Development of Hydrocarbon Fire Testing for Offshore Application

By

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14863

Dissertation submitted in partial fulfillment of

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
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(Civil)

Approved by,

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(Dr. Ibrisam Akbar)

UNIVERSITI TEKNOLOGI PETRONAS
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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.

(TAN YEE HONG)

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Introduction

1.1 Abstract

The use of glass fibre reinforced polymer (GFRP) in offshore oil and gas platforms has been on a rise in the recent decades mainly due to its advantages such as good strength to weight ratio, corrosive resistance and etc. Issues such as strength, durability as well as serviceability are the main issues as well. In the concern of fire testing qualification requirement set by the US Coast Guard, glass fibre reinforced polymer (GFRP) was tested under cellulosic fire which does not portray the real offshore platforms burning condition (ASTM E-119). It should instead be tested with hydrocarbon fire which simulates a higher spreading rate and a higher temperature compared to that of cellulosic fire. In this paper, the author aims to conduct an experiment to test the strength reduction of glass fibre reinforced polymer (GFRP) gratings under constant hydrocarbon burning of 15 minutes. The experiment is separated into 2 parts, 1 is the simulation of steady hydrocarbon burning of different types of glass fibre reinforced polymer (GFRP) gratings for 15 minutes by using kerosene, and another is the post fire test of the gratings by using three point bending test to evaluate the strength reduction in glass fibre reinforced polymer (GFPR). Based on the experiment done by Khairi Hafizi bin Kamarudin (2014), the previous researcher, he has determined in his experiments that the orientations of heat sensors locations that will result in temperature vs time curve similar and close to that of hydrocarbon curve. The highest temperature recorded was 1208℃ at sensor 3 and the hydrocarbon burning was steady for 9 minutes by using 16 litres of kerosene. To achieve the objective of this paper, which is to simulate steady hydrocarbon burning for 15 minutes for glass fibre reinforced polymer (GFRP), an empirical conversion is performed and the corresponding volume of kerosene needed is found out to be 26.67 L. The reliability of the experiment is solely dependent on the success of simulation of steady hydrocarbon burning for 15 minutes and achieving a temperature vs time curve of which similar to that of hydrocarbon curve.

1. 2 Background of Study

In the recent time, the studies of glass fibre reinforced polymer (GFRP) application in offshore oil and gas industry has become more frequent. The studies carried out have been surrounding the replacement of conventional material for construction, particularly steel in many cases. Generally, the consensus is that glass fibre reinforced polymer (GFRP) has greater advantage over steel in many aspects. Glass fibre reinforced polymer (GFRP) has higher resistance to environmental exposure, in other words, higher resistance to corrosion if compared to steel. If it is applied in large amount over steel, the structural load (dead load) can be reduced greatly as well due to the nature of lower density of glass fibre reinforced polymer (GFRP). Apart from that, glass fibre reinforced polymer (GFRP) also has advantages over steel in term of high specific strength, low electromagnetic signature as well as low heat conductivity.

As of general concern, the offshore oil and gas industry has severe and unpredictable environment. Though there are several edging advantages of glass fibre reinforced polymer (GFRP) over steel as construction material of offshore oil and gas industry structural elements, the issue of strength degradation under hydrocarbon fire remain to be studied. In glass fibre reinforced polymer (GFRP), there are 2 main phases, which are matrix which binds the reinforcement together and the reinforcement, which provide strength to the composite (Bagherpour 2006). Under increased temperature, the matrix has the tendency to volatize and the surrounding fibre will also creep at a faster rate. Till the rate of which the whole matrix undergone pyrolysis, reduced strength of the softened glass fibre reinforced polymer (GFRP) would not be able to take the applied load and thus failure of structure may occur (Boyd et al., 2006). Therefore, it is critically important to investigate the strength reduction of glass fibre reinforced polymer (GFRP) under exposure to hydrocarbon fire for an extended period of time (15 minutes). The simulation of burning the glass fibre reinforced polymer (GFRP) has to comply with the theoretical hydrocarbon curve as well to obtain reliability and accuracy of the report.

1.3 Problem Statement

In term of general load path in a building, applied load is first taken up by slab, then transfer to beams, columns, foundation and soil in sequence. In offshore platform, deck gratings are comparable to the function of slab. They carry and withstand the loads and transfer them to the other structural elements. Hence, deck grating is one of the most important structural elements in offshore platform. By using glass fibre reinforced polymer (GFRP) as the material of offshore platform deck gratings, it is therefore critically important to ensure the strength, durability, and serviceability of the material in the long run, especially in offshore environment that is exposed to harsh environment condition. Structural failures of gratings may cause unwanted accidents and risk of life to the workers on platform.

Therefore, when studies on offshore oil and gas industry are carried out, the performance requirement for glass fibre reinforced polymer (GFRP) has to be reassessed with a standard that illustrates and considers the real condition of offshore industry. This is due to the harsh and highly variable environment of the offshore oil and gas industry. One of the most significant differences is that in offshore oil and gas industry, the source of fire in most cases is hydrocarbon fire instead of cellulosic fire. In term of rate of spread of fire, hydrocarbon fire is much faster than cellulosic fire.

According to *Preliminary Fire Testing of Composite Offshore Pedestrian Grating* in *ASTM E-119*, hydrocarbon fire requires only 5 minutes time of heating to reach the temperature of 927 ℃, whereas for cellulosic fire, the time required to reach the same temperature of 927 ℃ would be 60 minutes. The concern arises when the structural integrity of the platform using glass fibre reinforced polymer (GFRP) and the strength degradation of the material are affected in a much faster rate under hydrocarbon fire compared to cellulosic fire. In short, the durability of the material in term of fire resistance has a direct impact to the strength of the material. The original text is quoted as below:

> 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 standardized time-temperature curve for a cellulosic fire (ASTM E-119). The exposure time is 60 minutes rising to a final temperature of 927 ℃. The temperature data obtained as part of this study demonstrate that this time-temperature 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).

Apart from that, there are different types of glass fibre reinforced polymer (GFRP) if they are to be classified in term of plastic matrix. Plastic matrix functions as binder of the glass fibres in the composite. The type plastic matrix in the composite affects the endurance of glass fibre reinforced polymer (GFRP) under high temperature condition. Some may withstand only a short duration of 1-5 minutes whereas some have longer time before the composite starts to fail.

The types of glass fibre reinforced polymer (GFRP) with different types of plastic matrix available for testing in Universiti Teknologi PETRONAS lab are Polyester, Vinylester and Phenolic. Thus the author has come up with tests that cover these variations of glass fibre reinforced polymer (GFRP). This procedure is to investigate and relate the type of plastic matrix (binder) and its effect to the strength degradation of glass fibre reinforced polymer (GFRP). The proposed condition, which is the key of the experiment, should always be hydrocarbon fire burning over an extended period of time (15 minutes).

1.4 Objectives

The objectives of this project are listed as below:

- To achieve **hydrocarbon fire** burning condition in experiment the **glass fibre reinforced polymer (GFRP) gratings**
- To achieve temperature-time relation which is similar to that of the **theoretical hydrocarbon fire curve**

- To achieve a **constant hydrocarbon fire burning** condition for an **extended period of 15 minutes** (previous experiment extend was 5 minutes)

1.5 Scope of the Project

In the first step of the project, the author will mainly focus on achieving hydrocarbon fire for experimenting purpose. This includes sourcing kerosene in nearby towns and cities. Apart from that, the author also practices the theories proven by the previous researcher on this topic. The practices are important to maintain a highly accurate and reliable testing condition and outcome. Such practice details include the use of kerosene for hydrocarbon burning, best location of thermocouple sensors during combustion for sensing high temperature distribution as well as determining proportionate volume of kerosene for extended burning of 15 minutes. In relation with previous experiment which uses 18 litres of kerosene to obtain a constant hydrocarbon burning, the volume of kerosene proportionally needed for 15 minutes burning would at least be 54 litres. Besides, the author has to ensure the surrounding of the experiment condition to be under control and simulate closely to the real condition at offshore platform site.

1.5.1 The Relevancy of the Project

The rising demand and attention on the use of glass fibre reinforced polymer (GFRP) as material for structural elements such as platform gratings in offshore oil and gas industry requires proven safety before it can be realized. This is especially important due to the high risk and harsh working environment of offshore oil and gas industry. To utilize the benefits of the material such as better weight to strength ratio, natural corrosion resistant, low maintenance requirement and etc., there is an urging need to rectify issues such as strength degradation under hydrocarbon burning as well as durability under hydrocarbon burning. Besides, the fire safety standard and requirement has to be amended solely based on the consideration of hydrocarbon fire burning if glass fibre reinforced polymer (GFRP) is used in offshore oil and gas industry due to the fact that there is no any standard up to date that includes the material application of glass fibre reinforced polymer (GFRP). To attain this, there is a need to investigate the strength degradation rate of glass fibre reinforced polymer (GFRP) under hydrocarbon fire burning over an extended period of time. Thus, the author believes that this project is working towards a beneficial direction for the future of offshore oil and gas industry.

1.5.2 Feasibility of the Project within the Scope and Time Frame

The author began the project by meeting the supervisor of this project, Dr. Ibrisam Akbar in the first week of the semester. The regular meeting and discussion on this project is set to be on Monday morning 9.00 a.m. The author has been gathering materials such as journals, books, online materials, safety standards, hydrocarbon book and newsletter for reading purposes. The reading is done with the aim to understand more about the characteristic of glass fibre reinforced polymer (GFRP) prior to and post hydrocarbon burning. The strength of the material and performance when loaded has to be understood as well. Besides that, the characteristic of hydrocarbon has to be realized so that the real condition of hydrocarbon fire burning can be achieved and be under controlled during experiment. Apart from that, the different types of plastic matrix in glass fibre reinforced polymer (GFRP) are important aspect to project too as these different binders affect the durability and endurance of the composite under hydrocarbon fire burning. For Final Year Project 1 (FYP 1), the author is expected to understand and illustrate all these important aspects that are stated above to ensure the accuracy of the experimenting condition and procedures as well as the reliability the results obtain in the later part, Final Year Project 2 (FYP 2). During Final Year Project 2 (FYP 2), the author mainly focuses on carrying out the experiment accurately, recording the results and analyzes the results obtained. Recommendations and discussions are to be provided based on the results and conclusion of the project has to be drawn as well during this period of time. The conclusion is drawn based on the reliability of the experiment, whether the burning condition of glass fibre reinforced polymer (GFRP) achieved the targeted hydrocarbon burning during the extended burning time of 15 minutes.

Chapter 2

Literature Review

2.1 Advantages of Using Glass Fibre Reinforced Polymer (GFRP)

2.1.1 Corrosion Resistance

Corrosion resistance is one of the most fundamental factors that bring forward the application of glass fibre reinforced polymer (GFRP) in offshore platform gratings. In the recent past decades, this material has emerged as one of the most promising solution to the degradation issue caused by corrosion in structures (Katawaki et al, 1992). The conventional material such as steel reacts easily with oxygen if the environment is moisture. This in scientific term is called electrochemical oxidation of metal. Offshore oil and gas industry, in this context, is a highly conducive environment for electrochemical oxidation of metal to occur due to its highly moisture environment.

Glass fibre reinforced polymer (GFRP) is a material of high resistance towards oxidation and corrosion (Pawel Bernard Potyrala, 2011). Due to this mechanical property, glass fibre reinforced polymer (GFRP) has been used to replace steel reinforcements in structures such as bridges, which are subjected to high moisture environment (Pawel Bernard Potyrala, 2011). Apart from bridges, earthquake-prone areas also use this material as reinforcements due to its corrosion resistance and easy-handling properties. By using glass fibre reinforced polymer (GFRP) in offshore platforms gratings, it increases the service life of the gratings and reduces any structural failure and risk particularly due to the steel corrosion of gratings.

As a matter of fact, there are numerous ways to protect the materials used in offshore oil and gas industry from reacting with the environment and causing corrosion to occur. These methods in particular, using special metal such as stainless steel and special treatment on the surface of material such as coating or waxing, are costing a huge investment and therefore, a cost effective solution for the offshore oil and gas industry in many situations to curb corrosion would be to use composite material such as glass fibre reinforced polymer (GFRP) (Matthew J. Lieser, 2010).

2.1.2 Lightweight

Nowadays, glass fibre reinforced polymer (GFRP) has gradually being considered as 1 of the suitable material as substitute for concrete and steel in construction sector due to its light-weightiness and high specific strength (Martin Alberto Masuelli, 2013).

Glass fibre reinforced polymer (GFRP) gratings are preferred over steel and other metals gratings due to its light-weightiness. Of equivalent size, glass fibre reinforced polymer (GFRP) has approximate reduction in weight of one quarter compared to steel in general. The density of steel is 7800 kg/m^3 whereas the density of glass fibre reinforced polymer (GFRP) stands at 1950 kg/m^3.

The use of glass fibre reinforced polymer (GFRP) has the benefit of reducing the dead load of the platform. This serves as a significant driver to the application of glass fibre reinforced polymer (GFRP) not only on gratings, but also on other parts of offshore platforms. The light-weightiness and in service reliability of glass fibre reinforced polymer (GFRP) are essentially important to enable the platforms to harness important technology and further their development in deep water up to 6000 feet of depth (Professor A.G. Gibson, 2003).

2.1.3 Strength

Glass fibre reinforced polymer (GFRP) in general is a type of composite with high strength to weight ratio which utilizes the glass fibre to enhance the strength and elasticity of polymer or plastic.

In glass fibre reinforced polymer (GFRP), fibre-matrix bonding dictates the mechanical properties of the material. The strength of fibre-matrix bonding is dependent on the angle between fibres. Highest strength of the bonding is attained by orientating all fibres in the corresponding direction of loading (Pawel Bernard Potyrala, 2011).

Though glass fibre reinforced polymer (GFRP) has proven high strength in the direction of the fibre arrangement, the right angle direction of the arrangement of the fibre becomes the weak spot. To solve this problem, the orientations of fibre in the composite are being varied by using woven fibre and the composite would attain good strength in multiple directions due to the spreading directions of fibre (Martin Alberto Masuelli, 2013).

2.1.4 Electromagnetic Neutrality

Due to the natural fact that glass fibre reinforced polymer (GFRP) does not contain metal in its composites, it is a material of electromagnetic neutrality (Pawel Bernard Potyrala, 2011). With this characteristic, it has minimal chance to interfere with the transmission or communication process that's vital in a remote area of offshore platforms.

2.1.5 Low Thermal Conductivity

Glass fibre reinforced polymer (GFRP) is a material with low thermal conductivity (J. Fitzwilliam, 2006). This can be extremely useful when applied as platforms gratings material shut-down due to hot work is not needed during modifications (Jerry G. William, 1999)

2.1.6 Environmental Effect

The application of non-corrosive component of glass fibre reinforced polymer (GFRP) as the basic material for facilities eliminates the use of application of corrosion-prevention-chemical for steel and this itself is a contribution to the environment (Jerry G. William, 1999).

2.1.7 Lower Costing

As a matter of fact, study across all industries has shown that China cost of corrosion is estimated to be $61 billion during 2001 and the recent cost of corrosion in the worldwide is expected to be $1.8 trillion in total (Matthew J. Lieser, 2010). The cost of corrosion here is referring to repair and replacement of corroded parts. Undoubtedly, this high amount of cost is needed to be reduced. In this particular case, the aim is to reduce the cost incurred in platform maintenance.

In offshore oil and gas environment, metallic materials are easily prone to corrosion. Several methods were mentioned before such as coating, waxing, using stainless steel to prevent corrosion but these methods are considered costly methods (Matthew J. Lieser, 2010). Corrosion management practice such as using glass fibre reinforced polymer (GFRP) as new material could help save the cost of corrosion (Matthew J. Lieser, 2010).

In conjunction with the costing issue, another study of application of glass fibre reinforced polymer (GFRP) in piping system of offshore oil and gas industry can be applied. There is a comparison study of costing for the same piping system using different materials. Of all materials such as carbon steel, glass fibre reinforced polymer (GFRP), stainless steel and copper nickel, glass fibre reinforced polymer (GFRP) and carbon steel has the relatively lowest cost for the piping system installation. (Jerry G. William, 1999) This is due to the easy handling of glass fibre reinforced polymer (GFRP), 40% reduction of time in installing the joints as well as lower labor cost and lower labor skill requirement (Jerry G. William, 1999). Apart from that, the cost of applying corrosion inhibitors as protective layers for steel can be omitted when using glass fibre reinforced polymer (GFRP) as grating materials (Jerry G. William, 1999).

Material	**Relative Cost**
Carbon Steel	1.0
Fibre Reinforced Polymer (FRP)	1.0
316 Stainless Steel	2.2
Copper Nickel (CuNi)	3.5

Norway, Offshore Installed Pipe Cost Comparison

<u>2.2 Case Study -Small Unmanned Platforms</u>

Unmanned platforms are platforms that are meant to operate remotely without the assistant of personnel at on it. In other words, there are no personnel on the platform for constant inspection of the facilities.

The applications of these small unmanned platforms are more frequently being applied recently to develop on small oil reservoirs that do not justify the investment of huge platforms. (Jerry G. William, 1999) One of the important characteristic that unmanned platforms should have is that the facilities and accommodation required minimal maintenance cycle. (Jerry G. William, 1999) This is due to the fact that there is no person on the platform to constantly inspect on the facilities and operations.

One of the significant examples is the Davy and Bessemer platform owned by the Amoco Exploration Corporation in the southern of North Sea. On that platform, the vastly varied topside facilities are applying fibre reinforced polymer (FRP) as their material (Jerry G. William, 1999) Such facilities include office, equipment room, tool room, handrails, ladders on topsides and on columns, gratings, fuel loading arm, drain pipe, caissons, diesel tank, lube tank and water utility tanks. As of most significant among all these, the material applied for the gratings on this platform is phenolic resin of glass fibre reinforced polymer (GFRP) (Jerry G. William, 1999).

All these application of fiber reinforced polymer including glass fibre reinforced polymer (GFRP) is mainly to achieve lighter weight and better corrosion resistance, at the same time, complying with the fire resistance standard (Jerry G. William, 1999).

2.3 Types of Glass Fibre Reinforced Polymer (GFRP)

2.3.1 Vinyl Ester

Vinyl ester is the principle combination of the both epoxy resin and polyester resin in term of chemical composition. It is however more similar chemically to epoxy resin.

Vinyl ester in a way has specific advantages over other glass fibre reinforced polymer (GFRP) and has high preference of use in specified industries. In general, vinyl ester has great chemical resistance, great water resistance, retention properties of strength as well as stiffness at high temperature.

Vinyl ester, having higher chemical resistance and higher water resistance when comparing with polyester, is much preferred as material application for pipelines requirement and chemical storage tanks. These properties of vinyl ester allow it to be specifically or preferably applied over other resins in pipelines and tanks applications in all fields, including offshore oil and gas industry.

Besides that, vinyl ester has also relatively lower shrinkage compared to polyester. In other words, vinyl ester resin shrinks less volumetrically in the long run, in comparison with polyester which shrinks significantly.

On the contrary, the cost of acquiring vinyl ester is doubled if compared to the cost of using polyester due to the higher design specification and performance of vinyl ester. If comparing to epoxy resin, however, vinyl ester resin is still cheaper in price.

2.3.2 Polyester

Polyester is one of the most typical type of glass fibre reinforced polymer (GFRP) used in all the industries. This is very much due to its lower cost attractiveness compared to other types of higher specification of glass fibre reinforced polymer (GFRP) such as epoxy and vinyl ester.

Apart from the positive impact on costing, polyester also possesses UV radiation resistance property that is absence in other type of glass fibre reinforced polymer (GFRP). This makes it less susceptible under sunlight effect and much more preferred as material of use for components that are exposed to sunlight.

In addition to that, polyester is also suitable in accepting various types of fillers. This ability makes polyester highly applicable in different types of projects.

As of the disadvantages, polyester is not as strong in term of mechanical properties if compared with vinyl ester and epoxy. Another setback is that polyester has a significantly high shrinkage in term of volume during the curing process. With these setbacks, however, polyester is still widely used in industries or components that concern majorly in costing but does not require high mechanical properties.

2.3.3 Phenolic Resin

Phenolic resin is a hard and highly heat resistant material formed from a reaction of aldehyde and a carbon-based alcohol.

One of the key advantages of phenolic resin is its ability to withstand mechanical load under high temperature. Under such condition, its deformation and creep are minimally affected compared to other types of glass fibre reinforced polymer (GFRP).

Moreover, phenolic resin is a highly chemical resistant material. In many cases, phenolic resin is able to shield the inner substrate from acids, corrosive chemical as well as harsh environment better than other types of glass fibre reinforced polymer (GFRP).

Apart from that, phenolic resin when burnt, has the production of smoke at relatively low level. Besides, the smoke produced is also relatively less toxic compare to the burning of other resins.

These advantages of phenolic resin allow the industries to make use of it for material in construction due to its minimal effect on structural integrity under burning condition. In addition, it is also used as protective layer in tanks to prevent attacks from chemicals on the inner layer materials. Relatively low toxic and low production of smoke gives it an edge as material preference in industries that require safety measure in relation to fire, smoke and toxic such as transportation and construction field.

2.4 Fire Concern of Glass Fibre Reinforced Polymer (GFRP)

In composite material application, fire property is the general concern especially with the application in construction field, buildings and other important sectors. Typically, these public sectors require great fire resistance.

As the matter of fact, glass fibre reinforced polymer (GFRP) is an organic material. Organic material in layman’s term means that it is composed of hydrogen, oxygen and carbon atoms in basic. Similar to other organic compound, glass fibre reinforced polymer (GFRP) is easily combustible.

This easily combustible property of organic compound of glass fibre reinforced polymer (GFRP) can be improved and modified by mixing them with fillers or addictive. Another plausible method would be to the change its composite structure. Under all these methods, the behavior of glass fibre reinforced polymer (GFRP) could be modified in a constructive manner in which it has reduced hazard under fire burning condition.

Fire condition, inevitably has become an alarming issue for glass fibre reinforced polymer (GFRP) due to its organic properties of being easily combustible. Due to this reason, there is also a need to classify and study different properties of fire, of which they have different temperature increment rate, different source of ignition, presence of fuel as well as different rate of spread of fire.

2.5 Types of Fire

2.5.1 Cellulosic Fire

Cellulosic fire is a type of fire that ignites with the source of cellulosic product. Cellulosic fire after experimented, shows that it reaches 900 ℃ in 60 minutes. Cellulosic fire in real condition is not a realistic assumption to be used as fire standards for offshore. (Burrell G. Jagger, 2012) The relationship of temperature in degree Celsius versus time in minutes for cellulosic curve is given in the formula below:

$$Temp.(°C) = 20 + 345 \times log_{10}(8t + 1)$$

2.5.2 Hydrocarbon Fire

Hydrocarbon fire, by all means, is the standard for fire ratings for offshore environment. In most of the cases, the offshore incidents that involve fire are most likely to be the cause of hydrocarbon fire instead of cellulosic fire. Under experimenting, hydrocarbon fire can reach a temperature of 900 ℃ in 5 minutes. Polyester gratings, would fail in 1.5 minutes and 5.5 minutes base on the different condition, 1 of which is loaded whereas the another one is unloaded. (Burrell G. Jagger, 2012) The relationship of temperature in degree Celsius versus time in minutes for hydrocarbon curve is given in the formula below:

$$Temp.(°C) = 20 + 1080 \times (1 - 0.325e^{-0.167t} - 0.675e^{-2.5t})$$

2.5.3 Simulation of Hydrocarbon Fire by Using Kerosene over Crude Oil

According to the experiment preparation of hydrocarbon pool fire prepared by Takaaki Yamaguchi and Kenji Wakasa, the source of fire was chosen to be kerosene rather than crude oil. Crude oil, having wide boiling point could induce changes in fluid composition. This happens due to evaporation occurring during combustion. Under such circumstances, there could hardly be constant combustion during the experiment. Apart from that, the layer thickness of source of fire, in this case the kerosene, has to be thicker in order to achieve prolong and steady state of hydrocarbon burning.

