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Experimental study on the coefficient of performance of a cold room unit with water spraying at the condenser

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Abstract—An experimental study has been carried out on the enhancement of coefficient of performance of cold room unit by water spraying technique on the condenser of the system. From collected data, it has been found that water spraying is a good option to enhance the coefficient of performance (COP). Comparison between two cases was conducted, one of them is with no water spraying, while the other one is with water spraying. The feedback of this process was positive in enhancing the COP of the cooling system (1.2% to 5.5%) approximately, when the evaporator load was 0.5 to 1.5 kW.

***Index Terms*—Mist water, Condenser, Heat exchanger**

I. INTRODUCTION

The refrigerant equipment working with water-cooled condenser has higher coefficient of performance than that working with air-cooled condenser. However, air-cooled equipment, such as air-cooled chillers are widely used because the air-cooled chillers are simple to install, easy to operate and maintain, and cost is less compared with water-cooled chillers. Also, there are some limitations about using freshwater in water-cooled chillers, due to scarcity of it. Considering that air-cooled equipment having already been used in industrial facilities, buildings, and in subtropical area. From forgoing reasons, it is worthy to increase their coefficient of performance (COP) by enhancing the operation condition of their components [1].

Zhang et al. [2] conducted that the COP of air cooled chillers using direct evaporative precoolers of air before entering the condenser could be enhanced by about 14.7% under climate conditions of Tianjin region in China.

Yu and Chan [3] found from a simulation analysis, that on an air-cooled chiller equipped with a direct evaporative cooler, a 1.3 - 4.6% increase in the refrigeration effect and a 1.4 - 14.4% decrease in chiller power by using head pressure control. In addition condenser temperature was reduced by about 2.1 - 6.2 ºC

Yu and Chan [4] reported some useful information about how the evaporative cooled air entering condenser and condensing temperature can be improved the coefficient of performance and electricity annual saving of air cooled chiller. The air cooled chiller model DOE-2.1E was modified by [5]. Energy analysis showed reduction of about a 19.84% can be achieved in the annual electricity consumption of the system and increase in the COP up to 9.8%.

Jia Yang et al. [6] showed that the efficiency of air cooled screw chiller can be enhanced by evaporative pre-cooling process. The experiments were carried out at various operation conditions in semitropical environmental condition. The results revealed decrease of the dry bulb temperature of air entering the condenser about 9.4ºC and 7.2ºC of the condensing temperature. Furthermore, COP was improved with a range from 3.8% to 18.6%.

A finned tube heat exchange and an air flow containing water droplets during experimental study has been examined by [7]. An experimental setup consist of a duct where an air flow with droplet of water size of about 25 µm crosses an exchanger fed with water. The results revealed that the decrease in the temperature of air cooling upstream to the heat exchanger by about 3.9 ºC, and this result is in good agreement with the results of the former studies reported by [8], [9].

An experimental study was conducted to improve of the heat exchange on a finned tube heat exchanger cooled by an air flow containing water droplets by [10]. The results showed that the maximum improvement of Nusselt number ratio Nu_f / $Nu_{w;withoutspray}$ was (23.5%) which occurred at nanofluid of (Al_2O_3) with a concentration of 2%.

The goal of this paper is to evaluate the coefficient of performance for cold room with and without water spraying on the air cooled condenser under different cooling load through an experimental study.

II. EXPERIMENTAL APPARATUS

A photograph of the rig test and the piping diagram of experimental work are illustrated in Figures 1, and 2. Cold room training system Model: RCO-SRT-A from LABTECH INTERNATIONAL LTD. was used in this study. The cold room consists of hermetic reciprocating compressor, condenser, thermostatic expansion valves, evaporator, and some auxiliary parts such as liquid receiver, and suction line accumulator. Type R134a was the refrigerant working fluid. The experimental study was done at the Vocational Training Center in Al-Buraimi, Sultanate of Oman.

Figure 3 illustrates water spraying system. The nozzle of the system spray the water on the front of the condenser fan with low speed water. Temperatures and pressures of the cold room recorded directly from the panel of the system.

