Boilover Fire: A Study in Laboratory Scale

by

Wan Nurul Izzah binti Wan Kamarudin

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor Of Engineering (Hons)
(Chemical Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

____

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

December 2012

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 persons.

WAN NURUL IZZAH WAN KAMARUDIN

ABSTRACT

By using a predictive calculation, the author attempt to investigate the effects of fuel layer thickness on the time to start of boilover. Petrol and diesel are chosen in the experiment. Three experimental trials are conducted during the first semester in order to reveal the characteristics of boilover. The results show that boilover occurred at about 1 hour after the ignition. For the second semester, few changes were made based on the results obtained from the first semester. The results from the experiments show that the time to start of boilover increased as the fuel layer thickness increased. The results also reveal that initial stage of fire, stable burning stage and boilover stage are involved in 30% petrol and 70% diesel mixture fire, but only initial stage of fire and steady burning appear in 100% petrol fire. The start of boilover phenomenon could be determined from the loud crackling sound and the enlargement of the fire.

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b	Boilover
c	Coefficient
h_o	Initial thickness of fuel, cm
R_c	Regression coefficient
t_b	Time to start of boilover, min

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Crude oil can be stored for an indefinite period of time. The exploration, production, and transportation of crude oil takes times, and the crude oil that reaches its destination is not always needed right away, so it is injected into storage tanks. Crude oil in storage serves as insurance against any unforeseen incidents, natural disasters, or other occurrences that may affect the production or delivery of crude oil. Unfortunately, these storage facilities are still prone to incidents such as fires and explosion. These catastrophic incidents can and still happened and would cause severe damage and high losses.

One of the most hazardous effects during the fires in storage tanks is when a sudden and violent ejection of fuels from the tank occurred due to a reaction of the hot layer and accumulation of water at the bottom of the tank. When the boiling point temperature of the fuels is higher than that of the water, heat transfer from the flame to the water take place and hence would induce water boiling and splashing that would pushed out the fuel, a phenomenon known as boilover [1] and [2]. The event of boilover is often encountered with fires leading to eruptive and explosive vaporization of water and hence the ejection of hot burning fuel. During the fire, the fuel is heated up to a temperature exceeding the boiling point temperature of the water. When the heated fuel reaches the water, the water is superheated and subsequently boils and expands explosively, causing the fuels to be ejected from the tank.

If a boilover occurs, a rule-of-thumb says that the expelled fuels may travel up to 10 times the tank diameter around the tank perimeter. As an example, in a crude oil tank that is 250 feet in diameter, expect the crude oil to cover an area of 2500 feet from the tank when boilover occurred. Therefore, careful considerations need to be taken if any boilover incidents happened.

Recently, a number of studies relating to the conditions under which boilover occurs has been made and was conducted inside or outside the laboratory [1], [2] and [3]. The studies reported that two of the most important factors that would influence the behaviour of the boilover are the fuel layer thickness and the tank diameter. The results of the studies for the effect of fuel layer thickness show that thicker fuel layers result in a stronger and faster ejection of the fuel from the tank toward the flame, and consequently in a more explosive and hazardous boilover event [4] and [5]. On the other hand, the results of the studies for the effect of tank diameter show that the larger the tank size, the higher the heat penetration rate, which is consistent with the increase of burning rate with the tank size. However, due to time constraint, the effect of the tank diameter on boilover is not dealt in this study.

1.2 PROBLEM STATEMENT

Despite some overlaps, these boilover studies are often quite different and comparative analysis is not always obvious since the various experimental set up. In fact, a complete understanding of boilover is still lacking, most likely because of the complexity of the mechanisms involved. During storage tank fires in Venezuela in 1982 [6], a violent explosion took place followed by another violent boilover 6 hours later that threw the tank contents hundreds of feet into the air, forming a large fire ball. Due to the presence of spectators and other people in the area of the fire without realizing the potential danger of the situation, dozens of people including civil defense personnel and fire fighters died in this incident. Thus, the objective of this study needs to be carried out in order to illustrate a simple mechanism about boilover and to make sure that the people are aware of this dangerous situation. The onset of boilover is also significantly important and hence the study will develop a simple predictive correlation in order to estimate the time to boilover.

1.3 OBJECTIVES AND SCOPE OF STUDY

This project aims:

- To study the feasibility of conducting small-scale boilover study through small-scale fire experiments.
- To investigate the effects of fuel layer thickness on the time to start of boilover.

The scope of this study is to conduct small-scale fire experiments and to measure the time to start of boilover as the results of changing the fuel layer thickness. Based on the results, a predictive correlation to estimate the time to boilover based on the fuel thickness is proposed as follows:

$$t_b = ah_o + b$$

1.4 RELEVANCY AND FEASIBILITY OF PROJECT

By using the predictive calculation, this project will provide simple explanations to the people who did not understand about effects of boilover. Few runs will be conducted during the experiments in order to measure the time to start of boilover. Within about 28 weeks for these two semesters, it is believed that this project will not only succeed but also provides some space for improvement in the future. After all consideration, this project will definitely finish on time required and give excellent performance.

