HEAT TRANSFER CHARACTERISTICS OF A HEAT EXCHANGER

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SUPERVISOR VERIFICATION

I have read this thesis and in my opinion this report is sufficient in aspects of scope and quality for the award
Bachelor of Mechanical Engineering (Thermal fluids)

Signature :…..…………………………..
Name of Supervisor :……………………………..
Date :………………………………

DECLARATION

"I hereby declare this report is a result from my own research except as cited in references"

Signature :………………………….

Author's Name :…………………………

Date :………………………….

DEDICATION

To my parents thank you for their endless love, support and encouragement

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ABSTRACT

This study explains an experimental and theoretical result of an automotive heat exchanger, car radiator. A car radiator model is designed and fabricated using three different approaches. First one is by using transparent plastic tubes to observe the water flow characteristic. This study used dye as a reference that represents heat and velocity characteristic. Second, study on a prototype of square radiator using similar materials as the real one. At the end of the study, an analysis is made by comparing the average value of overall heat transfer coefficient. Third, conduct a simple software analysis using CFD approach involving FLUENT and GAMBIT interface. Later, these three experimental data is gathered and analyzed. At the end of this study, predicted result such as outlet temperature for both water and air, radiator effectiveness and heat transfer performance is achieved.

ABSTRAK

Kajian ini menerangkan tentang salah satu daripada alat penukaran haba iaitu automotif radiator dari segi teori dan eksperimen. Sebuah model radiator kereta direka dan difabrikasikan dengan menggunakan tiga pendekatan yang berbeza. Pertama, tiub telus cahaya digunakan untuk memerhatikan sifat pergerakan air di dalam tiub radiator. Kajian ini menggunakan pewarna sebangai alternatif yang mewakili kadar pemindahan haba dan halaju air. Kedua, kajian ke atas prototaip radiator empat segi dengan menggunakan bahan yang hampir sama seperti radiator sebenar. Ketiga, kajian analisa CFD yang melibatkan penggunaan FLUENT dan GAMBIT turut digunakan. Di akhir kajian ini, melaui ketiga-tiga pendekatan yang dijalankan data yang diramalkan seperti suhu keluar dan masuk bagi air dan udara, keberkesanan radiator dan prestasi pemindahan haba berjaya diperolehi.

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CFD	=	Computational Fluid dynamics
ε	=	Effectiveness of a radiator
$L_{radiator}$	=	Radiator length
$H_{radiator}$	=	Radiator height
$W_{radiator}$	=	Radiator width
W_{tube}	=	Tube width
H_{tube}	=	Tube height
L_{fin}	=	Fin length
W_{fin}	=	Fin width
H_{fin}	=	Fin height
N_{tube}	=	Number of tube

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Automotive car radiator is a heat exchanger and its basic principle is to transfer heat between one medium to another. Heat exchanger is used to perform this kind of work from one side of a fluid to another without mixing them. It maximizes the use of surface area in order to get a higher rate of heat transfer between the systems. Nowadays, automotive radiator has some problems to deal with and the major problem is high demand in terms of enhancement of heat dissipation especially for advanced engines that are built in compact size. Most of the energy produced by the engine is lost due to combustion and it causes the engine to experience overheating. Overheating will lead to failure of the system such as wear formation between engine, metal damage of inner parts and inefficient lubricating process. A new generation of automotive heat exchanger must be able to perform high level of heat transfer while maintaining its compact and advanced design.

In this study, heat transfer performance of a radiator is conducted through experimental, theoretical and simulation method. From experimental and theoretical approach the result will be compared at the end of this study. Additionally, a simple simulation is made by using CFD software to substantiate the experimental and theoretical result. Later, an analysis is performed to discuss on these three methods in terms of heat characteristic of a heat exchanger.

1.2 PROBLEM STATEMENT

The uncertain flow characteristic of the fluids sometimes caused an imperfect flow of the fluids through all the tubes of the square automotive radiator. Heat transfer performance is not efficient as the fluids flow does not completely touch the surface area of the tubes or fins.

1.3 OBJECTIVES

To achieve a successful goal of this project, several objectives are made to guide the flow of the study:

a) To design and fabricate an experimental and prototype of automotive radiator.
b) To investigate heat transfer performance of heat exchanger unit.
c) To study the experimental and theoretical result of heat performance.