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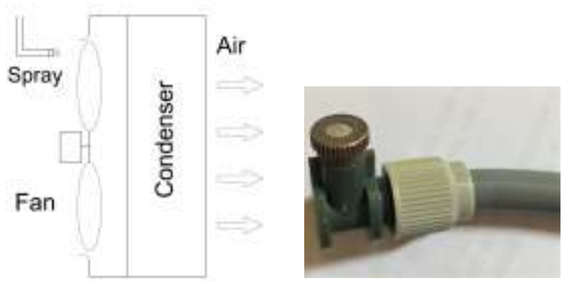
NOMENCLATURE

ΔTc	Temperature difference between condenser temperature and ambient temperature , ºC	q_{con}	Heat transfer from condenser per unit mass, kJ/kg
COP	Coefficient of performance	Qe	Cooling Load, kJ
h	Specific enthalpy, kJ/kg	W	Work of compression, kJ
m	Refrigerant mass flow rate kg/s	ΔTe	Temperature difference between evaporator temperature and cold room temperature , ºC
P	Pressure, bar	q_{evap}	Heat transfer from evaporator per unit mass, kJ/kg
Q_{con}	Condenser load, kJ	w_c	Compressor work per unit mass, kJ/kg

Figure 1: Photograph of the cold room system



(a) (b)

Figure 3: (a) Water spray system (b) Spray nozzle flow rate 2 l/hr at 2 bar pressure.

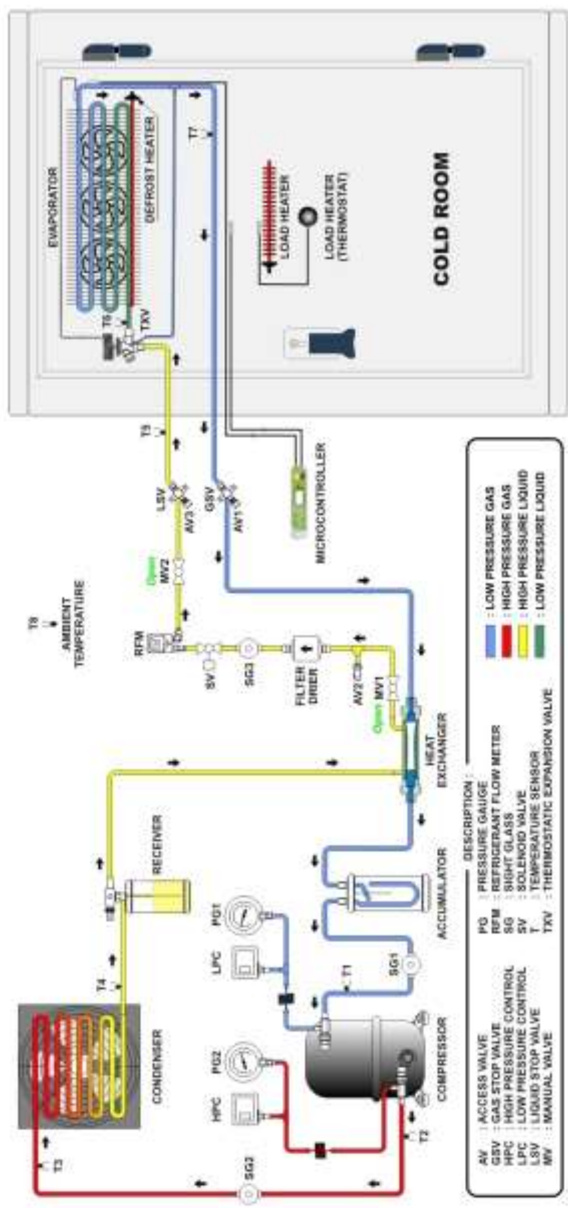


Figure 2: Piping diagram.

III. EXPERIMENTAL PROCEDURE

The main aim of this study is to measure the coefficient of performance for cold room with and without water spraying system on the condenser. The experimental procedure is as follows:

1) Running the refrigerant system until it reaches the steady condition within 30 minutes as recommended from LABTECH INTERNATIONAL LTD.
2) After reaching the steady state, temperatures, and pressures were recorded for different evaporator loads (0.5, 1, and 1.5) kW without water spraying on the condenser.
3) Repeating step 2 with water spraying on the condenser.

IV. MATHEMATICAL CALCULATIONS:

The main component of the basic refrigeration system is shown in Figure 4.

