Research Article

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Enhancement of the Heat Transfer Efficiency of Closed Wet Cooling Tower by a Water Spray Method

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Abstract-This research aimed to enhance the heat transfer efficiency of 200 TR (Ton of Refrigeration) closed wet cooling tower. According to the study, it was found that one factor that had effects on heat transfer was atmosphere temperature during 01:00-04:00 p.m. Summer temperature in Thailand which is higher than 36 ºC reduces the efficiency of heat transfer. To solve this problem, the researcher enhanced the efficiency by reducing the temperature around thermoelectric coolers by spraying water particles between 20–70 micron with a water flow rate of 20 liters per minute and spray distance of 20, 30, 40, 50, and 60 centimeters. The results showed that at the spray distance of 30 centimeters, the temperature could be reduced to a maximum of about 2.74 ºC. Secondly, a spray distance of 40 centimeters could reduce the temperature by approximately 2.23 ºC. Lastly, at the distance of 20 and 50 centimeters, the temperature was approximately reduced 2 .06 ºC and 1.68 ºC, subsequently. However, a spray distance of 60 centimeters could not reduce the temperature of heat exchange. When analyzing a break-even point, it was found that a payback period was about seven months. These results could be applied as guidelines to enhance the efficiency of heat transfer in factories, but the water flow rate used for spraying should be additionally studied.

Keywords: Water cooling, water spray method, cooling tower

1. Introduction

In the production process of industries, a part of the process will generate heat. The excess heat, for example, the atmosphere, will be released. Heat exchangers which ventilate heat to the atmosphere are divided into two types according to patterns of heat transfer. To begin with, air intake to heat based on the principle of sensible heat; the air intake to the system has a different temperature from the substance which is a coolant. The second one is a heat exchanger based on the principle of sensible heat together with latent heat. Since a tool called a cooling tower has high efficiency of heat transfer, the industries like to create cooling towers to use as the heat transfer medium. By this, the cooling tower uses water as the heat transfer medium which circulates in the cooling tower, passes spray nozzles, and flows through the filler. At the same time, the air is pulled out to come in contact with water, causing sensible heat transferred from water to the atmosphere. As the water temperature is higher than wet temperature causing some water to evaporate from the circulating water, latent heat will be transferred.

Lubricant industries need to use machines that cool down water from the clean cooling towers with no dregs and moss. Cooling down water with the cooling tower, therefore, must be the closed cooling tower in order to prevent water is not to contact with air directly which could cause dirt and contaminants, such as dust, etc. As can be seen in (Figure 1) which showed the production of the lubricant industry, it described that water temperature before entering the blow molding machine must be lower than 36 ºC. Presently, the average temperature in Thailand, especially in the summer season from March-May, is quite higher than 37 °C (Meteorological Department, 2021), this has an effect on works that have been designed. Thus, the cooling tower is needed to cool down by the spray system that would be operated if the inlet water temperature is higher than 36 ºC. At this point, ambient temperature is one factor that has an effect on water temperature. It was found that 01:00-04 .00 p.m. was the time when the inlet water temperature was higher than 36 ºC.

The cooling process in the cooling tower is commonly applied in three forms, including spraying, dropping, and heat exchanger application. Chutrakul *et al.* (2010) enhancement of close wet cooling tower to change by designed the PVC filler. The Old PVC filler is located above the copper tubes and the spray water will have flowed through the PVC filler. And a new pattern of PVC pattern designed to be smaller and inserted between the stack of copper tubes. As discussed in paper (Chutrakul, *et al.*, 2010), the most important is the mass transfer coefficient between spray water interface and air and the heat transfer coefficient between tubes and sprat water. As the same Facão and Oliveira (2004) designed small indirect contract cooling towers that could be enhancement of cooling tower and the same previous studied (Facão & Oliverira, 2000 ; Mizushina & Miyashita, 1968; Parker & Treybal, 1961).

Each form has limitations. Heat exchangers, for instance, have a high cost of operation whereas the dropping method is only suitable for specific areas. This research was interested in spray cooling since the operation of the chiller causes high energy consumption. And also would consider a break-even point of reducing the energy consumption of a cooling tower by the water spray method.

