Numerical Investigation of Flow behavior and Heat Transfer Characteristics inside Herringbone Microfin Tube

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Abstract
A numerical investigation is carried out for single phase flow behavior and heat transfer characteristics inside herringbone microfin tube by using a commercial CFD code FLUENT. It solves the three-dimensional Navier-Stokes equations in strong conservation form. Turbulence closure is provided by the standard k-ε turbulent model with enhance wall treatment. Numerical results showed that herringbone microfins generated four circulation flows in the tube's cross-section, where flow is accumulated from the core region to the wall in fin-diverging portion and moved away from the wall in fin-converging portion. Flow around the microfins is complicated and it affects local friction factor distribution. These cross-sectional flow behaviors play a significant role in heat transfer enhancement.

Keywords – Numerical investigation, Flow behavior, Heat transfer characteristics, Herringbone microfin tube.

1. INTRODUCTION
Herringbone microfin tubes are used in evaporator and condenser of refrigeration system due to its higher heat transfer coefficient over helical microfin tube and smooth tube. In herringbone microfin tube, trapezoidal shape microfins are installed inside of the tube in such a way that they form multi-V-shape in the flow direction, where fluid is removed and collected by the fins. Ebisu et al. [1] showed that herringbone micrfin tube provided approximately 90% higher heat transfer coefficient than that of helical microfin fin tube in evaporation and 100 to 200% higher in condensation. Miyara et al. [2] performed experimental investigation of various herringbone micrfin tubes and showed that tubes with larger helix angle provided higher heat transfer and pressure drop than that of smaller helix angle tube. Islam and Miyara [3] experimentally investigated the flow behavior inside herringbone microfin tubes and explained the heat transfer enhanced mechanism. Their investigation showed that herringbone fins can diverge and converge the liquid film and these actions are effected by helix angle, mass velocity and quality. Also droplet flow rate played an important role in heat transfer enhancement. However, it is difficult to observe the flow behavior inside herringbone microfin using experimental techniques. On the other hand, numerical technique is a useful technique to investigate the internal flow behavior. In order to explain the flow behavior and heat transfer characteristics inside herringbone microfin tube a numerical investigation is performed and results are explained in this paper.

2. NUMERICAL METHOD
Numerical investigation is performed for fully developed turbulent flow inside herringbone microfin tubes using a commercial CFD code "FLUENT". Considering the periodic repeating nature of herringbone fins, translational periodic boundaries are assigned to obtain the fully developed flow (Fig. 1). The assumption of periodicity implies that the velocity components repeat themselves in periodic planes. Also pressure drop over the periodic length is constant. Length of the computational domain is $p_l(= p/\tan\beta)$. Here p is the fin pitch and β is helix angle. Tetrahedral unstructured grids are generated by using "GAMBIT". Grid adaptation is performed in the solver to reduce the mesh size near the wall $Y^+<5$. Turbulent closure is provided by a two layer zonal model. In the fully turbulent region (turbulent Reynolds number $Re_y>200$), the standard k-ε model and in the viscosity affected region ($Re_y<200$) the one equation model of Wolfstein [4] is used.

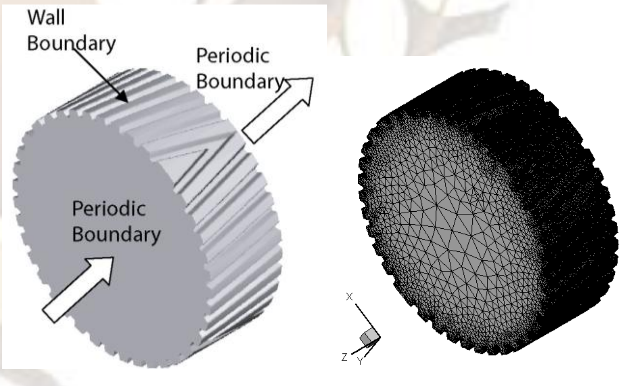


Fig. 1: Computational model with mesh

Investigations are performed for three herringbone microfin tubes. Fin arrangement and fin configuration of herringbone tube are shown in Fig. 2. Details dimensions of the herringbone tubes are shown in Table 1.

