DETERMINATION OF THE AREA AFFECTED BY THE SPREAD OF BURNING FUEL DUE TO BOILOVER

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CERTIFICATION OF APPROVAL

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By

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Approved by,

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TRONOH, PERAK

MAY 2013

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.

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ABSTRACT

Boilover is one of the most dangerous accidents that can happen in an atmospheric hydrocarbons storage tank, it happens when the water at the bottom of the storage tank is heated to a temperature where it is evaporate and push’s the hydrocarbons out of the tank causing a ground fire and flame enlargements. And the main objective of this study is determination of the area affected by the spread of ejected hydrocarbons from the storage tank due to boilover causing a ground fire which is extremely dangerous. And for achieving this objective a set of experiments have been performed on a hydrocarbons mixture consisting of 50 % Diesel oil and 50% Gasoline is used. This mixture has been chosen after running some experiments on three different types of mixtures. Tow set of experiments have been performed and from the result analysis we were able to find equation relating the volume of the mixture in the storage tank to the area affected. And from both set of experiments we found that the relation between the fuel volume and the area affected is best described as a polynomial relationship. Moreover a different set of experiments is also performed using crude oil which gave an unpromising result and we were unable to find an equation relating the area affected to the crude oil volume in the storage tank.

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In the name of Allah, the most Gracious and the most Merciful

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

A fire involving liquid hydrocarbon such as crude oil in a large open top tank, if left to burn may result in boilover**.** Boilover occurs when hot oil (normally called hot zone), resulting from radiative heat transfer from the fire to the liquid pool and the subsequent vaporisation process, reaches the layer of water that generally resides at the bottom of such storage tanks. Interaction between the hot oil and the water results in superheating of the water to a temperature at which it vaporises explosively, thereby ejecting large quantity of hot oil out of the tank. Moreover, boilover often happen suddenly after a period of quasi-steady burring. All these characteristic can make the fire out of control.

The boilover phenomenon also referred to as the hot zone formation, a zone of practically uniform temperature and composition that propagates through the interior of the fuel, which arises the heat transfer thought the fuel (Garo *et al*., 2007).

1.2 PROBLEM STATEMENT

Boilover is one of the most dangerous and harmful fire in oil tank fires. Boilover occur when the burning fuel is ejected aggressively from a storage tank due to the evaporation of water sub layer (Hristov, 2007), resulting in a massive fire growth and formation of fire ball and ground fire. When boilover happen in an oil storage tank a lot of burning oil is sprayed out, the flame goes up quickly and the flame radiation to the environment increase strongly (Hua *et al*., 1998). Several studies was performed to investigate the boilover in terms of time to boilover, stages of boilover; but almost none of the studies so far investigated the affected area due to the ejection of fuel from the storage tank

1.3 OBJECTIVE

The objective of this project is to determine the area affected by the spread of fuel ejection due to Boilover by finding a relation between the fuel volume in the storage tank and the area affected.

1.4 SCOPE OF WORK

The aim of this study is to experimentally examine the boilover phenomenon using diesel oil mixed with petrol in order to determine the affected area by the fuel mixture ejection from the storage tank due to Boilover. The tasks of this project are:

1. Prepare a suitable test method that can be used in investigating the area affected by the ejection of fuel due to boilover.
2. Development of fuel mixture that will suite the purpose of the experiment.
3. To perform data collection though experiment.
4. Finding a relation between the area affected and the fuel volume in the storage tank.

1.5 RELEVANCY OF STUDY

The boilover is dangerous and also it is very hard to extinguish, and it is always endanger the life of the response team and fire fighters, because fire of hydrocarbons that include water is a sleeping giant and no one knows how far the hydrocarbons will reach after the explosion, that’s why this study is to predict the area affected by the spillage of the fuel from the storage tanks after the boilover occurs for the safety of the response and fire fighters teams.

CHAPTER 2: LITERATURE REVIEW

2.1 BASIC PRINCIPLE

Most of the hydrocarbons atmospheric reservoir contain water, due to various reasons for example the condensation effect , drilling and transportation or due to the oil composition itself, if by accident a fire started at the surface , the flame will heat the duel and consequently the water layer until the water start to boil and expels the fuel from the reservoir.