CHAPTER 2

LITERATURE REVIEW

2.1 BOILOVER MECHANISMS

All fire related incidents are certainly highly volatile and dangerous situations. One complex fire related situation can occur in the storage tanks of fuels. However, if mistakes and poor judgment allow this fire to threaten the life of people, the results are far more dangerous than anyone will ever know. During fires in the storage tank, the most dangerous effects that could occur is when burning fuel is expelled from the tank due to the vaporization of water (with higher density but a lower boiling point temperature than the fuel). During the fire, the fuel is heated up to a temperature exceeding the boiling point temperature of the water. The water usually present due to condensation effects, drilling and transport, cleaning process of the tank, or even the natural composition of the fuel. When the heated fuel reaches the water that settles at the bottom of the tank, the water starts to vaporize and pushes the fuel out from the tank [1], [2], and [3].

The ejection of the fuel from the tanks can be divided into 3 categories namely slopover, frothover and boilover [3]. A slopover results when a water stream is applied, which might be caused by fire-fighting attempt, to the hot surface of burning fuel, causing the burning fuel to slop over the tank sides. A frothover is the overflowing of a tank when water boils under the surface of hot fuel that may occur during the filling of tanks. Another form of fire is known as boilover - a fiery tank overflow caused by hot residue that becoming denser and sinking in the fuel tank to form a hot layer which then eventually causes a violent eruption of burning fuel when the sinking hot layer comes in contact with water. It is one of the most hazardous aspects of fuel storage tank fires [7]. Storage tank fires, during which boilover occurred, have happened in Yokaichi, Japan in 1954 and in Nigata, Japan in 1964 [8]. It was well known that in both cases, the fuels involved (fuel oil and crude oil) were able to create a boilover in the case of a tank fire.

Figure 2.1 shows the mechanism of a boilover in a storage tank fire. Prior to boilover, the heat transfer from the flame is not absorbed at the surface of the fuel but inside the bulk of the liquid fuel [3]. This results in a boiling of the volatile components of the fuel in the upper layer, the heating of the heavier components, and thus the formation of an isothermal layer (hot zone) of uniform temperature at an appropriate thickness. The thickness of the isothermal layer increases with time after ignition. When the lower boundary of the isothermal layer reaches the layer of water that settles at the bottom of the tank, it produces a sudden transformation of expanding superheated steam at a ratio of 1:1700 / 2000 times depending on the temperature of the liquid, leading to sudden vaporization of water and overflow of the content. A key aspect that marks the beginning of the overflow is the sudden increase in temperature and thermal radiation environment throughout the area. The fuel is ejected violently and explosively from the tank forming a flame rise and expands sideways to make contact with the land. The fuel will continue propagating and moving in all directions destroying everything in its path. Prior to the ejection of fuel, excruciating noises similar to those crackling sound produced when hot frying oil contacted with water could be heard, indicating that the water starts to boil.

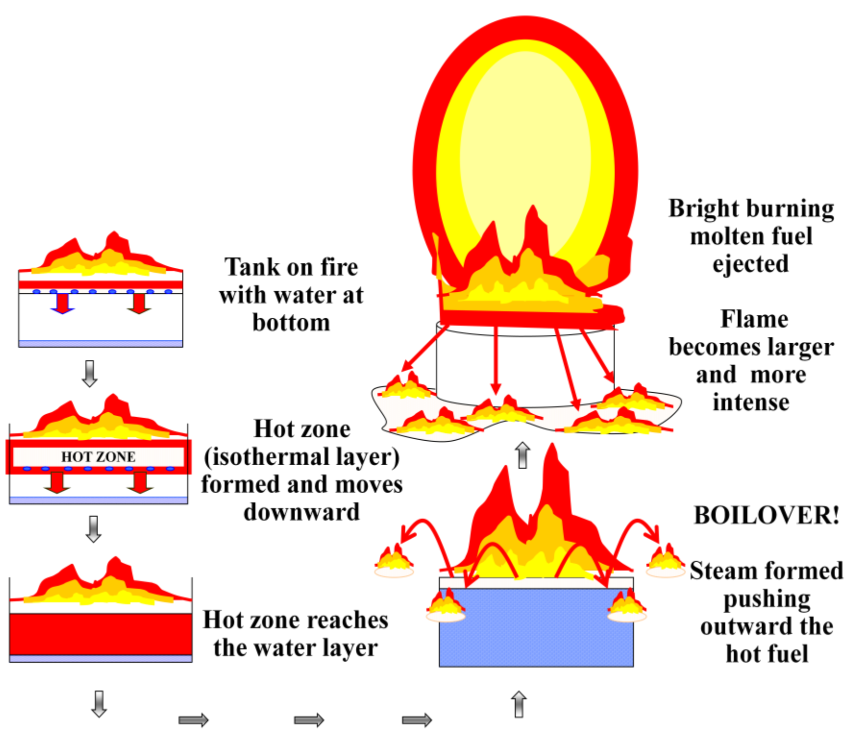


Figure 2.1: Mechanism of boilover fire

2.2 BOILOVER STUDIES

Recently, studies concerning the conditions under which boilover occurs has been made. Most of these studies have been conducted inside or outside a laboratory using small diameter pans. Although the test pans of the finite diameter cannot perfectly model the real situations, they ensure calm external conditions, stable flames and nearly uniform heat transfer to the fuel and the water interface. The time needed to reach boilover could be estimated from fuel depth, tank diameter and fuel type [9].

