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PERFORMANCE OF A WATER PUMP IN AN AUTOMOTIVE ENGINE COOLING SYSTEM

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Graphical abstract

Abstract

A cooling system employed in an automobile is to maintain the desired coolant temperature thus ensuring for optimum engine operation. Forced convection obtained by means of a water pump will enhance the cooling effect. Thus it is necessary to understand the system's pump operation and be able to provide for the ultimate cooling of the engine. The objective of this laboratory investigation is to study the water pump characteristics of an engine cooling system. The crucial water pump parameters are the head, power, and its efficiency. In order to investigate the water pump characteristic a dedicated automotive cooling simulator test rig was designed and developed. All of the data obtained are important towards designing for a more efficient water pump such as electric pump that is independent of the power from the engine. In addition to this fact, the simulator test rig can also be used to investigate for any other parameters and products such as radiator performance and electric pump before installation in the actual engine cooling system. From the experiment conducted to simulate for the performance of a cooling system of a *Proton Wira* (4G15), the maximum power equals to 37 W which indicates the efficiency of the pump is relatively too low as compared to the typical power consume by the pump from the engine which are about 1 to 2 kW. Whereas the maximum power and efficiency obtained from the simulator test rig simulator is equals to 42 W and 15% respectively.

Keywords: Water pump characteristic, cooling system, Proton Wira (4G15), simulator

1.0 INTRODUCTION

The burning of fuel in the internal combustion engine of a vehicle will produce enormous heat. During the burning of air-fuel mixture in the engine cylinders, the burning gas temperature can achieve to 2200°C or higher [1, 2 & 3]. The heat produced is transformed into kinetic energy by the pistons, connecting rod and other mechanical components in the engine to operate. However, not all the heat can be transferred into useful mechanical power [4, 5]. There are about one third of the energy produced by combustion is converted to the mechanical power. Meanwhile, another one third is dissipated as heat through the exhaust and the rest of the energy are transferred by the cooling system [6, 7].

To remove excess heat that produce by the engine, it is necessary to have cooling system. If the high temperature that produce by the burning air-fuel mixture are not controlled, it will cause the breakdown of the lubricating oil and lose its lubricating properties [8]. However, removing too much heat through the cylinder walls and head can lower engine thermal efficiency .The main purpose of the cooling system are to keep the engine its most efficient operating temperature at all engine speeds and all driving conditions [9]. When the engine is in cool condition, the cooling system will not normally operate to make the engine reach operating temperature quickly. The cooling system will only remove the excess heat when the engine reaches normal operating temperature.

Water pump is one of the important components of the engine's cooling system. The pump is a centrifugal type in a tight metal casing. The main purpose of the pump is to maintain the circulation of the coolant through the system. Coolant will enters pump through the suction side and is forced to rotate by its impeller. Then, the impeller that rotates will pull the coolant at the outlet of the radiator and transmit to the water jacket. The water pump is driven by the crank of the engine through a belt. In designing the engine cooling system, the pump performance is important which is takes about 4.5% to 5% of the mechanical power from the engine [3].

In the engine cooling system (Figure 1), the circulation starts from the water pump. The role of the pump is to circulate the coolant throughout the system. Firstly, it will transmit the coolant to the water jacket. Subsequently, the coolant is transferred to the thermostat. The purpose of the thermostat is to regulate water circulating in the system. When the system is under the warm-up condition, the coolant will not flow to the radiator but will be reroute via bypass pipe. Whenever the coolant temperature achieve the thermostat setting temperature, the flow will be diverted to the radiator and it will cool the coolant due to air being induced by the cooling fan.

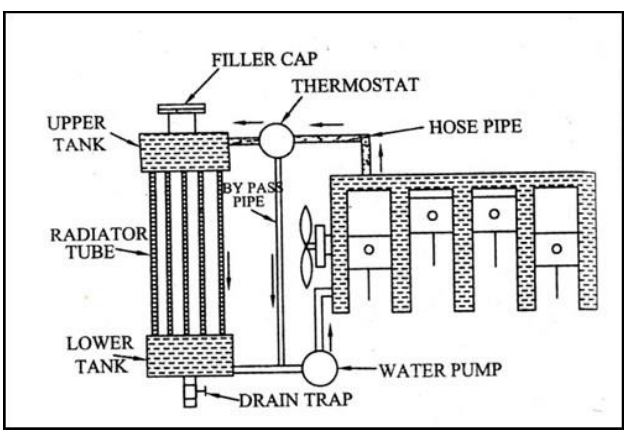

Figure 1 Circulation of coolant [10]

