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Parametric Study of Heat Transfer and Pressure Drop Characteristics of a Rectangular Offset Strip Fin Compact Heat Exchanger

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Compact heat exchangers are of great topics of interest while we are dealing with the enhancement of heat transfer rate. In this study, a rectangular offset strip fin compact heat exchanger is taken into consideration. The purpose of this study is to develop a numerical model to study the heat transfer characteristics as well as the pressure drop characteristics. The parametric study was done in FLUENT with a three dimensional computational domain in which air is selected as working fluid. The analysis was confined to the flow in laminar region and so the Reynolds number was limited to 1000. The variation of friction factor and Colburn factor with Reynolds number is also analysed. The results obtained were analysed and were also compared with an existing correlation. The findings of this study may serve as a helping tool to develop a correlation for fluid flow in offset strip fin geometry.

1. Introduction

The compact heat exchangers are defined as those heat exchangers having ratio of the heat transfer surface area to its volume, β (area density) greater than or equal to 700 m^2/m^3. Compact heat exchangers are commonly used in gas-to-gas and gas-to-liquid (or liquid-to-gas) heat exchangers to counteract with the low heat transfer coefficient associated with gas flow with increased surface area. They found applications in many engineering sectors such as refrigeration, power, automotive, process, cryogenics etc. Various types of plate fin compact heat exchanger surfaces such as plain rectangular, plain trapezoidal, offset strip fin, wavy, louvered and perforated configurations are available. Here a rectangular offset strip fin heat exchanger is considered. They cause high heat transfer enhancement when compared to other surface configurations. This is due to the breaking or interruption of boundary layers formed on the uninterrupted fin surface and their dissipation in the fin wakes.

The monograph on the experimental investigations on offset strip fin geometry by (Kays et al., 1984) is still being used as a sourcebook. (Joshi et al., 1987) presented analytical models to predict the heat transfer coefficient and friction factor of offset strip fin geometry in both laminar and turbulent regimes. (Wieting 1975) developed empirical correlations for heat transfer and flow friction characteristics of offset strip fin geometry for Reynolds numbers in both laminar and turbulent ranges excluding the intermediate transition region. (Manglik et al., 1995) too developed single heat transfer and pressure drop correlations for all flow regimes after reanalysing previous experimental studies. (Saidi et al., 2001) conducted a numerical investigation of heat transfer enhancement in offset strip fin surface in self- sustained oscillatory flows. (Bhowmik et al., 2009) used a three-dimensional model to study the heat transfer and pressure drop characteristics of offset strip fin geometry with water as working medium. (Asadi et al., 2013) conducted case studies on the functions of friction and colburn factors in compact heat exchangers. (Muzychka et al., 2009) presented a model for thermal – hydraulic characteristics for offset strip fin geometry for large Prandtl number liquids. This study mainly focuses on analysing the heat transfer and pressure drop characteristics of offset strip fin geometry. The basic offset strip fin geometry is shown in figure 1. As per the experiments conducted and correlations developed by (Wieting 1975), the flow with Reynolds number ≤ 1000 is primarily laminar and flow having

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Reynolds number range ≥ 2000 is primarily turbulent. In this study we are only dealing with laminar flow. The heat transfer enhancement in offset strip fin is due to the periodic starting and formation of boundary layers over the fin length and their dissipation in fin wakes.

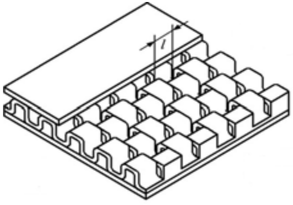

Figure 1: Offset strip fin geometry

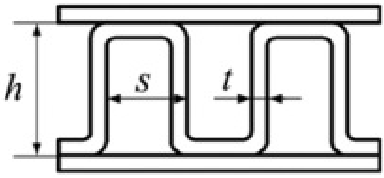

Figure 2: Nomenclature of offset strip fin

2. Problem description

The initial dimensions chosen were from the geometry designated as ¼ (s) – 11.1 used by (Kays et al.,1984). A three-dimensional computation domain was created using Solidworks as shown in figure 3. This simplification is based on the assumption that the flow is fully developed and it shows a periodic pattern (fully developed periodic flow). ANSYS FLUENT was used for studying heat transfer and pressure drop characteristics.