Different names give to the expulsion of fuel:

1. A slop over is a continuous frothing over of the fuel on one side of the tank
2. A forth over is a continuous and low intensity frothing of the burning material from the tank
3. The most dangerous one is boilover which include violent ejection of fuel, flame enlargement and formation of fireball and ground fire.

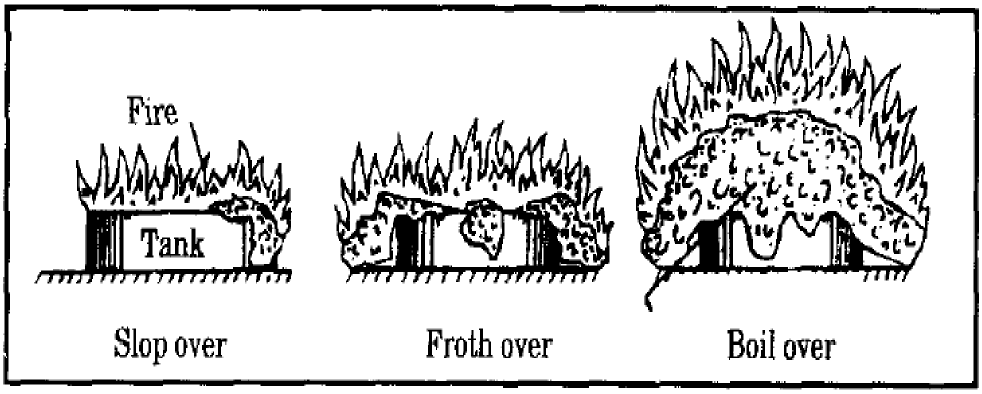


Figure 1: Type of fuel expulsion for a burning storage tank (Broeckmann & Schecker, 1995)

The boilover phenomenon is defined as a violent ejection of duel due to the vaporization of a water sub-layer, resulting in enormous fire enlargement and formation of fireball and ground fire (Laboureur, 2012) as Figure 1 showed. The condition to boilover have been studied by Hall (1925) and by Burgoyne & Katan (1947). Beneath the surface of a fully involved oil tank fire, a heat wave makes its way to trapped water sources which results in water to steam conversion. Expansion forces are enough to cause a major explosion, Initial wind conditions may lead to additional tank ignitions. A boilover may destroy everything within a 4 tank radius. Crude product left to burn may boilover repeatedly. The lingering fire will result in solid coke within the tank.

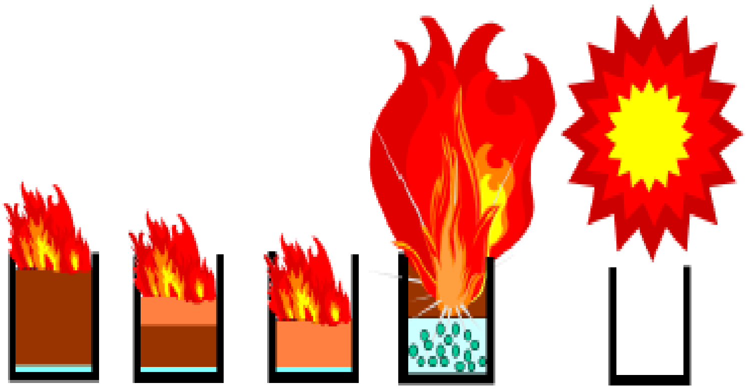


Figure 2: Boilover Basic Principle

2.2 BOILOVER THEORY

Boilover problem have been studied intensively in experiments and by models to understand how to control the Boilover phenomena. In 1925 Hall performed the first large scale systematic experiments into the phenomenon of Boilover, and he discovered that there was a layering effect in tank fire when boilover occurs, there is a very hot layer where the flames exist and then under that there is isothermal layer sitting above somewhat cooler layer. This led hall to conclude that to have a boilover a both a water sub layer and hot-zone must be presented. Burgoyne (1947) furthered Hall's work using a wider range of fuels and classified them as hot zone forming and non-hot zone forming fuels, and the former being of interest to boilover. And then he put forward the theory that the hot zone is due to a bulk Mass circulation of hot fluids (hot zone consisted of heavy ends of a viscous nature). And according to Koseki (1994) Boilover is Energy comes through radiation from flame and hot zone uniformity due to convection and fuel vapour stirring

Koseki and Mulholland (1991) conducted experiments to study the combustion characteristics of crude oil pool fires. It was noted that crude oil burned rapidly and gave off less thermal radiation compared with heptane, but when water boiling i.e. boilover occurred, the burning rate increased by a factor of two or more. The intensity of boilover is related to pan diameter and initial fuel layer thickness.