The function of a water pump is to maintain the circulation of the water through the system. Usually water pumps are impeller-type centrifugal pumps and are fitted at the front end of the cylinder block. The components in the water pump are housing, with inlet and outlet, and an impeller. The pump inlet is connected to the lower tank of the radiator by a hose. It is driven by the crank through a belt [4]. When the impeller rotates, the water between the blades is thrown out by centrifugal force and is forced to the pump outlet into the water jacket of the cylinder block. The water from radiator is drawn by the impeller into the pump to replace the coolant forced out through the outlet to water jacket.

Overall pump efficiency (Eq. 1) can be defined as the ratio of liquid power produced by the pump to the power transferred by the shaft [5].

$$\eta = \frac{\rho g Q H}{P_s} = \frac{H}{H_i} = \frac{Q}{Q_i} = \frac{\rho g Q_i H_i}{P_s} \quad (1)$$

The head of the pump can be determined by the experimental arrangement as in the Figure 2 by using the energy equation as Eq. 2:

$$H = \frac{p_2 - p_1}{\rho g} + z_2 - z_1 + \frac{V_2^2 - V_1^2}{2g} \quad (2)$$

Typically the differences in elevations and velocities are small so Eq. 2 is then finalized as Eq.3.

$$H \approx \frac{p_2 - p_1}{\rho g} \quad (3)$$

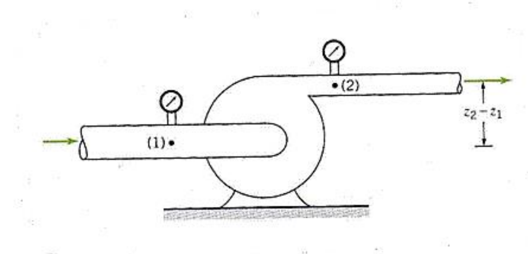

Figure 2 Typical experimental arrangement for determining the head rise gained by a fluid flowing through a pump [5]

The affinity law is the rules of the performance of a centrifugal pump when the speed or impeller diameter is changed. There are two sets of affinity laws which are the impeller diameter (D) is constant and the speed (N) is constant [6].

a) Impeller diameter is constant, D

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \quad (4)$$

$$\frac{H_1}{H_2} = \left(\frac{N_1^2}{N_2^2}\right) \quad (5)$$

$$\frac{BHP_1}{BHP_2} = \frac{N_1^3}{N_2^3} \quad (6)$$

b) Speed is constant, N

$$\frac{Q_1}{Q_2} = \frac{D_1}{D_2} \tag{7}$$

$$\frac{H_1}{H_2} = \left(\frac{D_1^2}{D_2^2}\right) \tag{8}$$

$$\frac{BHP_1}{BHP_2} = \frac{D_1^3}{D_2^3} \tag{9}$$

2.0 METHODOLOGY

The experiment is conduct for both using real engine cooling system and simulator test rig that has been developed.

Figure 3 shows the schematic diagram of the real engine cooling system with its instrumentation that has already installed. Figure 4 shows the schematic diagram of the simulator test rig engine cooling system with its instrumentation installed. Figure 5 on the other hand shows the completed simulator test rig.