2.5.4 Simulation of 15 Minutes Constant Hydrocarbon Burning

According to experiments done by Khairi Hafizi bin Kamarudin (2014), the previous researcher, it is determined empirically that the volume of kerosene needed for 15 minutes constant hydrocarbon burning is 26.67 litres. In experiment 4 conducted by Khairi Hafizi bin Kamarudin (2014), he used 16 litres of kerosene to achieve 9 minutes of constant hydrocarbon burning with a maximum recorded temperature of 1208℃ at sensor 3. Below are the empirical conversion for kerosene volume needed for 15 minutes hydrocarbon burning and orientations of sensors tested by Khairi Hafizi bin Kamarudin (2014):

16L of kerosene : 9 minutes constant burning

X L of kerosene : 15 minutes constant burning

$$X = \frac{15}{9} \text{ x } 16 = 26.67 \text{ L}$$

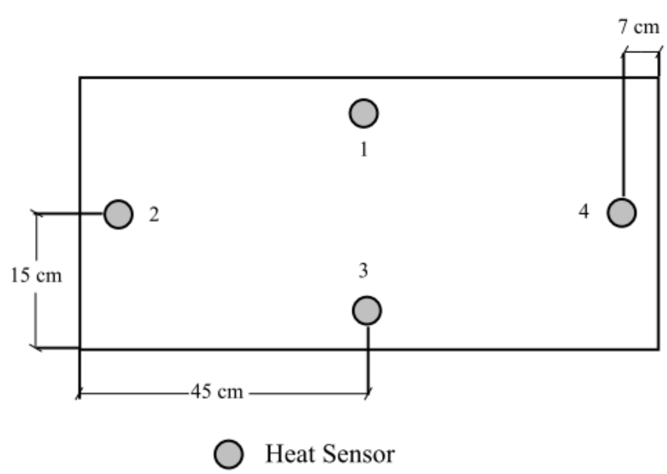


Figure 1: Heat Sensors Orientation 1

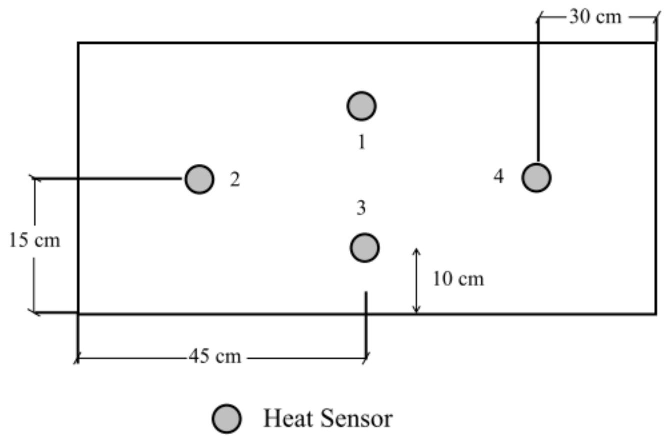


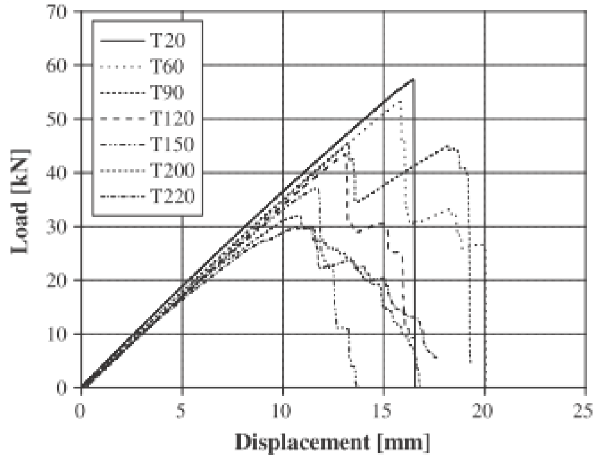
Figure 2: Heat Sensors Orientation 2

Based on Khairi Hafizi bin Kamarudin research (2014), experiment 4 with application of heat sensors locations of orientation 2 as shown above achieve a closer similarity of temperature vs time curve with the hydrocarbon curve. Orientation 1 has about the same pattern, however, achieve lower temperature as opposed to orientation 2.

2.6 The Effect of Fire on Glass Fibre Reinforced Fibre (GFRP)

2.6.1 Tensile Strength

At higher temperature, it is expected that the tensile strength of glass fibre reinforced polymer (GFRP) will be reducing progressively. According to J.R. Correia (2012), under burning up to 220 ℃, the reduction in tensile strength of glass fibre reinforced polymer (GFRP) represented by load vs displacement graph is still in linear relationship. The failure modes of the specimens up 150℃ and 220℃ equal or above are clearly seen as delamination and tensile rupture of fibre. The visual difference of both cases, however, is that the later (220℃ equal or above) has its failure mode affected by resin softening and decomposition. This sign is minimally found in the specimen of burning up to 150℃. (J.R. Correia, 2012) Besides, it is also observed that the failure happens mostly at the heated region for tensile test of glass fibre reinforced polymer (GFRP) under elevated temperature. Below is the graphical illustration of the results obtained by J.R. Correia in his research:

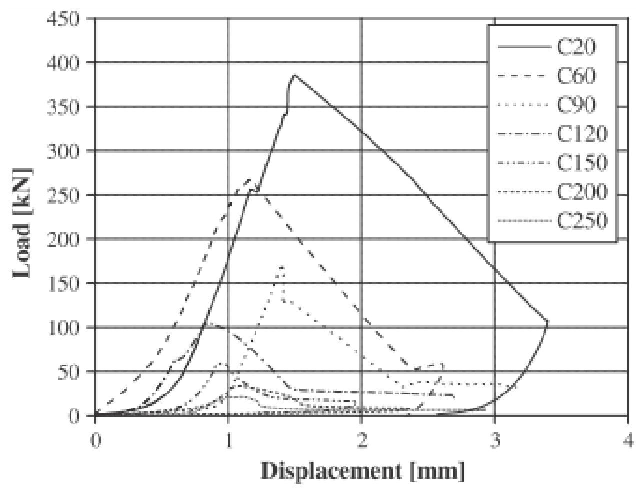


2.6.2 Compressive Strength

The compressive strength of glass fibre reinforced polymer (GFRP) is greatly affected by the effect of burning and elevated temperature. The compressive strength reduction under certain temperature degrees in comparison with the compressive strength under normal temperature are tabulated as below:

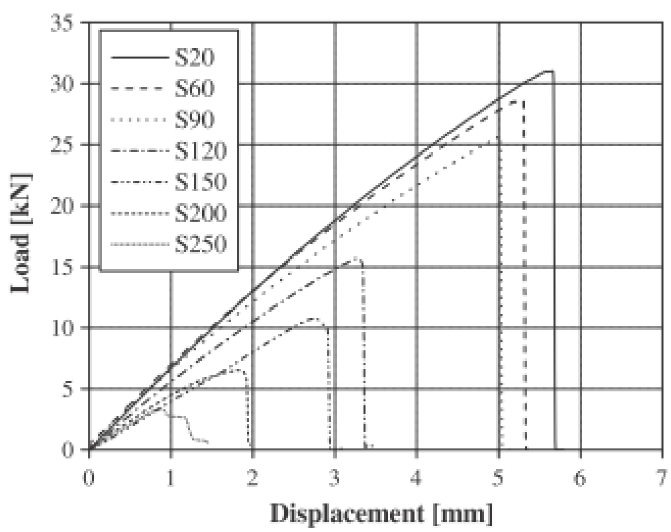
Temperature (℃)	Compressive Strength Reduction (%)
60	> 30
90	50
250	95

At higher temperature, the failure in compressive test of glass fibre reinforced polymer seems to be more focused at the middle section of the whole height. This can be linked with the resin softening induced by glass transitioning process. (J.R. Correia) Apart from that, the graphical illustration below which is the plot of relationship of compressive loading on glass fibre reinforced polymer (GFRP) vs the displacement also suggest the progressive reduction in stiffness of the glass fibre reinforced polymer (GFRP) member as the temperature is increased gradually.



2.6.3 Shear Strength

Shear strength is reduced throughout the gradual increase of temperature, in which there is a significant drop between temperature of 90℃ and 150℃ and this can be observed from the graphical illustration below. (J.R. Correia)



Under this interval, the resin is undergoing glass transition state. At elevated temperature up to 250℃, the shear test signifies a shear strength of 11% remained compared to the shear strength of glass fibre reinforced polymer under normal temperature. According to J.R. Correia, the shear failure often occurs at 10 degree off axis and is parallel to the rovings direction.

Chapter 3

Methodology

3.1 Preliminary Test

The author had started the research within several preliminary tests on the fire behavior. This preliminary tests are 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 through the project.

3.1.1 Conformance of Hydrocarbon Fire Behavior

This research was conducted to study and evaluate the performance of glass fibre reinforced polymer (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 using thermocouple attached to AM-800K Anritsu Datalogger. As the result of the test, the time-temperature curve getting from this test on fire should follow the behavior of hydrocarbon curve.

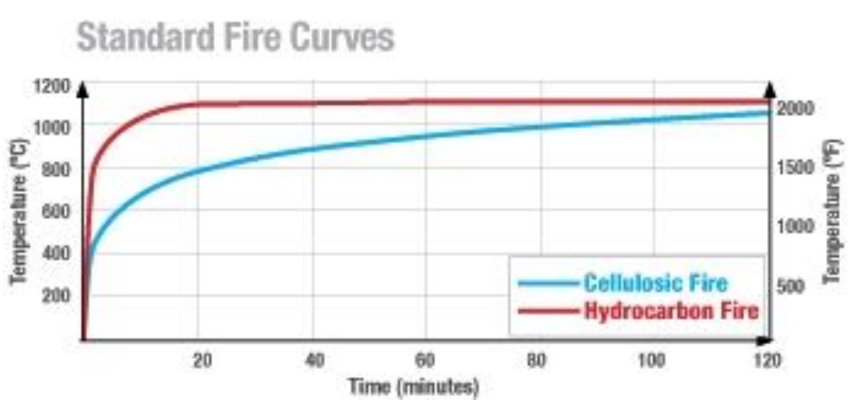
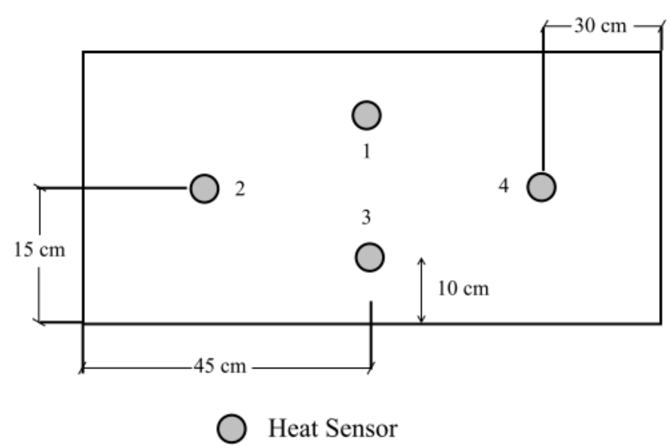


Figure 3: Hydrocarbon Fire Curve and Cellulosic Fire Curve

3.1.2 Steps in Using Thermocouple and Datalogger

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



Orientation of Heat Sensors Locations (Same as Figure 2)

Figure 4: Thermocouple sensor

Figure 5: AM-800K Anritsu Datalogger

Figure 6: Hydrocarbon pool tank

Thermocouple sensor AM-800K Anritsu Datalogger Hydrocarbon pool tank

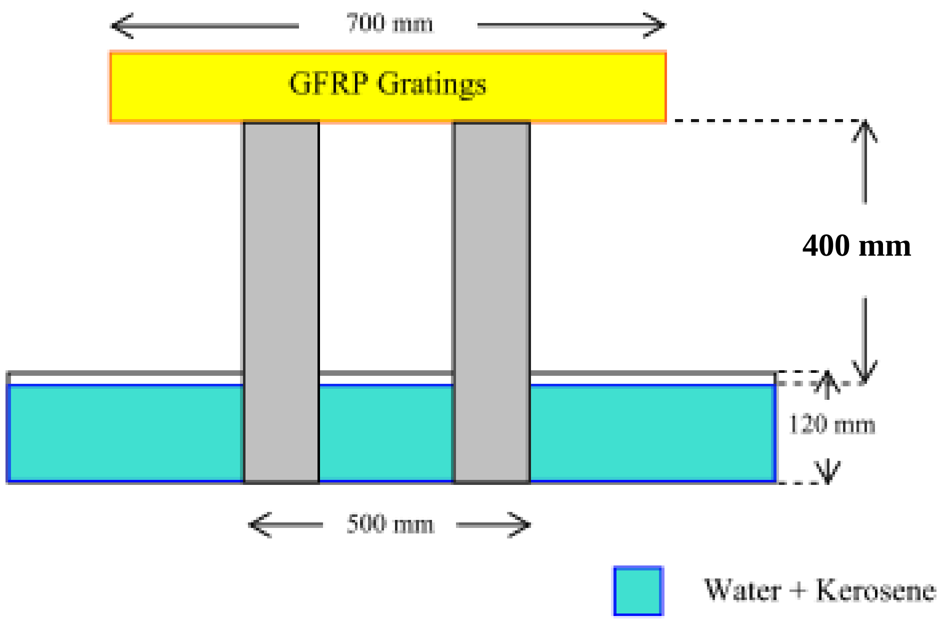


Figure 7: Setup of Experiment

3.1.3 Ultimate Fire-Resistivity Strength of Glass Fibre Reinforced Polymer (GFRP)

This test is conducted to measure time taken for each type of glass fibre reinforced polymer (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 glass fibre reinforced polymer (GFRP). For instance, after the test is conducted, the author found out that the time taken for polyester GFRP to fail is 6 minutes. Since the availability 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 as below:

Sample	Time of Exposure (min)	Strength Reduction (MPa)
1	1.5	?
2	2.0	?
3	2.5	?
4	3.0	?
5	3.5	?

Table 1: Increment time for each fire testing on Polyester GFRP (example)

3.2 Initial Strength Test of Glass Fibre Reinforced Polymer (GFRP)

The initial maximum strength of glass fibre reinforced polymer (GFRP) gratings 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 exposed to the hydrocarbon pool fire, the gratings will be let to cool down for several minutes before it is taken to be tested in post-fire test.

3.4 Post-Fire Test

The gratings samples that are 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 starts to crack or break, the load increment will be stopped and recorded.

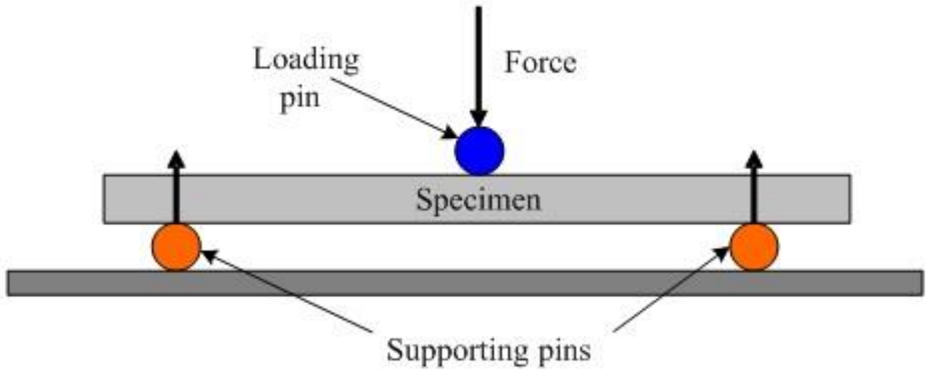


Figure 8: 3-Point Bending Test

3.5 Evaluation of Strength Reduction

The percentage strength reduction of glass fibre reinforced polymer (GFRP) grating can be calculated by using this formula:

Percentage of Strength Reduction (%) = (B-A) / (B X 1000)

Where:

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

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

The results obtained will be used to plot a graph of Strength Reduction (%) vs. Period of Fire Exposure (min) to obtain the graphical relationship between them.

Chapter 4

Key Milestone and Gantt Chart

4.1 Key Milestone

4.1.1 Calculating the Kerosene Volume Needed for Extended Hydrocarbon Burning for 15 minutes

The kerosene volume needed for extended burning of 5 minutes is calculated to be 26.67 litres by using empirical conversion by ratio with the input of information from previous researcher that the volume of kerosene needed for 9 minutes burning is 16 litres.

4.1.2 Sourcing of Cheapest Source of Keronsene in Pusing

The kerosene sourced by the previous researcher was RM 3.00 per litre. The author is currently sourcing for cheaper source of kerosene in the vicinity. Any cheaper source found could mean lower cost of experiment.

4.1.3 Conducting the Control Experiment to Confirm the Functioning of All Equipment

A control experiment to simulate the hydrocarbon burning and detect by using the experiment setup as shown in the Methodology Section is important to confirm the functioning of all equipment. This is to prevent wastage of kerosene used for burning if the equipment were to be found malfunctioning post experiment. Glass fibre reinforced polymer (GFRP) gratings are not being used in control experiment.

4.1.4 Simulating Hydrocarbon Burning During the Control Experiment

This simulation of hydrocarbon burning during control experiment is very important as a data input to the author that kerosene and the experiment setup used could be able to simulate hydrocarbon burning during the real test. This is of course o prevent wastage and to save up unnecessary use of time for conducting multiple times of experiment. The temperature vs time curve produced has to be similar to that of hydrocarbon curve.

4.2 Gantt Chart

PROJECT FLOW/ TASK	WEEK (Final Year Project I)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	22-Sep		**6-Oct**		**20-Oct**		**3-Nov**		**17-Nov**		**1-Dec**		**15-Dec**	
	5-Oct		**19-Oct**		**2-Nov**		**16-Nov**		**30-Nov**		**14-Dec**		**26-Dec**	
FYP Topic Selection i. Select and secure FYP topic with respective supervisor														
PROJECT INTRODUCTION i. Discussion withsupervisor on project description. ii. Literature Review of Cool Roof.														
EXTENDED PROPOSAL i. Preparation of extended proposal. ii. Submission of extended proposal.														
PROPOSAL DEFENSE i. Introduction to the lab for experiment conducting ii. Preparation of proposal defense iii. Proposal defense evaluation														
PROJECT PROGRESS i. Familiarize with the experiment ii. Visit to Pusing for material source and start experiment														
DRAFT REPORT i. Preparation of draft report ii. Submission of draft report														
FINAL REPORT i. Preparation of final report ii. Submission of final report														
END OF FYP I														

PROJECT FLOW/ TASK	WEEK (Final Year Project II)													
PROJECT FLOW/ TASK	1	2	3	4	5	6	7	8	9	10	11	12	13	14
PROJECT FLOW/ TASK	**12-Jan**		**26-Jan**		**9-Feb**		**23-Feb**		**9-Mar**		**6-Apr**		**20-Apr**	
PROJECT FLOW/ TASK	**25-Jan**		**8-Feb**		**22-Feb**		**8-Mar**		**5-Apr**		**19-Apr**		**1-May**	
Planning														
i. Discussion on preparation activities														
Equipment Assembling														
i. Inquiring equipment														
ii. Contacting personnel														
Material Sourcing														
i. Asking for the prices of kerosene per litre														
ii. Determining the lowest and nearest														
Control Experiment														
i. Conduct control experiment														
ii. Modification of setup														
Real Experiment														
i. Conduct real experiments														
Draft Report														
i. Preparation of draft report														
ii. Submission of draft report														
Final Report														
i. Preparation of final report														
ii. Submission of final report														
END OF FYP II														

Chapter 5

RESULTS & DISCUSSION

5.1 Control Experiment on Hydrocarbon Fire

All the Glass Fibre Reinforced Polymer (GFRP) gratings will not be tested before it is ensured that the fire produced is hydrocarbon-type of fire. This is to simulate the real condition of fire during extended burning. Apart from that, control experiments are done also to make sure the workability of all the equipment such as data logger and temperature sensors. These series of testing are divided into 2 parts, first part is the control experiment that measure the temperature-time curve to make sure that the hydrocarbon fire could be produced. As mentioned, the first part is also meant for testing the workability of the equipment. The second part is to conduct the real extended burning for 15 minutes with the known setup to simulate hydrocarbon fire.

In the first part, 2 control experiments by using different setup were conducted and the temperature-time curve produced varied.

5.1.1 Control Experiment 1 vs Control Experiment 2

The first setup is having the thermocouples set at 60 mm elevation from the top surface of the hydrocarbon tank. Whereas the second setup is having the thermocouples set at 460 mm above top surface of the hydrocarbon tank. The 2 curves produced varied greatly.

Table 2. Varying Elevation of Thermocouple from Top Surface of Hydrocarbon Tank

Control Experiment	Elevation from top surface of tank (mm)
1	60
2	460

5.1.2 Control Experiment 1

Location of heat sensors shown in Figure 9:

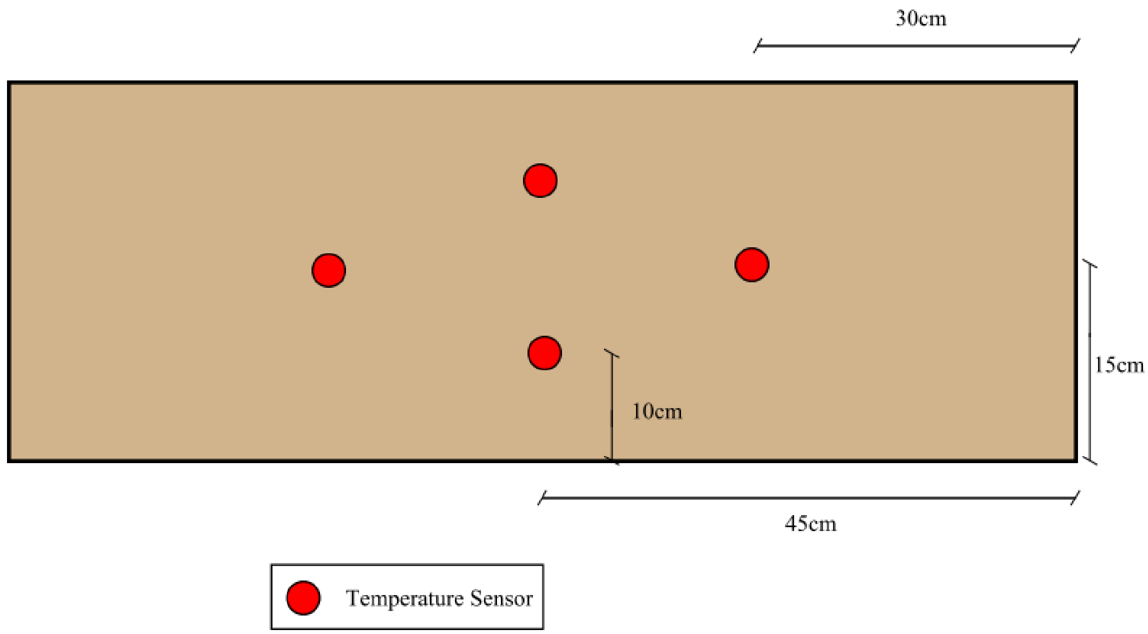


Figure 9. Plan View for the Location of Sensors

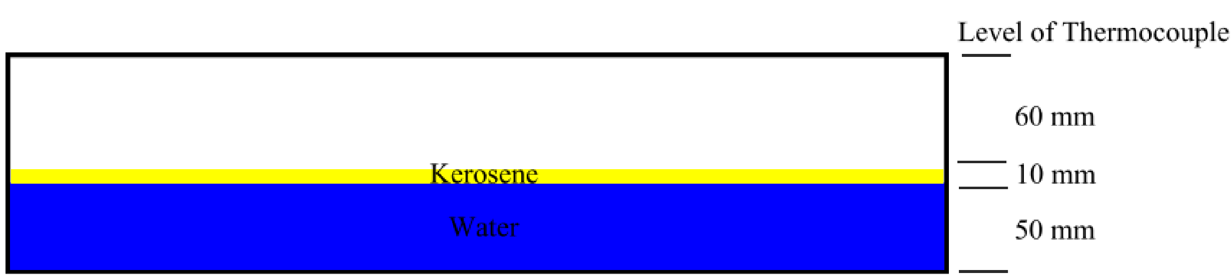


Figure 10. Height of Water & Kerosene in Hydrocarbon Pool Tank

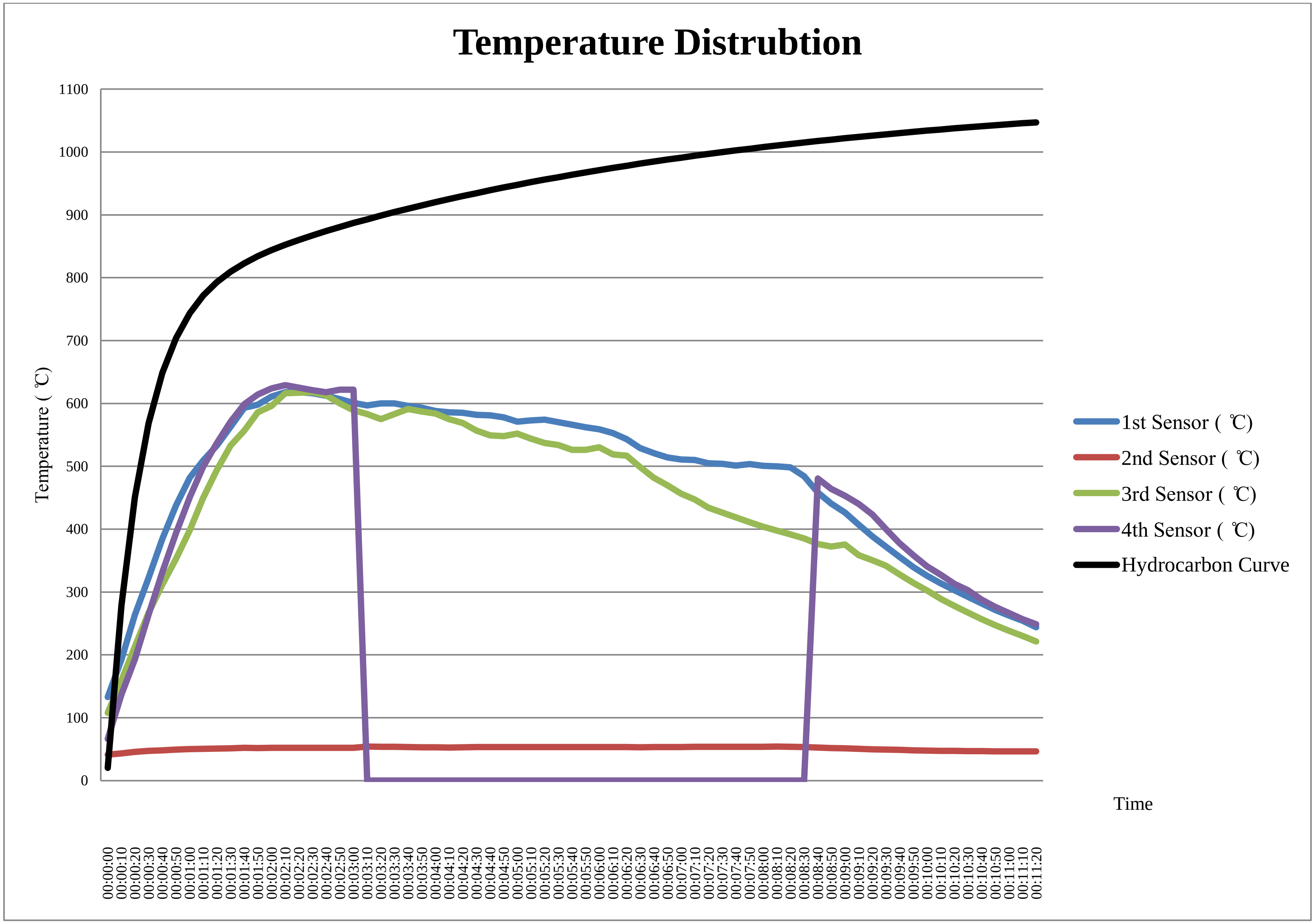
Table 3. Volume of Water and Kerosene used in Control Experiment 1:

Substance	Volume (L)
Water	8.1
Kerosene	2.7

Figure 11. Control Experiment 1

Table 4 shows tabulated results of temperature distribution for 4 thermocouple sensors:

Table 4. Tabulated Results in Control Experiment 1 (Refer to Appendices)


Temperature Distrubtion
Temperature (℃)
1100
1000
900
800
700
600
500
400
300
200
100
0
1st Sensor (℃)
2nd Sensor (℃)
3rd Sensor (℃)
4th Sensor (℃)
Hydrocarbon Curve
Time

5.1.3 Control Experiment 2

Location of heat sensors shown in Figure 12:

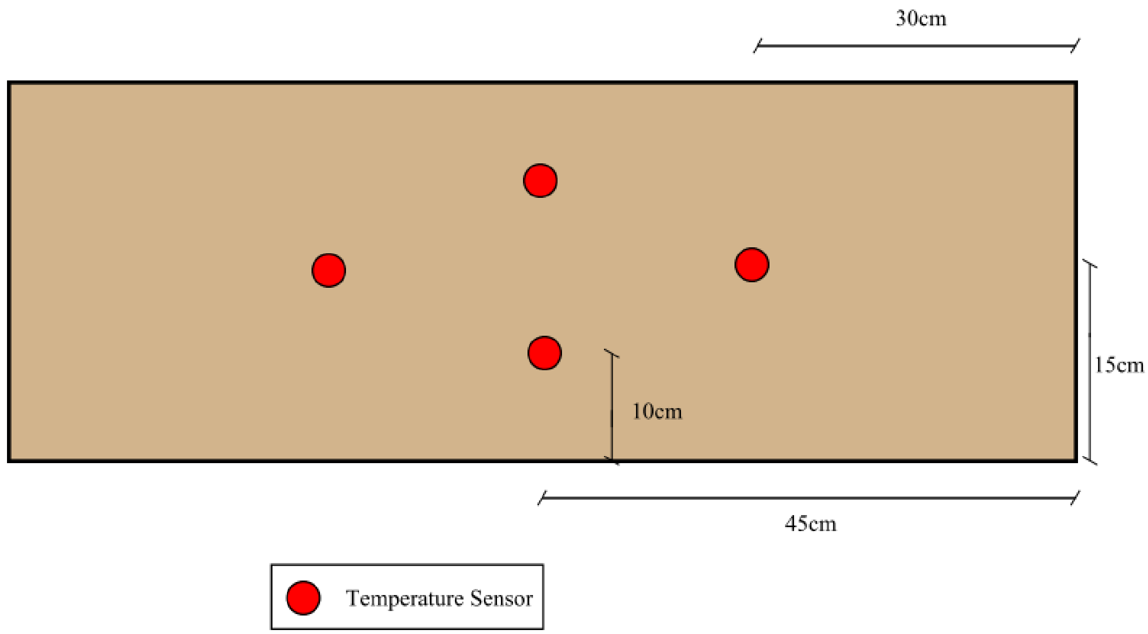


Figure 12. Plan View for the Location of Sensors

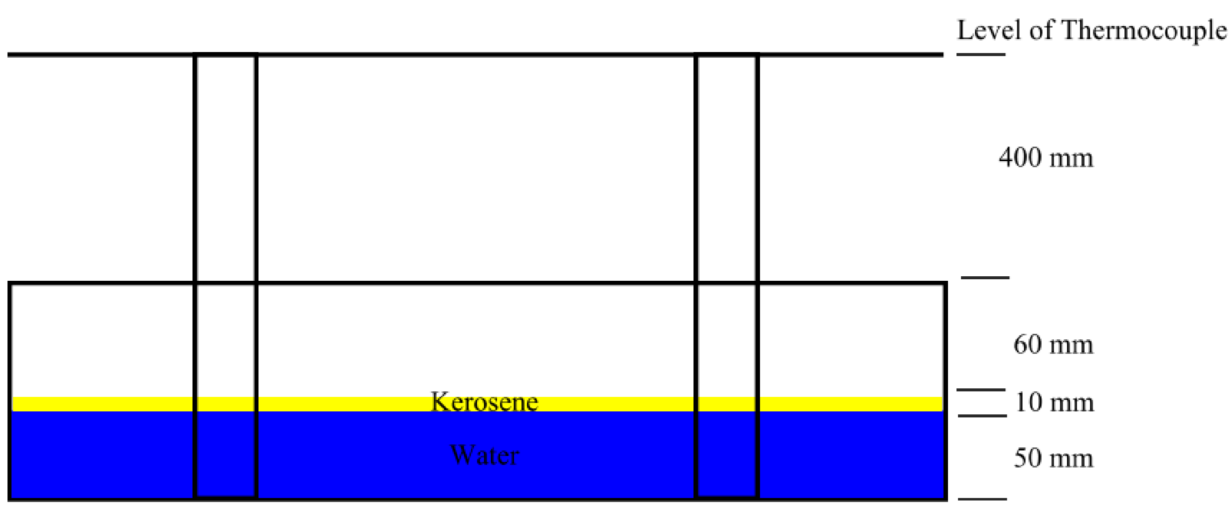


Figure 13. Height of Water & Kerosene in Hydrocarbon Pool Tank

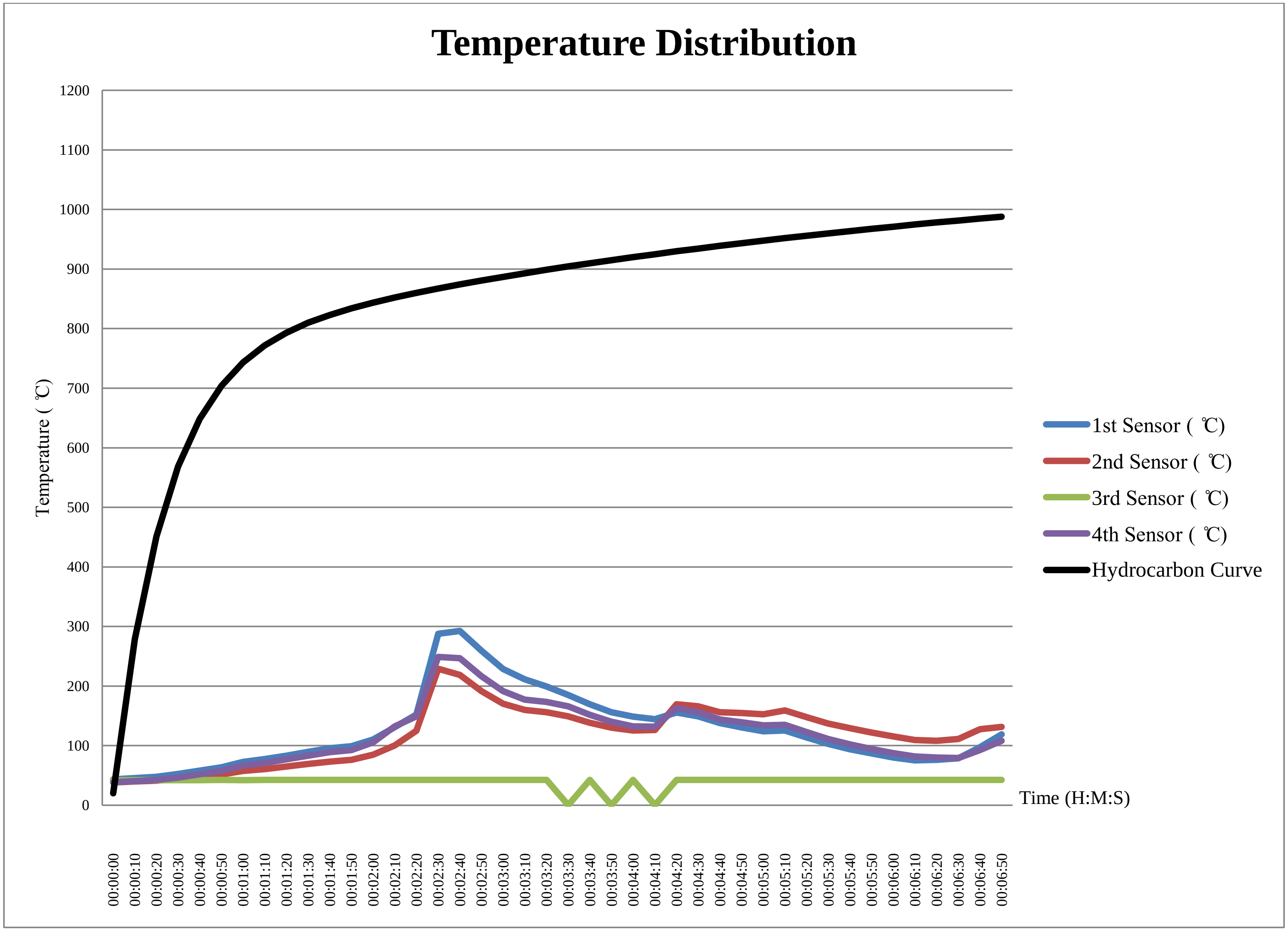
Table 5. Volume of Water and Kerosene used in Control Experiment 2:

Substance	**Volume (L)**
Water	8.1
Kerosene	2.7

Figure 14. Control Experiment 2

Table 6 shows tabulated results of temperature distribution for 4 thermocouple sensors:

Table 6. Tabulated Results in Control Experiment 2 (Refer to Appendices)



Temperature Distribution
Temperature (℃)
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Time (H:M:S)
00:00:00
00:00:10
00:00:20
00:00:30
00:00:40
00:00:50
00:01:00
00:01:10
00:01:20
00:01:30
00:01:40
00:01:50
00:02:00
00:02:10
00:02:20
00:02:30
00:02:40
00:02:50
00:03:00
00:03:10
00:03:20
00:03:30
00:03:40
00:03:50
00:04:00
00:04:10
00:04:20
00:04:30
00:04:40
00:04:50
00:05:00
00:05:10
00:05:20
00:05:30
00:05:40
00:05:50
00:06:00
00:06:10
00:06:20
00:06:30
00:06:40
00:06:50
1st Sensor (℃)
2nd Sensor (℃)
3rd Sensor (℃)
4th Sensor (℃)
Hydrocarbon Curve

5.1.4 Control Experiment 3

Location of heat sensors shown in Figure 15:

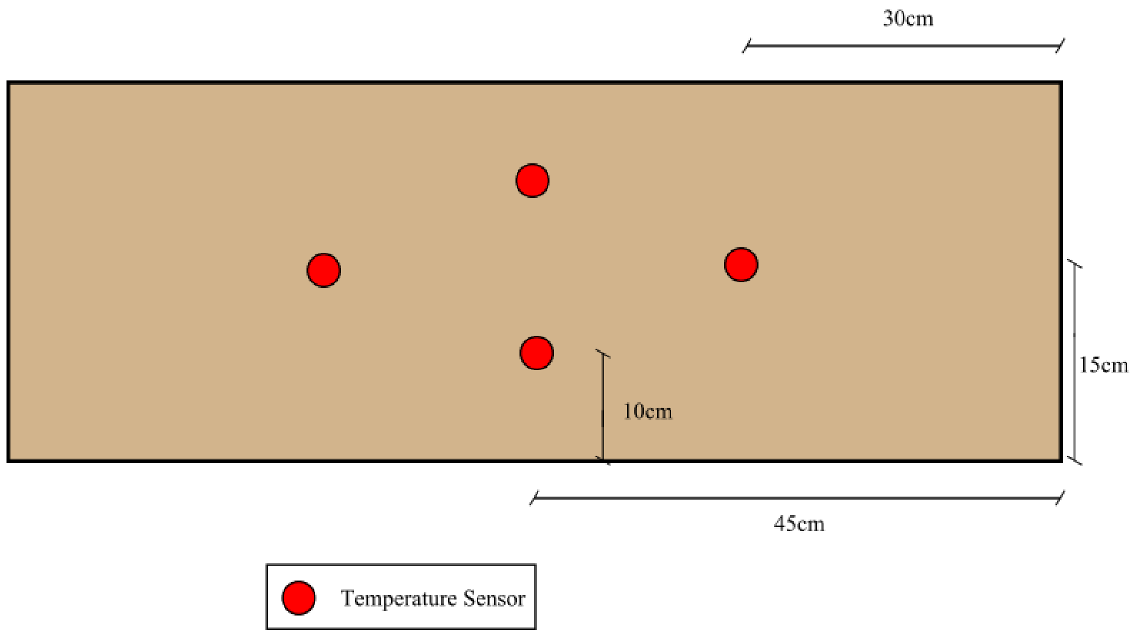


Figure 15. Plan View for the Location of Sensors

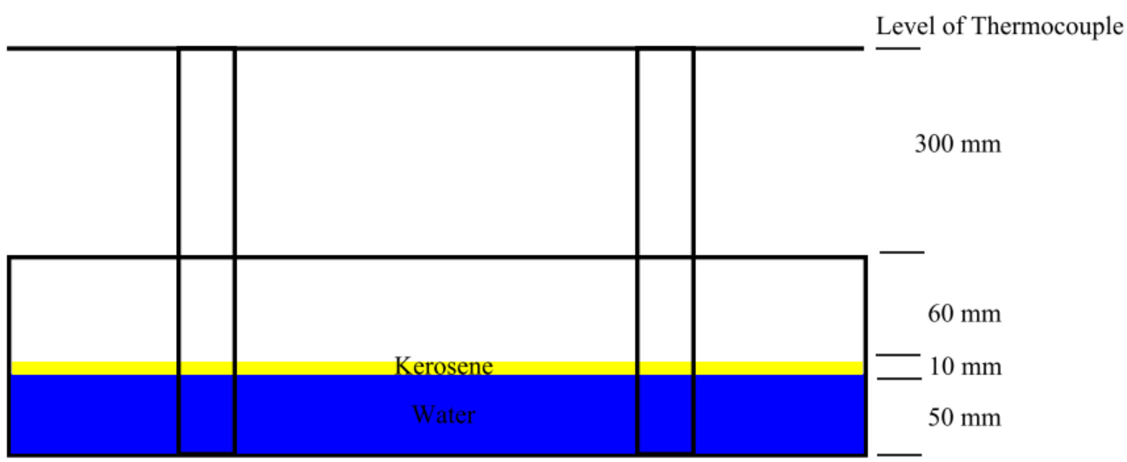


Figure 16. Height of Water & Kerosene in Hydrocarbon Pool Tank

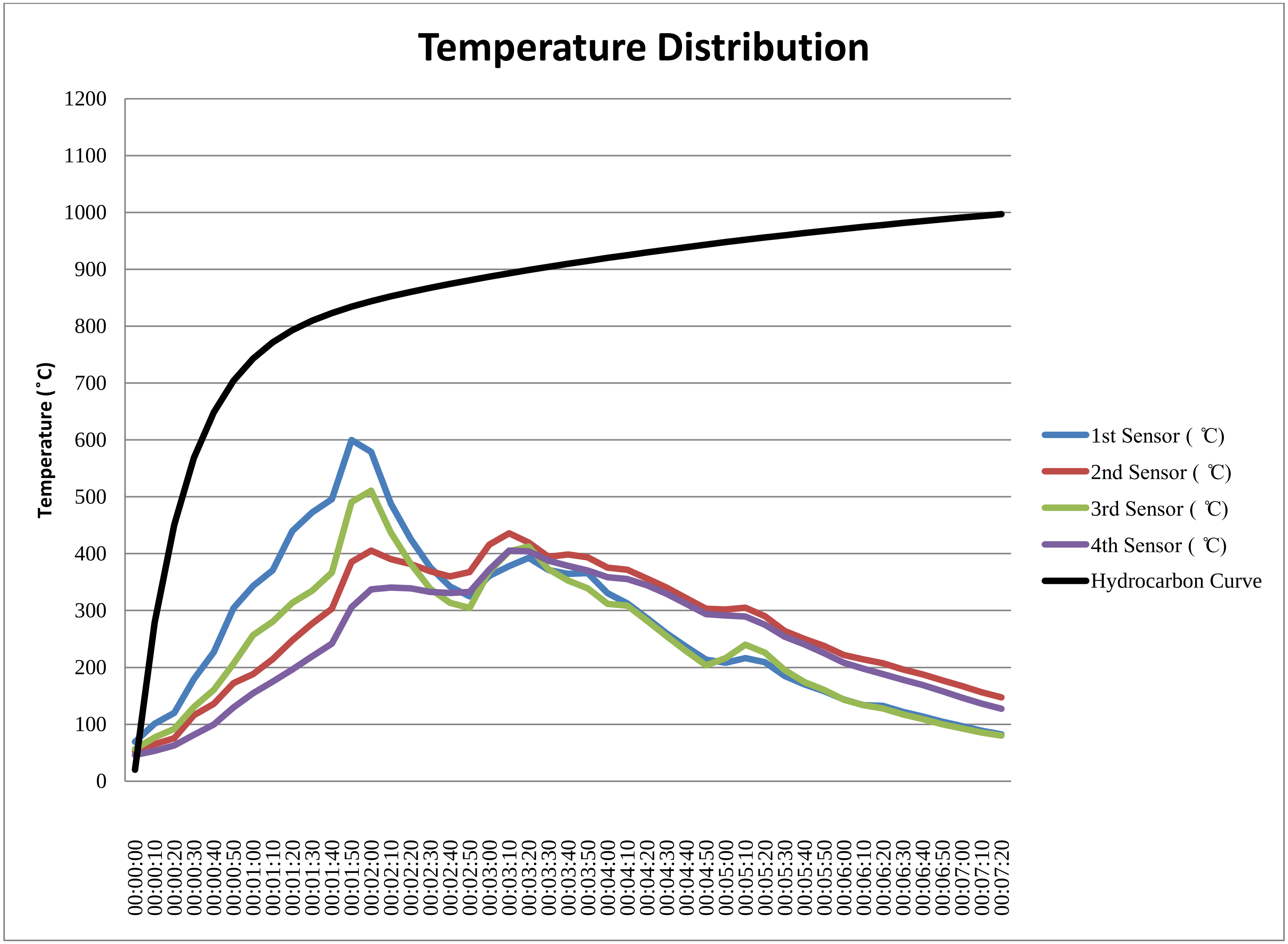
Table 7. Volume of Water and Kerosene used in Control Experiment 3:

Substance	**Volume (L)**
Water	8.1
Kerosene	2.7

Figure 17. Control Experiment 3

Table 8 shows tabulated results of temperature distribution for 4 thermocouple sensors:

Table 8. Tabulated Results in Control Experiment 3 (Refer to Appendices)


Temperature Distribution
Temperature (˚C)
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
1st Sensor (℃)
2nd Sensor (℃)
3rd Sensor (℃)
4th Sensor (℃)
Hydrocarbon Curve
00:00:00
00:00:10
00:00:20
00:00:30
00:00:40
00:00:50
00:01:00
00:01:10
00:01:20
00:01:30
00:01:40
00:01:50
00:02:00
00:02:10
00:02:20
00:02:30
00:02:40
00:02:50
00:03:00
00:03:10
00:03:20
00:03:30
00:03:40
00:03:50
00:04:00
00:04:10
00:04:20
00:04:30
00:04:40
00:04:50
00:05:00
00:05:10
00:05:20
00:05:30
00:05:40
00:05:50
00:06:00
00:06:10
00:06:20
00:06:30
00:06:40
00:06:50
00:07:00
00:07:10
00:07:20

5.1.5 Control Experiment 4

Location of heat sensors shown in Figure 18:

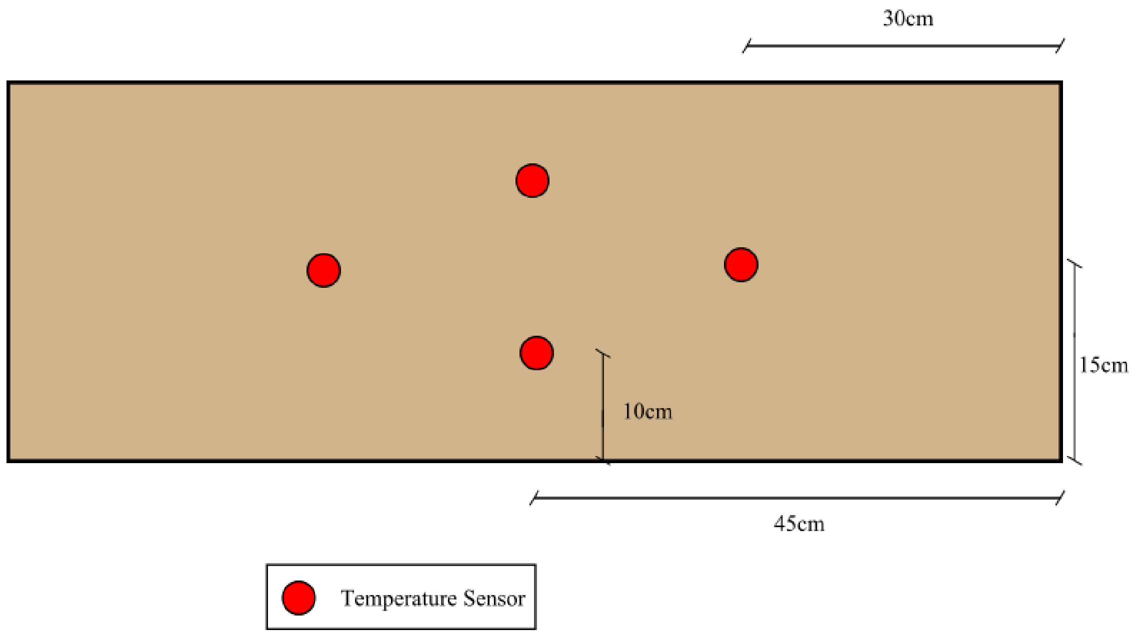


Figure 18. Plan View for the Location of Sensors

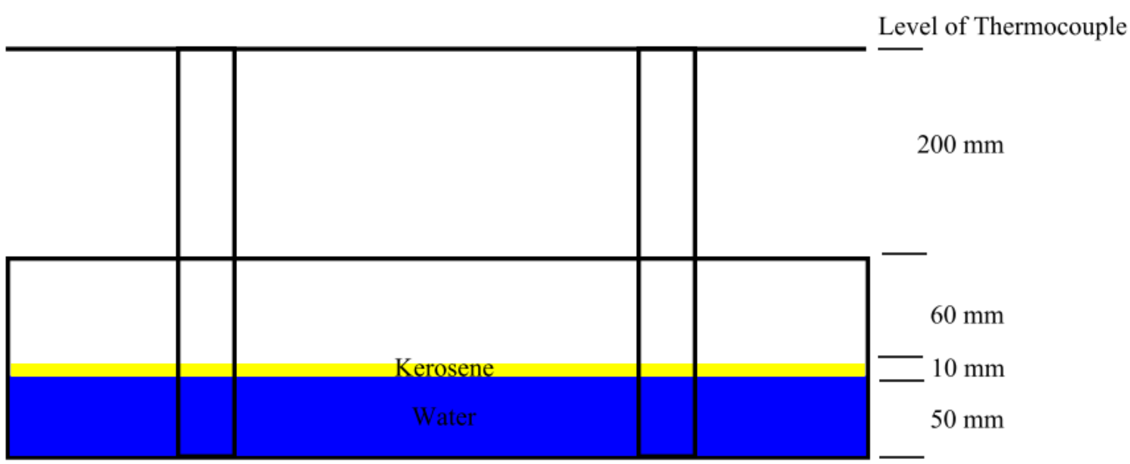


Figure 19. Height of Water & Kerosene in Hydrocarbon Pool Tank

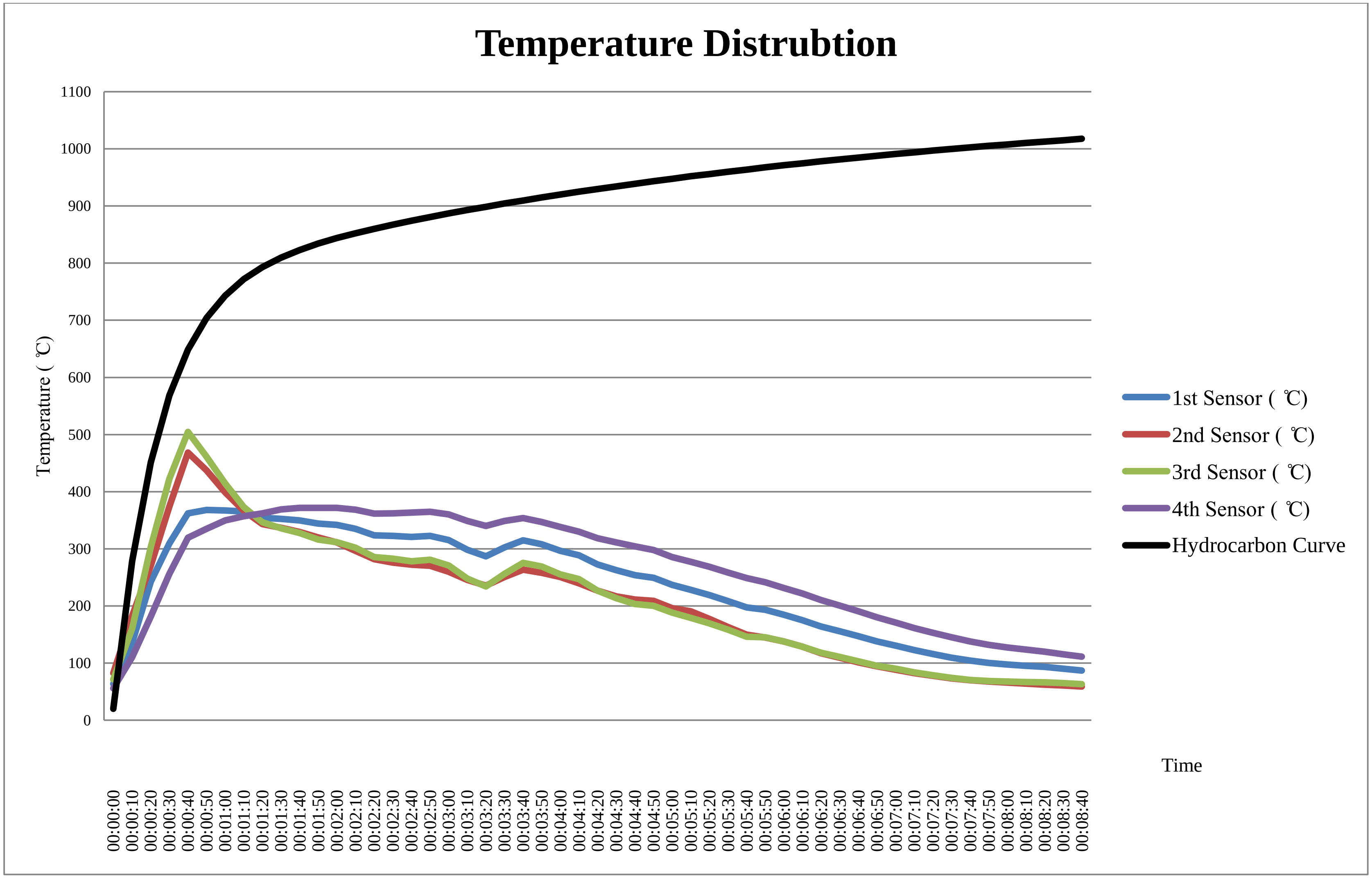
Table 9. Volume of Water and Kerosene used in Control Experiment 4:

