CHAPTER 1

INTRODUCTION

First chapter of this proposal will discuss about the introduction to this project, covered with background of study, problem statement, objective, scope of study and the reasons that lead to the implementation of this evaluation project.

1.1 Background of study.

This study is focusing on an automotive engine heat management system. The current automotive engine heat management is only working on controlling the engine temperature for initial startup and maintaining the temperature of its ideal running temperature that is handled by thermostat.

A typical automotive engine operates by burning fuel in the combustion chamber to move the piston cylinders. This cycle producing waste heat that must be absorbed by automotive cooling system. The basic components of cooling system are radiator, coolant which are usually combination of water, coolant (to improve heat absorption efficiency) , ethylene glycol (antifreeze), pressure cap, reserve tank, water pump and thermostat. The mixed liquid coolant is sent through passages in the engine block and head. As its circulating through the passages, it absorbs the heat from the engine. The heated liquid then flows to the radiator that is normally placed in front of engine compartment through rubber hose on the top of radiator. Inside the radiator the heated coolant will flow through several tubes. These tubes were arranged alternating with the cooling fins that are combination of zigzagged and flattened aluminum strips. The heat will then be transfer to the fins and will be cooled down as stream of air flow through the fin. The cooled liquid is then returned into the engine block through the rubber hose at the bottom of the radiator to continue the cycle of absorbing heat to cool down the engine. A typical radiator will be connected to a reserve water tank with a small rubber hose. This tank was placed either side in the engine compartment. This reserve tank will be used to store the released coolant fluid from the radiator and this fluid would then return to the cooling system after the engine cooled down. This cooling system was used to prevent the engine from overheating. Once the engine overheats, the consequences are the piston scuffing, rapid expansion of aluminum head, the crushing head gasket which leads to gasket failure and leaking of coolant or combustion gas into the combustion chamber or the coolant passage, cam scuffing, seizure, breakage and finally the permanent damage to the engine. Due to severe damage caused by overheating problem, the total repairing cost would be expensive.

Hence this project is actually aiming for a system that will provide some time for consumers to seek help and stop the vehicle in a safe place by delaying engine overheat other than to save the engine from suffering overheat. This system is also aided by the visual panel to signal to consumers as well as guidance on the engine situation. This system is basically working on the concept of evaporative cooler. Use of this concept with the help of some tools taking into account economic factors can produce high beneficial effects compared with the investment made especially in emergency situation when the car engine temperature rise rapidly and overheat. This system aims to avoid damage to the engine and provide better safety guarantees to the consumer

1.2 Problem Statement

1.2.1 Problem Identification

Cooling system is one of the most important systems for each vehicle engine. However, this cooling system is often associated with many problems that result brings a great harm that is over heat. This problem will have a big impact, such as permanent damage to the engine and expensive to repair. So this project should solve these three problems.

1) Help to maintain the engine temperature at safe range running temperature.

2) Give a warning and notify the user about the current condition of their engine's temperature.

3) Shutdown the engine if the temperature keeps increasing towards overheats.

1.2.2 Significant of the project

By using this system is assisted by a visual guidance system to provide early warning to consumers about the state of their vehicle engine if it is in dangerous situation. This warning system will give consumers the opportunity to act whether to stop the vehicle in a safe place or to find workshops nearby. In the meantime the SHMS itself will take a precaution steps to avoid the engine from overheat through series of action. This project will also give an improvement in automotive industry in providing more reliable vehicle in future.

1.3 Objective and Scope of Study

1.3.1 Objective

The main objective of this project is to develop Smart Heat Management System (SHMS) that is PnP (plug and play) basis to prevent the engine from overheat by solving the associated problem that may lead to overheat.

1.3.2 Scope of Study

This project will create a system to monitor continuously the temperature of the vehicle engine and will display the current engine condition. The system will warn the users if their vehicles engine in danger and leading to overheat problem. If the engine leading to overheat, the system will warn the user and in the meantime trying to delay the engine from overheat by communicating with mist spray to spray a thin layer of water particles onto the radiator. The thin water layer sprayed onto the radiator will evaporated as air flow through. This evaporation cooler is almost similar on how sweat cooling and maintaining our body temperature. The concept will be use to cool down the engine temperature at greater scale to prevent the temperature from keep increasing while giving the user and extra time to pull over their vehicle in safer place or nearby workshop

1.4 Relevancy of the project

All of the vehicles with engine will require the cooling system to continue working. The engine is much dependent on the cooling system and it will be worse if this cooling system fail. The failures of cooling system will also damaging the engine component and will cause a permanent damage to the engine besides could endanger the user if this situation happen. This system will help to delay the engine temperature from keep increasing before having an overheat problem by cooling down the radiator using the evaporation cooling concept which helped by a pump that will pump the water through mist sprinkler and will spread a thin layer of water particle onto the radiator. The air stream passed through the radiator will evaporate the thin layer of water as well as cooling down the radiator and the coolant fluid. This concept is similar to how sweating process cooling down and maintaining our body temperature. The project are about to optimize the system to fit the application while doing some relation and calculation to relate the entire variable into an equation.

1.5 Feasibility of the project

Two semesters is the time given to complete this project. This includes research, development, improvement and discussion. There will be several tests to record the efficiency data of the system and also to optimize the system to its best possibilities. The availability of hardware such as pump, sprinkler, thermostat switch and all related material make this project can be done without any delayed. Based on the availability of hardware, with tight schedule it is very clear that this project is feasible to be completed within the time frame assign by FYP coordinator.

CHAPTER 2

LITERATURE REVIEW

This chapter discusses about the theories and paperwork reviews related to this project. The first step of this project was to gather information on existing radiator designs and general heat exchangers. After gathering information, we gained a thorough understanding of how a radiator works, the current radiator designs and all the possibilities that may lead into overheat.

2.1 Theory

2.1.1 Heat Exchangers

A steady-state heat exchanger consists of a fluid flowing through a pipe or system of pipes, where heat is transferred from one fluid to another. Heat exchangers are very common in everyday life and can be found almost anywhere (Sonntag, et al. 2003).Some common examples of heat exchangers are air conditioners, automobile radiators, and a hot water heater. A schematic of a simple heat exchanger is shown in Figure below.

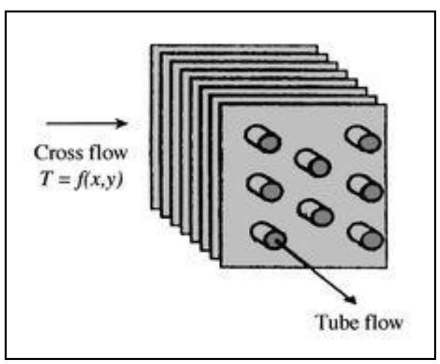


Figure 2.1 : Cross Flow Heat Exchanger (Yunus A Cengel, 2006)

2.1.2 Automobile Radiators

Almost all automobiles in the market today have a type of heat exchanger called a radiator. The radiator is part of the cooling system of the engine as shown in igure below. As you can see in the figure, the radiator is just one of the many components of the complex cooling system.

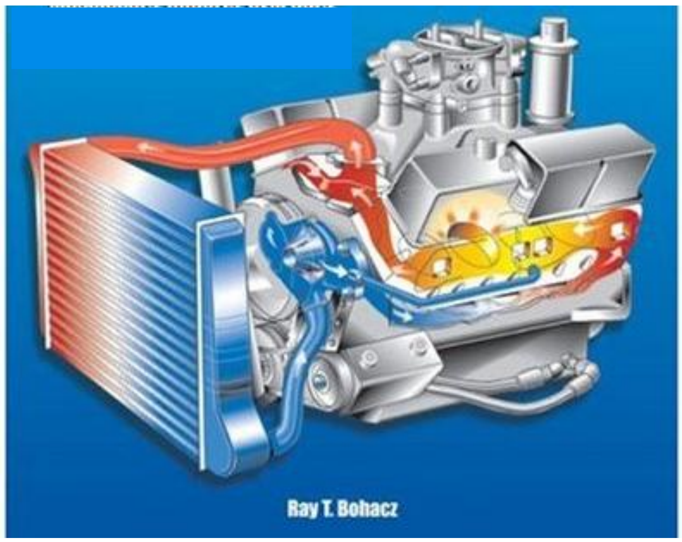


Figure 2.2 Automotive Cooling System (Ray T. Bohacz, 2007).

Most commonly made out of aluminum, automobile radiators utilize a cross-flow heat exchanger design. The two working fluids are generally air and coolant (50-50 mix of water and ethylene glycol). As the air flows through the radiator, the heat is transferred from the coolant to the air. The purpose of the air is to remove heat from the coolant, which causes the coolant to exit the radiator at a lower temperature than it entered at. The benchmark for heat transfer of current radiators is 140 kW of heat at an inlet temperature of 95 °C. The basic radiator has a width of 0.5-0.6 m (20-23“), a height of 0.4-0.7 m (16-27”), and a depth of 0.025-0.038 m (1-1.5”). These dimensions vary depending on the make and model of the automobile.

2. 2 Analogy Of Heat Transfer In Radiator

Below is the simplified diagram to explain on how the heat transfer occurs in the radiator component. T_a and T_b indicate the inlet and outlet temperature of the cooling water.

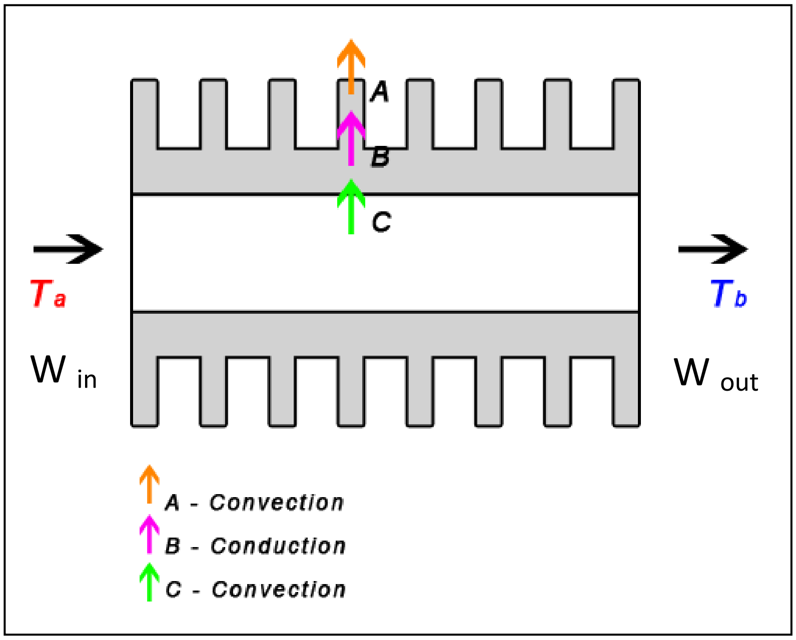


Figure 2.3: Heat Transfer Analogy (Yunus A Cengel, 2006)

Here, Arrow A represent the heat is transferred by convection from the radiator fin to the air stream. Arrow B represent the heat is transferred by conduction from the tube to the fin while Arrow C represent the heat is transferred by convection from the hot water flow to the tube surface.

2.3 Mechanism of Natural Convection

We know that a hot boiled egg on a plate eventually cools to the surrounding air temperature. The egg is cooled by transferring heat by convection to the air and by radiation to the surrounding surfaces.

As soon as the hot egg is exposed to cooler air the temperature of the outer surface of the egg shell drops somewhat, and the temperature of the air adjacent to the shell rises as the result of the heat conduction from the shell to the air. Consequently, the egg is surrounded by a thin layer of warmer air, and heat is then transferred from this warmer layer to the outer layer of air. The cooling process in this case is rather slow since the egg would always be blanketed by warm air, and it has no direct contact with the cooler air farther away. We may not notice any air motion in the vicinity of the egg, but careful measurements would indicate otherwise.

The temperature of the air adjacent to the egg is higher and thus its density is lower, since at the constant pressure the density of egg is inversely proportional to its temperature. Thus we have situation in which some low density or "light" gas is surrounded by a high density or "heavy" gas, and the natural gas dictates that the light gas rise. This phenomenon is characterized incorrectly by the phrase "heat rise" which is understood to mean "heated air rise". The space vacated by the warmer air in the vicinity of the egg is replaced by the cooler air nearby, and the presence of cooler air in the vicinity of the egg speeds up the cooling process. The rise of warmer air and the flow of cooler air into its place continue until the egg is cooled to the temperature of the surrounding air. The motion that results from continual replacement of the heated air in the vicinity of the egg by the cooler air nearby is called a natural convection current, and the heat transfer that is enhanced as a result of this natural convection current is called natural convection heat transfer. (Yunus A Cengel, 2006)

2.4 Convection on Radiator Surface

The similar concept applied to the radiator and instead of the egg that was used as an example above it is replaced by radiator fin that was made to increase the surface for better heat transfer and was proved by this simple equation ($Q = hA\Delta T$). Area of the surface that is exposed to heat transfer is indicating as "A" and proportional to the heat transfer rate, Q. The convection process happened to the egg are the same happened to the radiator fins if the car is not moving and the fan is not rotates. If the car is on moving or the radiator fan is rotates, the air stream is forced to flow through the radiator fins and carry the heat away. This is called forced convection. The heated air is replaced by cooler air with faster rate in forced convection rather than natural convection. (S. Mostafa Ghiaasiaan, 2011)

2.5 Evaporative Heat Transfer

Moisture content also affects the effective conductivity of porous mediums such as soils, building materials and insulations, and thus heat transfer through them. Several studies have indicated that heat transfer increases almost linearly with moisture content, at a rate of 3 to 5 percent for each percent increase in moisture content by volume. Insulation with 5 percent moisture content by volume, for example, increases heat transfer by 15 to 25 percent relative to dry insulation. (ASHRAE Handbook of Fundamentals, 1993)

Atmospheric air can be viewed as a mixture of dry air and water vapor, and the atmospheric pressure is the sum of the pressure of dry air and the pressure of water vapor, which is called the vapor pressure P_v. Air can hold a certain amount of moisture only and the ratio of the actual amount of moisture in the air at a given temperature to the maximum amount air can hold at that temperature is called the relative humidity φ. The relative humidity ranges from 0 for dry air to 100 percent for saturated vapor in saturated air (air that cannot hold any more moisture). The partial pressure of water vapor in saturated air is called saturation pressure P_{sat}.

The amount of moisture in the air is completely specified by the temperature and the relative humidity, and the vapor pressure is related to relative humidity by

$$P_v = \varphi P_{sat}$$

CHAPTER 3

METHODOLOGY

This chapter discusses about how the project would be carried out. It includes the method of research, tools, components, and software involved.

First of all, the project start with gathering all of the information about automotive cooling system, the problem associated with cooling system, all the causes and sign that will lead to overheat problem, study in details of each equipment associated with cooling system including the equipments specification and all the cooling system design available in automotive industry. All of this information will be useful to comply with project objective.

The next initial step is to recover all the related equation that may involve in the designing stage especially on heat transfer equation. All the theory will be kept for further reference and for modification to suit the new design. Then next is creating and drafting all the conceptual design to meet the objective to prevent the engine overheat problem. The drafts are including the action system, controlling system and display system. All the conceptual design will be then tested to eliminate all the possible causes that may lead to overheat problem. All the passed conceptual design will be brought to next stage where all the related component for each conceptual design will be analyzed theoretically for effectiveness and economic factor.

