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Numerical Investigation of Heat Transfer of Flow Over the Cylinder with High Conductivity Fins

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Keywords

Forced convective heat transfer,
Cylinder fins,
Nusselt number,
Reynolds number.

Abstract

The laminar forced convection across a heated cylinder is an important problem in heat transfer. In this study, the problem of forced convective heat transfer of flow over horizontal cylinder with equally spaced fins with high conductivity has been numerically investigated on the outer surface. The effect of the number of fins and their height on the average Nusselt number was investigated for Reynolds numbers within the domain 5-2000. The effect of the fins on the forced convective heat transfer over isothermal horizontal cylinder was studied for numerous combinations of fins (F=0-14), the height of fins (H=0.5-3) and different Reynolds number values (Re_D = 5-2000). Changing the average Nusselt number for a given value of Reynolds number due to the increased number of fins, the average Nusselt number at the same Reynolds number was normalized by the Nusselt number of finless cylinder and it was conducted because of the focus on the relatively effect of the increased fins. The results showed that there is an optimum number of fins to obtain the maximum Nusselt number for a given value of fins height and Reynolds number. Furthermore, the short fins decrease the Nusselt number at low Reynolds number.

1. Introduction

Heat transfer from horizontal cylinders has the most amount of literature out of all of the orientations. According to Morgan [1], who published an all-encompassing review article on the natural convection from smooth, circular cylinders, there is a wide dispersion in experimental results due to the axial heat conduction losses to the supporting structures of the horizontal cylinders, temperature measurement location, interference of the temperature and velocity fields by convective fluid movements and the utilization of the small containing chambers for the experiments. The natural convection heat transfer from a horizontal cylinder has been studied numerically and experimentally for more than 50 years but it is reported by Morgan [1], Fand and Brucker [2] that the obtained results show high levels of deviation among each other due to various reasons. Khan et al. [3] used an integral approach to analyze the fluid flow and heat transfer from a horizontal cylinder with constant surface temperature/heat flux. They determined the closed form expressions for the drag coefficients and the average Nusselt number. They continued their research for the case of power-law fluids [4] and determined the correlation between the Nusselt number and both the Reynolds and Prandtl numbers. The mixed convection around a circular cylinder with a constant temperature/heat flux surface was studied in detail for the parallel and contra flow regimes by Soares et al. [5] using the finite difference method. Campo and Cortés [6] used the 1D lumped analysis to demonstrate that using external baffles on the surface of a cylinder reduces the natural convective heat loss from the internal hot fluid to the ambient air. A reduction as high as 60% was calculated for an in-tube laminar oil flow and 11 baffles uniformly distributed on the exterior surface of the cylinder. Reymond et al. [7] studied natural convection heat transfer from a horizontal cylinder bounded with water and indicated that around the circumference of a cylinder, the average Nusselt number distribution show a maximum at the bottom of the cylinder ($\theta=0°$) and as the boundary layer developing it decreases towards the top ($\theta=180°$). Researchers continue to look for new methods of heat transfer control. The use of porous materials to alter the heat transfer characteristics has been reported by several researchers including Vafai and Huang [8], Al-Nimr and Alkam [9] and Abu-Hijleh [10]. The case of a horizontal cylinder with a constant surface heat flux that is provided with external uniformly distributed baffles and that loses heat by natural convection was analyzed by Neagu [11].

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Nazar et al. [12] established the non-similar solution of the boundary layer equations for the case of mixed convection from a horizontal circular cylinder with a constant surface heat flux immersed in a viscous and incompressible fluid. The influence of the mixed convection parameter on flow and heat transfer characteristics are studied for two values of Prandtl numbers: *Pr=1* and *Pr=7*. Fins have always been used as a passive method of enhancing the convection heat transfer from cylinders. [13-17] In this study, enhancing the forced convective heat transfer of flow over horizontal cylinder was numerically investigated by using high conductivity fins on the outer surface of cylinder. The commercial RANS-based code FLUENT, which follows a finite volume computational procedure, was used in this study. The working fluid of this study is air and the Reynolds number is between 5 to 2000, number of fins is between 0 to 14 and fin height is between 0.5 to 3.

