# Study of Boilover Fire: The Relationship between Fuel Layer Thickness and Time to Start Boilover.

by

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## CERTIFICATION OF APPROVAL

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Approved by,

__________________________

(MR. AZIZUL BIN BUANG)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 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 reference and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

________________________________

(Muhammad Izham Bin Mohd Yusof)

# ABSTRACT

Boilover is the most dangerous accident that can happen in an atmospheric storage tank which can lead to serious consequences especially to emergency responders. Boilover is a violent ejection of certain liquid hydrocarbon due to prolonged storage tank fire. The delayed boilover occurrence is an unknown strong parameter especially during the emergency response operations. It is important to understand what happens within the fuel in a storage tank during a fire. Such understanding is essential especially for predicting the start time of boilover. Accordingly, boilover experiments were planned and carried out with the intentions to evaluate the nature and consequences of boilover. In this work, it is aimed to investigate the relationship between the time to start boilover and the effect of fuel layer thickness. Boilover onset time upon full surface fire and the size of area affected due to the ejection of burning fuel will be observed and analysed. Based on the experimental results, a simple correlation to predict the time to start boilover will be proposed.

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**NOMENCLATURE**

| | |
|---|---|
| $h_o$ | Initial thickness of fuel, cm |
| $t_b$ | Time to start of boilover, minute |
| a | Regression coefficient (min/cm) |
| c | Regression coefficient (min) |

## CHAPTER 1

## INTRODUCTION

### 1.1 BACKGROUND OF STUDY

Feedstock, intermediate and product in the refineries are stored in storage tanks before being moved to their respective tank. There is an abundance of storage tank facilities built and being built in many countries. Due to the inherent properties of materials being stored, storage facilities and the possible risks of fire are of great concerns. The storage facilities are still prone to incidents such as fires and explosion. Fires in storage tanks pose a high treat and many results in fatalities, capital losses and environmental destruction.

Fires involving tank containing liquid hydrocarbons may lead to fuel eruption, for example slop over, froth over and boilover. (Broeckman and Schecken, 1995) Slop over is the least serious form of fuel eruption which is a discontinuous frothing release of fuel over part of tank wall. Froth over is a continuous fuel frothing release from a tank's over its wall. Boilover is the most dangerous accident of fuel eruption. A boilover is a violent ejection of fuel due to the vaporisation of water sub layer, producing in a vigorous fire enlargement and ground fire and formation of fire ball. Slopover and frothover fires are shown in Figure 1.1 and Figure 1.2.

*Figure 1.1: Slopover tank fire. [2]*

*Figure 1.2: Frothover tank fire [2]*

Catastrophic event which cause severe damages and high loses can be prevented if the mechanism of the boilover have been studied and understood specifically on the time for a boilover to occur. In the event of full surface fire in a storage tank, the surface of the liquid fuel receives heat from the flame. Heat is conducted into the fuel and vaporizes the light components of the fuel which is low boiling point. The heavy ends, which have been heated, sink and mix with and heat the colder fuel layer and further vaporize the lighter ends.

The rise in light ends vapour bubbles causes thorough mixing of the fuel in this region forming a uniform temperature and composition layer called hot zone. As the fire progresses, the hot zone slowly grows moves towards water or on other words, the heat will be transferred from the flame to the water. Upon reaching the boiling point, and pushed out the fuel and cause massive boilover which caught many by surprise. There is "rule of thumb" that a boilover fallout can extend 5 to 10 diameters in each direction from the tank. [2] Actual distance will depend on the quantity of fuel involved, the amount of vaporised liquid and wind direction.

Some of the boilover studies stated the importance of heat transfer in the direction normal to the fuel and water sub layer surfaces. When the hot zone reaches the water sub layer surfaces, the water is superheated and expands explosively, which eject the burning fuels on top out of the tank. The boilover is linked to the heterogeneous boiling nucleation at the water and fuel interface and in the water sub layer that has been superheated.

Most of the studies which related to boilover have been conducted on small or medium-scale fires in laboratory. The small and medium scales experiments offer a better control on the operations conditions, which ease the analysis on the parameters of the boilover phenomenon.

The influence of the major parameters of the problem which are fuel layer thickness, the pool diameter or diameter of the container, fuel boiling point and viscosity, the temperature history of fuel and water and time to start boilover are studied.[3] However, the most manipulated parameters are the thickness of fuel and diameter of the container. The studies were undertaken, mainly to study the rate at which the fuel was consumed and the heat transfer mechanism involved and to predict the time of boilover.

## 1.2 PROBLEM STATEMENT

A number of boilover associated with fires in large storage tanks that occurred have been reported. (Persson and Lonnermark, 2004) Some of these accidents resulted in high loss of life and significant property damage due to the ejection of burning fuel due to boilover. It is vital that all personnel retreat to a safe distance when this phenomenon occur as the result of boilover can be catastrophic and obviously exposed anyone in the vicinity to a high level of risk.

Boilover is a dangerous accidental phenomenon. A boilover can occur several hours after ignition without any obvious warnings or signs. Consequently, the time from the start of the fire to boilover is an unknown parameter which is of great importance especially for managing the emergency response operations.

Although, there are some findings regarding signs of boilover, there is currently no definitive method of determining when a boilover will occur. The transfer of the heat from the hot zone towards the water layer is not necessarily uniform throughout the burning process. Only a general 'rule of thumb' can be used to predict when boilover would occur such as using the information on regression rate of hot zone downwards that is at a speed of 1 to 2 meter every hour and linked in with the thickness of fuel layer presents in the tanks. Hence the time to boilover could be predicted. [2]

## 1.3 OBJECTIVE

The main objective of this work is to develop an understanding of boilover pertaining to fires involving liquid hydrocarbons in storage tanks. In particular, the purpose of the work is to study the parameter that would influence the time of start boilover.