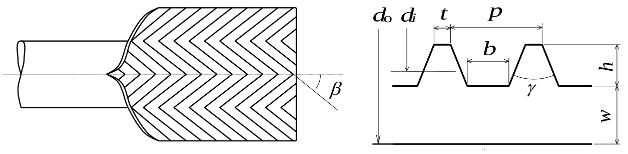


Fig. 2: Fin arrangement and configuration

Table 1: Dimensions of herringbone microfin tubes

Test tube	H1	H2	H3
d_o [mm]	7.00	7.00	7.00
d_m [mm]	6.34	6.32	6.31
p [mm]	0.33	0.34	0.40
l [mm]	0.17	0.18	0.20
b [mm]	0.18	0.15	0.25
t [mm]	0.09	0.09	0.10
α[°]	20	33	15
β [°]	8	14	28
w [mm]	0.27	0.27	0.28
number of fins	62	59	50
Area ratio	1.93	1.83	2.02

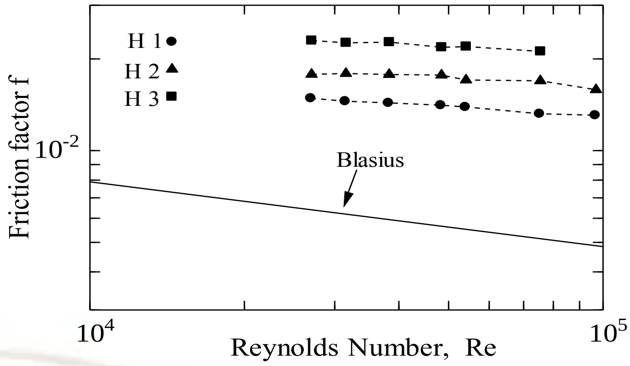


Fig. 3: Variation of friction factor with Reynolds number

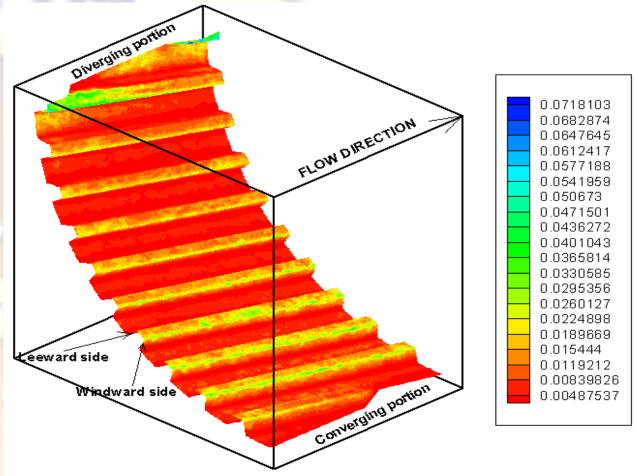


Fig. 4: Local friction factor distribution for H1 at Re = 27539

Numerical investigations are performed for the various Reynolds numbers from Re = 27539 to 97455 using R123 vapor as a working fluid. Governing equations are solved using segregated solver, in which governing equations and other turbulent equations are solved sequentially.

3. Result And Discussion

3.1 Friction factor

Friction factor for various herringbone tubes are plotted in Fig. 3. Larger helix angle tube shows higher friction factor than that of smaller helix angle tube. As a typical example, local friction factor distribution for tube H1 at Re=27539 is shown in Fig. 4. Fin tips are offered higher friction factor and fin toughs are offered lower friction factor. The maximum friction factor appears at the corner edge between winward side and fin tip. Diverging portions of herringbone fins are offered higher friction than that of converging portions. By comparing with other herringbone tubes, it was found that friction factor at fin tips is higher in larger helix angle tube than that of smaller helix angle tube.

3.2 Velocity vector and radial velocity

Velocity vector and streamlines at tube cross section, which is periodic boundary, are shown in Fig. 5 for tube H1. Velocity vectors illustrate clearly the converging and diverging action of herringbone microfin. Also, streamlines clearly show four recirculation flows inside the tube. The diverging portion of the herringbone microfin tube collects the fluid from core region and diverges to the converging portion using herringbone fins. On the other hand, the converging portion collect the fluid using the herringbone fins and disperses to the core region. Tube with higher helix angle showed stronger converging and diverging action compare to tube with smaller helix angle.