The best conceptual design will move to fabrication process. After the completion of fabrication, the system will be tested for several times to collect all the related data and variables to be analyzed for system optimization. The optimizations are including the material and easiness of fabrication, the cost reduction and also efficiency improvement. The system will also be tested under several conditions to test the system durability, estimation for life span and suitability for all engines available on the market.

3.1 Project Activity

Literature review and information gathering

All information involved being collected, obtained through article, book, journal paper and World Wide Web.

⇩

Drafting of conceptual design

After understanding the main operation of current cooling system and problem associated, the system will be draft to meet the main objective.

⇩

Analyze the conceptual design

Using all the drafted conceptual design, each of the design will be analyzed theoretically according to the equation and calculation.

⇩

Selection of the best conceptual design

The best conceptual design will be judge according to several criteria including the efficiency economic factor.

⇩

Fabrication of conceptual design

The preparation for fabrication including raw material and process procedures will be made. Each equipment will be assembly to build a complete system

⇩

Experiment and data collection

The system will be go into series of experiment under several condition to collect the related data and variables for system optimization.

⇩

System optimization

The system will be optimize for several criteria such as efficiency, economic factor and suitability for the all engine available on the market.

⇩

Discussion and Conclusion

3.2 Mathematical Model

This mathematical model is to relate the theoretical assumption to the equation related for clearer understanding. This mathematical model is the manipulation of the existed heat transfer equation and analogy to be fitted into this project condition and requirements according to the known variables.

3.2.1 Case Study 1

During a hot sunny day, a car was driven at speed of 80km/h and expected to have a problem with the engine cooling system. The car was equipped with SHMS and after reaching 105^0C that is preset temperature in SHMS, the system is activated and forcing the engine to cool down as fast as possible to avoid further temperature increment that will cause the engine over heat. The environment conditions are 1 atm, 35^oC and 40 percent relative humidity. Justify with calculation whether the SHMS will success or fail to avoid the engine from overheat.

Solution

The SHMS will spray a layer of water film onto the hot radiator to cool down the radiator and then the pump will circulate the cooled cooling fluid through the engine to reduce the engine temperature.

Assumptions

1. The low mass flux conditions exist so that the Chilton-Colburn analogy between heat and mass transfer is applicable since the mass fraction of vapor in air is low.
2. Both air and water vapor at specified conditions are ideal gases.
3. Radiation effects are negligible.
4. 80km/h to m/s = 23m/s

Properties

Because of low mass flux conditions, we can use dry air properties for the mixture at the average temperature of $(T_\infty + T_s)/2$ which cannot be determined at this point because of the unknown surface temperature T_s. We know that $T_s > T_\infty$ and, for the purpose of property evaluation, we take T_s to be 45 ^oC and the properties of dry air at the average temperature of 40 ^oC and 1atm are (Table A-9 and A-15, attached at last section)

Water: h_{fg} = 2407kJ/kg, P_v = 7.38 kPa ; also P_v = 5.63 kPa at 35 ^oC
Dry air: c_p = 1.007 kJ/kg ^oC, α = 2.346 x 10^{-5} m^2/s

The molar masses of water and air are 18 and 29 kg/kmol, respectively (Table A-1).Also the mass diffusivity of water vapor in the air at 40 ^oC is $D_{H2O\text{-}air}$ = 2.77 x 10^{-5} m^2/s (Table below)

<u>Analysis</u>

Utilizing the Chilton-Colburn analogy, the surface temperature of the radiator can be determined

$$T_s = T_\infty - \frac{h_{fg}}{c_p Le^{2/3}} \frac{M_v}{M} \frac{P_{v,s}-P_{v,\infty}}{P}$$

T_∞ = Surrounding temperature (^0C)

T_s = Surface Temperature (0C)

Where the Lewis number is

$$Le = \frac{\alpha}{D_{AB}} = \frac{2.346 \text{ x } 10^{-5} \text{m2/s}}{2.77 \text{ x } 10^{-5} \text{ m2/s}} = 0.847$$

$D_{AB} = D_{\text{H2O-air}}$ = The diffussion coefficeient of A in B, $(\frac{m^2}{s^2})$

α = Thermal diffusivity , $(\frac{m^2}{s^2})$

Note that we can take the Lewis number to be 1 for simplicity, but we chose to incorporate it for better accuracy.

The air at the surface is saturated, and thus the vapor pressure at the surface is simply the saturation pressure of water at the surface temperature (7.38 kPa). The vapor pressure of the air away from the surface is

$$P_{v,\infty} = \varphi P_{sat\,@\,T\infty} = (0.40)\, P_{sat\,@\,35^{o}C} = (0.40)(5.63\text{ kPa}) = 2.252\text{ kPa}$$

P_{sat} = Saturation Pressure, kPa

Noting that the atmospheric pressure is 1 atm = 101.3 kPa, substituting gives

$$T_s = 105^0C - \frac{2407\text{kJ/kg}}{(1.007\frac{\text{kJ}}{\text{kg}}.^{o}C)(0.847)^{2/3}}\ \frac{18kg/kmol}{29kg/kmol}\ \frac{7.38\ kPa - 2.252\ kPa}{101.3\ kPa}$$

$= 105^0C – 83.9^0C$

$= 21.1^0C$

T_s = Surface Temperature, (^0C)

Discussion

Therefore, the temperature of the radiator surface can be lowered up to 21.1 ^0C by this process. Even though, the temperature will not reach to that temperature in real application and also will not remain constant since there are always heat builds up when the engine is running. This mathematical model showing that the radiator and engine are possible to be cooled down using this process and the huge temperature difference will make the engine is able to run at safe temperature. So, the SHMS is basically successfully preventing the engine from over heat.

3.2.2 Case Study 2

During a hot sunny day, a car was driven at speed of 80km/h and expected to have a problem with the engine cooling system. The car was equipped with SHMS and after reaching 105^0C that is preset temperature in SHMS, the system is activated and forcing the engine to cool down as fast as possible to avoid further temperature increment that will cause the engine over heat. The environment conditions are 1 atm, 35^oC and 40 percent relative humidity. The SHMS are operating for 10 minutes to cool down the engine. The radiator dimensions are 0.6m height and 0.7m width. The rate of diffusivity water into air at 35 ^{o}C is

$$D_{H20-air} = \frac{2.68\ x\ 10^{-5} m^2}{s}.$$

Determine the heat transfer coefficient under same flow conditions.

<u>Solutions</u>

Air blown over a body covered with a layer of water, and the rate of heat transfer coefficient under same flow conditions over same geometry conditions is to be determined. The surface area of the radiator A_s = 0.42 m^2.

<u>Assumptions</u>

1. The low mass flux conditions exist conditions exist so the Chilton-Colburn analogy between heat and mass transfer is applicable (will be verified).
2. 80km/h to m/s = 23m/s
3. The

<u>Properties</u>

The molar masses of water and air are 18 and 29 kg/kmol, respectively (Table A-1).Because of low mass flux conditions, we can use dry air properties for the mixture at the 35 ^{o}C and 1 atm. The properties of dry air at the temperature of 35^oC and 1atm are (Table A-15, attached at last section)

Dry air @ 35 ^{o}C: ρ_{air} = 1.145 kg/m^{3,} c_p = 1.007 kJ/kg ^{o}C, α = 2.277 x 10^{-5} m^2/s

Analysis

The incoming surface temperature at the hot radiator is higher than the temperature at free stream air temperature. So we assume the surface temperature at 40^{o}C and the vapor pressure of water at this temperature is 7.384 kPa, its mass fraction at the surface is determined to be

$$W_{A,s} = \frac{P_{A,s}}{P}\left(\frac{M_{water}}{M_{air}}\right) = \frac{7384\ Pa}{101325\ Pa}\left(\frac{18\frac{kg}{kmol}}{29\frac{kg}{kmol}}\right) = 4.5\ x\ 10^{-2}$$

$W_{A,s}$ = Mass fraction of the water at the surface

This confirms that the low mass flux approximation is valid. The mass fraction of water in free stream air that is at 35^{o}C is determined to be

$$W_{A,\infty} = \frac{P_{A,\infty}}{P}\left(\frac{M_{water}}{M_{air}}\right) = \frac{5628\ Pa}{101325\ Pa}\left(\frac{18\frac{kg}{kmol}}{29\frac{kg}{kmol}}\right) = 3.4\ x\ 10^{-2}$$

$W_{A,\infty}$ = Mass fraction of the water at the surface

The rate of evaporation of water in this case is

$$\dot{m}_{evap} = \frac{m}{\Delta t} = \frac{0.100kg}{(10\ x\ 60s)} = 1.67\ x\ 10^{-4} kg/s$$

$$\dot{m}_{evap} = \text{Evaporation rate, kg/s}$$

Then the mass convection coefficient becomes

$$h_{mass} = \frac{\dot{m}}{\rho A_s\,(w_{A,s} - W_{A,\infty})} = \frac{1.67\ x\ 10^{-4} kg/s}{\left(1.145\,\frac{\text{kg}}{\text{m}^3}\right)(0.42\ \text{m}^2)(4.5\ x\ 10^{-2} - 3.4\ x\ 10^{-2})}$$

$$= 0.0316\ m/s$$

Using the analogy the heat and mass transfer, the average heat transfer coefficient is determined from

$$h_{heat} = \rho c_p h_{mass} \left(\frac{\alpha}{D_{H20-air}}\right)^{\frac{2}{3}}$$

$$= \left(1.145\,\frac{\mathrm{kg}}{\mathrm{m}^3}\right)\left(1007\,\frac{\mathrm{J}}{\mathrm{kg}}.\,^\circ\mathrm{C}\right)(0.0316\,m/s\,)\left(\frac{2.277\ \mathrm{x}\ 10-5\,\frac{\mathrm{m2}}{\mathrm{s}}}{\frac{2.68\ x\ 10^{-5} m^2}{s}}\right)^{\frac{2}{3}}$$

$$= 31\,\frac{W}{m^2}.\,^\circ\mathrm{C}$$

Discussion

Based on the calculation, by using the radiator with surface area of $0.42\mathrm{m}^2$ with the surface area assumed to be 40°C and the free stream air at 35 °C. When the layer of water sprayed onto the radiator surface the rate of heat transfer are about $31\,\frac{W}{m^2}.\,^\circ\mathrm{C}$ .For information, our body transfer the heat about $8.7\,\frac{W}{m^2}.\,^\circ\mathrm{C}$ when sweating for a normal man.

3.3 Preliminary Research

3.3.1 Thermostat Switch

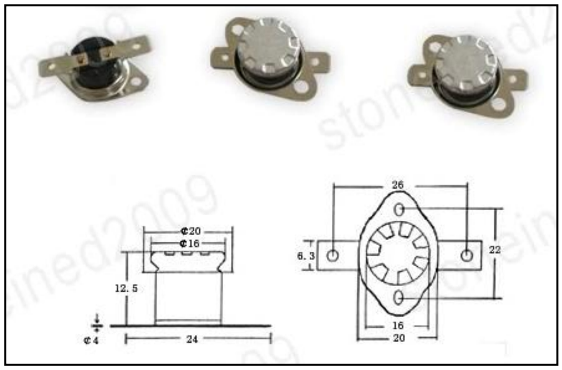


Figure 3.1: Thermostat switches

A thermostat is the component of a control system which regulates the temperature of a system so that the system's temperature is maintained near a desired set point temperature. The name is derived from the Greek words thermos "hot" and statos "a standing". The thermostat does this by switching heating or cooling devices on or off, or regulating the flow of a heat transfer fluid as needed, to maintain the correct temperature.

In this project two thermostat switches will act as on or off devices that will be responsible to measure the temperature of cylinder head temperature and sending the signal to the controller circuit board to be analyzed for the further response. Thermostat switch 1 was set at 95°C and 100°C for thermostat switch 2. These two thermostat switches were normally closed and will be open at the determined temperature.

When the cylinder head temperature reached 95°C, which mean the engine is having problem with the cooling system. The temperature switch 1 will be activated and sending the signal to the controller circuit board. The circuit board will display the warning on the display panel and in the meantime triggering the pump to pump the water through the sprinkler to spray a water mist to create a thin layer of water onto radiator surface. As the air stream flow through the radiator, the evaporation cooling concept will take place to help the radiator cooling faster at greater rate of heat transfer to reduce the engine temperature. In the meantime, the driver will be given an extra time to pull over the car at the safer place or nearby workshop.

If the temperature still rising until reached 100°C, the thermostat switch 2 will activated and sending the signal to the controller circuit board. The circuit board will then sending the signal to the display panel informing the driver the engine will be force to turn off in several minutes. Then the counter will start to count to zero and engine will be turned off.

3.3.2 Mist Spray System

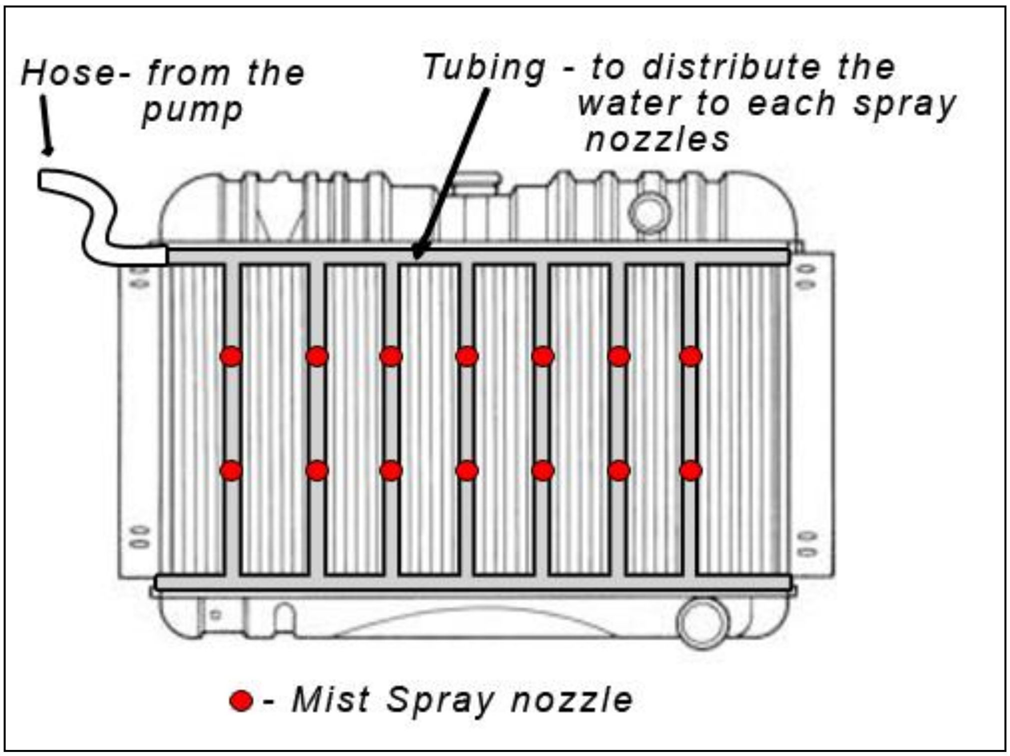


Figure 3.2: Spray Nozzles Arrangement.

