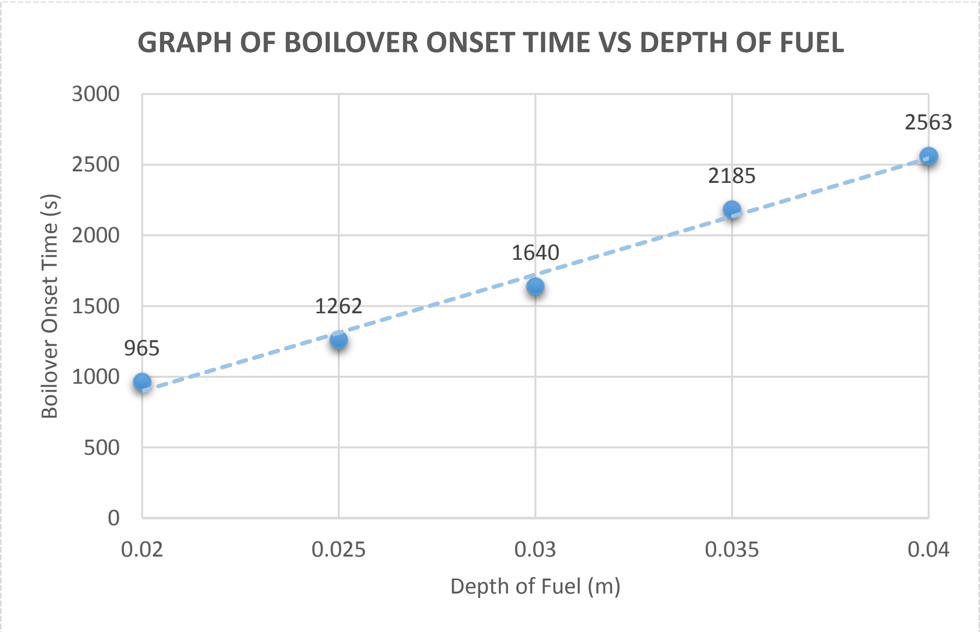

FIGURE 18 Graph of boilover onset time vs depth of fuel for tank B

Based on the graphs, the boilover onset time is increasing with the depth of the fuel in the tank, with average increasing time of 10 minutes for each depth for tank A and average increasing time of 5 minutes for each depth for tank B. Increasing depth indicate there will be more fuel to be heated, hence the distance for the heat flux to reach the water layer at the bottom is longer. Therefore, longer time needed for the fuel to boilover.

However, it can be observed from the graph for tank A, between the depth of 0.03m to 0.04m, a huge differences in time occurred which around 20 minutes. This may be due to the environment conditions during the experiment being conducted. Due to the monsoon season, the weather conditions was very windy and cold (high in humidity). Therefore, it can be assume that a huge loss of heat to the surrounding from the tank happened throughout the experiment.

4.2.3 Effect of Tank Diameter on Boilover Onset Time

It can be observed from the graph that the diameter of the tank does not affect the boilover onset time. For the same depth of 0.02m for tank A and tank B, the boilover onset time was 982s and 965s respectively. Only a difference of 17s for the boilover onset time. Another data point, for the same depth of 0.03m for tank A and tank B, the boilover onset time was 1660s and 1640s respectively, with 20s as the difference for boilover onset time.

From these data analysis, it can be concluded that the tank diameter does not affect the fuel boilover onset time. It can be assumed that the heat flux from the flame at the surface moving downwards with a constant rate once full surface ignition is achieved throughout the experiment. As a result, the diameter does not affect the movement of the heat flux from the fuel surface to the bottom of the fuel, thus giving the same onset time for any tank diameter.

4.3 Parameter Effecting Boilover Fuel Ejection

4.3.1 Data Table

Below data table show the volume of fuel left in tank A and tank B after boilover happened.

TABLE 7 Fuel left after boilover in tank A

No. of run	Initial depth of water (cm)	Initial depth of fuel (m)	Volume (ml)	Fuel left after boilover (ml)	Fuel left after boilover (%)
1	1	0.02	538	400	74.35
2	1	0.03	806	370	45.91
3	1	0.04	1075	330	30.70
4	1	0.05	1344	200	14.88
5	1	0.06	1613	200	12.40
*6	1	0.03	806	350	43.42
*7	1	0.04	1075	335	31.16

*Repeated experiment

TABLE 8 Fuel left after boilover in tank B

No. of run	Initial depth of water (cm)	Initial depth of fuel (cm)	Volume (ml)	Fuel left after boilover (ml)	Fuel left after boilover (%)
1	1	0.02	265	115	43.40
2	1	0.025	332	100	30.12
3	1	0.03	398	90	22.61
4	1	0.035	465	80	17.20
5	1	0.04	531	75	14.12

4.3.2 Effect of Volume of Fuel on Fuel Ejection

Based on the data table, graph of fuel left after boilover vs volume of fuel has been plotted for both tank A and tank B. The graphs are shown below.

