

## Investigation of appropriate refrigerant circuiting of fin-and-tube evaporator in an inverter air conditioner using ozone-friendly refrigerants as alternatives to R-22

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### Abstract:

*In this study, the effects of evaporator circuiting on the system performance of inverter air conditioner were investigated. Four evaporator configurations were tested using R-22, R-407C, R-417A, R-404A and R-507. The experimental results indicate that although the refrigerant circuiting is almost arranged properly with counter-cross flow configuration, however, the performance of R-407C and R-417A coils could be improved by parallel-cross flow configuration. This result is somewhat smaller at a low range of frequency. The two-circuit coil gives the maximum improvement in COP with lowest frequency. The three-inlet two-outlet configuration using R-417A can be properly used as substitute for the conventional configuration with R-22 under a wider range of frequency. This work also developed the improved models using tube-by-tube and segment-by-segment algorithms that are applicable to evaporator with complex circuitry under a wide range of refrigerant flow rate. The tube-by-tube- method has been found to suitably predict the experimental results.*

**Keywords:** alternative refrigerant; evaporator coil; path arrangement; modeling; variable capacity

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### 1. Introduction

A fin and tube evaporator is one of the main components in refrigeration system. The optimal coil design is complicated by a number of factors (Liang et al., 2001). Generally, the conventional air conditioner is designed and rated to satisfy the maximum load. However, the actual cooling load may vary during a day/year practically. Presently, an inverter is widely used to regulate the compressor rotation continuously matches to the load (Sarntichartsak et al., 2006). Therefore, the appropriate refrigerant path arrangement of evaporator for inverter air conditioner is interested. To effectively coil evaluation, the simulation program that able to consider most factors. As well known, the ozone layer depletion and global warming are still one of the main environment problems. Since R-22 contain chlorine, which is the cause of ozone depletion. In this study, R-407C, R-417A, R-404A and R-507 have been investigated as substitutes for R-22. Note that the comparison of the performance prediction using tube-by-tube procedure (Ding et al., 2011) and segment-by-segment approach (Kuo et al., 2006) with the improved identification of phase-change interface was also carried out. To simplify the problem, the typical four-type refrigerant circuiting of counter-cross flow type (Lee et al., 2003; Byun et al., 2007; Singh et al., 2008; Ge and Cropper, 2009), parallel-cross flow type (Lee et al., 2003; Byun et al., 2007), two circuits-type (Domanski et al., 2005) and half-circuit split type (Liang et al., 2001; Domanski et al., 2005) are considered.

### 2. Experimental setup and procedure

The inverter air conditioner with four evaporator circuitries using R-22, R-407C, R-417A, R-404A and R-507 were tested. The test was carried out corresponding to the ASHRAE test condition "A". The compressor frequency ( $f$ ) was varied from 30 to 90 Hz. The optimized circuitries are primarily performed by the proposed segment-by-segment procedure. Therefore, the configurations of three-circuit counter-cross (Coil A), three-circuit parallel-cross flow (Coil B), two-circuit counter-cross (Coil C) and two-inlet three-outlet (Coil D) were obtained as shown in Fig. 1.

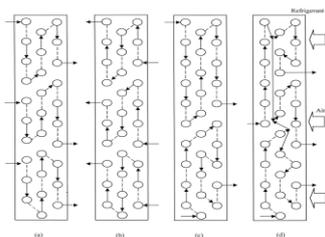
### 3. Description of the model

The number of transfer unit and effectiveness (NTU- $\epsilon$ ) method is used to analyze the heat

exchangers for numerical calculation. The evaporator coil was divided into a number of small and controllable volumes thus the total capacity was calculated by summing the heat transfer rate of each control volume.

The air-water film heat transfer coefficient (HTC) ( $h_{a,w}$ ) is calculated from the well known equation (Myers, 1967). The wet fin efficiency ( $\eta_{f,wet}$ ) is calculated from the correlation that was given by McQuiston and Parker (1994).

The evaporation HTCs ( $h_e$ ) can be calculated with the correlations that given by Yun et al. (2002) for R-22. The Choi et al. correlation (2000) was selected for the zeotropic mixtures (R-407C and R-417A). Sami and Desjardins (2000)'s correlations are used for R-404A and R-507.



**Fig. 1** The circuiting of finned tube evaporator: (a) Coil A, (b) Coil B, (c) Coil C, and (d) Coil D.

#### 4. Simulation procedures

In this work, two computation algorithms of the tube-by-tube procedure and the segment-by-segment approach were implemented comparatively. The identification of the phase change interface was also carried out. The efficacious method of Fibonacci search is adopted to find the interfacing position (Stoecker, 1989).

The defined division of finned tube is simulated with the appropriate algorithm. The new outlet values on refrigerant side and air side are determined. The comparison of new values with previous values is performed. If those differential values are higher than the minimally differential value, then repeating the procedure. This process is continuously carried out until the differential value is lower than defined value. Each control volume is numbered along tube. Finally, the summation of capacities ( $Q_e$ ) for all elements can be obtained.