The mist spray system contains several parts that are spray nozzle, aluminum tubing, water pump, water reservoir and rubber hose. All of these parts were attached to each other to build a complete mist spray system (MSS). This MSS begin with a high pressure pump and a spray nozzle designed to produce tiny water droplets that will spray onto the radiator to help cooling down the radiator and coolant liquid as they flash evaporate. Performance is enhanced by increasing the number of nozzles used and adjusting the water pressure.

When the pump was triggered by the controller circuit board, the pump will start pumping the water from the water reservoir tank. The water will flow into the hose and distributed in each aluminum tube in front of the radiator. The water will be forced to go out through each tiny hole of spray nozzles around 5 to 10 microns. These tiny holes will force the water to flow out as a tiny droplet and will be blow by the air to become mist. These mist will be distributed all over the radiator surface and will be evaporate when the air pass through.

3.3.3 Display and Visual Guidance Panel

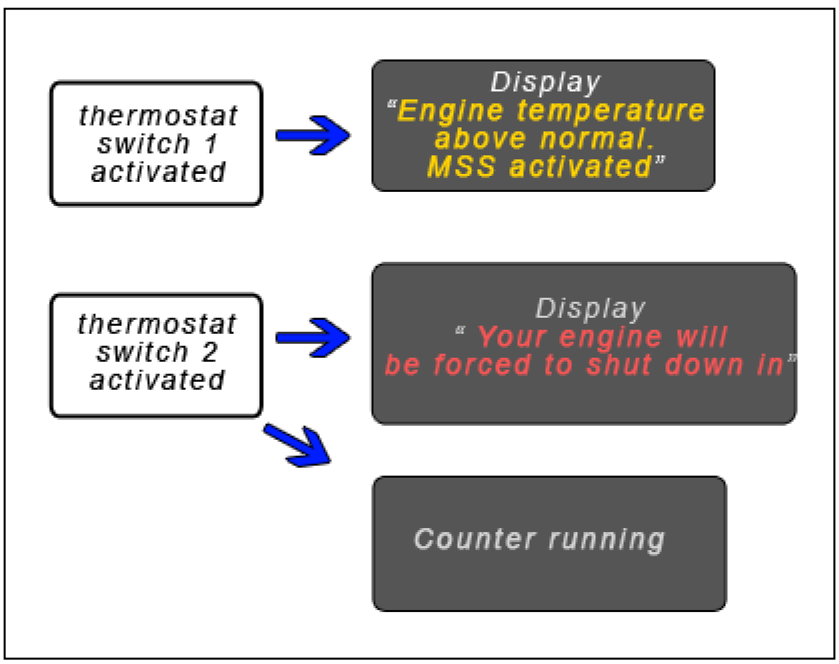


Figure 3.3: Display panel information.

The display panel will be design in small and neat to be easily placed on the dashboard or the visible place for the driver. The main function of the panel is to display the warning to the driver about the engine’s heat condition and the current preventive action taken by smart heat management system (SHMS).

When thermostat switch 1 activated, the controller circuit board will sending the signal to the display panel for informing the driver about the engine temperature is above normal and the Mist Spray System (MSS) was activated. The driver should understand this signal and begin to take action by pull over the car in safe place or nearby workshop to check on their vehicle cooling system condition. The MSS will cool down the engine temperature and giving the user several kilometers more to drive to the target location.

If the temperature still rising and the thermostat switch 2 will be activated, the controller circuit board will sending the signal to the display panel informing the driver that the vehicle’s engine must be turn off to avoid from overheat. The timer will also be activated to provide an emergency time for the user to determining the safe zone to make an emergency parking. When the counter reaches zero the engine will be forced to turn off

3.3.4 Complete Unit Of SHMS Unit Drawing

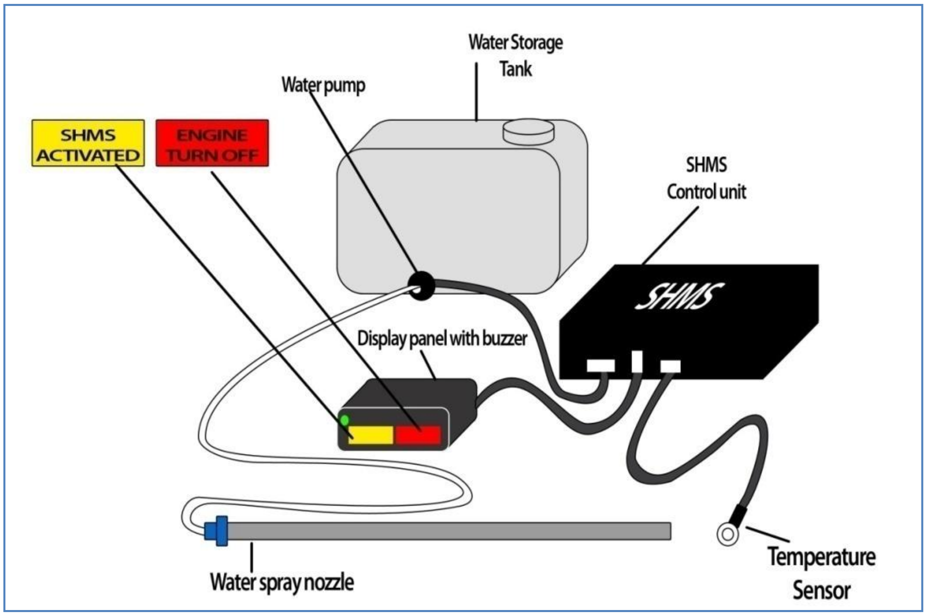


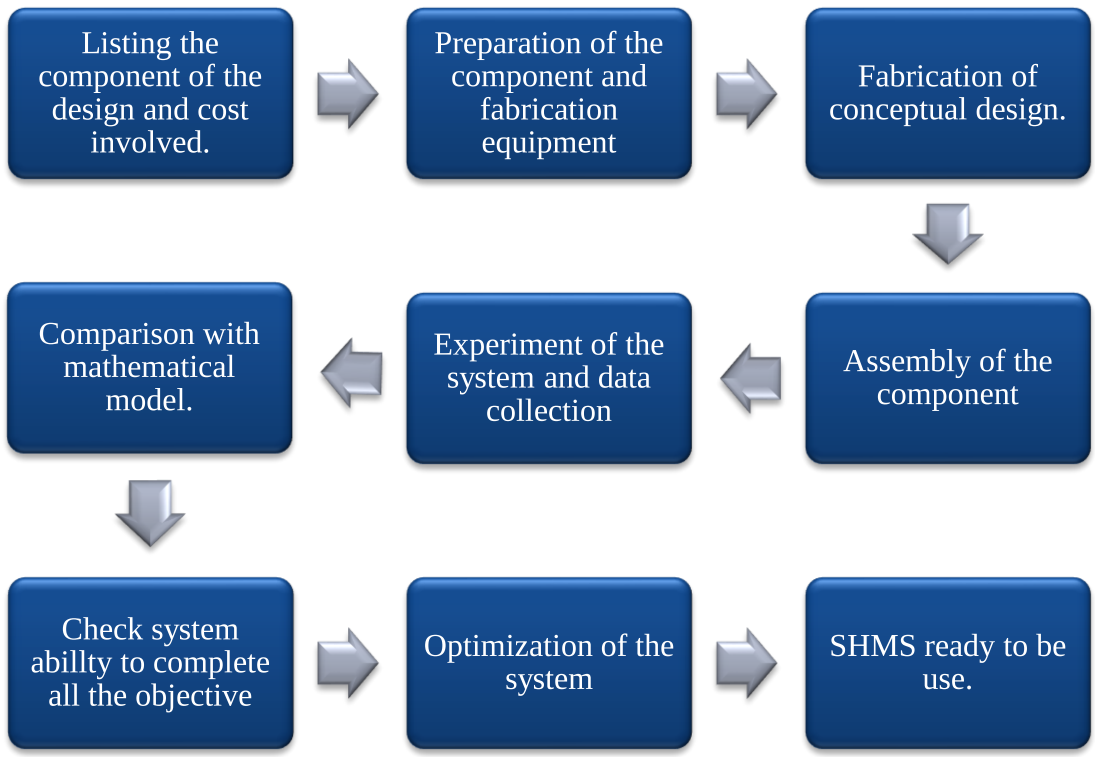
Figure 3.4: Drawing of Planned SHMS

TABLE 3.1 : Bill Of Material For planned SHMS

Bil Of Material For Planned SHMS Unit	
Bil	**Item**
1	SHMS control unit
1	Storage tank with water pump
1	Display panel
2	Connection cable
1	Temperature sensor with connection cable
1	Water Hose
1	Water Spray Nozzle

A drawing for the complete unit will act as a guide for each component completion. The system has been checked to satisfy the entire objective. The next stage work is to identify the exact component to be used for the housing and the internal component including the connection of all the parts.

3.4 Drafting And Fabrication Process Flow



3.5 Fabrication Process

3.5.1 SHMS Control Unit Fabrication

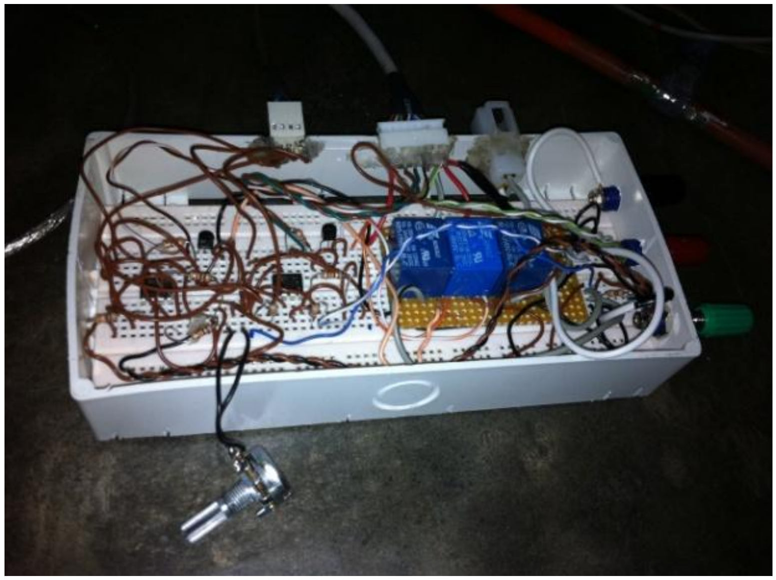


Figure 3.5 : The Control Unit

Before the fabrication process begins, some additional research has been done to act as guidance for similar circuit diagram. The similar circuit diagram then studied for each component responsibilities and working principal. The analysis and experimentation for each component have been done as well to reconfirm the function of each equipment. The main objective of the control unit then has been draft to identify the objective of the control unit and to specify the each work that will be control by the control unit. After all the responsibilities of the control unit have been listed out, then the circuit diagram now goes to sketching stage. The sketched circuit diagram then again compared to the all control unit responsibilities to match all the desired function. After final confirmation of the diagram and job function of the circuit board, then the electronic component will be assemble into one complete circuit board. The circuit board then powered to be tested all the function. The error and not functioning segment will be revised for the alternative circuit diagram. After the circuit board satisfied and capable of doing all the job, the circuit board again will be checked to minimize the space of the main board used.

3.5.2 Water Spray Fabrication

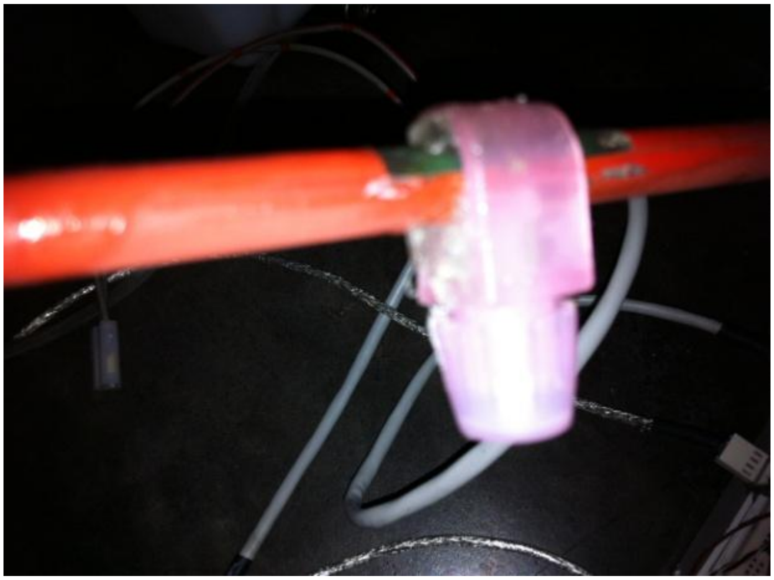


Figure 3.6 : The water Sprinkler

The water spray tubing firstly fabricated as tubing with a row of small holes and tested for the pressure and the coverage area on the top of the radiator surface. The process of fabrication included the cutting and drilling of the tubing before assembled with the rubber hose as the connection for the tubing from the water pump. The next fabrication involved the usage of an adjustable water spray, the fabrication moved into next stage difficulties of fabrication. The objective is to connect the three water spray with aluminum tubing without any leakage with capabilities to handle high pressure water. The decision made to connect the entire three spray nozzle with rubber hose that is hiding inside the aluminum tubing. This method used to satisfy the objective to avoid leakage of the connection. The tubing will give the support to the rubber hose to give a rigid structure for easiness in installation process.

3.5.3 Water Storage and Pump Assembly

Figure 3.7 : Water Storage Tank and Pump

The component for the water storage tank is available in the market and the process needed is to assembly the water storage tank with the pump and to connect the pump with wire for power supply. The connection for the wire used 2 pin female and male connections for both end. The clip is make sure to be in a tight connection to avoid the wire from accidentally disconnect that may cause a harm.

3.5.4 Display Panel Fabrication

Figure 3.8 : The Display Panel

The display panel was fabricated using the phone splitter as the base with internal modification to suit the purpose as the display panel. The smoked plastic then used to give distinguish the on and off of the display panel. A hole drilled to be installed with a green LED for power indicator. Then two of the connection socket in the splitter been modified for installation a LED inside the compartment and finally covered with smoked plastic cover. The buzzer that is initially require a big space to install, then trimmed to suit the spaced inside the splitter. The entire component installed inside the display panel are 3 LED with one buzzer. For the connection, the single core wire has been used and finally connected to the 8 pin small connector. The connection of the wire and the connector will require soldering job.

