

## Effects of refrigerant circuiting of fin-and-tube condenser on performances of an inverter air conditioner using ozone-friendly refrigerants as alternatives to R-22

Pongsakorn Sarntichartsak<sup>1,\*</sup>, Pongsakorn Kaewcholkram<sup>1</sup>, Sirichai Thepa<sup>2</sup>

<sup>1</sup>Faculty of Sciences and Industrial Technology, Prince of Songkla University, Surat Thani, Thailand

<sup>2</sup>School of Energy, Environment and Materials, King Mongkut 's University of Technology Thonburi, Thailand

### Abstract:

*This paper presents the investigation of the proper refrigerant circuiting in the finned tube condenser for an inverter air conditioner. The experimental study was carried out with four coil configurations using R-22, R-407C, R-417A, R-404A and R-507 under a variety of refrigerant flow conditions. The test results indicate that refrigerant path arrangement affects the performance of variable capacity system significantly. The efficiency of retrofitted system could be improved by using the inner-split configuration with R-417A for a wide range of frequency, although Z-type path and upstream-split configurations would give better performances at low and high ranges of frequency, respectively. The finned-U tube models were developed using tube-by-tube and segment-by-segment algorithms comparatively. The simplified model with tube-by-tube method can predict capacities with acceptable accuracy level.*

**Keywords:** alternative refrigerant; condenser; inverter; modeling; refrigerant path arrangement

\*Corresponding author. Tel./Fax: +77-355-453

E-mail address: pongsakorn111@hotmail.com

### 1. Introduction

A finned tube condenser is one of the main components in refrigeration system. A lot of factors have significant influence on the performances (Liang et al., 2000). Presently, the inverter system is widely used to regulates the compressor rotation continuously matches to the load (Sarntichartsak et al., 2007). Hence, the proper circuiting arrangement of condenser coil under a wide range of refrigerant flow rate is interested. As well known, refrigerant R-22 is controlled substance under the Montreal Protocol. Therefore, the objectives of this study are to examine the proper refrigerant circuiting in condenser using R-407C, R-417A, R-404A and R-507 for the existing R-22 inverter air conditioner experimentally, and to develop the heating coil model especially for the operation under a wide range of flow rate. To simplify the problem, four most commonly used circuiting of upstream-split type (Liang et al., 2000), inner-split type (Liang et al., 2000; Kuo et al., 2006), Z-type type (Liang et al., 2000; Wang et al., 1999; Lee et al., 2002; Kuo et al., 2006) and U-type (Wang et al., 1999; Lee et al., 2002; Kuo et al., 2006) are considered.

### 2. Experimental setup and procedure

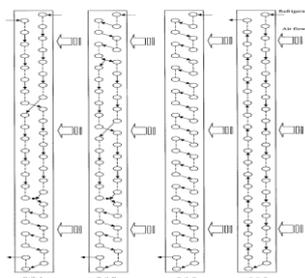
The air conditioner with 4-type circuitries using R-22, R-407C, R-417A, R-404A and R-507 as working fluids was tested. The tested air conditioning was carried out corresponding to the ASHRAE test condition "A". The frequency ( $f$ ) was varied from 30 to 90 Hz. For the mathematical modeling, the tube-by-tube and segment-by-segment methods were used to build the simulation models comparatively. Four circuitries were designed by the simulation tool, as shown in Fig. 1.

### 3. Description of the model

The condenser can be divided into various small control volumes thus the total capacity is calculated by summing the heat transfer rate of each region. The number of transfer unit (NTU) and effectiveness ( $\epsilon$ ) method is used to analyze the heat exchangers for numerical calculation.

The condensation of heat transfer coefficients (HTC) for R-22 and ternary mixtures (R-407C and R-417A) are calculated by Sami et al.'s correlation (1995) and Goto et al.'s correlation (1995), respectively. Sami and Fontaine (2000)'s correlations are used for R-404A and R-507.

The air-side HTC ( $h_a$ ) are often expressed in term of the Colburn  $j$  factor. Therefore, it can be calculated from the proposed equations that given by Madi at al. (1998). The average value of inlet and outlet air temperature ( $T_{a,i}$ ,  $T_{a,o}$ ) is used to evaluate the thermal properties of moist air.



**Fig. 1** The path configurations: (a) upper-split, (b) inner-split, (c) nearly Z-type, (d) U-type.

#### 4. Simulation procedures

In this study, the tube-by-tube and segment-by-segment methods were used to build the simulation models comparatively. The segment-by-segment model can be reduced to the tube-by-tube model by extending a length of segment to the entire length of coil. The phase change interface can be identified by checking the outlet enthalpy of refrigerant with saturated enthalpies of vapor and liquid along tube. Although Ding et al. (2011) proposed the binary search method for seeking the phase change interface. In this study, the efficacious method of Fibonacci search was adopted to find the interfacing position (Stoecker, 1989). It should be noted that the phase change interface of the tube-by-tube approach can be investigated similarly to the section-by-section model. For the whole coil simulation, the summation of capacities for all elements is obtained.