The aims of this project:

- To study the relationship between the thickness of fuel layer and the time to start boilover.
- To measure the distance of fuel fallout from container as the consequences during the phenomenon of boilover.

## 1.4 SCOPE OF STUDY

The scope of the study is to conduct upon ignition small-scale fire experiments in which the time to start of boilover as the result of changing the fuel layer thickness will be observed and analysed. The experiment is conducted outside the laboratory with appropriate precaution steps taken. A correlation to estimate the time to boilover based on the fuel thickness is proposed as follows:

$$t_b = ah_o + c$$

It should be noted that parameters such as the tank diameter and the wind velocity are not going to be considered in this work.

## 1.5 RELEVANCY OF PROJECT

The objective of the work is to study the parameters that would affect the time to boilover. This is appropriate and relevant to the real problems and needs whenever emergency response action is required in handling storage tank fires with the potential to boilover. Such information is important to recognize appropriate mitigation strategies in order to prevent or minimize the boilover's consequences.

## 1.6 FEASIBILITY OF PROJECT

The works involve the burning of common liquid hydrocarbon, for example, petrol and diesel and the fuel container used is a readily available tin container. Such requirements make it possible to conduct the study within the time given. In addition, proper risk assessments are carried out to ensure the possibility of conducting the work in safe manners.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 CATASTROPHIC EVENT

Although fires involving storage tanks can be considered infrequent, they still happened and posed a threat to life safety. Fires were the most frequent accidents involving storage tanks. (Chang and Lin, 2006)

Most storage tanks are classified according to their roof type consisting of fixed roof, internal floating roof, open-top floating roof, and domed external floating roof types. Physical characteristic of the product stored in a tank and the tank's location are the factors that specify which storage tank type must be used for special flammable or combustible liquid. [6] Large cone-roof tanks, smaller low pressure vertical or horizontal tanks, or underground tanks are typically appropriate one to store combustible liquids. Flammable liquids are commonly stored in open-top or internal floating roof tanks in bulk quantities, in small low-pressure vertical or horizontal tanks, or in underground tanks.

Fires that mostly occur in large diameter open top floating roof tanks. Vapour leaks through the seals between the roof and the tank shell might be ignited produced small fires. [4] The small fires then if not controlled would be escalated to full surface fire. The types of tank fires and its escalation are shown in Figure 2.1 and Figure 2.2.

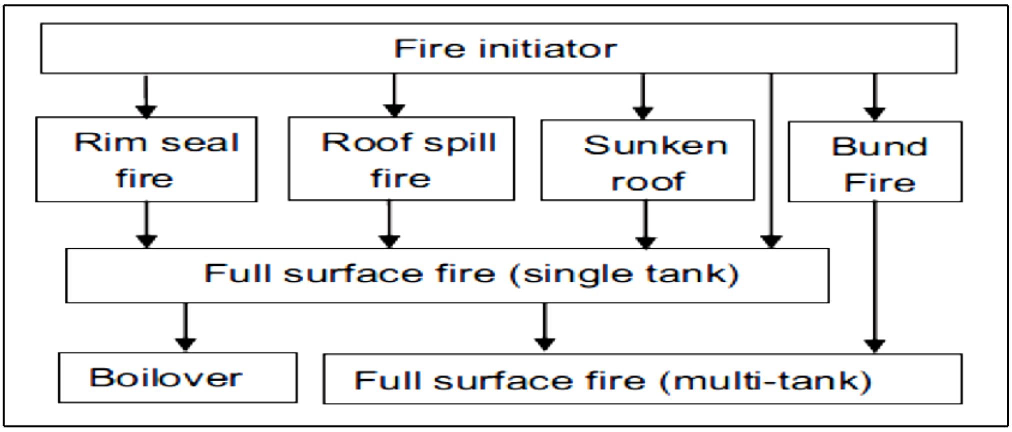


*Figure 2.1: Types of Fire and Escalation [5]*

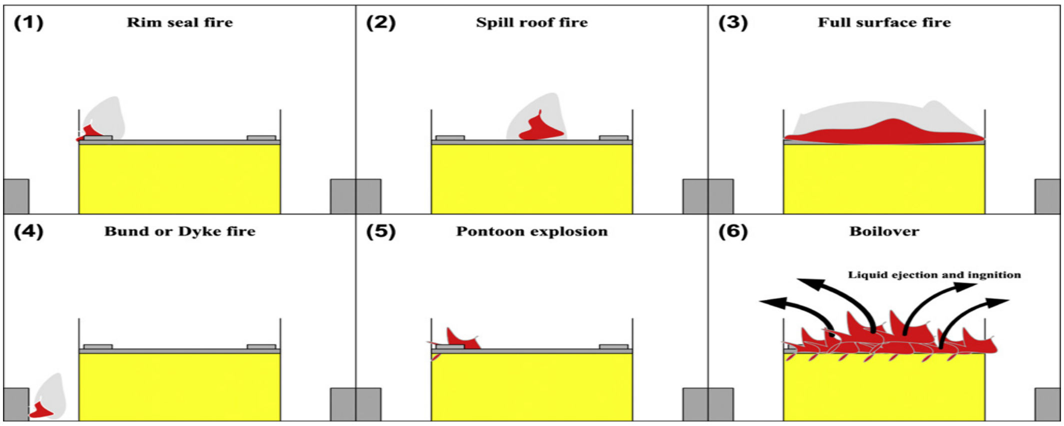


*Figure 2.2: Potential Tank Fire Scenarios [7]*

Unfortunately, a number of boilovers associated with large full surface fires have being reported. (Persson and Lonnermark, 2004) Boilover phenomenon is often encountered with fires involving large storage tanks containing multicomponent fuels which particularly crude oil leading to explosive vaporization of the water present on the bottom of the tanks.