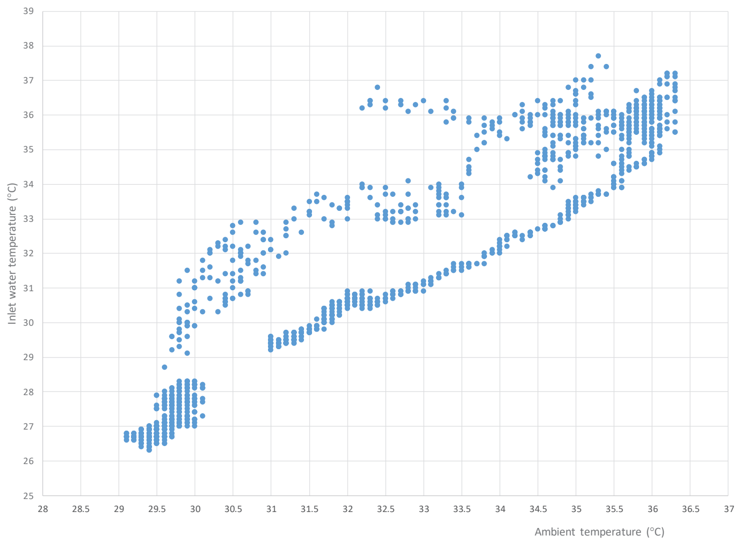


Figure 1. The relationship between ambient temperature and inlet water temperature.

2. Method

Cooling Tower is one part of the refrigeration system that cools down the heat with water. High-efficiency cooling towers will decrease the condensation temperature of refrigerants and helps saving energy consumption of the refrigeration system as well as increasing refrigeration efficiency. Cooling towers are then regarded as important equipment in the operation of the refrigeration system.

Closed Cooling Tower is a cooling tower that works in a closed system by air suction cross flowing with stainless steel coils which are installed in the machine as presented in (Figure 2) Inside the cooling tower, the water in the closed system that flows through the coils will be cooled down and is not in contact directly with the air. At this point, heat will be pulled out by cooling water in the closed system which drops through stainless steel coils. This type of cooling tower is then regarded as a clean and pure system.

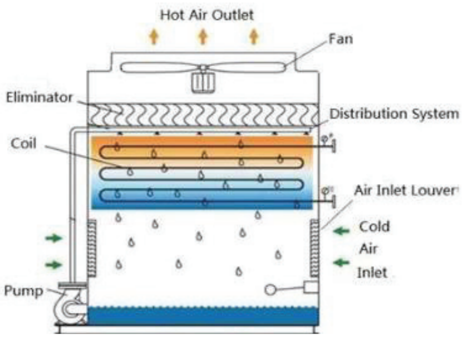


Figure 2. Heat transfer by air in the closed system (Deecha & Jaojaruek, 2014)

Calculation of heat transfer rates with temperature changes was presented in equation (1):

$$Q = \dot{m}C_P\Delta T \qquad (1)$$

When Q is heat transfer rate (J/s);

$\dot{m}$ is mass flow rate of substance (kg/s) ;

C_p is specific heat of water which is equal to 4.18 KJ/kg ºC ;

ΔT is difference water temperature between inlet and outlet temperature (ºC)

COP is the ratio of how much useful heat (or cold) a cooling tower will produce if we give it certain energy input. A COP can be calculated based on equation (2).

$$COP = Q/W \qquad (2)$$

where Q is heat of the heater generates if give it a certain amount of work (W).

The payback period is the time in which the initial outlay of investment is expected to be recovered through the cash inflows generated by the investment. The formula to calculate the payback period is showed in equation (3). The interest rate used to calculate was 6.345% per year.

Payback Period = Initial Investment / Net Cash Flow per Period (3)

3. Tools and Procedures

3.1 Collect the Primary Data to Design an Experiment,

such as the atmosphere temperature, quantity of heat in and out of the system, etc. The cooling tower used in this experiment was the Italian 200 TR cooling tower brand Green Box, model Fc 61/91 AC with an air-cooling system. This cooling tower operates by using fans at the top of the machine to ventilate air from outside passing tube condensers which are inside installed on each side of the cooling tower. The cooling tower has two sets of tube condensers in which one set consists of six ventilating fans working based on load and are controlled by a microcontroller. The refrigeration system is used in the lubricant factory located in Pathum Thani Province.