In previous experimental studies, it was reported that fuel thickness is an important parameter in regard to boilover [4] and [5]. The results show that the thicker the fuel layer, the longer time is required to boilover and more violent the boilover is. Few other experimental studies were conducted and it was further shown that the time needed to start boilover increased when the fuel thickness increased [1], [5] and [10]. Another experimental study was conducted in order to investigate the effect of fuel layer thickness on burning of the fuel layer spilled on water [2]. The results show that when the fuel thickness is increased, there is a longer period of time for the fuel to reach boilover. Dealing with highly flammable liquids, all of the studies were conducted in a laboratory-scale experiment in order to achieved better controlled safety throughout the work.

CHAPTER 3

METHODOLOGY

3.1 PROJECT ACTIVITIES - EXPERIMENTAL

3.1.1 Experimental Site

As this study involved with the burning of highly flammable liquid fuels, it is decided to conduct the experiments outside the laboratory for safety reasons.

3.1.2 Design Apparatus / Settings

3.1.2.1 Fuel Used

The proposed fuels to be used in the experiments were mixture of petrol and diesel. One of the conditions for boilover to occur is that the fuel involved in the fire should have a wide range of boiling point temperature such as crude oil. Petrol is highly volatile and hence acts as the light component in the fuel mixture and diesel, having the higher boiling point temperature, acts as the heavy components. Since both petrol and diesel offer a relatively high boiling point temperature (25^oC–390^oC) than that of the water, they are high enough to heat the water underneath to its boiling point.

3.1.2.2 Tank / Container

The burning tests of fuel layer floating on water are conducted in a tin container. An appropriate size of tin container should be used in order to observe the conditions inside (or outside) the beaker during the burning of fuels. The diameter of the container used is 19 cm and the height of the container wall is 6.5 cm.

3.1.2.3 Video Recording

The physical changes of the fire and boilover occurrence (i.e. large fire enlargement, ejection of fuel and spread of fuel) are recorded by a video camera.

3.1.3 Design of Experiments

3.1.3.1 Number of Experimental Run

In order to study the effects of fuel layer thickness on the time to start of boilover, different initial fuel depth is tested. Water thickness inside the tank had no significant effect on the onset of boilover [2]. Hence, during the burning of fuels, the water thickness inside the container is remained fixed. The tests will be repeated few times (if time permits) to obtain more accurate results for the calculations. However, the numbers of tests to be performed are minimized, due to:

- ***Safety factors*** - a higher number of tests will increase the risk of container failure and hence increase the likelihood of accidents.
- ***Economic factors*** - the quantities of fuel will raise the cost of testing.

3.1.3.2 Measurements and Observation

Theoretically, the fuel and water temperature need to be measured with thermocouples or temperature data measurement system. However, due to some restrictions in the experiments, instead of measuring the temperatures, time to start of boilover will be measured. The tests are recorded with video camera in order to study the flame height. The camera is fixed at pre-calculated distances so that the flames could be viewed entirely. The start of boilover in this work is determined by the sudden fire enlargement and the concurrent ejection and spread of the burning fuels outside the tin container. Apart from the measurement, the video recording is used to observe and monitor the physical changes of the fire (in terms of size and state of turbulence) throughout the burning tests.

3.2 BRIEF EXPERIMENTAL PROCEDURES

Preparation of chemical (petrol and diesel are mixed)

Water is added to the fuel mixture

The fuel is lighted up and the combustion is recorded

The fuel mixture is waited to boilover
(until the fire is extinguished)

The waste is disposed in the waste bottle

3.3 GANTT CHART

Table 3.1 shows the proposed gantt chart for this project conducted during the first semester. The project will focus on preliminary research work for the boilover study. Most of the time is spent on the literature review since it required some time to gather the information. Few experimental trials are conducted to study the characteristic of boilover.

Table 3.1: Gantt chart for first semester

Activities / Week	May		June				July				August			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
First meeting with coordinator and supervisors							Mid semester break							
Preliminary research work • Background study • Data gathering • Literature review														
Project conformation – Boilover Study														
Submission of extended proposal														
Proposal defense presentation														
Project work continues • Experimental trials • Result analysis														
Submission of interim draft report														
Submission of interim report														

For second semester, the project is continued by conducting few experimental runs to obtain the results. The results are then analyzed in order to achieve the objectives of the project. **Table 3.2** shows the proposed gantt chart for this project conducted during the second semester.