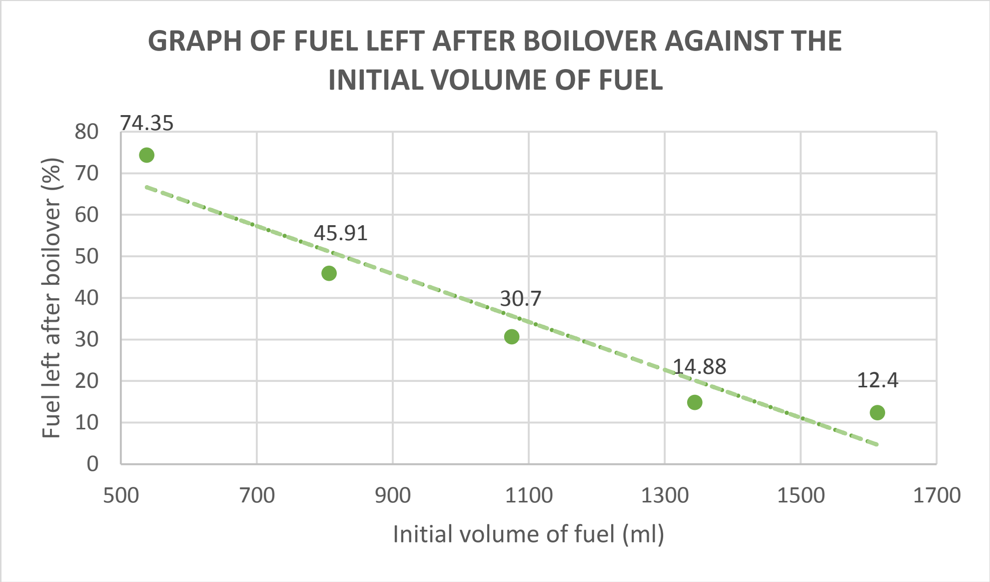

FIGURE 19 Graph of fuel left after boilover vs initial volume of fuel in tank A

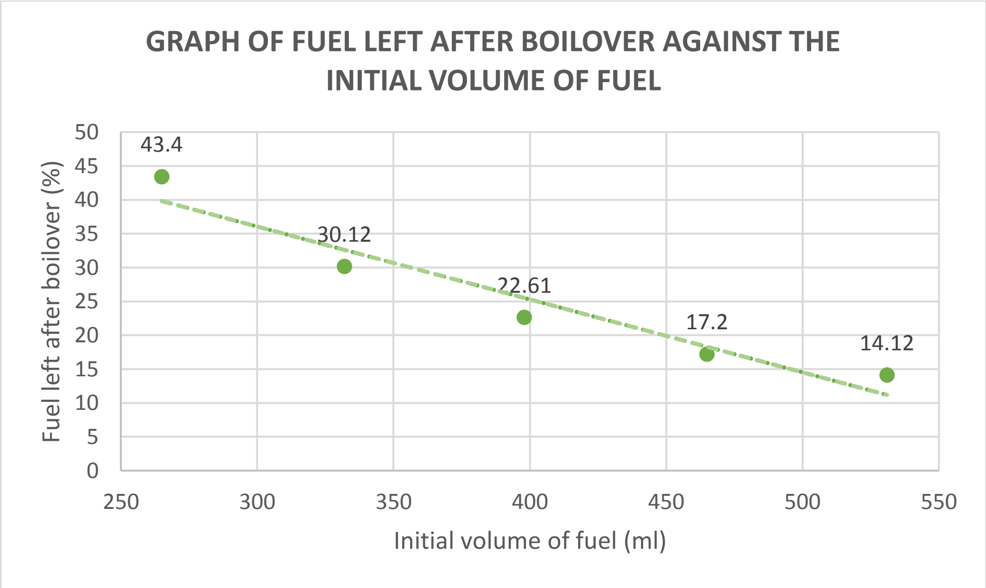

FIGURE 20 Graph of fuel left after boilover vs initial volume of fuel in tank B

Based on the graphs plotted, it can be observed that the larger the initial volume of fuel, the smaller the percent of fuel left in the tank after boilover. Comparing the data for tank A, for the volume of 806ml, the percent of fuel left was 45.91%, while for the volume of 1075ml, the percent of fuel left was 30.70%. From this observation, it can be assume that larger volume of fuel eject more fuel during boilover phase. A larger volume of fuel produce more heat flux during the combustion, hence creating more violent fuel injections, leaving smaller volume left in the tank.