Substance	**Volume (L)**
Water	8.1
Kerosene	2.7

Figure 20. Control Experiment 4

Table 10 shows tabulated results of temperature distribution for 4 thermocouple sensors:

Table 10. Tabulated Results in Control Experiment 4 (Refer to Appendices)


Temperature Distrubtion
Temperature (℃)
1100
1000
900
800
700
600
500
400
300
200
100
0
1st Sensor (℃)
2nd Sensor (℃)
3rd Sensor (℃)
4th Sensor (℃)
Hydrocarbon Curve
Time
00:00:00
00:00:10
00:00:20
00:00:30
00:00:40
00:00:50
00:01:00
00:01:10
00:01:20
00:01:30
00:01:40
00:01:50
00:02:00
00:02:10
00:02:20
00:02:30
00:02:40
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00:03:00
00:03:10
00:03:20
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00:04:00
00:04:10
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00:05:20
00:05:30
00:05:40
00:05:50
00:06:00
00:06:10
00:06:20
00:06:30
00:06:40
00:06:50
00:07:00
00:07:10
00:07:20
00:07:30
00:07:40
00:07:50
00:08:00
00:08:10
00:08:20
00:08:30
00:08:40

5.1.6 Control Experiment 5

Location of heat sensors shown in Figure 21:

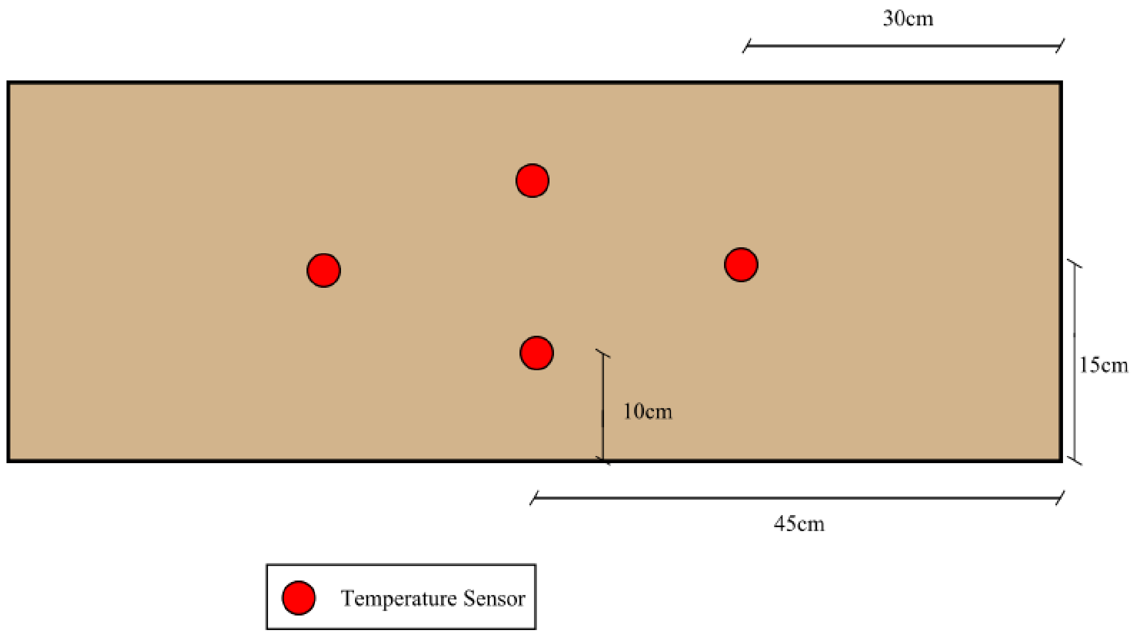


Figure 21. Plan View for the Location of Sensors

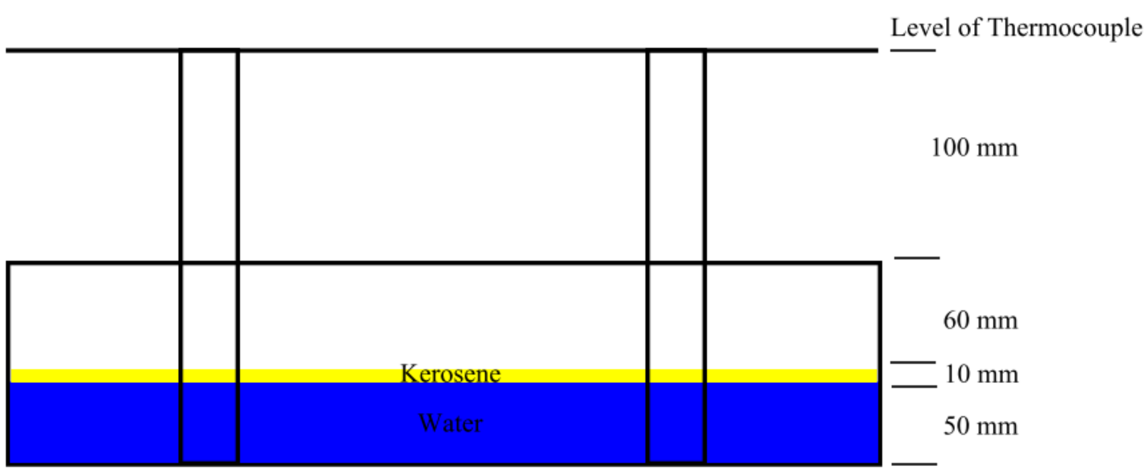


Figure 22. Height of Water & Kerosene in Hydrocarbon Pool Tank

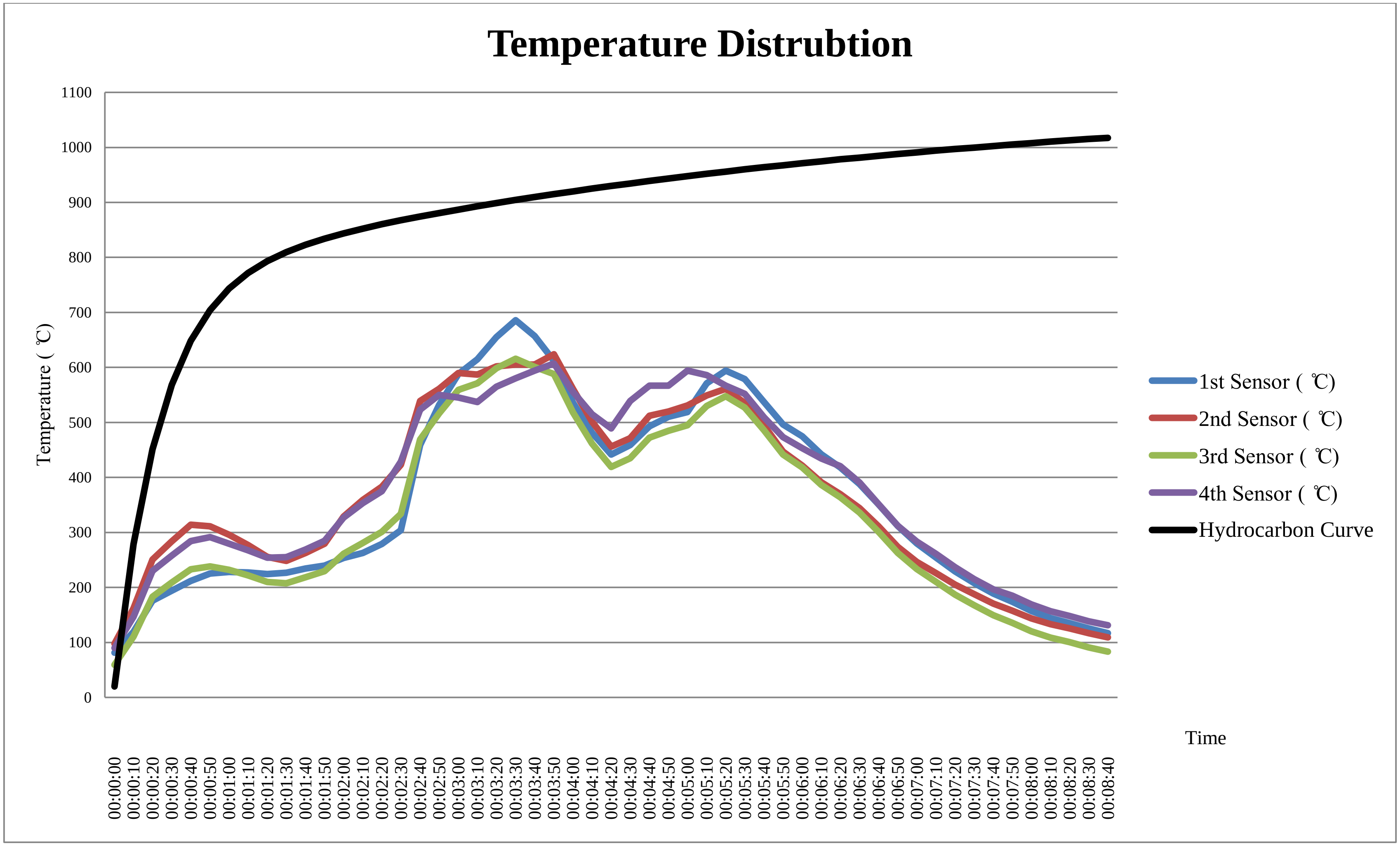
Table 11. Volume of Water and Kerosene used in Control Experiment 5:

Substance	**Volume (L)**
Water	8.1
Kerosene	2.7

Figure 23. Control Experiment 5

Table 12 shows tabulated results of temperature distribution for 4 thermocouple sensors:

Table 12. Tabulated Results in Control Experiment 5 (Refer to Appendices)


Temperature Distrubtion
Temperature (℃)
1100
1000
900
800
700
600
500
400
300
200
100
0
1st Sensor (℃)
2nd Sensor (℃)
3rd Sensor (℃)
4th Sensor (℃)
Hydrocarbon Curve
Time
00:00:00
00:00:10
00:00:20
00:00:30
00:00:40
00:00:50
00:01:00
00:01:10
00:01:20
00:01:30
00:01:40
00:01:50
00:02:00
00:02:10
00:02:20
00:02:30
00:02:40
00:02:50
00:03:00
00:03:10
00:03:20
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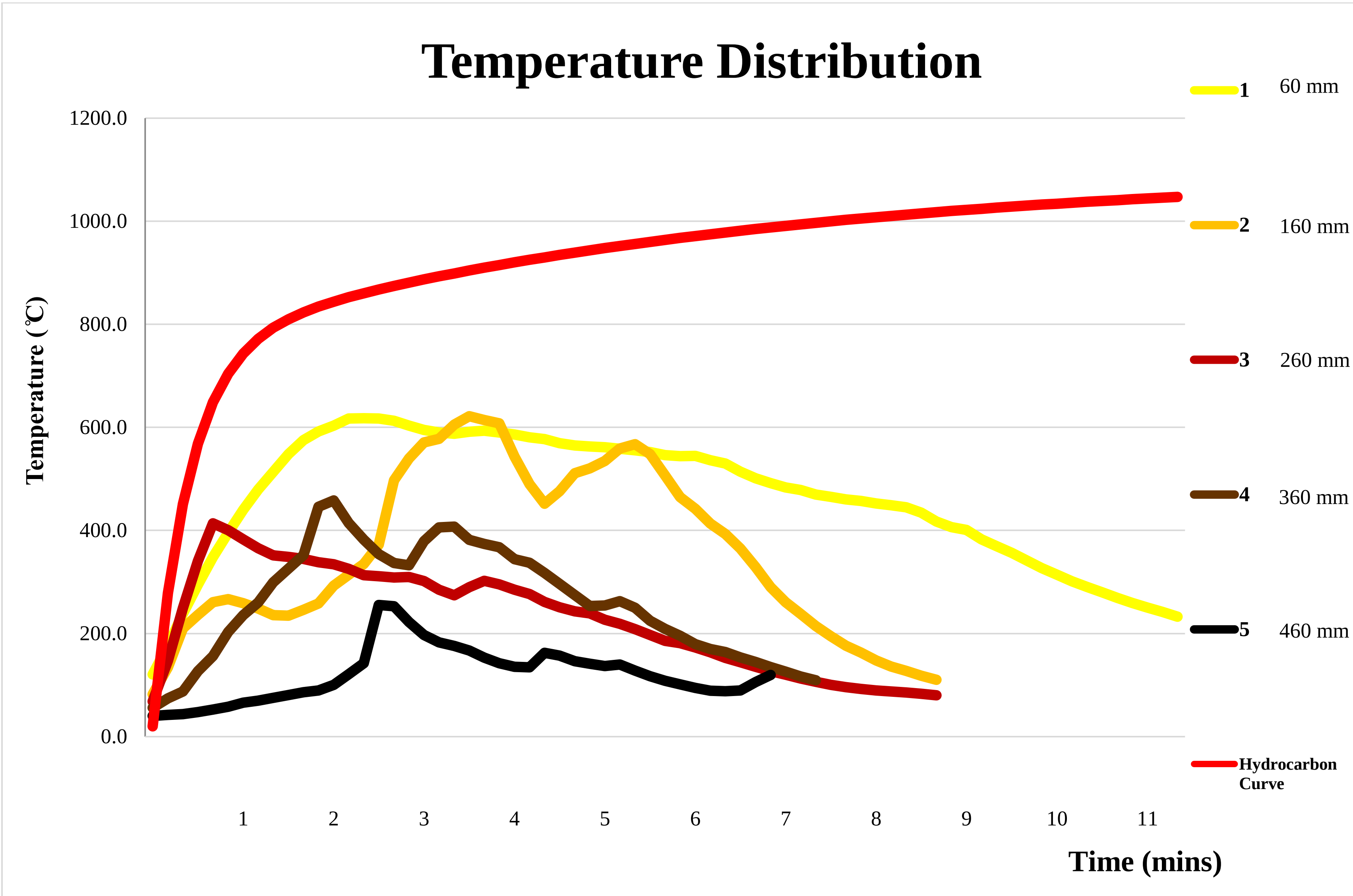
00:06:00
00:06:10
00:06:20
00:06:30
00:06:40
00:06:50
00:07:00
00:07:10
00:07:20
00:07:30
00:07:40
00:07:50
00:08:00
00:08:10
00:08:20
00:08:30
00:08:40

5.1.7 Averaging Temperature Data from All Control Experiments (1-5)

Table 13 shows tabulated results of temperature distribution for 5 different control experiments, with averaging all 4 temperature data from 4 thermocouples sensors into a single representative temperature at a given time for a control experiment:

Table 13. Tabulated Results in Averaged Temperature of All 5 Control Experiments

(Refer to Appendices)



Temperature Distribution
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
Temperature (℃)
1 2 3 4 5 6 7 8 9 10 11
Time (mins)
1 60 mm
2 160 mm
3 260 mm
4 360 mm
5 460 mm
Hydrocarbon Curve

5.1.8 Discussion on Varying Factor – The Height of Sensors from Kerosene Level

As the result of 5 control experiments with varying height being tested, it is concluded that **sensors at 260 mm height from the kerosene surface level is the optimum height**.

This is because the **rate of increment for the 1st minute is the highest for control experiment with 260 mm height**. The fact is that the **maximum temperature reachable by the burning of kerosene would be the same for all 5 control experiments (assuming unlimited time and unlimited volume of kerosene are given), therefore the detrimental factor in choosing optimum height is the rate of increment of temperature in the first minute**, rather than the temperature obtained.

Apart from that, by comparing the lowest height (60 mm) and greatest height (460 mm), the 60 mm control experiment and the 460 mm control experiment produce temperature distribution graphs with huge disparity. The maximum temperatures obtained are 629 ℃ and 246.8 ℃ respectively.

Apart from that, the gradient of the curve for 60 mm control experiment shows indication of similarity in pattern of the gradient of curves (not temperature) with the hydrocarbon curve, though only sustained up to 3 minutes. The remaining burning time showed decreased in temperature linearly over time till the experiment is stopped.

As for the 460 mm control experiment, the gradient is totally out of shape in comparison with the hydrocarbon curve. The rate of change of temperature (gradient) was increasing till the peak of temperature, 246.8 ℃ is reached, and the remaining burning time showed the decreasing rate of change of temperature (gradient) until the experiment is stopped.

Both control experiments has showed signs of increasing temperature at start and decreasing temperature at the end. The difference lies in the rate of increment at the beginning for 60 mm control experiment is much close to linear type of increment whereas the 460 mm control experiment has a sharp positive rate of increment of temperature.

In addition, the 60 mm control experiment has showed sign of sustained temperature at peak for approximately 1 minute (from 2nd minute to 3rd minute) whereas the 460 mm control experiment has an immediate drop post-peak temperature.

The oblique gradient and curves shown in 460 mm control experiment is much due to the **windy condition causing the swaying of the tip of the hydrocarbon fire** at the top (shown in Figure 11, 5.1.3 Control Experiment 2). Several control experiments (3rd, 4th, 5th control experiments) have to be carried out to rectify this issue. The reduction in elevation of thermocouple sensors from the top surface of hydrocarbon tank and also ventilated surrounding (wind shielded) could largely offset the wind effect or the inconsistent fire form at the tip top area.

Besides that, it is obvious as the peak values have portrayed, that the maximum temperatures are far from reaching the targeted temperature of 1000 ℃. Therefore in the actual experiment, the author has to **increase the volume of kerosene inside the hydrocarbon pool tank**.

5.1.9 Extended Burning with 260 mm Optimum Height - Control Experiment 6

Location of heat sensors shown in Figure 24:

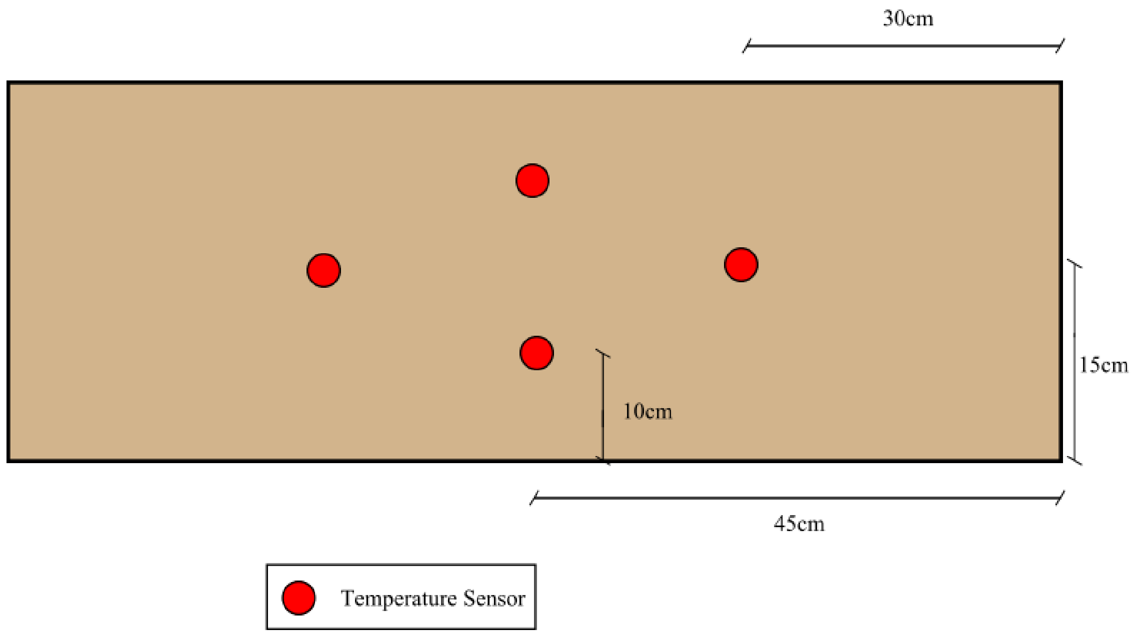


Figure 24. Plan View for the Location of Sensors

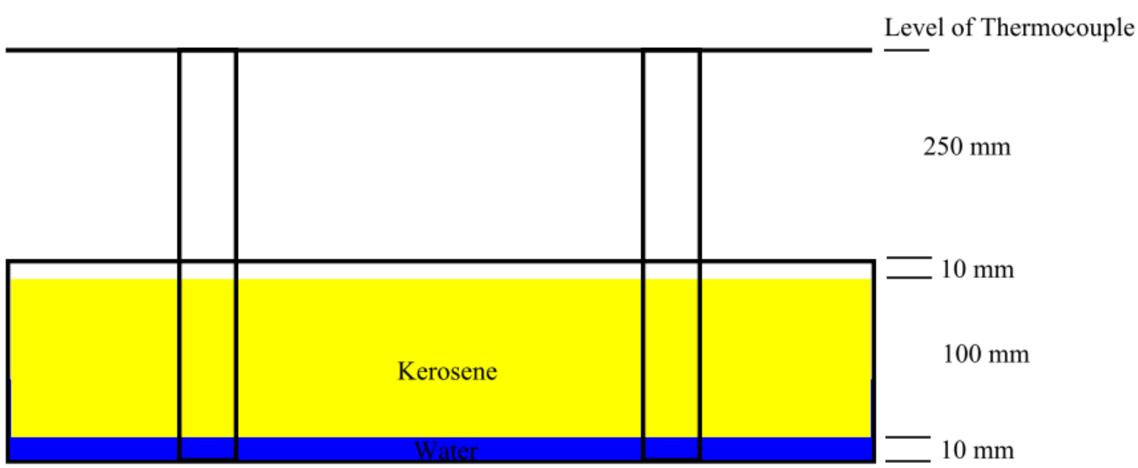


Figure 25. Height of Water & Kerosene in Hydrocarbon Pool Tank

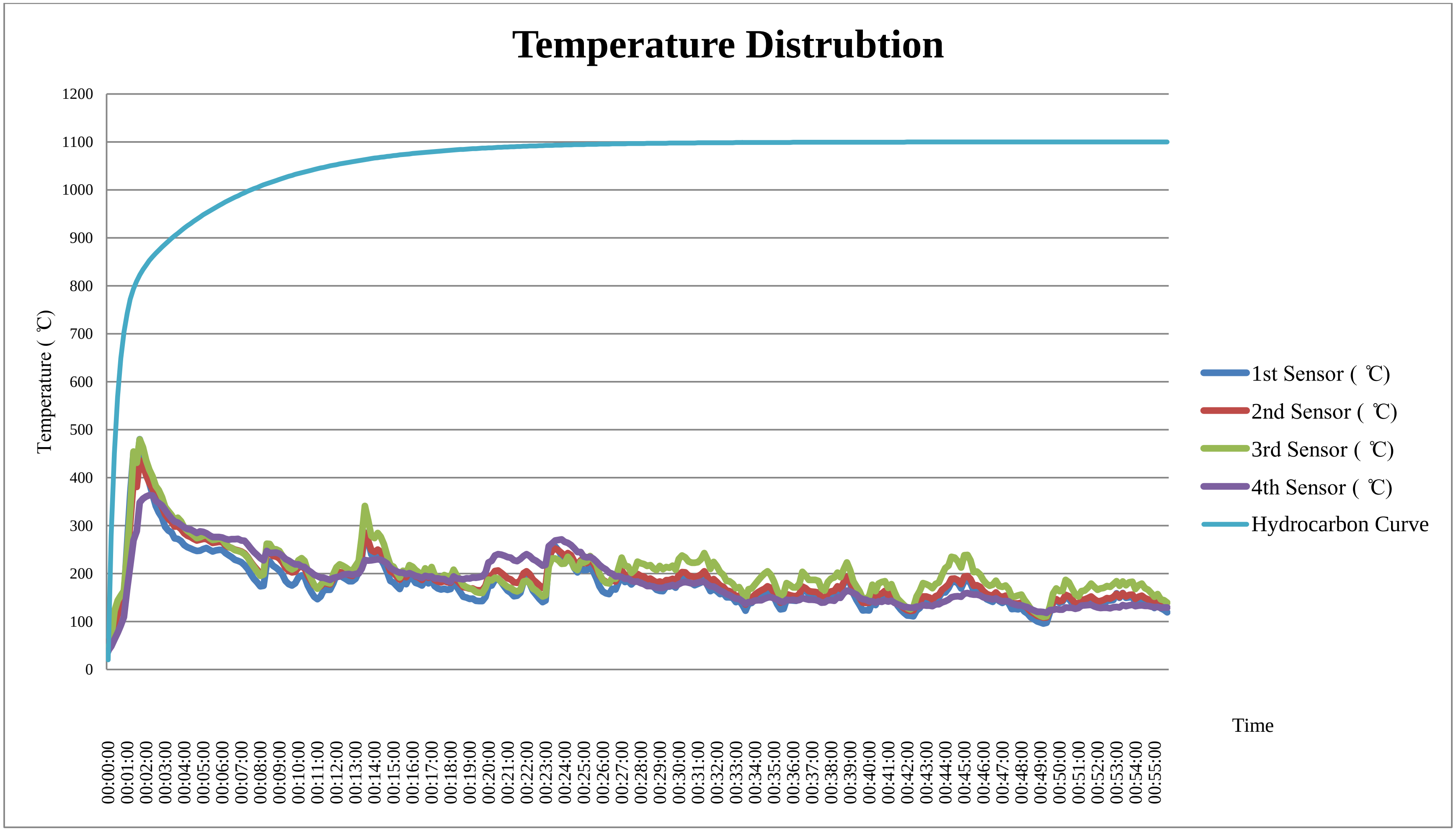
Table 14. Volume of Water and Kerosene used in Control Experiment 6:

Substance	**Volume (L)**
Water	2.7
Kerosene	27

Figure 26. Control Experiment 6

Table 15 shows tabulated results of temperature distribution for 4 thermocouple sensors:

Table 15. Tabulated Results in Control Experiment 6 (Refer to Appendices)



Temperature Distrubtion
Temperature (℃)
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
1st Sensor (℃)
2nd Sensor (℃)
3rd Sensor (℃)
4th Sensor (℃)
Hydrocarbon Curve
Time
00:00:00
00:01:00
00:02:00
00:03:00
00:04:00
00:05:00
00:06:00
00:07:00
00:08:00
00:09:00
00:10:00
00:11:00
00:12:00
00:13:00
00:14:00
00:15:00
00:16:00
00:17:00
00:18:00
00:19:00
00:20:00
00:21:00
00:22:00
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00:24:00
00:25:00
00:26:00
00:27:00
00:28:00
00:29:00
00:30:00
00:31:00
00:32:00
00:33:00
00:34:00
00:35:00
00:36:00
00:37:00
00:38:00
00:39:00
00:40:00
00:41:00
00:42:00
00:43:00
00:44:00
00:45:00
00:46:00
00:47:00
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00:49:00
00:50:00
00:51:00
00:52:00
00:53:00
00:54:00
00:55:00

5.1.10 Extended Burning with 260 mm Optimum Height - Control Experiment 7

Location of heat sensors shown in Figure 27:

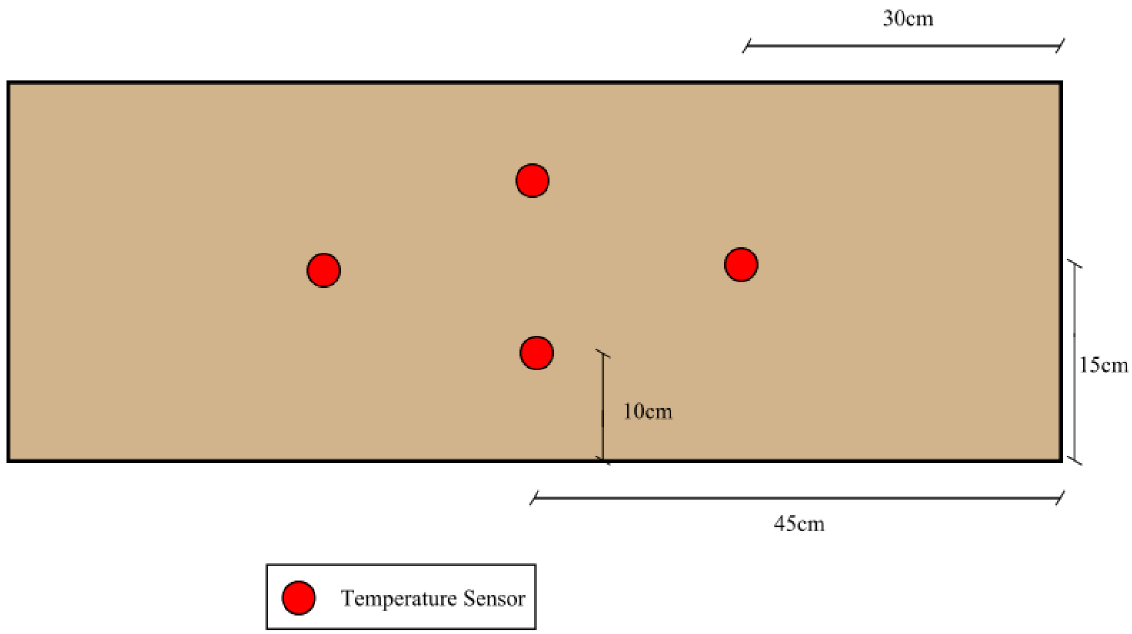


Figure 27. Plan View for the Location of Sensors

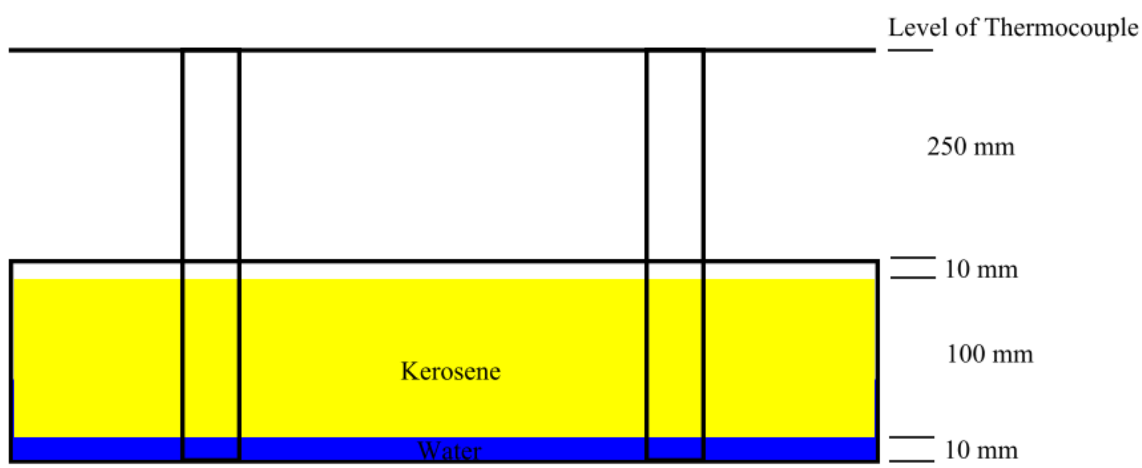


Figure 28. Height of Water & Kerosene in Hydrocarbon Pool Tank

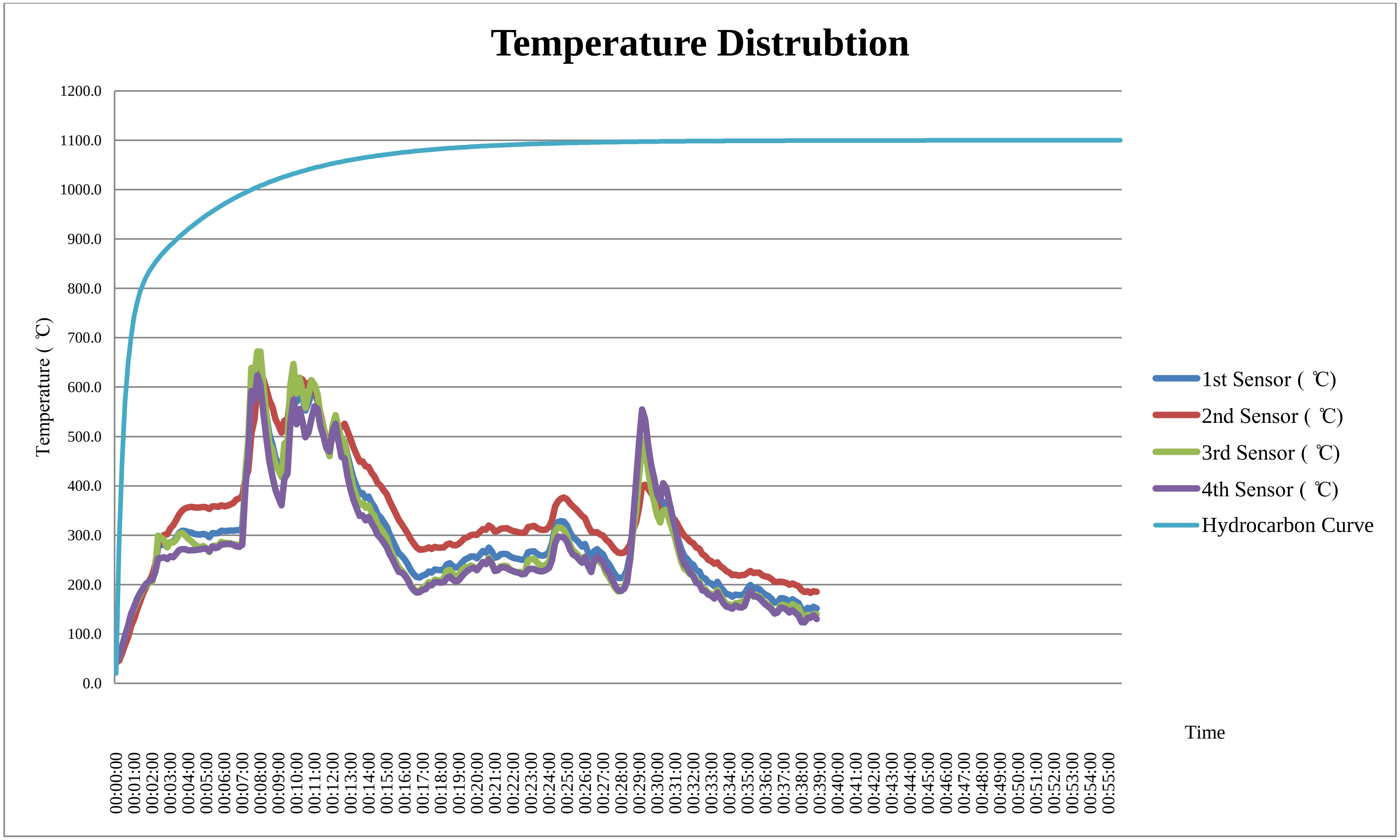
Table 16. Volume of Water and Kerosene used in Control Experiment 7:

Substance	Volume (L)
Water	2.7
Kerosene	27

Figure 29. Control Experiment 7

Table 17 shows tabulated results of temperature distribution for 4 thermocouple sensors:

Table 17. Tabulated Results in Control Experiment 7 (Refer to Appendices)


Temperature Distrubtion
Temperature (℃)
1200.0
1100.0
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
1st Sensor (℃)
2nd Sensor (℃)
3rd Sensor (℃)
4th Sensor (℃)
Hydrocarbon Curve
Time
00:00:00
00:01:00
00:02:00
00:03:00
00:04:00
00:05:00
00:06:00
00:07:00
00:08:00
00:09:00
00:10:00
00:11:00
00:12:00
00:13:00
00:14:00
00:15:00
00:16:00
00:17:00
00:18:00
00:19:00
00:20:00
00:21:00
00:22:00
00:23:00
00:24:00
00:25:00
00:26:00
00:27:00
00:28:00
00:29:00
00:30:00
00:31:00
00:32:00
00:33:00
00:34:00
00:35:00
00:36:00
00:37:00
00:38:00
00:39:00
00:40:00
00:41:00
00:42:00
00:43:00
00:44:00
00:45:00
00:46:00
00:47:00
00:48:00
00:49:00
00:50:00
00:51:00
00:52:00
00:53:00
00:54:00
00:55:00

5.1.11 Extended Burning with 260 mm Optimum Height - Control Experiment 8 (Partial Wind Shielded)

In this test run, the dominant wind direction on that day is determined. **The setup of the experiment is shielded by 2 steel plates on this direction to reduce the effect of wind causing swaying to the fire.**

This experiment is to study the effect of wind as a varying factor on temperature curve produced.

Location of heat sensors shown in Figure 30:

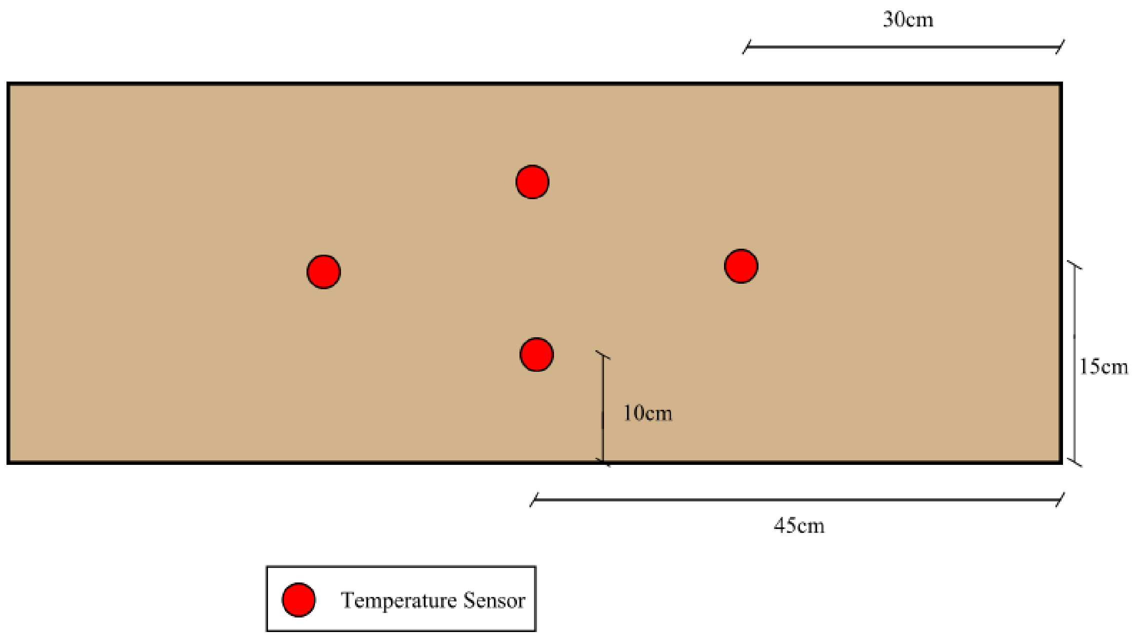


Figure 30. Plan View for the Location of Sensors

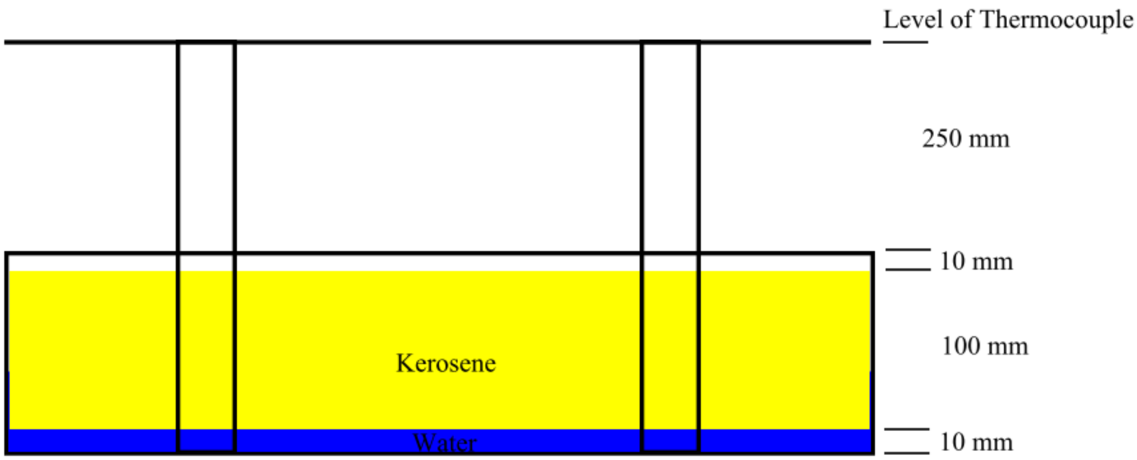


Figure 31. Height of Water & Kerosene in Hydrocarbon Pool Tank

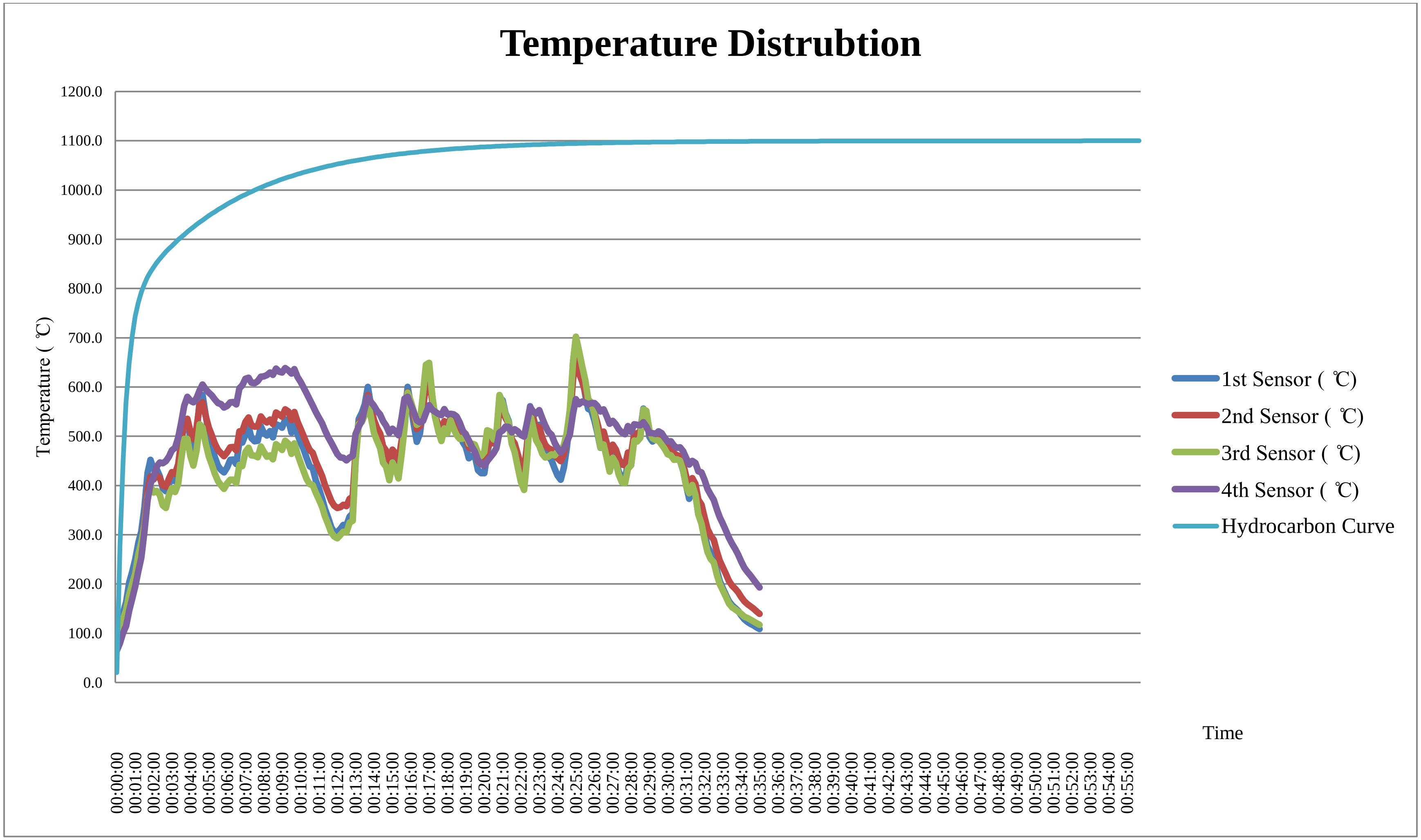
Table 18. Volume of Water and Kerosene used in Control Experiment 8:

Substance	**Volume (L)**
Water	2.7
Kerosene	27

Figure 32. Control Experiment 8

Table 19 shows tabulated results of temperature distribution for 4 thermocouple sensors:

Table 19. Tabulated Results in Control Experiment 8 (Refer to Appendices)



Temperature Distrubtion
Temperature (℃)
1200.0
1100.0
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
1st Sensor (℃)
2nd Sensor (℃)
3rd Sensor (℃)
4th Sensor (℃)
Hydrocarbon Curve
Time
00:00:00
00:01:00
00:02:00
00:03:00
00:04:00
00:05:00
00:06:00
00:07:00
00:08:00
00:09:00
00:10:00
00:11:00
00:12:00
00:13:00
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00:16:00
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00:18:00
00:19:00
00:20:00
00:21:00
00:22:00
00:23:00
00:24:00
00:25:00
00:26:00
00:27:00
00:28:00
00:29:00
00:30:00
00:31:00
00:32:00
00:33:00
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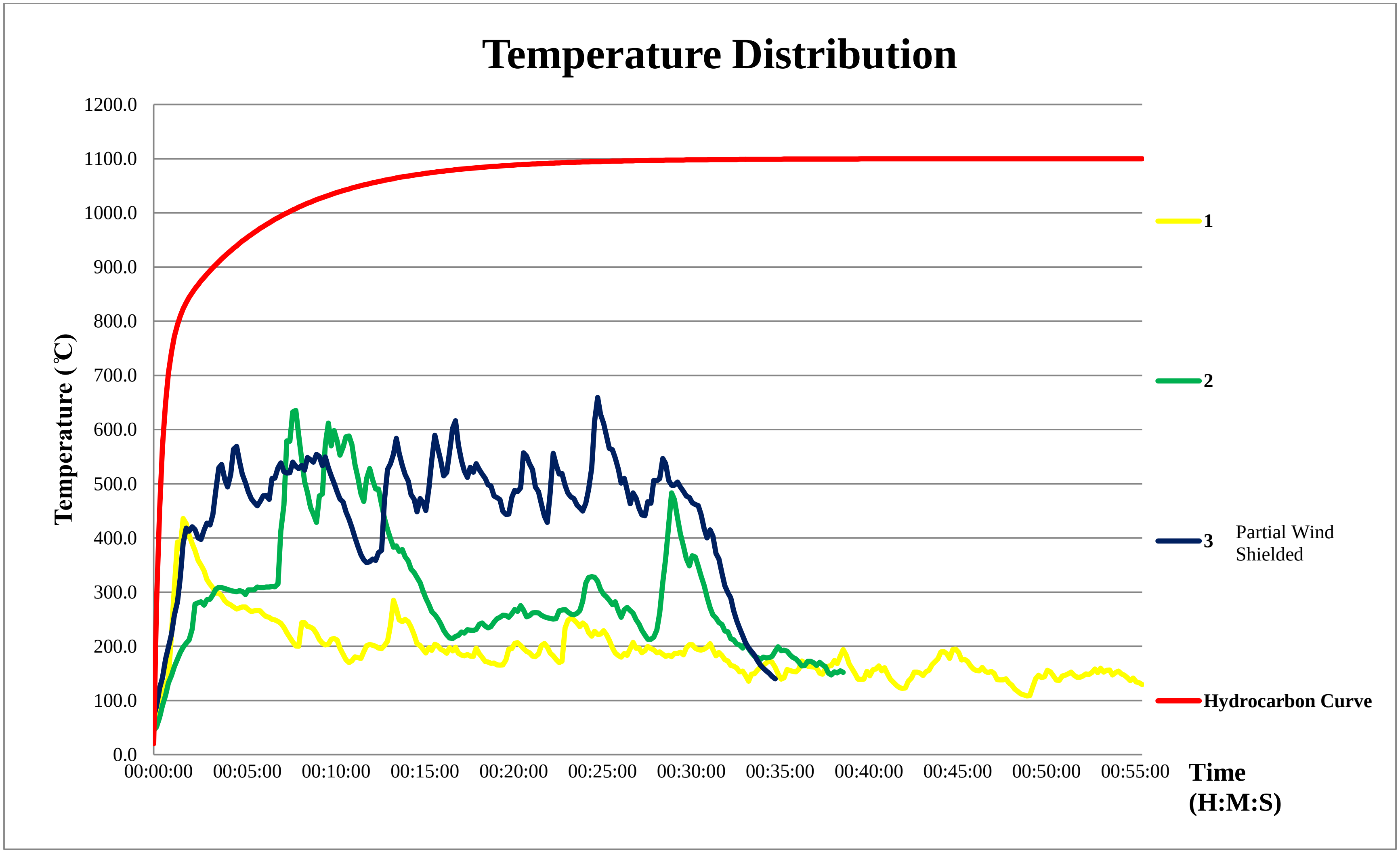
00:35:00
00:36:00
00:37:00
00:38:00
00:39:00
00:40:00
00:41:00
00:42:00
00:43:00
00:44:00
00:45:00
00:46:00
00:47:00
00:48:00
00:49:00
00:50:00
00:51:00
00:52:00
00:53:00
00:54:00
00:55:00

5.1.7 Averaging Temperature Data from All Control Experiments (1-5)

Table 20 shows tabulated results of temperature distribution for 3 control experiments with the same 260 mm height, with averaging all 4 temperature data from 4 thermocouples sensors into a single representative temperature at a given time for a control experiment:

Table 20. Tabulated Results in Averaged Temperature of All 3 (6^{th} – 8^{th}) Control Experiments (Refer to Appendices)



Temperature Distribution
Temperature (℃)
1200.0
1100.0
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
00:00:00
00:05:00
00:10:00
00:15:00
00:20:00
00:25:00
00:30:00
00:35:00
00:40:00
00:45:00
00:50:00
00:55:00
Time (H:M:S)
1
2
3
Partial Wind Shielded
Hydrocarbon Curve

5.1.13 Discussion on Wind Effect

As the result of 3 control experiments with same height being tested (260 mm), it is concluded that sensors at 260 mm height from the kerosene surface level has the **temperature-time curve which is more consistent if wind effect on the environment is reduced.** Max temperature reached could also be elevated if there wind causing the swaying of fire is under control. **Less swaying of fire results in concentrated and consistent fire burning**, thus obtaining consistent temperature-time curve and higher temperature **(702℃ Max Temp. for partial wind shielded experiment vs. 672℃ Max Temp for without wind shield)**.