Table 3.2: Gantt chart for second semester

Activities / Week	September		October				November				December				
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
Project work continues • Experimental runs • Result analysis							**Mid semester break**								
Submission of progress report															
Project work continues • Experimental runs • Result analysis															
Pre-EDX															
Submission of draft report															
Submission of dissertation (soft bound)															
Submission of technical paper															
Oral presentation															
Submission of project dissertation (hard bound)															

CHAPTER 4

RESULTS AND DISCUSSION

4.1 EXPERIMENTAL TRIALS – USING BEAKER

4.1.1 Results

In order to observe the situation of how boilover occurred, four experiment trials are conducted by burning different composition of fuels in a different size of beaker. The objectives of these trials are to see whether it is feasible to conduct the boilover testing using a glass beaker and to observe the formation of the hot zone layer. **Table 4.1** summarizes the results of the experiment trials. In Trial #1 and Trial #4, the flames were distinguished automatically after boilover occurred. In Trial #2 and Trial #3, the fire was extinguished at about 59 min and 22 min respectively after ignition.

Table 4.1: Summary of the experimental trial results

Trial no.	#1	#2	#3	#4
Beaker	ID = 10.3 cm V = 1000 mL	ID = 10.3 cm V = 1000 mL	ID = 10.3 cm V = 1000 mL	ID = 10.3 cm V = 1000 mL
Water thickness (cm)	1 cm	2 cm	2 cm	3 cm
Fuel composition (out of 250 mL fuel)	30% petrol 70% diesel	30% petrol 70% diesel	40% petrol 60% diesel	40% petrol 60% diesel
Time to boilover (min)	49	-	-	77
Burning time (min)	49	59	22	77

4.1.2 Discussion

Few aspects have been taken into consideration during the conduct of the experiment trials. These aspects were believed to give a better understanding about boilover for the next experimental runs. The aspects include:

- Fuel colour changes
- Fuel thickness
- Boilover

4.1.2.1 Fuel Colour Changes

Throughout the combustion of fuel inside the beaker, changes in colour of fuel can be observed clearly. For all of the experiment trials, after ignition, the colour changed from yellowish to orange before turned into dark brown and then into almost black right before the boilover. These changes are due to the changes of the fuel mixture composition due to the burning of light composition of fuel (petrol) and followed by heating and burning of the heavy composition of the fuel (diesel). **Figure 4.1** shows the changes in colour of the fuel throughout the burning.