3.5.5 The Sensor Connection

Figure 3.9 : The NTC Temperature Sensor

The sensor function is to sense the temperature difference and the component used is the NTC (negative temperature coefficient) with the connection to an eyelet for easiness during installation process. Two NTC used to sense the temperature difference has been insert into the eyelet connection socket. For a better heat transfer the gap inside the connection socket has been filled with heat sink compound. Finally the connection has been wrapped with heat shrink for a clean finishing with tight connection. Another end of the sensor cable has been installed with 4 pin connector male and female socket. This connection is to connect the cable with the control unit/

3.6 Model Development

3.6.1 Water Spray Unit Development

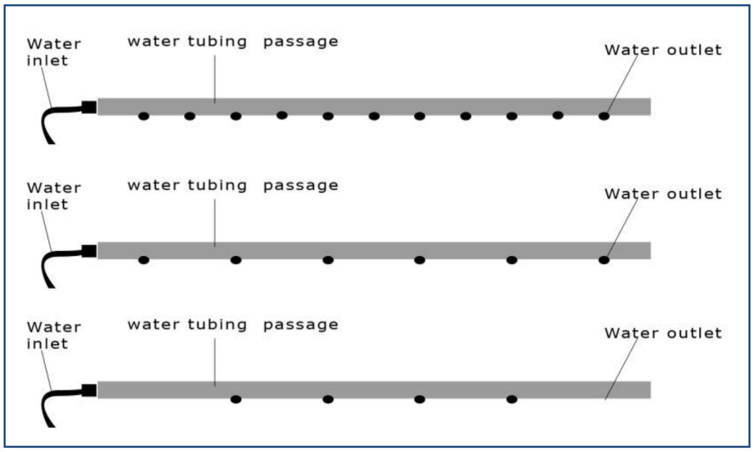


Figure 3.10 : Water Spray Trial 1

Trial 1

The water passage was previously tested for the optimum flow rate of water and optimum coverage over the radiator. The lesser holes over the tubing resulting higher flow rate due to higher pressure.

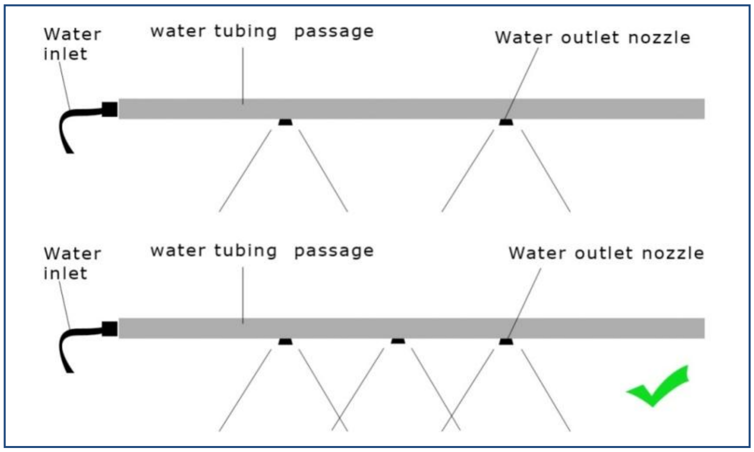


Figure 3.11 : Water Spray Trial 2

Trial 2

The water outlet have been tested using the nozzle and resulting a better coverage area and smaller water droplet size and simultaneously will elongate water discharge time.3 nozzle option have a better coverage area over the radiator surface.

3.6.2 The Control Unit Development

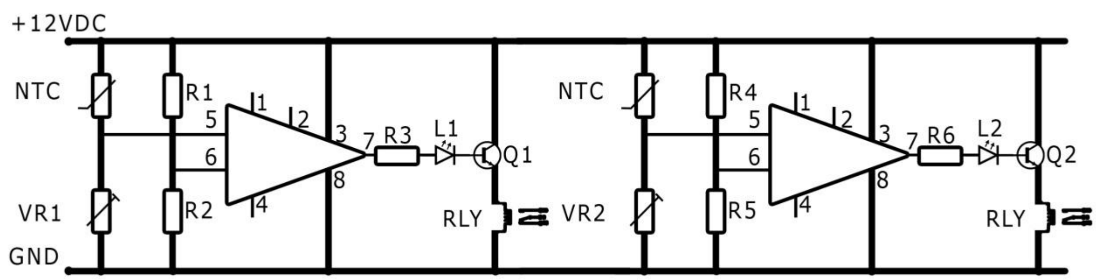


Figure 3.12 : Control Unit Trial 1

Trial 1

The initial power source of the circuit board is 9v DC that is more complicated to be installed on the car which is run on 12v DC.

Trial 2

The improvement have been made to have the control unit to handle a 12v supply by exchange the relay to avoid the relay from burned due to over voltage.

Trial 3

The final improvement made on the power supply to have it running on the vehicle power source which is 12v DC. The circuit been added few additional electronic component to avoid from damaging the circuit

3.6.3 The Display Panel Development

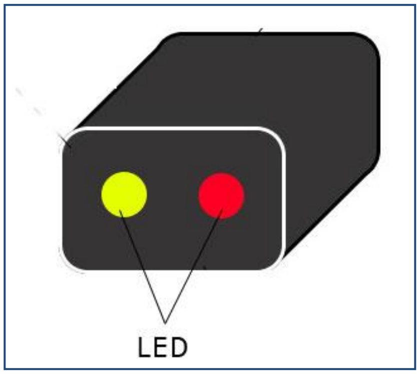


Figure 3.13 : Display Panel trial 1

Trial 1

The initial display panel was too simple and wasn't delivering the message to the user. The display also missed a power signal to indicate the system is running.

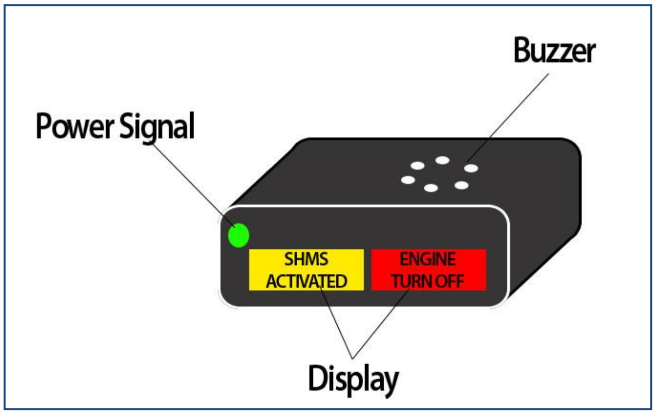


Figure 3.14 : Display Panel trial 2

Trial 2

The display panel was improved by additional buzzer to alert the user and a proper panel with yellow and red backlight.

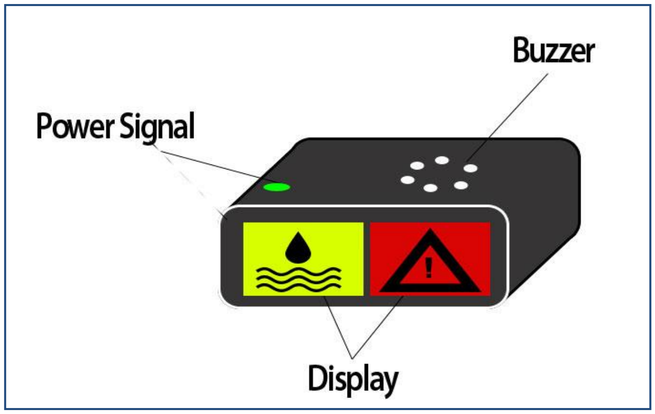


Figure 3.15 : Display Panel trial 3

Trial 3

The previous display font is unreadable due to small font and the significant symbol has been used instead. The symbol can be explained further in user guide book.

3.7 Experiment and Test Run

3.7.1 Introduction

This experiment is carried out to study the effect of evaporative cooling effect over the engine cooling system. The experiment was using a Mitsubishi MIVEC engine in block 15 as the subject. The first experiment was done by measuring the increment temperature during the engine warm up. The engine is located in a closed lab mounted at steel base support. The engine temperature is measured at the cylinder head of the engine using multi meter. The running temperature of the engine is around 71-75 °C.

3.7.2 Objective

The objectives of this experiment are

a) To investigate the effectiveness of evaporative cooling to cool down the engine
b) To investigate the engine temperature curve when applied with SHMS mist spray system at different stage of engine temperature.

3.7.3 Theory

The Principle Of Evaporative Cooling System

As water is evaporated, energy is lost from the air, reducing the temperature. Two temperatures are important in the scope of evaporative cooling systems.

Dry Bulb Temperature

- The dry-bulb temperature is the temperature of air measured by a thermometer freely exposed to the air but shielded from radiation and moisture. Dry bulb temperature is the temperature that is usually thought of as air temperature, and it is the true thermodynamic temperature. It is the temperature measured by a regular thermometer exposed to the airstream. Unlike wet bulb temperature, dry bulb temperature does not indicate the amount of moisture in the air.

Wet Bulb Temperature

- The wet-bulb temperature is a type of temperature measurement that reflects the physical properties of a system with a mixture of a gas and a vapor, usually air and water vapor. Wet bulb temperature is the lowest temperature that can be reached by the evaporation of water only. It is the temperature one feels when one's skin is wet and is exposed to moving air. Unlike dry bulb temperature, wet bulb temperature is an indication of the amount of moisture in the air..

When considering water evaporating into air, the wet-bulb temperature, as compared to the air's dry-bulb temperature is a measure of the potential for evaporative cooling. The dry and wet bulb temperature can be used to calculate the relative humidity.

Evaporation will take place when the humidity is below 100% and the air begins to absorb water. Any given volume of air can hold a certain amount of water vapor and the degree of absorption will depend on the amount it is already holding.

The term humidity describes how much water is already in the air; relative to the amount it is capable of holding. Air is saturated when it cannot hold any more water. Imagine it as a sponge, if the sponge held half as much water as it was capable of holding, it would be 50% saturated. In the case of air, we would describe the Relative Humidity as being 50%.

Energy is required to change water from liquid to vapor. This energy is obtained in an adiabatic process from the air itself. Air entering an evaporative air cooler gives up heat energy to evaporate water. During this process, the dry bulb temperature of the air passing through the cooler is lowered.

3.7.4 Equipment preparation

Apparatus

The engine now equipped with SHMS to preset the effective temperature to deploy water spray onto the radiator frontal area.

SHMS unit consists of

- 1 SHMS control unit
  This control unit will be used to preset the temperature for sensor 1 and 2. The sensor 1 will activate the pump to spray the water onto radiator frontal area and sensor 2 will turn off the engine.

- 1 Storage water tank with water pump
  Storage water tank will be used to store the water and the water will be pump into water spray nozzle when activated by control unit.

- 1 Display panel and alert
  The display panel used to give a visual and audio alert to the user by using a backlight panel assisted with buzzer.

- 2 Connection cable
  The connection cable used to connect the SHMS to the engine power supply and to connect the SHMS to engine power wire for safety turn off purpose.

- 1 Temperature sensor with connection cable
  The temperature sensor will measure the engine cylinder head temperature and send the signal to the SHMS control unit to be analyze for further action.

- 1 Water Hose
  Water hose used to connect the water storage tank and pump to the water spray nozzle.

- 1 Water Spray Nozzle

  Water spray nozzle used to spray the thin layer of water onto the radiator frontal area.

Figure 3.16 : SHMS setup

The engine is now equipped with SHMS and multi meter to measure the engine temperature

Figure 3.17 : Sensor location

The NTC (negative temperature coefficient) and multi meter sensor probe attach to the engine cylinder head using eyelets to measure the temperature.

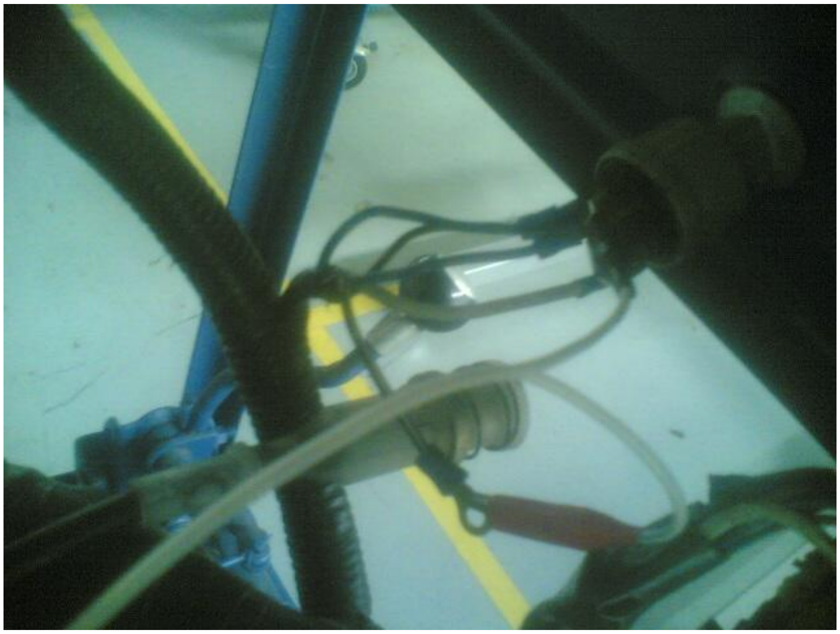


Figure 3.18: SHMS connection to the switch

The connection cable connected to the engine switch for safety engine turns off purposed.

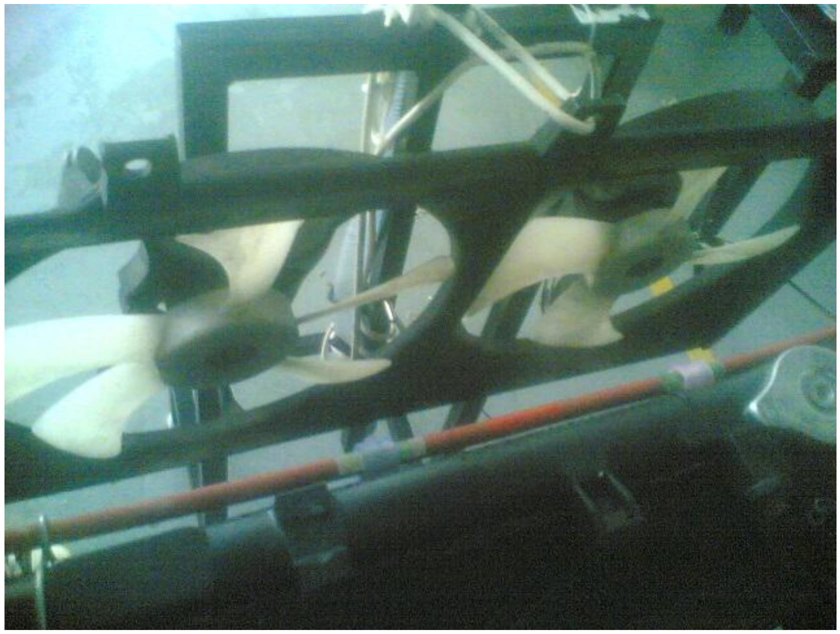


Figure 3.19: Fan configuration

Two fans to simulate the air flow through the radiator when vehicle moving.