Broeckmann and Schecker (1995) carried out experiments on a wide range of fuels and looked specifically at the mechanisms of heat transfer as they burned. The research concluded that the hot-zone expansion was due to this intensive convection caused by the vapour bubble formation of lighter fuel fractions at the interface.

Boilover phenomena have been studied by experimental simulation and it was concluded that (Fan, Hua & Laio, 1998):

1. Boilover process of oil-tank fires supported on water may be divided into three stages: a quasi-steady period, a boilover premonitory period and a boilover period,

2. Micro-explosion noise which occurs during the liquid fuel burning process on the water layer can be classified as combustion micro-explosion noise emitted in the boilover premonitory period and vapour explosion noise emitted in the boilover period,

3. combustion micro-explosion is one of the prominent premonitory phenomena of boilover

Hua, Fan, and Liao (1998) conducted a Boilover experimental study. It was focused on the premonitory phenomena of Boilover. The emission of the micro-explosion noise was investigated. The investigation revealed that it is a possible means for early and remote detection of the occurrence of Boilover. However in real situation the micro-explosion is always contaminated by the environmental noise. An experimental study of large-scale Boilover was conducted using water emulsified crude oil, and the effect of water in the fuel on Boilover was studied. It was noted that Boilover occurred after steady burning. In proceeding to Boilover radiation increased rapidly. Time to Boilover was shorter than the expectation. The reasons were inferred as; the presence of emulsified water in the fuel. It should be noted that for crude oil containing a large fraction of water, Boilover occurs easily due to the existence of emulsified water.

2.3 STAGES OF BOILOVER

Generally it is found that a typical process of liquid fuel burning on water (Boilover) can be divided into three stages, from the ignition of fuel until the end of the fuel burning after Boilover, the three stages are: a quasi-steady period, a Boilover premonitory period and a Boilover period (Fan, Hua, & Liao, 1998) from the temperatures and sound measurement round the fuel-water interface the three stages are described as below (Laboureur, 2012).

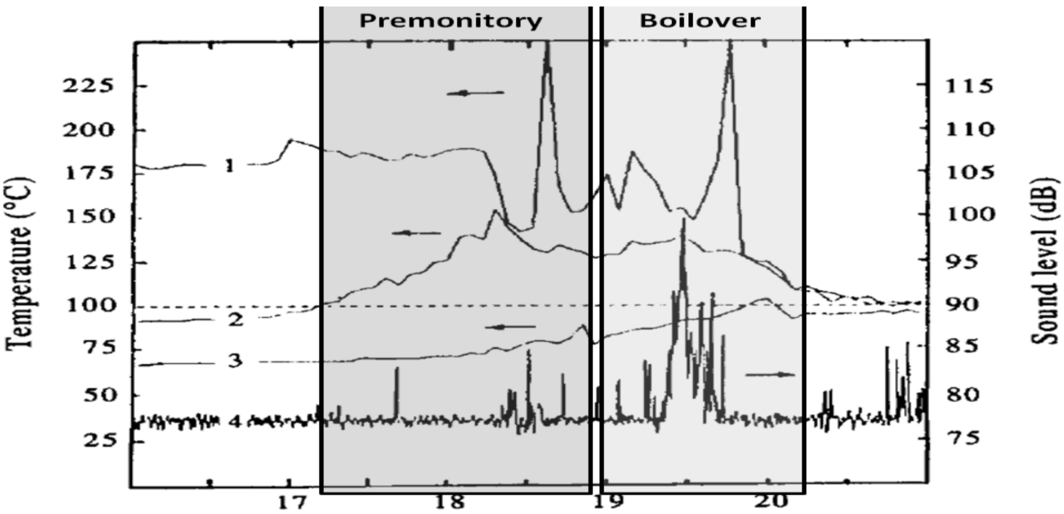


Figure 3: Different Step of Boilover apparition illustrated with temperature and sound level measurements (1: Temperature in the fuel, 2: Temperature at the fuel water interface, 3: Temperature in water) (Laboureur, 2012)

1. **Quasi-steady period**

This period starts after the ignition of the fuel surface and a small induction period where the flame propagates along the whole fuel surface. The pool fire is burning in a regular way, with very few influence of the water sub-layer. The flame is stable and the _re properties like the burning rate or the flame size are constant with time. During this period, the fuel layer in combustion progressively heats the water sub-layer. In Figure (2) this period last from 0 min burning time (not visible in the figure) to a bit more than 17 min of burning time.