3.2 Design the Cooling Tower

without the added heat of the chiller during 01:00-04:00 p.m. It was found that the heat transfer rate of the cooling tower is not transmission to the system. Because the system must be a different temperature of approximately 2.9 °C and a heat transfer rate of 360 kW that the transmission to the system.

3.3 The Design of the Spray System

can be seen in (Figure 3) The flow of water in the closed system is needed to cool down and an operation of the spray system, start from water flows out of the machine ❶ before entering the water pump of the cooling tower ❷ Next, the water will be delivered to the cooling tower ❸ After passing the process of heat exchange, the water will flow from both cooling towers through ❹ and enter the machine ❺ In case of water temperature T_1 is higher than 36 ºC, the spray system will be operated. By this, the controller system which measures the temperature as presented in ❾ will manage the operation of the water spray pump in ❼ Water will be sprayed to both sides of the condenser ❸ After the water temperature T_1 in the system is lower than 36 ºC, the spray system will be stopped. Water used in the spray system is filtered by Reverse Osmosis (R.O.) which is stored in the water tank ❻.

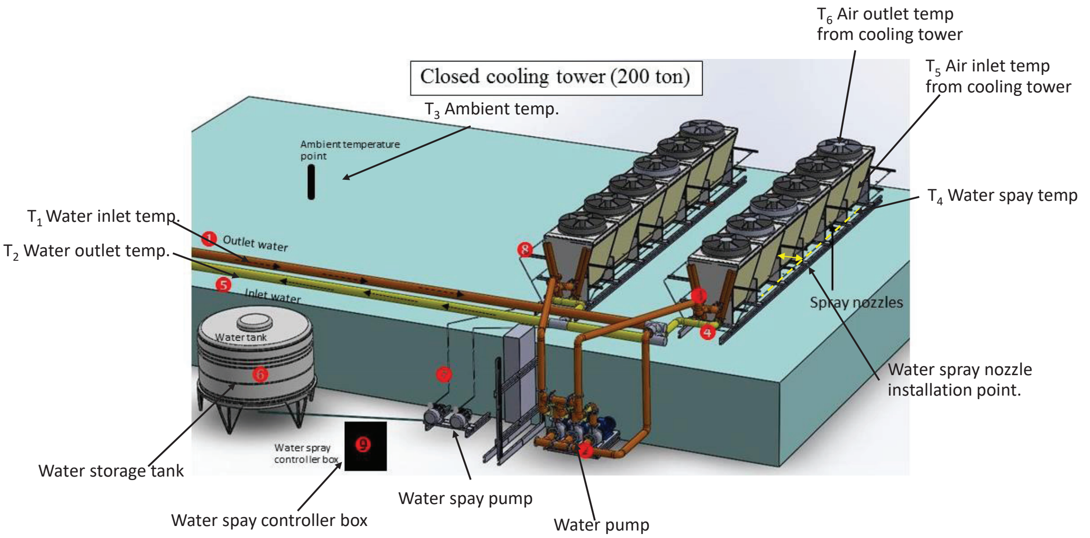
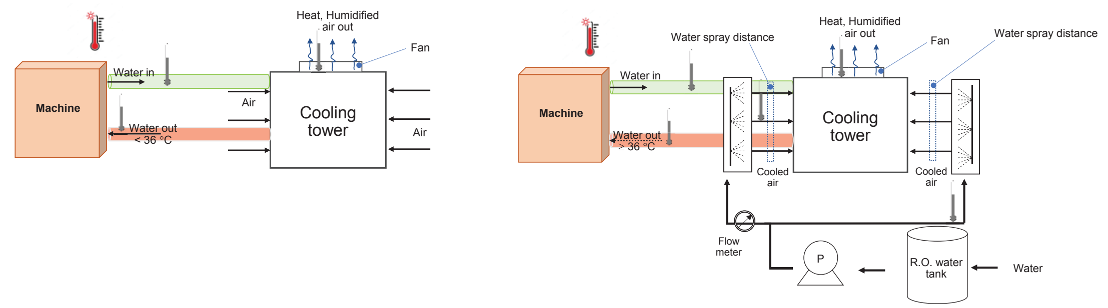


Figure 3. Diagram of the operation of cooling tower after adaptation.