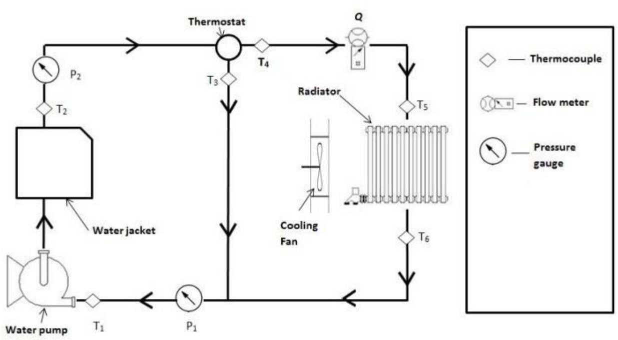

Figure 3 Schematic diagram of the real engine cooling system

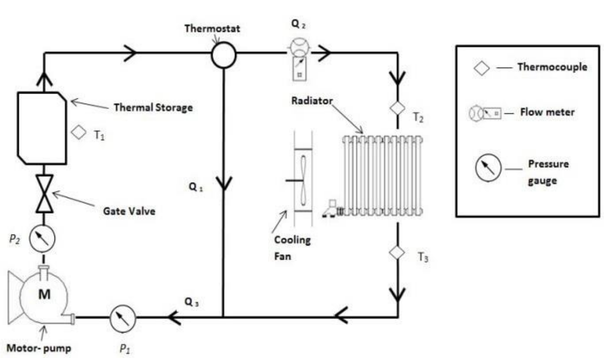

Figure 4 Schematic diagram of the simulator test rig

Figure 5 Simulator test rig

The different between the real engine and simulator is that the water jacket in the former is substituted with the thermal storage and its mechanical pump is substitute with the electric motor pump.

3.0 RESULTS AND DISCUSSIONS

3.1 Real Engine

Figure 6 to 10 show the temperature profiles for different locations using thermocouple probes placed in the engine cooling system, at engine speed ranging from 1000 rpm to 3000 rpm. This results are obtained when the car in the static condition.

The cyclic shape in Figure 6, 7 and 8 means that the electric fan at the radiator is switch off and on automatically for a certain period of time. Moreover, the controller will automatically switch off and on the thermostat attached near to the outlet of the radiator. Whenever the temperature of water at the thermostat switch reaches at certain temperature, the thermostat switch will switch on to allowed the fan to rotate and pull air from in front of the radiator and vice versa when the temperature is decrease.

There are different period of time for each cycle at different engine speed. The higher the engine speed, the longer the time taken to complete the cycle. This indicates that the cooling system need more time to gain heat generated from the combustion chamber before cool it down because of the combustion inside the combustion chamber continuously burn rapidly and the temperature inside the combustion chamber is increase as the engine speed increase [13].

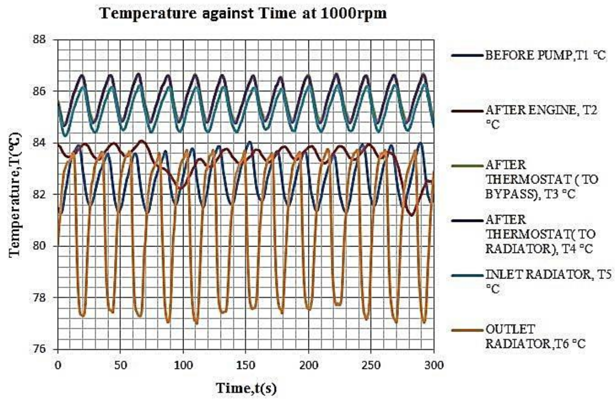

Figure 6 Graph of temperature against time at 1000 rpm of engine speed

However, the temperature profiles for the 2500 rpm and 3000 rpm as shown in the Figure 9 and 10, do not indicate the cyclic pattern. The temperature keeps increasing for the whole period of time as shown in the graph. This indicates that the fan will keep on rotating because there is a lot of heat produce in the combustion process inside the combustion chamber. In addition to that, the cooling system also cannot lower down the temperature and maintain it as the heat produce is too large. This graph may be vary if the experiment is done while the car move at the highest speed as there will be lot of air come from the in front of the radiator.

