A numerical simulation of fluid flow of Refrigeration R32 in annular pipe

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Abstract. To increase the performance of Air conditioning it is needed to propose any modifications. One of the potential modification is installing internal heat exchanger which is typically an annular pipe. The objective of this study is to explore fluid flow and heat transfer characteristics of Refrigerant R32 in an annular pipe heat exchanger. The fluids flow in the inner annulus is hot fluid and the cold-water flows in the outer annulus. In this study, CFD model is developed which is solved using ANSYS Fluent and validated with the previous available data, the dimension of annulus internal heat exchanger for heat fluid diameter of 6.35 mm. The working pressure and temperature are 290 psi and 32.5°C, respectively. While the cold fluid flows at annular with outer diameter of 9.525 mm and working pressure and temperature are 90 psi and -8°C, respectively. In addition, the external diameter is 19.05 mm, the direction of the fluids is a counter flow between hot and cold fluids for the numerical simulation. The fluid flow characteristics are plotted and the heat transfer rates are examined.

1. Introduction

A heat exchanger is a device that can be used to transfer the heat from one fluid flow to the other fluid flow. The heat exchanger is now being used in many industrial applications such as power plant, drying, food industry, air conditioning, etc. In the air conditioning system, vapor compression cycle is typically used to provide refrigeration. The vapor compression cycle, at least, consists of compressor, condenser, evaporator, and expansion device. Here, the condenser and evaporator are categorized as heat exchanger. The flows consist of refrigerant inside the tube and air on the outer surface. The vapor compression cycle consumes significant amount of energy. Thus, many researchers have focused their research on the improvement of vapor compression cycle.

One of the promising devices that can be used to improve the performance of a vapor compression cycle is internal heat exchanger. Studies on the effect of internal heat exchanger to the performance of a vapor compression cycle have been found in literature. Navarro-Esbri et al. [1] reported an experimental analysis of the internal heat exchanger influence on a vapor compression system performance working with R1234yf as a drop-in replacement for R134a. A total of 36 steady-state tests have been obtained for analyses. The results show that cooling capacity and COP decreasing between 6% and 13% when the refrigerant R1234yf is used to replace R134a. Installing internal heat exchanger can help to lessen these reductions between 2% to 6%. Mota-Babiloni [2] analyzed drop-in of an internal heat exchanger in a vapor compression system using R1234ze(E) and R450A as alternatives for R134a. The results
show that internal heat exchanger has a positive impact on the energy efficiency for all tested refrigerants. The COP (coefficient of performance) gain using R1234ze(E) is the highest observed (overcomes the R134a COP for the same conditions). The R1234ze(E) and R450A discharge temperature increments are lower than those of R134a so does not reach dangerous values and the IHX pressure drops are also below that of R134a. Llopis et al. [3] investigated the effect of internal heat exchanger at low temperature cycle in a cascade refrigeration plat. The cascade refrigeration plant consists of R134a and CO₂ subcritical cycle. The results reveal that internal heat exchanger slightly reduce the cooling capacity but it can increase the total COP up to 3.7%. Recently, Ambarita [4] reported an experimental study on a modified air conditioning system where an internal heat exchanger was installed to the system. The compressor capacity of the tested system was 1 horse power. The results show that refrigeration effect of the modified system is higher than the original one in order of 3.6%. In addition, the work of compressor of the modified system was 12.5% higher than the original one and the COP system was 11.7% higher. It was shown that combination internal heat exchanger and condenser precooling shows positive impact on the performance of the air conditioning system [5 – 9].

The literatures show that study on the internal heat exchanger in a vapor compression cycle can be viewed in many aspects. It can be from the effect of the different refrigerant, effect of different system and also combination with others device. The objective of this study is to explore fluid flow and heat transfer characteristics of Refrigerant R32 in an internal heat exchanger of a vapor compression cycle. The internal heat exchanger is an annular pipe heat exchanger. The fluids flow in the inner annulus is hot fluid and the cold-water flows in the outer annulus. The results are expected to supply the necessary information in development high performance vapor compression cycle.