As the flow in the offset strip fin geometry shows a fully developed periodic pattern, the inlet and outlet sections were given periodic boundary condition. The fins and the parting sheets were specified to be in isothermal condition (350 K). No slip condition was given for wall boundaries. The material for fin was specified as aluminium and the working fluid as air. The air is modelled as an ideal incompressible gas. The air enters the offset strip fin geometry at a low temperature (249 K) and as it flows through the geometry, the temperature of air increases.

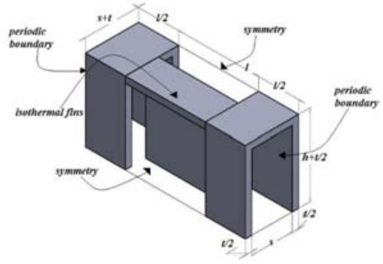

Figure 3: Computational domain

In this study a pressure-based solver was used. The semi implicit method for pressure – linked equation (SIMPLE) was used to solve the continuity, momentum and energy equations. The fluid flow was considered to be steady and incompressible. A convergence criterion of 10^{-4} was selected for the continuity and momentum equations and a convergence criterion of 10^{-6} was selected for the energy equation.

The continuity equation is given by:

$$\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0 \tag{1}$$

The momentum equation in x-direction is given by:

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial w}{\partial z}\right)= -\frac{\partial P}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial x^2}\right) \tag{2}$$

The Reynolds number for the flow is given by:

$$Re=\frac{U_C D_h}{\upsilon} \tag{3}$$

Now the free flow area denoted as A_{ff} for the computational domain can be written as, A_{ff} = sh. The hydraulic diameter D_h is given by:

$$D_h=\frac{4\,A_{ff}}{A/l}=\frac{4shl}{2(sl+hl+th)+ts} \tag{4}$$

The friction factor f is given by:

$$f = \frac{2\Delta P}{\rho U_C}\left(\frac{D_h}{4\,L_m}\right) \tag{5}$$

The Colburn j factor is given by:

$$j = \frac{\bar{h} Pr^{2/3}}{\rho C_p U_m} \tag{6}$$

3. Results and discussions

The computational domain was analysed in FLUENT and the obtained results were compared with an existing correlation made by Manglik & Bergles (1995). They had given the correlations for the friction factor as well as for the Colburn factor. The correlations were:

$$f = \frac{9.6243\,Re^{-0.7422}\alpha^{-0.1856}\delta^{0.3053}\gamma^{-0.2659}}{1+(7.669\times10^{-8}\,Re^{4.429}\alpha^{0.920}\delta^{3.767}\gamma^{0.236})} \tag{7}$$

$$j = \frac{0.6522\,Re^{-0.5403}\alpha^{-0.1541}\delta^{0.1499}\gamma^{-0.0678}}{1+(5.269\times10^{-5}\,Re^{1.340}\alpha^{0.504}\delta^{30.456}\gamma^{-1.055})} \tag{8}$$

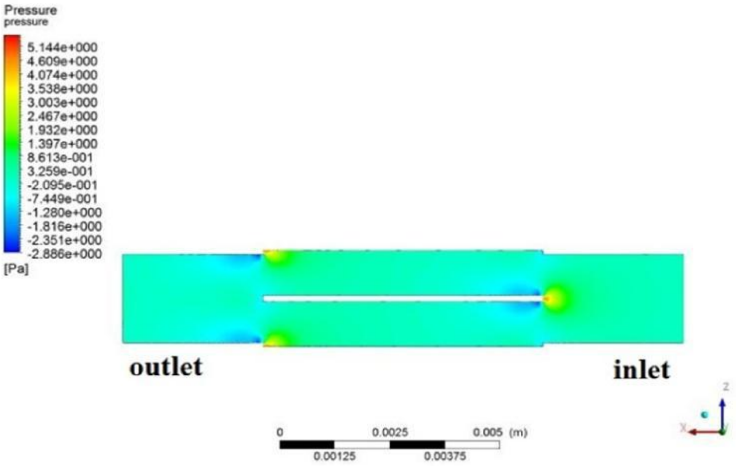

Figure 4: Pressure contour

The pressure, temperature and velocity contours for a flow through an offset strip fin geometry (Re = 500) are shown in figures 4, 5 and 6 respectively. It was observed that there occurs a pressure drop as the fluid flows through the offset strip fin geometry. Also, the periodic behaviour of the flow can clearly be observed from the velocity contour.

