Performance of GFRP After Exposure to Open Hydrocarbon Fire: Development of Hydrocarbon Fire

By

Khairi Hafizi Bin Kamarudin

15077

Dissertation submitted in partial fulfilment of

The requirements for the

Bachelor of Engineering (Hons)

(Civil Engineering)

May 2014

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION

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.

KHAIRI HAFIZI BIN KAMARUDIN

CERTIFICATION OF APPROVAL

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Approved by,

(Dr Ibrisam B. Akbar)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2014

ABSTRACT

Due to its vast advantages compared to steel, most of oil and gas companies have shifted their interests to glass fibre reinforced polymer (GFRP) as a new alternative material used in oil platform's grating. Offering resistance from the environment, cost-cutting as well as mass reduction of platform weight, GFRP has become a perfect solution to recover the weaknesses imposed by steel as platform grating material. However, as GFRP is still considered new in application as a material for grating, engineers do not have a complete set of guide to determine the strength of the GFRP after it has been exposed to hydrocarbon fire for a certain period of time. Consequently, there is no indicator whether the GFRP still can be used or should be replaced with the new one in case there is occurence of fire that consists of hydrocarbon.

In order to proceed on research of the performance of GFRP under exposure of open hydrocarbon fire, study of behaviour of hydrocarbon fire itself is a must. Thorough and detail analysis on several parameters of hydrocarbon fire such as period of combustion and temperature distribution had been conducted by author so that the results from this research could be referred by another author who will proceed on research regarding the performance of GFRP after it being exposed to open-hydrocarbon fire.

ACKNOWLEDGEMENT

I would like to express my gratitude and appreciation to all those who gave me the possibility to complete this report. A special thanks to my Final Year Project supervisor, Dr Ibrisam Akbar, whose help, stimulating suggestions and encouragement, helped me to coordinate my project especially in writing this report.

I would also like to acknowledge with much appreciation the crucial role of the staff of Concrete Laboratory, who gave the permission to use all required machinery and the necessary material to complete this project.

Last but not least, many thanks go to Final Year Project 2 coordinator, Dr Raza, whose have given his full effort in guiding us in achieving the goal as well as his encouragement to maintain our progress in track. I would like to appreciate the guidance given by other supervisors as well as the panel of examiners especially in our project presentation that has improved our presentation skills by their comment and tips.

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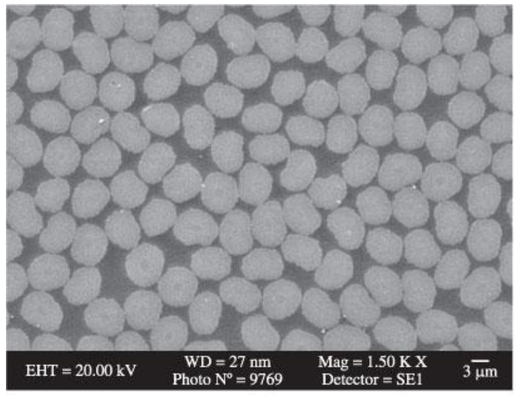
CHAPTER 1

INTRODUCTION

1.1 Background of Study

Nowadays, glass fibre reinforced polymer (GFRP) has become one of the most sophisticated materials in replacing conventional materials either in construction, civil infrastructure or offhore structure. Due to its great attributes such as lightness, high-strength, good insulation properties,better durability as well as low maintenance, the application of GFRP as a material for offshore-platform grating is the best choice to counter the harsh environment that always happen at offshore platform. Apart from that, GFRP also offer benefits over conventional materials due to their high specific strength, excellent corrosion resistance, low electromagnetic signature, overall improved operational performance and low heat conductivity (Boyd, Case, & Lesco, 2006).

Generally, the structure of a composite material like GFRP is consists of two phases, matrix and reinforcement. Each has different function. For the reinforcement, its function is to provide strength to the composite material while the matrix act as connector that binds all these reinforcement together (Bagherpour, 2006). However, as GFRP consists of binding agent that known as polymeric matrix, this matrix tend to volatilize when there is increase in temperature and hence increase the creep rate of the surrounding fibres. After the entire matrix had undergone pyrolysis, failure can occur when the strength of the softened glass fibre has reached point below the applied stress or load(Boyd et al., 2006). At this point, the GFRP is no longer suitable to be used as grating because the reduction of its strength may cause harm to worker that step onto it. Hence, it is paramount of importance to investigate the strength reduction of GFRP grating exposed to hydrocarbon fire for a certain period of time. This report was produced from a series of test that had been conducted by the author in order to give clear indication to offshore engineers regarding this matter.



(a)

Figure 3. Alignment of composite materials in GFRP.

(Picture taken from www.scielo.br)

1.2 Problem Statement

Deck grating is one of the most vital components to be used in offshore platform. Due to its function as flooring part of the platform, therefore, it is very important for authorities at the offshore platform to ensure that its strength and durability is preserved for a long-term period. In recent years, the extensive usage of GFRP as grating material has become a major concern in terms of safety aspect that may be affected by the aggresive environment at the offshore platform. Fatal unwanted accidents such as explosion may trigger the occurence of fire at the platform in rapid pace as a result of the behaviour of the fire itself, that is hydrocarbon fire.

When talk about hydrocarbon fire, it should be noticed that this kind of fire is flammable liquid fire because of its constitution of hydrogen and carbon. Moreover, the rate of spread for hydrocarbon fire is short compared to other types of fire such as cellulosic fire (ASTM E-119). As quoted in *Preliminary Fire Testing of Composite Offshore Pedestrian Grating* :

> As part of its qualification requirements for structural fire integrity gratings, the US Coast Guard specifies that sample gratings are tested in a furnace and exposed to a standardised time-temperature curve for a cellulosic fire (ASTM E-119). The exposure time is 60 minutes rising to a final temperature of 927 °C. The temperature data obtained as part of this study demonstrate that this time-

temperature profile is not representative of a hydrocarbon pool fire scenario, which can reach this temperature in 5 minutes. Therefore, the results may be misinterpreted to give a false sense of confidence that the gratings can support loads for longer than they can in an actual hydrocarbon pool fire.(Burrell, Jagger, & Johnson, 2012)

GFRP have different types of plastic matrix(Polyester, Vinylester, Phenolic etc.) which act as the 'binder' of the glass fibres inside the composite and hence their performance during and post fire condition must not be the same. Some types of GFRP may only endure the high-temperature condition just within 1 to 5 minutes before it starts to show discernable lack of integrity whilst others may have longer time before the composite fails. These are all depends on the polymeric matrix used in the manufacturing of the GFRP.

Thus, to address this problem, the author had decided to came up with a series of test on different types of GFRP (Polyester, Vinylester and Phenolic) in order to investigate the strength reduction of each type of GFRP after it was exposed to hydrocarbon fire for a period of time. However, due to time and cost constraint, the author had divided this project research into two major parts; hydrocarbon fire development and GFRP post-fire performance test, in which the author only assigned to complete the first part of the project that is hydrocarbon fire development.

1.3 Objectives

The objectives of this project are listed as follows:

- To confirm that the fire produce from the combustion of kerosene is a hydrocarbon fire.
- To measure the period of combustion based on volume usage of kerosene.
- To find the best location of thermocouple sensors during combustion which resulted in high temperature distribution.

1.4 Scope of the Project

The first part of this research will mainly focus on the conformance of hydrocarbon fire and study of the behaviour of hydrocarbon fire. Thorough and details analysis will be implemented throughout the research in order to come out with an effective results that later will be used as a guide for safety bodies at offshore platform. Thus, during the research, the author must ensure that all conditions had to simulate the real condition that might happen at the real working environment; offshore platform.

1.4.1 The Relevancy of the Project

Fire incident that frequently happen at offshore platform is something that is uncontrollable. The impact of the incident become worse as it deals with hydrocarbon fire as the fire is triggered by the presence of hydrogen and oxygen elements that will definitely increase the rate of burning and spread of the fire itself. Up till now, there is no precise and clear guide for engineers to decide whether deck grating made up from GFRP is able to be used after the occurence of hydrocarbon fire at offshore platform. This matter arises due to the lack of knowledge on the percentage of strength reduction for a certain type of GFRP grating. Thus, after thorough study had been done on this topic, the author think that this project should be carried out as it will provides tones of benefits to the oil and gas industries in future.

1.4.2 Feasibility of the Project within the Scope and Time Frame

This project begins by collecting reading material such as books, journals, related websites and newsletter for more insight on the performance of GFRP during and after the exposure to hydrocarbon fire. It is expected that for Final Year Project (FYP) 1, the author is able to get the real the picture and some sort of knowledges about the topic in order to ensure the ease of project flow in FYP 2. Meanwhile for FYP 2, the project will focus on the real testing of GFRP to observe and evaluate its strength by varying the time of exposure to hydrocarbon fire.

CHAPTER 2
LITERATURE REVIEW

2.1 Lesson from Past Accidents

In 20 April 2010, an explosion on drilling rig *Deepwater Horizon* located at the Gulf of Mexico had caused the death of 11 workers while many others had suffered from severe injuries. Other than that, the environment was atrociously polluted by the release of 5 million barrels of crude oil into the ocean. Thorough investigation that had been carried out was proven that this disastrous accident had been believed was caused by one major reason; fire, after ignition of released hydrocarbons(Nolan,2011).

According to Christou and Konstantinidou (2012), “While consequences of potential accidents to life and health of the workers, pollution of the environment and especially of the neighbouring coastal areas, and direct economic damage are direct effects and can be easily be assessed, indirect economic damage and effects of the accident to security of energy supply are more difficult to be assessed” (p.8). In addition, Christou and Konstantinidou also relate the impact of the incident that happen to *Deepwater Horizon* with the major share loss(50% decrease of share price) of the operating company, British Petroleum (BP). Furthermore, in the forthcoming EU offshore legislation, it is compulsory for oil and gas company that operates offshore platform to share all the required informations such as:

- unintended release of hydrocarbons;
- loss of well control, or failure of a well barrier;
- failure of a safety critical element;
- significant loss of structural integrity, or loss of protection against the effects of fire or explosion;
- vessels on collision course and actual vessel collisions with an offshore installation;
- helicopter accidents;

- any fatal accident; any serious injuries to 5 or more people in the same accident;
- any evacuation of non-essential personnel;
- a major accident to the environment.

From these required informations, the 4th item, '*Significant loss of structural integrity, or loss of protection against the effects of fire or explosion*' is one of the major concern that was stressed in the EU offshore legislation. As this matter become more apparent, many companies that own and operate oil rig, especially the one that uses GFRP deck grating, have started to find a breakthrough and conduct researches to study the performance of this new material(GFRP) against the effects of hydrocarbon fire at the offshore platform.