Magnitude of radial velocity for various Reynolds number and helix angle at periodic boundary are shown in Figs. 6-8. Secondary flow behavior inside herringbone microfin tube can be explained quantitatively using radial velocity. Although magnitude of the radial velocity is much lower than that of axial velocity, the radial flow may have an effect on pressure drop and heat transfer. In these figures, solid lines show positive radial velocity, that means flow toward the wall, and dotted lines show negative radial velocity, that means flow away from the wall. Maximum and minimum velocity regions appear at just overhead of diverging and converging fins, respectively. Magnitude of radial velocity is increased with increase of helix angle.

Moreover velocity is increased with increase of Reynolds number.

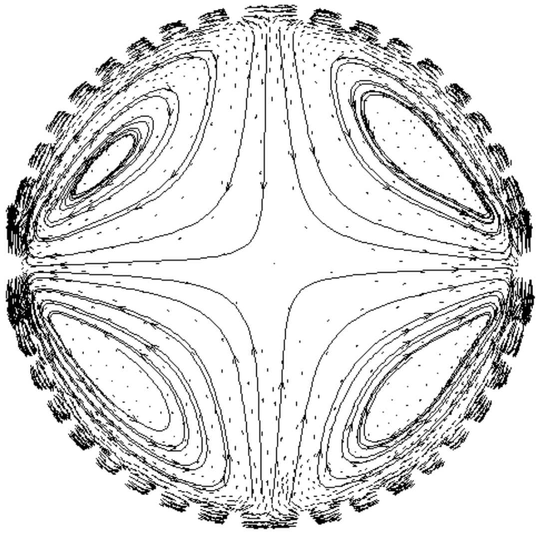
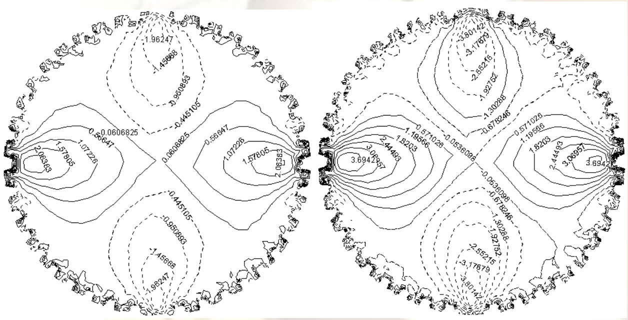
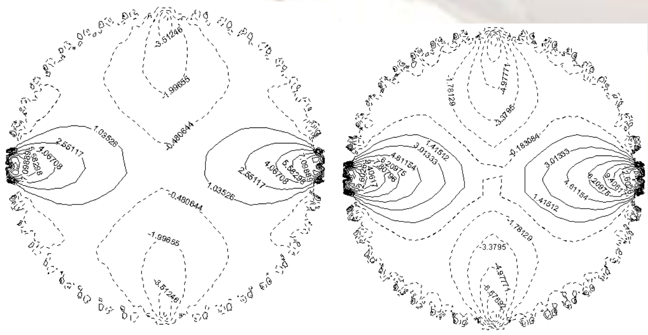


Fig. 5: Velocity vector with stream lines at Re = 48727 for tube H1



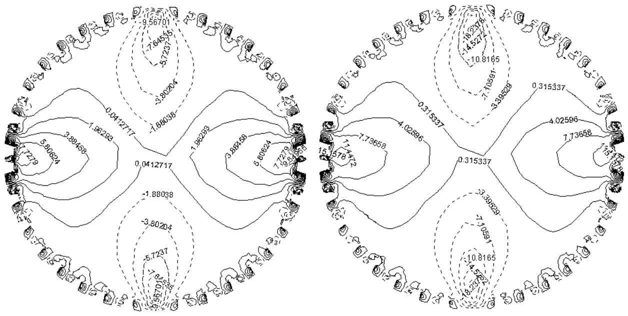
(a) (b)

Fig. 6: Radial velocity contour for tube H1 (a) Re=32485 and (b) Re=48727



(a) (b)

Fig. 7: Radial velocity contour for tube H2 (a) Re=32485 and (b) Re=48727



(a) (b)