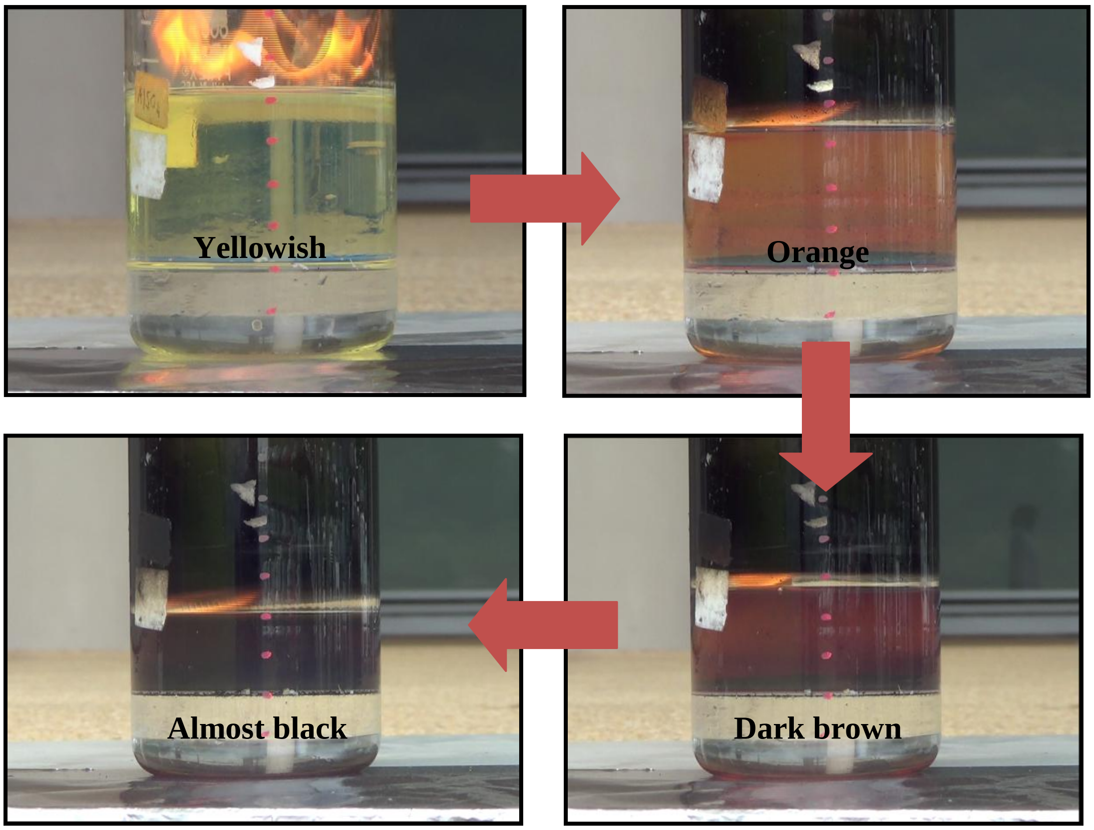


Figure 4.1: Fuel colour changes in Trial #2

4.1.2.2 Fuel Thickness

Referring to **Figure 4.1**, it has been observed that the thickness of the fuel layer for all experiment trials is slowly reduced by the combustion of fuel, starting from the ignition until boilover.

4.1.2.3 Boilover

During boilover, flame enlargement can be observed right before the flame was distinguished along with splashing of water and fuel that can be seen around the beaker. **Figure 4.2** shows the event of boilover that occurred in Trial #4.

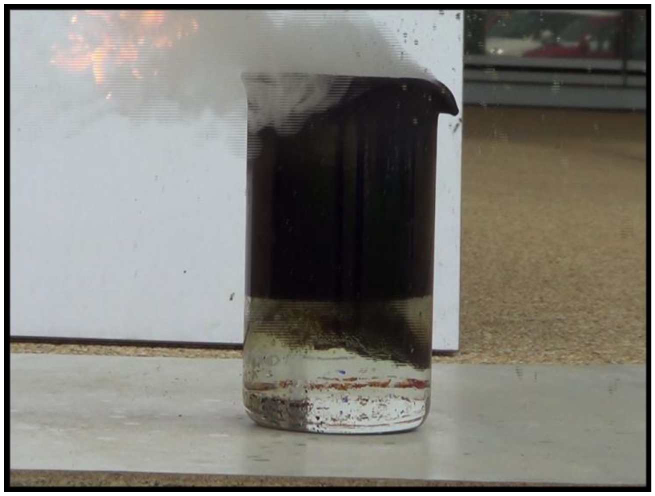


Figure 4.2: Boilover in Trial #4

However, in Trial #2 and Trial #3, instead of having a boilover, the flames from the combustion of the fuel extinguished few minutes after ignition. This observation could be related to various factors. One of possible reason is due to the dimension of the beaker and the quantity of fuel, the fire could not be retained due to the lack of air (oxygen) entrained into the flame. It may also due to the fact that the fuel was running out of petrol composition as it was assumed to be vaporized during the combustion.

Based on these early trials, it is decided that it is not feasible to conduct the boilover tests using laboratory glass beaker since the results have demonstrated that the beaker could not sustain the fire. Instead of using a glass beaker, a tin container with the height of 6.5 cm is to be used for the next experiments. This will ensure good combustion since the height between the fuel surface and the height of the edge of the wall is small to ensure good flow of air (oxygen) into the flame.

In addition, fuel composition of 30% petrol and 70% diesel is selected to be used in the next experimental runs since it is shown in these early trials that this fuel mixture could boilover. Furthermore the composition is considered to be the ideal composition as 30% petrol is sufficient enough to heat the other 70% diesel during the combustion.

4.2 EXPERIMENTAL RUNS – USING TIN CONTAINER

4.2.1 Results

Few changes were made based on the results obtained from the previous experimental trials to improve the results of the runs. By maintaining the fuel compositions (70% diesel and 30% petrol), another four experimental runs were conducted by burning the fuels at different thickness in a tin container with the same diameter.

4.2.1.1 Time to Boilover

Table 4.2 summarizes the results of the experimental runs. In Runs #1-4, the flames' size was significantly reduced after the boilover before they died. The burning time represents the period from the ignition until the fire extinguished.

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

Run no.	#1	#2	#3	#4
Tin plate	ID = 19 cm H = 6.5 cm	ID = 19 cm H = 6.5 cm	ID = 19 cm H = 6.5 cm	ID = 19 cm H = 6.5 cm
Water thickness (cm)	1 cm	1 cm	1 cm	1 cm
Fuel thickness (cm) [out of 70% diesel and 30% petrol]	**2 cm (567mL)** diesel = 397 mL petrol = 170 mL	**3 cm (850mL)** diesel = 595 mL petrol = 255 mL	**4 cm (1134mL)** diesel = 794 mL petrol = 340 mL	**5 cm (1418mL)** diesel = 993 mL petrol = 425 mL
Time to boilover (min)	14.10	20.35	27.28	34.34
Burning time (min)	14.32	23.10	28.26	36.19

4.2.1.2 Physical Observation

Throughout the burning test, it is observed that the fire behaviour showed three distinct phases. **Figure 4.3**, **4.4** and **4.5** show the three phase of the fire behaviour.

Figure 4.3: Initial ignition phase

Initial ignition phase – the ignition of the fuel was fast and in seconds, full surface burning was achieved. The flame was very turbulence as the light components (petrol) was burning fast and vigorously.