2.2 Advantages of Using GFRP as Offshore Deck Grating

The use of GFRP as deck grating material at offshore platform replacing steel as the conventional material is the best alternative to resist the demolishing effect imposed by hydrocarbon fire. As mentioned in *Fire Protection System for Building Floors Made of Pultruded GFRP Profiles*, in order to prevent the structural collapse under the effect of fire, structural elements are expected to have a great fire resistance properties(Correia, Branco, Ferreira, Bai, & Keller, 2010). Among the fire resistance properties of GFRP is due to its good heat insulation. The significance of this attribute is that it will retards or slowing the spread of fire in the occurrence of burning or explosion(Dodds, Gibson, Dewhurst, & Davies, 2000).

Apart from that, as the environment at the offshore itself that possess high-humidity surrounding air, its impact on steel will contribute to rusting. Hence, to enhance the structure service life of the grating, the use of GFRP as the material for the deck grating is the correct and effective way to counter this issue. In terms of weight, GFRP has 75% less weight compared to steel and because of this, it will reduce the cost of handling for GFRP-type grating.

2.3 Strength and Durability of Different Types of GFRP

Depending on the type of resin being used, the properties and attributes of the GFRP will definitely differ from each other after it has been exposed to elevated temperature. The selection of the type GFRP to be used will depends on its purposes and objective of the usage(low cost, high strength, etc.).

2.3.1 Polyester

Polyester resins are the simplest, most economical, and show good performance. Due to this reason, there are vast usage for this type of GFRP. Generally, polyesters exhibit low thermal stability, chemical resistance, poorest adhesion, has the highest water absorption and highest shrinkage. Furthermore, this type of GFRP is said to have the highest fracture tendency among the others (https://redrockstore.com/resin.htm).

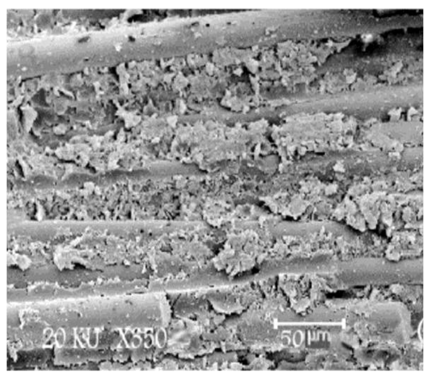


Figure 4. Microstructure of Polyester GFRP

2.3.2 Vinyl-Ester

The usage of Vinyl Ester as the resin material in GFRP had enhanced its properties in terms of strength and durability. Vinyl Ester is the combination between two resins; polyester and epoxy, in which epoxy has been added to enhance the main molecular structure of polyester. However, this type of GFRP should not be used without proper evaluation of the required strength needed as it will imposed high project cost (http://www.fibermaxcomposites.com/shop/index_files/resinsystems.html).

2.3.3 Phenolic

Phenolic resins are polycondensation products of phenols and formaldehyde. Phenolic GFRP have excellent high-temperature properties and also unique in their chemical resistance. The use of phenolic resins in composites is rapidly growing, mainly due to law requirement on flame spread, smoke generation, and smoke toxicity. Apart from that, the reasonable cost of the phenolic GFRP is one of the main factors that contribute to the selection of this type of GFRP as offshore deck grating (http://www.fibermaxcomposites.com/shop/index_files/resinsystems.html).

2.4 Performance of GFRP Under Exposure of Fire

In the past, several researches have been conducted to investigate the performance of GFRP under the exposure of fire. According to the research done by Burrell, Jagger, and Johnson on *Preliminary Fire Testing of Composite Offshore Pedestrian Gratings*, they did their research on two different types of grating; Isophtalic Polyester and Phenolic. The research was divided into two major parts; Fire Testing and Post-Fire Evaluation. During the fire testing, both loaded and unloaded Isophtalic Polyester have failed after 1.5 to 5.5 minutes exposed to fire. However, Phenolic had shown different results. Both loaded Phenolic grating failed between 2:47 and 5:11 minutes. However, the unloaded gratings which passed the fire testing were tested on post-fire evaluation. During the post-fire evaluation, the gratings were tested by placing a 40 kg mass and uniformly-distributed load (UDL). The gratings had passed all the test and hence satisfying the structural fire integrity for Level 2 and Level 3 requirements. Nevertheless, if the structural fire integrity for Level 1 is requested, the phenolic grating was classified as failed because the grating broke as soon as the foot of a 90 kg man stepped onto it during forward travel.

In another researches, it was shown that the strength and the elastic modulus of GFRP change with temperature (Wang, Zha, & Ye, 2009). During the test, Wang et al. try to predict the temperature distribution and mechanical performance of FRP rebar reinforced concrete columns in fire. However, the ‘fire’ described in the research was referred to ISO-834 which is not hydrocarbon-content fire. Besides that, Correia et al. in their research work entitled *Fire Protection System for Building Floors Made of Pultruded GFRP Profiles* stated that, "When FRP materials are exposed to high temperatures (300 - 500°C), the organic matrix decomposes, releasing heat, smoke, soot and toxic volatiles" (p. 617). The results obtained from their tests also had revealed that under fire exposure, the loss in compression strength is more rapid compared to tensile strength for GFRP pultruded profiles.

2.5 Behaviour of Hydrocarbon Fire

Hydrocarbon fire is a type of fire that will normally occur in petrochemical installations or oil and gas production facilities when hydrocarbon chemicals and fuels ignite(http://www.pfpsystems.com/assets/Uploads/HydrocarbonBook1.pdf). According to Croce and Mudan (1986), theoretically, hydrocarbon fire can reach up to 1100°C just within a few minutes after ignition begin and may cause reduction of strength to any structure affected by the fire. This strength reduction is something unfavourable especially when the structure like offshore platform where as its location at the middle of the sea would cause harm to any personnel due to structure collapse.

2.5.1 Phase of Fire

According to Pretrel, Saux, and Audouin (2013), burning process of hydrocarbon occur in clearly defined stages. Each phase (or stage) is characterized by differences in room temperature and atmospheric composition. Basically, as quoted in http://www.lbfdtraining.com , there are three main phases of fire:

1) Incipient Phase (Growth Stage)

In the first phase, the oxygen content in the air has not been significantly reduced and the fire is producing water vapor, carbon dioxide, perhaps a small quantity of sulfur dioxide, carbon monoxide and other gases. Some heat is being generated, and the amount will increase with the progress of the fire. The fire may be producing a flame temperature well above

1,000^{0}F (537^{0}C), yet the temperature in the room at this stage may be only slightly increased.

2) Free-Burning Phase (Fully Developed Stage)

The second phase of burning encompasses all of the free-burning activities of the fire. During this phase, oxygen-rich air is drawn into the flame as convection (the rise of heated gases) carries the heat to the upper most regions of the confined area. The heated gases spread out laterally from the top downward, forcing the cooler air to seek lower levels, and eventually igniting all the combustible material in the upper levels of the room. This heated air is one of the reasons that firefighters are taught to keep low and use protective breathing equipment. One breath of this super-heated air can sear the lungs. At this point, the temperature in the upper regions can exceed 1,300^{0}F (700^{0}C). As the fire progresses through the latter stages of this phase, it continues to consume the free oxygen until it reaches the point where there is insufficient oxygen to react with the fuel. The fire is then reduced to the smoldering phase and needs only a supply of oxygen to burn rapidly or explode.

3) Smoldering Phase (Decay Stage)

In the third phase, flame may cease to exist if the area of confinement is sufficiently airtight. In this instance, burning is reduced to glowing embers. The room becomes completely filled with dense smoke and gases to the extent that it is forced from all cracks under pressure. The fire will continue to smolder, and the room will completely fill with dense smoke and gases of combustion at a temperature of well over 1,000^{0}F (537^{0}C). The intense heat will have vaporized the lighter fuel fractions such as hydrogen and methane from the combustible material in the room. These fuel gases will be added to those produced by the fire and will further increase the hazard to the firefighter and create the possibility of a backdraft.

2.5.2 Flame Radiation Characteristics

In the past, extensive research had been carried out to investigate the flame radiation characteristics of hydrocarbon pool fire. This is one of the most important parameters that should be taken care by researcher when dealing with hydrocarbon pool fire. In *Flame Radiation Characteristics of Open Hydrocarbon Pool Fires* , Ufuah and Bailey (2011) had conducted a research mainly focused on the flame radiation of open hydrocarbon pool fire. This research began by understanding the pool fires and flame geometry such as flame height as well as pool fire diameter. As cited by Ufuah and Bailey, the ratio of height of a flame to its diameter could be related to Froude Number, according to Thomas(1963). Among two formulas that had been derived by Thomas are:

$$(1)\ \frac{H}{D} = 42(Fr)^{0.61}$$

$$(2)\ \frac{H}{D} = 55(Fr)^{0.67}(u_\circ)^{-0.21}$$

Where H is the flame height and D is its diameter with equation (1) is used in calm air condition while equation (2) used in windy condition.

As the final outcome of the research, Ufuah and Bailey had concluded based on their model prediction that the radiative energy flux is largely dependent on the hydrocarbon pool fire diameter. Radiative flux or also known as heat flux is the amount of power radiated through a given area, in the form of photons or other elementary particles, typically measured in W/m^2.However, as the diameter of the pool fire extend beyond 200m, there is no more increase in radiative energy flux from the flame.

CHAPTER 3
METHODOLOGY

3.1 Preliminary Test

The author had started the research with several preliminary tests on the fire behaviour. This preliminary tests is very crucial and need to be carried out in order to thoroughly study the hydrocarbon fire properties to avoid any wastage and budget over-spend throughout the project.

3.1.1 Conformance of Hydrocarbon Fire Behaviour

This research was conducted to study and evaluate the performace of GFRP under exposure of hydrocarbon fire in terms of its strength reduction. Thus, before fire testing was commenced, author had to ensure that the type of fire produced had satisfied the properties of hydrocarbon fire in order to suit the real condition of fire breakout occur at offshore platform. For this test to be carried out, kerosene will be used as the combustion fuel and the fire temperature was measured by using thermocouple(Figure 3) attached to AM-800K Anritsu Datalogger(Figure 4).

