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The Effectiveness Investigation of Evaporative Cooling Using Radiator for Pre-Cooling System

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Abstract

Due to the systems of mechanical vapor compression have a high energy consumption for air-conditioned space. Therefore, the system of evaporative cooling presents as a promising alternative option for the air-conditioning system. Moreover, the pre-cooling system is normally used to reduce an intake ambient air temperature before the air-conditioning system. As mentioned above, this research aims to investigate the effectiveness of evaporative cooling system by using a car radiator for air pre-cooling. In this research, the commercial car radiator was used for cooling inlet ambient air by cooling water. The evaporative cooling system consisted of evaporative cooling panel with a maximum water rate of 40 lite/minute and a maximum air rate of 5,100 m^3/hr. The results show that the most suitable water flow rate of radiator is 10 lite/minute and this radiator can make the differences of air temperature of about 8.9 °C. Moreover, the results also show that the effectiveness of evaporative cooling system could reach about 73.31 % with a maximum sensible heat of 8.43 kW.

Keywords : Evaporative Cooling; Radiator; Pre-Cooling

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1. Introduction

Due to widely use of air-conditioned system nowadays, the pre-cooling system is gaining a lot of attention worldwide and more research is needed to reduce the energy consumption of the main air-conditioned system. Moreover, a large number of car radiator becomes waste in Thailand. This leads to apply the car radiator to use as a heat exchanger for the pre-cooling process combined with an evaporative cooling.

The evaporative cooling system is one of the solutions that used to reduce energy used from refrigeration system as compared to the system of vapor-compression refrigeration. However, the evaporative cooling could lead to a less reduction of temperature differences and affect to a highly humidity of supply air. Consequently, the evaporative cooling is suggested to use only in opened-air space. In order to solve the problem above and improve the efficiency of evaporative cooling system, this research was used a car radiator to reduce an inlet air temperature, which called as the pre-cooling system, before the evaporative cooling. The objective of this research is to investigate the evaporative cooling system combined with car radiator for the pre-cooling system.

