PERFORMANCE INVESTIGATION OF AIR COOLED CHILLER SYSTEM USING PURE HYDROCARBONS AS REFRIGERANT

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ABSTRACT: An air-cooled chiller system (ACCs) that are designed to work with R-22 was used as a test unit to assess the possibility of using hydrocarbons as a refrigerant. Pure propane namely R-290 were used as a refrigerant. The purpose of this study was to determine the performance of air cooled chiller systems using hydrocarbon R-290 which contains pure propane. The performance of the ACCs using hydrocarbons as a refrigerant was investigated and compared with the performance of ACCs when R-22 was used as a refrigerant. The effect of discharge pressure and suction pressure on refrigerating effect, a heat of compression, and COP were investigated. Finally, the COP and other results are obtained in this experiment can provide a positive indication of using hydrocarbons as a refrigerant in the system ACCs.

1 INTRODUCTION

R-22 has been widely used as the working fluid in the system of air-conditioning (AC) and refrigeration. It is acceptable because the R-22 has suitable qualifying properties such as non-flammability, non-toxicity, stability and good materials compatibility (Powell 2002). Unfortunately, it belongs to the family of hydrochlorofluorocarbon (HCFC) refrigerants, which were considered as harmful working fluids to the environment and controlled by the Montreal protocol. HCFC refrigerants will be phased out by 2020 in developed countries and 2030 in developing countries (Park and Jung 2009, Bolaji 2010).

Since 1st January 2015, the Government of Indonesia determined that the type of refrigerant HCFC-22 and HCFC-141b are prohibited for use in filling in the production process AC and other refrigeration appliance. Therefore, it requires being replaced with environmentally friendly refrigerants to protect the environment (Devotta et al. 2005a). Among R-22 alternative refrigerants for the air-conditioning system are grouped into three categories: (i) natural refrigerants, such as hydrocarbons (HC) and carbon dioxide; (ii) a mixture of HFC refrigerants; and (iii) a mixed refrigerant HFC/HC (Mohanraj et al., 2009).

The previous researchers had attempted to replace the refrigerant R-22 in air-conditioning systems with various types of alternative refrigerants. The use of HFC mixtures such as R-404A, R-407C, and R-410A as leading substitutes for replacing R-22 based on the suitability of compression refrigeration systems, air-conditioning, and heat pump (Yang & Wu 2013). Out of these three substitutes, R-404A is a good R-22 for low-temperature applications (Ge & Cropper 2008, Bolaji 2011). Similarly, R407C was reported as a possible R-22 alternative for compression based systems used for refrigeration, air-conditioning, and heat pump systems by changing the lubricant (Devotta et al., 2005b, Liu et al., 2008). Experiments using the R-410A on air-conditioning and heat pump systems as a replacement for R-22 gives hope of better but require some changes and replacement of components (Zaghdoudi et al. 2010).

The refrigerant type of hydrocarbons such as R-290, R-1270, and R-600a has been identified could be used as an alternative to R-22 for system air-conditioning and heat pump (Chang et al., 2000, Palm 2008, Corberán et al. 2008). However, some problems still found. There is no working substance which could be called an ideal replacement for different R-22 applications. Therefore, manufacturers are presented R-22 substitute in each application.

The purpose of this study was to determine the performance of air cooled chiller systems using hydrocarbon R-290 which contains pure propane. The performance of systems that use R-290 will be investigated and the results were compared with the performance ACCS that use R-22. The results obtained from this study are expected to provide a positive indication to the use of hydrocarbons as refrigerants in air-conditioning systems. So that the process of replacement refrigerant (drop-in) is recommended for old equipment with remaining life. This involves the pure exchange of the refrigerant without any modifications to the refrigerating system and keeping the existing lubricant oil.

2 MATERIALS AND METHODS

Figure 1 shows a schematic diagram of the experimental apparatus. It includes a refrigerant circuit and a water circuit. Also, necessary instrumentation and safety and operational controls are installed. R-22 or R-290 is used as a primary working fluid while water is used as a secondary heat transfer fluid at the evaporator.

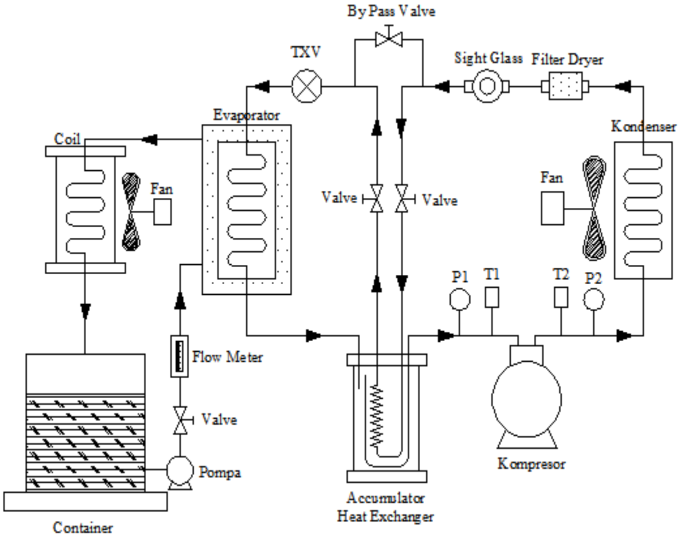

Figure 1. Schematic installation of air-cooled chiller as an experimental apparatus.