Figure 3. Thermocouple sensor

Figure 4. AM-800K Anritsu Datalogger

The time-temperature curve getting from this test on fire should follow the behaviour of the red curve(hydrocarbon curve) as shown in figure 5 below:

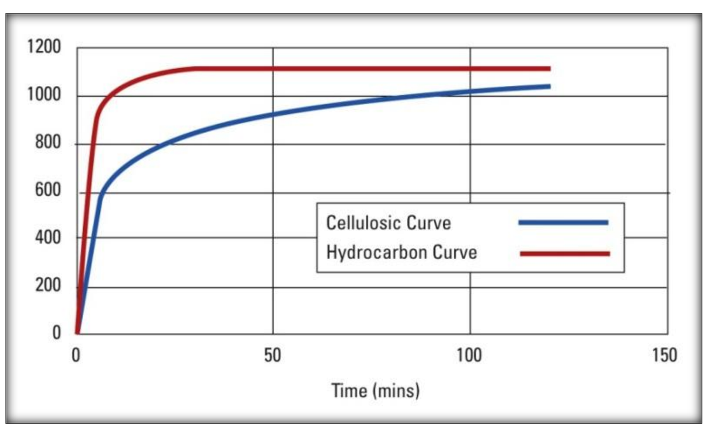


Figure 5. Graph of temperature versus time

It should be noted that the rate of hydrocarbon fire spread is more rapid than the cellulosic fires because it is fuelled by oil and gas. This hydrocarbon fire can reach temperature of 1000°C in between 5 to 7 minutes and can reach up to 1100°C just within 30 minutes period (Bai & Keller, 2010).

3.1.2 Steps in Using Thermocouple and Datalogger

1. The thermocouple sensors was placed at the desired location where temperature to be measured.
2. Connector (yellow color) legs was connected to the datalogger.
3. Data logger was switched on by pressing ‘ON’ button.
4. When everything was ready, temperature reading were started to be measured by pressing ‘START’ button on the data logger.
5. Data logger stopped collect temperature data when ‘STOP’ button was pressed.
6. The connector was disconnected from the data logger.
7. AMS-850 software was installed prior connection between data logger and PC was made.
8. Data logger was connected to PC by using USB.
9. The software that was previously installed was open and at the menu bar at the top, click on ‘Communication’ > ‘Input Data’.
10. Data logger will start transferring all data into the PC.

3.1.3 Volume of Kerosene Vs. Time of Combustion

Before the real testing on GFRP begin, the author had to study the combustion time for different volume of kerosene usage. This test has to be carried out in order to know how long the hydrocarbon fire burning for a certain volume kerosene poured into the hydrocarbon pool tank(Figure 6). The test started by pouring a little amount of kerosene and its burning time(period) is measured by using stopwatch. The test was repeated for another amount of volume. Figure

7and 8 shown the dimension of the tank that will be used for the whole project experiment:

Figure 6.   Hydrocarbon pool tank

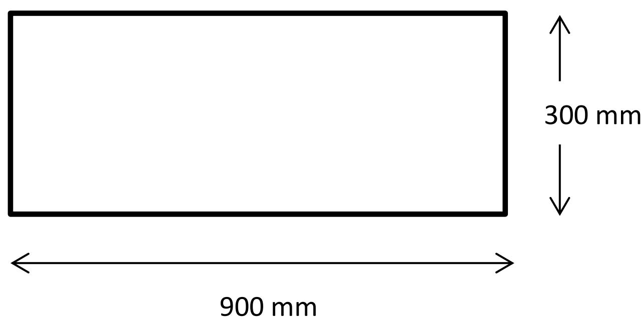


Figure 7.   Plan View

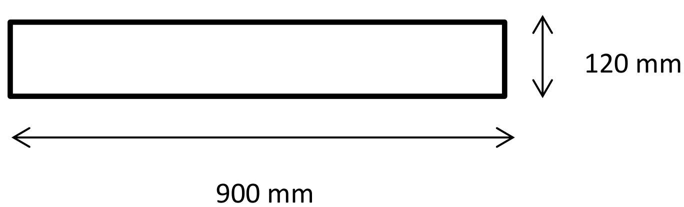


Figure 8.   Side View

3.1.4 Ultimate Fire-Resistivity Strength of GFRP

This test is conducted to measure time taken for each type of GFRP before it started to fail or cracked. From this test, the author is able to plan for the most suitable time increment during the real testing on GFRP. For instance, after conducted the test, the author found that the time taken for polyester GFRP to fail is 6 minutes. Since the available quantity left for Polyester GFRP is only 5 units, then, by dividing the time by quantity left (6 minutes/5 units), the author know that the suitable increment of time in the real testing should be around 1.5 minutes (90 seconds).

Hence, the data collected for Polyester in the real testing should be like this:

Table 1. Increment time for each fire test on Polyester GFRP

Sample	Time of exposure (min)	Strength reduction(MPa)
1	1.5	?
2	3.0	?
3	3.5	?
4	4.0	?
5	4.5	?

3.2 Initial Strength Test of GFRP

The initial maximum strength of GFRP grating need to be measured before fire testing is commenced. This initial maximum strength is required for the calculation of strength reduction of the grating later on.

3.3 Fire Testing

During the fire testing, the thermocouple will be attached to the grating in order to measure the temperature increment versus time. After a certain period of time expose to the hydrocarbon pool fire, the grating will be let to cool down for several minutes before it is taken to be tested in post-fire test.

Table 2. Available quantity of GFRP

Type of GFRP	Colour	Quantity
Polyester	Grey	9
Vinylester	Red	8
Phenolic	Brown	9

3.4 Post-Fire Test

The grating sample that already exposed to hydrocarbon pool fire for a certain period of time will be tested in three-point bending test. Load will be increased gradually in order to evaluate the maximum load that can be sustained by the grating. The moment grating start to crack or break, the load increment will be stopped and recorded.

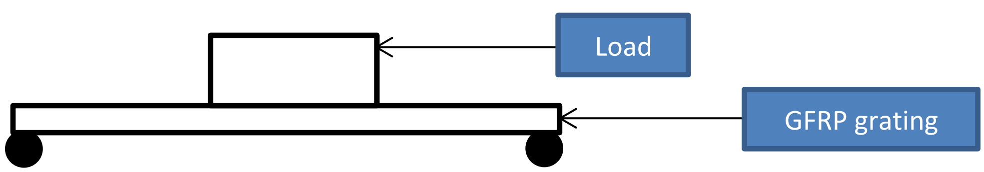


Figure 9. Three-Point Bending Test

3.5 Evaluation of Strength Reduction

The percentage strength reduction of GFRP grating can be calculated by using this formula:

$$\textit{Percentage of Strength Reduction}(\%) = (B-A)/B * 100$$

where:

A: Maximum load that can be sustained by grating after fire testing (MPa)

B: Initial maximum load can be sustained by grating before fire testing (MPa)

Eventually, graph of '*Strength Reduction against Period of Exposure*' (Figure 5) and '*Maximum Load against Period of Exposure*' (Figure 6) will be produced as a guideline for engineer at offshore platform.

Table 3. Expected result of percentage of strength reduction of GFRP

Type of GFRP	Initial strength (MPa)	Strength after exposed to hydrocarbon fire (MPa)	Period of exposure (min)	Percentage of strength reduction, %
Polyester	150	100	3	33.33
Polyester	150	80	5	46.67
Vinylester	180	150	2	16.67
Vinylester	180	120	4	33.33

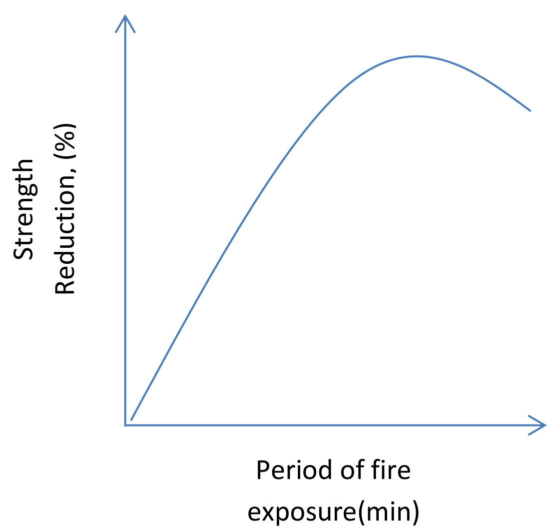


Figure 10. Sample Graph of Strength Reduction vs Period of Exposure

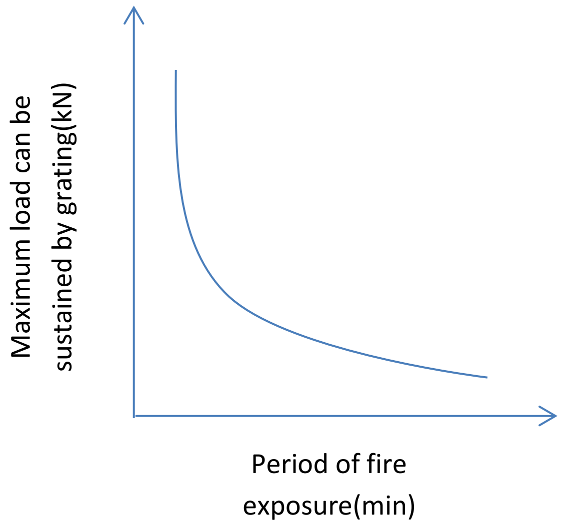


Figure 11. Sample Graph of Maximum Load vs Period of Exposure

3.6 Gantt Chart

Activities	Week No/ Date														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Fire test on period of combustion of kerosene	■	■													
Data analysis on period of combustion			■												
First hydrocarbon-fire test				■	■										
Second hydrocarbon-fire test						■	■								
Submission of progress report								■							
Third hydrocarbon-fire test								■	■						
Fourth hydrocarbon-fire test										■	■				
Pre-SEDEX										■					
Submission of Draft Final Report											■				
Submission of Dissertation												■			
Submission of Technical Paper												■			
Viva													■		
Submission of Project Dissertation (Hard Bound)															■

CHAPTER 4

RESULTS & DISCUSSION

4.1 Preliminary Test on Hydrocarbon Fire

All the GFRP's grating will not be tested before it is ensured that the fire produced is hydrocarbon-type fire. This is to imitate the real condition of fire occur at the offshore platform in case of fire breakout. Thus, from a series of preliminary tests that had been conducted, author had been able to produce some results that conform with the behavior of hydrocarbon pool fire. These series of preliminary tests are divided into two parts in which in the first part, the author had measured the period of combustion by varying the volume of kerosene used. In the second part, the author had to evaluate the temperature curve produced by the fire in several arrangements of thermocouple sensors.