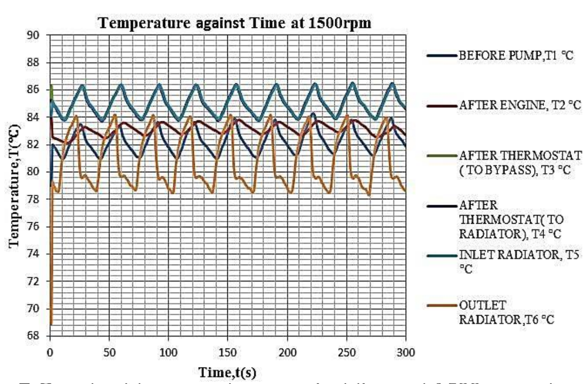

Figure 7 Graph of temperature against time at 1500 rpm of engine speed

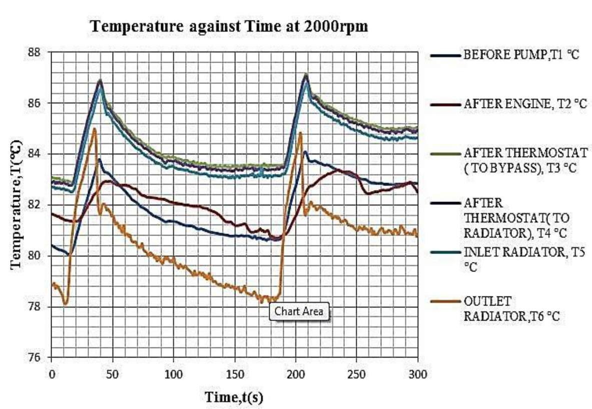

Figure 8 Graph of temperature against time at 2000 rpm of engine speed

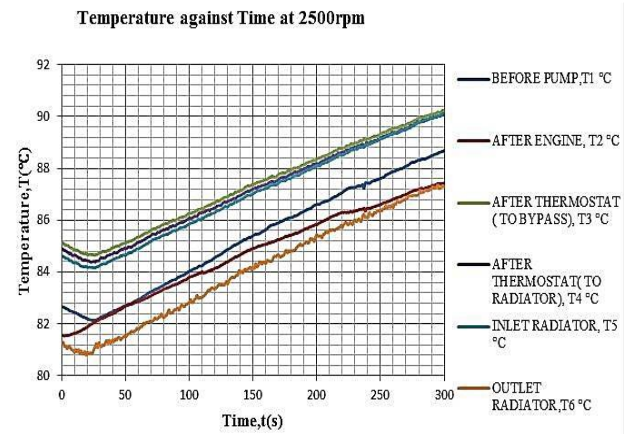

Figure 9 Graph of temperature against time at 2500 rpm of engine speed

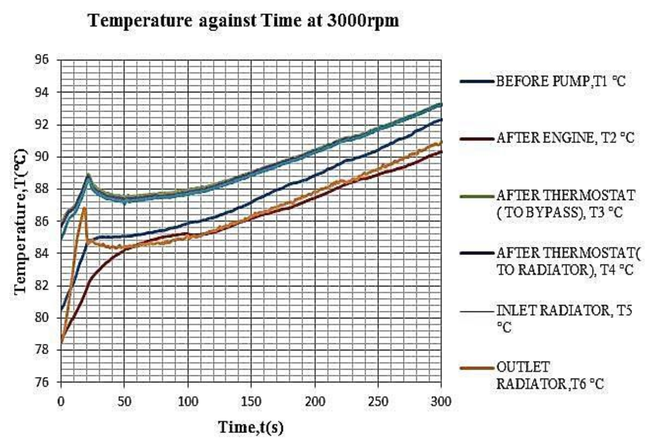

Figure 10 Graph of temperature against time at 3000 rpm of engine speed

In Figure 11, the flow rate of the cooling water increase linearly to the engine speed. In addition to that, the highest flow rate is equal to 0.00038 m^3/s at 3000 rpm of the engine speed. Furthermore, the equation obtained from the graph is Q = 1E-07N. The linear relationship shows that the relationship between the engine speeds and the flow rate is obeying the affinity law. Affinity law states that the flow rate is proportional to the shaft speed of the pump [12]. It is also note that the engine speed is not equal to the shaft speed of the pump. The ratio of the engine speed to the pump shaft speed is 1.1 [14].

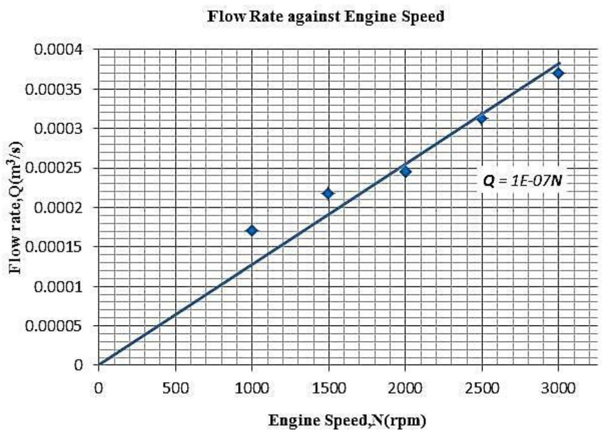

Figure 11 Graph of coolant flow rate against engine speed

From Figure 12, the power of the water pump is increased as the flow rate of the cooling system increase. The maximum power is recorded as 37 W at 0.00037 m^3/s of the flow rate, which is at 3000 rpm of the engine speed. In addition to that, the power here means that the output power gained by the water from the engine crankshaft rotation.

