Numerical simulation of fluid flow and heat transfer in enhanced copper tube

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Abstract. Inner grooved tube is enhanced with grooves by increasing the inner surface area. Due to its high efficiency of heat transfer, it is used widely in power generation, air conditioning and many other applications. Heat exchanger is one of the example that uses inner grooved tube to enhance rate heat transfer. Precision in production of inner grooved copper tube is very important because it affects the tube’s performance due to various tube parameters. Therefore, it is necessary to carry out analysis in optimizing tube performance prior to production in order to avoid unnecessary loss. The analysis can be carried out either through experimentation or numerical simulation. However, experimental study is too costly and takes longer time in gathering necessary information. Therefore, numerical simulation is conducted instead of experimental research. Firstly, the model of inner grooved tube was generated using SOLIDWORKS. Then it was imported into GAMBIT for healing, followed by meshing, boundary types and zones settings. Next, simulation was done in FLUENT where all the boundary conditions are set. The simulation results were observed and compared with published experimental results. It showed that heat transfer enhancement in range of 649.66% to 917.22% of inner grooved tube compared to plain tube.

1. Introduction
Inner groove tube has become more popular because its heat transfer efficiency can be increased by 20-30% and energy can be saved up to 15% as compared to the traditional plain tube. This inner groove tube is usually used in air conditioning which requires high efficiency of heat transfer and low energy consumption [1]. Tube parameters that involved are geometry of inner grooved shape, type of refrigerant, fin height, tube wall thickness, apex angle and helix angle [2]. Several studies have been done by previous researchers on the effect of the parameters of inner grooved tube to heat transfer rate in order for them to optimize the heat transfer performance. Kadir et al [3] studied relationship between different types of grooved tubes and surface heat transfer using fully developed turbulent air flow. The grooved tubes used in this experiment were circular, trapezoidal and rectangular. Parameters such as length of tube, diameter of tube and Reynolds’s number for the fluid flow were fixed in this experiment so that they wouldn’t affect the results of heat transfer enhancement. From

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the experimental results using smooth tube as the comparison, heat transfer enhancement showed 63% for circular groove, 58% for trapezoidal groove and 47% for rectangular groove.

Akio et al [4] conducted an experiment to determine the effects of fin height and helix angle on condensation inside a herringbone micro-finned tube by using R410 as refrigerant. They stated that herringbone micro-finned tube is able to increase the heat transfer coefficient 2 to 4 times compared to the conventional helical micro-finned tube. The highest heat transfer can be achieved by 0.18 mm; any higher fin would get the same heat transfer enhancement at fin height of 0.18 mm but it would result in increasing of pressure drop. Chamra et al [5] conducted research of R22 condensation of heat transfer and pressure drop for single grooved tube and cross-grooved tube with outer diameter of 15.88 mm and mass flow rate of 45181 kg/h. The parameters set for single-grooved are internal fins of 74-80, 0.35 mm fin height, and 30° fin included angle whereas for cross-grooved tube, it has two sets of grooves where first set is the same as the single grooved with the same helix angle and second set was the opposite angular direction as the first set. Data was collected for the condensation at 24.0°C in a 2.44 m long test section. Throughout the research, they found out that R22 condensation heat transfer performance in cross-grooved tube is higher as compared to single-grooved tube. They also reported that cross-grooved tube has the highest heat transfer performance at helix angle of 27°. Other than that, Uchida et al [6] also did an experiment to study the evaporative and condensation heat transfer performance on R407C on smooth tube, single-grooved tubes and cross-grooved tubes. The results showed that cross-grooved tube heat transfer coefficients are three times and 20-40% higher than the other two.