Amoco refinery fire is one of the examples of boilover accident as in Figure 2.4. It was occurred on 30th August 1983 when a fire broke out in one the tanks of Amoco refinery at Mildford Haven, Pembrokeshire on the West coast of Wales. [16] The tragedy occurred after a 256-foot-diameter floating roof tank containing over 46,000 tonnes of crude oil ignited.

Other major accident that involved boilover phenomenon was Tacoa power plant explosion as in Figure 2.3 which occurred on 19th December 1982. [17] Tacoa disaster was the worst oil-storage fire history when 150 people perished and about 300 more people were burned and injured. Property losses reached more than 20 million dollars.

*Figure 2.3:Tacoa Power Plant Explosion[17]*

*Figure 2.4: Amoco Refinery Fire[16]*

## 2.2 BOILOVER MECHANISM

Boilover is a violent explosion of certain liquid hydrocarbon or fuel due to prolonged tank fires. There is a sudden increase in fire size and intensity due to the explosion of the burning fuel from a tank. When a full surface fire is established, the flame heats up the fuel in the tank and vaporises components with low boiling and hence increasing the surface temperature.

Further burning will caused the temperature increase in the deeper layer of the fuel and further boils the low boiling point components whilst heating up the high boiling point. The vapour formation due to the boiling of low boiling point components mixes and stirs the fuel and a zone of uniform temperature layer was established. The zone is called a hot zone as the burning progresses, more of the low boiling point components will be vaporized and more of the high boiling point components will be heated. The hot zone grows further and moves towards the bottom of the tanks.

When this hot zone reaches any encapsulated water source (such as within the tank’s sump located at the tank floor) it will begin to heat that water through its boiling point until the water converts to steam. An expansion rate of 1,700 to 1 will turn that dormant water residue into a violent vapour air explosion. [1] If for example, there was 500 gallons of water contained at some level within the tanks, the rapid expansion explosion would propel 850,000 gallons of steam upward through the volume of crude and cause an explosion that could potentially reach outwards up to 6 tanks diameters as it falls back to the ground.

Heat losses to the water below may cause its boiling and induce an eruptive vaporization of explosive and violent character referred to as thin layer boilover. [3] Besides, the ejection of the fuel from the tanks can be divided into 3 categories which are slopover, froth over and boilover. Boilover type of fire appears excessively hazardous in a situation where a semi-enclosed oil or petrochemical fuelled fire is being extinguished with water. If the water content of the tank is allowed to convert to steam, an expansion rate of 1,700 to 1 will turn that dormant water residue into a violent vapour air explosion. [1]

The water boils, turn to steam and pushes up through the fuel above. The result is a massive eruption of tank content that can spread to several tank diameters away from the tank. Other fuels that can produce boilovers include petroleum, intermediates such as “tops” or crude distillates, residual oils, heavy fuel oils and refined products contaminated with another product with a different boiling point. [2]

## 2.3 BOILOVER STUDIES

Most of the studies have been conducted on small or medium-scale tanks involving burning of pure or multi-component fuels. The small or medium-scale tests ensure calm external conditions; stable flames and nearly uniform heat transfer at the interface. [3] This facilitates the experiments and the result should give a better understanding of the boilover process.

Burning intensity is closely related to the thickness of the initial fuel layer and the hot zone. [10] Koseki who is the author of one of the boilover studies stated that strong convection and fuel vapour stirring influence the uniformity of the hot zone as the transfer of the heat through the crude oil. [18] He uses the ratio of maximum fuel regression rate and average fuel regression rate during quasi-steady state of burning as the parameters in his study. As a result from his analysis, increasing diameter of pan will decrease the amount of intensity and also the radiation of heat gives the energy for the hot zone formation which relatively small amount.

Hasegawa had come up with his study of boilover which focus on the influence of the tank dimension on the heat wave progression. In his work, different sizes of top cylindrical container are used and he tests to burn a few types of oil namely, diesel, gasoline and the mixture of both oils. Theory of his stated that the properties of oil influence only the container which greater than 0.9 meter of diameter.[9] Temperature and density of the oil are always the parameters which are measured and analysed throughout his work. As a result, he had proved his earlier hypothesis which hot zone formation is dependent on size of the container.

Detailed analysis had been done by Broeckmann and Schecker on the heat transfer mechanism in burning oil-water system. The theory is that temperature development is totally influenced by the two distinct heating phases in the crude oil tank fire. Temperature increment in the heat up phase is the first phase and growth of the hot zone under fuel surface is the second phase. [15] Possibility of the formation of the uniform temperature zone is cause by an extent of boiling range. Analysis from their study shows that uniform temperature and composition layer as a result of extensive mixing of the fuels and intense convective event causing the hot zone expansion.

The review from a few studies above show that for a boilover to occur, appropriate thickness and the temperature that come from isothermal layer or hot zone needs to form in the burning oil. Therefore, the researches above had showed much information on the identification of fuels that might boilover and that might not, time estimation to boilover and the consequences on form of fire enlargement.