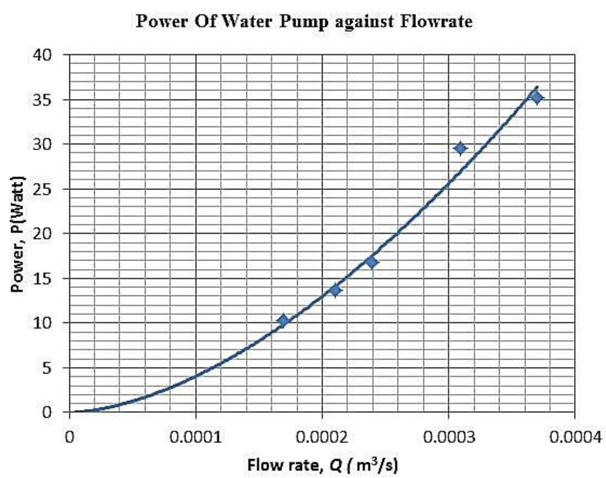

Figure 12 Graph of power of water pump against flow rate of water with different engine speed

It is observed that not all of the power from the crankshaft is being transferred to the fluid. Basically, there are three losses in the pump i.e. i) hydraulic losses, ii) mechanical losses and iii) volumetric losses. Hydraulic losses are the internal losses in the impeller and volute or diffuser due to friction in the walls of the liquid passageways and the continual change of direction of the liquid as it moves through the pump. Besides, the mechanical losses is the frictional losses that occurs in the moving parts of the pump which are in contact especially bearings or seal. Lastly, the volumetric loss is due to leakage of a usually small amount of liquid from the discharge side of the centrifugal pump to the suction side.

The water pump is predicted to consume approximately 1 to 2 kW of power supplied via the engine crankshaft [15]. Based on the maximum power shown in Figure 12, the efficiency of the water pump is too low. By replacing the engine driven water pump with a small electric water pump of 30 to 60 W rating, the fuel consumption can be reduced further thus increase the performance of the engine especially for traction.

3.2 Actual Engine

In Figure 13, the power, head, and efficiency of the pump against flow rate is plotted in the same graph to get more clearly view of the pump characteristic with the constant motor speed of 2000 rpm. Based on the graph, the maximum head or shut-off head is equals to 30.50 m and the maximum flow rate is equals to 0.00053 m^3/s.

The efficiency reaches a maximum value at the certain value of the flow rate. This point referred as the normal or design flow rate or capacity for the pump. Moreover, the points of power and head curve that correspond to the maximum efficiency are denoted as the best efficiency point as shown in the graph. Based on the graph, the value for the best efficiency point for the power is equals to 42 W, head equals to 17 m and efficiency equals to 15%. In addition to that, the normal or design flow rate is equals to 0.00025 m^3/s.

In addition, the graph in the Figure 13 is almost the same with the typical performance characteristic of centrifugal pump [11] and the experiment result from the previous study [9].

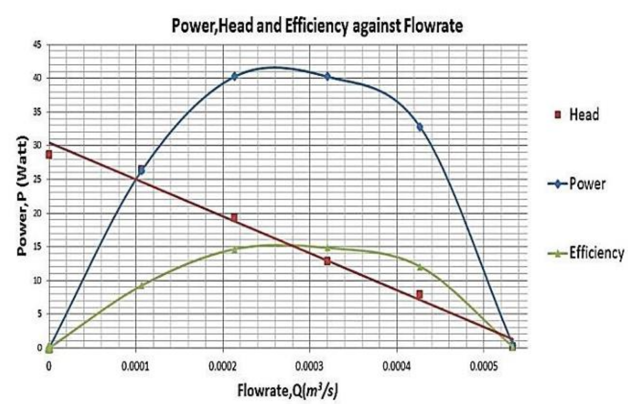

Figure 13 Graph of power, efficiency, and head of the pump against flow rate at the speed of motor 2000 rpm

Figure 14 is the graph showing the power requirement of the tested water pump for both real engine and simulator cooling system. The data for the simulator is taken at 80°C to create similar operating condition in the real engine.

