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The Role of Condenser Approach Temperature on Energy Conservation of Water Cooled Chiller

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This paper presents numerical and experimental study on condenser approach temperature and its effects to the temperature and energy performances of water-cooled chillers. Performance characteristic of the chillers was analyzed at different approach temperatures and refrigerants. Numerical models have been developed in EES (Engineering Equations Solver) program to simulate the performance of chiller systems. The models were validated using data obtained from experimental investigation in hotel industries. The results showed that the increase of condenser approach temperature could cause the chiller system to operate at a lower performance. The increase of condenser approach temperature by 1 K could reduce coefficient of performance (COP) of about 3.45%, 3.4%, 3.3% and 3.6% respectively for chillers with R-22, R-134A, R-407C or R-410A. This paper also presents the characteristic of condenser approach temperature that can be used as early warning system for chiller operation and maintenance in order to keep the best possible performance.

Keywords: Approach Temperature, Condenser, Performance, Water-Cooled Chiller System.

1. INTRODUCTION

In Indonesia, energy consumption of commercial sector includes office buildings, hospitals, hotels, trade center (supermarkets and department stores) and airports was about 3.7% of total national energy consumption.[1] The energy consumption growth of the sector was the second highest just after transportation with consumption growth of 4.58% per year.[2] Energy saving potential of the commercial sector was estimated to be ranging from 10% up to 30% and energy saving target of the sector in 2025 was estimated to be 15%.[3]

For hotel building, the growth of the buildings in past three years could reach an average of 11.2%.[4] This would consequently increase the energy consumption of the sector. Hotel facilities with energy significant include air conditioning (AC) and hot water supply systems. Energy consumption of both systems can reach 70% of total energy use.[5]

Energy conservation efforts done for hotel buildings would therefore have significant potential on the reduction of energy consumption and environmental impact of the commercial sector.[6] The reduction of energy use would also be useful for hotel buildings to reduce operational cost and increase profit as well as hotel competitiveness. For the country, it could nationally reduce energy supply demand and greenhouse gas emissions.

One factor that might constrain the efforts to achieve energy saving in air conditioning system for commercial buildings was that shortness of knowledge of operators about critical-operation parameters. The parameters include evaporator and condenser approach temperatures. The increase of approach temperatures indicates that heat transfer in both condenser and evaporator has restricted. The chillers would operate at higher condensation temperature and lower evaporation temperature. These would cause temperature lift and energy consumption of chillers compressor high. The increase of approach temperatures also provides indications that the condenser and evaporator must be cleaned to maintain optimum temperature and energy performances as well as to prevent the condenser and evaporator from further damage.

Methods to detect fouling on the surface of condenser pipe were reported by Zhao et al.[7] It was demonstrated causes of damage in a chiller which included shortage of cooling water in condenser, insufficient chilled water in evaporator, low or over refrigerant charging and condenser fouling. It was found that condenser fouling had highest potential to instigate damage on a chiller system. Fouling could boost up approach temperature to become strong influence toward heat transfer capacity of a condenser and performance of a chiller system.

Approach temperature of a condenser has major influence to chiller system performance compared with evaporator approach temperature. A chiller system with high condenser approach temperature would require higher condensation temperature to reject heat to the cooling water. This would increase working pressure and energy consumption of a chiller. A study case showed that when approach temperature of a condenser was not tightly monitored, it could make condenser pipes crack and leak. Evaporator approach temperature, on the other hand, is not significantly

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influenced by fouling. It is usually used as an indicator how efficient a chiller system can perform. Evaporator approach temperature in combination with compressor discharge superheat can also be used to determine the most efficient refrigerant charge.[8]

In order to reduce effects of condenser approach temperature, cooling water temperature should be optimized. A control strategy could be applied which regularly reset temperature of the cooling water in such a way with the intention that the approach temperature would not influence condensation temperature. The control strategy would increase the speed of cooling fan of the cooling tower to satisfy the requirement of cooling water for condenser when the approach temperature increased. This meant energy consumption of the cooling tower would increase. The control strategy, however, was reported to provide energy saving up to 4% per year.[9]