2. **Premonitory period:**

Once the water layer temperature is getting close to the boiling point, water bubbles develop at the fuel - water interface. They escape from the interface, pass through the fuel layer, and erupt from the fuel surface into the flame zone as oil-water dissolution droplets. The combustion of these oil-water bubbles emits a typical crackling sound. This sound can be observed in Figure 3 as peaks in signal 4, between 17 min and19 min of burning time.

3. **Boilover period:**

When the water vaporization is strong enough to push the fuel layer, the Boilover starts, and the burning fuel is sprayed out of the tank and the flame height increases significantly and quickly. The flame increase and the violent water vaporization also emit noise, with stronger amplitude than the micro-explosion noise. This period can be observed between 19 and 20 min of burning time in Figure 3.

CHAPTER 3: METHODOLOGY

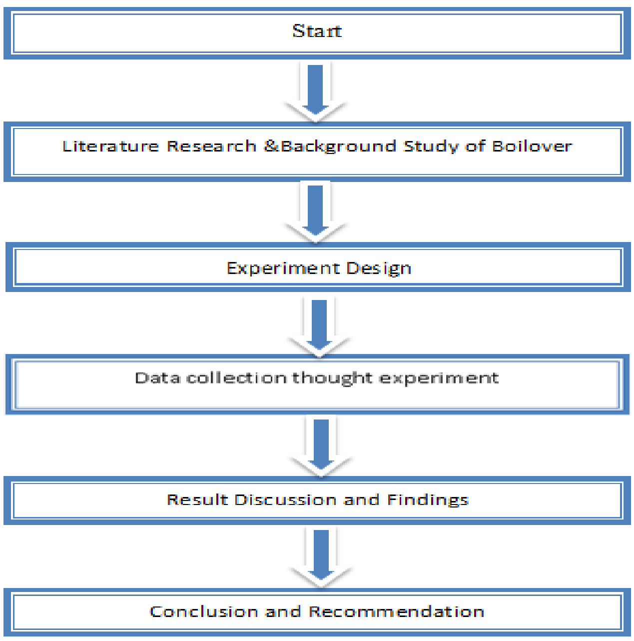
3.1 KEY MILESTONE

Upon the commencing of the project, intensive studying has been conducted along with experiments in order to understand the scope and objectives of the project. Therefore the project can be broken into three key delicate milestone based on process order.

1. Fuel mixture development
2. Experimenting on the selected fuel mixture and collecting required data
3. Data processing.

Then upon reaching the last stage the equation for predicting the area will be the product of the project, in which it will allow us to predict the area affected of the spread of fuel due Boilover.

3.2 PROJECT ACTIVITIES



The chart describes the main tasks that have to be undertaken. The first phase of the project with will be researching of the Boilover phenomena for full understanding of all aspects of Boilover.

The second phase of these research will be on the experiments with will be divided in to two main parts

1. Suitable Fuel mixture development
2. Determination Area Affected

The two type of fuel will be used for mixture are Diesel and Patrol.

3.3 TOOLS REQUIRED

The following are the equipment that will be used in these project, some of the basics procedures that are need to accomplish the experiment are also being detail out here.

Table 1:Tools and Materials Required

Equipment	Purpose
Container	To be used as a storage tank
Lighter	For starting the fire
Digital Camera	For recording purposes
Diesel	Fuel
Patrol	Fuel
Crude oil	Fuel
Fire extinguisher	For safety
Spray paint	For preparing the experiment ground and the container.
measuring glass	to measure the fuel volume needed

Figure 4:fuel container

3.4 FUEL MIXTURE DEVELOPMENT

The first part of the experiment phase is to develop a fuel mixture that is suitable for determination the area. There are two factors that we have taken into consideration when we decided in the perfect fuel mixture, which are:

1. Time to boil-over: time to Boilover is the fist and main factor for determining the best fuel mixture because time is very crucial to this study as our goal is to do as many experiments as possible. It is decreasing the fuel density will result in shorter time to boilover.