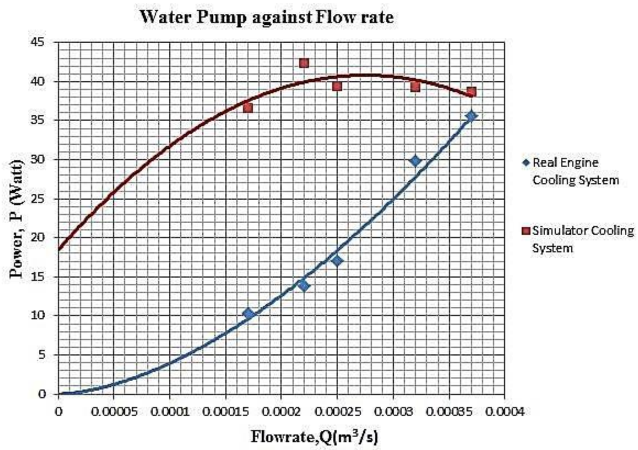

Figure 14 Graph of power of water pump against flow rate for the real engine and simulator cooling system

The real engine water pump power is increasing as the engine speed is increased but not for the simulator. For the simulator cooling system the water pump power is increase and reaches peak at 0.00026 m^3/s and then decrease slightly. The differences behavior of the water pump power between the real engine and simulator are obvious. This is due to different of the power input for the both condition. For the simulator, the input power is almost same throughout the experiment which is from the same electrical source with the constant speed (2000 rpm) of the motor. The different values of water pump power is only due to the variation of valve opening. Otherwise, the water pump power input in the real engine system will depends on the engine speed variation (1000 to 3000 rpm). The pump receives power transfer from the engine crankshaft pulley to the pulley that connected to the pump shaft through the belt.

Figure 15 shows the effect of temperature on the power of pump. The behavior of the power is not constant for different temperature. This is due to decreasing of water density when the temperature is rise. When the water is heating, the volume will increase. The pressure also will be not the same for the different temperature.

Figure 16 shows the maximum power produced at the each temperature based from the data in Figure 15. This graph indicates that the power will be increased when the temperature is increased. The increasing of power consumption is also due to the increasing of the pressure when the temperature is rise. In addition to this, the increasing of temperature will cause the molecule of the water move rapidly thus raising the temperature.

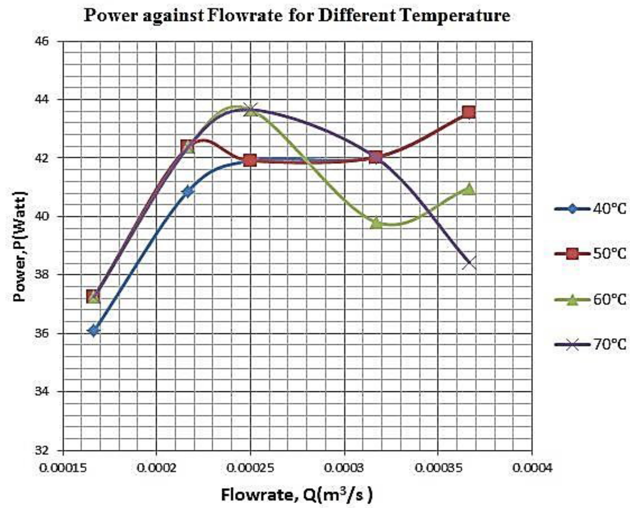

Figure 15 Graph of power against flow rate for different temperature

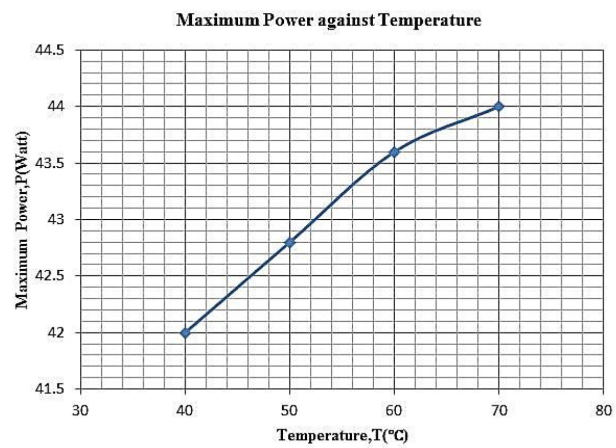

Figure 16 Maximum power against Temperature

4.0 CONCLUSION

The outcome of this investigation can be divided into two parts focussing on i) experiment work on a real engine cooling system and ii) experiment work using a simulator test rig that has been fabricated for the purpose of this evaluation.