3.4 Experimental Data

were collected to evaluate the heat transfer value, Coefficient of Performance (COP), and economic value. If the water out from the cooling tower is lower than 36 ºC, the cooling system just is enough as in Figure 4a. The spray water working, that the water out from cooling tower must be higher and equal than to 36 ºC, the spray system as in (Figure 4b). This research applied water flow rate at 20 liters per minute with 50 bar pressure and spray distance of 0, 20, 30, 40, 50, and 60 centimeters respectively, as shown in (Figure 4b). This research used a full cone spray nozzle with particles between 20-70 microns because cone-shaped spray pattern with round impact area and saving water. The period of time to study the experiment was 01:00-04:00 p.m.

As shown in Figure 3, the inlet and outlet water temperature of the cooling tower, inlet and outlet water spraying, and dry bulb temperature are measured by type K thermocouple. The flow rate of spray water is measured by the ultrasonic flow meter. At air out is mean dry bulb temperature and humidity are measured with a Testo 608-H2, that the primary measure information is converted into entropy by the used a psychometric chart.



(a) Cooling tower without chiller (b) Cooling tower with water spray

Figure 3. Schematic diagram of cooling tower.

4. Results

4.1 The Relationship Between Water Temperature (T_1) and Atmosphere Temperature

in each period as presented in Figure 4 indicated that ambient temperature was a factor causing inlet water temperature higher than 36 ºC. It was also found that an average time that caused water temperature higher than 36 ºC was 01:00-04:00 p.m. This research then only investigated the results during that specific time. However, the water temperature showed in the picture might be inexact because during the experiment most of the temperature T_1 from 12:00 noon was higher than 36 ºC. The researcher, hence, had to reduce the temperature in order to make the cooling tower continued the operation.

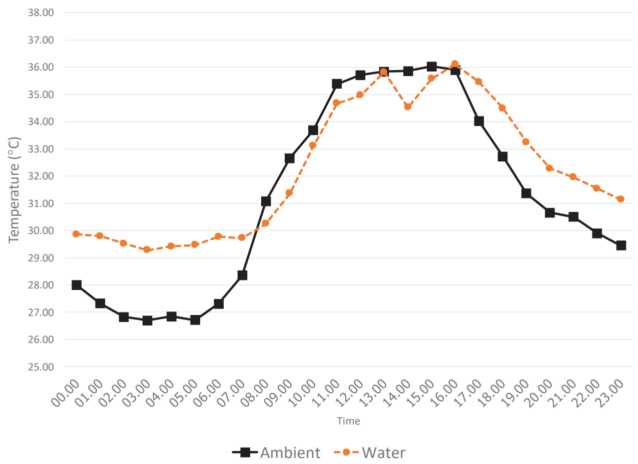


Figure 4. The relationship between ambient temperature and inlet water temperature (T_1).

4.2 The Relationship Between Inlet and Outlet Temperature Differences (T_2-T_1:ΔT)

and spray distance during the experiment as described in (Figure 5) showed that if assumed the water was sprayed at the flow rate of 20 liters per minute with 50 bar pressure, spray distance of 60 centimeters could not decrease water temperature since the sprayed water did not reach the condenser. Spray distances of 20 and 40 centimeters could decrease the temperature not differently about 2.15 ºC. The distance of 50 centimeters could also decrease the temperature but not much, about 1.68 ºC. Meanwhile, a spray distance of 30 centimeters was the best range that could decrease the temperature by about 2.74 ºC as the water could be sprayed to cover the surface of the condenser more than other distances that had been studied.

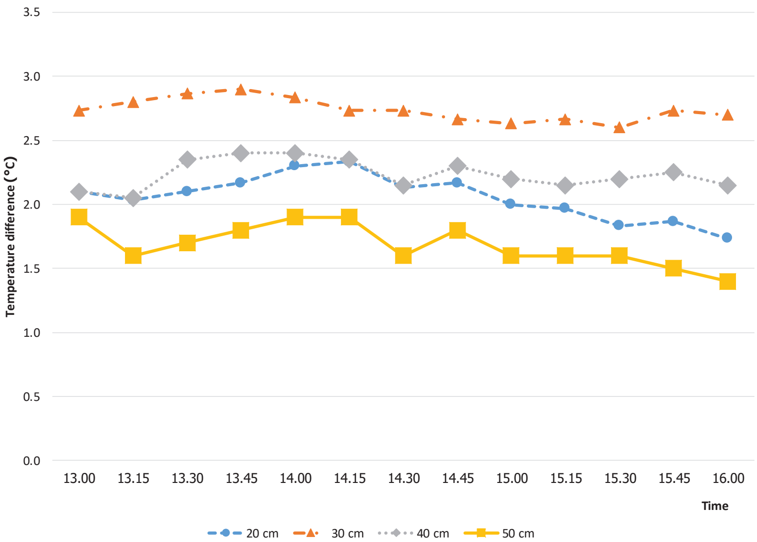


Figure 5. The decrease of temperature by water spray cooling.