4.1.1 Volume of Kerosene vs Period of Combustion

Table 4. Volume of Kerosene vs Period of Combustion

Volume of Kerosene (L)	Period of Combustion (min)
3	11
6	20
9	32
12	45

4.1.2 Test 1

Location of heat sensor shown in Figure 12:

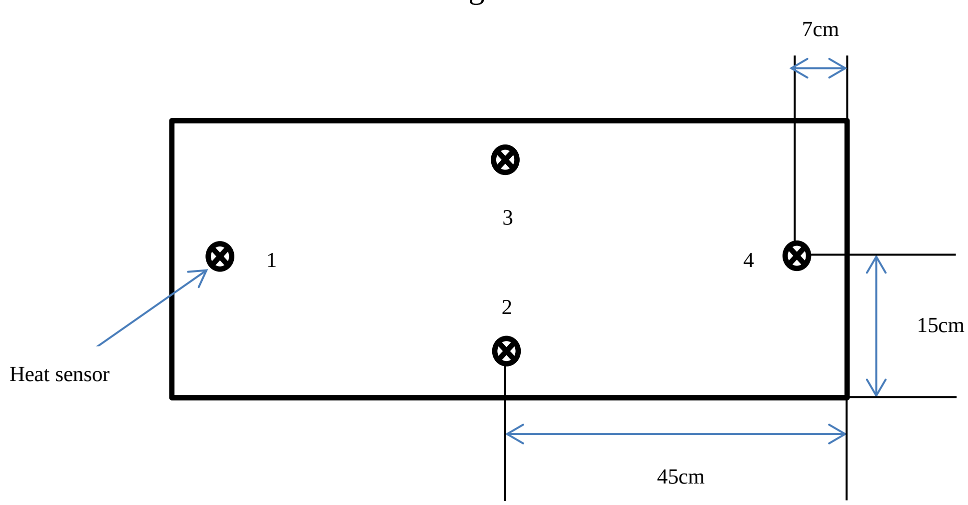


Figure 12. Plan view for the location of sensors in first test

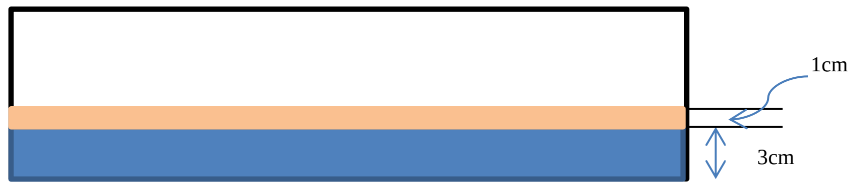


Figure 13. Height of water & kerosene in hydrocarbon pool tank.

Volume of water & kerosene used shown in Table 5:

Table 5. Volume of water and kerosene used in first test

Substance	Volume (L)
Water	8.1
Kerosene	2.7

Table 6 shown tabulated results of temperature distribution for four thermocouple sensors:

Table 6. Tabulated results in first preliminary test

Sample No.	H: M: S	Sensor1 [°C]	Sensor2 [°C]	Sensor3 [°C]	Sensor4 [°C]
1	00:00:00	168.1	183.4	85.6	153.1
2	00:00:10	248.7	231.6	101.7	182.8
3	00:00:20	324.1	297.1	128.9	238.1
4	00:00:30	354.3	366.6	136.3	300.4
5	00:00:40	378.6	452.8	150.7	348.7
6	00:00:50	414.4	511	170.4	406.4
7	00:01:00	441.1	523	215.1	463.5
8	00:01:10	476.3	554	244	506
9	00:01:20	512	585	273.4	528
10	00:01:30	536	600	288.1	551
11	00:01:40	548	603	294.9	559
12	00:01:50	564	619	307.7	559
13	00:02:00	576	627	316.4	559
14	00:02:10	591	641	334.9	554
15	00:02:20	606	650	348.7	547
16	00:02:30	609	653	357.3	537

17	00:02:40	613	665	367	537
18	00:02:50	617	667	374.3	532
19	00:03:00	623	664	381.5	532
20	00:03:10	627	647	383.6	522
21	00:03:20	627	648	383.3	516
22	00:03:30	622	640	382.8	524
23	00:03:40	618	628	387.6	516
24	00:03:50	619	612	389.8	509
25	00:04:00	617	615	391.9	503.7
26	00:04:10	613	641	393.8	503.3
27	00:04:20	607	643	404.7	519
28	00:04:30	607	635	428.2	527
29	00:04:40	607	619	455.4	516
30	00:04:50	608	601	465.2	510
31	00:05:00	604	588	465.5	514
32	00:05:10	574	563	451.8	516
33	00:05:20	545	537	443.8	500
34	00:05:30	527	518	434.4	504.4
35	00:05:40	524	490.8	431.1	485.9
36	00:05:50	514	461.5	422.1	468.2
37	00:06:00	501.8	439.9	407.1	448.2
38	00:06:10	483.8	417.9	397	432.9
39	00:06:20	460.1	389.2	382.2	410.7
40	00:06:30	432.9	370.3	369.1	386.1
41	00:06:40	408.1	349.7	357.5	365.1

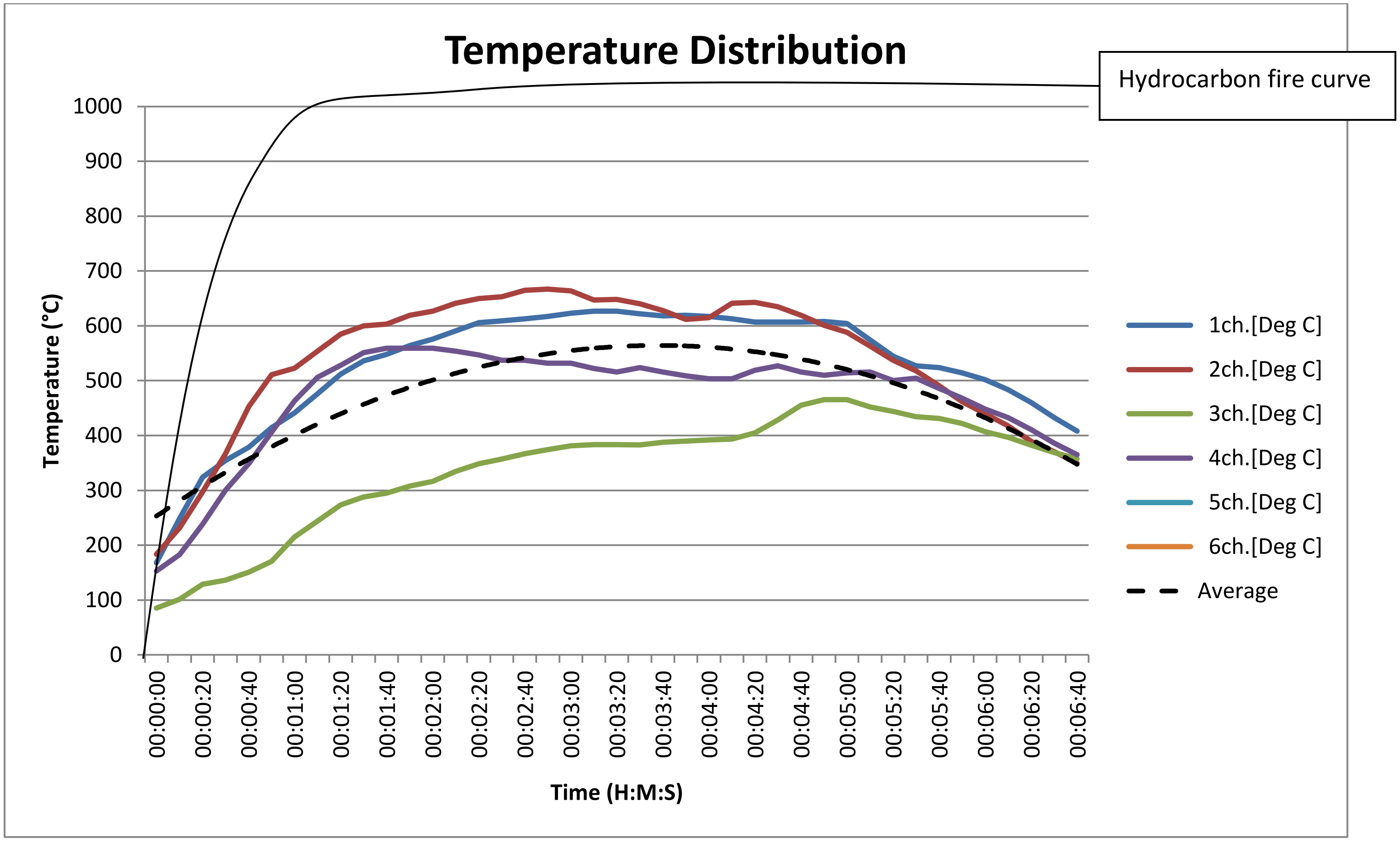


Figure 14. Graph of temperature versus time for first preliminary test

4.1.3 Test 2

Location of heat sensor for second test as shown in Figure 15 below:

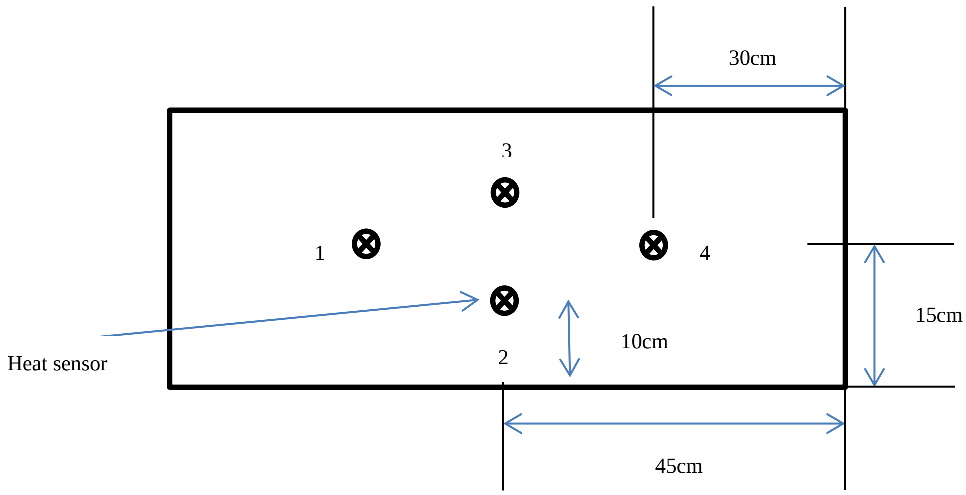


Figure 15. Plan view for the location of sensors in second test

The volume of kerosene and water used in test 2 shown in Table 7:

Table 7. Volume of water and kerosene used in second test

Substance	Volume (L)
Water	8.1
Kerosene	2.7

The tabulated result and plotted graph for second test shown in in Table 8 and Figure 16 respectively:

Table 8. Tabulated results in second preliminary test

Sample No.	H: M: S	Sensor1 [°C]	Sensor2 [°C]	Sensor3 [°C]
1	00:00:00	63.8	100.7	70.8
2	00:00:10	109.9	152.1	82.1
3	00:00:20	147.9	208.8	85.6
4	00:00:30	209.1	256.1	114.9
5	00:00:40	254.7	303.3	135.3
6	00:00:50	314.8	355.8	162.6
7	00:01:00	335.3	409.3	172.6