#### 5. Results and discussion

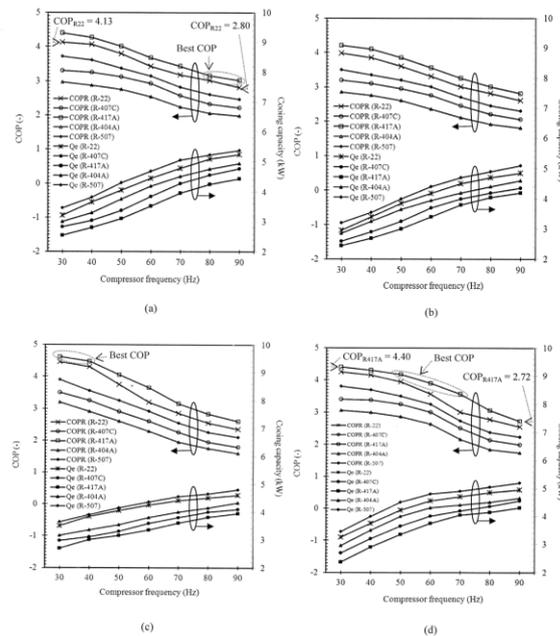
##### 5.1 Comparison of performances

As shown in Fig. 2(a), Coil A using R-417A obtains the maximum COPs of 3.15 and 3.01, although R-507 obtains the maximum capacities of 5.24 and 5.38 kW with frequencies of 80 and 90 Hz, respectively. This is because the azeotropic mixture has greater power consumption. Moreover, although R-404A obtains higher capacity than the zeotropic mixtures, however, the highest power consumption causes to lowest COP.

Typically, the refrigerant circuits are almost arranged with counter-cross flow configuration. For R-407C, the parallel-cross flow arrangement of Coil B obtains COP closed to Coil A at low frequency as showed in Fig. 2(b). The zeotropic blend obtains the lower capacities compared to R-507, R-22 and R-404A, respectively, due to lowest mass flow rate, highest pressure drop and negative effects of temperature glide.

From Fig. 2(c), although Coil C obtains higher log-mean temperature difference owing to lowest suction pressure at a highest frequency, however, the lowest capacity is occurred due to lowest refrigerant flow rate. Fortunately, Coil C gives the maximum improvement in COP with low

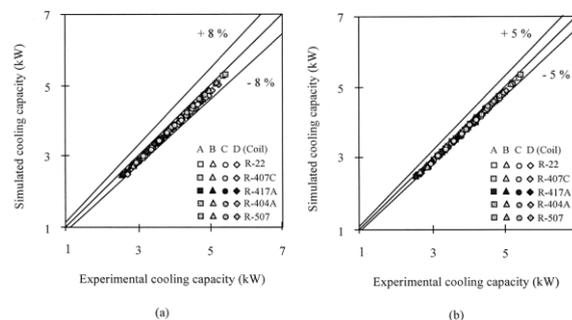
frequencies. At this point, R-417A gives highest COP of 4.62 and 4.48 at 30 and 40 Hz, respectively. In Fig. 2(d), Coil D gives the moderate performances under a wider range of frequency. Due to two-upstream tubes obtain higher refrigerant velocity, consequently, the local HTC's are expected to increase then the capacities are higher than those of three circuit configurations. It can be seen that Coil D using R-417A gives the appropriate efficiencies under wider range of frequency. It should be noted that the COPs of R-417A with Coil D are higher than R-22 with Coil A about 6.54–1.32% for frequencies of 30-80 Hz.



**Fig. 2** Comparisons of COPs and cooling capacities ( $Q_c$ ) versus compressor frequency of the variable capacity system using (a) Coil A (b) Coil B (c) Coil C and (d) Coil D.

### 5.2 Model verification

Fig. 3 shows the comparisons of experimental and simulated of cooling capacities. The tube-by-tube and segment-by-segment models tend to under-predict and slightly under-predict, respectively. Because of the air-side HTC was correlated with uniform air flow, however, it not uniformly distributed over the coil surface in this study, and the average evaporating temperature is slightly over-predicted. The results agree to within  $\pm 8\%$  and  $\pm 5\%$  accuracies for the tube-by-tube model and the section-by-section approach, respectively.



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

### 6. Conclusion

The results can be concluded as follows: (1) The performances of the three-circuit counter-cross configuration are higher than those at a high range of frequency. (2) The three-circuit parallel-cross

flow configuration using R-417A and R-407C has the closed performances to that are obtainable with the counter-cross arrangement especially at low frequencies. (3) The two-circuit counter-cross flow configuration has the advantage of energetic efficiencies improvement at low frequency. (4) It can be concluded that the two-inlet three-outlet configuration is suggested to reduce the sudden change in the performances. (5) The predicted values of capacities were agreed with the experimental data within the maximum error of 8 and 5% for the tube-by-tube and segment-by-segment modeling approaches, respectively.

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