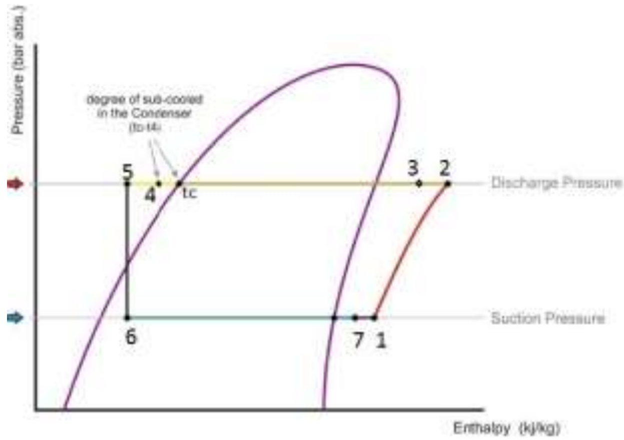


Figure 4: Shows the schematic diagram of compression refrigeration cycle and presented on (P-h) diagram.

Neglecting kinetic and potential energies, the steady flow energy equations for the components of the cycle will yield the following equations reported by [11]:

- Compressor: (1 -2)

$$W = m_r \, w_c$$
$$w_c = h_2 - h_1 \qquad (1)$$

- Condenser: (3-4)

$$Q_{con} = m_r \, q_{cond}$$
$$q_{cond} = h_3 - h_4 \qquad (2)$$

- Thermostatic expansion valve: (5-6)

$$h_5 = h_6 \qquad (3)$$

- Evaporator: (6-7)

$$Q_e = m_r \, q_{evap}$$
$$q_{evap} = h_7 - h_6 \qquad (4)$$

- Coefficient of performance is defined as(Cooling effect / Work input):

$$COP = \frac{Q_e}{Work} = \frac{h_7 - h_6}{h_2 - h_1} \qquad (5)$$

All enthalpies h_1, h_6, and h_7 measured from refrigerant table R134a according to the evaporator pressure and temperature that were read from main panel (Temperature display) for each point. Also enthalpy h_2 measured in same way from condenser pressure and temperature.

V. RESULTS AND DISCUSSION

The obtained results can be discussed as follows:

A. *Refrigerant condensing temperature and pressure*

Figure 5 illustrates the variation of refrigerant condensing temperature and air ambient temperature (ΔTc) under different evaporator loads, these were -0.7 ºC and -0.3 ºC at 0.5 and 1 kW respectively, while increase to 1.1 ºC when increasing evaporator load 1.5 kW, which was due to the effect of water spray on the condenser. In addition, ΔTc was changed from 1.8 to 3.8 positively without water spray on the condenser. This result is agreed with the result that has been reported by [6] when used water mist pre-cooling system to improve the performance of air-cooled chillers in China.

Furthermore, condenser pressure reduced by 0.9 bar with spraying water in comparison without spraying water on the condenser, through changing the evaporator load as shown in Figure 6, from which it can be seen that the relation is almost linear trend.

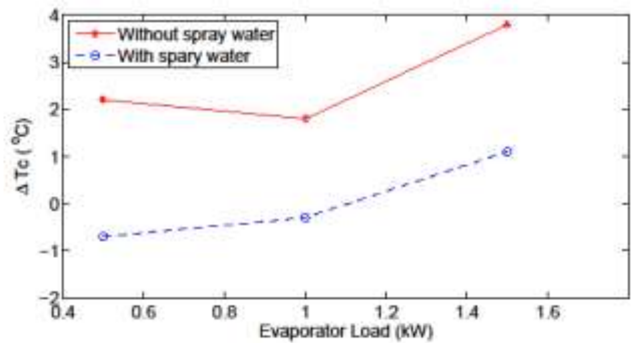


Figure 5: Variation of temperature difference between condenser temperature and ambient temperature (ΔTc) with different evaporator loads