The test was conducted on an air-conditioning system (Sanyo) with a capacity of 9495 kJ and the flow rate of the water flowing into the cooling coil kept constant is set at 0.4 m/s by regulating the valve opening and measured by a flowmeter (Mueller). On both sides of the high and low pressure mounted pressure gauge (Robin water) and two temperature sensors (Lutron) placed in the inlet and outlet of the compressor. During the study, the temperature of the environment was kept at 28^0C ± 2^0C. At the beginning of the research, the system was operated using R-22 to obtain baseline data of the performance ACCs. Before the second data retrieval, the system was flushed using nitrogen to eliminate dirt, moisture and other substances in the system which might affect its performance. Then, the system was filled with R-290. Data capture started when the temperature of the water was 14^0C, with the assumption that the system was steady. Next, changes were observed until the temperature of the water reached 10^0C.

3 RESULTS AND DISCUSSION

3.1 *Refrigerating effect*

Figure 2 shows the results of the refrigerating effect of an air-cooled chiller system using R-22 dan R-290. In general, the refrigeration effects generated by R-290 has a higher value than R-22. In the R-22 system, the refrigerating effect generated when the water temperature was 14^0C is 153.43 kJ/kg. Then increasing slowly to 155.85 kJ/kg when the water temperature is 10^0C. On the other hand, in the system which used R-290, the refrigerating effect generated when the water temperature reaches 14^0C is 244.02 kJ/kg. Further, this decreased slowly to 239.78 kJ/kg when the water temperature is 10^0C. Based on the results, there had been a 50% increase of refrigeration effect in the system using R-290. The highest value of the refrigerating effect on systems using R-290 due to it has the high latent heat of vaporization so resulting in better cooling capacities.

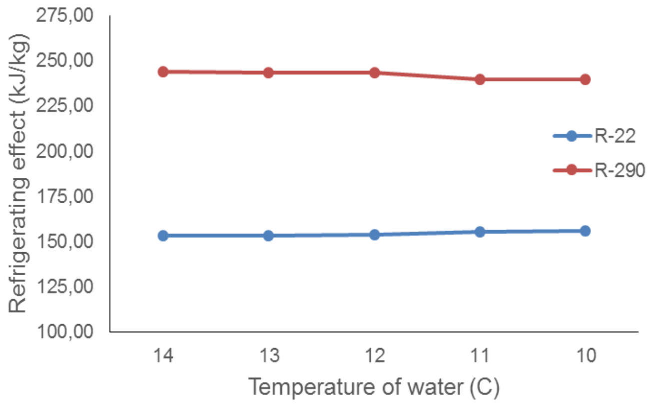

Figure 2. Data of the refrigerating effect of an air-cooled chiller system using R-22 dan R-290.

3.2 *Heat of compression*

Figure 3 shows the heat of compression of the air-cooled chiller system using R-22 and R-290. In general, the heat of compression generated by the system using R-290 has a higher than that of the system using R-22. In the R-290 system, the heat of compression generated when the water temperature of 14^0C was 102.92 kJ/kg. Then, this increased gradually to 107.90 kJ/kg when the temperature dropped to 10^0C. On the other hand, in the system which used R-22, the heat of compression generated when the water temperature was 14^0C was 35.56 kJ/kg. Further, this gradually decreased to 33.88 kJ/kg when the water temperature reaches 10^0C. Based on the results, the heat of compression increased approximately 68% when R-290 is used as the working fluid in the system ACCs. This is due to the high-pressure ratio of refrigerant and an increasing in the enthalpy of the refrigerant at inlet and outlet of the compressor.

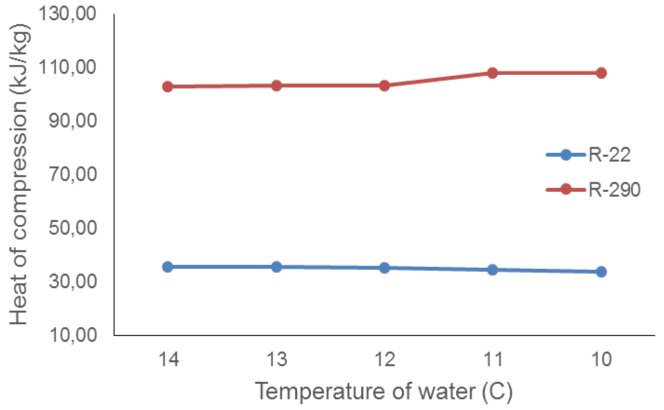

Figure 3. The heat of compression of the air-cooled chiller system using R-22 and R-290.