Commercial building, such as hotels, consumed substantial amount of energy.[10] For that reason, it was recommended to continuously monitor performance of the chiller system so as to detect early warning of performance reduction due to fouling in the condenser. A multivariable analysis involving chilled and cooling water temperatures showed that operational variables had to be tightly monitored to improve chiller performance with higher technical efficiency.[11,12] A study on energy consumption of chiller systems in hotel buildings was investigated by Barry et al.[13] It was reported that ambient temperature which directly correlated to cooling water and approach temperatures showed significant influence on chiller system. The chiller system consumed the highest electrical energy among other hotels services. Similar study was also reported by Yu et al.[14]

Preliminary observation results on commercial buildings in Indonesia showed that most of chiller operators spent very little time on monitoring condenser and evaporator approach temperatures. A case study in a star hotel at North Jakarta showed that the chiller systems operated at condenser approach temperature reaching 10 K. Cooling capacity of the chiller system could not satisfy hotel load demand any more. The chiller consequently could not maintain room temperature at required comfort level especially during day time. Energy consumption of the chiller system also increased. De-scaling the condenser could make the chiller operate at approach temperature below 1 K and the cooling capacity could significantly be improved. Other case was also found in a supermarket in Bali—Indonesia. Condenser pipes of a chiller in this supermarket were cracked and exploded. Investigation results showed that waterside surfaces of condenser pipes were totally covered by thick salt-scale. Another case which showing the importance of condenser temperature needed to be tightly monitored has also observed at terminal building of Ngurah Rai Airport Bali. In this building, the condenser approach temperature was regularly recorded and evaluated. In six months operation, the chillers were found to have a condenser approach temperature more than 5 K. The condenser surface was totally covered by salt-scale. This high increase rate of approach temperature indicated the quality of makeup water was below recommendation or blow down water rate of cooling tower need to be fine-tuned.

This paper presents results of theoretical and empirical investigation on effects of condenser approach temperatures to energy performance of water cooled chillers. The investigation demonstrated variation of energy consumption and cooling capacity of the chiller system at different condenser approach temperatures. Four chiller systems with different refrigerants R-22, R-134A, R-407C and R-410A were included in the investigation.

2. CONCEPT AND METHODOLOGY

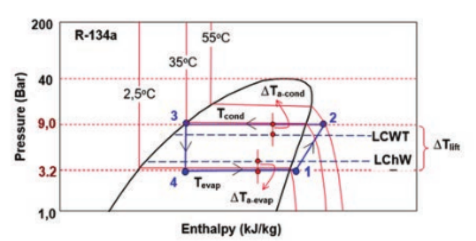
Condenser approach temperature shows temperature difference between cooling water temperature leaving the condenser and refrigerant condensation temperature. Concept of approach temperatures of chiller system in a pressure-enthalpy diagram is shown in Figure 1.

This research was based on numerical and experimental analyses of critical operation parameters on a water cooled chiller applied for central air conditioning system. The chiller system is used for commercial building application, especially hotel buildings. The system comprises chillers, cooling water pump, chilled water pump, cooling tower and loading systems.

Variables investigated comprises dependent and independent variables. Dependent variables include energy consumption, cooling capacity and coefficient of performance (COP). Whilst independent variables consist of evaporator and condenser approach temperatures, evaporation and condensation temperatures of refrigerant respectively in evaporator and condenser, chilled and cooling water temperatures, ambient temperature, low and high system pressures, refrigerant flow rate, chilled and cooling water flow rate.

Instruments used for numerical and experimental investigations included EES (Engineering Equations Solver) program, thermocouples, pressure transducers, data logger, energy meter and flow meter. EES program was applied for numerical analysis. Experimental investigation was directly conducted in the plant room of hotel buildings in Jakarta. The data obtained was processed in a spread sheet program. The results of experimental testing were applied for validating numerical models established in EES program.

The increase of condenser and evaporator approach temperatures indicates that heat transfer in condenser and evaporator has decreased. Maintaining cooling capacity of a chiller system with high condenser and evaporator approach temperatures require higher condensation temperature and lower evaporation temperature. As the result, compressor temperature lift of the chiller system increases. This also increases system pressure ratio and energy required for compressor, consequently reduces chiller system performance.