J. Jintawat was tested car radiator as heat exchanger to compare the differences between the inner surface appearances. In this previous study, the water was used as medium fluid and flow in car radiator as turbulent flow. The results showed that the smooth inner surface tube has the most cooling efficiency [1]. S.Pakdee (2000) was studied the effect of variant distribution air velocities on car radiator. The results showed that high difference between a maximum and a minimum air velocity effected to a higher decreasing of car radiator efficiency. By every 1 m/s differences between a maximum and a minimum air velocity were affected to 2.67% decreasing of car radiator efficiency [2]. G. Heidarinejad et al. were investigated the effectiveness of two-stage indirect/direct evaporative cooling system in various climatic conditions and compared the results between Indirect Evaporative Cooling (IEC) combined with unit of Indirect Evaporative Cooling (IEC) and Direct Evaporative Cooling (DEC). The results showed that under various outdoor conditions, the effectiveness of IEC ranged between 55% to 61% and the effectiveness of IEC/DEC combined unit ranged over 108–111%. Besides, more than 60% power saving could be obtained by IEC/DEC system as compared to the mechanical vapor compression systems [3]. B. Riangvilaikul and S. Kumar, were studied of a novel dew point evaporative cooling system to investigate the outlet air conditions and the system effectiveness at different inlet air conditions (i.e., temperature, humidity and velocity), covering dry, temperate and humid climates. The results showed that the wet bulb effectiveness and the dew point effectiveness were ranged between 92-114% and 58-84%, respectively. Moreover, a continuous operation of the system during a typical day of summer period also showed that the wet bulb effectiveness and the dew point effectiveness were almost reached a constant at about 102% and 76%, respectively [4]. B. Riangvilaikul and S. Kumar were also explored a numerical study of a novel dew point evaporative cooling system and presented the theoretical performance of a dew point evaporative cooling system, operating under various inlet-air conditions (typically covering dry, moderate and humid climate) and influence of major operating parameters (i.e., velocity, system dimension and the ratio of working air to intake air). In this previous study, a model of the dew point evaporative cooling system was developed. The results of simulations and experiments were comparable for various inlet air conditions of intake air velocities ranged from 1.5–6 m/s. Also, a model could predict the outlet air temperature and effectiveness within 5% and 10% discrepancies, respectively, as compared to the experimental results [5]. S. Delfani et al. were studied on energy saving potential of an indirect evaporative cooler as a pre-cooling unit for mechanical cooling systems in Iran. The performance of Indirect Evaporative Cooling (IEC) system to pre-cool air for a conventional mechanical cooling system was investigated for the four cities of Iran. The combined of an IEC unit followed by a Packaged Unit Air-conditioner (PUA) was made and tested. Two air simulators were designed and used to simulate indoor heating load and outdoor design conditions to estimate an energy reduction capability of combined system. The results showed that an IEC can reduce a cooling load up to 75% during cooling seasons. Moreover, IEC can be reduced by 55% of electrical energy consumption of PUA [6]. In addition, the study of M. Farmahini-Farahani and G. Heidarinejad, (2012) were aimed to increase effectiveness of evaporative cooling by pre-cooling using nocturnally stored water. The methodology of this previous study was used a multi-step system of nocturnal radiative cooling and two-stage evaporative cooling. The water was circulated from a storage tank to two radiative panels during the night time of summer period. And then, the water was used to coolant in a cooling coil unit for reducing the intake ambient air in a cooling coil unit and a two-stage evaporative cooler. The results showed that the multi-step system had a higher effectiveness than conventional two-stage evaporative coolers. Due to an energy saving of the multi-step system ranged between 75-79% as compared to the mechanical vapor compression systems [7]. H. Hussain et al. were simulated and analysis of three stage indirect/direct evaporative cooling system to make use of cold condensate water by using a transient system simulation software (TRNSYS). The three stage system are consists of a water to air cooling coil, an indirect evaporative cooler, and a direct evaporative cooler. The weather condition's data are using of the city of Lahore, Pakistan. The simulation result showed that the relative humidity of outdoor air are greatly influence to EER, the best performance of cooling system are appeared during the driest mouth (May) of the year [8]. S. K. Soylu et al. were investigated of evaporative cooling effectiveness on the performance of air-cooled chillers. Normally, the evaporative cooler performance is greatly dependent on its own effectiveness. The investigation are consider to 3 different evaporative coolers with 0.6, 0.7 and 0.8 effectiveness are investigated. The condition of the various inlet air temperature values are consider as 26, 28, 30, 32, 34 and 36°C, which the 4 levels of relative humidity as 30, 40, 60 and 80%. The analysis results showed that with high effectiveness and at hot and dry regions, evaporative cooling is a very useful method for decreasing inlet air temperature of condensers. Moreover, the Air-conditioning systems can be consumed lower energy consumption compared to conventional air –cooled chillers. [9].

Based on the information and literature review above, this research can be designed of the methodology and experimental procedures as following.

2. Research Methodology

The heat transfer rate of heat exchanger are normally use Log Mean Temperature Difference (LMTD) method to calculate [10], [11]. A heat transfer rate of heat exchanger (Q) can be determine as,

$$Q = UA_S \Delta T_{tm} \tag{1}$$

Where

U = Overall heat transfer coefficient ($W/m^2 \cdot K$)

A_S = Area of heat transfer surface (m^2)

ΔT_{tm} = Log mean temperature difference (K)

The overall heat transfer coefficient (U) can be determine by total thermal resistant (R). In case of tube heat exchanger can be calculate total thermal resistant as

$$R = \frac{1}{UA_s} = \frac{1}{h_i A_i} + \frac{\ln(D_o/D_i)}{2\pi kL} + \frac{1}{h_o A_o} \tag{2}$$

Where

h_i, h_o = Convection coefficient of inner and outer tube ($W/m^2 \cdot K$)

A_i, A_o = Surface area of inner and outer tube (m^2)

D_i, D_o = Diameter of inner and outer tube (m)

The log mean temperature difference in equation (1) can be determine as follow,

$$\Delta T_{tm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} \tag{3}$$

The temperature difference of ΔT_1 and ΔT_2 can be expressed as,

$$\Delta T_1 = T_{a,\,in} - T_{w,\,in} \tag{4}$$
$$\Delta T_2 = T_{a,\,out} - T_{w,\,out}$$

Where

$T_{a,\,in}$ = Temperature of inlet air of heat exchanger (ºC)

$T_{w,\,in}$ = Temperature of inlet water of heat exchanger (ºC)

$T_{a,\,out}$ = Temperature of outlet air of heat exchanger (ºC)

$T_{w,\,out}$ = Temperature of outlet water of heat exchanger (ºC)