# CHAPTER 3

# METHODOLOGY

## 3.1 GANTT CHART AND KEY MILESTONE

Table 3.1 shows the gantt chart for the project to be conducted during the first semester. The project is focused on research work on boilover study for weeks. Literature review on boilover study is fully drafted from various informations gathered from many sources. A few experimental trials and demonstration have been conducted.

*Table 3.1: Gantt chart of boilover study (FYP I)*

| Activities/Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Meeting with coordinator and supervisor | ■ | ■ | | | | | | | | | | | | |
| Preliminary research work<br>-Background study<br>-Literature review | | ■ | ■ | ■ | ■ | ■ | | | | | | | | |
| Project conformation - Boilover (Time vs Fuel) | | | | | | ■ | ■ | | | | | | | |
| Submission of extended proposal | | | | | | | ● | | | | | | | |
| Proposal defence | | | | | | | | ■ | ■ | | | | | |
| Continuation of project work<br>-Experimental trials<br>-Analysis of result | | | | | | | | | | ■ | ■ | ■ | | |
| Submission of interim draft report | | | | | | | | | | | | | ● | |
| Submission of interim report | | | | | | | | | | | | | | ● |

■ Process ● Milestone

Table 3.2 shows the Gantt chart for the project to be conducted. The project work is continued from previous work research in previous semester. After full understanding of the project, the experimental run is conducted a few times before doing full analysis throughout the semester.

*Table 3.2: Gantt chart of boilover study (FYP II)*

| No. | Detail/Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Project Work Continues | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | |
| 2 | Submission of Progress report | | | | | | | ● | | | | | | | |
| 3 | Project Work Continues | | | | | | | | ■ | ■ | ■ | ■ | ■ | | |
| 4 | Pre-SEDEX | | | | | | | | | | ● | | | | |
| 5 | Submission of Draft Final report | | | | | | | | | | | ● | | | |
| 6 | Submission of Dissertation (soft bound) | | | | | | | | | | | | ● | | |
| 7 | Submission of Technical Paper | | | | | | | | | | | | ● | | |
| 8 | Viva | | | | | | | | | | | | | ● | |
| 9 | Submission of Project Dissertation (hard bound) | | | | | | | | | | | | | | ● |

■ Process ● Milestone

## 3.2 EXPERIMENT METHODOLOGY

### 3.2.1 Experimental Site

The boilover experiment will be conducted using a small-scale container outside the laboratory. The laboratory is an enclosed area and can bring a lot of hazard if this experiment conducted in laboratory which involved the burning of highly flammable fuels. The idea is to prepare the chemicals in the laboratory and conduct the experiment which involved the apparatus in the isolation area for safety reason. Isolation area for the experiment to be done is 10 to 15 times the diameter of container away from the container itself which is approximately 2 meter. The risk assessment has been conducted as in Table 3.4 in order to conduct experiment at isolated safe place outside laboratory with full safety precautions.

### 3.2.2 Design Apparatus and Chemicals

*Table 3.3: List of apparatus and materials*

| Apparatus | Materials/Chemicals |
|---|---|
| 1. Appropriate size of tin container which the diameter is 18.5 cm and height is 7 cm (suggested)<br>2. Beakers<br>3. Waste bottle<br>4. Digital video camera<br>5. Masking tape<br>6. Measuring tape | 1. Petrol<br>2. Diesel<br>3. Water<br>4. Extinguisher |

### 3.2.3 Fuel Used

The proposed fuels used in the experiment are petrol and diesel. It is possible to heat the water through its boiling points as the two fuels used are basically with high boiling temperatures range which is from about 30$^{o}$C to a temperature greater than 300$^{o}$C. As in theory, the petrol will act as light component which also is highly volatile and diesel will act as heavy component which come in higher boiling point than petrol. These two proposed fuels made suitable mixture because one of the conditions for boilover to occur is that the fuels involved should have a wide range of boiling point temperature.

### 3.2.4 Container

The container which will be used is a cylinder-type container with height of 7 cm and diameter of 18.5 cm. The container with this measurement should be suitable for the experiment as the diameter is greater than the height of the container (diameter is close to three times the height) which it is easier in order to observe the conditions inside the container during the burning of fuels.

### 3.2.5 Measuring Distance

The distance of the fuel fallout from container should be measured during the phenomenon of boilover. The longest distance of fuel fallout from the container is measured. The idea is to determine exactly how far the explosion of boilover could travel considering worst case scenario. This observation is recorded with throughout the variation of thickness of water and the fuel mixture.

### 3.2.6 Video Recording

All the time to start boilover is recorded by using stopwatch. However, the boilover occurrence and all the changes of the fire such as fire enlargement spread of fuel and ejection of fuel from the container is recorded by a digital video camera. The confirmation of the time to start boilover can be referred to the recorded video if there is human error during recording the time using stopwatch or technical error such as broken stopwatch.

### 3.2.7 Design of Experiments

**Variables**

The time to start boilover will be different when using different initial fuel depth. The initial fuel layer thickness is the manipulated variables in order to determine the time taken for boilover to occur. The ratios of the fuel mixture which contain petrol and diesel that will be used are 3:7 and the thickness of the fuel mixture will vary by 0.5 cm. Besides, the other objective of this project is to determine the distance covered by explosion of boilover which influenced by the initial fuel layer thickness. The time to start boilover and distance covered by the explosion of boilover should be the responding variables in this experiment. The water thickness inside the tank had no significant effect on the onset of boilover and therefore will be fixed throughout the experiment which is 1cm. Other variable which also fixed are the diameter and height of container which is 18.5 cm of diameter and 7 cm of height.