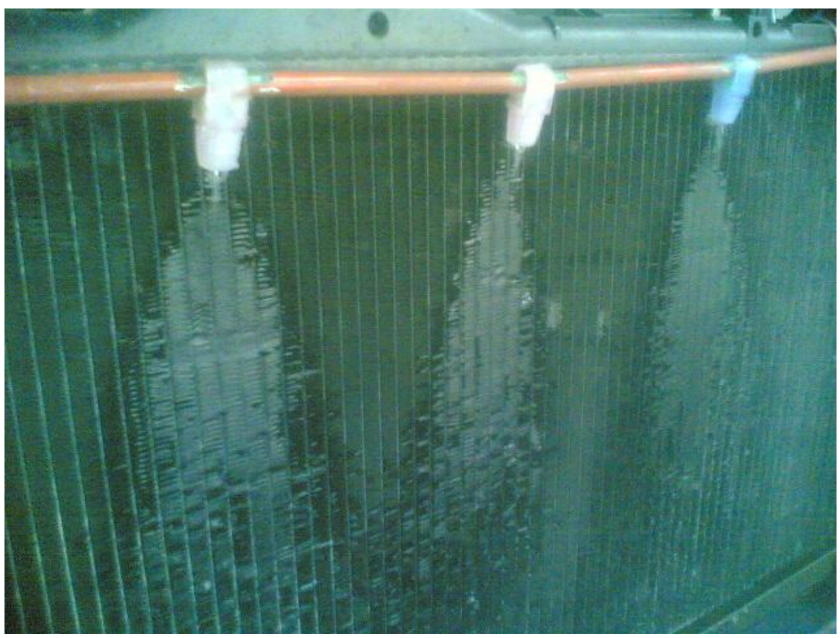


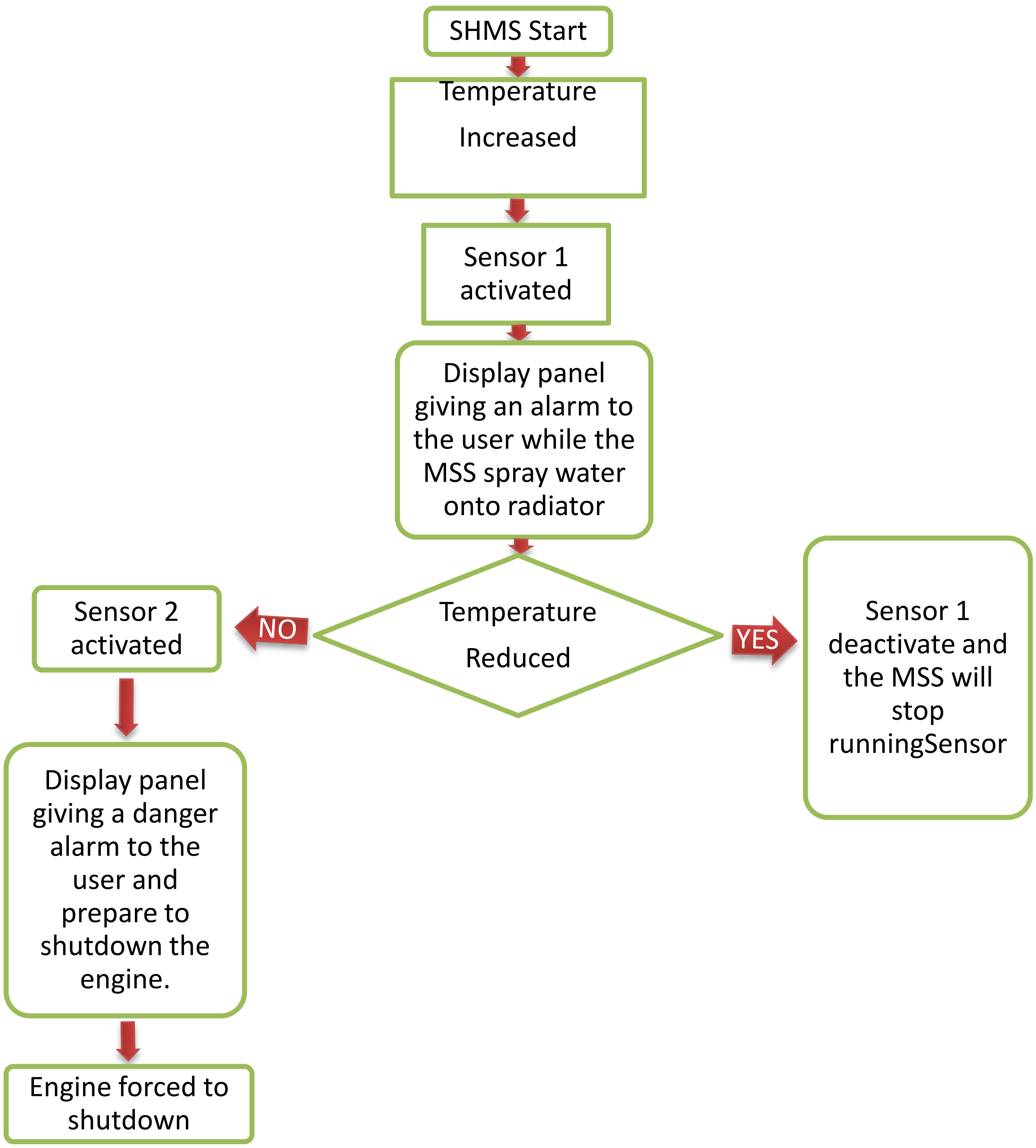
Figure 3.20: Nozzle configuration

Three water spray nozzle arranged in row to spray onto radiator frontal area.

3.7.5 Procedure

1. The engine will be warm up and the temperature increment over time recorded.
2. The SHMS will be pre set at the desired temperature for water spray deployment.
3. The cooling fan will be turn off to raise the temperature of the engine at desired level.
4. The two fans will be turn on to simulate the vehicle on moving estimated at 30km/h
5. When SHMS activated, the time taken for water discharge and the temperature curve recorded.
6. The experiment will be repeated at different level of temperature that is 60°C, 80° and 90°C.

3.8 SHMS Process Flow Diagram



3.9 Tools And Equipment

3.9.1 Flow meter

Instrument to monitor, measure, or record the flow rate. This device will be used to gather the data of actual cooling system flow rate to be used in the simulation and system drafting as reference data.

3.9.2 Temperature Gun / Thermometer

To determine temperature of device, fluid, ambient, environment when perform the experiment.

3.9.3 Milling machine

The fabrication machine to be used in the fabrication stage where some part will needed a custom fabrication.

3.9.4 Drilling

An equipment to drill a hole

3.9.5 Soldering kit

An equipment to solder electronic chip and devices over the circuit board

3.9.6 Multi meter

Equipment used to measure voltage, temperature, current, resistance and connectivity for electrical devices and circuit board.

CHAPTER 4
RESULT AND DISCUSSION

4.1 Summary of the operation

The fabrication of the prototype is finally complete and tested for the operation and meets all the desired objective of the project. The SHMS should be able to avoid the engine from overheat that was caused by any reasons. The SHMS will also have the ability to cool down the engine temperature by cooling down the radiator by using the evaporative cooling principle. This capability will only effective with the presence of the cooling fluid that circulates inside the radiator and engine's water passage. By having this capability, the user will have extra traveling distance to seek for help. On top of the protection, the SHMS will stop the engine before the engine's temperature reach at the dangerous level of temperature that cause the engine overheat.

Below are several common causes of overheat that is successfully handled by SHMS

- Thermostat Failure
- Cooling system leaks
- Leaky Head Gasket
- Fan Failure
- Leaky Water pump
- Slipping Belt
- Lower And Upper Radiator Hose Collapsing
- Plugged or Dirty Radiator
- Overworking the engine

The completion of the fabrication and experiment of prototype has taken four month that includes research on mechanical and electrical field. The prototype also had been through several stages of development for improvement to meet the objective.

4.2 The Complete SHMS Unit

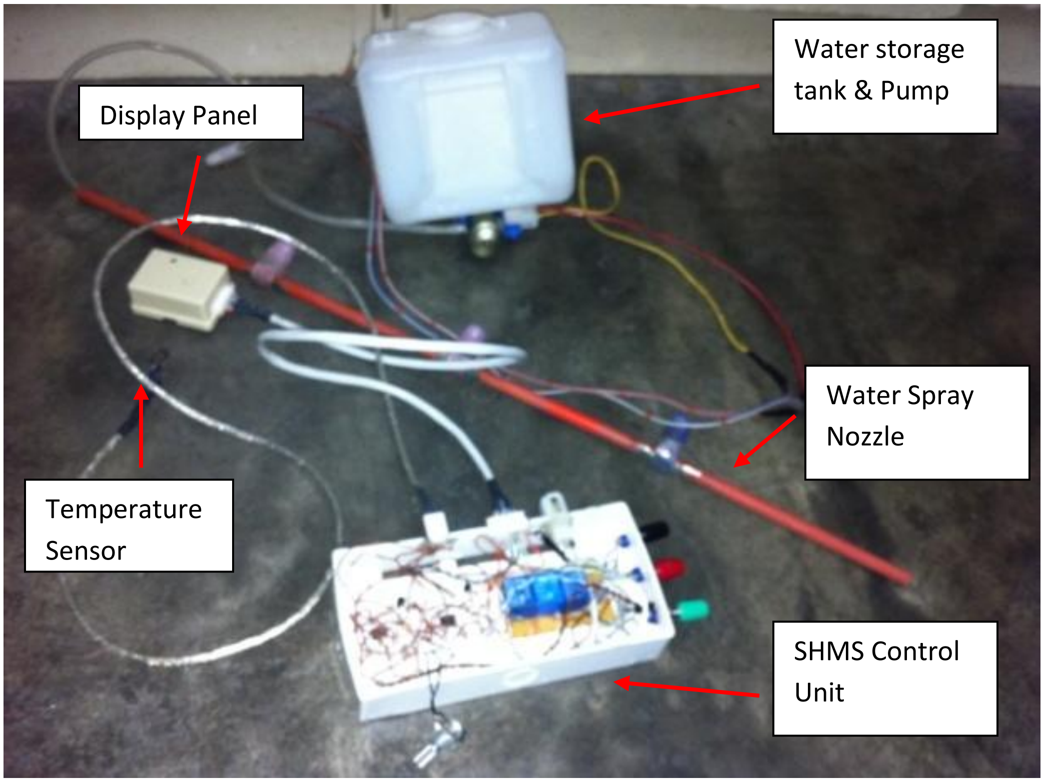


Figure 4.1 : The Complete SHMS Unit

Table 4.1 : Bil of Material for SHMS

Bil Of Material for SHMS Unit		
Bil	**Item**	**Cost**
1	SHMS control unit	RM 150
1	Storage tank with water pump	RM 70
1	Display panel	RM 15
2	Connection cable	RM 10
1	Temperature sensor with connection cable	RM 7
1	Water Hose	RM 3
1	Water Spray Nozzle	RM 9
	Total	RM 264

4.3 Potentiometer Temperature Correlations

The SHMS prototype was build with the potentiometer to vary the preset temperature to be handled by the control unit. Below are the relations of the potentiometer value against the temperature sensor.

Table 4.2 Potentiometer and Temperature Correlations

Temperature (celcius)	Potentiometer Value (ohm)
93	277
91	301
89	331
87	362
85	387
83	459
81	472
79	517
77	540
75	570
73	609
71	669
69	725
67	772
65	854
63	939
61	980
59	1017
57	1089
55	1187
53	1228
51	1323

The preset potentiometer is the variable resistor that will restrict the discharge of current flow from NTC (negative temperature coefficient) to the ground. The current value will be measure by the IC (integrated circuit) to turn on the transistor and the current will power up the relay coil. These differences in resistances preset potentiometer will reflect the temperature value.

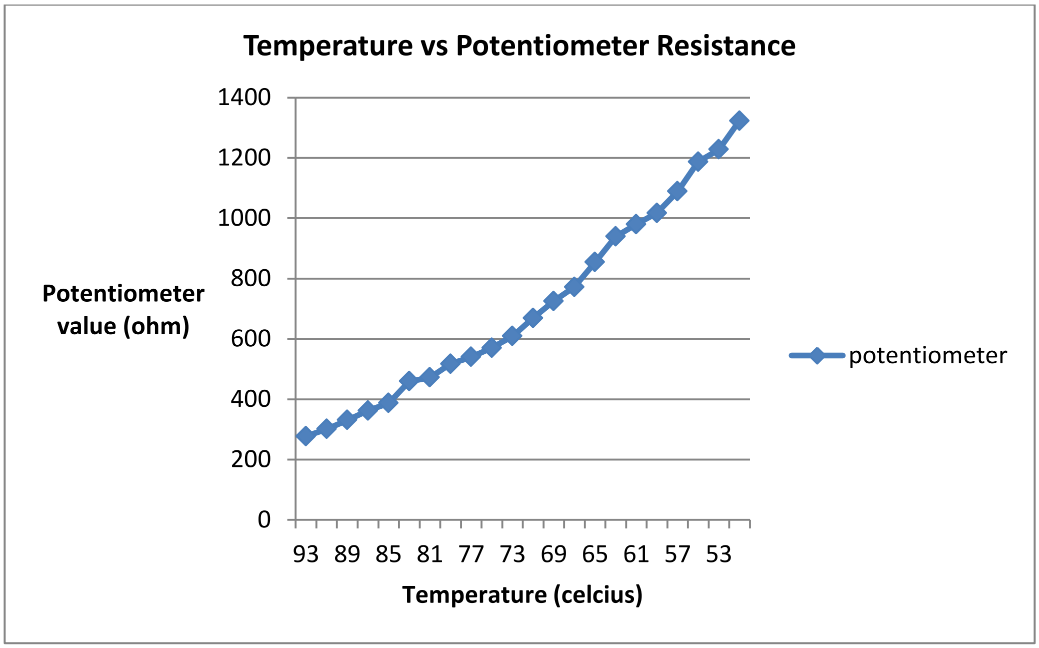


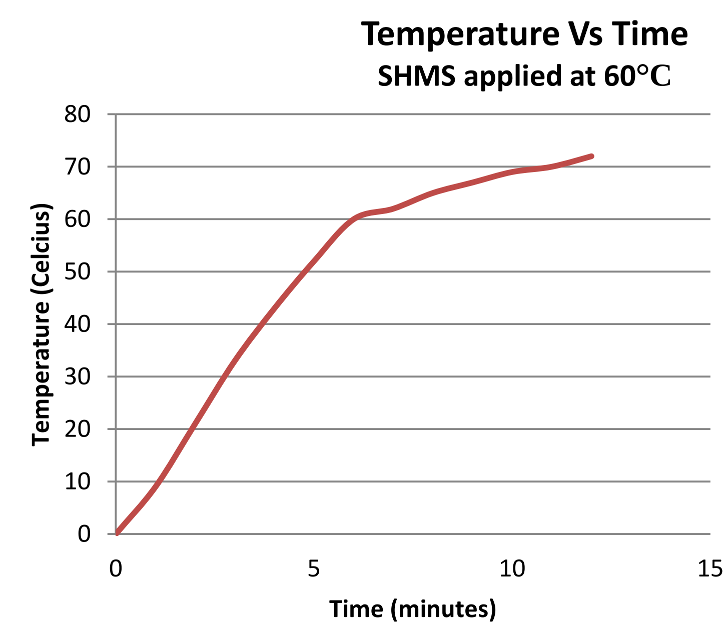
Figure 4.2 : Potentiometer vs Temperature

Based on the graph above, the potentiometer value is linear toward the temperature decrement. The lower preset temperature will have a higher potentiometer value. This trend will give estimation for the potentiometer value to preset the temperature.