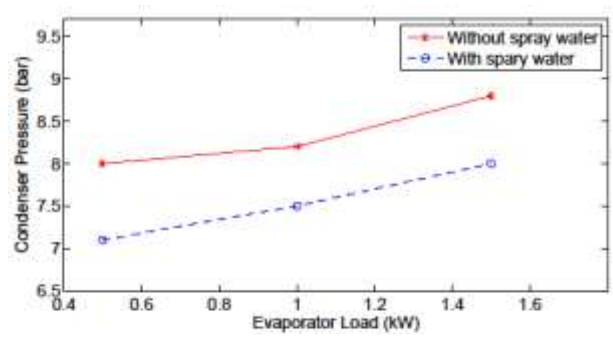


Figure 6: Variation of condenser pressure with different evaporator loads

B. *Evaporator pressure and temperature*

Figure 7 shows the variation of difference evaporator temperature and cold room (cabinet) temperature (ΔTe) under different evaporator loads. Cold room temperature was set at -6 ºC. The values of ΔTc were about 2 ºC, 1 ºC, and 0.5 ºC with increasing the load from 0.5 kW, 1 kW, and 1.5 kW respectively.

Moreover, Figure 8 illustrates the change of evaporator pressure against evaporator load. It is very clear to see that the change of the pressure in the evaporator was very small at each casing load. The reason for that is to keep cooling load at the setting condition.

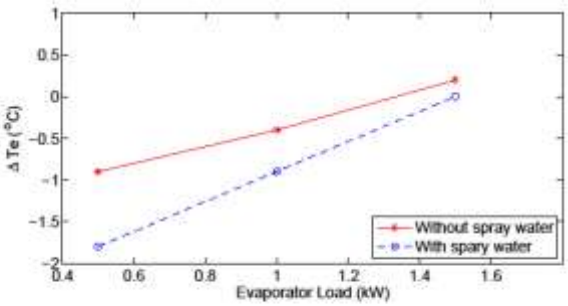


Figure 7: Variation of temperature difference between evaporator temperature and cold room temperature (ΔTe) with different evaporator loads

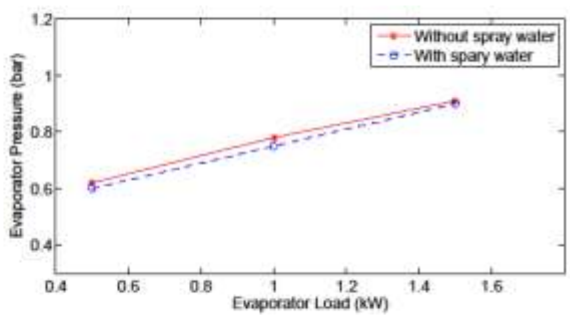


Figure 8: Comparison of evaporator pressure for condenser sprayed by water and another without spraying water with different evaporator loads

C. *Coefficient of performance*

The COP of the cold room operating with water spraying was compared with the COP of cold room without water spraying under similar operating conditions, as shown in Figure 9, from which it can be concluded that there is no significant increase of the COP in 0.5 kW and 1 kW evaporator load which were 1.2% and 2.8% respectively. The reason for this result is that the vapor compression system works at partial load, while increase the percentage of the COP up to 5.5% when it works at full load.

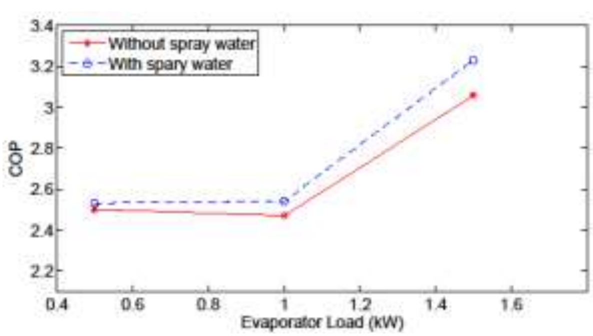


Figure 9: Variation of COP with different evaporator loads

VI. CONCLUSION

The obtained results in this article clearly showed that the condenser pressure was reduced by a certain amount by water spraying process. In addition, the relation between the condenser pressures with different evaporator loads found to be almost liner relationship. Moreover, the coefficient performance of the air-cooled condenser of cold room has been investigated. The most essential conclusion was that the direct water spraying on the condenser of the employed system can be used to improve the COP parameter with different evaporator loads. The COP of the cooling system was enhanced with (1.2% , 2.43%, and 5.5%) at evaporator loading of 0.5, 1, and 1.5 kW respectively.

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