4.1 Real Engine Cooling System Experiment

i) The temperature profile, flow rate and pressure inside the system can be determined by installing the thermocouple, flow meter and pressure gauge in the real engine cooling system.
ii) The linear relationship between flow rate and engine speed is obtained. The equation is Q = 1E-07N where Q equals to volume flow rate in m3/s and N equals to engine speed. In addition to that, the relationship is obeying the affinity law.
iii) From the value of the pressure and flow rate, the power of the pump can be worked out. The

maximum power obtain from the plotted graph is equals to 37 W. Moreover, the efficiency of the pump can be said relatively too low when comparing the value of the highest power with the power consume by the pump as stated in the discussion. The engine driven pump can be replaced by the small electric water pump that can give the same flow requirement to the engine which can increase the performance of the engine.

4.2 Simulator Test Rig Experiment

A water pump characteristic can be determined from a series of experiment using a simulator test rig. The pump characteristics will include power, head, and efficiency of the pump. The maximum efficiency of the pump is 15%, maximum power of the pump is equals to 42 W and the head at this point is equals to 17 m. The point is refers to design flow rate of 0.00025 m^3/s. In addition to that, the shut-off head where there is no flow for this pump is 30.5 m.

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References

[1] Crouse, W. H., and Anglin, D. L. 1986. *Automotive Engines.* 7th ed. New York: McGraw-Hill Book Company.

[2] Sharief, A., Chandrashekar, T., Antony, A., and Samaga, B., 2008, Study on Heat Transfer Correlation in IC Engines, SAE Technical Paper No. 2008-01-1816.

[3] Ebersole, G., Myers, P., and Uyehara, O. 1963. The Radiant and Convective Components of Diesel Engine Heat Transfer. SAE Technical Paper 630148.

[4] Alizon, F., Guibert, P., Dumont, P., and Dupont, A. 2005. Convective Heat Transfers in the Combustion Chamber of an Internal Combustion Engine Influence of In-Cylinder Aerodynamics, SAE Technical Paper 2005-01-2028.

[5] Khaled Loubar, Jérome Bellettre, Mohand Tazerout. 2005. Unsteady Heat Transfer Enhancement Around an Engine Cylinder in Order to Detect Knock. *J. Heat Transfer.* 127(3): 278-286.

[6] John, H., Lienhard, V., John, H. Lienhard, IV. 2013. *A Heat Transfer, Textbook.* Fourth Edition. Dover Civil and Mechanical Engineering. ISBN-13: 978-0486479316.

[7] Richard, D. Atkins. 2013. *An Introduction to Engine Testing and Development.* SAE International. ISBN-13: 978-0768020991.

[8] Ananthamurugam, K. 1998. Hydraulic Design of a Water Coolant Pump for a Car. Universiti Teknologi Malaysia, Johor Bahru: Thesis Bachelor of Engineering.

[9] Jain, K. K., Asthana R. B. 2002. *Automobile Engineering*. 1st Ed. New Delhi: Tata McGraw-Hill Publishing Company Limited.

[10] Munson, B. R., Young, D. F, Okiishi, T.H., Huebsch, W. W. 2010. *Fundamentals of Fluid Mechanics*. 6th Edition. Wiley.

[11] Michael, V. 2005. *Pump Characteristic and Applications*. Taylor & Francis Group

[12] Pulkrabek, W. W. 2004. *Engineering Fundamentals of Internal Combustion Engine*. Pearson Prentice Hall.

[13] Sani, K. 2013. Simulating Wira Cooling System, Universiti Teknologi Malaysia, Industrial Training Technical Report.

[14] Mardani, A. S. 2000. Effect of Impeller Geometry of a Water Pump on the Engine Cooling System. Universiti Teknologi Malaysia, Johor Bahru: Thesis.

[15] Bhavik M. Patel, Ashish J. Modi, Pravin P. Rathod, 2013, Analysis on Engine Cooling Water Pump of Car and Significance of its Geometry. *Intl. Journal of Mechanical Engineering and Technology.* 4(3): 100-107. ISSN 0976 – 6340.