2. Numerical Methods

2.1. Mathematical Analysis

The steady-state equations for 2D laminar forced convection over a horizontal cylinder are presented [15] in Eq. (1) to Eq. (5) as

$$\frac{1}{r}\frac{\partial(ru)}{\partial r}+\frac{1}{r}\frac{\partial v}{\partial \theta}=0 \tag{1}$$

$$u\frac{\partial u}{\partial r}+\frac{v}{r}\frac{\partial u}{\partial \theta}-\frac{v^2}{r}=-\frac{1}{\rho}\frac{\partial p}{\partial r}+\nu\left[\frac{\partial^2 u}{\partial r^2}+\frac{1}{r}\frac{\partial u}{\partial r}-\frac{u}{r^2}+\frac{1}{r^2}\frac{\partial^2 u}{\partial \theta^2}-\frac{2}{r^2}\frac{\partial v}{\partial \theta}\right] \tag{2}$$

$$u\frac{\partial u}{\partial r}+\frac{v}{r}\frac{\partial u}{\partial \theta}+\frac{uv}{r}=-\frac{1}{\rho}\frac{\partial p}{\partial r}+\nu\left[\frac{\partial^2 v}{\partial r^2}+\frac{1}{r}\frac{\partial v}{\partial r}-\frac{v}{r^2}+\frac{1}{r^2}\frac{\partial^2 v}{\partial \theta^2}+\frac{2}{r^2}\frac{\partial u}{\partial \theta}\right] \tag{3}$$

$$u\frac{\partial T}{\partial r}+\frac{v}{r}\frac{\partial T}{\partial \theta}=\alpha\nabla^2 T \tag{4}$$

Where

$$\nabla^2\equiv\left[\frac{\partial^2}{\partial r^2}+\frac{1}{r}\frac{\partial}{\partial r}+\frac{1}{r^2}\frac{\partial^2}{\partial \theta^2}\right] \tag{5}$$

2.2. Geometric Model and Dimensions

Cylinder with high conductivity fins was simulated in two-dimensional model (Figure 1). As it can be seen in Figure 2, there are different types of geometry due to the flow condition, the number of fins and the height of fins. Gambit software was used for modeling and grid generation.

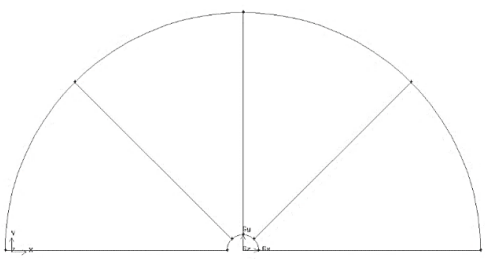


Figure 1. Geometric model

2.3. Sample of Different Types of Geometry

Table 1 and Figure 3 show the parameters of different geometries and the size of different types of geometry of this study.

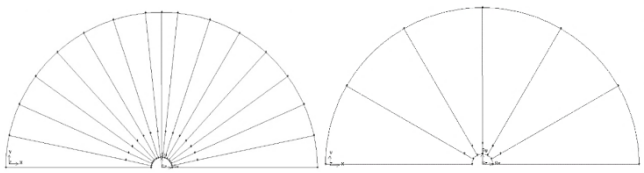


Figure 2. Different types of geometry

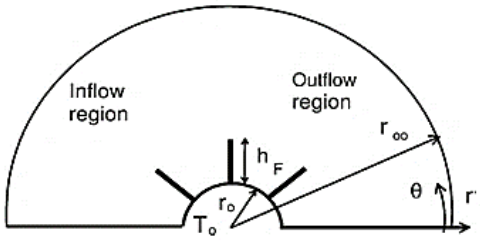


Figure 3. Geometric parameters [15]

Table 1. Geometric parameters

θ° (Angle of flow)	F (Number of fins)
90	1
45	3
30	5
18	9
12	14

2.4. Grid Independency

Grid generation is conducted by using GAMBIT. As it can be seen in Figure 4, for optimizing the number of mesh and making higher accuracy with reducing the time and cost of computing, mesh generation around the cylinder has higher density and its density decreases when it distanced from this region.