#### 5. Results and discussion

##### 5.1 Comparison of heating capacities

For the conventional system, R-22 with Coil A gives maximum capacities of 6.51, 6.95 and 7.24 kW with frequencies of 70, 80 and 90 Hz, respectively, as shown in Fig. 2. Due to refrigerant flow rate and overall HTC are highest compared to other configurations. When the frequency is decreased to 50 and 60 Hz, Coil B gives the maximum capacities of 5.31 and 5.87 kW, respectively. At low frequency, it can be seen that higher overall HTCs can be obtained by the single-path configurations (Coil C and D) give higher capacities because overall HTCs are higher.

For the retrofitted refrigerant, the capacities for R-507 are the highest, due to highest mass flow rates, greatest overall HTCs and higher mean temperature difference are obtained.

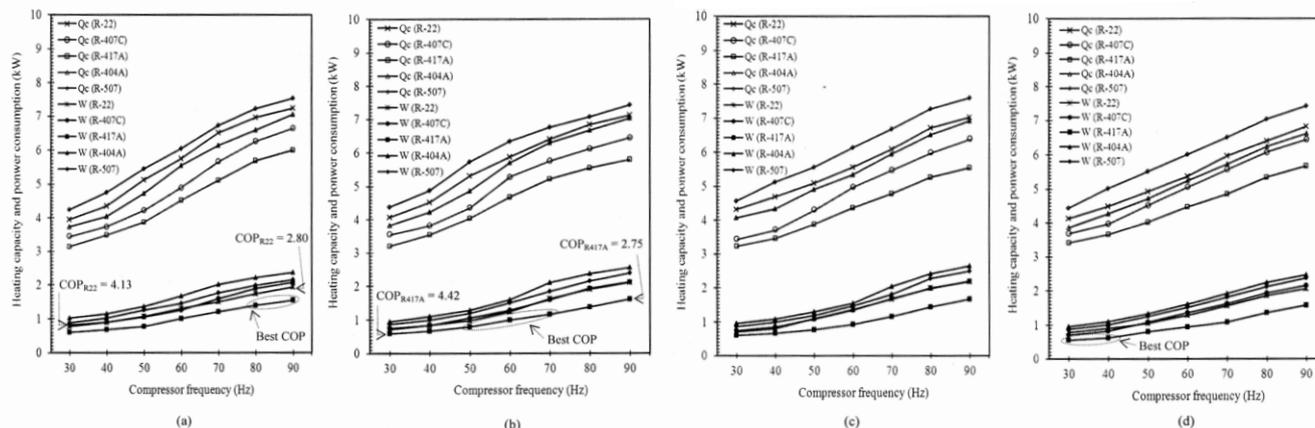
In Fig. 2(b), Coil B gives the best capacities with moderate frequency. Moreover, its capacities are gradually increased and decreased with increasing and reducing frequency, respectively. Fortunately, the highest capacity ranges of R-507 and R-417A with Coil B can be extended to 5.74–6.76 and 4.04–5.23 kW, respectively, in the frequency ranges of 50–70 Hz.

From Fig. 2(c), it can be seen that Coil C using R-507 gives maximum capacities of 4.57 and 5.13 kW, which are higher than Coil D, for frequencies of 30 and 40 Hz, respectively. Due to better temperature matching and refrigerant flow are obtained. The results also show that capacities of R-22 and R-404A can be also improved by Coil C at low frequency similar to R-507.

The tendencies of R-407C and R-417A with Coil A and B are similar to R-22 except with Coil D at low frequency, as presented in Fig. 2(d). The capacities of Coil D using R-407C and R-417A are higher than with Coil A about 4.8–7.5 and 5.6–6.1% under frequency ranges of 30–50 and 30–40

Hz, respectively. It can be concluded that the performances of zeotropic blends can be improved by U-type path circuiting, due to appropriate temperature matching are occurred.

The tendency of R-404A is similar to R-22. Fig. 2(d) also shows that Coil D using R-404A gives the worst performances under a wide range of frequency.



**Fig. 2** Comparisons of heating capacity ( $Q_c$ ) and power consumption ( $W$ ) versus compressor frequency of variable capacity system using (a) Coil A (b) Coil B (c) Coil C and (d) Coil D.

## 5.2 Comparison of power consumptions and energetic efficiencies

As seen in Fig. 2, the power consumption of R-22 is the lowest, although it has refrigerant flow rate higher than R-407C, however, the pressure ratio and suction pressure are the lowest.

