

HEAT TRANSFER ANALYSES OF VARIOUS COOLING MEDIUM IN A CONDENSER ON COMPUTER LINKED REFRIGERATION SYSTEM

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ABSTRACT

A condenser is a cooling device uses refrigerant that induces condensation to high-pressure refrigerants by ventilating the heat of the high-temperature refrigerant away from a system while maintaining its pressure. The application of the cooling medium or coolant such as water is crucial in absorbing heat as it will result in the effectiveness of the condenser. This research is to evaluate and identify the effectiveness of various coolant that used in cooling system of a condenser thus upgrading the effectiveness of the heat transfer medium device by comparing their rate of heat transfer capability. The experiment is carried out using a computer linked refrigeration system test bench. The working fluids for cooling system in condenser used are tap water (Coolant A) and to be compared with conventional Deions Premixed Long-Life Coolant. The Deions coolant is prepared in two concentration which is 10 % (Coolant B) and 12.5% (Coolant C). The mass flow rate of the system is ranging from 0.5 lpm to 2.75 lpm with the interval of 0.25 lpm. The initial temperature of each coolant at the inlet is constant at 26°C. During the experiments, each coolant flows in the piping system, passing through the condenser that carries out the dissipation of the unwanted heat before flowing out of the pipe. Both temperatures of the coolant before and after passing through the condenser were measured with the thermocouple provided and the cooling rate is calculated. Based on the findings, the Coolant C with higher concentration and mass flow rates is the expected to be the most effective coolant compared to others.

Keywords: Refrigeration, Condenser, Cooling system, Concentration, Heat Transfer

1. INTRODUCTION

Malaysia is undeniably one of growing and developing countries along with other countries all around the world. The manufacturing sector can be considered as the backbone that plays a crucial role in the economic development of the country that has created countless machines and devices to ease and bring comfort to humankind [1]. The most common home appliances that can be taken as an example is the refrigerator and air-conditioner (A/C). According to a research, the refrigeration and air conditioning industry have used 20% of the electrical power consumed worldwide in the year 2019. Moreover, an estimation by the International Institute of Refrigeration, the electric demand of the sector could increase over a 100% by 2050 [2], [3]. In other function, by controlling temperature and humidity, refrigeration and A/C systems maintain the essential climatic conditions, preserving a sterile and germ-free environment that can improve patients' health and stop the spread of diseases [4].

Refrigeration is produced by a cyclic device called refrigerators and the most frequently applied refrigeration cycle is vapor-compression cycle. In a refrigeration system, condenser is a highly efficient device that is a must that transfers unwanted heat refrigerant to surrounding or a secondary fluid. A good condenser depends on the refrigerant used as the working medium that will dissipate the heat produced by the device to prevent overheating. Overheating can cause unavoidable damage to the system circuit components and, in the worse scenario, can also cause injury, fire, or even an explosion. The damages are usually irreversible which makes it crucial to have a good cooling medium system by ensuring that it has a high rate of heat transfer in the system. The efficiency of the refrigeration system could be enhanced by resetting the condensing temperature according to the outdoor temperature [5]. This will also result in an increment in the importance and demands of a good condenser function which is one of the most crucial parts of the refrigeration and A/C system. The increase of efficiency of condenser can be achieved by having an aid by heat exchanging through

secondary working fluid in a cooling system. This concept is related to heat transfer which the energy transfer that results from temperature variations between two medias. Whether it is gases, liquids, or solids, the heat can be transported from one medium to another. The liquid and gases, though, are the most frequently used medium in the condenser system. The temperature difference between them causes heat to naturally transfer into the working fluid during the condenser's heat transfer operation [6]. Various parameters can affect the rate of heat transfer. However, working fluid or a coolant can seem like the primary component as there are several types of coolant existing in a building and manufacturing industries [7], [8].