3.3 *Coefficient of performance (COP)*

Figure 4 presents coefficient of performance (COP) systems that use R-22 and R-290. In general, the COP of R-22 is higher than that of R-290. The obtained COP in the use of R-22 was 4.32 when the temperature of the water was 14^0C. Then, the COP of 4.60 was obtained when the water temperature was 10^0C. Further, when the system used R-290, COP decreased significantly. When the temperature of the water was 14^0C, the obtained COP was 2.37. Then, the value slightly decreased to 2.22 when the water temperature was 10^0C. The COP difference between the uses of R-22 to R-290 approximately 50%. It is clearly shown in this figure that when the water temperature decreases the COP reduce for R-290. COP is inversely proportional to the heat of compression, therefore, increase in heat of compression reduce the COP of the system.

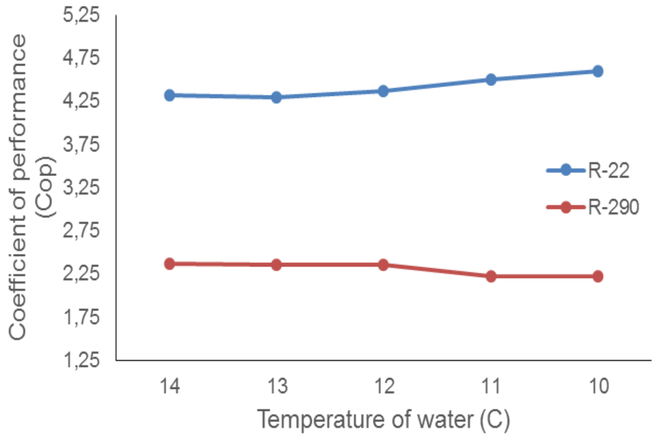

Figure 4. Data coefficient of performance (COP) systems that use R-22 and R-290.

4 CONCLUSION

Research investigation on the use of R-290 as an alternative R-22 has been implemented. In general, R290 is a promising alternative refrigerant to R22 because it has the ability to absorb heat more than the R-22 (Refrigerating effect is higher). Though, COP value for R290 is slightly lower, but it can be improved by specially designing a refrigeration system for it.

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6 REFERENCES

Bolaji, B.O., 2010. Experimental analysis of reciprocating compressor performance with eco-friendly refrigerants. Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, 224(6), pp.781–786.

Bolaji, B.O., 2011. Performance investigation of ozone-friendly R404A and R507 refrigerants as alternatives to R22 in a window air-conditioner. *Energy and Buildings*, 43(11), pp.3139–3143.

Chang, Y.S., Kim, M.S. & Ro, S.T., 2000. Performance and heat transfer characteristics of hydrocarbon refrigerants in a heat pump system. *International Journal of Refrigeration*, 23(3), pp.232–242.

Corberán, J.M. et al., 2008. Review of standards for the use of hydrocarbon refrigerants in A/C, heat pump and refrigeration equipment. *International Journal of Refrigeration*, 31(4), pp.748–756.

Devotta, S., Padalkar, A.S. & Sane, N.K., 2005a. Performance assessment of HC-290 as a drop-in substitute to HCFC-22 in a window air conditioner. *International Journal of Refrigeration*, 28(4), pp.594–604.

Devotta, S., Padalkar, A.S. & Sane, N.K., 2005b. Performance assessment of HCFC-22 window air conditioner retrofitted with R-407C. *Applied Thermal Engineering*, 25(17-18), pp.2937–2949.

Ge, Y.T. & Cropper, R., 2008. Performance simulation of refrigerated display cabinets operating with refrigerants R22 and R404A. *Applied Energy*, 85(8), pp.694–707.

Liu, Z. et al., 2008. Performance comparison of air source heat pump with R407C and R22 under frosting and defrosting. *Energy Conversion and Management*, 49(2), pp.232–239.

Mohanraj, M., Jayaraj, S. & Muraleedharan, C., 2009. Environment friendly alternatives to halogenated refrigerants-A review. *International Journal of Greenhouse Gas Control*, 3(1), pp.108–119.

Palm, B., 2008. Hydrocarbons as refrigerants in small heat pump and refrigeration systems - A review. *International Journal of Refrigeration*, 31(4), pp.552–563.

Park, K.J. & Jung, D., 2009. Performance of heat pumps charged with R170/R290 mixture. *Applied Energy*, 86(12), pp.2598–2603.

Powell, R.L., 2002. CFC phase-out: Have we met the challenge? *Journal of Fluorine Chemistry*, 114(2), pp.237–250.

Yang, Z. & Wu, X., 2013. Retrofits and options for the alternatives to HCFC-22. *Energy*, 59, pp.1–21.

Zaghdoudi, C. et al., 2010. A comparative study on the performance and environmental characteristics of R410A and R22 residential air conditioners for Tunisian Market. *Journal of Environmental Science and Engineering*, 4(12), pp.37–56.