4.4 Experiment Results

4.4.1 Experiment 1

The experiment 1 is measuring the engine temperature curve from the beginning of the engine start and operates the SHMS (Smart Heat Management System) water spray at 60°C.



Time (minutes)	Temperature (°C)
0	0
1	9
2	21
3	33
4	43
5	52
6	60
7	62
8	65
9	67
10	69
11	70
12	72

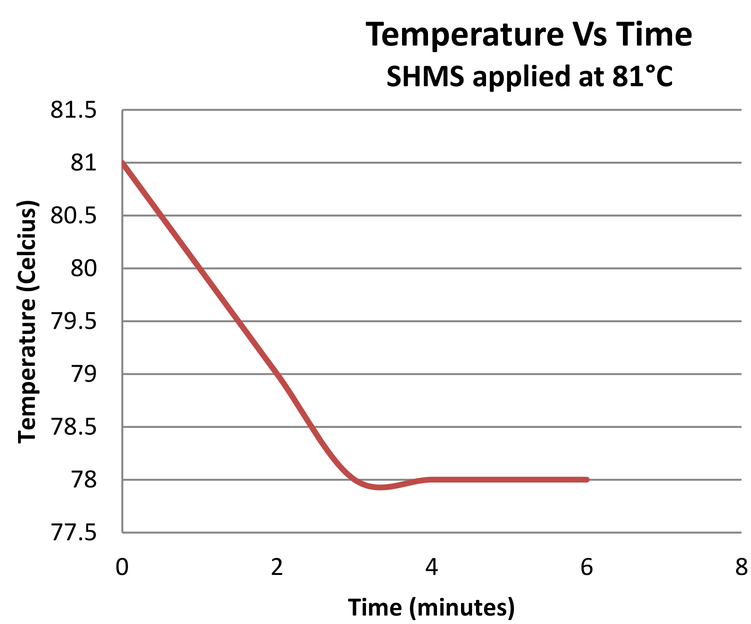
Figure 4.3 : Engine temperature during warmup

<u>Discussion</u>

The engine temperature will keep increase to warm up the engine until it reaches the running temperature. When the SHMS applied on 60°C temperature, the engine temperature is still increasing since the engine is still not reaching its running temperature but the time to increase for each degree will take longer time. The SHMS runs after 6 minutes engine warm up until the water in the storage tank is finish 6 minutes later. The engine temperature increase around 60°C for the first 6 minutes before the SHMS runs and only rise around 12°C after the SHMS runs for the last 6 minutes. The temperature is still increase because the energy supplied to water molecules is not enough to evaporate the water and simultaneously carry the heat away but the SHMS is successfully slowing down the temperature increment.

4.4.2 Experiment 2

The experiment 2 is measuring the engine temperature curve when SHMS activated the water spray unit after the engine reach 81°C. Based on current water spray nozzle, water storage tank and water pump configuration, the water will be discharge in 6 minutes.



Time (minutes)	Temperature (°C)
0	81
1	80
2	79
3	78
4	78
5	78
6	78

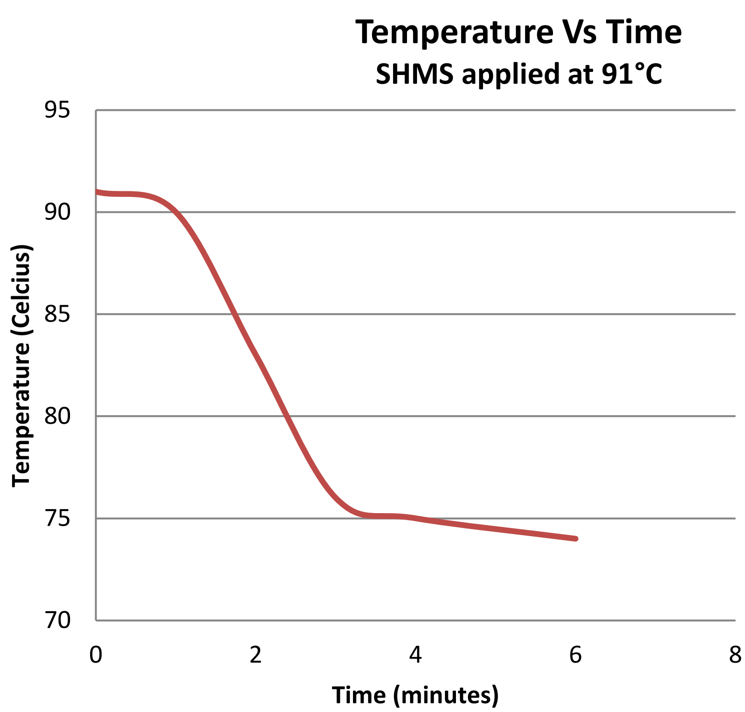
Figure 4.4 : Engine temperature when SHMS applie at 81°C

<u>Discussion</u>

After the engine is reaching its running temperature around 75 °C the engine fan was cut off to simulate the situation of the cooling fan failure. The temperature of the engine is increasing up to 81°C and then the SHMS activated the water spray onto the frontal area of the radiator surface. The engine is then blown by two fans to simulate the air stream pass through the radiator when the car is moving. The air stream is estimated as the car is moving around 30km/h. Based on the statistical data collected, the temperature decrease about 3 degree in 6 minutes that is until the water in storage tank is running out. The temperature decrement is small due to small amount of the water evaporates because of insufficient heat energy transferred to the water. The lower boiling point medium or fluid can be used to increase the heat absorption into the medium and evaporate to carry the heat away.

4.4.3 Experiment 3

The experiment 3 is measuring the engine temperature curve when SHMS activated the water spray unit after the engine reach 91°C.



Time (minutes)	Temperature (°C)
0	91
1	90
2	83
3	76
4	75
6	74

Figure 4.5 : Engine temperature when SHMS applie at 91°C

Discussion

The next temperature level is 90°C and the engine cooling fan is turn off until it reach the desired temperature before the SHMS activated the water spray system. The engine is then blown by two fans to simulate the air stream pass through the radiator when the car is moving. The air stream is estimated as the car is moving around 30km/h. The boiling temperature of the water is 100°C (212°F). When the water sprayed onto the frontal area of the radiator that is around 91°C, the water quickly absorb the heat and evaporates, This circulation carry the heat away and cooling down the radiator, cooling fluid and finally cooling the engine. Based on the data obtained, after 6 minutes SHMS runs, the temperature drop is about 17 °C. The higher engine temperature near the water boiling temperature, the higher amount of heat energy absorbed and more water evaporates. This will carry more heat away from the engine and cooling down the engine.

Below are the tables of the engine temperature increment. For the experiment 1 table, the temperature recorded for each minutes until the engine is reaching the running temperature. For the experiment 2 table, the engine was pre set at 80°C before the SHMS activated the water spray system. The time consumed for each degree Celsius decrement recorded. Finally the table for experiment 3, the engine was pre set at 90°C before the SHMS activated the water spray system and then the time consumed for each degree Celsius decrement recorded

Table 4.3 Engine Warm-up vs. Time

Experiment 1	
Time (minutes)	**Temperature (°C)**
0	0
1	9
2	21
3	33
4	43
5	52
6	60
7	62
8	65
9	67
10	69
11	70
12	72
13	74

Table 4.4 Time and Temperature Correlations

Experiment 2	
Temperature (°C)	**Time (minutes, seconds)**
81	0m00s
80	0m27s
79	1m30s
78	3m06s
78	4m00s
78	5m00s
78	6m00s

Table 4.5 Time and

Temperature Correlations

Experiment 3	
Temperature (°C)	**Time (minutes, seconds)**
91	0m0s
90	0m57s
89	1m13s
88	1m19s
87	1m22s
86	1m24s
85	1m26s
84	1m31s
83	2m03s
82	2m07s
81	2m11s
80	2m20s
79	2m23s
78	2m28s
77	2m33s
76	2m58s
75	3m12s
75	3m36s
74	3m48s
75	4m00s
75	4m42s
74	4m54s
75	5m12s
74	5m54s

4.4.4 Estimation Of Travelling Distance Gained.

The SHMS system will be pre set at 90°C for the first sensor and 100°C for the second sensor. The first sensor will give the signal to the control unit to activate the pump and spray onto the radiator to cool down the engine and the second sensor will give the signal to the control unit to turn off the engine. The sensor from the signal will have the range around 3°C from the preset temperature to give the signal to the control unit. Below is the estimation of the traveling distance gained by using SHMS based on the current configuration.

From the table for experiment 3 the time taken to drop the temperature 3°C from 90°C to 87°C is about 25 seconds. The total discharge time for 1 liter water based on current pressure and configuration is 6 minutes. The SHMS will run again the pump when the temperatures reach at 90°C. The experiment is the simulation of vehicle with cooling fan failure running at 30km/h.

The Assumption made

- Vehicle move at constant speed 30km/h
- The time cycle of temperature decrease and increase is constant
- The air stream flow is constant

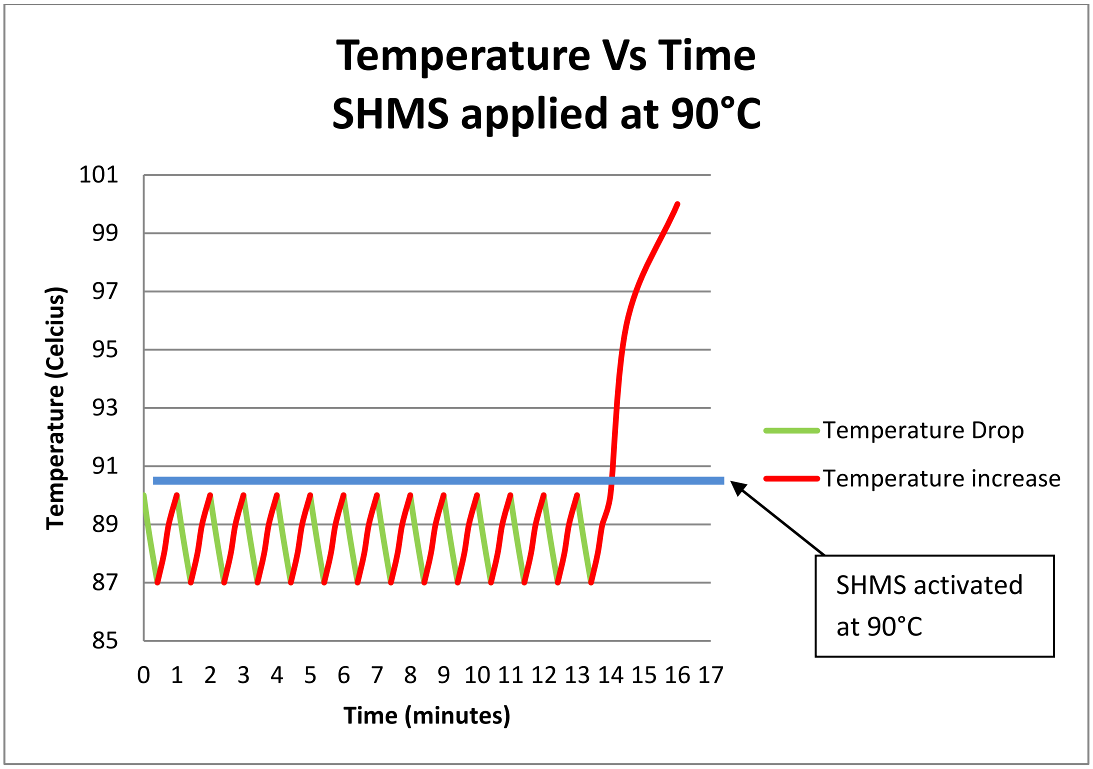


Figure 4.6 : Engine temperature when SHMS applie at 90°C

$$\boldsymbol{Water\ usange = \frac{Pump\ running\ time}{Pump\ total\ running\ time}\ x\ 1\ liter}$$

$$= \frac{25\ seconds}{6\ x\ 60\ seconds}\ x\ 1\ liter = 0.07\ liter$$

Based on this ON-OFF configuration, the pump will run when the temperature reach at 90°C and will turn off when temperature reach 87°C. The time taken is about 25 seconds to drop 3°C temperature. Since the pump with limitation of 1 liter storage water can run only in 6 minutes, so the number of times pump run will be

$$\boldsymbol{Pump\ run} = \frac{\boldsymbol{Pump\ Total\ running\ time}}{\boldsymbol{Pump\ 3℃\ drop\ running\ time}}$$

$$= \frac{6\ x\ 60\ seconds}{25\ seconds} = 14.4\ times$$

The estimation made, the engine will take around 35 seconds to increase 3°C back to 90°C before the SHMS reactivated that is 10 seconds longer due to existence of air stream when vehicle is moving. The total time for cooling down and increment (*Tc*) is 1 minutes. Total time gained before the water in storage running out

$$\boldsymbol{Total\ time\ gained = pump\ run\ x\ Tc}$$

$$= 14.4\ times\ x\ 1\ minutes$$

$$= 14.4\ minutes$$

14.4 minutes is equal to 14 minutes 24 seconds. Finally for the temperature to reach the 100°C is about additional 1 minute 36 seconds. So the total time before the engine turn off is around 16 minutes. If the vehicle is moving about 30km/h, the total travelling distance gained is

$$\boldsymbol{Total\ distance\ gained = Vehicle\ speed\ \left(\frac{km}{h}\right) x\ \frac{1\ hour}{60\ min}\ x\ Tt(min)}$$

$$= \frac{30}{60}\ \ x16 \quad = 8\ km$$

4.4.5 Experiment Conclusion

Based on the experimented data collected, the objective of the experiment is now clear that the evaporative cooling is effective to cool down the engine temperature. There are several factor that influence the effectiveness of the evaporative cooling that are humidity, air stream flow rate, and temperature difference. The engine temperature curve obtained can be used as a reference to improve this project into another level of improvement. As a conclusion this experiment is meet the expectation and the project objective is success.

4.5 Demand Study

This project operation is basically based on monitoring the temperature of a subject and try to cool down the subject if the temperature is over the pre set temperature and finally shut down the subject when the temperature reach dangerous level as a safety measure to avoid the subject from damage due to overheat and cause damage.

The demand of this potential system is basically for everything that involves cooling system. Below are the few potential users that may need a system to monitor the temperature for their system.

- Vehicle

  Each vehicle has the cooling system and some of motorcycles also have fluid cooling system instead of air cooling system. The vehicle cooling system will be required to suit the operating range of the engine. The overheat issue will damage the engine, engine component and change the properties of the material. That is where the SHMS can be used to avoid lots of money and time wasted on repairing the vehicle. A 30 Ringgit Malaysia upper water hose rupture can cause the engine overheat quickly and finally cost for around a thousand ringgit for repairing that might take around 2 or 3 weeks of time. The SHMS can save the engine before overheat and will only cost 40 ringgit including labor cost to change to hose within half an hour time.

- Plant

  Each plant that uses the heat will need a system to monitor the temperature. Even a nuclear reactor still requires a heat or temperature control. Some nuclear reactors use Very High Temperature Reactor (VHTR) that is a Generation IV reactor concept that uses a graphite-moderated nuclear reactor with a once-through uranium fuel cycle. The VHTR is a type of High Temperature Reactor (HTR) that can conceptually have an outlet temperature of 1000°C. Even this high temperature reactor will have a safety running ranges that allow the reactor to reach only 1100°C. The SHMS is basically can be used to suit the need of the reactor and assisted by series of precaution, corrective or safety measure to avoid the reactor from overheat that can cause a disaster to the world.