It is said to be essential to have an ideal coolant unit to have a good condenser and a promising refrigeration and A/C system. Up till now, water is the one referred to as the best cooling medium for a condenser or any cooling medium device for refrigeration and A/C [9]. However, there are still some downsides to using water as a coolant since the water tends to boil faster than the other coolants. It also seems like the water alone is not adequate to keep the system cool as it is easy to evaporate. Each coolant has different properties that lead to differences in its cooling rate. In the aspect of its concentration, a coolant should maintain an appropriate concentration level because if it is too low, it will result in the corrosion of the pipe or other components. At the same time, if it is too high, the rate of heat transfer will be less [10]. For the flow rate of the coolant, the rate of the heat transfer is directly proportional to the flow rate of the coolant. Based on the equation of the thermodynamics, which is the rate of the heat transfer, Q , that can be calculated by the multiplication of the mass flow rate, m , the specific heat of water, C , and the difference of temperature, ΔT . By equation (1), if the mass flow rate of the coolant increased, it will have resulted in the increment of the rate of heat transfer [6], [8].

$$Q = mC\Delta T \quad (1)$$

Nowadays, there are various types of working fluid that can be used and applied in all types of condenser units. This is due to the usage of the coolant whether in the home appliances that come with the condenser unit including air conditioner, (A/C), in the vehicles' engines, and applied in the industrial sector such as power plants, and most manufacturing machines such as milling machine, cutting machine, and grinding machine [10]. Based on these examples, we can see that usage of the working fluid is surely high which encourage the related industries to produce more of the coolant that varies in their properties since the different type of coolant can surely affect the performance of the condenser as a cooling device. Thus, in solving the problems related to the quality and the performance of the refrigeration and A/C units including not being able to cool a room or space due to the unsatisfactory performance of the condenser, a study has been made to identify and analyze how to increase the performance of condenser. Since the coolant in a cooling system that exchange heat from the condenser plays a crucial role that will affect the performance of refrigeration and A/C unit not only by changing the flow rates, concentration of coolant may affect cooling rate [4], [5], [11], [12].

The most common coolant used are including the water (H_2O) the glycol-based automotive coolants, and antifreeze and these coolants are in the liquid state as most individuals and industries prefer liquid type of working fluid. To have a good and leading coolant, it needs to have high thermal capacity, low in its viscosity aside from its properties that will not resulted in corrosion. The coolant should also be in range of the economical price and high in its freezing and boiling point so that it will have a wide range of operation [13]. The concentration of a coolant has the ability to make changes in the condenser's performance. Coolant concentration is a pure coolant which has the solubility of water that will be mixed with water in the right ratio to modify its concentration. At first, the chemical coolant will have 100% of its concentration. To modify its concentration rate, it can be blended with water, chemicals or any other liquids that are suitable. However, the most common liquid used is water since it is easy to access. If the desired coolant has the concentration of 10%, it should be mixed with 90% of water and 10% of the coolant. The modification is significant to the performance of the condenser as if the coolant is to concentrate, its heat transfer abilities will be low and if the concentration is too low, it will affect the performance [14].

The mass flow rate of a coolant plays a vital role in the overall performance of the condenser. Theoretically, a condenser is installed to maintain a system's temperature by removed the excess heat produces using a working fluid or a coolant. With the unsuitable mass flow rate of the coolant, whether it is too high or too low, both the cases can lead to the overheating and malfunctioning of the system. With the increment in the coolant mass flow rate, is will automatically increase the Reynolds number of the coolant which will affect the rate heat transfer that occurred when the heat from the system flows into the coolant since it has lower temperature before being dissolve in the surrounding. The mass flow rate is basically a measurement of the

amount of mass passed through a distinct point over a length of time. In calculating the mass flow rate of a fluid, the most common equation that used to be applied is the one as referred by as shown in Equation 2 below. The mass flow rate is equal to the density of the fluid multiplied by the area of the flow and the velocity of the fluid.

$$\dot{m} = \rho AV \quad (2)$$

where:

\dot{m} = Mass flow rate of a fluid (kg/s); ρ = Density of a fluid (kg/m³)
 A = Area of the fluid's flow (m²); V = Velocity of a fluid (m/s)

Hence, an experiment is conducted to analyze the tips to enhance the heat transfer features and cooling rates of the device using various coolants which are water, commercial Deions Premixed Long-Life Coolant with two different concentrations as well as having different mass flow rates. Thus, an analysis of the heat transfer of the coolants will be carried out based on the different coolants, same coolants with different concentrations, and different mass flow rates.

2. METHODOLOGIES

As the problem of this study has been identified, the objectives of the study are identified to evaluate and identify the most effective coolant that used in a condenser to upgrade the effectiveness of the heat transfer medium device by comparing their rate of heat transfer capability as well as to analyze the optimum concentration and mass flow rate of coolant. The experiment was carried out using a Computer Linked Refrigeration System Laboratory Unit as shown in Figure 1 which located in Thermofluids and Heat Transfer Laboratory, Universiti Teknologi MARA (UiTM) Terengganu. The equipment is attached with computer which a software to measure real-time data such as compressor power, motor speed, fluid pressure, fluid temperature, and others. The specification for the equipment can be referred in Table 1.