The effectiveness of evaporative cooling system are depend on state of saturated air before and after flow through the evaporative panel that can be consider as saturation efficiency form (ε_{sat}), the saturation efficiency can be determine as follow,

$$\varepsilon_{sat} = \left[\frac{T_{db,\,i} - T_{db,\,o}}{T_{db,\,i} - T_{wb,\,i}}\right] \times 100\% \tag{5}$$

Where

ε_{sat} = Effectiveness of evaporative cooling (%)

$T_{db,\,i}$ = Dry bulb temperature of inlet air of evaporative panel (ºC)

$T_{db,\,o}$ = Dry bulb temperature of outlet air of evaporative panel (ºC)

$T_{wb,\,i}$ = Wet bulb temperature of inlet air of evaporative panel (ºC)

2.1 Experiment procedure

The research was used three size of the commercial car radiator as 523×658×27 mm (large), 470×658×27 mm (medium) and 350×638×27 mm (small), the figure of car radiator show as **Fig. 1.**

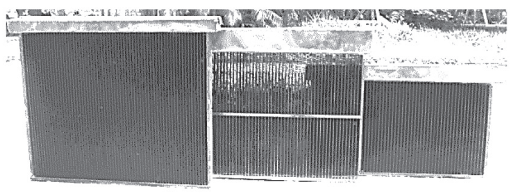

Fig. 1 The figure of car radiator

Experiment conditions are designed to varied temperature of inlet water of heat exchanger as 20, 24 and 28 ºC, respectively. The inlet water flow rate conditions of heat exchanger are varied as 5, 10 and 15 L/min, respectively. The inlet air of heat exchanger are controlled temperature of 30±3 ºC and humidity of 55±3 %RH at the constant flow rate as 3,000 Cubic feet per minute (CFM) and each conditions of experiment are tested three time for more accuracy. The detail of evaporative cooling system combined with car radiator show as **Fig. 2**.

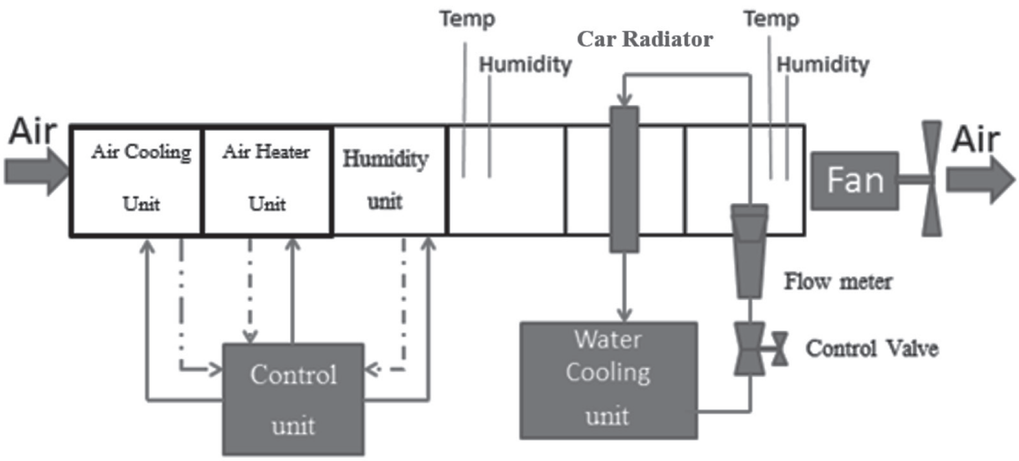

Fig. 2 The schematic of evaporative cooling system combined with car radiator

The measurement device in this experiment was used Testo model 435 to measure air-velocity in the flow rate range of 0 to 8,000 fpm, measurement range of 0 to 20 m/s which accuracy ±1digit and resolution of 0.01 m/s. The temperature measurement device was used Hanna model 93532, the measurement range of -200 ºC to 1,370 ºC which accuracy ±0.2% and resolution of 0.1 ºC. The flow rate meter was used Rotameter which measurement range of 1.8 to 18 L/min.

3. Results and Discussion

The experiment results of the effectiveness of evaporative cooling system by using car radiator for air pre-cooling were scope on the temperature difference result of heat exchanger varied by inlet water temperature, the relative humidity difference result of heat exchanger varied by inlet water temperature, and the effectiveness result of varied by inlet water temperature of heat exchanger.