Figure 4.4: Steady state burning phase

Steady state burning phase – the flame was observed to be less turbulence and the size of the flame was stable. At the end of this phase, micro explosion (sound produced when water is fried with hot fuel) could be heard.

Figure 4.5: Final / Boilover phase

Final / Boilover phase – a series of continuous explosion could be heard. Intermittent flame enlargement was observed. Finally, a sudden enormous fire enlargement was observed. Concurrently, hot burning fuel was ejected and spread out to the container surrounding. Automatically after the fuel ejection, the flame size was reduced significantly. The fire continued to burnt until the flame extinguished by itself.

4.2.2 Discussion

4.2.2.1 Boilover

Few effects are observed before and during the boilover fire. In Runs #1-4, there were vapor bubbles formed since the start of the fire until the boilover occurred. The vapor bubbles were formed by vaporization of the components with low boiling points (30% petrol). The bubbles rise and stirred the fuel in the container before the vapor is burned at the fuel surface. The components with the higher boiling points (70% diesel) remained in the liquid phase and being heated to form a hot isothermal layer called the hot zone. This occurred during the steady state burning phase. When the hot zone reached the bottom of the tin container, the bottom fuel layer and water phase were heated up. During this final burning phase, distillation process of the fuel continued, resulting in the further formation of vapor bubbles. These bubbles give a significant bubbling sound as water started to vaporize and it is substituted by a crackling sound when boilover occurred. **Figure 4.6** shows the vapor bubbles that formed in Run #2 during the combustion of the fuels.

Figure 4.6: Vapor bubbles formation

Flame enlargements are also observed during the boilover. A fireball-like flame rise up to the atmosphere that reaching up to the height equivalent to be 6 – 8 times of the tin container wall. When the boilover occurred, the flame length increases by a factor of 2 – 3, resulting in flame lengths about 95 cm for the 19 cm diameter tin container. This boilover fire is accompanied by splashing of water and fuel that spilled into the surroundings. **Figure 4.7**, **4.8**, **4.9** and **4.10** show the fire enlargement during the boilover that occurred in Runs #1-4.

Figure 4.7: Boilover in Run #1

Figure 4.8: Boilover in Run #2

Figure 4.9: Boilover in Run #3

Figure 4.10: Boilover in Run #4

4.2.2.2 Micro Explosion

As an early indication of boilover, a crackling sound started to be heard, and followed by a series of micro explosions. Then, the fuel boilover occurred. Boilover comes with a typical noise, normally referred to as crackling sound. This is due to the water vapor bubbles exploding and ejecting the fuel to the flames, intermittently. Thus, the start of the phenomenon could be determined by the sound level of the fire.

4.2.2.3 Time to Boilover vs. Initial Fuel Layer Thickness

Figure 4.11 shows the graph of the time to start boilover vs. the initial fuel layer thickness. It shows the regression line determined from the correlation of the experimental runs results. The equations of the line take the form shown below, where t_b and h_o are expressed in min and cm, respectively:

$$t_b = ah_o + b$$

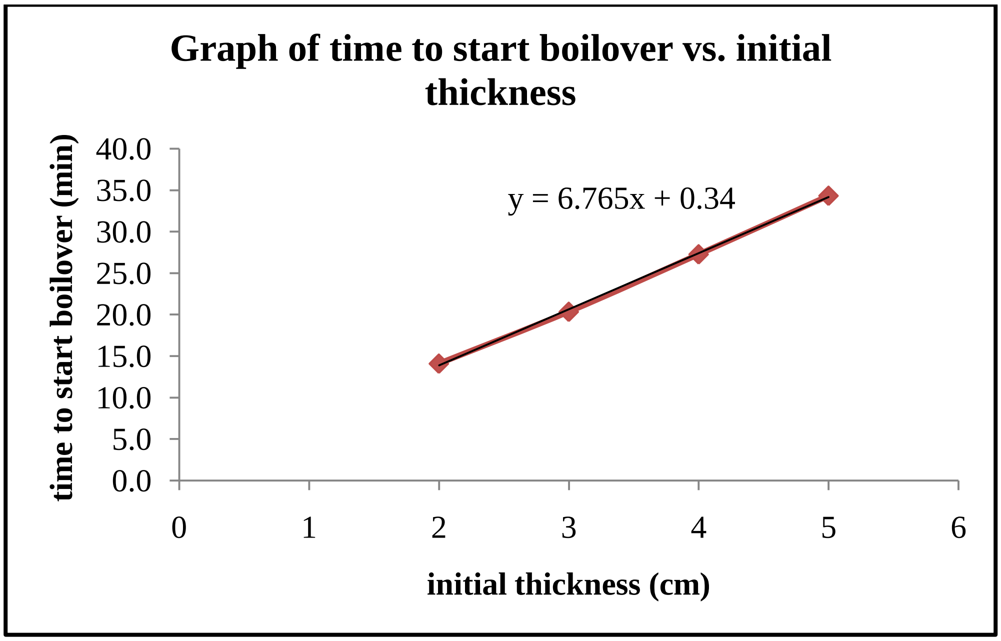


Figure 4.11: Graph of time to start of boilover vs. initial fuel layer thickness

The graph shows that the time to start boilover increases in a liner way with the initial thickness of the fuel layer. Boilover occurs later if the initial fuel layer is thicker because of the heat transfer. More time is required to heat up the bulk fuel to reach the boiling temperature at the fuel-water interface. Thus, the thicker the layer of fuel, the longer the time needed for the fuel-water interface to reach the boiling temperature of water.