Chapter 6

Conclusion

In conclusion, with the conduct of the first 5 control experiments, the setup of the experiment needs to be modified to an optimum level for the thermocouple sensors from the surface of the kerosene of 260 mm. This is done based on the rate of increment of the temperature in the first minute, in which at the height of 260 mm, the rate of increment of temperature is the highest among all varied heights.

Apart from that, with the conduct of the 6^{th} – 8^{th} control experiments, the setup of the experiment needs to be modified to accommodate the wind effect causing the inconsistent fire tip at top. The inconsistency has been shown in the much varied gradient and pattern of temperature distribution curve from the targeted simulation of hydrocarbon curve. Taking into consideration the wind effect and to achieve constant burning, the setup of the experiment is aimed to be reducing the sensitivity of thermocouple sensors towards wind effect. Due to the fact that the setup is relatively small sized and the fire in this case has to be concentrated within a small setup, any swaying of fire due to wind will be a huge discount to temperature growth and detection at the location of thermocouple sensors are placed. The 6^{th} and 7^{th} control experiments are showing huge fluctuations and irregularities in temperature curves. These are the effect of wind in causing the inefficiency in detection of temperature during experimentation.

In relation to solving this wind issue causing inefficiency in detection of temperature by concentrated location of thermocouple, the 8^{th} control experiment is run with partial wind shield, which means the dominant wind direction on that day is determined and shielded to reduce the effect of wind towards the open hydrocarbon burning. The result of the 8^{th} control experiment has shown huge disparity with the previous 2 control experiment (6^{th} and 7^{th}). **The fluctuation is smaller and lesser to be seen in the temperature distribution curve produced**. In addition to that, the maximum temperature reached is also higher for **702 ℃ Max Temperature obtained for partial wind shielded experiment, compared to 672℃ Max Temperature for without wind shield.** This indicates the factor of wind effect in this experiment is critical to the achievement of development of hydrocarbon fire.

With the optimum height of the experiment being determined as 260 mm, the main error of the experiment is much concerning with the effect of wind on the consistency of burning during real testing. Therefore, for future recommendation on improvement and completing the experiment setup, it is suggested that the experiment is shielded from wind from 4 sides completely, rather than just shielding the wind from the dominant directions.

Apart from that, another recommendation is that, the hydrocarbon tank size should be increased in term surface area count. This is because a wide-spread of hydrocarbon fire could largely offset the effect of fire swaying. For example the fire swaying at the middle portion away from middle area could be complemented with fire at other sides of the hydrocarbon pool tank swaying towards the middle section, assuming that the thermocouple sensors are concentrated at the middle portion of the hydrocarbon tank. The detection of fire is much lesser disrupted in wide-spread fire. The current setup is rather small in size and surface area count, in which any swaying of fire could not be complemented by fire from other area of the surface due to limited fire and space. In relation to this suggestion, the cost of the experiment will also increase linearly due to more kerosene needed for wider burning of hydrocarbon fire and a larger hydrocarbon pool tank.

References

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Professor A.G. Gibson (2003). The Cost Effective Use of Glass Fibre Reinforced Composites Offshore.

Appendices

Table 4: Control Experiment 1

Sample No.	H: M: S	1st Sensor (℃)	2nd Sensor (℃)	3rd Sensor (℃)	4th Sensor (℃)
1	00:00:00	133	41	107.7	66.4
2	00:00:10	192.6	43.2	159.7	136.9
3	00:00:20	263.5	45.5	213.1	192.9
4	00:00:30	322.6	47.1	267.1	264.2
5	00:00:40	384.4	48.2	311.9	331.4
6	00:00:50	437.7	49.2	352.8	393.9
7	00:01:00	481.8	50.1	398.2	450.7
8	00:01:10	509	50.5	449.8	499.4
9	00:01:20	533	50.7	494.3	537
10	00:01:30	563	51.3	533	571
11	00:01:40	593	51.9	557	599
12	00:01:50	598	51.8	586	614
13	00:02:00	611	52.1	596	624
14	00:02:10	618	52.1	616	629
15	00:02:20	618	52.1	617	625
16	00:02:30	616	52.1	618	621
17	00:02:40	612	52.1	613	618
18	00:02:50	607	52.1	600	622
19	00:03:00	601	52.1	589	622
20	00:03:10	597	54.1	583	0
21	00:03:20	600	53.9	575	0
22	00:03:30	600	53.6	583	0
23	00:03:40	596	53.2	591	0
24	00:03:50	593	52.9	587	0
25	00:04:00	588	52.8	584	0
26	00:04:10	586	52.7	575	0
27	00:04:20	585	52.9	569	0
28	00:04:30	582	53.2	557	0
29	00:04:40	581	53.4	549	0
30	00:04:50	578	53.3	548	0
31	00:05:00	571	53.2	552	0
32	00:05:10	573	53.3	544	0
33	00:05:20	574	53.4	537	0
34	00:05:30	570	53.4	534	0
35	00:05:40	566	53.4	526	0
36	00:05:50	562	53.4	526	0
37	00:06:00	559	53.3	530	0
38	00:06:10	553	53.3	519	0

39	00:06:20	543	53.3	517	0
40	00:06:30	529	53.1	498.7	0
41	00:06:40	521	53.2	481.7	0
42	00:06:50	514	53.3	469.8	0
43	00:07:00	511	53.4	456.1	0
44	00:07:10	510	53.7	447.2	0
45	00:07:20	504.9	53.8	434.2	0
46	00:07:30	504	53.8	426.6	0
47	00:07:40	501.3	53.8	418.7	0
48	00:07:50	503.4	53.9	411.2	0
49	00:08:00	500.9	53.9	403.8	0
50	00:08:10	499.7	54	397.6	0
51	00:08:20	498.2	53.9	391.6	0
52	00:08:30	484.1	53.4	385.1	0
53	00:08:40	458.5	52.3	376.4	480.7
54	00:08:50	440.6	51.5	372.3	463.8
55	00:09:00	426.4	51.1	375.5	453
56	00:09:10	406.9	50.4	358.4	440.1
57	00:09:20	388.4	49.8	350.6	423.1
58	00:09:30	371.8	49.2	341.5	399.9
59	00:09:40	355.8	48.7	328	377.4
60	00:09:50	339.4	48.2	314.4	358.5
61	00:10:00	325.7	47.7	302.3	340.9
62	00:10:10	313.7	47.4	289.1	327.6
63	00:10:20	302.7	47.1	277.9	312.9
64	00:10:30	292.2	46.8	267.3	302.7
65	00:10:40	281.7	46.7	256.9	287.9
66	00:10:50	271.4	46.5	247.1	276.2
67	00:11:00	262.4	46.3	238.3	266.5
68	00:11:10	254.2	46.3	230.2	257
69	00:11:20	244	46.3	221.1	248.7

Table 6: Control Experiment 2

Sample No.	H: M: S	1st Sensor (℃)	2nd Sensor (℃)	3rd Sensor (℃)	4th Sensor (℃)
1	00:00:00	43.1	38.2	42	38.4
2	00:00:10	45.6	39.7	42.1	40.3
3	00:00:20	47.7	41.1	42.1	42.3
4	00:00:30	52.4	44.2	42.1	46.5
5	00:00:40	57.9	48	42.1	51.9
6	00:00:50	63.7	51.6	42.2	57.6
7	00:01:00	72.5	57.7	42.1	66.6

8	00:01:10	77.2	60.6	42.2	70.9
9	00:01:20	83.1	64.8	42.2	77.1
10	00:01:30	89.3	69	42.2	82.9
11	00:01:40	95.4	73.2	42.2	89.2
12	00:01:50	99.1	75.9	42.3	92.7
13	00:02:00	110.3	84.7	42.3	105.6
14	00:02:10	131.1	100.1	42.3	132.1
15	00:02:20	151.9	124.8	42.3	149.3
16	00:02:30	287.9	228.9	42.3	249
17	00:02:40	292.6	218.7	42.3	246.8
18	00:02:50	259.2	191.4	42.3	216.5
19	00:03:00	228.6	170.4	42.4	191.4
20	00:03:10	211.1	160.1	42.4	177
21	00:03:20	199.1	155.8	42.3	173.1
22	00:03:30	185.1	149.1	0	165.9
23	00:03:40	169.3	138.4	42.5	151.6
24	00:03:50	156.2	130.1	0	139.9
25	00:04:00	148.6	125.4	42.6	132.1
26	00:04:10	144.5	126.4	0	131.9
27	00:04:20	155.5	169.3	42.3	162.7
28	00:04:30	149.3	165.9	42.3	155.9
29	00:04:40	137.8	156.2	42.3	143.9
30	00:04:50	130.3	154.7	42.3	139.3
31	00:05:00	124	152.4	42.4	134
32	00:05:10	125.3	158.9	42.4	134.7
33	00:05:20	113.7	147.7	42.4	122.6
34	00:05:30	102.7	137.2	42.4	111
35	00:05:40	93.9	129.3	42.4	101.8
36	00:05:50	87.1	122	42.5	94.2
37	00:06:00	80.1	115.6	42.5	87.3
38	00:06:10	75.1	109.4	42.6	81.7
39	00:06:20	76.1	108.2	42.6	80.1
40	00:06:30	78.6	111.2	42.6	79.2
41	00:06:40	97.2	127.6	42.6	92.3
42	00:06:50	118.7	131.2	42.6	108

Table 8: Control Experiment 8

Sample No.	H: M: S	1st Sensor (℃)	2nd Sensor (℃)	3rd Sensor (℃)	4th Sensor (℃)
1	00:00:00	69.3	52.4	56.5	45.9
2	00:00:10	101	65.2	76.9	53.1
3	00:00:20	119.9	75.7	91.9	62.6

4	00:00:30	179.6	115.9	130.6	81.3
5	00:00:40	227	135.9	160.7	99.7
6	00:00:50	304.1	172.3	206.3	129.8
7	00:01:00	343.3	188.2	256.6	154.7
8	00:01:10	370.9	214.5	280.5	174.8
9	00:01:20	439.8	247.9	313.4	196.6
10	00:01:30	472.7	277.1	334.8	219.6
11	00:01:40	495.9	303.2	366.9	241.9
12	00:01:50	600	385.6	490.8	306.1
13	00:02:00	579	405.4	511	337.4
14	00:02:10	488.3	390.4	437.3	340.3
15	00:02:20	425.8	381.6	382.3	338.9
16	00:02:30	375.7	369.1	338.1	332.9
17	00:02:40	342.4	360.2	313.4	330.7
18	00:02:50	325	367.9	304.4	332.6
19	00:03:00	360.9	415.8	368.4	371.6
20	00:03:10	378.1	436	403.9	405.4
21	00:03:20	392.8	419.6	412.8	404.1
22	00:03:30	371.2	394.4	372.9	387.7
23	00:03:40	364.3	398.7	352.9	378.6
24	00:03:50	365.9	393.4	339.1	370.3
25	00:04:00	330.3	375.6	311.9	358.7
26	00:04:10	312.6	371.6	308.8	355.3
27	00:04:20	286.8	356.3	282.4	344.4
28	00:04:30	260.1	340.4	255	329.6
29	00:04:40	236.3	321.6	228.5	311.9
30	00:04:50	213.6	303.1	203.6	293.4
31	00:05:00	208.2	301.6	216.2	291.3
32	00:05:10	216.2	304.8	239.9	289.7
33	00:05:20	209	289.8	225.8	275.2
34	00:05:30	185.1	264.1	195.4	254
35	00:05:40	170.2	249.8	174	240.6
36	00:05:50	158.3	237.6	160.3	225.1
37	00:06:00	143.5	221.7	143.3	208.2
38	00:06:10	133.6	213.9	133.5	197.6
39	00:06:20	132.1	207.4	127.6	188.3
40	00:06:30	122	196.6	117.2	178.2
41	00:06:40	113.7	187.8	109	169.2
42	00:06:50	104.4	177.3	99.9	158.4
43	00:07:00	96.8	167.1	92.9	146.9
44	00:07:10	88.8	156.4	85.7	136.3
45	00:07:20	82.4	147.3	80.1	127.3

Table 10: Control Experiment 4

Sample No.	H: M: S	1st Sensor (℃)	2nd Sensor (℃)	3rd Sensor (℃)	4th Sensor (℃)
1	00:00:00	63.6	82.6	71.3	55.9
2	00:00:10	135.45	182.9	160.5	110.4
3	00:00:20	242.25	270.3	303	181.5
4	00:00:30	309.4	373.9	422.7	256.1
5	00:00:40	362.2	468.6	504.8	319.6
6	00:00:50	368.15	437.4	461.2	335.1
7	00:01:00	367.15	398.7	414.4	349.9
8	00:01:10	365.1	366.6	373	357.2
9	00:01:20	354.4	343.2	346.7	362.1
10	00:01:30	352.5	336.8	336.1	368.9
11	00:01:40	349.8	329.3	327.8	371.8
12	00:01:50	344	320	316.2	371.8
13	00:02:00	341.7	311.1	311.5	371.9
14	00:02:10	335.2	296.3	302	368.4
15	00:02:20	323.55	281.9	285.7	361.4
16	00:02:30	322.45	276.1	282.8	362.1
17	00:02:40	320.9	272.3	278.4	363.4
18	00:02:50	322.85	270.6	281	364.7
19	00:03:00	315.5	259.8	270.7	360.3
20	00:03:10	298.3	245.6	248	348.6
21	00:03:20	287.05	235.7	234.2	339.9
22	00:03:30	302.65	250.8	256.3	349
23	00:03:40	314.75	263.7	275.6	353.9
24	00:03:50	307.8	258.1	268.8	346.8
25	00:04:00	296.7	250.5	255.1	338.3
26	00:04:10	288.55	239.6	246.9	330.2
27	00:04:20	272.65	226.8	226.6	318.7
28	00:04:30	262.45	216.8	213.5	311.4
29	00:04:40	253.75	211.4	203.4	304.1
30	00:04:50	249.15	209.1	200.4	297.9
31	00:05:00	236.95	196.1	188.2	285.7
32	00:05:10	228.2	190.4	179.2	277.2
33	00:05:20	219.1	177.1	169.7	268.5
34	00:05:30	208.6	163.1	158.6	258.6
35	00:05:40	197.65	149.6	146.3	249
36	00:05:50	193.3	144.9	145.2	241.4
37	00:06:00	184.6	137.8	138	231.2
38	00:06:10	175.05	128.7	128.5	221.6
39	00:06:20	164.2	117.2	118.2	210.2
40	00:06:30	155.65	109.3	110.7	200.6

41	00:06:40	147	101	103.2	190.8
42	00:06:50	137.65	94.1	95.4	179.9
43	00:07:00	130.55	88.3	90.2	170.9
44	00:07:10	122.6	82.4	83.8	161.4
45	00:07:20	115.65	77.6	78.5	152.8
46	00:07:30	109.5	73.3	74	145
47	00:07:40	104.25	69.8	70.6	137.9
48	00:07:50	100.3	67.7	68.6	132
49	00:08:00	97.55	65.8	67.6	127.5
50	00:08:10	95.2	63.9	66.8	123.6
51	00:08:20	93.25	62.3	66.4	120.1
52	00:08:30	90.2	60.8	64.9	115.5
53	00:08:40	87.2	59.2	63.2	111.2

Table 12: Control Experiment 5

Sample No.	H: M: S	1st Sensor (℃)	2nd Sensor (℃)	3rd Sensor (℃)	4th Sensor (℃)
1	00:00:00	81.4	97.4	59.4	90
2	00:00:10	119.2	161.7	110.45	146.6
3	00:00:20	175.6	250.7	183.15	230.1
4	00:00:30	194.1	283.6	208.85	257.9
5	00:00:40	211.8	314.1	232.95	284
6	00:00:50	225.4	311.1	238.25	291.2
7	00:01:00	228	295.8	231.9	279.2
8	00:01:10	226.9	277	221.95	267.3
9	00:01:20	224.1	255.4	209.75	253.9
10	00:01:30	226.8	248.3	207.55	255.2
11	00:01:40	234.1	262.7	218.4	269.1
12	00:01:50	239.6	279.2	229.4	284.9
13	00:02:00	253.7	328.9	261.3	326.8
14	00:02:10	262.6	359.3	280.95	353.3
15	00:02:20	279.1	383.2	301.15	375.1
16	00:02:30	303.9	423.1	333.5	428.5
17	00:02:40	458.8	539	468.9	523
18	00:02:50	532	561	516.5	550
19	00:03:00	588	590	559	545
20	00:03:10	615	587	571	537
21	00:03:20	655	602	598.5	565
22	00:03:30	686	605	615.5	580
23	00:03:40	657	605	601	594
24	00:03:50	612	624	588	607
25	00:04:00	536	561	518.5	556

26	00:04:10	481.6	501.7	461.65	515
27	00:04:20	441.8	456.2	419	489.1
28	00:04:30	458.8	471.3	435.05	539
29	00:04:40	492.8	512	472.4	567
30	00:04:50	510	520	485	567
31	00:05:00	519	531	495	594
32	00:05:10	571	549	530	586
33	00:05:20	594	561	547.5	567
34	00:05:30	579	535	527	552
35	00:05:40	537	494.2	485.6	509
36	00:05:50	496.4	446.7	441.55	473.4
37	00:06:00	474.9	421.6	418.25	453.2
38	00:06:10	442.1	391.1	386.6	434.2
39	00:06:20	418.2	369.4	363.8	420.3
40	00:06:30	387.8	344.4	336.1	390.9
41	00:06:40	351.1	311.3	301.2	351.3
42	00:06:50	311.7	273.8	262.75	312.1
43	00:07:00	280	246.5	233.25	283.4
44	00:07:10	254.4	226.4	210.4	261.1
45	00:07:20	229.2	204.9	187.05	236.5
46	00:07:30	207.9	187.7	167.8	215
47	00:07:40	188.6	170.5	149.55	196.2
48	00:07:50	173.8	157.5	135.65	184.7
49	00:08:00	157.2	143.5	120.35	169.2
50	00:08:10	144.2	133.1	108.65	156.7
51	00:08:20	135.2	125.6	100.4	147.8
52	00:08:30	125.4	116.6	91	138.5
53	00:08:40	116.7	109.3	83	131.3

Table 13. Tabulated Results in Averaged Temperature of All 5 Control Experiments (1^{st} – 5^{th})

H: M: S	Ctrl Exp 1	Ctrl Exp 2	Ctrl Exp 3	Ctrl Exp 4	Ctrl Exp 5
00:00:00	120.4	82.1	68.4	56.0	39.9
00:00:10	176.2	134.5	147.3	74.1	41.9
00:00:20	238.3	209.9	249.3	87.5	43.7
00:00:30	294.9	236.1	340.5	126.9	47.7
00:00:40	348.2	260.7	413.8	155.8	52.6
00:00:50	395.3	266.5	400.5	203.1	57.6
00:01:00	440.0	258.7	382.5	235.7	65.6
00:01:10	479.4	248.3	365.5	260.2	69.6

00:01:20	513.7	235.8	351.6	299.4	75.0
00:01:30	548.0	234.5	348.6	326.1	80.4
00:01:40	575.0	246.1	344.7	352.0	85.9
00:01:50	592.0	258.3	338.0	445.6	89.2
00:02:00	603.5	292.7	334.1	458.2	100.2
00:02:10	617.0	314.0	325.5	414.1	121.1
00:02:20	617.5	334.6	313.1	382.2	142.0
00:02:30	617.0	372.3	310.9	354.0	255.3
00:02:40	612.5	497.4	308.8	336.7	252.7
00:02:50	603.5	539.9	309.8	332.5	222.4
00:03:00	595.0	570.5	301.6	379.2	196.8
00:03:10	590.0	577.5	285.1	405.9	182.7
00:03:20	587.5	605.1	274.2	407.3	176.0
00:03:30	591.5	621.6	289.7	381.6	166.7
00:03:40	593.5	614.3	302.0	373.6	153.1
00:03:50	590.0	607.8	295.4	367.2	142.1
00:04:00	586.0	542.9	285.2	344.1	135.4
00:04:10	580.5	490.0	276.3	337.1	134.3
00:04:20	577.0	451.5	261.2	317.5	162.5
00:04:30	569.5	476.0	251.0	296.3	157.0
00:04:40	565.0	511.1	243.2	274.6	146.0
00:04:50	563.0	520.5	239.1	253.4	141.4
00:05:00	561.5	534.8	226.7	254.3	136.8
00:05:10	558.5	559.0	218.8	262.7	139.6
00:05:20	555.5	567.4	208.6	250.0	128.0
00:05:30	552.0	548.3	197.2	224.7	117.0
00:05:40	546.0	506.5	185.6	208.7	108.3
00:05:50	544.0	464.5	181.2	195.3	101.1
00:06:00	544.5	442.0	172.9	179.2	94.3
00:06:10	536.0	413.5	163.5	169.7	88.7
00:06:20	530.0	392.9	152.5	163.9	88.1
00:06:30	513.9	364.8	144.1	153.5	89.7
00:06:40	501.4	328.7	135.5	144.9	105.7
00:06:50	491.9	290.1	126.8	135.0	119.3
00:07:00	483.6	260.8	120.0	125.9	
00:07:10	478.6	238.1	112.6	116.8	
00:07:20	469.6	214.4	106.1	109.3	
00:07:30	465.3	194.6	100.5		
00:07:40	460.0	176.2	95.6		
00:07:50	457.3	162.9	92.2		
00:08:00	452.4	147.6	89.6		
00:08:10	448.7	135.7	87.4		
00:08:20	444.9	127.3	85.5		

00:08:30	434.6	117.9	82.9
00:08:40	417.5	110.1	80.2
00:08:50	406.5		
00:09:00	401.0		
00:09:10	382.7		
00:09:20	369.5		
00:09:30	356.7		
00:09:40	341.9		
00:09:50	326.9		
00:10:00	314.0		
00:10:10	301.4		
00:10:20	290.3		
00:10:30	279.8		
00:10:40	269.3		
00:10:50	259.3		
00:11:00	250.4		
00:11:10	242.2		
00:11:20	232.6		

Table 15: Control Experiment 6

H: M: S	1st Sensor (℃)	2nd Sensor (℃)	3rd Sensor (℃)	4th Sensor (℃)
00:00:00	37	59.0	41.1	38.8
00:00:10	58.8	57.9	66.5	48.4
00:00:20	100.9	95.4	122.2	63.1
00:00:30	123.2	114.9	144.2	77.2
00:00:40	138	127.9	154.1	91.7
00:00:50	152	141.9	164.3	109.5
00:01:00	259.6	223.8	244.1	167.6
00:01:10	368.5	307.7	336.2	218.5
00:01:20	452.6	392.4	454.6	269.9
00:01:30	422.6	380.7	430.9	288.6
00:01:40	480.1	436.0	479.6	348.2
00:01:50	458.9	426.2	463.4	356.3
00:02:00	419.4	405.4	436.1	360.7
00:02:10	388.6	389.4	416.4	363.2
00:02:20	364.6	376.7	402.4	363
00:02:30	341.2	358.4	382.5	351.5
00:02:40	327.9	349.8	374.2	347.2
00:02:50	317	339.5	359.4	342.1
00:03:00	297.5	323.1	339.1	332.6
00:03:10	289.6	314.5	330.4	323.4