2. Steadiness of Boilover: since this study is dealing with determination of the area affected by spread of fuel, what we want is a smooth burning and explosion so that the detection of the area affected will be easier.

For identifying the best mixture of fuel three experiments was carried out. We chose 3 cm as the fuel thickness for all three experiments and we varied the percentage ratio of diesel to patrol mixture while fixing the water thickness into 1 cm for all three experiments. Also the same container is used for all.

Table 2:Fuel mixture experiments information

Experiment No.	Fuel layer thickness (cm)	Fuel volume (cm^3)	Mixing fractions (Diesel % to Patrol %)
1	3	850	70:30
2	3	850	40:60
3	3	850	50:50

3.5 DETERMINATION OF AREA AFFECTED

The second part of the experimenting phase is designed for the purpose of determining the area affected. Before carrying on with the experiment the ground on which the experiment will be conducted on was prepared with marking so that it will be easy to determine area that the fuel cover when the Boilover occur. Moreover the marking on the experiment ground was made according to the container diameter in a circle shapes.Figure4is showing the place of the experiment and the marking on the ground.

Figure 5:Experiment ground

On the other hand in this stage of the experiment phase we will fix the concentration of the mixture into the selected mixture and vary the fuel thickness, as we are trying to the study the effect of fuel thickness (volume) on the area affected. So we will be using the fuel thickness in the tank to predict the area affected. Four different thicknesses will be considered in this study 2, 3, 4, and 5 cm fuel thickness and we are fixing the water thickness into 1 cm in all the experiments.

CHAPTER 4: RESULT & AND DISSCUSSION

This section will briefly discuss the result achieved from the methodology. Moreover the result that presented in this chapter is divided into two parts; the first part of the result is from the fuel development and choosing the best mixer that is suitable for carrying out the experiments. And the second part shows the result for the main objective of the study which determination of the area affected by the spread of fuel.

4.1 Fuel Mixture Development:

As it has been stated in chapter 4, three experiments have been carried out in order to find a suitable fuel mixture, below are the result from these three experiments.

Table 3: Time to Boilover

Experiment No.	Mixing fractions (Patrol % to Diesel %)	Time to Boilover (Minutes)
1	70:30	18
1	40:60	17
3	50:50	15

As we can see from the table above there is no significant change in the time to Boilover when we change the concentration of the fuel. We predicted that decreasing the fuel density or decreasing the amount of diesel which is the more dense fuel will result in decreasing the time because denser fuel needs longer time to burn. and through the experiment this prediction was proven to be correct and the time deceased as we decreased the density even though the time deduction is not that significant we can see that mixture number three (50:50) is best because we are looking for shorter time to boileover, this is from the first factor which is time to Boilover.

As for the other factor which is the clearness of the explosion or the stability of the Boilover. For the first mixture (figure 5) the Boilover happened over a period of time it which means this mixture is not the most suitable one because for determining the area we need the instant Boilover to happen so that we can know exactly how much area is covered by the spread of the fuel.

Figure 6:Expriment 1 (70% :30%).

Figure 7: Figure: Experiment 2 (60%:40%)

Figure 8: Experiment 3 (50%:50%)

As for the second mixture (60:40) it was almost the same as the first one, also it did not show a smooth Boilover and it happened over a period of time . But for the last mixutre (50 : 50) the Boilover happened once only and we were alble to see the area affected clearly because there was no side explsions, So from both Factros time to boile over and Smoothness (steadiess) of Boilover we can say that mixuer number three which conisit of 50 % Diesel and 50 % Patrol are the best mixure for this study.

4.2 Area Affecetd first trial

The second part of the expriment phase was conducting the expriment to determine the area affected. in this part we fixed the fuel compocition to 50:50 and we varied the fuel thickness of the fuel layer in the containerto study the affect of fuel theckness on the area affected by the spread of fuel due to Boilover. Below are the reuslt of the foure different fuel thickness.