1.4 SCOPE OF WORK

An experimental approach by using transparent plastic tubes in order to study the flow characteristic. Second, by using prototype radiator to study the heat transfer performance. Third, simple CFD analysis is done to support the experimental result. Later, experimental result and theoretical calculation of heat transfer characteristic of a square radiator is analyzed.

CHAPTER 2

LITERATURE REVIEW

2.1 BACKGROUND OF HEAT EXCHANGER

A heat exchanger is a vital component in certain system and its purpose is to transfer thermal energy of solid and fluid surface or between fluid and particulates of solid surface involving two or more medium in temperature varies condition that in thermal contact. The medium usually fluids, can be mixtures or single compound. Basic principle of heat exchanger involving process of heating or cooling of concerned fluid stream, evaporation or condensation process of the fluid components and even heat gain or heat rejection of the system.

In some cases, the aim of heat exchanger can be to sterilize, pasteurize, filtration, concentrate or control the process of the fluid. Flow characteristic in certain heat exchangers are in direct contact while the other the heat transfer takes place between fluids in its separating walls in a proper manner. Besides, in most of heat exchangers, the medium, fluids, are set apart by heat transfer surface and ideally they are not mixing. This kind of heat exchanger is referred as direct transfer type or recuperators while, heat exchangers that deal with intermittent heat transfer between hot and cold region through thermal energy storage and rejection is known as indirect transfer type or regenerators.

However, this regenerator type is familiar with leakage issue and improper flow of fluid from one stream to another. Heat exchanger can be classified based on its transfer process, construction, surface size, fluids amount, functions and mechanism of the heat transfer (Said Moataz, 2009).

2.2 AUTOMOTIVE HEAT EXCHANGER

Automotive heat exchanger or car radiator operates similarly with another heat exchanger to make sure the engine is cool to function at its best performance. Basically, fluid is pumped by the internal combustion engine, and then the fluid is flows into the radiator and meets numerous numbers of tubes which attached with large amount of fins. The purpose of fins is to increase the surface area in order to enhance the cooling effect of the air flow through the radiator. Furthermore, the movement of a car, together with radiator fan forces air to flow through the fins and the surrounding tubes of the radiator. This phenomenon helps to eliminate heat from the water flowing process through all the fins and tubes and dissipate it to the surrounding air (Carl M, Guy D).

Basically, a radiator works when pump transport the fluid to the engine where it will travels through it and then it flows back to the head cylinder of the engine. Inside it, there is a device called thermostat that control the whole flow located at the outlet. Later, plumbing near the thermostat will force the fluids to return to the pump directly if the thermostat is closed. If the thermostat is open, the fluid will travel through the radiator only then it returns to the pump (J.P Yadav, 2011). **Figure 2.1** presents the flow chart of cooling process.