Range of manipulated variable:

| Variable | Range of Variable | | | |
|---|---|---|---|---|
| Initial fuel layer thickness (cm) | 2.0 | 2.5 | 3.0 | 3.5 |

Fixed variables:

| | |
|---|---|
| Fuel composition | 30% petrol and 70% diesel |
| Water thickness | 1 cm |
| Container size | Diameter = 18.5 cm, Height = 7 cm |

Responding variables:

1. Time taken for boilover to occur (measured in minute)
2. Distance of explosion of boilover away from container (measured in centimetre).

**Experimental Run**

In order to get accurate and average measurement of result and calculations, the experiment will be repeated a few times. This is because the unwanted factors or surrounding factors can affect the process of burning fuel which also can affect the result of time taken for boilover to occur. However, the numbers of experimental run to be performed also be minimized due to a few factors which are the time period, safety and economic. The cost of this experiment can be increased due to high amount of fuels used and the probability for the container to fail is high when a higher numbers of experimental run are taken. Besides, the period of time given for this project to be completed is not enough for high numbers of experimental test to be taken. Risk assessment has been conducted as shown in Table 1.

*Table 3.4: Risk assessment of experiment.*

| Activity | Location | Potential Hazard | Existing Control Measure | Preventative Measures | Responsibilities |
|---|---|---|---|---|---|
| Preparation of samples (petrol and diesel) | Laboratory | Diesel - Flammable. Diesel vapours can irritate eyes, nose, throat and lungs. Breathing diesel vapours for long periods of time can cause kidney damage and reduce clotting ability of blood. | If contact - immediately flush eyes with plenty of water. Flush contaminated skin with plenty of water. If inhaled - remove to fresh air and get medical attention. If swallowed - do not induce vomiting and get medical attention. | Use personal protective equipment, wear protective gloves. Conduct the preparation in the fume chamber. Keep away from ignition source. | Student and supervisor. |
| | | Petrol - Extremely flammable liquid and vapour. May be fatal if swallowed and enter airways. Can cause skin irritation. May cause genetic defects and cancer | Eye contact - immediately flush with plenty of water. Skin contact - wash with soap and water. Ingestion - immediately rinse mouth and drink plenty of water. Do not induce vomiting. | Use personal protective equipment, wear protective gloves. Conduct the preparation in the fume chamber. Keep away from ignition source. | Student and supervisor. |
| Conducting experiment | Outside laboratory, isolation area, safe place area. | Fire and explosion hazard - Vapours of petrol and diesel may cause flash fire. Vapours may accumulate in low or confined areas or travel a considerable distance to a source of ignition and flash back. | Use water fog, foam, dry chemicals or carbon dioxide. Do not use water jet in case of flash fire. Avoid dispersal of spilled material and runoff contact with soil. | Prepare fire extinguisher. Place the fuel container out of distance of 5 times the diameter of the container itself. Isolate the area so that there are no people passing by accidentally. Use personal protective equipment and wear protective gloves. | Student and supervisor. |
| Housekeeping | Laboratory | Flash fire hazard which come from left out of the waste fuel in the container. | Immediately flush with plenty of water if contact with eyes or skin. | Conduct the process of transferring the waste into the waste bottle in the fume chamber. Wear full protective equipment including glove and goggles. | Student and supervisor. |

### 3.3 Experimental Procedure

1. Preparation of chemical in laboratory. Petrol and diesel are measured by using beaker and measuring cylinder.
2. Water is measured and poured into the tin container. Fuel mixture is poured into the tin container.
3. Prepare a fire extinguisher at the experimental location outside laboratory as safety precaution. (Refer Table 3: risk assessment)
4. Place the tin container at the experimental location and make sure it is safe to ignite the fuel (no flammable fluid or things nearby)
5. Fuel mixture is ignited and waited to boilover. The experiment is conducted until the flame is extinguished by itself.
6. The process of combustion and phenomenon of boilover is observed and recorded using digital video camera.
7. The distance of fuel fallout is measured using measuring tape after the whole combustion process is completed.
8. The oily waste is disposed into waste bottle.

### 3.4 Project Activities

Many journals had been reviewed in first semester in order to get understanding on boilover phenomenon. Meeting with supervisor throughout the period of project also give a lot of information towards this work. Furthermore, a demonstration on boilover phenomenon has been made by experienced supervisor to give full picture on how this phenomenon can occur. All the theories in many studies have been studied in order to investigate properly the objective for this work. Basically, the project on first semester is focused on literature review of boilover phenomenon because it is important to know exactly what the project is all about.

On next semester, the project is continued and started a few experimental runs based on detailed procedure prepared from previous semester. Besides, the briefing and seminars also have been conducted by coordinator for this work from time to time throughout in the second semester which gives full guidance in order to do proper research on the boilover phenomenon. Risk assessment has been conducted in many aspects (preparation of chemical, conducting experiment and housekeeping) to be used as the safety precautions for the experiments to be conducted safely. The experimental run is conducted and repeated a few times in order to get precision data.

There are some obstacles or errors that may influence the result of the experiments and therefore, all the data obtained from the result are not exact data that indicate real phenomenon because of some error throughout carrying the experiment.

# CHAPTER 4

# RESULT AND DISCUSSION

## 4.1 Result

### 4.1.1 Experimental Run

The ratio of the fuel mixture selected for the experiment to be conducted for petrol and diesel which is 3:7 respectively is an ideal composition for the phenomenon of boilover to occur. By using this composition, four experimental runs were conducted using a tin container with different initial fuel mixture thickness and same water thickness. However, another two experimental runs were conducted by using fuel composition of 100% petrol and 100% diesel respectively with same initial fuel thickness.