Figure 9: Experiment 1 (2 cm fuel thickness)

Figure 10: Experiment 2 (3 cm fuel thickness)

Figure 11: Experiment 3 (4 cm fuel thickness)

Figure 12: Experiment 4(5 cm fuel thickness)

The area affected is determined in term of the container diameter and it has been assumed that the furthest point the fire reaches resembles the area affected because the fuel does not spread in a uniform manner. And also by doing this we are considering the worst case senior for the spread. Below are the summary of the result from the first set of experiments:

Table 4:summary of the results

Experiment No.	Fuel Thickness (cm)	Fuel Volume (cm^3)	Distance (D) (D= container diameter)	Distance (cm)	Area Affected (cm^2)
1	2	657	2 D	38	1,134
2	3	850	3 D	57	2,552
3	4	1134	5 D	95	7,088
4	5	1418	3 D	76	4536

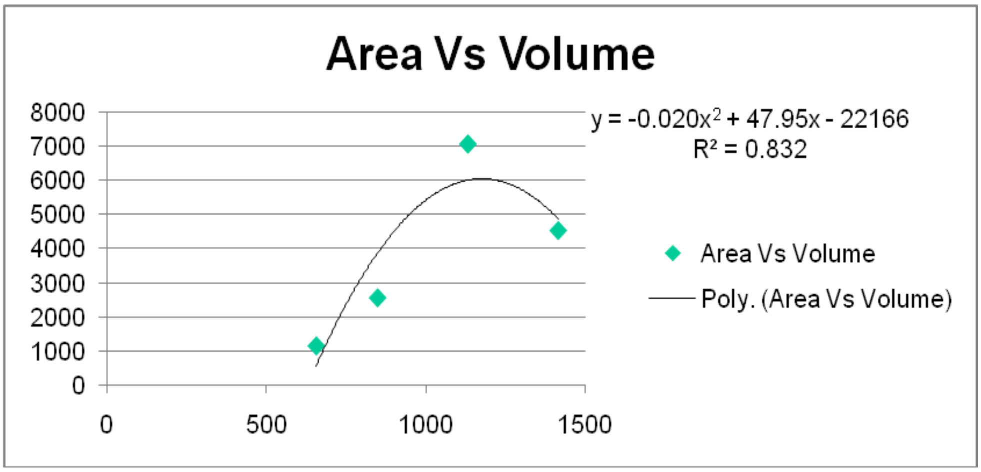


Figure 12: fuel Volume vs. Area Affected (4 points)

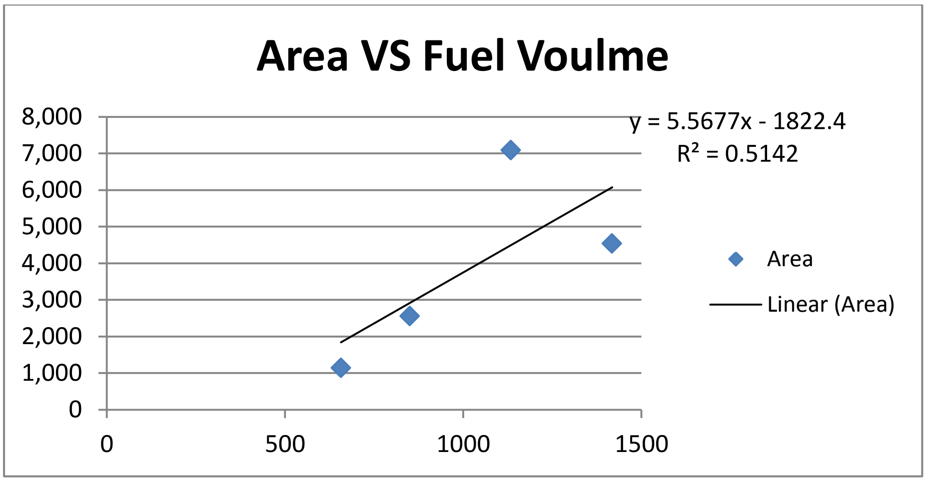


Figure 13: Area vs. Fuel volume

Figure (8, 9, 10 and 12) show caption of the Boilover from the four experiments, as we can see in these figures the area affected by the spread of fuel was really clear, and we were able to determine the area affected in term of diameter because it is easier and more convenient for this study, because due to some limitation it is not possible to measure the area exactly but measuring the area in term of diameter is more easier and accurate to some extent.