The result of the temperature difference result of heat exchanger varied by inlet water temperature show that the almost temperature difference trend to decrease when inlet water temperature increase, and temperature difference trend to increase when inlet water flow rate increase. The experiment result show that the medium size car radiator are most temperature difference. The detail of the temperature difference result of heat exchanger varied by inlet water temperature show as **Fig. 3.**

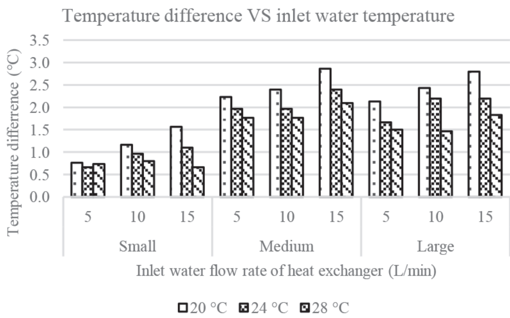

Fig. 3 The temperature difference result of heat exchanger varied by inlet water temperature

The result of the relative humidity difference result of heat exchanger varied by inlet water temperature show that the almost relative humidity difference trend to decrease when inlet water temperature increase, and also the relative humidity difference trend to decrease when inlet water flow rate increase. The size of car radiator are made slightly difference of relative humidity difference due to the surface temperature of car radiator was tested in same condition. The detail of the humidity difference result of heat exchanger varied by inlet water temperature show as **Fig. 4.**

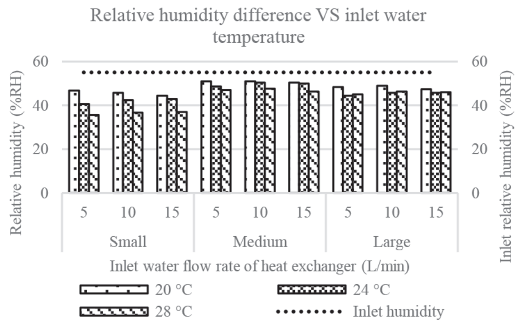

Fig. 4 Humidity result of varied inlet water temperature of heat exchanger

The result of the effectiveness result of varied by inlet water temperature of heat exchanger show that the almost temperature difference trend to decrease when inlet water temperature increase, and temperature difference trend to increase when inlet water flow rate increase.

The effectiveness result are directly to temperature difference result that concordantly to equation (5). The detail of the temperature difference result of heat exchanger varied by inlet water temperature show as **Fig. 3.**

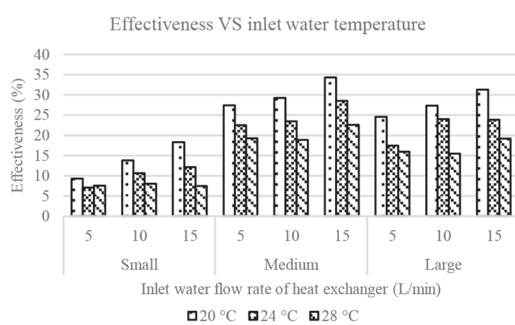

Fig. 5 Effectiveness of varied inlet water temperature of heat exchanger

From the experiment result, the effectiveness result can be consider to effectiveness curve as linear tended which coefficient of determination (R^2) show as **Table 1.**

Table 1 Effectiveness curve of varied inlet water flow rate

	Water flow Rate (L/min)	Efficiency curve	Coefficient of determination (R^2)
Small	5	y = 4.4892x + 4.8251	R^2 = 0.99
	10	y = 2.5437x + 4.8347	R^2 = 0.95
	15	y = -0.0639x + 7.7987	R^2 = 0.05
Medium	5	y = 3.4357x + 23.454	R^2 = 0.93
	10	y = 3.0027x + 18.808	R^2 = 0.87
	15	y = 1.6599x + 16.925	R^2 = 0.67
Large	5	y = 3.3863x + 20.947	R^2 = 0.99
	10	y = 3.1979x + 15.364	R^2 = 0.73
	15	y = 1.6424x + 13.561	R^2 = 0.64

The results obtained from an effectiveness curve showed that the increase in water flow rate was resulted to the decreasing in accuracy of an effectiveness curve. Therefore, in this previous study an effectiveness curve at a flow rate of less than 10 L/min was recommended.

4. Conclusion

The investigate the effectiveness of evaporative cooling system by using car radiator for air pre-cooling can be conclude that the medium size car radiator is best selected to used as heat exchanger for air pre-cooling in the evaporative cooling system, which best effectiveness result concordantly to temperature difference result. The effectiveness curve of varied inlet water flow rate which coefficient of determination value was reported.

5. Acknowledgement

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