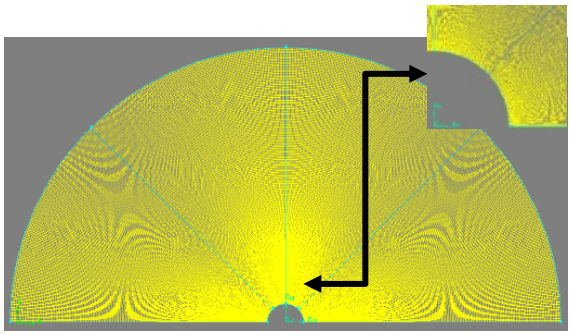


Figure 4. A view of entire grid

- The number of regions depend on the number of fins. In Fig. 4, four regions are available.
- The number of cells: 734124
- The type of elements: two dimensional – tetrahedral

In order to investigate the grid independency, the Nusselt number based on number of grids is studied. There was a

negligible difference between the results of the smallest grid and the grid with 734124 cells. Thus, in order to save computation time, the grid with 734124 cells is used to obtain the results. Figure 5 shows the details of grid independency.

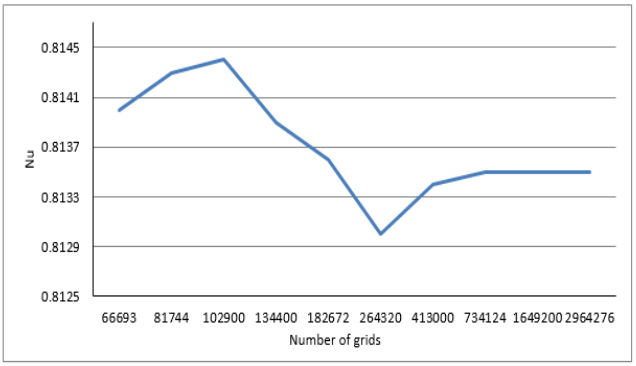


Figure 5. Details of grid independency

2.5. Numerical Approach and Boundary Conditions

In this study, governing equations were analyzed by using finite volume method (FVM) and second order upwind method. The finite volume method (FVM) is the most common approach used for obtaining CFD simulation. In order to coupled velocity and pressure equations SIMPLEC method was used. Eq. (1) to Eq. (4) are subjected to the following boundary conditions [15]:

- On the cylinder surface, i.e., $r = r_o, u = v = 0$, and $T = T_o, T = 700\ K$.
- Far-stream from the cylinder, i.e., $r \to \infty, u \to U_\infty cos(\theta)$, and $v \to -U_\infty sin(\theta), \theta = 0°$, T=300 K.
- Isothermal Fins with high conductivity coefficient, thickness is not considerable and $T = T_0, T = 700\ K$.

As for the temperature, the far-stream boundary condition is divided into an outflow ($\theta \leq 90$ degrees) and an inflow ($\theta > 90$ degrees) regions, Figure 3 shows the far-stream temperature boundary conditions are $T = T_\infty$ and $\partial T/\partial\theta = 0$ for the inflow and outflow regions, respectively.

- Plane of symmetry; $\theta = 0$ and $\theta = 180$ degrees; $v = 0$ and $\partial u/\partial\theta = \partial T/\partial\theta = 0$.

Table 2 shows the properties of inlet velocity based on Reynolds number.

Table 2. Properties of inlet velocity based on Reynolds number

u (inlet velocity)	Re (Reynolds number)
3.65 e^{-5}	50
5.11 e^{-4}	70
1.4 e^{-3}	200
3.65 e^{-3}	500
7.3 e^{-3}	1000
1.4 e^{-2}	2000

3. Validation

In order to validate the results of this study with the results of Abu-Hijleh [15], ratio of Nusselt number from the cylinder surface are compared to each other. As it can be seen in Figure 6, the results are in good agreement with the results of the present study which indicates the accuracy of the results of present study.