Table 4 summarizes the most important finding of these four experiment which is the area affected, for experiment 1 ,2 and 3 the area affected is increasing as we kept increasing the fuel layer thickness but for the fourth one (5 cm) the area did not increase. And the relation between the fuel amount (volume/ thickness) and the area affected is polynomial relation as we can see from figure 12 and the R^2 value is 0.83, and as we can see from figure 13 the linear relation between the area affected and the fuel thickness gave us a lower value of R^2 which is 0.5142 and this value is not high enough to say that these values have a linear relation , so what we can conclude for this set of experiments that the polynomial relation gives a better estimation of the area affected.

4.3 Area Affected second trial:

Below are the results for the second run of the experiments for determining the area affected, as in the first trial we varied the thickness of the fuel mixture (50:50) in the fuel container and measured the area affected after the Boilover occur.

Figure 14:50: 50 2 cm second trial

Figure 15: 50:50 3 cm second trial

Figure 16: 50:50 4 cm second trial

Figure 17: 50:50 5 cm second trial

Table 5:summary of the results

Experiment No.	Fuel Thickness (cm)	Fuel Volume (cm^3)	Area affected (D= container diameter)	Distance (cm)	Area Affected (cm^2)
1	2	657	2 D	38	1,134
2	3	850	3 D	57	2,552
3	4	1134	5 D	95	7,088
4	5	1418	6 D	76	10,207