- Factory

  Many of the factories using heat in their manufacturing process. In Advance Micro Device (AMD) that is a computer manufacturer factory also have the process that require heat to melt the composite before fabrication. The mistake for letting the system goes overheat will cause fire and hazard to the workers and nearby population. The SHMS that is flexible can be adjusted to suit the needs of monitoring the fire chamber. The SHMS capable of handling more task before reaching the dangerous level and able to respond in short response time.

4.6 Cost Projection

Below are the projection for the cost of 100 units SHMS

Table 4.6 Cost projection for 100 units of SHMS

Bil Of Material for SHMS Unit		
Bil	**Item**	**Estimated Cost**
100	SHMS control unit	RM 7000
100	Storage tank with water pump	RM 4000
100	Display panel	RM 1200
200	Connection cable	RM 800
100	Temperature sensor with connection cable	RM 500
100	Water Hose	RM 250
100	Water Spray Nozzle	RM 900
	Labor Cost	RM5000
Total		RM 19650

From the estimated cost above based on some research obtained from factory distributor brochures. The estimation cost for each complete unit SHMS is RM196.50. The total saving for these 100 units is around RM6750 that is 25.6% of the initial cost. This cost still can be reduced for bigger quantities with some material and design improvement

4.7 Total Saving

Vehicle Production

Below are the total worldwide car productions each year issued by the International Organization of Motor Vehicle Manufacturers.

> OICA - (Organisation Internationale des Constructeurs d'Automobiles) - The International Organization of Motor Vehicle Manufacturers comprising 43 national trade associations around the world, including all major automobile manufacturing countries, thereby covering virtually the entire motor vehicle industry all over the world.

Table 4.7 World car production

Year	**Cars produced in the world**
2009	51,971,328
2008	52,940,559
2007	54,920,317
2006	49,886,549
2005	46,862,978
2004	44,554,268
2003	41,968,666
2002	41,358,394
2001	39,825,888
2000	41,215,653
1999	39,759,847

It is estimated that over 600,000,000 passenger cars travel the streets and roads of the world today.

In the United States alone, 247,421,120 "highway" registered vehicles were counted in 2005, of which 136,568,083 passenger cars. (Bureau of Transportation Statistics U.S. Department of Transportation)

It is estimated 0.01% of the vehicle have an overheat problem each year worldwide from the total vehicle travel that results 6,000, 000 for total. Each user is estimated need to spend around USD300 to USD800 including labor cost to repair the vehicles. The average is about USD400 (RM1240) for each vehicle.

<u>Component Cost</u>

Below are the average costs for each component in cooling system that may lead into overheating problem if failed. The labor cost average is about RM100 for each component replacement.

- Radiator (RM350)
- Upper hose (RM 30)
- Lower hose (RM30)
- Thermostat (RM45)
- Pressure cap (RM35)
- Fan (RM150)
- Water pump (RM70)

Situation 1

A vehicle was equipped with SHMS and assumed to have a problem with severe radiator damage that needs a replacement. The vehicle also need to be tow and charged RM150 for towing alone.

The total cost of repair will be

```
  RM350 – Radiator
  RM100 – Labor cost
+ RM150 – Towing
---------------------------
  RM600 – Total
---------------------------
```

.

From the calculation above the total cost of repair including investment in SHMS cost will be (RM264 + RM600 = RM864)

Based on the estimation 6,000,000 car in world have an overheat problem each year and on average each vehicle will be cost RM1240 for repair cost due to overheat problem. So the saving will be

```
   RM1240
-  RM864
---------------------------
   RM376 – Savings
---------------------------
```

Situation 2

A car was equipped with SHMS system and having an upper hose radiator. Luckily the user has the basic tools in car and has some experience in repairing car. The car is managed to reach the spare parts shop before the SHMS switching off the engine. The user just bought and replaces the upper hose by himself. The total cost is

RM30 – Upper hose
+ RM15 – Hose sealant

RM45 – Total

From the calculation above the total cost of repair including investment in SHMS cost will be (RM264 + RM45= RM309)

So the total saving will be

RM1240
- RM309

RM931 – Savings

4.8 Discussion

Typical engine will require heat to run at ideal running state in the higher thermal efficiency region but an excessive heat will damage the engine performance and parts. The failure of the engine caused by overheat may leave a permanent damage to the engine since the engine's part have a very small tolerance set by the manufacturer.

The damage caused by overheat will be also be higher due to severe damage and may become a big problem to the user. A conventional temperature gauge may be useful to measure the heat generated by the engine but unable to notify the user when the temperature rise to dangerous level. Overheat also happen caused user negligence or sudden damage of the part that is sometimes hard to be notice.

The development of SHMS will be a solution for all the associate causes that may lead into overheat problem. The SHMS will act like an engine guardian that only responsible to monitor the engine's temperature and notify the user if the abnormalities happen. Finally the SHMS will be the saver by turning off the engine before reaching to an overheat temperature even without the existence of the user.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

As the conclusion, this project is generally have achieve the objective of developing a Plug and Play (PnP) basis system that can be widely used for any vehicle and system that require a heat monitor system. This prototype is successfully completed all the task required such as Miss Spray System (MSS), the process of cooling down the engine using the evaporative cooling method and top engine protection by prevent the engine temperature goes beyond the preset limit through automatic turn off capability. After considering all the capabilities of the system, the prototype named Smart Heat Engine Management that suits its responsibilities. With a little investment, all the vehicle user do not have to worry about their engine heat management again as there is SHMS in place to guard the engine all the time.

5.2. Recommendation

The SHMS can be improved by proper fabrication with machinery and tools. The printed circuit board can be developed to produce a neat finishing for the control unit circuit board. The printed circuit board will also reduce the size of the board that results a smaller control unit.

The display panel also can be improved by using a proper design of the case using injection molding machine. The overall production cost can be reduced by mass production.

There a few improvements can be used to improve the efficiency of the system. The higher efficiency of the system will results in higher amount of the engine temperature decrement.

a) Smaller water droplets

   Smaller droplets of water will result a thinner layer of water sprayed onto the radiator. This will reduce the water waste and longer the duration of water discharge.

b) Wider jet angle of nozzle spray

   The wider angle of nozzle spray will increase the coverage over the frontal area of the radiator that will increase the heat energy absorption and evaporation rates.

c) Higher water pump pressure

   The higher water pump pressure will allow the usage of smaller nozzle holes that will produce a tinier water droplets or mist.

d) Lower boiling point of fluid

   Lower boiling point of fluid can be use instead of water to have the heat absorption and evaporation happen at lower temperature. This alternative can be used if the temperature needs to be maintained at lower temperature.

References

[1] Shabany, Younes.(2010). Heat transfer: thermal management of electronics ..Taylor and Francis Group, LLC

[2] Sonntag, Borgnakke, Van Wylen 2003. Fundamentals of Thermodynamics, Sixth Edition. New Jersey: John Wiley & Sons, Inc.

[3] Ray T. Bohacz, (2007). Engine Cooling Systems HP1425: Cooling System Theory, Design and Performance For Drag Racing, Road Racing,Circle Track, Street Rods, Musclecars, Imports, OEM Cars, Trucks, RVs and T

[4] Douglas , John F . (2000). Fluid mechanics Harlow, Essex, England : Longman Scientific & Technical ; New York : Wiley

[5] Greg F. Naterer (2002). Heat Transfer in Single and Multiphase Systems

[6] Holman, J. P. (Jack Philip). Heat transfer Boston : McGraw Hill Higher Education, c2010.

[7] Michalski, L. Temperature measurement West Sussex : John Wiley & Sons Ltd, 1991

[8] Yunus A Cengel, (2006) Heat And Mass Transfer, A Practical Approaches. 3rd] Edition. McGraw Hill

[9] S. Mostafa Ghiaasiaan, (2011), Convective Heat and Mass Transfer

[10] Larry R. Genskow, (2007), Perry's Chemical Engineers' Handbook 8/E Section 12:Psychrometry, Evaporative Cooling, and Solids Drying

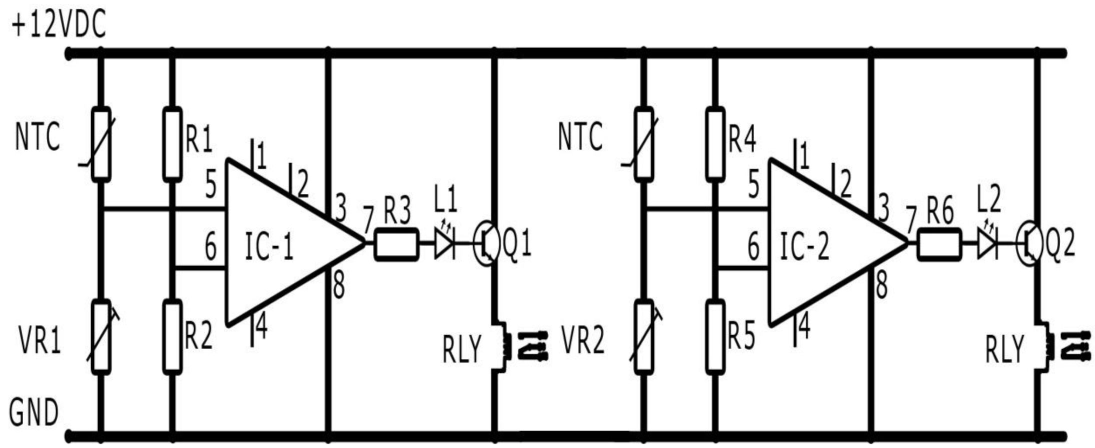
Appendix A : Gantt Chart

Activity	FYP1				FYP2			
	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
Earlier documentation of FYP								
Literature review related to evacuated solar water heater								
Studies on related theories and mathematical equation to apply								
Model development and optimization.								
Conduct experiment and analyze data.								
Analysis of result								
End stage documentation								

Appendix B : Key Milestone

Key Milestones	FYP1				FYP2			
	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Completion of experiment								
Analysis of result								
Simulation, result and analysis								

Appendix 1: SHMS Control Unit Circuit Diagram



Component	
Symbol	**Description**
IC-1, IC-2	741 (8 PIN)
R1, R4	10K (Brown, Black, Orange)
R2, R5	10K (Brown, Black, Orange)
R3, R6	390R (Orange, White, Brown)
Q1, Q2	9012 (PNP)
VR1, VR2	5K (Preset Potentiometer)
RLY	Relay 12V SPDT
NTC	Negative Temp Coefficient
L1, L2	LED (light Emitting Diode)

TABLE 5.1 :Source: Page782 , Yunus A Cengel, Heat And Mass Transfer, A Practical Approaches. 3rd Edition. McGraw Hill

TABLE 14–4

In a binary ideal gas mixture of species *A* and *B*, the diffusion coefficient of *A* in *B* is equal to the diffusion coefficient of *B* in *A*, and both increase with temperature

T, °C	D_{H_2O-Air} or D_{Air-H_2O} at 1 atm, in m^2/s (from Eq. 14–15)
0	2.09×10^{-5}
5	2.17×10^{-5}
10	2.25×10^{-5}
15	2.33×10^{-5}
20	2.42×10^{-5}
25	2.50×10^{-5}
30	2.59×10^{-5}
35	2.68×10^{-5}
40	2.77×10^{-5}
50	2.96×10^{-5}
100	3.99×10^{-5}
150	5.18×10^{-5}

TABLE 5.2 : Source: Page842 , Yunus A Cengel, Heat And Mass Transfer, A Practical Approaches. 3rd Edition. McGraw Hill

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APPENDIX 1

TABLE A–1

Molar mass, gas constant, and ideal-gas specific heats of some substances

Substance	Molar Mass M, kg/kmol	Gas Constant R, kJ/kg · K*	Specific Heat Data at 25°C c_p, kJ/kg · K	c_v, kJ/kg · K	$k = c_p/c_v$
Air	28.97	0.2870	1.005	0.7180	1.400
Ammonia, NH_3	17.03	0.4882	2.093	1.605	1.304
Argon, Ar	39.95	0.2081	0.5203	0.3122	1.667
Bromine, Br_2	159.81	0.05202	0.2253	0.1732	1.300
Isobutane, C_4H_{10}	58.12	0.1430	1.663	1.520	1.094
n-Butane, C_4H_{10}	58.12	0.1430	1.694	1.551	1.092
Carbon dioxide, CO_2	44.01	0.1889	0.8439	0.6550	1.288
Carbon monoxide, CO	28.01	0.2968	1.039	0.7417	1.400
Chlorine, Cl_2	70.905	0.1173	0.4781	0.3608	1.325
Chlorodifluoromethane (R-22), $CHClF_2$	86.47	0.09615	0.6496	0.5535	1.174
Ethane, C_2H_6	30.070	0.2765	1.744	1.468	1.188
Ethylene, C_2H_4	28.054	0.2964	1.527	1.231	1.241
Fluorine, F_2	38.00	0.2187	0.8237	0.6050	1.362
Helium, He	4.003	2.077	5.193	3.116	1.667
n-Heptane, C_7H_{16}	100.20	0.08297	1.649	1.566	1.053
n-Hexane, C_6H_{14}	86.18	0.09647	1.654	1.558	1.062
Hydrogen, H_2	2.016	4.124	14.30	10.18	1.405
Krypton, Kr	83.80	0.09921	0.2480	0.1488	1.667
Methane, CH_4	16.04	0.5182	2.226	1.708	1.303
Neon, Ne	20.183	0.4119	1.030	0.6180	1.667
Nitrogen, N_2	28.01	0.2968	1.040	0.7429	1.400
Nitric oxide, NO	30.006	0.2771	0.9992	0.7221	1.384
Nitrogen dioxide, NO_2	46.006	0.1889	0.8060	0.6171	1.306
Oxygen, O_2	32.00	0.2598	0.9180	0.6582	1.395
n-Pentane, C_5H_{12}	72.15	0.1152	1.664	1.549	1.074
Propane, C_3H_8	44.097	0.1885	1.669	1.480	1.127
Propylene, C_3H_6	42.08	0.1976	1.531	1.333	1.148
Steam, H_2O	18.015	0.4615	1.865	1.403	1.329
Sulfur dioxide, SO_2	64.06	0.1298	0.6228	0.4930	1.263
Tetrachloromethane, CCl_4	153.82	0.05405	0.5415	0.4875	1.111
Tetrafluoroethane (R-134a), $C_2H_2F_4$	102.03	0.08149	0.8334	0.7519	1.108
Trifluoroethane (R-143a), $C_2H_3F_3$	84.04	0.09893	0.9291	0.8302	1.119
Xenon, Xe	131.30	0.06332	0.1583	0.09499	1.667

*The unit kJ/kg · K is equivalent to kPa · m³/kg · K. The gas constant is calculated from $R = R_U/M$, where R_U = 8.31447 kJ/kmol · K is the universal gas constant and M is the molar mass.