The regression coefficient (R_c) of the line in **Figure 4.11** is in **Table 4.3**. It is important to highlight that the coefficient of the regression line suits only to the conditioning of the experimental works conducted in the context of this study.

Table 4.3: Coefficients of the regression line in Figure 4.11

Diameter (cm)	a (min/cm)	b (min)
19	6.765	0.34

4.2.2.4 Fuel Composition

In Runs #1-4, the tests were conducted by burning a mixture of 70% diesel and 30% petrol. However, in Run #5-6 the experimental tests were conducted by changing the fuel composition to 100% petrol and 100% diesel. **Table 4.4** summarizes the results of the experimental runs. In Run #5, no boilover occurred and the flames extinguished as the fuel has been consumed to the state that it could not sustained the fire. However, boilover did occur in Run #6.

Table 4.4: Summary of the experimental runs results (100% petrol and diesel)

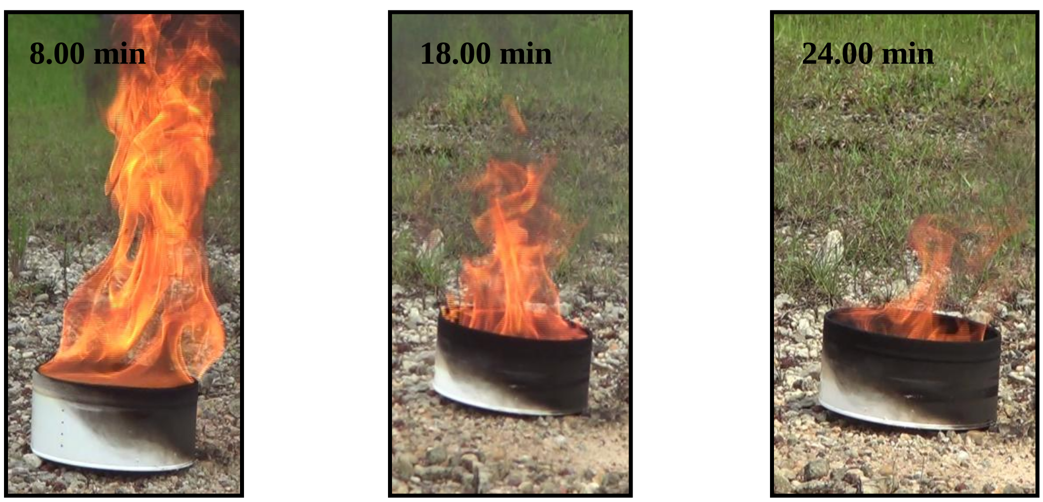
Run no.	#5	#6
Tin plate	ID = 19 cm H = 6.5 cm	ID = 19 cm H = 6.5 cm
Water thickness (cm)	1 cm	1 cm
Fuel thickness (cm)	**4 cm (1134mL)** 100% petrol = 1134 mL	**4 cm (1134mL)** 100% diesel = 1134 mL
Time to boilover (min)	-	40.30
Burning time (min)	24.12	42.00

Different from Runs #1-4, the result shows that no boilover occurred during the burning of the fuel in Run #5. The petrol is burnt at the surface and as the surface regressed towards the bottom of the tank, there is no or insufficient hot layer thickness to vaporize and superheat the water layer. Hence there is no boilover.

On the other hand, boilover did occur during the combustion of 100% diesel in Run #6. Theoretically, the combustion should not induce any occurrence of boilover as it composed of only the heavy components of crude oil. However, boilover could occur because the diesel (commercial diesel) used could have some additive which eventually affect the composition of the diesel.

4.2.2.5 Flame Height

It can be seen that the height of flame changes obviously in different combustion stages in Run #5, as shown in **Figure 4.12**. In initial combustion stage, the combustion is violent and the height of flame is big when lighter components in fuel burns while the combustion and the height of flame is stable when heavier components in oil burns. The height of flame then decreases when the fuel is used up. The flame height is related to the type of fuel. The fuel is lighter; the flame height is bigger for the same diameter of tin container. These observation could be relate to the different burning / combustion stage as observed in all the other tests and as discussed in section 4.2.1.2.