### 4.1.2 Time to Boilover

Table 4.1 summarizes the result of two experimental runs which using fuel composition of 100% petrol and 100% diesel. Water thickness and initial fuel thickness for both petrol and diesel are fixed throughout the experimental runs. Burning time indicates the time recorded right after the flame is fully extinguished.

*Table 4.1: Summary of experimental run results (100% petrol and 100% diesel)*

| Run | 1 | 2 |
|---|---|---|
| Container diameter (cm) | 18.5 | 18.5 |
| Container height (cm) | 7 | 7 |
| Fuel thickness (cm) | 2 (538 ml)<br>100% Petrol = 538 ml | 2 (538 ml)<br>100% Diesel = 538 ml |
| Water thickness | 1 | 1 |
| Time to boilover (min) | - | 17.37 |
| Burning time (min) | 11.05 | 20.24 |

Table 4.2 summarizes the result of four experimental runs which using composition of 30% petrol and 70% diesel. Water thickness is fixed throughout the experimental runs. Burning time indicates the time recorded right after the flame is fully extinguished.

*Table 4.2: Summary of the experimental run results (30% petrol and 70% diesel)*

| Run | 3 | 4 | 5 | 6 |
|---|---|---|---|---|
| Container diameter (cm) | 18.5 | 18.5 | 18.5 | 18.5 |
| Container height (cm) | 7 | 7 | 7 | 7 |
| Fuel thickness (cm) 30% Petrol, 70% Diesel | 2 (538 ml)<br>Diesel = 377 ml<br>Petrol = 161 ml | 2.5 (673 ml)<br>Diesel = 471 ml<br>Petrol = 202 ml | 3.0 (807 ml)<br>Diesel = 565 ml<br>Petrol = 242 ml | 3.5 (942 ml)<br>Diesel = 659 ml<br>Petrol = 283ml |
| Water thickness | 1 | 1 | 1 | 1 |
| Time to boilover (min) | 13.58 | 17.09 | 19.05 | 25.56 |
| Burning time (min) | 15.14 | 18.04 | 23.13 | 27.12 |

### 4.1.3 Distance of Fuel Fallout

Table 4.3 summarizes the result of distance of the fuel fallout from container during the phenomenon of boilover for all six experimental runs that were conducted. The fuel mixture thickness is fixed for the first two experimental runs that using 100% petrol and 100% diesel respectively, while the fuel mixture thickness is vary by 0.5 cm in the next four experimental runs which start from 2 cm. Water thickness is fixed throughout six experimental runs. The distance of fuel fallout is measured by using measuring tape. Considering worst case scenario, the longest distance of fuel fallout for respective experimental runs is measured.

*Table 4.3: Summary of distance of fuel fallout from container.*

| **Run** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|
| Container diameter (cm) | 18.5 | 18.5 | 18.5 | 18.5 | 18.5 | 18.5 |
| Container height (cm) | 7 | 7 | 7 | 7 | 7 | 7 |
| Fuel thickness (cm) | 2 (538 ml)<br>Petrol = 538 ml | 2 (538 ml)<br>Diesel = 538 ml | 2 (538 ml)<br>Diesel = 377 ml<br>Petrol = 161 ml | 2.5 (673 ml)<br>Diesel = 471 ml<br>Petrol = 202 ml | 3.0 (807 ml)<br>Diesel = 565 ml<br>Petrol = 242 ml | 3.5 (942 ml)<br>Diesel = 659 ml<br>Petrol = 283 ml |
| Water thickness (cm) | 1 | 1 | 1 | 1 | 1 | 1 |
| Distance of fuel fallout (cm) | - | 53 | 47 | 67 | 155 | 217 |

### 4.1.4 Observation

The behaviour of fire and all surrounding factors that contribute to the burning test are observed throughout all the experimental runs. However, parameter such as wind velocity is not being considered in this work. There are a few stages during the process of combustion which are ignition, burning, boilover and extinguished flame. Figure 4.1 to 4.4 show the process of combustion during the experimental runs.

*Figure 4.1: Ignition*

Initial stage – the fuel mixture is ignited and the flame covered the surface of the fuel only in a few seconds. The flame is not turbulent at first.

*Figure 4.2: Burning*

Burning stage – the amount of soot produce reflect the fuel consumed for the combustion. Flame is steady and sound of water boiled heard during this stage.

*Figure 4.3: Boilover stage*

Boilover stage – an explosion occur and sudden enlargement of the flame can be observed. The fuel and water can be seen ejected upward and to surrounding.

*Figure 4.4: Flame extinguished*

Extinguished flame – after the explosion, decreasing fuel subsequently reduced size of flame. After a few minutes, the flame extinguished itself.

## 4.2 Discussion

### 4.2.1 Boilover Phenomeon

During the phenomenon of boilover, sudden change of flame size can be observed. This is because the water at the bottom of the tin container already achieved its boiling point which subsequently starts to vaporize and explode upward and to surrounding. In the first two experimental runs which using 100% petrol and 100% diesel, it can be seen that there is no boilover fire occur when using 100% composition of petrol.

Combustion of petrol alone is not enough to transfer the heat wave through the water. In other words, water could not reach its boiling point as there is no wide range of boiling points between the mixtures of two fuels which can be a medium to transfer the heat wave to water at the bottom. The flame will extinguish itself by the time the water is near to boiling point to vaporize itself because of fast consumption of petrol alone in experimental run 1.