00:03:20	285.9	307.8	322.3	315.1
00:03:30	273.6	298.1	311.8	308.8
00:03:40	272.5	298.4	316.3	306.5
00:03:50	268.1	293.0	309.3	301.5
00:04:00	259.3	284.0	296.3	296.3
00:04:10	255.3	279.2	289.3	292.9
00:04:20	252.2	276.2	284.6	291.8
00:04:30	249.8	272.6	279.6	288.4
00:04:40	247.4	268.8	274.1	284.9
00:04:50	248.1	270.7	275.8	288.2
00:05:00	251.2	272.5	279.2	287
00:05:10	253.2	272.5	280	284.2
00:05:20	249.6	267.9	274.3	279.8
00:05:30	246.1	264.1	270.1	276.1
00:05:40	248.4	265.4	271.4	276.4
00:05:50	249.7	266.3	272.8	276.5
00:06:00	249.6	265.5	271.4	275.4
00:06:10	242.7	259.0	262.2	272.2
00:06:20	238.3	255.1	256.3	270.7
00:06:30	234.5	253.4	253.7	271.9
00:06:40	228.7	249.9	248.8	272.1
00:06:50	226.4	248.7	247.2	272.4
00:07:00	223.7	245.9	245.2	268.8
00:07:10	217.8	242.3	240.5	268.6
00:07:20	209.9	234.7	233.3	260.9
00:07:30	199.3	225.2	223.4	252.9
00:07:40	189.4	216.0	213.7	245
00:07:50	181.8	208.3	204.4	238.8
00:08:00	173.6	200.3	195.4	232
00:08:10	174.6	200.1	197.9	227.9
00:08:20	221.2	243.6	262.6	247.1
00:08:30	225.4	243.3	261.8	242.8
00:08:40	216.5	236.9	251.2	243.1
00:08:50	211.9	235.5	250.4	244.1
00:09:00	206.4	231.8	247.3	241.7
00:09:10	197.6	223.5	236.4	236.4
00:09:20	184.9	212.4	221.4	230.8
00:09:30	177.9	205.9	212.4	227.3
00:09:40	175.4	202.3	208.9	222.7
00:09:50	179.7	203.8	212.6	219.1
00:10:00	191.8	213.0	228	219.3
00:10:10	196.2	214.3	232.1	214.7
00:10:20	193.7	211.3	226.6	213.7

00:10:30	175.2	196.1	205.6	207.4
00:10:40	162.4	185.1	190	202.9
00:10:50	151.7	175.2	176.5	197.5
00:11:00	146.7	170.0	168.7	194.6
00:11:10	152.2	173.4	176.2	191.7
00:11:20	165.4	180.3	183.9	191.7
00:11:30	166.5	179.0	181.2	189.3
00:11:40	166.1	177.6	179.6	187.2
00:11:50	179.9	189.8	198.7	190.9
00:12:00	197.3	201.1	213.4	192.6
00:12:10	196	203.3	219.5	194.3
00:12:20	192.4	202.0	216.4	197.3
00:12:30	188.7	200.1	212.9	198.6
00:12:40	183.9	196.8	207.4	199.1
00:12:50	183.9	195.5	205.3	197.4
00:13:00	189.2	201.5	215.9	199.4
00:13:10	203	209.7	225.8	200.2
00:13:20	229.7	238.3	275.1	210.1
00:13:30	285.9	285.1	340.9	228.4
00:13:40	268.1	268.8	311.4	226.9
00:13:50	240.1	248.8	278.7	227.5
00:14:00	232.4	245.1	274.1	228.9
00:14:10	234.9	249.8	284.7	229.9
00:14:20	230.8	245.6	276.9	229
00:14:30	219	235.1	261	225.3
00:14:40	203.2	220.8	237.9	221.3
00:14:50	184.8	204.9	217.7	212.2
00:15:00	181.4	201.3	214.6	207.9
00:15:10	174.9	194.1	202.4	204.9
00:15:20	168.1	187.4	192.1	202.1
00:15:30	183.4	197.2	206.1	202.2
00:15:40	178.3	192.3	200.1	198.6
00:15:50	192.9	203.8	217.6	200.8
00:16:00	189.6	200.8	214.5	198.3
00:16:10	180.7	194.5	207.5	195.2
00:16:20	178.8	191.8	202.8	193.9
00:16:30	175.4	187.2	195.6	190.6
00:16:40	185.3	197.2	210.9	195.3
00:16:50	179.8	191.6	201.6	193.4
00:17:00	186.5	198.2	213.9	194.2
00:17:10	174	187.1	197.7	189.7
00:17:20	169.3	183.7	191.7	190.2
00:17:30	167.1	182.1	190.6	188.7

00:17:40	168.5	184.8	197.2	188.6
00:17:50	166.3	181.7	194	184.9
00:18:00	168.1	181.2	192.3	183.1
00:18:10	187.8	196.7	208.3	194
00:18:20	172.7	186.1	195.7	189.8
00:18:30	162.1	179.4	186.7	189.3
00:18:40	152	171.9	175.9	187.9
00:18:50	150.1	170.8	171.9	190.4
00:19:00	147.2	168.7	169	190
00:19:10	147.6	169.0	167.3	192.1
00:19:20	143.6	165.7	162.1	191.4
00:19:30	142.8	165.3	160.4	192.8
00:19:40	142.8	165.6	159.8	194.3
00:19:50	151.3	174.8	170.8	202.3
00:20:00	173.9	194.9	187.4	223.5
00:20:10	175.2	195.8	185.8	226.4
00:20:20	186.7	205.3	191.7	237.6
00:20:30	190	206.7	189.6	240.6
00:20:40	181.8	201.4	182.7	239.7
00:20:50	172.6	195.8	177.3	237.4
00:21:00	164.7	190.5	172.3	234.6
00:21:10	160.3	187.9	170.1	233.4
00:21:20	153.1	182.1	165.1	228
00:21:30	154.2	180.9	162.7	225.9
00:21:40	160.4	185.8	166.3	230.6
00:21:50	182.8	200.9	183.4	236.6
00:22:00	189.2	205.1	185.3	240.7
00:22:10	179.4	198.6	179.8	236.7
00:22:20	164	187.5	168.7	229.9
00:22:30	155.5	182.1	164.4	226.5
00:22:40	147.4	175.8	158.4	221.6
00:22:50	140.7	170.0	152.6	216.7
00:23:00	143.9	172.2	154.5	218.3
00:23:10	228.4	233.8	215.6	257.4
00:23:20	248.8	247.7	231.4	262.8
00:23:30	256.6	252.3	231.5	268.9
00:23:40	248.2	248.6	227.7	270
00:23:50	236.7	242.8	220.4	271.2
00:24:00	221.6	236.4	221.3	266.4
00:24:10	229.6	242.7	234.8	263.8
00:24:20	227.8	238.1	226.8	259.8
00:24:30	211.3	225.3	211.9	252.8
00:24:40	202.7	218.5	207.7	245

00:24:50	213.9	227.9	225.1	244.8
00:25:00	207.2	221.9	222.9	235.5
00:25:10	207.4	222.4	226	233.8
00:25:20	214.6	228.9	236.8	235.2
00:25:30	204	221.6	229.6	231.2
00:25:40	189.6	211.0	218.6	224.9
00:25:50	173.7	197.3	200	218.1
00:26:00	163.2	187.7	187.1	212.9
00:26:10	158.9	182.8	180.9	208.6
00:26:20	157.3	179.7	179.6	202.3
00:26:30	168.5	186.7	191.7	199.9
00:26:40	167.1	183.5	189.2	194.3
00:26:50	181.7	195.8	211.2	194.6
00:27:00	194.5	207.0	233.4	193.2
00:27:10	182.6	196.2	216.8	189.3
00:27:20	184.9	196.6	215.1	189.9
00:27:30	177.6	188.0	201.6	184.8
00:27:40	184.6	191.8	207.7	183.1
00:27:50	189.7	199.5	225	183.7
00:28:00	184.6	195.5	221.8	180.2
00:28:10	182.1	193.4	219.8	178.3
00:28:20	174.4	188.2	216.1	174.1
00:28:30	176.5	189.5	217.8	174.2
00:28:40	172.3	185.2	210.4	172.8
00:28:50	166.4	181.6	207.5	170.8
00:29:00	164.2	183.4	215.8	170.3
00:29:10	163.6	181.0	209.2	170.2
00:29:20	173.1	186.6	213.9	172.9
00:29:30	173.2	186.5	212.1	174.2
00:29:40	175	189.2	216.3	176.4
00:29:50	170.7	184.4	208.3	174.1
00:30:00	183.3	197.2	230.3	178.1
00:30:10	189.6	202.9	238	181.2
00:30:20	191.7	202.8	234.1	182.7
00:30:30	181.2	196.1	225.6	181.4
00:30:40	179.5	194.0	222.6	179.9
00:30:50	176	192.7	222.6	179.5
00:31:00	178.7	194.7	224	181.4
00:31:10	181.4	198.2	229.9	183.3
00:31:20	188.1	204.6	242.6	183.1
00:31:30	175.3	193.8	229	177.2
00:31:40	163.6	182.3	209.7	173.7
00:31:50	168.1	188.5	224.5	172.8

00:32:00	163.6	182.6	215.3	169
00:32:10	157.3	175.0	203.1	164.6
00:32:20	158.9	172.7	197.3	161.9
00:32:30	150.9	164.5	185	157.6
00:32:40	150.5	163.4	184.4	155.2
00:32:50	149.4	159.9	179.3	151.1
00:33:00	140.6	152.6	169.4	147.8
00:33:10	143.5	154.2	171.9	147.1
00:33:20	135	146.0	160.9	142.2
00:33:30	122.9	135.4	145.9	137.3
00:33:40	137.3	148.5	167.6	140.7
00:33:50	138.9	149.6	169.1	140.8
00:34:00	147.3	156.3	177.5	144.2
00:34:10	153.5	161.2	185.6	144.4
00:34:20	156.2	164.9	193.8	144.7
00:34:30	158.1	168.8	200.4	147.8
00:34:40	166.2	173.6	204.6	150
00:34:50	162.1	170.3	197.6	151.2
00:35:00	150.4	160.8	183.7	148.4
00:35:10	136.4	149.1	165.1	145.9
00:35:20	125.5	139.5	151	142.1
00:35:30	126.4	141.8	158.6	140.5
00:35:40	145.8	157.2	180.2	145.6
00:35:50	144.5	155.2	176.4	144.7
00:36:00	143.8	153.6	171.2	145.7
00:36:10	143.6	153.0	171.1	144.2
00:36:20	148.3	157.6	179.3	145.2
00:36:30	166.1	173.0	203.9	148.9
00:36:40	164.8	169.4	196.2	147.1
00:36:50	157.3	163.4	187.1	145.7
00:37:00	153.6	162.1	187.2	145.6
00:37:10	152.5	161.6	187.2	145.1
00:37:20	152.7	160.3	184.6	143.6
00:37:30	142.8	150.5	169.2	139.6
00:37:40	140.4	148.3	164.7	139.8
00:37:50	150.6	159.2	182.5	144.4
00:38:00	155	163.1	190	144.4
00:38:10	156.9	164.1	191.9	143.6
00:38:20	168.2	173.7	202.2	150.8
00:38:30	162.2	167.9	192.3	149.3
00:38:40	178.1	182.0	208.8	159.1
00:38:50	193.1	193.7	223.5	164.6
00:39:00	179.3	183.1	206.9	163.1

00:39:10	158.7	167.5	184.2	159.6
00:39:20	145.2	158.1	172.9	156.2
00:39:30	135.2	149.6	163.7	149.9
00:39:40	123.2	139.2	147.8	146.7
00:39:50	123.8	138.9	147.6	145.4
00:40:00	123.2	139.4	152.9	142.2
00:40:10	141.8	153.6	176.9	142.1
00:40:20	134.3	145.7	163.6	139.3
00:40:30	147.9	156.4	179	142.2
00:40:40	150.7	158.2	182.7	141.3
00:40:50	163.5	163.8	184.2	143.8
00:41:00	151.8	154.6	170.2	141.7
00:41:10	159.2	160.2	178.2	143.3
00:41:20	145.1	148.3	161	138.7
00:41:30	133.2	139.1	147.7	136.3
00:41:40	124.8	133.2	141.3	133.4
00:41:50	118.3	127.8	134.5	130.6
00:42:00	112.9	123.7	128.1	130.1
00:42:10	112.2	122.1	125.6	128.6
00:42:20	110.9	123.2	129.8	129
00:42:30	123.4	135.7	152.4	131.2
00:42:40	128.4	141.3	164	131.6
00:42:50	142.6	152.4	180.3	134.2
00:43:00	144.9	152.1	178.3	133.1
00:43:10	143	150.2	174.6	133.1
00:43:20	137.3	146.3	169.6	132
00:43:30	144.7	153.1	178.7	135.9
00:43:40	150.3	155.8	181.3	135.9
00:43:50	160.9	166.2	197.7	140.1
00:44:00	160.8	171.5	211.4	142.4
00:44:10	169.6	177.2	216.5	145.6
00:44:20	182.1	189.4	235.2	150.9
00:44:30	183.6	189.8	233.3	152.4
00:44:40	180.4	186.1	225.3	152.7
00:44:50	169.2	177.8	212.6	151.6
00:45:00	184	193.6	238.4	158.5
00:45:10	186.3	194.9	238.7	159.6
00:45:20	180.1	188.4	227.7	157.4
00:45:30	164.1	174.6	203.3	156.4
00:45:40	166.4	175.6	204.3	156.2
00:45:50	163.4	172.2	198.3	154.8
00:46:00	153.4	163.6	186.6	150.9
00:46:10	146.9	158.1	178.6	148.8

00:46:20	143.9	155.3	174.5	147.6
00:46:30	141.2	154.7	176.8	146.2
00:46:40	149.3	161.0	185.1	148.5
00:46:50	142.6	153.7	173.9	144.6
00:47:00	139	151.3	172.5	142.5
00:47:10	143.2	153.9	175.4	143.1
00:47:20	139	149.7	168.1	142
00:47:30	126.2	138.5	151.5	137.7
00:47:40	126.5	138.0	152.1	135.5
00:47:50	125.7	138.0	154.6	133.8
00:48:00	128.8	139.7	156.2	134.1
00:48:10	121.2	132.7	145.5	131.4
00:48:20	116.7	127.8	136.8	129.9
00:48:30	108.9	120.6	126.8	126.1
00:48:40	104.6	116.4	121.3	123.4
00:48:50	100.3	112.3	116.1	120.6
00:49:00	98	110.2	112.1	120.4
00:49:10	95.9	108.4	109.7	119.7
00:49:20	97.5	108.8	110.9	118.1
00:49:30	118.9	124.5	131.1	123.6
00:49:40	138.8	140.5	158.5	124.2
00:49:50	144.5	146.6	169.1	126.1
00:50:00	139	142.5	163.3	125.1
00:50:10	141.9	143.7	164.3	124.9
00:50:20	151	155.6	186.7	129.2
00:50:30	147.1	152.7	182.1	128.9
00:50:40	138.3	145.5	169.3	129
00:50:50	128.9	137.5	156.9	126.8
00:51:00	130.1	137.0	152.5	128.4
00:51:10	138.3	145.1	163.5	133.4
00:51:20	140.2	146.4	164.8	134.1
00:51:30	141.3	148.7	170.6	134.3
00:51:40	142.2	152.2	179.4	135.1
00:51:50	135.1	146.5	172.7	131.8
00:52:00	131.5	142.5	166.3	129.7
00:52:10	130.3	142.7	169.3	128.4
00:52:20	136.3	145.1	170.2	128.9
00:52:30	143.4	148.9	174.3	128.9
00:52:40	143.8	148.1	172.7	127.9
00:52:50	145.1	151.2	178.3	130.1
00:53:00	159.1	158.1	184.4	130.7
00:53:10	149.6	151.3	174.7	129.6
00:53:20	159.6	159.2	183.7	134.4

00:53:30	149.4	152.5	175.9	132.2
00:53:40	150.4	155.5	182.1	133.9
00:53:50	151.3	156.3	182.8	134.9
00:54:00	141.2	147.1	168	132.2
00:54:10	145.6	151.5	175.6	133.3
00:54:20	149.5	154.1	179	133.7
00:54:30	144.1	148.8	169.6	132.7
00:54:40	140.5	146.4	166.1	132.7
00:54:50	135.2	141.8	159.3	130.9
00:55:00	128.4	136.7	151.9	129.8
00:55:10	136.2	141.4	157.2	130.7
00:55:20	127.6	134.2	146.2	128.9
00:55:30	124.5	132.8	144.4	129.5
00:55:40	119.4	129.3	139.3	129.3

Table 17: Control Experiment 7

H: M: S	1st Sensor (℃)	2nd Sensor (℃)	3rd Sensor (℃)	4th Sensor (℃)
00:00:00	44.5	41.9	46.3	45.3
00:00:10	50.9	45.9	52.9	53.9
00:00:20	69.0	60.1	73.6	73.2
00:00:30	90.6	78.1	96.4	97.2
00:00:40	109.5	94.5	117	116.9
00:00:50	132.1	115.8	140	140.6
00:01:00	146.1	130.8	151.9	155.6
00:01:10	162.4	149	167	171.3
00:01:20	175.9	165.9	178.5	183.4
00:01:30	188.7	181.9	191.9	192.2
00:01:40	198.3	195.1	197.9	201.9
00:01:50	205.8	207.6	202.8	207
00:02:00	211.4	218.6	205.8	209.7
00:02:10	231.6	239.9	229.6	225.2
00:02:20	278.0	282.3	298.8	253
00:02:30	280.2	291.8	294.8	254
00:02:40	282.0	300.6	290.1	255.3
00:02:50	276.1	301.6	275.3	251.5
00:03:00	285.9	313.9	286.5	257.3
00:03:10	286.9	320.1	285.2	255.4
00:03:20	295.0	331	291.1	262.8
00:03:30	305.0	342.1	302.8	270.2
00:03:40	308.9	350.2	304.8	271.8
00:03:50	308.4	354.2	299.6	271.5

00:04:00	306.4	356.5	293.4	269.2
00:04:10	305.1	357.7	288.1	269.5
00:04:20	302.8	356.5	282.1	269.8
00:04:30	301.5	355.7	278	270.7
00:04:40	300.9	356.2	275.4	271.2
00:04:50	302.7	357.3	277.9	272.9
00:05:00	301.1	356.3	274.1	272.9
00:05:10	295.7	353.3	266.1	267.6
00:05:20	304.1	358.4	276.6	277.4
00:05:30	304.0	358.7	279.2	274
00:05:40	304.2	357.6	279	276.1
00:05:50	309.2	360.5	286.3	280.9
00:06:00	308.3	358.5	284.8	281.6
00:06:10	308.5	359.6	283.6	282.4
00:06:20	309.3	362.1	283.6	282.2
00:06:30	309.1	365.5	281.6	280.3
00:06:40	310.3	372.4	280.9	277.5
00:06:50	310.0	374.8	278.9	276.4
00:07:00	315.1	378.9	285.9	280.4
00:07:10	413.1	415.9	426.9	396.4
00:07:20	460.8	430.6	490.2	461.7
00:07:30	579.0	506	639	592
00:07:40	578.3	535	626	574
00:07:50	632.3	601	672	624
00:08:00	635.3	630	672	604
00:08:10	590.0	617	604	549
00:08:20	543.9	596	540	495.7
00:08:30	504.3	574	487.6	451.3
00:08:40	483.9	560	472.5	419.2
00:08:50	456.2	535	442.1	391.5
00:09:00	444.0	523	432.3	376.6
00:09:10	428.9	508	417.9	360.7
00:09:20	477.3	532	485.9	414.1
00:09:30	481.1	529	489.4	424.8
00:09:40	571.7	585	603	527
00:09:50	612.0	615	647	574
00:10:00	570.0	598	587	525
00:10:10	598.0	619	619	556
00:10:20	578.7	615	591	530
00:10:30	552.8	602	558	498.4
00:10:40	567.7	609	586	508
00:10:50	586.7	610	614	536
00:11:00	588.0	598	605	561

00:11:10	572.3	576	585	556
00:11:20	535.3	546	540	520
00:11:30	511.5	518	517	499.6
00:11:40	481.6	490.4	478.3	476.2
00:11:50	467.2	471.8	460.1	469.7
00:12:00	509.9	499.6	520	510
00:12:10	528.0	515	543	526
00:12:20	507.4	517	517	488.2
00:12:30	490.2	519	493.3	458.4
00:12:40	490.4	526	490.1	455.2
00:12:50	461.4	511	453.4	419.7
00:13:00	436.3	494.7	422.1	392.2
00:13:10	415.3	478.1	396.3	371.5
00:13:20	399.0	463.4	378.6	354.9
00:13:30	383.0	448.8	361.2	339.1
00:13:40	385.2	449.7	365.7	340.1
00:13:50	375.2	439.7	355.6	330.2
00:14:00	378.6	438.6	360.6	336.7
00:14:10	365.4	426.3	345.2	324.7
00:14:20	357.6	418.9	338.9	314.9
00:14:30	342.4	406	320.4	300.8
00:14:40	335.8	399.9	313.8	293.8
00:14:50	327.1	391.3	304.5	285.5
00:15:00	317.7	383	294.2	275.8
00:15:10	301.9	368.8	274.9	262.1
00:15:20	289.0	356.6	259.9	250.6
00:15:30	276.9	344.8	247.5	238.5
00:15:40	264.0	331.4	234.6	226.1
00:15:50	258.2	322	228.4	224.3
00:16:00	250.9	313.1	221.4	218.3
00:16:10	241.2	303	211.6	208.9
00:16:20	229.5	292	199.4	197.2
00:16:30	220.9	283.4	191.1	188.3
00:16:40	215.1	275.3	186.4	183.7
00:16:50	214.2	270.5	187.5	184.7
00:17:00	218.3	271.2	194.3	189.4
00:17:10	220.1	272.1	197.7	190.6
00:17:20	226.5	275.3	205.1	199.1
00:17:30	224.5	272.2	202.9	198.3
00:17:40	230.6	276.6	210.3	204.9
00:17:50	229.5	274.9	208.7	204.9
00:18:00	229.0	275.1	208.3	203.6
00:18:10	231.0	275.6	212.7	204.8

00:18:20	240.5	280.9	227.8	212.8
00:18:30	243.1	283.1	229.8	216.3
00:18:40	237.4	280.2	221.7	210.2
00:18:50	234.1	279.6	216.8	206
00:19:00	236.5	282.1	219.1	208.3
00:19:10	244.4	288.2	228.9	216.2
00:19:20	250.8	294.6	234.7	223.1
00:19:30	253.4	296.1	235.6	228.4
00:19:40	257.1	300.1	238.7	232.4
00:19:50	257.0	301.4	235.7	233.8
00:20:00	253.4	300.4	230.8	228.9
00:20:10	260.2	306.4	237.9	236.2
00:20:20	267.9	312.4	245.7	245.5
00:20:30	264.6	310.9	241.4	241.5
00:20:40	274.9	319.5	254.1	251.2
00:20:50	266.9	315.6	243.7	241.5
00:21:00	254.5	307.7	228.4	227.4
00:21:10	256.5	308.9	231.7	228.9
00:21:20	261.6	313.1	237	234.8
00:21:30	262.2	313.6	238	235.1
00:21:40	261.7	314.3	237.7	233.2
00:21:50	257.2	310.9	231.1	229.7
00:22:00	254.3	308.4	227.2	227.3
00:22:10	252.7	307.6	225.1	225.4
00:22:20	251.6	305.6	225.5	223.7
00:22:30	250.3	304.9	225.5	220.4
00:22:40	251.0	305.5	225.5	221.9
00:22:50	265.3	316.3	248.8	230.8
00:23:00	266.7	317.4	251.1	231.6
00:23:10	267.7	318.9	252.6	231.6
00:23:20	262.9	314.6	245.2	228.8
00:23:30	259.2	311.6	239.2	226.9
00:23:40	258.3	310.7	237.6	226.7
00:23:50	260.4	311.4	240.1	229.7
00:24:00	265.8	316.7	247.1	233.6
00:24:10	283.0	330.3	269.9	248.9
00:24:20	316.5	358.2	307.3	283.9
00:24:30	327.0	368.3	316.1	296.7
00:24:40	328.6	374.2	315.2	296.4
00:24:50	327.5	376.4	310.8	295.4
00:25:00	319.6	372.8	299.3	286.8
00:25:10	305.2	364.5	280.7	270.5
00:25:20	295.9	358.4	268.8	260.5

00:25:30	291.4	352.8	263.9	257.4
00:25:40	284.8	346.6	257.3	250.6
00:25:50	276.9	338.9	247.6	244.3
00:26:00	282.3	334.7	256.3	256
00:26:10	265.6	319.6	239.8	237.4
00:26:20	253.6	307.2	227.9	225.6
00:26:30	267.4	305.9	248.3	247.9
00:26:40	271.5	305.9	251.9	256.6
00:26:50	266.0	301.8	245.6	250.6
00:27:00	261.0	298.9	238.7	245.4
00:27:10	248.7	291.1	223.4	231.6
00:27:20	241.2	285.7	214.1	223.7
00:27:30	229.8	277.4	202.6	209.5
00:27:40	220.3	270	193.1	197.8
00:27:50	213.1	264.7	185.9	188.7
00:28:00	213.1	263.8	188.6	186.9
00:28:10	216.9	264.9	193.9	191.9
00:28:20	230.3	271.6	213.7	205.6
00:28:30	261.4	281.4	248.4	254.3
00:28:40	317.9	311.1	309.3	333.2
00:28:50	361.6	326.3	349.8	408.8
00:29:00	424.8	358.1	424.1	492.3
00:29:10	483.0	399.9	494.2	555
00:29:20	470.6	402.1	475.8	534
00:29:30	437.0	394.3	432.9	483.7
00:29:40	407.7	385.3	395.7	442.2
00:29:50	384.7	373.9	366.4	413.8
00:30:00	361.7	361.2	340.2	383.7
00:30:10	348.7	350.4	325.8	369.9
00:30:20	367.3	347.3	349.3	405.3
00:30:30	364.6	346.4	351.6	395.9
00:30:40	348.1	342.9	332.6	368.7
00:30:50	329.7	336.8	312.4	340
00:31:00	312.0	329.9	292.4	313.8
00:31:10	291.1	319.6	268.6	285.1
00:31:20	271.0	307.9	246.4	258.7
00:31:30	257.9	299.2	232.6	241.9
00:31:40	251.9	293.7	227.5	234.5
00:31:50	243.8	287.1	220.6	223.7
00:32:00	240.3	284	219.8	217.2
00:32:10	228.2	274.7	206.7	203.3
00:32:20	226.8	272.7	205.8	201.8
00:32:30	213.8	261.6	191.7	188.1