Initial combustion stage   Stable combustion stage   Extinguishment stage

Figure 4.12: Change of height of combustion flame in Run #5

4.2.2.6 Wind Consistency

The wind plays a great role on the fuel combustion. It can be seen from **Figure 4.13** that the direction of wind from each runs, when it is captured 10 min after ignition is inconsistent. Regardless of the immixture of air around, boilover did occur linearly with the changing of initial fuel layer thickness. There is also a possibility that the wind fluctuations can cool down the surface of the fuel during the combustion which eventually increases the burning time of the fuel.

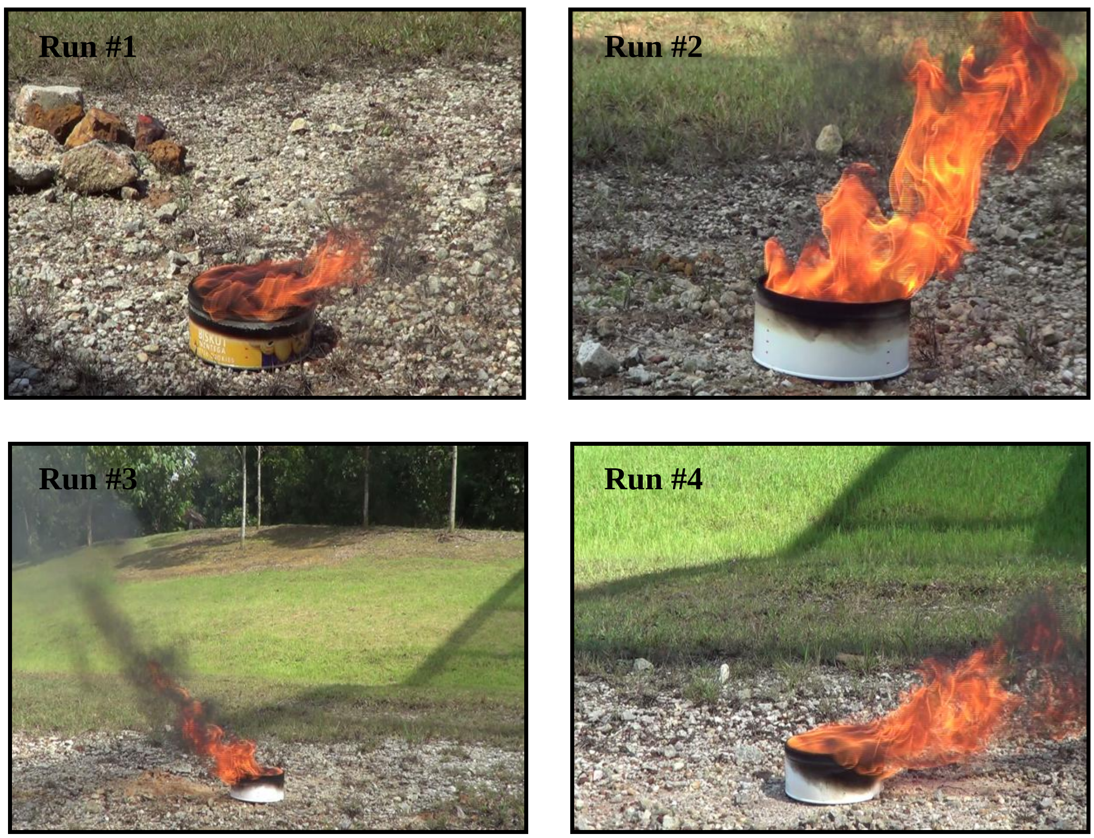


Figure 4.13: Wind directions captured 10 minutes after ignition

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

A series of experimental runs was carried out in order to investigate the effect of fuel layer thickness on the time to start of boilover. The analysis of these experiments brought the following conclusion. As in many previous experiments, the results show that boilover will be more violent when the fuel layer is thicker. Other experimental studies were conducted which results in longer time of boilover when the fuel thickness is increased. From the present experimental runs results, it is observed that the time to start of boilover corresponds to the initial fuel layer thickness. Graph of the time to start boilover showed a linear dependency on the initial fuel layer thickness. The start of boilover phenomenon could be determined from the loud crackling sound and the enlargement of the fire. The result also shows that no boilover occurred during the burning of the 100% petrol fuel in Run #4. The flame height is related to the type of fuel. The fuel is lighter; the flame height is bigger for the same diameter of tin container. The results obtained from the present experimental runs show that there were some consistencies with the results of previous experimental studies.

5.2 Recommendation

5.2.1 Use of Thermocouple / Thermometer

The fuel and water temperature should be measured with thermocouples or temperature data measurement system for the ease of identifying the temperature of the fuels before, during and after burning the fuel.

5.2.2 Tank / Container

An appropriate size should be used in order to observe the conditions inside the tank / container during the burning of fuels as well as to ensure enough air supply into the tank / container for a steady combustion to occur.

5.2.3 Wind Condition

To obtain more accurate results, all of the experimental runs should be conducted in a steady wind condition as it affects the combustion of fuels.

5.2.4 Use of Stopwatch

A stopwatch should be used in order to make sure that the time recorded during the burning of fuels is accurate.

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