4.3 Calculation of Heat Transfer

as presented in (Figure 6) might be inexact since the data had to be collected while the system was working with the distance of 0 and 60 centimeters as the defaults of heat transfer. This research indicated time to spray water daily at 02:30 p.m., 03:30 p.m., and 12:30 p.m. because the inlet water temperature was higher than 36 ºC causing the system could not work. This was one factor that caused unequal values of heat transfer at the starting distances because the inlet water had to be reduced the temperature. After that, the system started to cool down the heat inside the cooling tower in which the heat transfer value of each time and distance was like each other. When spraying water at a distance of 30 centimeters, it resulted that this range had the highest value of heat transfer because the water could be sprayed to cover the entire surface of the condenser. For an overall heat transfer value, it was found that the distance of 20, 30, 40, and 50 centimeters, the heat transfer rates were 251.58 kW, 306.812 kW, 263.8 kW, and 245.4 kW, respectively. However, the distance of 60 centimeters had a heat transfer rate of 160.96 kW as the temperature could not be reduced. When comparing an average value of COP in each distance, it described that the cooling tower which had been installed a spray set at a distance of 30 centimeters had the highest capacity at 6.16. Meanwhile, the spray set installed at the distance of 40, 20, and 50 centimeters caused the cooling tower to have the capacity of COP at 4.80, 4.42, and 4.14, subsequently.

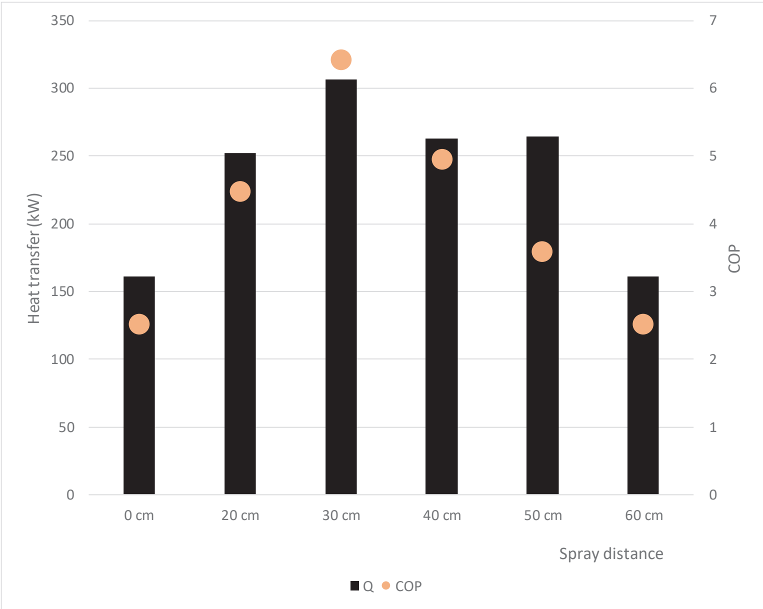


Figure 6. The heat transfer (Q) and COP.

4.4 In this Case, if the Spray Machine wasn't Installed; It Would Cost Approximately 988,788 Baht Per Month.

On the other hand, if installing the nozzles, the investment cost was about 180,000 Baht included spray nozzles, pump, Reverse Osmosis (R.O.) water system. The installation cost involves labor and construction of a water spray system estimated at 45,000 Baht. For the system which operated 26 days per month. The energy consumption of the spray cooling tower system helps cut energy costs by saving up to 513,858 Baht per year. The operation cost of water and electricity used for the water spray system of 5,748 Baht per year. Total replacement cost estimated 25,000 Baht per year for spray nozzle replaced at the end of 2 and 4 years and the life-time of project 5 years. An interest rate at 6.345% per year and an average cost of electricity at 3.70 baht per kWh. In addition, the distance of 30 centimeters had the fastest payback period about 0.47 years.