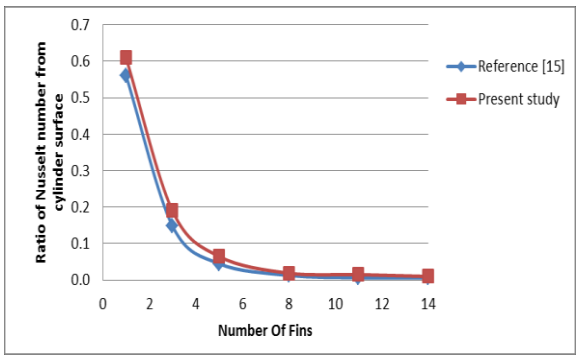


Figure 6. Comparision betwwen the ratio of Nusselt number from the cylinder surface of the present study and with the results of Abu-Hijleh [15]

4. Results and Discussion

The results are investigated at Reynolds numbers from 5 to 2000, the number of fins from 0 to 14 and a height of 0.5 to 3 by using Fluent software. The increase of fin height has large effect on streamlines. (Figure 7) Due to addition of fins to cylinder, flow over the cylinder will be decreased in a same value of Reynolds number which is caused to increase average Nusselt number and heat transfer from cylinder. The increases of value of Reynolds number and fins height generate vortexes between the fins which is caused more Nusselt number and heat transfer. (Figures 8, 9)