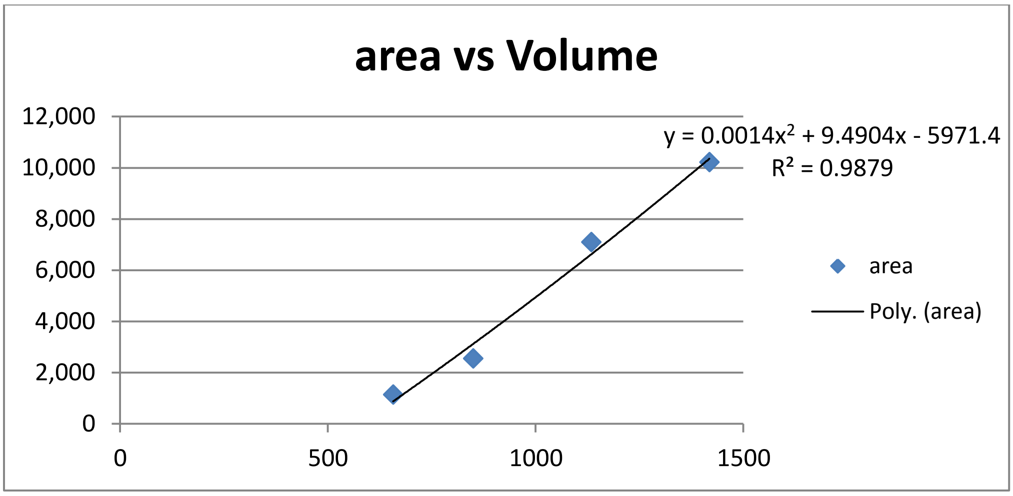


Figure 18: area vs. fuel volume second trial

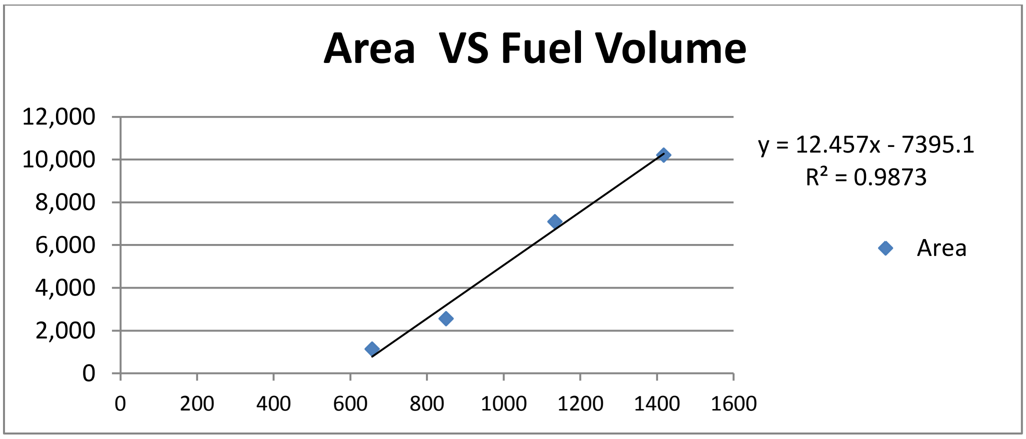


Figure 19: Area vs. Volume second trial

For the figures above (14, 15, 16 and 17) we can see clearly that when we increased the fuel thickness the area affected increased for all the fuel thickness and from figure (19) we can see that the relation between the fuel thickness and the area affected is linear with R^2 value of 0.987 which is very close to 1. But the polynomial relation from figure 18 gave us a higher coefficient of determination (R^2) equals to 0.9879 which is closer to 1. This confirms that the polynomial relation gives a better estimation of the area affected.

4.4 Crude Oil Experiments result:

A third set of experiment was carried out using cure oil. Also is this set of experiments the thickness of crude oil is varied between (2-5cm) in the storage tank while the water thickness is fixed at 1 cm. below are the results:

Figure 20: Crude Oil 2 cm

Figure 21: Crude Oil 3 cm

Figure 22: Crude oil 4 cm

Figure 23: Crude oil 5 cm

Table 6: crude oil results summary

Experiment No.	Fuel Thickness (cm)	Fuel Volume (cm^3)	Area affected (D= container diameter)	Distance (cm)	Area Affected (cm^2)
1	2	657	2 D	38	1,134
2	3	850	1 D	19	283.5
3	4	1134	1 D	19	283.5
4	5	1418	2 D	38	1,134

From the figures (20, 21, 22 and 23) we can clearly see that increasing the crude oil volume in the tank has not effect on the area affected. And from table 6 we can conclude that the experiments with crude oil did not give any significant result, because it was expected that by increasing the volume of crude oil in the container the area affected should be increased. This may be due to the quality of the crude oil used as fuel, also the crude oil used is an old stock since 2010, and the crude oil used is refined one.

CHAPTER 5: CONCLUSIONAND RECOMMENDATIONS

5.1 CONCLUSION

In conclusion we can say that a suitable fuel mixture was developed successfully as it was the first key milestone of this project and chosen type of mixture is 50 % diesel mixed with 50 % patrol. As for the other key millstone which performing the experiment and data analysis, 2 set of experiments was carried out successfully and analysed for finding a suitable equation for predicting the area affected. The first set of experiments showed polynomial relation between the area affected and the fuel volume with a coefficient of determination R^2 = 0.83.And for the second set of experiments the relation between the area affected and the fuel volume is also polynomial relationship with a coefficient of determination close to one (0.9879). On the other hand the crude oil experiments result showed no relation between the crude volume and area affected.

Succinctly, from the results obtained which are the recordings of the area affected by the spread of fuel due to boilover we can say that the area affected can be determined if the volume of the fuel in the tank is known

5.2 RECOMMENDATIONS

In recommendation for future work, the experiments should be performed in a larger scale because the results we obtained from the small scale might not be applicable for the large scale situations. And more experiments should be conducted with a wide range of fuel thickness.

APPENDIX

1. FYP I GANTT CHART

	1	2	3	4	5	6	7	Break	8	9	10	11	12	13	14
Selection of the project topic															
Preliminary research work **(Background of the Boilover …)**															
Submission of extended proposal															
Proposal defence Oral Presentation															
Experiment Design															
Submission of intern report draft to supervisor															
Submission of intern report draft to coordinator															

2. FYP II GANTT CHART

	1	2	3	4	5	6	7	break	8	9	10	11	12	13	14	15
Continue from FYP1 **- experiment design and fuel mixture development**	■	■	■													
Carry on experiment for determining the area affected				■	■	■										
Submission of Progress Report																
Finish experiments and data analysis									■	■	■	■				
Pre-EDX											◆					
Submission of Draft Report												◆				
Submission of Final Dissertation (soft Cover)													◆			
Technical Report																
Oral presentation															◆	
Submission of Final Dissertation (Hard Cover)																◆

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