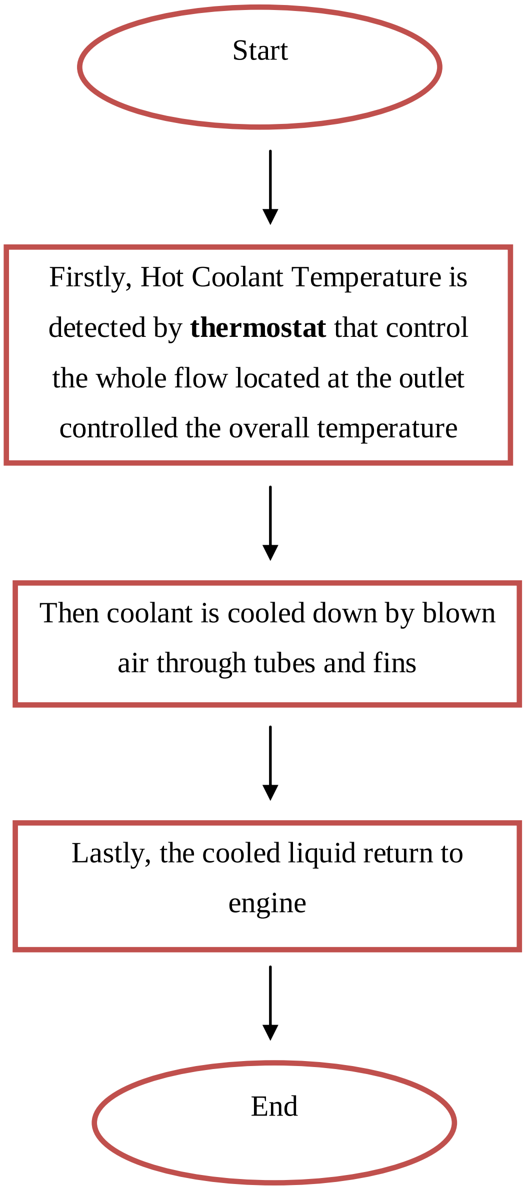

Figure 2.1: Flow chart of cooling process

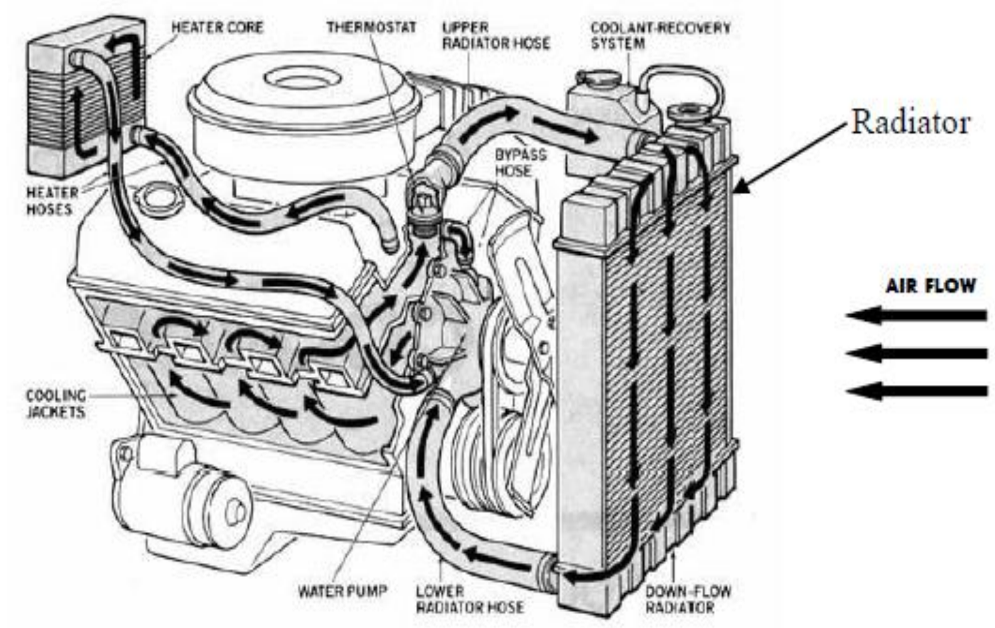

Figure 2.2: Automobile Engine Cooling System (Scott Janowiak, 2007)

In addition, most common radiator as **Figure 2.2** which made from aluminium base and utilizes heat exchanger design of cross flow type. The main reason of using aluminium instead of others is because aluminium is much lighter and cheaper. Besides, medium involved in radiator are air and coolant that made up of 50% of mixed water and the remaining half is ethylene glycol. General purpose of presence of air is to get rid of heat from the coolant and later causes the coolant to end up at lower temperature at the exit compare to its entrance temperature. The criteria for heat transfer of current radiators are 140 kW of heat and 95^{o}C of inlet temperature of basic radiator size. However, this benchmark may be varies depending on the model of a radiator (Scott Janowiak, 2007).

Nevertheless, there are a few ways to improve heat transfer performance of a radiator. Some of the ideas are by changing the fins design, increase the core depth, changing tube types, proper flow arrangement, discuss fin material and increase surface area to coolant ratio.

2.2.1 Heat Transfer Performance

Heat transfer occurs when there is difference in temperature between two or more channels of a medium. It involves transit process of thermal energy due to personal space temperature difference (Incopera, F.P).

As a rule, heat transfer process is divided into three physical mechanism conduction, convection and radiation. All of these three mechanisms solely depend on temperature difference. Conduction is a process of heat transfer from one region to another by short contact range of a molecular scale. Conversely, convection is a heat transfer mechanism of both process of conduction and fluid mixing. While, radiation is energy emission process by any bodies in terms of electromagnetic wave above the absolute zero temperature condition (Avallone, E.A).