8	00:01:10	347.4	459.3	183.3
9	00:01:20	357.8	491.3	191.7
10	00:01:30	372.4	525	198.1
11	00:01:40	388.6	555	195.4
12	00:01:50	393.7	581	201.4
13	00:02:00	434.7	596	216.2
14	00:02:10	458.2	611	233.1
15	00:02:20	458.4	622	237.2
16	00:02:30	484.6	636	256.3
17	00:02:40	502.5	651	269.8
18	00:02:50	526	663	282.4
19	00:03:00	517	672	283.4
20	00:03:10	510	677	292.7
21	00:03:20	494.2	686	289.4
22	00:03:30	477.8	687	289
23	00:03:40	484	693	292.7
24	00:03:50	495.2	686	292.4
25	00:04:00	497.9	667	291
26	00:04:10	506	653	290.5
27	00:04:20	486.2	646	283.4
28	00:04:30	459.3	641	273.1
29	00:04:40	465.2	642	281.5
30	00:04:50	475.1	632	293.3
31	00:05:00	480.5	624	324.2
32	00:05:10	483.6	619	348.9
33	00:05:20	465.4	614	332.4
34	00:05:30	479.9	593	322.5
35	00:05:40	453.7	587	302.7
36	00:05:50	442.1	579	294.2
37	00:06:00	442.9	577	290.8
38	00:06:10	433.9	582	284.7
39	00:06:20	435.4	581	284.2
40	00:06:30	445.9	582	284.5
41	00:06:40	439.2	579	281.5
42	00:06:50	441.7	575	280.3
43	00:07:00	454.4	574	322.6
44	00:07:10	455.8	567	365.6
45	00:07:20	454.4	558	389.7
46	00:07:30	456.8	552	407.9
47	00:07:40	449.1	546	415.6
48	00:07:50	454.2	542	422.2

49	00:08:00	437.3	534	433.9
50	00:08:10	432.1	527	431
51	00:08:20	429.3	513	424.2
52	00:08:30	407.1	498.1	399.8
53	00:08:40	378.9	493.2	369.8
54	00:08:50	356.9	488.5	350.1
55	00:09:00	346.4	478.8	355.1
56	00:09:10	328.5	472.1	344.9
57	00:09:20	311.3	466.3	338.9
58	00:09:30	295.1	459.1	325
59	00:09:40	273.9	452.2	302.8
60	00:09:50	257.8	439.9	278.8
61	00:10:00	254.9	424.4	263
62	00:10:10	249.8	408.2	247
63	00:10:20	256.1	390	237.9
64	00:10:30	252.7	371.2	230.8
65	00:10:40	243.9	351.6	219.7

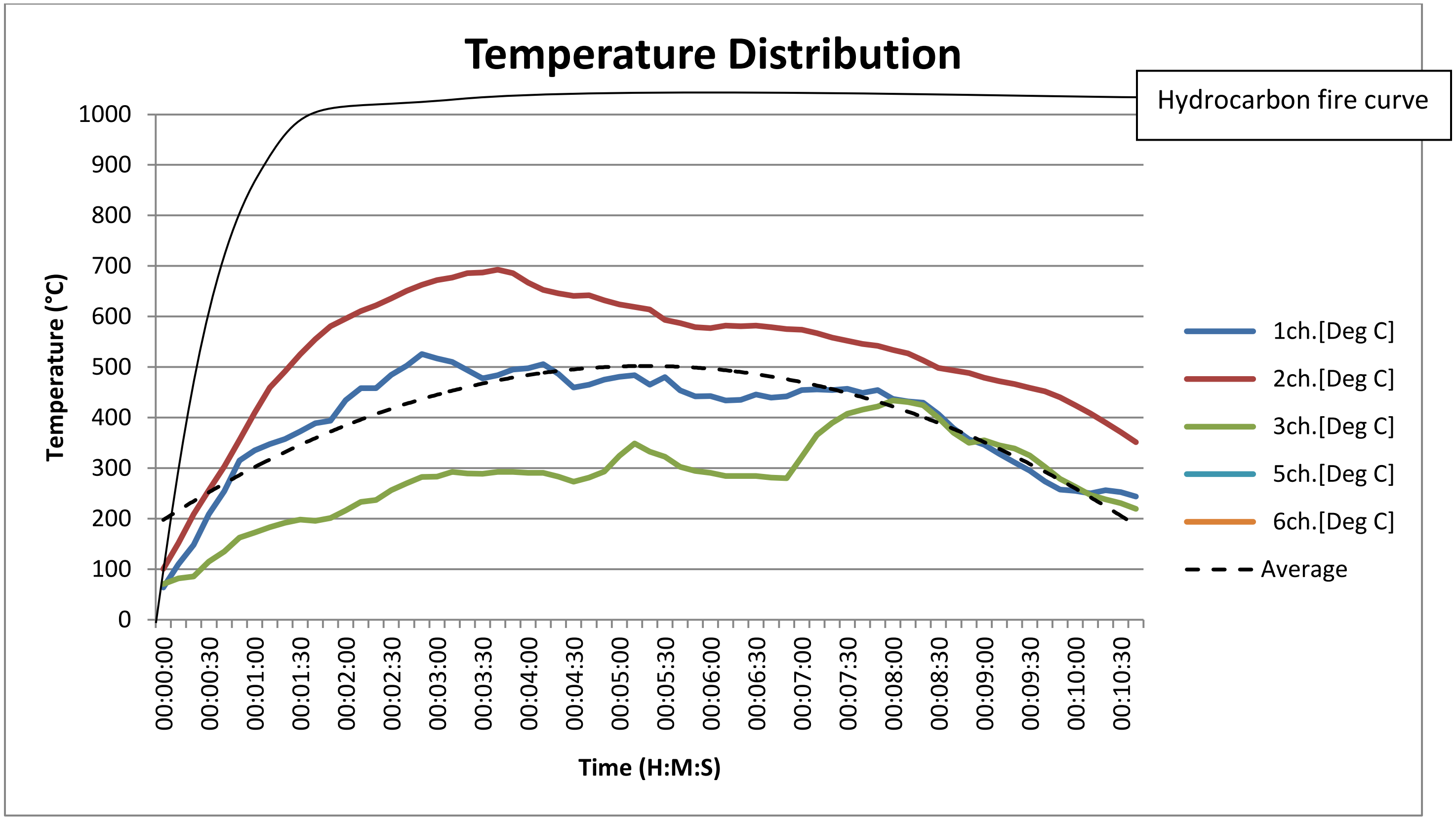


Figure 16. Graph of temperature versus time for second preliminary test

As compared to the first test, second test shown a decrease in average temperature curve. This temperature reduction was mainly due to misconnection between thermocouple connector and its sensor. From the temperature distribution graph, the maximum average temperature that could be achieved by the fire was merely 500°C. Obviously, it was far more from reaching the targeted temperature of 1000°C. Therefore, in third test, the author had added up the volume of kerosene inside the hydrocarbon pool tank.

4.1.4 Test 3

Location of heat sensor for third test as shown in Figure 17 below:

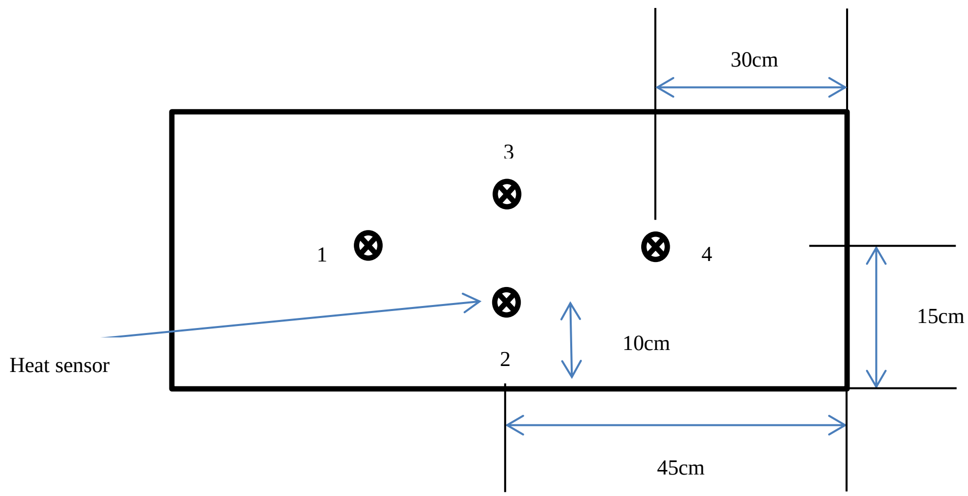


Figure 17. Plan view for the location of sensors in third test

It has been proved that higher distance from a centre of a flame will give a hotter temperature(Puri & Santoro, 1994). A little bit modification was done on the experimental setup by increasing the height of the thermocouple sensors from the combustion source(kerosene) as shown in Figure 18. The new height of the sensors is 480mm from the source (Figure 19).

Figure 18. New experimental setup

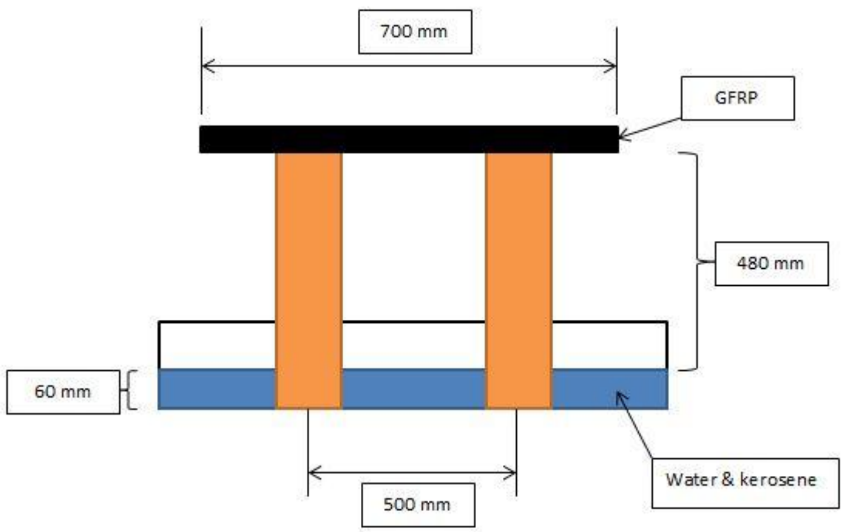


Figure 19. Height of thermocouple sensors from kerosene

Another modification was done on the volume of kerosene used. Previously, the author only used 2.7 L. However, the resulted temperature during the combustion did not achieved the required temperature. The author added up the volume as stated in table 9 below.