$\Delta T_{a\text{-}cond}$ = Condenser approach temperature = T_{cond} - LCWT
$\Delta T_{a\text{-}evap}$ = Evaporator approach temperature = LChWT − T_{evap}
T_{cond} = Condensing temperature,
T_{evap} = Evaporating temperature
LCWT = Leaving Cooling Water Temperature
LChWT = Leaving Chilled Water Temperature

Fig. 1. Concept of approach temperatures in a chiller system with R-134A.

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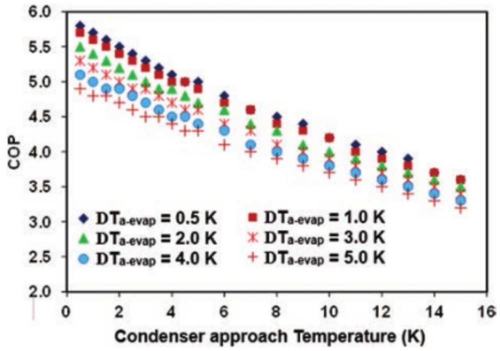

Fig. 2. COP of the chiller system with refrigerant R-134A at different approach temperatures.

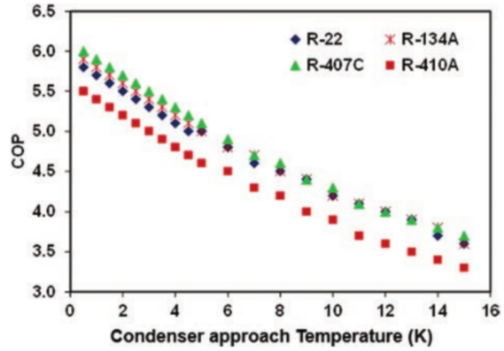

Fig. 4. COP of the chiller system with different refrigerants and approach temperatures.

3. RESULTS AND DISCUSSION

Numerical models of water cooled chillers have been established in this research. The models include chiller systems with refrigerant R-22, R-134A, R-407C or R-410A and have been validated by using data obtained from experimental tests. Models were subsequently used to simulate effects of evaporator and condenser approach temperatures to energy performance of the chiller system.

Figure 2 shows characteristic of COP (coefficient of performance) at different evaporator and condenser approach temperatures of water cooled chiller systems working with refrigerant R-134a. The COP generally decreases when the approach temperatures increase. At evaporator approach temperature of 0.5 K, the COP of chiller system drops down of about 27.5% when condenser approach temperature increases from 0.5 K to 10 K. The reduction of COP would become worse when condenser approach temperature rises to above 10 K and evaporator approach temperature also increase to more than 0.5 K.

Conversely, power consumption of chiller system increases when evaporator and condenser approach temperatures rises as shown in Figure 3. Power consumptions presented in the figure were simulated in the model which has been validated using data from experiment at a water cooled chiller system of cooling capacity 650 TR (tons of refrigeration). The intensification of power consumption could reach 28% when condenser approach temperature rises up to 10 K. Other consequence, cooling capacity of the chiller system could drop by 7.4%.

The increase of power consumption and the decrease of cooling capacity result in significant reduction on the COP of a chiller system. Hence, maintaining evaporator and condenser approach temperatures as low as possible would be very essential to keep the chiller system operating in optimum performance.

Figures 4 and 5 show COP characteristic and power consumption of chillers systems with different refrigerants respectively. The results were investigated at evaporator approach temperature of 0.5 K. From the figures, it can be seen that effects of the increase of condenser approach temperature to the reduction of system COP and intensification of power consumption quite significant on the chiller system with R-22. However the effects are relatively low when the chiller system using refrigerant R-134A or R-407C.

Specific effects of condenser approach temperature to the performance of the chiller system are shown in Figure 6. The figure illustrates that 1 K increment of condenser approach temperature causes power consumption to raise of about 3%, 2.9%, 2.9%

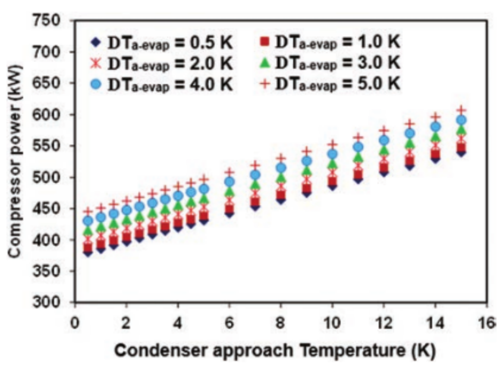

Fig. 3. Power consumption of the chiller system with refrigerant R-134A at different approach temperatures.