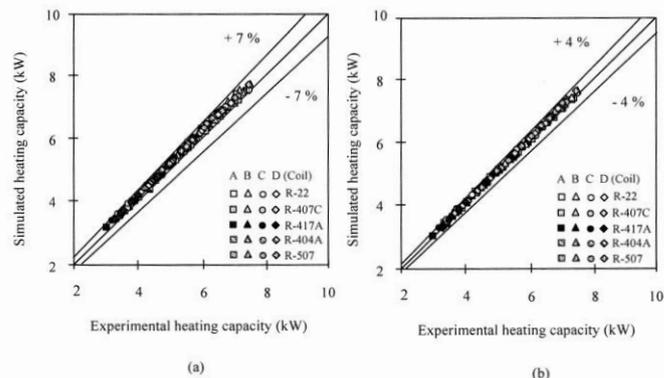
For the mixtures of R-407C and R-417A, Coil A give higher and lower power consumptions than R-22 about 5.7–7.9 and 22.5–24.5%, respectively, at high frequency range of 80–90 Hz. At low frequency, Coil D gives higher capacities compared to Coil C while the power consumptions seem to be similar. Therefore, Coil D using zeotropic blends give highest performances compared to other configurations as seen in Fig. 2(d).

For the azeotropic mixture, the power consumptions of Coil A using R-507 are higher than R-407C, R-22 and R-417A, respectively. Hence, it has COPs of 2.60 and 2.46, which are lower than R-22 and R417A with frequencies of 80 and 90 Hz, respectively, although the capacities are the highest. However, the tendency of R-507 is similar to R-22 at low frequency.

For the near-azeotropic mixture, although R-404A obtains higher capacity than the zeotropic mixtures, however, the highest pressure ratio and higher flow rate causes to the highest power consumption, consequently, the lowest COP is occurred under a wide range of frequency. Hence, it is not suggested as retrofitted fluid for this system.

## 5.3 Comparison of simulation models

The comparisons of experimental and simulated capacities are shown in Fig. 3. The simplified model and section-by-section model tend to over-predict and slightly over-predict which have the results agree within  $\pm 7\%$  and  $\pm 4\%$  accuracies, respectively. The experimental and simulation results are in good agreement with the segment-by-segment model due to it is able to predict non-uniform air distribution and local refrigerant condition.



**Fig. 3** Comparison of experimental and simulated of heating capacity ( $Q_c$ ): (a) tube-by-tube procedure and (b) segment-by-segment approach.

## 6. Conclusion

The results can be concluded as follows: (1) The performances of upstream-split configuration are higher than other coils at high frequency. However, there are degraded than those at lower frequency. (2) The inner-split configuration has the advantage of higher efficiency improvement at moderate frequencies. It is suggested to reduce the sudden decrease in the performances. This configuration using R-417A is suggested as an efficient and environmentally acceptable option. (3) To improving the overall energetic performance under low flow rate, the single path configurations are used. However, the performances are rapidly degraded at higher frequency. (4) The U-type path configuration is suggested for R-407C and R-417A at low frequency (5) The tube-by-tube modeling approach has been found to suitably predict the experimental results.

## 7. References

- Madi, M.A., Johns, R.A., and Heikal, M.R. 1998. Performance characteristics correlation for round tube and plate finned heat exchanger. *International Journal of Refrigeration* 21(7): 507–517.
- Ding, W.K., Fan, J.F., He, Y.L., Tao, W.Q., Zheng, Y.X., Gao, Y.F., and Song, J. 2011. A general simulation model for performance prediction of plate fin-and-tube heat exchanger with complex circuit configuration. *Appl. Therm. Eng.* 31: 3106–3116.
- Goto, M., Inoue, N., and Koyama, K. 1995. Condensation heat transfer of R-22 and its alternative refrigerants inside an internally grooved horizontal tube (pp. 254–260). *Proceedings of the Nineteen International Congress on Refrigeration. The Hague 4a*.
- Kuo, M.C., Ma, H.K., Chen, S.L., and Wang, C.C. 2006. An algorithm for simulation of the performance of air-cooled heat exchanger applications subject to the influence of complex circuitry. *Applied Thermal Engineering* 26: 1–9.
- Lee, J.H., Bae, S.W., Bang, K.H., and Kim, M.H. 2000. Experimental and numerical research on condenser performance for R-22 and R-407C refrigerants. *International Journal of Refrigeration* 25: 372–382.
- Liang, S.Y., Wong, T.N., and Nathan, G.K. 2000. Study on refrigerant circuitry of condenser coils with exergy destruction analysis. *Applied Thermal Engineering* 20: 559–577.
- Sami, S.M., Tulej, P.J., and Song, B. 1995. Study of heat and mass characteristics of ternary nonazeotropic refrigerant mixtures inside air/refrigerant-enhanced surface tubing. *ASHRAE Transaction* 101(1): 1402–1411.
- Sami, S.M., and Fontaine, M. 2000. Prediction of condensation characteristics of alternatives to R-502 inside air-refrigerant enhanced surface tubing. *Applied Thermal Engineering* 20: 199–212.
- Sarntichartsak, P., Monyakul, V., and Thepa, S. 2007. Modeling and experimental study on performance of inverter air conditioner with variation of capillary tube using R-22 and R-407C. *Energy Conversion and Management* 48: 344–354.

- Wang, C.C., Jang, J.Y., Lai, C.C., Chang, Y.J. 1999. Effect of circuit arrangement on the performance of air-cooled condenser. *International Journal of Refrigeration* 22: 275–282.
- Stoecker, W.F. 1989. *Design of thermal systems*. Malaysia: McGraw-Hill.