In experimental run 2, 100% composition of diesel is used. Basically, it takes longer time for a boilover fire to occur when diesel is used instead of petrol. In the experiment, the time to boilover when using 100% composition of diesel is 17.37

minutes. Theoretically, the flash point of diesel is higher than petrol which brings to the failure of early ignition of diesel. Burning time recorded are 20.24 minutes and 11.05 minutes when using diesel and petrol respectively. These show that the burning time of using diesel is twice as the burning time of using petrol. As a matter of fact, diesel is different from petrol in term of heating the water until it vaporizes as the time taken for the combustion and consumption of diesel is much longer than petrol. This is because the volatility of the diesel itself which is less volatile than petrol can heat the water until its boiling points.

In another four experimental runs, petrol and diesel are used for the fuel mixture in ratio of 3:7 respectively. In this case, the fuel thickness is varying by 0.5 cm. In the experiment, there was vapour bubbles formed after a few minutes the fire started until the boilover occur. Basically, the low boiling points fuel which is petrol will form bubbles when it is vaporize and move towards the surface. During the steady state burning stage, higher boiling points component which is diesel is remained as liquid phase and formed a hot isothermal layer called the hot zone after being heated. The hot zone will move toward the bottom and when it reached the bottom of tin container, fuel layer at the bottom and water layer at the bottom were heated up.

This resulting more formation of bubbles which indicates that water will start to vaporizes at any time. Besides, there were sounds of these bubbles and crackling as the sound produced when water is pour to hot fuel. Boilover fire occurs right after the vigorous bubbles formation and crackling sound produced.

### 4.2.2 Time to Boilover vs. Initial Fuel Layer Thickness

Figure 4.5 shows the graph of time to start boilover versus the initial fuel layer thickness. The linear equation obtained from the graph is y=3.79x + 9.345. This is the correlation obtained after four experimental data inserted which have been collected after a few experimental runs conducted. The correlation also can be expressed as:

$$t_b = 3.79h_o + 9.345$$

where $t_b$ and $h_o$ are in minutes and centimetres respectively.

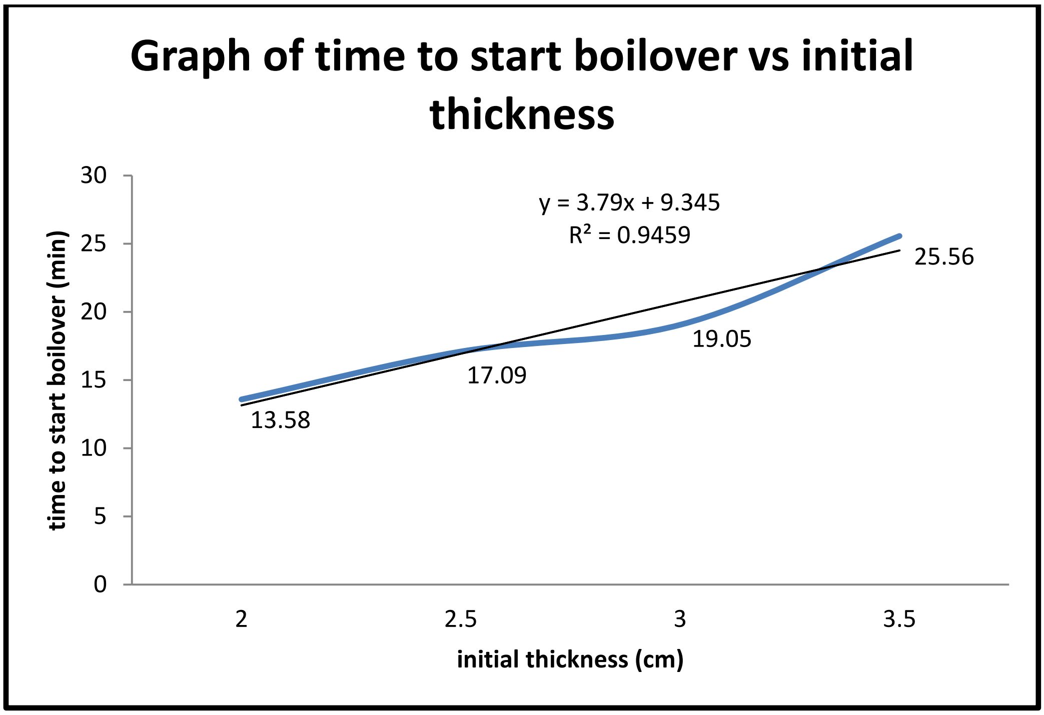


Figure 4.5: Graph of time to start boilover vs. initial fuel layer thickness

From the graph, the regression line is determined from the correlation of the experimental results. The time to start boilover increases linearly with the initial thickness of the fuel layer which concludes that boilover phenomenon takes longer time to occur when the initial fuel layer is thicker than previous one and therefore more time required heating up the fuel to reach boiling temperature at the fuel-water interface. The regression coefficient of ***a*** (min/cm) and ***c*** (min) are 3.79 and 9.345 respectively. The coefficient of this regression line is only applicable to the conditioning of experimental works conducted in the context of this study.

### 4.2.3 Area Affected

In experimental run 1 which using petrol as the fuel, boilover was not occurred hence there is no area affected around the container or in other words, the distance covered by the fuel fallout is none. Experimental run 2, the boilover does occur when using diesel as the fuel and the time for the fuel to fully burned is twice the burning time when using petrol as the fuel. The explosion from boilover will cause to fuel fallout from container and the distance recorded when using 100% diesel is 53 cm. Distance of the fuel fallout is measured based on the longest distance travelled by the fuel when it is exploded. This shows that the presence of diesel as the fuel which has greater boiling point than petrol can eject fuel further from the container. For the first two experiments, it is 100% in composition of petrol and diesel respectively.