00:32:40	212.0	257.9	191.1	186.9
00:32:50	204.2	250.3	182.7	179.6
00:33:00	202.4	247.7	181.8	177.7
00:33:10	196.5	242.1	175.6	171.9
00:33:20	205.6	245	188.3	183.6
00:33:30	195.8	237.3	177.9	172.3
00:33:40	188.1	233.4	168.7	162.1
00:33:50	181.4	227.6	161.2	155.3
00:34:00	179.4	224.5	159.7	153.9
00:34:10	175.5	218.9	156.2	151.4
00:34:20	179.8	220.3	161.8	157.3
00:34:30	178.3	218.1	162.7	154.1
00:34:40	178.9	219.1	164.4	153.2
00:34:50	181.2	219.8	167.2	156.6
00:35:00	191.0	223.3	175.8	173.9
00:35:10	198.9	227.3	182.4	186.9
00:35:20	191.9	223.2	175.6	176.8
00:35:30	192.7	224.1	178.7	175.2
00:35:40	190.8	223.6	176.2	172.7
00:35:50	184.2	218.8	168.1	165.7
00:36:00	179.6	216.6	162.6	159.7
00:36:10	176.7	215.4	159.2	155.6
00:36:20	170.9	211.4	151.9	149.5
00:36:30	163.5	205.6	143.6	141.4
00:36:40	164.4	205.3	144.9	143.1
00:36:50	172.2	205.9	157.3	153.3
00:37:00	172.1	204.9	159	152.4
00:37:10	169.6	203.2	156.4	149.2
00:37:20	164.6	199.8	151	143.1
00:37:30	170.3	202.4	160.4	148.1
00:37:40	165.7	198.9	155.8	142.3
00:37:50	162.5	196.8	153.6	137.2
00:38:00	150.3	188.3	138.9	123.8
00:38:10	147.0	185.1	132.8	123.2
00:38:20	152.6	186.6	138.8	132.4
00:38:30	150.9	183.2	136.8	132.7
00:38:40	154.9	186.3	140	138.3
00:38:50	151.9	185.3	140.3	130.2

Table 19: Control Experiment 8

H: M: S	1st Sensor (℃)	2nd Sensor (℃)	3rd Sensor (℃)	4th Sensor (℃)

00:00:00	78.2	70.8	68.9	65.4
00:00:10	98.7	89.4	90.2	79.2
00:00:20	140.3	122.6	127.7	99.9
00:00:30	163.2	141.9	147.5	114.9
00:00:40	203.6	176.4	178.5	147.0
00:00:50	224.3	198.1	200.1	169.8
00:01:00	250.4	222.6	221.6	195.9
00:01:10	284.4	257.3	260.4	227.1
00:01:20	306.6	281.4	284.3	253.4
00:01:30	355.5	327.1	318.5	307.2
00:01:40	425.9	390.2	374.4	370.2
00:01:50	452.1	418.2	399.3	403.2
00:02:00	433.1	412.4	386.0	418.2
00:02:10	433.1	420.4	389.1	439.1
00:02:20	418.4	415.3	380.4	447.0
00:02:30	394.4	399.8	360.0	445.1
00:02:40	388.2	397.4	354.5	449.4
00:02:50	403.1	414.5	381.6	458.9
00:03:00	414.5	427.2	395.0	472.1
00:03:10	408.8	424.1	386.9	476.6
00:03:20	428.6	443.2	404.0	497.1
00:03:30	480.5	485.9	450.9	526.4
00:03:40	531.9	529.5	494.7	561.9
00:03:50	532.1	535.8	494.9	580.4
00:04:00	494.4	508.6	459.3	572.0
00:04:10	473.0	494.2	440.7	568.8
00:04:20	503.3	517.2	470.9	577.4
00:04:30	573.2	563.7	524.4	593.4
00:04:40	583.7	568.9	518.0	605.0
00:04:50	542.9	541.3	485.6	595.4
00:05:00	505.2	517.5	458.9	588.5
00:05:10	480.9	502.4	443.3	583.1
00:05:20	457.2	485.3	423.9	574.7
00:05:30	440.0	472.2	409.1	567.5
00:05:40	431.4	465.5	399.9	565.1
00:05:50	426.5	459.4	393.2	558.6
00:06:00	436.5	467.5	404.6	561.3
00:06:10	452.4	477.8	412.1	569.0
00:06:20	452.7	478.1	411.9	569.7
00:06:30	443.7	471.1	404.7	564.9
00:06:40	490.1	510.0	442.1	597.9
00:06:50	487.4	510.1	439.5	603.5
00:07:00	503.1	529.3	468.2	616.7

00:07:10	519.5	538.3	476.4	618.9
00:07:20	496.4	522.0	461.0	608.7
00:07:30	490.1	519.6	460.8	608.0
00:07:40	490.8	520.1	457.7	611.9
00:07:50	520.1	540.1	479.4	620.9
00:08:00	507.5	532.5	468.5	621.5
00:08:10	501.6	528.0	458.4	624.0
00:08:20	510.6	533.7	461.1	629.4
00:08:30	497.7	525.2	453.2	624.6
00:08:40	524.1	548.5	483.9	637.4
00:08:50	521.9	544.0	478.7	631.4
00:09:00	517.2	539.7	472.2	629.6
00:09:10	534.0	554.4	490.7	638.6
00:09:20	533.0	550.6	485.0	633.9
00:09:30	507.3	533.1	464.4	627.6
00:09:40	527.1	549.6	485.4	636.2
00:09:50	504.2	529.5	463.8	620.4
00:10:00	487.4	514.6	446.0	610.4
00:10:10	474.3	501.2	430.1	599.3
00:10:20	455.9	485.1	412.7	586.8
00:10:30	438.9	471.9	402.6	574.1
00:10:40	435.5	466.4	401.3	562.5
00:10:50	410.0	448.3	385.5	549.3
00:11:00	393.6	434.3	371.4	537.9
00:11:10	373.8	419.0	356.6	526.7
00:11:20	352.4	400.7	337.5	512.1
00:11:30	334.7	384.8	321.3	498.3
00:11:40	315.2	369.1	304.7	487.4
00:11:50	305.6	359.3	296.6	475.8
00:12:00	305.9	354.3	293.0	464.0
00:12:10	311.9	356.2	299.7	457.1
00:12:20	319.8	360.8	306.0	456.6
00:12:30	318.9	358.3	304.8	451.1
00:12:40	337.1	373.0	324.9	457.1
00:12:50	343.1	377.1	328.4	459.9
00:13:00	455.1	469.8	449.7	504.6
00:13:10	535.2	526.7	525.0	519.8
00:13:20	548.0	536.4	529.2	532.1
00:13:30	564.6	554.8	542.9	557.0
00:13:40	600.5	583.9	571.8	579.3
00:13:50	561.3	556.3	538.4	569.3
00:14:00	531.5	533.7	507.5	562.1
00:14:10	508.4	516.9	490.7	551.7

00:14:20	495.3	505.0	475.8	543.9
00:14:30	462.3	479.8	446.4	530.7
00:14:40	453.9	471.0	437.6	521.4
00:14:50	426.5	448.1	410.9	506.9
00:15:00	455.7	472.7	446.7	515.6
00:15:10	451.2	465.3	434.4	510.2
00:15:20	434.6	450.5	414.6	502.2
00:15:30	473.1	491.7	463.7	538.2
00:15:40	538.1	543.6	516.5	576.2
00:15:50	600.2	589.7	588.6	580.2
00:16:00	564.0	566.3	570.9	563.9
00:16:10	525.5	542.1	551.6	549.3
00:16:20	488.7	514.8	523.5	532.2
00:16:30	505.8	520.7	528.0	528.2
00:16:40	556.8	559.0	588.6	531.5
00:16:50	615.5	602.8	645.6	547.4
00:17:00	635.9	616.1	649.2	563.1
00:17:10	578.6	571.8	583.2	553.7
00:17:20	539.6	542.6	538.7	549.6
00:17:30	514.2	523.6	511.1	545.4
00:17:40	502.1	511.8	490.2	543.2
00:17:50	520.4	530.6	516.0	555.3
00:18:00	512.6	521.3	506.4	544.8
00:18:10	532.4	536.8	532.2	545.9
00:18:20	518.1	526.0	515.1	544.7
00:18:30	510.3	517.8	502.8	540.3
00:18:40	506.9	510.0	494.9	528.2
00:18:50	488.0	498.1	495.0	511.2
00:19:00	479.0	495.9	505.1	503.7
00:19:10	455.6	477.2	484.8	491.3
00:19:20	460.1	474.6	485.3	478.4
00:19:30	459.9	470.5	483.2	468.5
00:19:40	430.8	449.1	465.3	451.1
00:19:50	425.1	443.5	459.9	445.4
00:20:00	425.1	444.1	467.9	439.4
00:20:10	464.0	475.2	512.0	449.6
00:20:20	496.8	487.9	509.7	457.2
00:20:30	498.3	485.7	493.4	465.3
00:20:40	498.2	492.6	504.2	475.4
00:20:50	579.3	557.0	583.7	507.9
00:21:00	573.3	551.1	568.1	511.8
00:21:10	546.8	537.0	544.8	519.5
00:21:20	531.2	526.0	527.4	519.3

00:21:30	489.3	494.0	484.8	507.9
00:21:40	474.6	485.6	467.9	514.2
00:21:50	443.0	463.3	436.8	510.0
00:22:00	411.0	440.3	407.1	502.7
00:22:10	395.1	428.6	390.9	499.7
00:22:20	466.7	482.2	452.4	527.4
00:22:30	561.2	556.0	547.1	559.7
00:22:40	539.1	535.4	517.2	549.9
00:22:50	515.3	517.8	491.9	546.2
00:23:00	523.2	519.1	481.1	552.9
00:23:10	490.5	496.8	463.8	536.0
00:23:20	469.1	482.6	457.1	521.6
00:23:30	459.2	475.5	458.4	508.8
00:23:40	451.4	472.6	463.4	503.1
00:23:50	434.3	460.8	461.4	486.6
00:24:00	420.2	455.3	469.7	476.0
00:24:10	411.8	449.5	470.0	466.8
00:24:20	436.1	464.0	481.7	474.3
00:24:30	475.5	489.9	506.1	488.0
00:24:40	531.5	529.6	553.4	503.9
00:24:50	648.3	614.8	649.7	546.3
00:25:00	700.4	659.4	702.5	575.4
00:25:10	645.5	628.1	673.8	565.1
00:25:20	622.4	611.7	642.3	570.5
00:25:30	583.4	588.4	613.8	568.1
00:25:40	555.5	565.3	575.3	565.1
00:25:50	552.3	562.7	568.7	567.2
00:26:00	532.1	547.7	543.9	567.2
00:26:10	507.6	527.0	512.1	561.3
00:26:20	476.7	501.3	476.9	550.4
00:26:30	490.5	509.6	483.5	554.9
00:26:40	465.9	488.3	457.8	541.2
00:26:50	436.1	463.2	428.1	525.5
00:27:00	460.7	482.9	456.6	531.3
00:27:10	449.6	472.9	445.4	523.8
00:27:20	428.4	454.9	422.1	514.2
00:27:30	413.9	442.6	406.4	507.5
00:27:40	413.9	441.1	405.0	504.3
00:27:50	445.7	466.8	434.0	520.8
00:28:00	441.6	463.9	440.9	509.1
00:28:10	502.1	506.0	491.6	524.3
00:28:20	504.5	505.7	489.5	523.2
00:28:30	509.1	509.4	496.8	522.3

00:28:40	556.2	546.4	554.6	528.5
00:28:50	539.3	537.0	551.9	519.9
00:29:00	498.9	505.9	512.1	506.7
00:29:10	489.2	497.2	495.9	506.4
00:29:20	495.3	497.6	492.6	504.9
00:29:30	508.1	503.2	491.6	510.0
00:29:40	492.3	494.0	483.2	506.6
00:29:50	487.1	485.8	473.9	496.4
00:30:00	479.4	477.3	463.1	489.3
00:30:10	472.4	474.6	461.4	489.9
00:30:20	462.3	465.2	452.1	481.1
00:30:30	454.8	461.6	453.3	476.6
00:30:40	450.5	459.5	450.3	477.6
00:30:50	429.9	443.5	430.7	469.8
00:31:00	399.5	417.4	397.5	455.3
00:31:10	372.9	400.1	384.5	442.8
00:31:20	393.5	414.9	401.3	449.9
00:31:30	383.0	403.2	380.6	446.0
00:31:40	342.5	370.9	341.4	428.7
00:31:50	334.8	361.5	322.8	426.9
00:32:00	302.4	334.8	290.4	411.5
00:32:10	276.8	311.8	265.2	393.5
00:32:20	264.6	298.9	250.8	381.3
00:32:30	253.8	289.5	243.9	370.7
00:32:40	227.4	265.8	218.7	351.3
00:32:50	205.7	247.1	200.0	335.6
00:33:00	191.1	233.3	186.8	321.9
00:33:10	177.2	219.4	173.3	307.7
00:33:20	164.9	206.5	160.8	293.9
00:33:30	156.9	197.0	152.6	281.6
00:33:40	151.2	190.3	148.4	271.4
00:33:50	146.0	183.4	144.3	260.0
00:34:00	136.2	173.6	139.2	245.4
00:34:10	128.1	165.0	133.7	233.1
00:34:20	122.7	159.3	130.7	224.6
00:34:30	119.4	154.8	127.7	217.2
00:34:40	116.1	149.8	124.2	209.1
00:34:50	111.9	144.3	120.5	200.6
00:35:00	108.8	139.7	117.2	193.1

Table 20: Tabulated Results in Averaged Temperature of All 3 (6^{th} – 8^{th}) Control Experiments

Time (H:M:S)	Ctrl Exp 6	Ctrl Exp 7	Ctrl Exp 8 (Wind-Shielded)
00:00:00	44.0	44.5	70.8
00:00:10	57.9	50.9	89.4
00:00:20	95.4	69.0	122.6
00:00:30	114.9	90.6	141.9
00:00:40	127.9	109.5	176.4
00:00:50	141.9	132.1	198.1
00:01:00	223.8	146.1	222.6
00:01:10	307.7	162.4	257.3
00:01:20	392.4	175.9	281.4
00:01:30	380.7	188.7	327.1
00:01:40	436.0	198.3	390.2
00:01:50	426.2	205.8	418.2
00:02:00	405.4	211.4	412.4
00:02:10	389.4	231.6	420.4
00:02:20	376.7	278.0	415.3
00:02:30	358.4	280.2	399.8
00:02:40	349.8	282.0	397.4
00:02:50	339.5	276.1	414.5
00:03:00	323.1	285.9	427.2
00:03:10	314.5	286.9	424.1
00:03:20	307.8	295.0	443.2
00:03:30	298.1	305.0	485.9
00:03:40	298.4	308.9	529.5
00:03:50	293.0	308.4	535.8
00:04:00	284.0	306.4	508.6
00:04:10	279.2	305.1	494.2
00:04:20	276.2	302.8	517.2
00:04:30	272.6	301.5	563.7
00:04:40	268.8	300.9	568.9
00:04:50	270.7	302.7	541.3
00:05:00	272.5	301.1	517.5
00:05:10	272.5	295.7	502.4
00:05:20	267.9	304.1	485.3
00:05:30	264.1	304.0	472.2
00:05:40	265.4	304.2	465.5
00:05:50	266.3	309.2	459.4
00:06:00	265.5	308.3	467.5
00:06:10	259.0	308.5	477.8
00:06:20	255.1	309.3	478.1
00:06:30	253.4	309.1	471.1
00:06:40	249.9	310.3	510.0
00:06:50	248.7	310.0	510.1

00:07:00	245.9	315.1	529.3
00:07:10	242.3	413.1	538.3
00:07:20	234.7	460.8	522.0
00:07:30	225.2	579.0	519.6
00:07:40	216.0	578.3	520.1
00:07:50	208.3	632.3	540.1
00:08:00	200.3	635.3	532.5
00:08:10	200.1	590.0	528.0
00:08:20	243.6	543.9	533.7
00:08:30	243.3	504.3	525.2
00:08:40	236.9	483.9	548.5
00:08:50	235.5	456.2	544.0
00:09:00	231.8	444.0	539.7
00:09:10	223.5	428.9	554.4
00:09:20	212.4	477.3	550.6
00:09:30	205.9	481.1	533.1
00:09:40	202.3	571.7	549.6
00:09:50	203.8	612.0	529.5
00:10:00	213.0	570.0	514.6
00:10:10	214.3	598.0	501.2
00:10:20	211.3	578.7	485.1
00:10:30	196.1	552.8	471.9
00:10:40	185.1	567.7	466.4
00:10:50	175.2	586.7	448.3
00:11:00	170.0	588.0	434.3
00:11:10	173.4	572.3	419.0
00:11:20	180.3	535.3	400.7
00:11:30	179.0	511.5	384.75
00:11:40	177.6	481.6	369.05
00:11:50	189.8	467.2	359.3
00:12:00	201.1	509.9	354.25
00:12:10	203.3	528.0	356.2
00:12:20	202.0	507.4	360.8
00:12:30	200.1	490.2	358.25
00:12:40	196.8	490.4	373
00:12:50	195.5	461.4	377.1
00:13:00	201.5	436.3	469.8
00:13:10	209.7	415.3	526.65
00:13:20	238.3	399.0	536.4
00:13:30	285.1	383.0	554.8
00:13:40	268.8	385.2	583.85
00:13:50	248.8	375.2	556.3
00:14:00	245.1	378.6	533.65

00:14:10	249.8	365.4	516.9
00:14:20	245.6	357.6	505
00:14:30	235.1	342.4	479.8
00:14:40	220.8	335.8	470.95
00:14:50	204.9	327.1	448.05
00:15:00	201.3	317.7	472.65
00:15:10	194.1	301.9	465.25
00:15:20	187.4	289.0	450.45
00:15:30	197.2	276.9	491.65
00:15:40	192.3	264.0	543.55
00:15:50	203.8	258.2	589.65
00:16:00	200.8	250.9	566.25
00:16:10	194.5	241.2	542.1
00:16:20	191.8	229.5	514.8
00:16:30	187.2	220.9	520.65
00:16:40	197.2	215.1	558.95
00:16:50	191.6	214.2	602.8
00:17:00	198.2	218.3	616.05
00:17:10	187.1	220.1	571.8
00:17:20	183.7	226.5	542.6
00:17:30	182.1	224.5	523.55
00:17:40	184.8	230.6	511.8
00:17:50	181.7	229.5	530.55
00:18:00	181.2	229.0	521.25
00:18:10	196.7	231.0	536.8
00:18:20	186.1	240.5	525.95
00:18:30	179.4	243.1	517.8
00:18:40	171.9	237.4	509.95
00:18:50	170.8	234.1	498.05
00:19:00	168.7	236.5	495.9
00:19:10	169.0	244.4	477.2
00:19:20	165.7	250.8	474.55
00:19:30	165.3	253.4	470.5
00:19:40	165.6	257.1	449.05
00:19:50	174.8	257.0	443.45
00:20:00	194.9	253.4	444.1
00:20:10	195.8	260.2	475.15
00:20:20	205.3	267.9	487.9
00:20:30	206.7	264.6	485.65
00:20:40	201.4	274.9	492.55
00:20:50	195.8	266.9	556.95
00:21:00	190.5	254.5	551.05
00:21:10	187.9	256.5	537

00:21:20	182.1	261.6	525.95
00:21:30	180.9	262.2	494
00:21:40	185.8	261.7	485.55
00:21:50	200.9	257.2	463.25
00:22:00	205.1	254.3	440.25
00:22:10	198.6	252.7	428.55
00:22:20	187.5	251.6	482.15
00:22:30	182.1	250.3	555.95
00:22:40	175.8	251.0	535.4
00:22:50	170.0	265.3	517.75
00:23:00	172.2	266.7	519.05
00:23:10	233.8	267.7	496.75
00:23:20	247.7	262.9	482.55
00:23:30	252.3	259.2	475.45
00:23:40	248.6	258.3	472.6
00:23:50	242.8	260.4	460.75
00:24:00	236.4	265.8	455.25
00:24:10	242.7	283.0	449.5
00:24:20	238.1	316.5	464
00:24:30	225.3	327.0	489.85
00:24:40	218.5	328.6	529.55
00:24:50	227.9	327.5	614.75
00:25:00	221.9	319.6	659.4
00:25:10	222.4	305.2	628.1
00:25:20	228.9	295.9	611.7
00:25:30	221.6	291.4	588.4
00:25:40	211.0	284.8	565.25
00:25:50	197.3	276.9	562.7
00:26:00	187.7	282.3	547.7
00:26:10	182.8	265.6	527
00:26:20	179.7	253.6	501.3
00:26:30	186.7	267.4	509.6
00:26:40	183.5	271.5	488.3
00:26:50	195.8	266.0	463.2
00:27:00	207.0	261.0	482.85
00:27:10	196.2	248.7	472.9
00:27:20	196.6	241.2	454.9
00:27:30	188.0	229.8	442.55
00:27:40	191.8	220.3	441.05
00:27:50	199.5	213.1	466.8
00:28:00	195.5	213.1	463.85
00:28:10	193.4	216.9	505.95
00:28:20	188.2	230.3	505.7

00:28:30	189.5	261.4	509.4
00:28:40	185.2	317.9	546.4
00:28:50	181.6	361.6	537
00:29:00	183.4	424.8	505.9
00:29:10	181.0	483.0	497.15
00:29:20	186.6	470.6	497.6
00:29:30	186.5	437.0	503.2
00:29:40	189.2	407.7	494
00:29:50	184.4	384.7	485.75
00:30:00	197.2	361.7	477.25
00:30:10	202.9	348.7	474.55
00:30:20	202.8	367.3	465.15
00:30:30	196.1	364.6	461.55
00:30:40	194.0	348.1	459.45
00:30:50	192.7	329.7	443.45
00:31:00	194.7	312.0	417.4
00:31:10	198.2	291.1	400.05
00:31:20	204.6	271.0	414.85
00:31:30	193.8	257.9	403.15
00:31:40	182.3	251.9	370.85
00:31:50	188.5	243.8	361.5
00:32:00	182.6	240.3	334.75
00:32:10	175.0	228.2	311.8
00:32:20	172.7	226.8	298.9
00:32:30	164.5	213.8	289.45
00:32:40	163.4	212.0	265.8
00:32:50	159.9	204.2	247.05
00:33:00	152.6	202.4	233.25
00:33:10	154.2	196.5	219.35
00:33:20	146.0	205.6	206.5
00:33:30	135.4	195.8	197
00:33:40	148.5	188.1	190.3
00:33:50	149.6	181.4	183.4
00:34:00	156.3	179.4	173.6
00:34:10	161.2	175.5	164.95
00:34:20	164.9	179.8	159.3
00:34:30	168.8	178.3	154.75
00:34:40	173.6	178.9	149.8
00:34:50	170.3	181.2	144.3
00:35:00	160.8	191.0	139.65
00:35:10	149.1	198.9	
00:35:20	139.5	191.9	
00:35:30	141.8	192.7	

00:35:40	157.2	190.8
00:35:50	155.2	184.2
00:36:00	153.6	179.6
00:36:10	153.0	176.7
00:36:20	157.6	170.9
00:36:30	173.0	163.5
00:36:40	169.4	164.4
00:36:50	163.4	172.2
00:37:00	162.1	172.1
00:37:10	161.6	169.6
00:37:20	160.3	164.6
00:37:30	150.5	170.3
00:37:40	148.3	165.7
00:37:50	159.2	162.5
00:38:00	163.1	150.3
00:38:10	164.1	147.0
00:38:20	173.7	152.6
00:38:30	167.9	150.9
00:38:40	182.0	154.9
00:38:50	193.7	151.9
00:39:00	183.1	
00:39:10	167.5	
00:39:20	158.1	
00:39:30	149.6	
00:39:40	139.2	
00:39:50	138.9	
00:40:00	139.4	
00:40:10	153.6	
00:40:20	145.7	
00:40:30	156.4	
00:40:40	158.2	
00:40:50	163.8	
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00:41:30	139.1	
00:41:40	133.2	
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00:42:10	122.1	
00:42:20	123.2	
00:42:30	135.7	
00:42:40	141.3	

00:42:50	152.4
00:43:00	152.1
00:43:10	150.2
00:43:20	146.3
00:43:30	153.1
00:43:40	155.8
00:43:50	166.2
00:44:00	171.5
00:44:10	177.2
00:44:20	189.4
00:44:30	189.8
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00:46:20	155.3
00:46:30	154.7
00:46:40	161.0
00:46:50	153.7
00:47:00	151.3
00:47:10	153.9
00:47:20	149.7
00:47:30	138.5
00:47:40	138.0
00:47:50	138.0
00:48:00	139.7
00:48:10	132.7
00:48:20	127.8
00:48:30	120.6
00:48:40	116.4
00:48:50	112.3
00:49:00	110.2
00:49:10	108.4
00:49:20	108.8
00:49:30	124.5
00:49:40	140.5
00:49:50	146.6

00:50:00	142.5
00:50:10	143.7
00:50:20	155.6
00:50:30	152.7
00:50:40	145.5
00:50:50	137.5
00:51:00	137.0
00:51:10	145.1
00:51:20	146.4
00:51:30	148.7
00:51:40	152.2
00:51:50	146.5
00:52:00	142.5
00:52:10	142.7
00:52:20	145.1
00:52:30	148.9
00:52:40	148.1
00:52:50	151.2
00:53:00	158.1
00:53:10	151.3
00:53:20	159.2
00:53:30	152.5
00:53:40	155.5
00:53:50	156.3
00:54:00	147.1
00:54:10	151.5
00:54:20	154.1
00:54:30	148.8
00:54:40	146.4
00:54:50	141.8
00:55:00	136.7