2. Methods
In our laboratory, we have developed an experimental equipment related to modification of vapor compression cycle in an air conditioning unit. In this study, the internal heat exchanger in the modified vapor compression cycle is analysed numerically. The internal heat exchanger is categorized as annulus type heat exchanger. The dimensions are inner diameter and outer diameter is 6.35 mm and 9.35 mm, respectively. The flow in the heat exchanger is counter flow type. The Ansys Fluent commercial code computational fluid dynamic is employed. In the numerical method, the governing equations are firstly developed. They are mass conservation, momentum equation and energy equation. The governing equations are presented below.

\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0
\]

\[
\frac{\partial}{\partial t} [(\rho \vec{v}) + \nabla \cdot (\rho \vec{v} \vec{v})] = - \nabla p + \rho \vec{g} + \vec{f}
\]

\[
\frac{\partial}{\partial t} [\rho e] + \nabla \cdot ([(\rho e + p) \vec{v}]) = \nabla (k_{\text{eff}} \nabla T - \sum_j h_j \vec{J}_j) + (\tau_{\text{eff}} \cdot \vec{v})
\]

In those equations, parameter \(t\), \(\rho, \vec{v}\), and \(p\) is time, mass density, vector velocity and pressure respectively. In addition, the parameter \(e, \vec{f}, k_{\text{eff}}\) and \(h_j\) is internal energy, body force, thermal conductivity effective and enthalpy of \(j\) species, respectively. The flux diffusion of \(j\) species is shown by \(\vec{J}_j\) and \(\tau_{\text{eff}}\) is the representation of tensor stress.

The above equations are discretized using first order up-wind scheme. The velocity field and pressure field are coupled with SIMPLE algorithm. In the simulation, the boundary values are as follows. The flow inside the inner tube has inlet pressure and temperature of 290
psi and 32.5°C, respectively. On the other hand, flow in annulus has the pressure and temperature of 90 psi and -8°C, respectively. Figure 1(a) and figure 1(b) shows the internal heat exchange model and the meshing, respectively. The model is developed using Ansys design modeler and meshing is employed to divide computational domain into mesh. The refined mesh method is employed to improve the quality of the mesh closed to solid domain where the fluid is predicted has high velocity gradient. Here, the number of node and element is 162946 and 305375, respectively. The properties of fluid are drawn from the thermal properties provided by the Ansys Fluent. The working fluid is Refrigerant R23.

![Model and meshing](image)

**Figure 1.** The model and meshing of the internal heat exchanger

3. **Results and Discussions**

As a note, in this study the type of the internal heat exchanger consists of two small pipes inside the third pipe which has bigger diameter. Figure 2 shows the pressure distribution in the internal heat exchanger. It can be seen that the pressure is relatively higher in the inlet and decrease gradually to the outlet. On the other hand, the pressure int the refrigerant at lower temperature is lower that at higher temperature.

![Pressure distribution](image)

**Figure 2.** Pressure distribution in the internal heat exchanger
Figure 3. Streamlines in the internal heat exchanger

Streamlines in the heat exchanger is shown in figure 3. The flow in the annulus dominated by blue lines and in the small tube by green lines. This figure can used to estimate the flow characteristics within the heat exchanger. Figure 4 shows the temperature distribution within the internal heat exchanger. In the heat exchanger the highest and the lowest temperature is 32.5°C [305.5 K] and -8°C [261 K], respectively. The temperature distribution varies between these values.

Figure 4. Temperature distribution in the internal heat exchanger

Heat transfer characteristics of the internal heat exchanger had been calculated using the temperature distribution. The total heat transfer between two streams is 165.61 Watt.

4. Conclusions
Computational fluid dynamics has been used to simulate fluid flow of an internal heat exchanger of a vapor compression cycle. The results show that the developed method can be used to estimate the fluid flow and heat transfer characteristics within the internal heat exchanger. It is suggested to use the method to design a high performance internal heat exchanger that can be used to improve the performance of a vapor compression cycle.

5. References
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