During the fifth and sixth experiment run in tank A, it can be observed that two major boilover happened after the onset time. Comparing this observation with the first and second experiment run, only one major boilover happened for both experiment run. Additionally, based on observation, larger initial volume of fuel in the tank created bigger flame enlargement. Therefore, it can be concluded that larger volume of fuel create more vigorous fuel ejection and flame enlargement.

4.3.3 Effect of Tank Size & Diameter on Fuel Ejection

Based on the data table, by comparing the same depth of fuel for tank A and tank B, it can be seen that smaller diameter giving smaller percent of fuel left in the tank after boilover. For the same depth of 0.02m, the fuel left in the tank after boilover occurred in tank A and tank B are 74.35% and 43.40% respectively. Another data point, for the same depth of 0.04m, the fuel left in the tank after boilover occurred in tank A and B are 31.16% and 14.12% respectively. Tank B gives smaller percent of volume left in the tank after boilover phase.

From this data observation, it can be conclude that smaller size and diameter eject more fuel during boilover phase. This observation can be explain due to the fact that smaller tank contain smaller volume of fuel, thus less force needed to eject the fuel during boilover occurrence. Furthermore, Tank B has lower tank height, making the fuel ejection is more easily compared to Tank A.

4.4 Prediction of Boilover Onset Time based on Thermodynamic Law

In order to verify the feasibility of the model, predicted results of the model are compared to the results of the experimental study. Below calculation show the predicted boilover onset time based on thermodynamic equation.

Tank geometry:

TABLE 9 Tank geometry

Tank	Height (m)	Diameter (m)
A	0.08	0.19
B	0.06	0.13

Fuel properties:

Type = Used engine oil

Oil boiling temperature = 573.15K

Oil storage temperature = 298.15K

Oil density at storage temperature = 828 kg/m^3

Oil specific gravity = 0.83

4.4.1 Calculated Parameters

Vaporized oil density at boiling point,

$\rho_v = 828 - [7.10 \times 10^{-4}(573.15 - 298.15)] + [2.37 \times 10^{-7}(573.15 - 298.15)^2]$

$\rho_v = 827.82\ kg/m^3$

Specific heat oil at storage temperature,

$$C_{p,st} = \frac{1.685 + 3.4 \times 10^{-3}(298.15)}{0.83}$$

$$C_{p,st} = 3251.46 \frac{J}{kg.K}$$

Specific heat at oil boiling point,

$$C_{p,bp} = \frac{1.685 + 3.4 \times 10^{-3}(573.15)}{0.83}$$

$$C_{p,bp} = 4377.96 \frac{J}{kg.K}$$

Heat of vaporization,

$$H_v = \frac{251.47 - 377.136 \times 10^{-3}(573.15)}{0.83}$$

$$H_v = 58905.3\ \frac{J}{kg}$$

Heat of combustion,

$$H_c = 46513 - 8800(0.83)^2 + 3142(0.83)$$

$$H_c = 4.31 \times 10^7 \frac{J}{kg}$$

Burning rate (surface regression rate),

$$\dot{m}_v = \frac{1.0 \times 10^{-3}(4.31 \times 10^7)}{827.82[58905.3 + 4377.96(573.15 - 298.15)]}$$

$$\dot{m}_v = 4.12 \times 10^{-5} \frac{m}{s}$$

Mass burning rate,

$$r_{comb} = 4.12 \times 10^{-5}(828)$$
$$r_{comb} = 3.41 \times 10^{-2}\,\frac{kg}{m^2.s}$$

Heat flux from flame radiated to burning fuel surface (assuming x_r to be in order of 0.5%, hence $x_r = 0.005$.

$$\frac{\dot{Q}}{A} = (0.005).(\,3.41 \times 10^{-2}).(\,4.31 \times 10^{7})$$
$$\frac{\dot{Q}}{A} = 7.35 \times 10^{3}\,\frac{W}{m^2}$$

4.4.2 Time Prediction Result

In order to solve for the time to boilover, the proposed experimental setup requires the input of boilover temperature. Currently, the determination or calculation of boilover temperature is extremely complex due to the huge number of parameters it depends on. Hence, an experimental measure value is used in the calculation, $T_{bo} = 130℃ = 403.15K$.

Hence, the final equation to predict the onset time,

$$t = \frac{828 \times h_0 \times 3251.46(403.15-298.15)}{(7.35\times10^{3})-(4.12\times10^{-5})\times[827.82\times58905.3-828\times3251.46(403.15-298.15)]}$$

$$t = \frac{28.27 \times 10^{7}}{16.99 \times 10^{3}}\,h_0$$

$$t = 16.64 \times 10^{3} h_0$$

The predicted time to boilover for each initial height for tank A and tank B is shown in the table below.