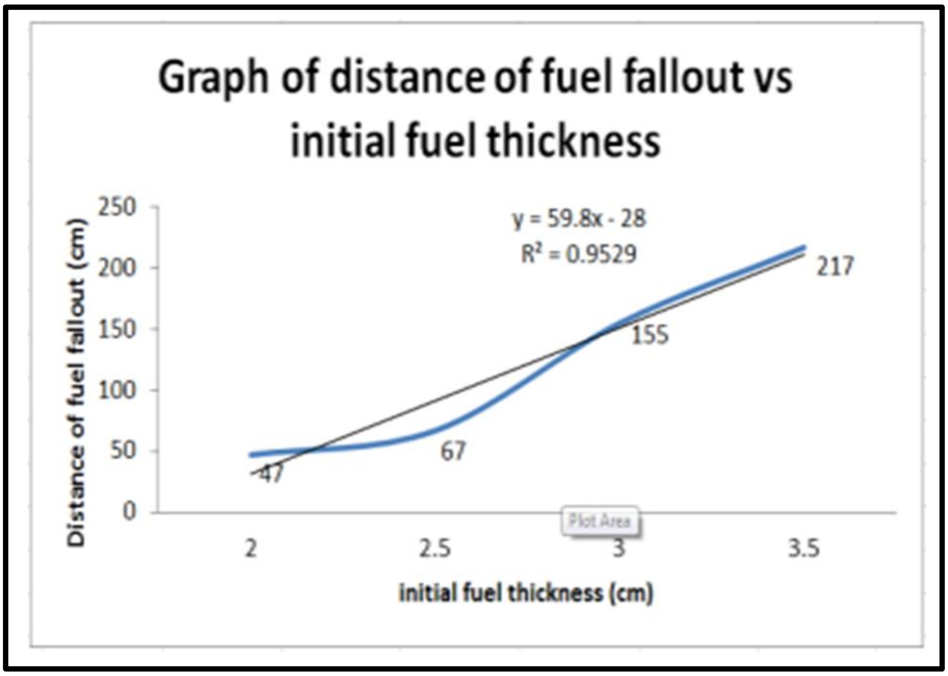


Figure 4.6: Graph of distance of fuel fallout vs. initial fuel thickness

Figure 4.6 shows the graph of distance of fuel fallout vs. initial fuel thickness. The initial fuel thickness of experimental run 1 and 2 which using 100% petrol and 100% diesel are excluded from the graph. In experimental run 3, the distance covered by the fuel is 47 cm, while 67 cm is the distance of fuel fallout in experimental run 4. 155 cm and 217 cm are the distance covered by the fuel fallout from container for experimental run 5 and 6 respectively. The regression coefficient of ***a*** and ***c*** (cm) are 59.8 and -28 respectively. The coefficient of this regression line is only applicable to the conditioning of experimental works conducted in the context of this study.

The result shows that the area affected increasing as the thickness of the fuel mixture increase. In other words, the greater the fuel thickness, the greater the distance of fuel falls out from container. This is because the greater the content of mixture of diesel and petrol in the container, the explosion of the boilover will become more massive which subsequently push out fuel further from the container.

Theoretically, the distance of the fuel fallout from the container can be up to three times the diameter of the container itself. In the experiment, the longest distance covered is 217 cm with 3.5 cm of fuel thickness which is the greatest fuel thickness used in this experiment and the diameter of the container is 18.5 cm. Basically, the distance of fuel fallout is approximately 11 times the diameter of the container itself in this experiment. Therefore, it can be concluded that the most safety distance allowed in carrying the experiments is at least 12 times the diameter of the container used in this work. However, it is important to highlight that this hypothesis suits only to the context of this study.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

This project is important as it deals with the safety concerns in any refineries and petrochemical plants. Any indications before the boilover start in this experiment can be useful in the real phenomenon if occur in any refineries.

The fuel thickness is the most important factors in determining the exact time for the boilover to occur. The greater the fuel thickness, the time taken for boilover to occur is longer. It is proved that single component with low boiling point such as petrol will not undergo boilover as it will takes forever to transfer the heat wave towards water the bottom of the tank. Unlike diesel, boilover fire still can occur when the fuel is used alone because of its high boiling point. Increasing fuel layer thickness also influence a few other factors which is the flames will becomes larger during the phenomenon of boilover.

Besides, the distance of fuel fallout indicated the area affected outside the container. Therefore, greater the fuel thickness, the further the distance of the fuel fallout thus, the wider area affected outside container. After the experiments have been done, allowed distance for safety has been determined which 12 times the diameter of the container.

The process of combustion need fuel, oxygen and heat in order to complete the process. The fuel layer thickness will decrease over time as fuel is the most essential element in the combustion process.  Therefore, the objectives are said to be achieved which to investigate the effect of fuel layer thickness on the time to start boilover and area affected outside the container.

## 5.2 Recommendation

### 5.2.1 Wind Condition

Steady wind condition can be necessary for obtaining more accurate result as too windy may influence the combustion of fuels, thus influence the data.

### 5.2.2 Container

Transparent container with high durability can be useful so that it is easy to observe the conditions inside the container during the process of burning fuels.

### 5.2.3 Soot Measurement Device

The combustion of certain amount of fuels can produce amounts of soot which may disturb the quality of air. The soot measurement device can be used to minimize and optimize the usage of fuel in order to keep high quality of air.

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