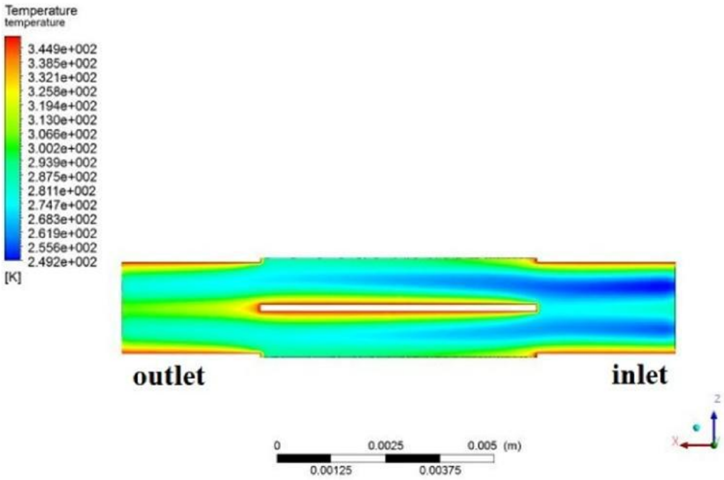

Figure 5: Temperature contour

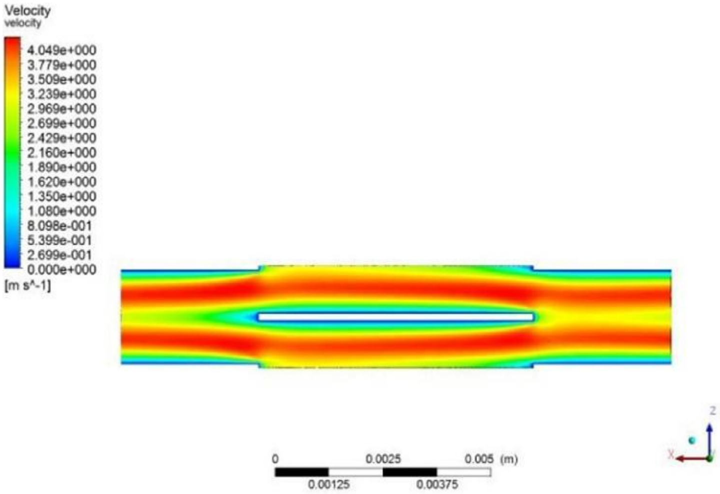

Figure 6: Velocity contour

3.1 Variation of *f* and *j* factors with Reynolds number

Initially, the variation of f and j factors with respect to Reynolds number was analysed. From the figure 7 below it is clear that the functions of f and j factors decrease with increasing Reynolds number. At lower flow velocities the air spends more time around the fins and thus it helps in enhancing the heat transfer rate.
As the flow velocity increases the time spend by air around the fins decreases resulting in less heat transfer. The computed results of f factor obtained were very close to the values predicted by the Manglik & Bergles correlation, and the j factors deviated by about 12%. And also, the values of friction factors were about 10 times the values of j factors at the same Reynolds number.

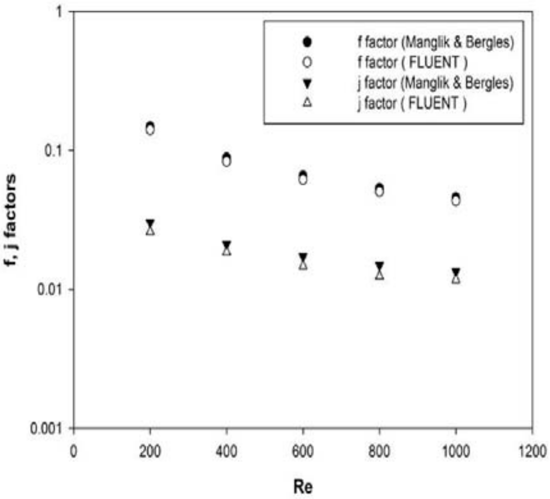

Figure 7: Variation of f and j factors with Reynolds number

3.2 Variation of *f* and *j* factors with dimensionless parameter α

Now the heat transfer and pressure drop characteristics of the offset strip fin geometry was analysed by varying the dimensionless parameter α = s/h. The dimensionless parameter α was varied by changing the fin height h. The variation of f & j factors with variation of α is shown in figure 8. At low values of α, the functions of f and j factors are high and the trend shows that the f and j factors decrease with increasing values of α.