Table 9. Volume of water and kerosene used in test 3

Substance	Volume (L)
Water	8.1
Kerosene	8.1

The tabulated result and plotted graph for third test shown in in Table 10 and Figure 20 respectively:

Table 10. Tabulated results in third preliminary test

Sample No.	Time (H: M: S)	Sensor1 [°C]	Sensor2 [°C]	Sensor3 [°C]	Sensor4 [°C]
1	00:00:00	33	26.4	32.6	33.4
2	00:00:10	34.2	26.9	33.2	34.1
3	00:00:20	36	31.3	34.9	35.6
4	00:00:30	39.4	38.6	38.2	37.9
5	00:00:40	43.5	43.2	42.2	41.1
6	00:00:50	47.4	57.7	48.2	44.7
7	00:01:00	52.3	66	54.2	48.5
8	00:01:10	54.7	70.2	59.2	52.2
9	00:01:20	57.1	75.7	64.2	55.8
10	00:01:30	60.6	83.7	170.2	59.6
11	00:01:40	134.6	154.6	217.8	104.1
12	00:01:50	190.6	284.3	558.8	172.3
13	00:02:00	237.8	331.9	739.9	246.2
14	00:02:10	244.1	454.9	770.7	248.1
15	00:02:20	231.4	699.9	880.9	252.7
16	00:02:30	222.4	748.3	891.9	254.7
17	00:02:40	219.3	747.4	960.3	256.8
18	00:02:50	213.3	742.7	940.3	255.9
19	00:03:00	201.5	831.7	903.8	248.8
20	00:03:10	223.8	890.3	904.8	244.4
21	00:03:20	294.3	826.3	907.3	241.5
22	00:03:30	211.2	879.3	836.8	244.1
23	00:03:40	316.4	878.9	852.9	241.2
24	00:03:50	338.7	825.1	874.3	242.7
25	00:04:00	266.4	775.5	827.3	249.4
26	00:04:10	376.3	729.4	854.1	254.6
27	00:04:20	404.3	786.3	790.6	259.3
28	00:04:30	420.1	752.2	719.3	267.6

29	00:04:40	410.2	748	739.4	275.4
30	00:04:50	399.7	766.7	752.2	279.3
31	00:05:00	414.1	753.2	771.7	286.8
32	00:05:10	396.5	796	782.3	292.8
33	00:05:20	380.6	802	789.3	295.4
34	00:05:30	382.4	802	794.2	297.5
35	00:05:40	368.6	806.3	799.6	299.1
36	00:05:50	350.3	780.4	752.6	299.8
37	00:06:00	336.8	756.9	700.4	296.9
38	00:06:10	327.1	754.3	680.4	294.9
39	00:06:20	316.6	732.6	604.1	289.9
40	00:06:30	263.8	724.5	609	287.2
41	00:06:40	276.4	716.4	620	290.3
42	00:06:50	285.1	701.1	710.2	297.3
43	00:07:00	282.1	694.2	655.3	300.8
44	00:07:10	285.7	673.4	634	308.7
45	00:07:20	279.9	674.8	636	311.6
46	00:07:30	279.2	672.7	651	317.7
47	00:07:40	279.6	650.3	662	324.4
48	00:07:50	278.5	648.7	655	327.2
49	00:08:00	276.4	624.9	660	337.2
50	00:08:10	275.3	600.2	659	340.6
51	00:08:20	266.8	589.2	644	338.1
52	00:08:30	256.1	563.7	629	334.2
53	00:08:40	254.5	576.4	623	338.3
54	00:08:50	254.5	568.3	611	333.8
55	00:09:00	251.1	561	593	333.2
56	00:09:10	258.2	550.4	595	333.4
57	00:09:20	272.7	572.6	588	334.2
58	00:09:30	295	553.9	584	357.3
59	00:09:40	307.3	546.4	573	370.7
60	00:09:50	312.5	540.7	564	391.4
61	00:10:00	318.6	534	551	394.7
62	00:10:10	320.4	543	533	406.2
63	00:10:20	327.1	561	515	411.7
64	00:10:30	337.4	567	496.1	414.7
65	00:10:40	345.2	572	477.1	418.6
66	00:10:50	344.2	567	459.4	419.4
67	00:11:00	349.3	570	443.4	422.7
68	00:11:10	345.7	528	425.2	422
69	00:11:20	352.1	509	410.3	418.3

70	00:11:30	352.8	543	400.7	417.1
71	00:11:40	362.9	567	391.2	413.8
72	00:11:50	394	551	378.9	414.3
73	00:12:00	396.1	562	366.3	411.1
74	00:12:10	414.7	560	355.2	410.4
75	00:12:20	429.7	556	344.4	407.6
76	00:12:30	441.5	576	336.8	406.6
77	00:12:40	469.5	575	328.6	403.4
78	00:12:50	491.2	575	320.2	401.6
79	00:13:00	511	570	312.8	402.4
80	00:13:10	489.9	566	306.8	401.7
81	00:13:20	509	522	297.7	399.2
82	00:13:30	518	488.9	286.7	393.1
83	00:13:40	538	444.2	270.1	380.6
84	00:13:50	497.3	436.4	262.4	368.7
85	00:14:00	467.4	424.6	256.5	356.8
86	00:14:10	475.4	430.1	253.7	351.3
87	00:14:20	497.2	395.2	235.5	339.7
88	00:14:30	508	369.6	218.3	329.8
89	00:14:40	488.9	360.7	206.7	318.4
90	00:14:50	477.9	350.4	197.3	311.1
91	00:15:00	409.7	347.7	185.3	296.2
92	00:15:10	391.1	340	173.8	285.2
93	00:15:20	377.7	361.7	166.4	271.2
94	00:15:30	357.6	352.1	158.8	260.3
95	00:15:40	357.3	353.2	151.3	250.8
96	00:15:50	342.2	333.4	146.5	242
97	00:16:00	328.9	346.2	144	234.4
98	00:16:10	309.9	336.1	142.6	227.9
99	00:16:20	292.9	319.4	140.2	222.2
100	00:16:30	281.4	309.4	139.2	218
101	00:16:40	261.2	301.9	133.6	210.9
102	00:16:50	243.6	301.1	126.6	201.8
103	00:17:00	215.6	280.2	118.6	193.1
104	00:17:10	202.3	270.6	115.3	189.2
105	00:17:20	194.8	261.7	112.9	181.9
106	00:17:30	187.9	254.4	110.2	175.1
107	00:17:40	182.5	245.8	107.2	167.9
108	00:17:50	171.9	235.9	103.3	161.7
109	00:18:00	171.7	234.3	102.3	157.8
110	00:18:10	168.3	226.4	99.9	153.2

111	00:18:20	169.8	218.3	98.7	149.8
112	00:18:30	169	212	97.4	145.8
113	00:18:40	165.6	208.1	96.2	141.9
114	00:18:50	159.4	208.9	95.4	137.8
115	00:19:00	156.9	201.3	93.3	135.1
116	00:19:10	151.3	192.7	90.6	132
117	00:19:20	141.3	183.2	87.2	127.1
118	00:19:30	139	174.9	86.2	125.1
119	00:19:40	139	172.8	85.5	122.8
120	00:19:50	134.5	163.6	83.1	118.9
121	00:20:00	125.1	153	80.6	114.7
122	00:20:10	116.4	142.7	78.8	110.7
123	00:20:20	108.6	132.9	75.2	106.7

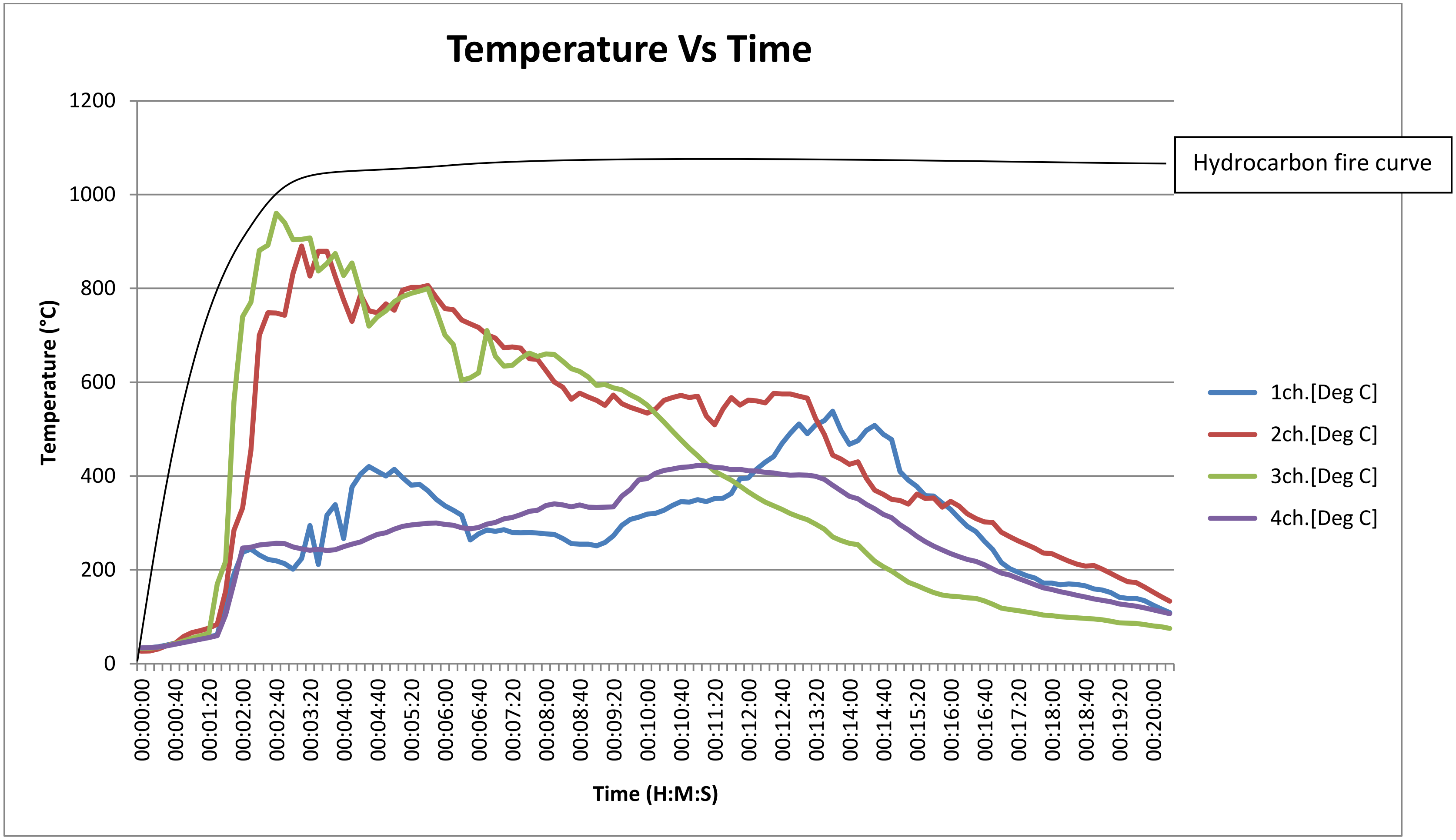


Figure 20. Graph of temperature versus time for third preliminary test

From figure 20, obviously the effect of increasing the volume of kerosene and height from the fire sources had been take place. Sensor 2 and 3 almost reached temperature of 1000°C. However, for sensor 1 and 4, recorded temperature is much lower. This occurence could be explained by the intensity of heat at the middle of the tank as marked in red circle as Figure 21 below.