Investigation in heat transfer and pressure drop characteristics in a spirally grooved tube with and without twisted tape insert using water as the medium was done by Bharadwaj at al [7]. By comparing with the normal smooth tube, they found that the spirally grooved tube without twisted tape is able to achieve maximum heat transfer enhancement up to 400% in the laminar range and 140% in the turbulent range by supplying constant pumping to the tube. Colombo et al [8] did an investigation on flow boiling and convective condensation for oil-free R134 with three tubes which are two micro-finned tubes and a plain tube. This experiment operated horizontally and the tubes were cooled or heated using water stream. The micro-finned tubes’ specifications were set to have fins with an apex angle of 40° and fin number of 54 and 82, respectively. For evaporative conditions, it was set to have 5°C nominal temperature and 0.2941 kg/m²s mass flux whereas for condensation condition, the nominal temperature of 35°C and mass flux of 0.2273 kg/m²s were set. During the experiment, average heat transfer coefficient were monitored and measured. In comparison between two micro-finned tubes and plain tube, it showed that micro-finned tubes has higher heat transfer coefficient for both evaporative and condensation processes. However, differences showed between these two micro-finned tubes when in condensation process. A micro-finned tube with smaller number of fins showed a better performance than that in micro-finned with larger number of fins.

It can clearly be observed from the overview above that all the research works reported are conducted experimentally to evaluate the performance of enhanced tubes. Development of experimental facilities is very tedious and expensive at the same time running the experimentation is also time consuming hence there is a need to evaluate the performance of enhanced tube through numerical simulation. Therefore, the objective of this paper is to report the outcomes of a numerical simulation study in evaluating the heat transfer characteristics of inner grooved copper tube.

2. Methodology

2.1. Model generation

SOLIDWORKS was used in modelling inner grooved tube. The specifications of the inner grooved tube are taken according to previous researcher [2] in order to validate the model. Modification has been done to the length of the tube whereas it has been reduced from 3.67 m to 0.5 m and number of grooves from 50 grooves to 40 grooves. These modifications are due to limitation of computer facility.
and time. Tube specifications are as shown in Table 1 and the model of inner grooved tube is shown in Figure 1.

| Tube parameter                  | Value  |
|---------------------------------|--------|
| Outer diameter, \(d_o\)         | 7.00 mm|
| Inner diameter, \(d_i\)         | 6.50 mm|
| Groove height, \(h\)            | 0.21 mm|
| Bottom wall thickness, \(bwt\)  | 0.25 mm|
| Total wall thickness            | 0.46 mm|
| Apex angle, \(\gamma\)         | 40.00° |
| Helix angle, \(\alpha\)        | 18.00° |

Table 1. Specifications of enhanced tube.

Figure 1. Model of inner grooved tube

2.2. Computational Fluid Dynamics (CFD) Simulation

The working fluids for this simulation were water and refrigerant R22 where the heat exchanger was counter flow (water and refrigerant flow in opposite direction) as shown in Figure 2.

Figure 2. Schematic diagram of counter flow heat exchanger (a) condensation (b) evaporation

3. Results and Discussion

The pressure contours and pressure drop in enhanced tube are shown in Figure 3. It is evident that the pressure drop in refrigerant region is much higher compared to the water region.

Figure 3. Pressure contours and pressure drop in enhanced tube (a) pressure contour (b) pressure drop
It can be observed (Figure 3b) that there is a drastic drop in pressure (starting from right side) for the first 50 mm (450 mm-500 mm) which is due to the existence of grooves inside the tube. This phenomenon occurred because of friction between the working fluid and inner tube surface. As the friction increases, the resistance of working fluid to move along the tube increases. The pressure after the drastic drop is very low. Hence, it is assumed to be no pressure change afterward.

A total of four cases were simulated and the results are shown in Table 2. The results are also compared with experimental results reported in [2]. The differences are in the range of 9.43% to 11.87%. Theoretically, the total heat transfer coefficient should be higher in simulation because in simulation it is assumed that the tube is well insulated and no heat loss to the surrounding.

| Cases | Overall heat transfer coefficient, $U_0$ (W/m².K) |
|-------|-------------------------------------------------|
|       | Experiment [2] | Simulation | Difference (%) |
| 1     | 2511            | 2212.87    | 11.87          |
| 2     | 2696            | 2574.25    | 4.51           |
| 3     | 2211            | 2425.60    | 9.70           |
| 4     | 3543            | 3877.11    | 9.43           |

4. Conclusions
Flow of refrigerant (R22) through enhanced copper tube for two different conditions, i.e., condensation and evaporation was simulated by CFD and the results were compared with published experimental results. The overall heat transfer coefficient of enhanced tube is found to be higher compared to plane tube. A moderately good agreement was observed between simulation and experimental results.

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