Source: Specific heat values are obtained primarily from the property routines prepared by The National Institute of Standards and Technology (NIST), Gaithersburg, MD.

TABLE 5.3 : Source: Page854 , Yunus A Cengel, Heat And Mass Transfer,

A Practical Approaches. 3rd Edition. McGraw Hill

TABLE A–9

Properties of saturated water

Temp. T, °C	Saturation Pressure P_{sat}, kPa	Density ρ, kg/m³ Liquid	Density Vapor	Enthalpy of Vaporization h_{fg}, kJ/kg	Specific Heat c_p, J/kg · K Liquid	Specific Heat Vapor	Thermal Conductivity k, W/m · K Liquid	Thermal Conductivity Vapor	Dynamic Viscosity μ, kg/m · s Liquid	Dynamic Viscosity Vapor	Prandtl Number Pr Liquid	Prandtl Number Vapor	Volume Expansion Coefficient β, 1/K Liquid
0.01	0.6113	999.8	0.0048	2501	4217	1854	0.561	0.0171	1.792×10^{-3}	0.922×10^{-5}	13.5	1.00	−0.068 × 1
5	0.8721	999.9	0.0068	2490	4205	1857	0.571	0.0173	1.519×10^{-3}	0.934×10^{-5}	11.2	1.00	0.015 × 10
10	1.2276	999.7	0.0094	2478	4194	1862	0.580	0.0176	1.307×10^{-3}	0.946×10^{-5}	9.45	1.00	0.733×10^{-3}
15	1.7051	999.1	0.0128	2466	4185	1863	0.589	0.0179	1.138×10^{-3}	0.959×10^{-5}	8.09	1.00	0.138×10^{-3}
20	2.339	998.0	0.0173	2454	4182	1867	0.598	0.0182	1.002×10^{-3}	0.973×10^{-5}	7.01	1.00	0.195 × 10
25	3.169	997.0	0.0231	2442	4180	1870	0.607	0.0186	0.891×10^{-3}	0.987×10^{-5}	6.14	1.00	0.247 × 10
30	4.246	996.0	0.0304	2431	4178	1875	0.615	0.0189	0.798×10^{-3}	1.001×10^{-5}	5.42	1.00	0.294 × 10
35	5.628	994.0	0.0397	2419	4178	1880	0.623	0.0192	0.720×10^{-3}	1.016×10^{-5}	4.83	1.00	0.337×10^{-3}
40	7.384	992.1	0.0512	2407	4179	1885	0.631	0.0196	0.653×10^{-3}	1.031×10^{-5}	4.32	1.00	0.377 × 10
45	9.593	990.1	0.0655	2395	4180	1892	0.637	0.0200	0.596×10^{-3}	1.046×10^{-5}	3.91	1.00	0.415 × 10
50	12.35	988.1	0.0831	2383	4181	1900	0.644	0.0204	0.547×10^{-3}	1.062×10^{-5}	3.55	1.00	0.451 × 10
55	15.76	985.2	0.1045	2371	4183	1908	0.649	0.0208	0.504×10^{-3}	1.077×10^{-5}	3.25	1.00	0.484×10^{-3}
60	19.94	983.3	0.1304	2359	4185	1916	0.654	0.0212	0.467×10^{-3}	1.093×10^{-5}	2.99	1.00	0.517×10^{-3}
65	25.03	980.4	0.1614	2346	4187	1926	0.659	0.0216	0.433×10^{-3}	1.110×10^{-5}	2.75	1.00	0.548 × 10
70	31.19	977.5	0.1983	2334	4190	1936	0.663	0.0221	0.404×10^{-3}	1.126×10^{-5}	2.55	1.00	0.578 × 10
75	38.58	974.7	0.2421	2321	4193	1948	0.667	0.0225	0.378×10^{-3}	1.142×10^{-5}	2.38	1.00	0.607×10^{-3}
80	47.39	971.8	0.2935	2309	4197	1962	0.670	0.0230	0.355×10^{-3}	1.159×10^{-5}	2.22	1.00	0.653×10^{-3}
85	57.83	968.1	0.3536	2296	4201	1977	0.673	0.0235	0.333×10^{-3}	1.176×10^{-5}	2.08	1.00	0.670 × 10
90	70.14	965.3	0.4235	2283	4206	1993	0.675	0.0240	0.315×10^{-3}	1.193×10^{-5}	1.96	1.00	0.702 × 10
95	84.55	961.5	0.5045	2270	4212	2010	0.677	0.0246	0.297×10^{-3}	1.210×10^{-5}	1.85	1.00	0.716 × 10
100	101.33	957.9	0.5978	2257	4217	2029	0.679	0.0251	0.282×10^{-3}	1.227×10^{-5}	1.75	1.00	0.750×10^{-3}
110	143.27	950.6	0.8263	2230	4229	2071	0.682	0.0262	0.255×10^{-3}	1.261×10^{-5}	1.58	1.00	0.798×10^{-3}
120	198.53	943.4	1.121	2203	4244	2120	0.683	0.0275	0.232×10^{-3}	1.296×10^{-5}	1.44	1.00	0.858 × 10
130	270.1	934.6	1.496	2174	4263	2177	0.684	0.0288	0.213×10^{-3}	1.330×10^{-5}	1.33	1.01	0.913 × 10
140	361.3	921.7	1.965	2145	4286	2244	0.683	0.0301	0.197×10^{-3}	1.365×10^{-5}	1.24	1.02	0.970×10^{-3}
150	475.8	916.6	2.546	2114	4311	2314	0.682	0.0316	0.183×10^{-3}	1.399×10^{-5}	1.16	1.02	1.025×10^{-3}
160	617.8	907.4	3.256	2083	4340	2420	0.680	0.0331	0.170×10^{-3}	1.434×10^{-5}	1.09	1.05	1.145 × 10
170	791.7	897.7	4.119	2050	4370	2490	0.677	0.0347	0.160×10^{-3}	1.468×10^{-5}	1.03	1.05	1.178 × 10
180	1,002.1	887.3	5.153	2015	4410	2590	0.673	0.0364	0.150×10^{-3}	1.502×10^{-5}	0.983	1.07	1.210 × 10
190	1,254.4	876.4	6.388	1979	4460	2710	0.669	0.0382	0.142×10^{-3}	1.537×10^{-5}	0.947	1.09	1.280×10^{-3}
200	1,553.8	864.3	7.852	1941	4500	2840	0.663	0.0401	0.134×10^{-3}	1.571×10^{-5}	0.910	1.11	1.350×10^{-3}
220	2,318	840.3	11.60	1859	4610	3110	0.650	0.0442	0.122×10^{-3}	1.641×10^{-5}	0.865	1.15	1.520 × 10
240	3,344	813.7	16.73	1767	4760	3520	0.632	0.0487	0.111×10^{-3}	1.712×10^{-5}	0.836	1.24	1.720 × 10
260	4,688	783.7	23.69	1663	4970	4070	0.609	0.0540	0.102×10^{-3}	1.788×10^{-5}	0.832	1.35	2.000×10^{-3}
280	6,412	750.8	33.15	1544	5280	4835	0.581	0.0605	0.094×10^{-3}	1.870×10^{-5}	0.854	1.49	2.380×10^{-3}
300	8,581	713.8	46.15	1405	5750	5980	0.548	0.0695	0.086×10^{-3}	1.965×10^{-5}	0.902	1.69	2.950 × 10
320	11,274	667.1	64.57	1239	6540	7900	0.509	0.0836	0.078×10^{-3}	2.084×10^{-5}	1.00	1.97	
340	14,586	610.5	92.62	1028	8240	11,870	0.469	0.110	0.070×10^{-3}	2.255×10^{-5}	1.23	2.43	
360	18,651	528.3	144.0	720	14,690	25,800	0.427	0.178	0.060×10^{-3}	2.571×10^{-5}	2.06	3.73	
374.14	22,090	317.0	317.0	0	—	—	—	—	0.043×10^{-3}	4.313×10^{-5}			

Note 1: Kinematic viscosity ν and thermal diffusivity α can be calculated from their definitions, $\nu = \mu/\rho$ and $\alpha = k/\rho c_p = \nu/\text{Pr}$. The temperatures 0.01°C, 100°C, and 374.14°C are the triple-, boiling-, and critical-point temperatures of water, respectively. The properties listed above (except the vapor density) can be used at any pressure with negligible error except at temperatures near the critical-point value.

Note 2: The unit kJ/kg · °C for specific heat is equivalent to kJ/kg · K, and the unit W/m · °C for thermal conductivity is equivalent to W/m · K.

Source: Viscosity and thermal conductivity data are from J. V. Sengers and J. T. R. Watson, *Journal of Physical and Chemical Reference Data* 15 (1986), pp. 1291–1322. Other data are obtained from various sources or calculated.

TABLE 5.4 : Source: Page860 , Yunus A Cengel, Heat And Mass Transfer,

A Practical Approaches. 3rd Edition. McGraw Hill

TABLE A–15

Properties of air at 1 atm pressure

Temp. T, °C	Density ρ, kg/m³	Specific Heat c_p, J/kg · K	Thermal Conductivity k, W/m · K	Thermal Diffusivity α, m²/s²	Dynamic Viscosity μ, kg/m · s	Kinematic Viscosity ν, m²/s	Prandtl Number Pr
−150	2.866	983	0.01171	4.158×10^{-6}	8.636×10^{-6}	3.013×10^{-6}	0.7246
−100	2.038	966	0.01582	8.036×10^{-6}	1.189×10^{-5}	5.837×10^{-6}	0.7263
−50	1.582	999	0.01979	1.252×10^{-5}	1.474×10^{-5}	9.319×10^{-6}	0.7440
−40	1.514	1002	0.02057	1.356×10^{-5}	1.527×10^{-5}	1.008×10^{-5}	0.7436
−30	1.451	1004	0.02134	1.465×10^{-5}	1.579×10^{-5}	1.087×10^{-5}	0.7425
−20	1.394	1005	0.02211	1.578×10^{-5}	1.630×10^{-5}	1.169×10^{-5}	0.7408
−10	1.341	1006	0.02288	1.696×10^{-5}	1.680×10^{-5}	1.252×10^{-5}	0.7387
0	1.292	1006	0.02364	1.818×10^{-5}	1.729×10^{-5}	1.338×10^{-5}	0.7362
5	1.269	1006	0.02401	1.880×10^{-5}	1.754×10^{-5}	1.382×10^{-5}	0.7350
10	1.246	1006	0.02439	1.944×10^{-5}	1.778×10^{-5}	1.426×10^{-5}	0.7336
15	1.225	1007	0.02476	2.009×10^{-5}	1.802×10^{-5}	1.470×10^{-5}	0.7323
20	1.204	1007	0.02514	2.074×10^{-5}	1.825×10^{-5}	1.516×10^{-5}	0.7309
25	1.184	1007	0.02551	2.141×10^{-5}	1.849×10^{-5}	1.562×10^{-5}	0.7296
30	1.164	1007	0.02588	2.208×10^{-5}	1.872×10^{-5}	1.608×10^{-5}	0.7282
35	1.145	1007	0.02625	2.277×10^{-5}	1.895×10^{-5}	1.655×10^{-5}	0.7268
40	1.127	1007	0.02662	2.346×10^{-5}	1.918×10^{-5}	1.702×10^{-5}	0.7255
45	1.109	1007	0.02699	2.416×10^{-5}	1.941×10^{-5}	1.750×10^{-5}	0.7241
50	1.092	1007	0.02735	2.487×10^{-5}	1.963×10^{-5}	1.798×10^{-5}	0.7228
60	1.059	1007	0.02808	2.632×10^{-5}	2.008×10^{-5}	1.896×10^{-5}	0.7202
70	1.028	1007	0.02881	2.780×10^{-5}	2.052×10^{-5}	1.995×10^{-5}	0.7177
80	0.9994	1008	0.02953	2.931×10^{-5}	2.096×10^{-5}	2.097×10^{-5}	0.7154
90	0.9718	1008	0.03024	3.086×10^{-5}	2.139×10^{-5}	2.201×10^{-5}	0.7132
100	0.9458	1009	0.03095	3.243×10^{-5}	2.181×10^{-5}	2.306×10^{-5}	0.7111
120	0.8977	1011	0.03235	3.565×10^{-5}	2.264×10^{-5}	2.522×10^{-5}	0.7073
140	0.8542	1013	0.03374	3.898×10^{-5}	2.345×10^{-5}	2.745×10^{-5}	0.7041
160	0.8148	1016	0.03511	4.241×10^{-5}	2.420×10^{-5}	2.975×10^{-5}	0.7014
180	0.7788	1019	0.03646	4.593×10^{-5}	2.504×10^{-5}	3.212×10^{-5}	0.6992
200	0.7459	1023	0.03779	4.954×10^{-5}	2.577×10^{-5}	3.455×10^{-5}	0.6974
250	0.6746	1033	0.04104	5.890×10^{-5}	2.760×10^{-5}	4.091×10^{-5}	0.6946
300	0.6158	1044	0.04418	6.871×10^{-5}	2.934×10^{-5}	4.765×10^{-5}	0.6935
350	0.5664	1056	0.04721	7.892×10^{-5}	3.101×10^{-5}	5.475×10^{-5}	0.6937
400	0.5243	1069	0.05015	8.951×10^{-5}	3.261×10^{-5}	6.219×10^{-5}	0.6948
450	0.4880	1081	0.05298	1.004×10^{-4}	3.415×10^{-5}	6.997×10^{-5}	0.6965
500	0.4565	1093	0.05572	1.117×10^{-4}	3.563×10^{-5}	7.806×10^{-5}	0.6986
600	0.4042	1115	0.06093	1.352×10^{-4}	3.846×10^{-5}	9.515×10^{-5}	0.7037
700	0.3627	1135	0.06581	1.598×10^{-4}	4.111×10^{-5}	1.133×10^{-4}	0.7092
800	0.3289	1153	0.07037	1.855×10^{-4}	4.362×10^{-5}	1.326×10^{-4}	0.7149
900	0.3008	1169	0.07465	2.122×10^{-4}	4.600×10^{-5}	1.529×10^{-4}	0.7206
1000	0.2772	1184	0.07868	2.398×10^{-4}	4.826×10^{-5}	1.741×10^{-4}	0.7260
1500	0.1990	1234	0.09599	3.908×10^{-4}	5.817×10^{-5}	2.922×10^{-4}	0.7478
2000	0.1553	1264	0.11113	5.664×10^{-4}	6.630×10^{-5}	4.270×10^{-4}	0.7539

Note: For ideal gases, the properties c_p, k, μ, and Pr are independent of pressure. The properties ρ, ν, and α at a pressure P (in atm) other than 1 atm are determined by multiplying the values of ρ at the given temperature by P and by dividing ν and α by P.

Source: Data generated from the EES software developed by S. A. Klein and F. L. Alvarado. Original sources: Keenan, Chao, Keyes, Gas Tables, Wiley, 198; and Thermophysical Properties of Matter. Vol. 3: Thermal Conductivity, Y. S. Touloukian, P. E. Liley, S. C. Saxena, Vol. 11: Viscosity, Y. S. Touloukian, S. C. Saxena, and P. Hestermans, IFI/Plenun, NY, 1970, ISBN 0-306067020-8.