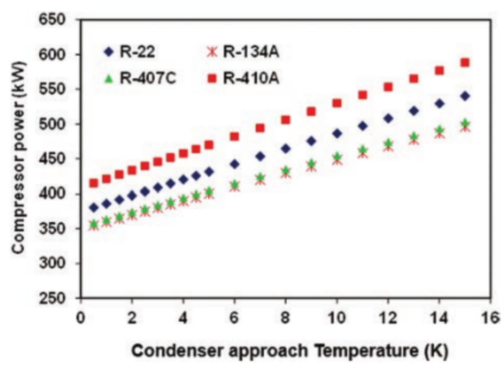

Fig. 5. Power consumption of the chiller system with different refrigerants and approach temperatures.

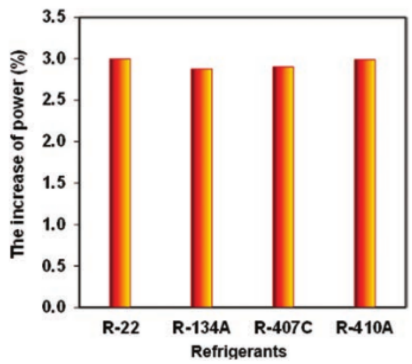

Fig. 6. Increase of power consumption of the chiller at 1 K increment of condenser approach temperature.

and 3.0% respectively for chiller system with refrigerant R-22, R-134A, R-407C or R-410A. Figure 7 shows the effects to cooling capacity (Q_{evap}) and COP of a chiller system. Cooling capacity seems to decline not more than 1% but COP may drop in the range of 3.3% and 3.6% per 1 K addition of condenser approach temperature.

From Figures 6 and 7 can also be noticed that evaporator and condenser approach temperatures are very important operational parameters of a water cooled chiller system. The parameters can be used to monitor effectiveness of evaporator and condenser as well as temperature and energy performance of the chiller system. By regularly monitoring and recording both parameters as part of operational and maintenance programs, it can provide early warning that waterside surfaces of evaporator and

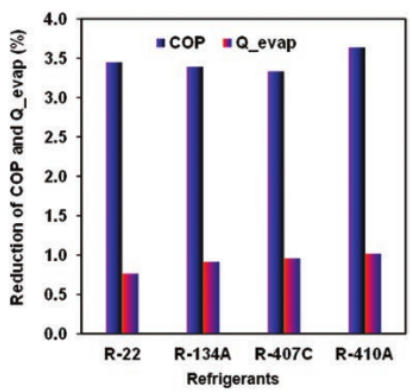

Fig. 7. Reduction of COP and cooling capacity at 1 K increment of condenser approach temperature.

condenser have been dirty and have occurred heat transfer constraint in the both components. At normal conditions which is when the condenser and evaporator are clean, the approach temperature was found in the range between 0.5 K and 0.8 K. Due to the importance of the approach temperatures, it is recommended to maintain evaporator and condenser approach temperatures lower than 2 K by implementing regular de-scaling process. At this conditions, the energy performance of the chiller system will drop of about 4% from its normal conditions. This finding is in agreement with chiller manufacturer recommendation.[8]

4. CONCLUSIONS

Condenser and evaporator approach temperatures could provide significant impact on the energy and temperature performance of a water cooled chiller system. The approach temperatures are also considered as critical operation parameters which are very functional for monitoring and evaluating performance of a chiller system. The increment of 1 K condenser and evaporator approach temperatures could cause an increase of power consumption of about 3% and reduction of cooling capacity by 1%.

The investigation results on the chiller system which were simulated at different type of refrigerants such as R-22, R-134A, R-407C and R-410A have showed reduction in COP at a range between 3.3% and 3.6% per 1 K increase of condenser approach temperature.

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