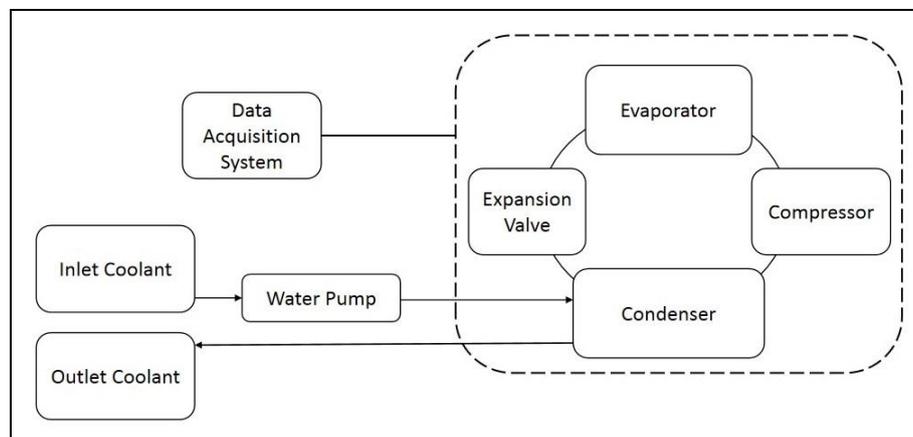


Figure 1: Schematic Diagram of Computer Linked Refrigeration System.

Table 1: Specification of Computer Linked Refrigeration System

Item	Details
Compressor	Bore : 40 mm Stroke : 30 mm No. of Cylinders : 2 Swept Volume : 4.52 m ³ /hr 1000 RPM Pulley Size : 180 mm
Refrigerant	R-134a
AC Motor	Rated Power : 1 HP Rated Speed: 1500 RPM Pulley Size: 60 mm

Expansion Valve	Type: Thermostatically controlled Orifice: No. 01
Evaporator	Variable Load Heater: Max. 1500 Watt No. of Heaters: 2 units
Condenser	Type: Plate Heat Exchanger Nominal Surface: 0.2 m ² Plate Material: 316L stainless steel/copper brazed
Power	415VAC/50Hz (3 phase)
Water Pump	Power: 15W Max. Flow Rate: 0.28 l/s Frequency: 50/60Hz

Fluid coolant is chosen among the other coolant types is because the fluid type considered to be the best one since they offer higher thermal conductivity. Therefore, fluid coolants such as tap water as Coolant A is compared with a conventional coolant in the auto car care market, Deions Premixed Long-Life Coolant with two different concentrations and mass flow rate. The Deions coolant includes the one with 10%, Coolant B, and Coolant C with 12.5% concentration. All coolants will be used for this purpose with a flow rate of 0.5 lpm until 2.75 lpm with each increment of 0.25 lpm as it is the maximum flowrate that water pump could support. A total of two containers are used for the pump system of the coolant represents inlet and outlet respectively. The inlet coolant is controlled at room's temperature approximately 26°C, whilst outlet coolant is accumulated after drained from the condenser. The temperature is measured using portable thermocouple and each data is taken after 5 minutes.

The experiment is carried out by having each mass flow rate for several times, so that the average of the data and values can be obtained. For the Coolant B and C, both are from the same type of coolant, however they are different in terms of its concentration. The 5 liters of Deions Premixed Long-Life Coolant were divided into two groups before being added and mixed with different amount of tap water based on the required concentration. Each group of coolant is 2.4L while the extra 0.2L are not used. For Coolant B, it has 10% concentration, which means that the coolant was mixed with 90% of tap water while Coolant C, 12.5% concentration were added with 87.5% of tap water. The modification of the coolants regarding its concentration were made based on the Equation 3. Based on the formula, since having the data of volume of the pure coolant, 2.4L and the percentage of required concentration, 10% for Coolant B and 12.5% for Coolant C, the volume of total coolant including the tap water were obtained. Thus, the volume of tap water needed to be mixed with the pure coolant can be calculated by subtracted the total volume with the coolant's volume. The amount of tap water that has been calculated will then be added into the designated coolant.

$$\frac{V_{PureCoolant}}{V_{TotalCoolant}} = \%ofCoolant \quad (3)$$

where:

$V_{PureCoolant}$: Volume of the pure coolant, L

$V_{TotalCoolant}$: Volume of total coolant including tap water, L

% of Coolant: Percentage of required concentration

To run the experiment, initially, the power supply for the Refrigeration Laboratory Unit and its main switches were switched on. Next, after the heater for evaporator was turned on and set at 1000 W, while the motor speed for compressor was set to 1000 rpm. The system is run to stabilize the initial reading before experiment started. The water valve located at the piping system were opened slowly until it reached the targeted mass flow rate of the working fluid. The water as Coolant A is to be flowed from the water supply using a water pump through the inlet of the cooling water piping system in the condenser before the heat transfer process occurred. The water then is flowed out from the piping system through the outlet pipe that was connected to the drain. All the values of parameters including the temperatures of the working fluid at the inlet and the outlet of the pipes were measured, as well as the pressure, mass flow rate, and others. The data were recorded automatically by data logger software in a computer connected to the Refrigeration Laboratory Unit. The average data for Coolant A is taken in the experiments for another mass flow rate until all 10 sets of mass

flow rate were obtained. The same procedures are repeated for Coolant B and Coolant C. As the coolant will be recycled many times until the data and results of all mass flow rates were obtained, it is crucial to ensure that the coolant that exited the outlet pipe have the room's temperature quickly.

Table 2: Properties for Coolant Samples

Properties	Coolant A (Tap Water)	Coolant B (10% Concentration of Deions Premixed Long- Life Coolant)	Coolant C (12.5% Concentration of Deions Premixed Long- Life Coolant)
Specific Heat Capacity, C (kJ/kg.K)	4.184	4.089	4.066
Density, ρ (kg/m ³)	1000.0	1009.2	1012.0
Specific Gravity, SG	1.0	1.1153	1.1153

Using the acquired results and data, the comparisons will be made and the one with the highest rate of heat transfer will be concluded as the most effective coolant that was used in this experiment. Thus, the characteristics for an ideal coolant can be studied and determined. The properties of Coolant A, Coolant B, and Coolant C can be referred in Table 2 for heat transfer rate.

3. RESULTS AND DISCUSSION

Figure 2 exhibits the effect of heat transfer rate, Q , against various coolant flowrate. From the experiment, each coolant namely Coolant A (water), Coolant B (10% concentration of Deions Premixed Long-Life Coolant) and Coolant C (12.5% concentration of Deions Premixed Long-Life Coolant) shows a fluctuation pattern along the increment of flowrate and heat transfer rate. At the beginning, Coolant A shows the highest heat transfer rate which is 6.00×10^5 kJ/kg.K at the lowest flowrate which is 0.5 lpm compared to Coolant C and Coolant B which are 5.84×10^5 kJ/kg.K and 4.96×10^5 kJ/kg.K respectively. However, the trend for Coolant A becomes the lowest along the increment of flowrate compared to the other two coolants. The mass flow rate of the coolant and its heat transfer are directly proportional to each other. It is based on the trendline of the graphs where both data have positive gradient. Hence, if the mass flow rate increases, it will also cause in the increment of the heat transfer of Coolant A.

At the highest flowrate which is 2.75 lpm, Coolant B shows the highest heat transfer rate which is 9.62×10^5 kJ/kg.K. This follows by Coolant C and Coolant A where the heat transfer rates are 8.69×10^5 kJ/kg.K and 6.57×10^5 kJ/kg.K respectively. Based on the analysis made on the graph for Coolant B above, we can see that the heat transfers and the mass flow rate are directly proportional to each other. The result of experiment shows heat transfer will increase along the mass flow rate of the coolant. This can be proven with the trendline and the gradients' value where 30% for Coolant B as the highest, while 16% and 4% gradient for Coolant C and Coolant A respectively. As for the Coolant C with 12.5% of concentration, all the calculations in obtaining the data for the analysis are the same as the other two coolant samples.