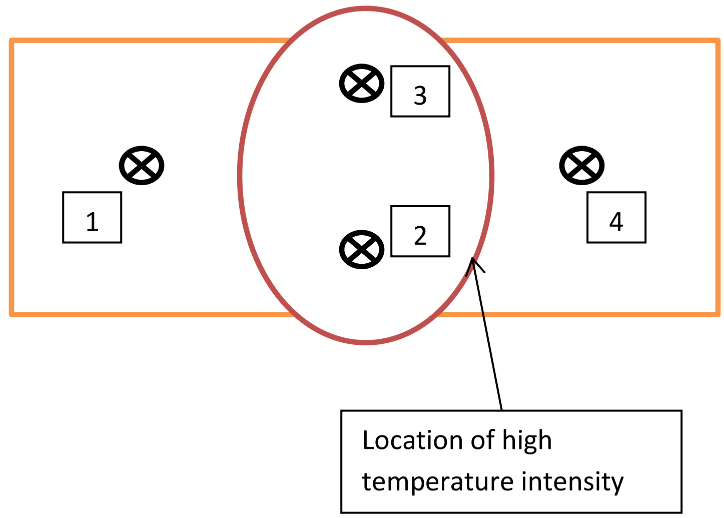


Figure 21. Location of higher heat intensity

Despite almost achieved the required temperature to validate the behaviour of hydrocarbon fire, temperature curve on sensor 2 and 3 dropped rapidly. This occurence could be explained by the volume depletion of the kerosene because in this project, pump had not been used to provide and sustained the volume of kerosene inside the hydrocarbon pool tank. Thus, temperature could not be maintained. In test 4, the author might increase the volume of the kerosene in order to provide excess volume that could generate a steady temperature curve after the fire reached a temperature of approximately 1000°C.

4.1.5 Test 4

Location of heat sensor for fourth test as shown in Figure 22 below:

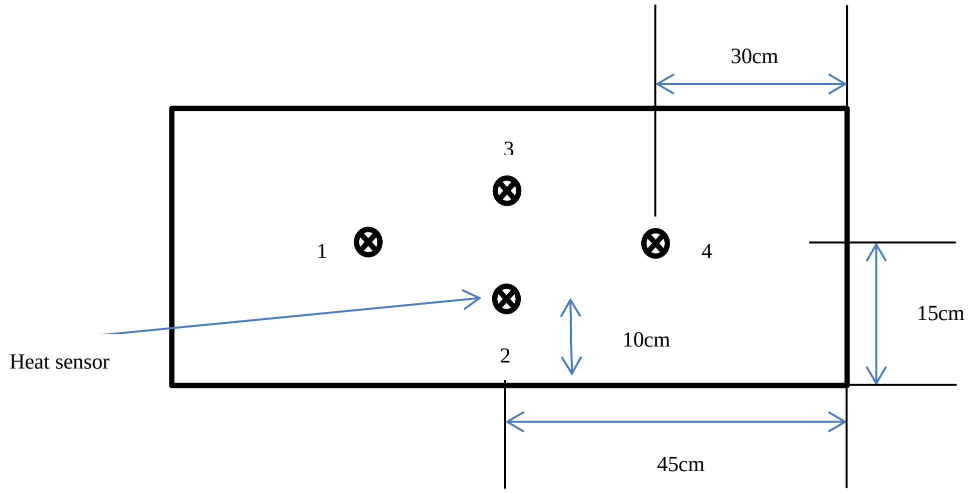


Figure 22. Plan view for the location of sensors in fourth test

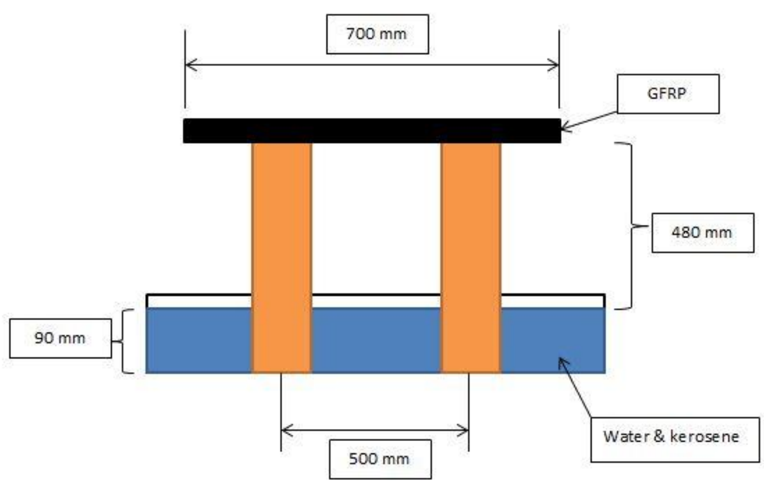


Figure 23. Height of thermocouple sensors from kerosene

Table 11. Volume of water and kerosene used in test 4

Substance	Volume (L)
Water	8.1
Kerosene	16.0

The tabulated result and plotted graph for fourth test shown in in Table 12 and Figure 23 respectively:

Table 12. Tabulated results in fourth preliminary test

Sample No.	H: M: S	Sensor1[°C]	Sensor2[°C]	Sensor3[°C]	Sensor4[°C]
1	00:00:00	63.8	26.4	32.6	183.4
2	00:00:20	109.9	86.9	43.2	231.6
3	00:00:40	147.9	131.3	54.9	297.1
4	00:01:00	209.1	238.6	118.2	366.6
5	00:01:20	254.7	547.2	272.2	452.8
6	00:01:40	314.8	757.7	388.2	511
7	00:02:00	335.3	866	504.2	523
8	00:02:20	347.4	970.2	859.2	554
9	00:02:40	357.8	1075.7	1208.9	585
10	00:03:00	372.4	1100.5	1193.4	600
11	00:03:20	388.6	1083.7	1180.3	603
12	00:03:40	393.7	1076.4	1158.8	619
13	00:04:00	434.7	1085.9	1163.7	627
14	00:04:20	458.2	1056.3	1200.4	641
15	00:04:40	458.4	1073.2	1180.3	650
16	00:05:00	484.6	1092.4	1183.5	653
17	00:05:20	502.5	1035.6	1002.5	665
18	00:05:40	526	1024.3	1010.2	667
19	00:06:00	517	998.4	1150.3	664
20	00:06:20	510	985	1142.7	647
21	00:06:40	494.2	980.2	1130	648
22	00:07:00	477.8	997.9	1127.4	640
23	00:07:20	484	1001.7	1132.5	628
24	00:07:40	495.2	1005.2	1134.6	612
25	00:08:00	497.9	975.5	1140.9	615
26	00:08:20	506	987.9	1128.6	641

27	00:08:40	486.2	990	1120.6	643
28	00:09:00	459.3	981.3	1118.9	635
29	00:09:20	465.2	967.8	1179.4	619
30	00:09:40	475.1	985.1	1000.7	601
31	00:10:00	480.5	992.8	971.7	588
32	00:10:20	483.6	995.6	988.5	563
33	00:10:40	465.4	990.7	989.3	537
34	00:11:00	479.9	952.8	994.2	518
35	00:11:20	453.7	924.6	999.6	490.8
36	00:11:40	442.1	900.3	952.6	461.5
37	00:12:00	442.9	910.2	948.5	500.3
38	00:12:20	433.9	894.3	956.4	550.5
39	00:12:40	435.4	880.5	923.6	389.2
40	00:13:00	445.9	892.7	952.1	370.3
41	00:13:20	439.2	900.1	947.4	349.7
42	00:13:40	441.7	934.2	956	397.3
43	00:14:00	454.4	941.8	912.6	380.8
44	00:14:20	455.8	856.6	899.2	385.6
45	00:14:40	454.4	832.1	870.4	420.6
46	00:15:00	456.8	842.9	888.3	377.7
47	00:15:20	449.1	864.7	870.3	404
48	00:15:40	454.2	880	880.8	401.5
49	00:16:00	437.3	892.4	885.2	398.6
50	00:16:20	432.1	910.2	823.1	340.6
51	00:16:40	429.3	815.4	849.5	338.1
52	00:17:00	407.1	798.2	865.3	334.2
53	00:17:20	378.9	774.5	852.9	338.3
54	00:17:40	356.9	788.9	848	333.8
55	00:18:00	346.4	790.2	832.7	333.2
56	00:18:20	328.5	750.4	829.4	333.4
57	00:18:40	311.3	743.2	825.1	334.2
58	00:19:00	295.1	739.8	800.3	357.3
59	00:19:20	273.9	737.5	789.4	370.7
60	00:19:40	257.8	789.5	790.5	391.4
61	00:20:00	254.9	810.2	794.3	394.7
62	00:20:20	249.8	724.3	795.6	406.2
63	00:20:40	256.1	700.3	785.4	411.7
64	00:21:00	252.7	690.5	783.2	414.7
65	00:21:20	243.9	689.4	780.4	418.6
66	00:21:40	344.2	682.1	779.2	419.4
67	00:22:00	349.3	685.3	760.5	422.7