TABLE 10 Predicted time to boilover for tank A

Fuel initial height, h_0 (m)	**Predicted time to boilover (s)**
0.020	332.28
0.030	499.20
0.040	665.60
0.050	832.00
0.060	998.40

TABLE 11 Predicted time to boilover for tank B

Fuel initial height, h_0 (m)	**Predicted time to boilover (s)**
0.020	332.28
0.025	416.00
0.030	499.20
0.035	582.40
0.040	665.60

4.4.3 Experimental Data vs. Predicted Data for Onset Time

Below tables show the experimental time to boilover and the predicted time to boilover for both tank A and tank B.

TABLE 12 Onset time data for tank A

Fuel initial height, h_0 (m)	**Experimental time to boilover (s)**	**Predicted time to boilover (s)**
0.020	982	332.28
0.030	1660	499.20
0.040	2771	665.60
0.050	3030	832.00
0.060	4119	998.40

TABLE 13 onset time data for tank B

Fuel initial height, h_0 (m)	**Experimental time to boilover (s)**	**Predicted time to boilover (s)**
0.020	965	332.28
0.025	1262	416.00
0.030	1640	499.20
0.035	2185	582.40
0.040	2563	665.60

Based on the data table above, a huge differences between the experimental time and predicted time can be seen. Since, the weather condition during the experimental run was windy and high in humidity (due to the monsoon season), this differences may be assume because of the heat loss to the surrounding was very large, hence the fraction of radiative heat feedback to fuel was extremely small. To prove this hypothesis, new predicted time was calculated using $x_r = 0.001$.

$$\frac{\dot{Q}}{A} = (0.001).(3.41 \times 10^{-2}).(4.31 \times 10^{7})$$

$$\frac{\dot{Q}}{A} = 11.11 \times 10^{3} \frac{W}{m^2}$$

Therefore, $t = \frac{28.27 \times 10^7}{11.11 \times 10^3} h_0 = 25.45 \times 10^3 h_0$

Below tables show the experimental time to boilover and the predicted time to boilover for both tank A and tank B, using new $x_r = 0.001$.

TABLE 14 Onset time data for tank A using new x_r

Fuel initial height, h_0 (m)	Experimental time to boilover (s)	Predicted time to boilover (s)
0.020	982	509.00
0.030	1660	763.50
0.040	2771	1018.00
0.050	3030	1272.50
0.060	4119	1527.00

TABLE 15 Onset time data for tank B using new x_r

Fuel initial height, h_0 (m)	Experimental time to boilover (s)	Predicted time to boilover (s)
0.020	965	509.00
0.025	1262	636.25
0.030	1640	763.50
0.035	2185	890.75
0.040	2563	1018.00

Based on the new data table, the differences using new x_r is getting smaller. Therefore, it can be conclude that the huge difference of the experimental data with the predicted data is due to the large heat loss to the surrounding resulting in extremely small radiative heat feedback to the fuel surface. From this analysis, it is believe that fraction of heat radiative feedback is a concern when calculating the prediction boilover onset time.

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

As a conclusion, it is certain that boilover can occur in used engine oil. Varies boiling range in used engine oil making it possible for boilover to occur. Due to the lack of equipment, the temperature profile does not being measured in this experiment studies. Nevertheless, in the future, it is recommended to use a thermocouple to measure the temperature profile in the fuel tank, as this data might be useful.

Apart from that, for future study, it is recommended to identify the composition in the used engine oil. As the fuel came in bulk from the workshop, it will definitely came from different vehicle using different brand of engine oil. Hence, different composition of the engine oil, might affect the data obtain from the experiment conducted. Thus, this step is highly recommended.

From the experiment conducted, it is believe that boilover for used engine oil can be predict through physical observation such as the presence of higher sound level and flame enlargement. Furthermore, it can be conclude that the deeper the depth of the fuel, the higher the boilover onset time. This is due to increasing distance of the heat flux to transfer in the fluid, thus creating longer time to boilover. However, the diameter of the container does not affect the boilover onset time.

Additionally, increasing volume of fuel creating more vigorous fuel ejections and flame enlargement. More heat flux is produce in a larger volume of fuel, thus creating the dynamic behavior of boilover. However, smaller volume of fuel inside a smaller tank, with a same depth need less force to eject the fuel during boilover occurrence.

In addition, it can be conclude that prediction time for boilover can be calculate using simple equation of thermodynamic. Nevertheless, the fraction of heat radiative feedback is a concern when calculating the prediction time. This can be relate with the heat loss to the surrounding during the experimental study. In future study, it is recommend to conduct the experiment during hot weather, thus avoiding windy and humid weather. In this way, huge heat loss to the surrounding can be avoided as to obtain more accurate data.

By identifying all parameters, hopefully the prediction of boilover onset time for used engine oil can be determined. Hopefully, using the data in this report, prediction of boilover onset time for used engine oil during fire emergency can be predicted, thus avoiding severe accident to happen.

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