Fig. 8: Radial velocity contour for tube H3 (a) Re=32485 and (b) Re=48727

3.2 Heat transfer characteristics

Temperature field is solved in computational domain after solving the flow field for constant fluid properties. Wall boundary of the computational domain is maintained at constant temperature of 325°K. The variation of wall heat flux with number of iterations was monitored, and convergence of the solution was concluded only when the value of the wall heat flux became constant. Nusselt number for tube H1, H2 and H3 are plotted against Reynolds number in Fig. 9. Gnielinski's correlation and Dittus-Boelter correlations for smooth tube also plotted to show the heat transfer enhancement over smooth tube. Tube H3 provided higher Nusselt number than H2 and H1. H3 provided 3.4 to 4.2 times higher Nu than that of smooth tube. Also H2 showed 1.8 to 2.5 times higher and H1 showed 1.2 to 1.8 times higher Nu than that of smooth tube. Fig. 10 showed the Nusselt number distribution over the herringbone fins for tube H3 at Re= 27539. Fin tips are offered higher Nusselt number and fin troughs are offered lower Nusselt number. Maximum Nussult number is obtained at the corner edge between windward side and fin tip. Also diverging portions of herringbone fin are offered higher Nusselt number than converging portions. By comparing with other herringbone tubes, it was found that fin tips of larger helix angle tube showed higher Nusselt number than that of smaller helix angle tube.

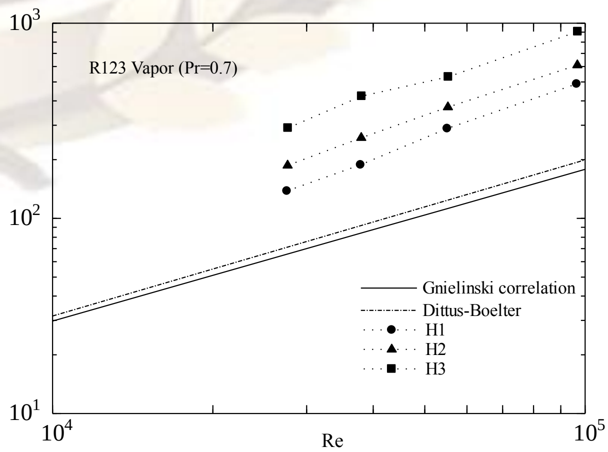


Fig. 9: Variation of Nusselt number with Reynolds number

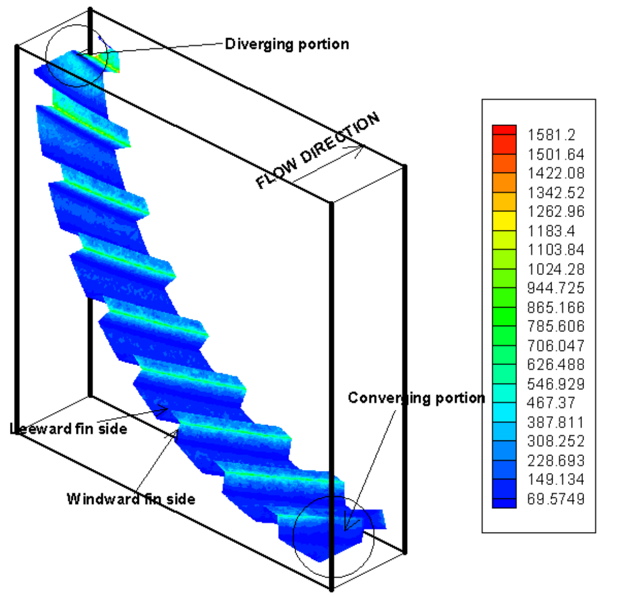


Fig. 10: Local Nusselt Number distribution for Tube H3 at Re = 27539

4. CONCLUSION

Flow behavior and heat transfer characteristics of herringbone microfin tubes have been investigated using numerical technique. Flows are accumulated from the core region to the fin-diverging portion and dispersed from the fin-converging portions to the core region. These accumulation and dispersion actions are described in terms of velocity vectors and radial velocity. Tube with larger helix angle showed higher radial velocity than the tube with smaller helix angle. Local friction factor distribution is also analyzed. Fin tip offers higher friction factor than that of fin trough. Also diverging portions offered higher friction factor than that of converging portion. Tube with larger helix angle provides higher Nusselt number than that of lower helix angle tube. Fin tip offered higher Nusselt number than that of fin trough.

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