5. Discussion and Conclusion

This case study was research on guidelines for reducing the temperature of cooling water of a cooling tower in order to increase the efficiency and economic worthiness. There are various ways to increase heat transfer. In this research, reducing temperature around thermoelectric coolers had been studied by spraying water particles between 20-70 micron with a water flow rate of 20 liters per minute and spray distance of 20, 30, 40, 50, and 60 centimeters. The results showed that at the spray distance of 30 centimeters, the temperature could be reduced to a maximum of about 2.74 ºC. Secondly, a spray distance of 40 centimeters could reduce the temperature by approximately 2.23 ºC. Lastly, at the distance of 20 and 50 centimeters, the temperature was approximately reduced 2 .06 ºC and 1.68 ºC, subsequently. However, a spray distance of 60 centimeters could not reduce the temperature of heat exchange.

When comparing the value of heat exchange per ton of the cooling tower, it showed that the distance of 30 centimeters presented a heat transfer value of about 1.53 kW/ton. Next, 40 and 50 centimeters presented a value of about 1.32 kW/ton, and 20 centimeters pointed out the value of approximately 1.27 kW/ton. Conversely, the value of heat transfer was 0.81 kW/ton if the cooling tower was not given water spray. Moreover, when comparing an average value of COP in each distance, it indicated that the cooling tower with a set of spray systems at 30 centimeters had the highest capacity at 6.16. Besides, at the distance of 40, 20, and 50 centimeters, it presented the capacity at 4.80, 4.42, and 4.14, respectively.

However, this research should consider the quantity of heat changed from latent heat and sensible heat. This is because that system had heat exchange between water and air in which water was sprayed to the condenser, and latent heat was caused by spraying water to the condenser which used air to cool down the heat. Furthermore, the water flow rate should be additionally examined as it is regarded as one factor for heat cooling. At this point, Duangrudee *et al.* (2010) had summarized the data of the efficiency of water flow rate on heat cooling. Likewise, Mahdi and Jaffal (2016) indicated that water flow rate and air have an effect on heat transfer. Lastly, Pachanapan (2016) suggested that relative humidity should be included in the research since it might have an influence on cooling down the heat as well. However, the problems are associated with water spray on the heat transfer caused corrosion, slag, corrosion, rusting of metal equipment.

6. Acknowledgement

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7. References

Chutrakul, D., Asadamongkok, P. & Suksangpanomrung, A. (2010). The study and design of heat transfer enhancement of closed wet crossflow cooling tower. *Srinakharinwirot University (Journal of Science and Technology)*, *2* (1), 47-58.

Daongrudee, C., Asadmongkon, P. & Suksangpanomrung, A. (2010). The study and design of heat transfer enhancement of closed wet crossflow cooling tower. *Srinakharinwirot University Journal of Science and Technology, 2*, 47-58.

Deecha, C. & Jaojaruek, K. (2014). Efficiency enhancement of air cooling tower by spraying water at the condenser unit. *The 28th conference of Mechanical Engineering Network of Thailand.*

Facão, J. & Oliveira, A. (2004). Heat and mass transfer correlations for the design of small indirect contract cooling towers. *Applied Thermal Engineering, 24*, 1969-1978.

Facão, J. & Oliverira, A. (2000). Thermal behavior of closed wet cooling towers for use with chilled ceilings. *Applied Thermal Engineering, 20* (13), 1225-1236.

Mahdi, Q.S. & Jaffal, H.M. (2016). Thermal Characteristics of Closed Wet Cooling Tower Using Different Heat Exchanger Tubes Arrangement. *Journal of Engineering, 22* (1), 140-158.

Meteorological Department, (2021). *Weather forest*. https://www.tmd.go.th/services /weekly_report.php

Mizushina, R. & Miyashita, H. (1968). Characteristics and methods of thermal design of evaporative coolers. *Chemical engineering, 8* (3), 532-538.

Pachanapan, P. (2016). Minimizing electricity cost in chiller air-conditioner: a case study of temperature reduction of condenser. *Kasetsart Engineering Journal,* 152-154.

Parker, R. & Treybal, R. (1961). The heat and mass transfer characteristics of evaporative coolers. *Chemical Engineering Progress Symposium, 57* (32), 138-149.