Obviously, the heat transfer mechanisms involved in coolant are conduction and convection as these two mechanisms describe the cooling effect process of air flow inside the radiator and its link from the core of radiator to the surrounding heat generated. In essence, in radiator world three kinds of heat transfer mechanism take place, as conduction occurred between the metal surfaces and the fins surfaces. Convection occurs between fins surfaces and ambient temperature of surrounding. Last one, radiation happens when there is a source of heat in this case, a heat from the engine. **Figure 2.3** presents the heat transfer mechanism of a radiator

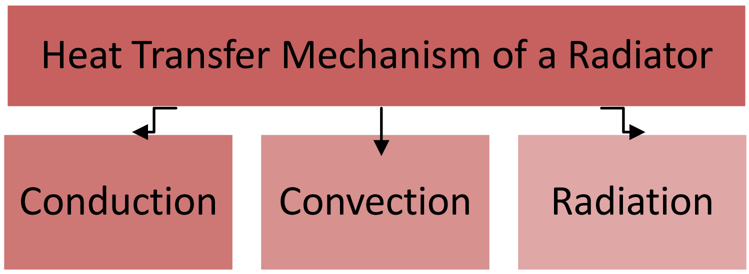

Figure 2.3: Heat transfer mechanism of a radiator

Moreover, automotive heat exchangers have some certain criteria that will oppose large effect to the heat transfer of a cooling system for instance, temperature differential, supply heat load and radiator design. Temperature differential is the largest temperature difference recorded between two points at instant specified test volume. Temperature differential between cooling air and basic radiator core temperature is the process that initiates the cooling effect or heat transfer process through the cool air flow medium from the radiator and coolant. Heat is originated from the internal combustion and later heat is created up to predestine operating temperature and coolant starts to flow and passes the whole radiator as the thermostat leave to open.

At the beginning, engine and coolant take in heat through conduction and convection and continue until it surpasses the cooling air flow temperature. At this stage, heat transfer process from the hot region to the cooling air commences. Coolant temperature keep rising until it meets a stage of temperature differential of the core radiator and cooling air is huge enough to deliver the whole heat load to cooling air; at this moment steady state level is achieved. Of all cooling system the heat transfer characteristic is regulate by heat load to the cooling system value. Heedless of either poorly or perfectly designed radiator is used, the heat load also known as the heat rejection of a cooling system is sent to the cooling system by the automotive heat exchanger. The main reason cooling system analysis is hard is because of quantifying procedure of the radiator performance the result of heat rejection is same whether it is done by a good or poor radiator. For difference types of radiator geometry, the different between these two good and poor radiators is a good radiator inlet temperature manages to stabilize itself at lower temperature of the core performance. Therefore, overheating phenomenon of the coolant boiling can be prevented as in **Figure 2.4.** Besides, it has been proven that design of radiator core will not affect much on heat load capabilities handling but it will help to get a lower steady state achievement. In average cars, most of them will have 88^{o}C temperature of bottom tank while as for the top is 82^{o}C and this make 85^{o}C as mean operating temperature. (Crook, R.F., 2007). In whatever way, design criteria can help to improve heat transfer performance through three considerations:

i. Coolant flow rate
ii. Cooling air flow
iii. Radiator face area

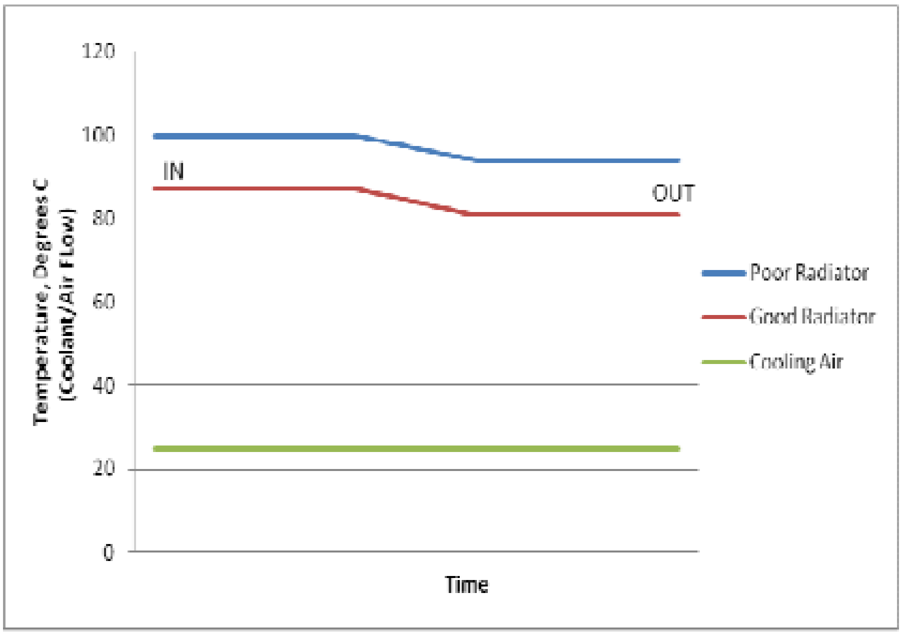

Figure 2.4: Heat Load Performance of Radiators (Crook, R.F. 2007)

On the other hand, in helically coiled finned heat exchanger research, when the inlet of hot and cold temperature, and together with the mass flow rate of cold water are remained constant, the result of outlet cold water temperature will be increased as the mass flow rate of hot water increase. This is due to heat transfer from hot to cold water region increases as the mass flow rate of hot water increased. By referring at **Figure 2.5**, it is proved at certain inlet criteria when the outlet temperature decrease, the greater temperature difference between inlet and outlet hot water temperature recorded. As a result, the perfect way to maintain the equal rate of heat transfer performance is by adjusting the cold water mass flow rate to a higher value (P. Naphon, 2006)

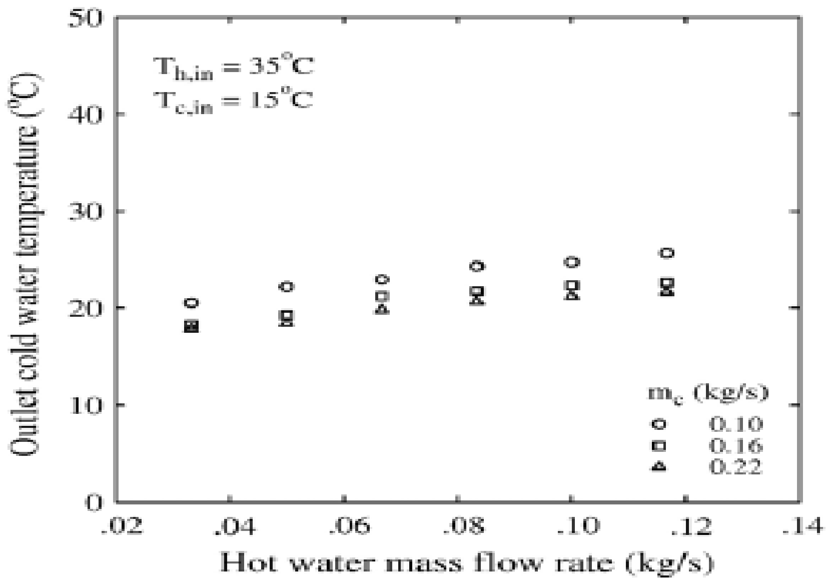

Figure 2.5: Different outlet cold water temperature with hot water mass flow rate in helical coiled finned heat exchanger (International Communications in Heat and Mass Transfer, 2007)

In addition, a wide range of Reynolds number can also affect the heat transfer performance. A research has been made where large range of Reynolds number from 30 to 30 000 Newtonian fluids in two different configurations a chaotic and helical heat exchanger. However, the number of the heat exchanger curved and surface area are kept constant within these two types. The results shows at lower value of Reynolds number, heat transfer rate is almost similar to the normal heat exchanger but it increase at chaotic design without any requirement of extra energy. The utmost heat transfer coefficient is at 250 of Reynolds number at chaotic type is recorded (C. Chagny, 1999)

2.2.2 Fins Design

Heat transfer performance is greatly influenced by the types of fins used inside the radiator. As refer to heat transfer principle, as the area increases the rate of heat transfer will also increases. Moreover, numerical research has proven that fin type affects the heat transfer characteristic. In first case, S- shaped fins is investigated