The f and j factor variation obtained by FLUENT with respect to α, deviated from the predicted f factor by about 5% and the from the predicted j factor by about 12%.

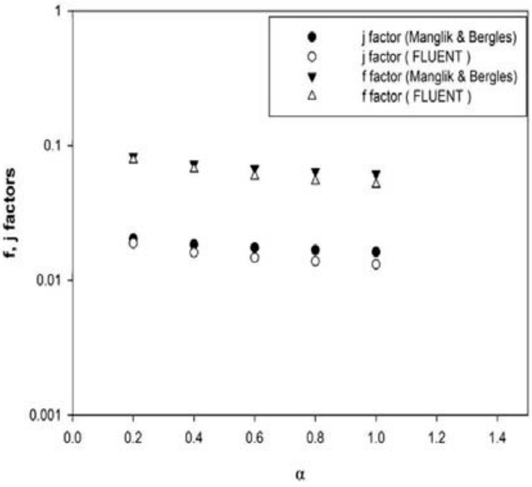

Figure 8: Variation of f and j factors with dimensionless parameter α

3.3 Variation of *f* and *j* factors with dimensionless parameter δ

The f & j factor variations with respect to the dimensionless parameter δ = t/l was also obtained. Both the offset fin length and fin thickness will have an influence on the flow field. When the fins are thicker, they offer large form drag. Also, in an offset strip fin geometry having smaller offset fin length, the breaking of boundary layers formed on the uninterrupted fin length and their dissipation in fin wakes will be more often when compared to a geometry having larger offset fin length. As a result, the pressure drops and colburn j factor tends to increase. As indicated in the figure 9, the functions of f and j factor increases with increase in δ. In this study, the δ was varied by changing the fin uninterrupted length l. So, for large values of δ, the offset fin length was small resulting in higher values of f and j factors. The deviation of friction factor data obtained from FLUENT deviated from the existing values by about 8% and the deviation in case of colburn factor was found to be 10%.

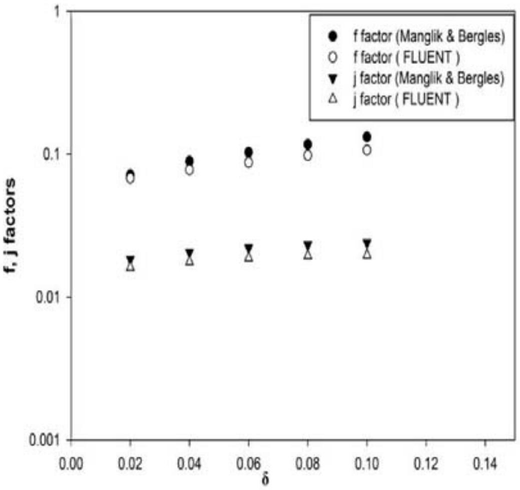

Figure 9: Variation of f and j factors with dimensionless parameter δ

4. Conclusions

In this study, a three dimensional parametric analysis of a rectangular offset strip fin heat exchanger using ANSYS FLUENT 14.0 was carried out. The analysis was carried out for Reynolds number ≤ 1000. A three-dimensional computational domain was created and suitable boundary conditions were defined. The heat transfer characteristics and pressure drop characteristics were analysed by varying dimensionless parameters such as Reynolds number, $\alpha = s/h$, $\delta = t/l$. The results show that f & j factors decrease with respect to increase in Reynolds number and $\alpha = s/h$. On the other hand, f & j factors increase with respect to increase in $\delta = t/l$. It was also found that the main factors influencing the design of a compact heat exchanger are Colburn j factor and Fanning friction factor.

Nomenclature

A_{ff}	free flow area
D_h	hydraulic diameter
f	friction factor
h	fin height
h	mean heat transfer coefficient
j	colburn factor
l	offset fin length
L_m	length of computational module
Pr	Prandtl number
Re	Reynolds number
s	fin spacing
t	fin thickness
U_m	mean velocity
U_c	velocity at minimum free flow area
μ	dynamic viscosity
v	kinematic viscosity
ρ	density
P	pressure
u	velocity component in x direction
v	velocity component in y direction
w	velocity component in z direction

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