68	00:22:20	345.7	680.4	752.8	422
69	00:22:40	352.1	681.3	700.4	418.3
70	00:23:00	352.8	682.7	690.3	417.1
71	00:23:20	362.9	679	683.2	413.8
72	00:23:40	345.2	679.5	650.1	414.3
73	00:24:00	346.8	679.3	620.9	411.1
74	00:24:20	414.7	680	600.4	410.4
75	00:24:40	429.7	656.5	590.3	407.6
76	00:25:00	441.5	576	580.6	406.6
77	00:25:20	469.5	575	572.4	403.4
78	00:25:40	491.2	575.3	535.9	401.6
79	00:26:00	511	570	523.7	402.4
80	00:26:20	489.9	566	500.2	401.7
81	00:26:40	509	522	480.5	399.2
82	00:27:00	518	488.9	488.6	393.1
83	00:27:20	538	444.2	478.3	380.6
84	00:27:40	497.3	436.4	450.3	368.7
85	00:28:00	467.4	424.6	428.7	356.8
86	00:28:20	475.4	430.1	417.4	351.3
87	00:28:40	497.2	394.7	400.6	339.7
88	00:29:00	508	369.6	387.6	329.8
89	00:29:20	488.9	359.8	360.5	318.4
90	00:29:40	477.9	352.4	375.2	311.1
91	00:30:00	409.7	347.7	348.6	296.2
92	00:30:20	391.1	340	330	285.2
93	00:30:40	377.7	361.7	302.5	271.2
94	00:31:00	357.6	352.1	295.6	260.3
95	00:31:20	357.3	353.2	278.4	250.8
96	00:31:40	342.2	333.4	250.1	242
97	00:32:00	328.9	346.2	256.7	234.4
98	00:32:20	309.9	336.1	247.3	227.9
99	00:32:40	292.9	319.4	230.2	222.2
100	00:33:00	281.4	309.4	200.9	218
101	00:33:20	261.2	301.9	175.4	210.9
102	00:33:40	243.6	301.1	187.6	201.8
103	00:34:00	215.6	280.2	155.3	193.1
104	00:34:20	202.3	270.6	130.5	189.2
105	00:34:40	194.8	261.7	122.9	181.9
106	00:35:00	187.9	254.4	110.2	175.1
107	00:35:20	182.5	245.8	107.2	167.9
108	00:35:40	171.9	235.9	103.3	161.7

109	00:36:00	171.7	234.3	102.3	157.8
110	00:36:20	168.3	226.4	99.9	153.2
111	00:36:40	169.8	218.3	98.7	149.8
112	00:37:00	169	212	97.4	145.8
113	00:37:20	165.6	208.1	97.2	141.9
114	00:37:40	159.4	208.9	95.4	137.8
115	00:38:00	156.9	201.3	93.3	135.1
116	00:38:20	151.3	192.7	90.6	132
117	00:38:40	141.3	183.2	85.2	127.1
118	00:39:00	139	174.9	86.2	125.1
119	00:39:20	139	172.8	85.5	122.8
120	00:39:40	134.5	163.6	83.1	118.9
121	00:40:00	125.1	153	80.6	114.7
122	00:40:20	116.4	142.7	79.3	110.7
123	00:40:40	108.6	113.6	65.8	106.7

Figure 24 below shows the plotted graph of temperature versus time for fourth preliminary test.

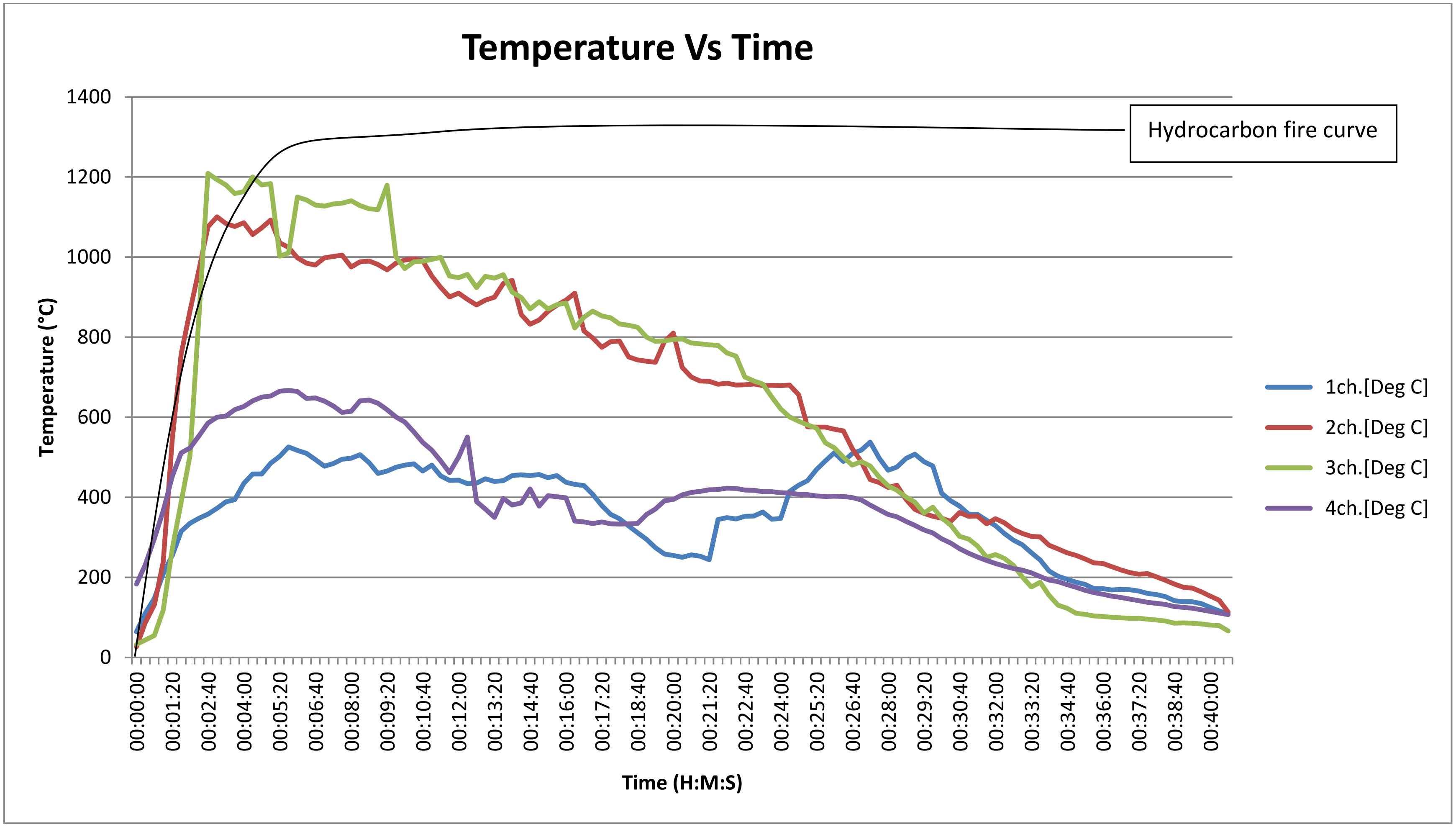


Figure 24. Graph of temperature versus time for fourth preliminary test

Previously, during test 3, the maximum temperature could not be sustained for a longer period of time. It dropped rapidly. However, the effect of additional volume of kerosene in test 4 had changed the trend of the temperature curve. The slope of temperature curve for sensors 2 and 3 are more gentle compared to when it was in test 3. This trend shown that the flame could maintained its temperature for a longer period if there is enough supply of kerosene inside the tank.

From the above graph, similar to figure 20 for third test, there was temperature difference between sensor 2 and 3 with the sensor 1 and 4. This difference as explained before by the author, was caused by the effect of higher heat intensity at the center of the tank that caused sensors 2 and 3 to produce higher temperature compared to sensors 1 and 4.

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

The study of the behaviour of open-hydrocarbon pool fire is matter of paramount of importance especially in oil and gas industries. In the past, there were billion of profit loss caused by oil platform damage due to the hydrocarbon fire breakout. The author believe that lack of knowledge on the behaviour of hydrocarbon pool fire is one of the contributing factor that leads to the structure damage, consequently threaten life of personnel working at the offshore platform.

As the title implies, *Performance of GFRP After Exposure to Open Hydrocarbon Fire: Development of Hydrocarbon Fire*, the super plan of this research is to investigate the performance of Glass Fibre Reinforced Polymer(GFRP) under exposure of hydrocarbon fire. However, due to time constraint, the author thinks that it would be impossible to complete this whole research. Hence, the author had only focused on the study of hydrocarbon fire development in which the result from this extensive research will be used by next researcher who will conduct the study on the performance of GFRP under exposure of open-hydrocarbon fire.

After finished the whole research on the hydrocarbon fire, the outcomes of the result concluded that the best volume of kerosene to be used in the research to get the optimum temperature that matched with hydrocarbon temperature curve would be 16 L as shown in fourth hydrocarbon test. Initially, the author had began the test with 2.7L of kerosene. For 2.7L-kerosene, the temperature could not reached the optimum temperature curve of hydrocarbon fire. Then, in third test, the volume of the kerosene used was increased to 8.1L and the temperature had reached almost up to 1000°C. Despite achieved those temperature that would categorized it under hydrocarbon fire, the author found that the temperature dropped rapidly. By using 16L-volume of kerosene, the temperature still dropped but not as fast as before. Thus, the author suggested that in the next research on GFRP performance under open hydrocarbon fire, the volume of kerosene used should be 16L or more otherwise the experiment will not be valid.

Apart from volume of kerosene, the author had made some changes on the arrangement of the thermocouple sensors. The arrangement of sensors in first hydrocarbon test was different from second, third and fourth test. It should be noticed that the changes on the sensors arrangement did not contribute much towards temperature difference as depicted in Table 13 below.

Table 13. Temperature diffence(%) between first and second hydrocarbon test

Test	T_{max}(°C)	Volume of kerosene(L)	Temperature difference,%
1	667	2.7	2.99
2	687	2.7	

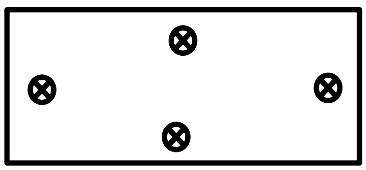
The calculated temperature difference(%) was only 2.99% and thus the author concluded that the change in sensors arrangement did not gave much effect on the temperature increase/decrease.

In third and fourth test, there was some changes in the experimental setup where the author had increased the distance of sensors from flame surface due to the facts that the heat transfer is greater inside continuous flame region where it is located slightly above the flame source (http://www.doctorfire.com/flametmp.html). All results for hydrocarbon tests were summarized in Table 14 below:

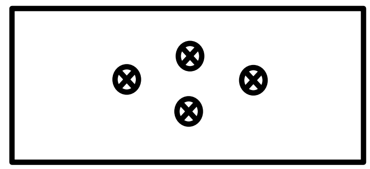
Table 14. Summary of results for first, second, third and fourth tests

Test	Arrangement	Max temperature,T_{max}(°C)	Time at T_{max} (min:sec)	Time completed(min:sec)	Height of sensors from flame(mm)
1	First	667	2:50	6:40	80 mm
2	Second	687	3:30	10:30	80 mm

3	Second	960.3	2:40	20:00	480 mm
4	Second	1208.9	2:40	40:00	480 mm



First Arrangement



Second Arrangement

As recommendation, the author suggested that for later advancement of this research, a pump should be used in order to pump in kerosene inside the hydrocarbon pool tank to maintain and keep the volume of kerosene for a longer period of time. By having a pump, the experiment will be more valid as it imitates real situation that may happen in offshore platform in the event of fire. After all, the author had successfully completed this research with all the research's objectives were achieved.

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