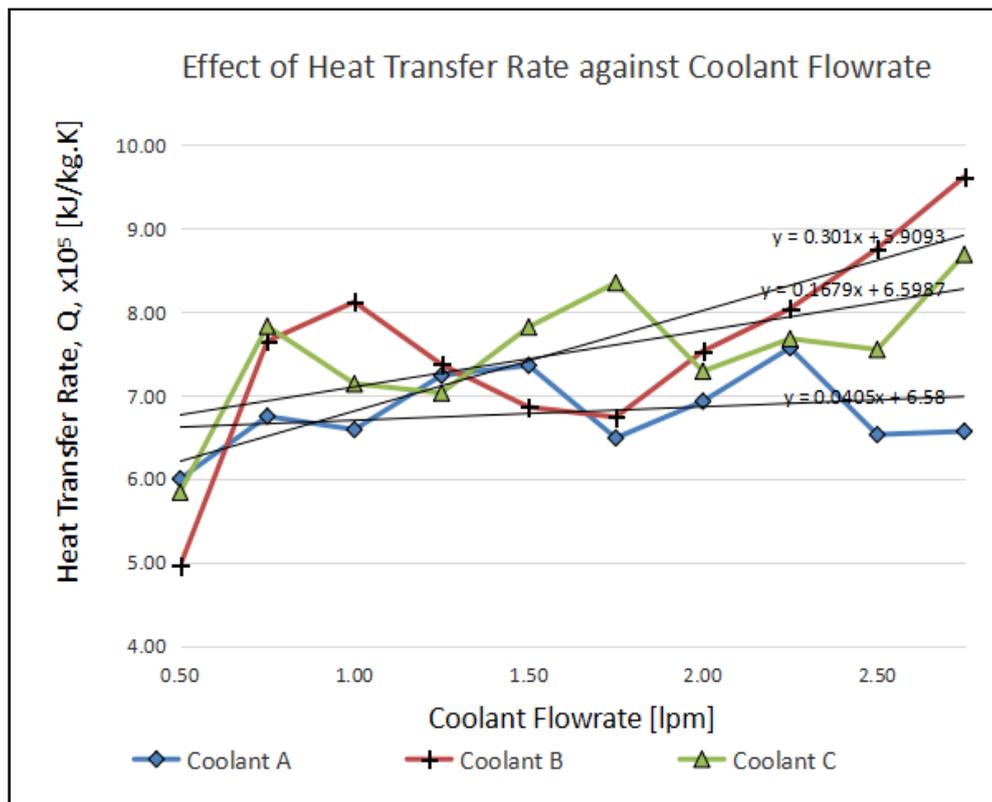


Figure 2: Heat Transfer of Various Coolant Against Flow Rate

Several studies made by researchers, where the coolant with higher concentration will result in the increment of the coolant's heat transfer. The effects of liquid mass flux, impinging velocity, droplet size, and convection on the total rate of heat transfer can be consider [15]. It is also can be proven using the equation of the mass flow rate, which is equal to the mass of the coolant, multiplied by the specific heat capacity of the coolant and its difference in temperature. With the increment of a fluid's concentration, its density will also increase. Hence, the mass flow rate along with the difference in the fluid's temperature will also increase. This resulted in the increasing of the heat transfer of a fluid. The increase in Reynolds number of the coolant may affects the rate heat transfer that occurred when the heat from the system flows into the coolant since it has lower temperature before being dissolve in the surroundings. According to a research, a constant flow distribution is overly conservative and leads to overcooling and unnecessary pumping power expenditure [16].

The experimental result shows that the highest heat transfer is for Coolant B, 10% concentration, since it has the highest value of gradient compared to Coolant C and Coolant A. The inconsistency of the temperature is might due to the surroundings. As the experiments were conducted on different days, the weather and the temperature does affect the temperature of the coolant that is pumped into the piping system. Thus, with the different on coolant's initial temperatures, it does affect the ability of the coolant to absorb heat from the condenser. As for Coolant A, it has the lowest heat transfer compared to the other coolant samples and the difference between the value are extremely big. Thus, the water is not the best type of coolant compared to the other coolants, while the coolant with the 10% concentration, Coolant B is the one that performs well as a working fluid during flowrate of 2.75 lpm for the system.

4. CONCLUSIONS

The focus of this study is to evaluate and identify the best coolant among the three samples of coolant used. It is crucial to compare their heat transfer capabilities so that the optimum concentration and mass flow rate of a coolant along with the properties of an ideal working fluid can be determined. Based on the data and results analysis that has been made, it can be concluded that the Deions Premixed Long-Life Coolant, with 10% concentration and mass flow rate of 2.57 lpm is the optimum condition coolant compared to the other samples used. As for the mass flow rate of the coolant, it is also proved that the increasing in the coolant's mass flow

rate, will automatically increase the Reynolds number of the coolant before affecting the rate heat transfer that occurred when the heat from the system flows into the coolant since it has lower temperature before being dissolve in the surroundings.

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