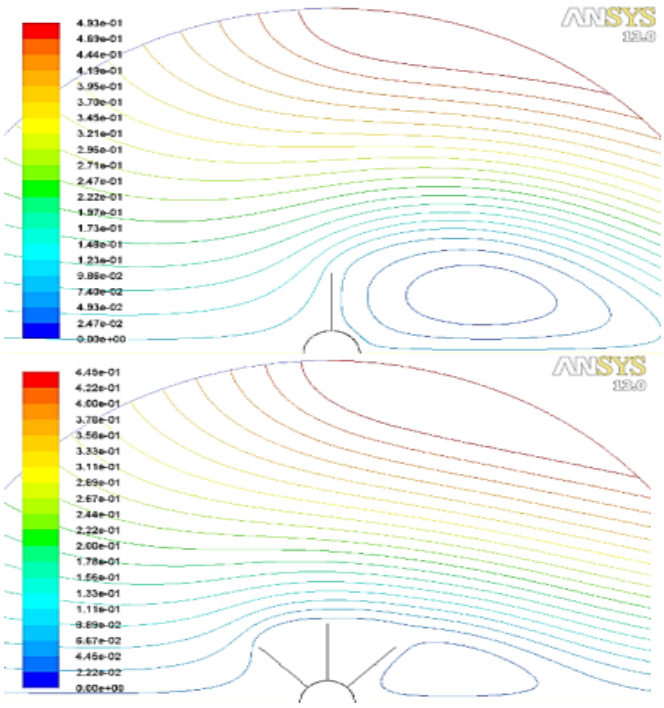


Figure 7. Effect of adding fins on streamlines

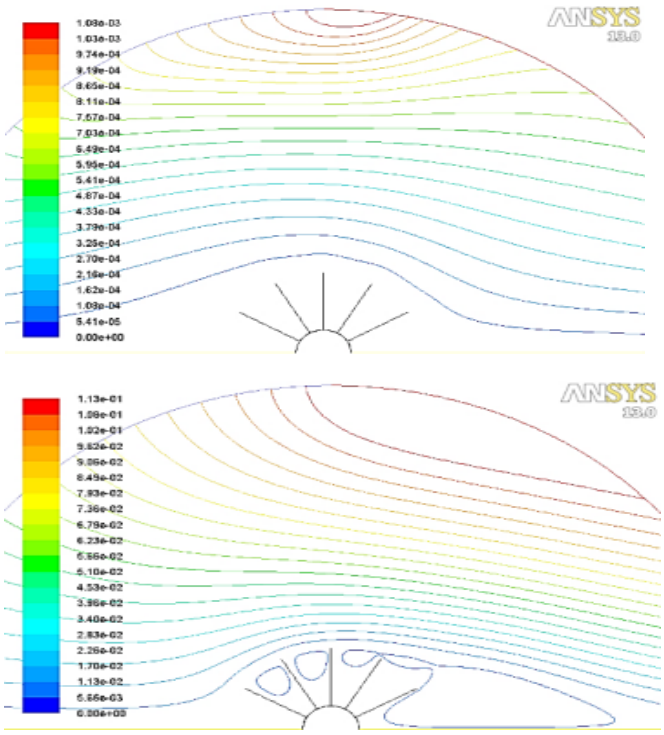


Figure 8. Effect of increasing Re_D on streamlines

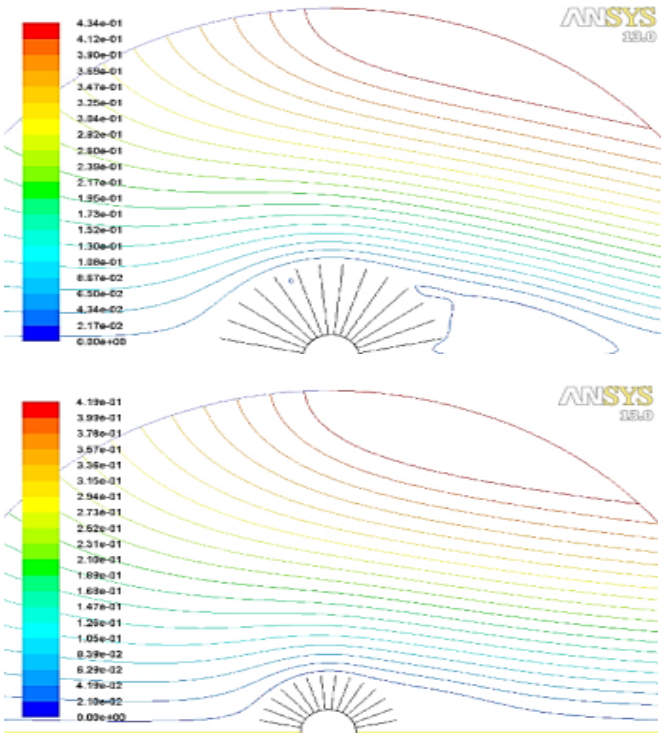
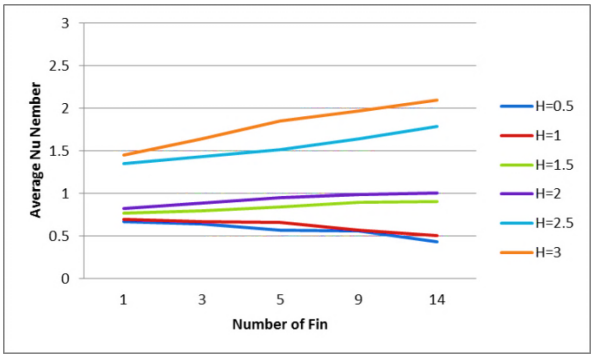
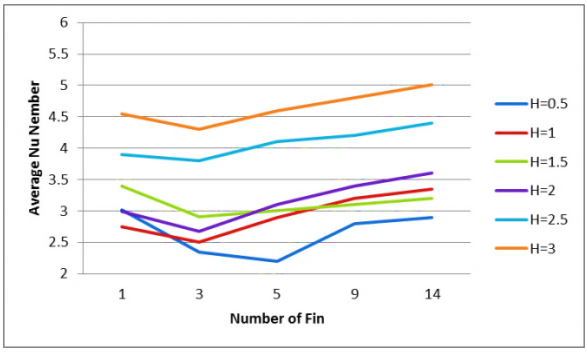


Figure 9. Effect of increasing fin height on streamlines

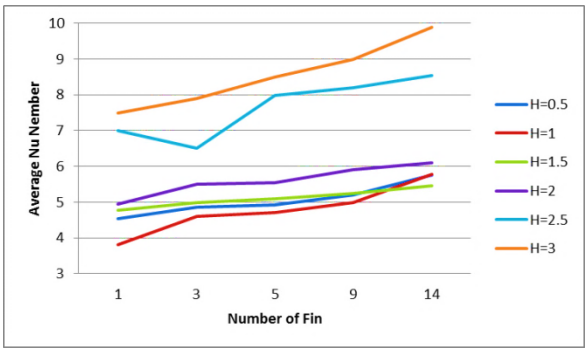
Figure 10 shows that with increasing the number of fins in the same Reynolds number, the average Nusselt number has increased.



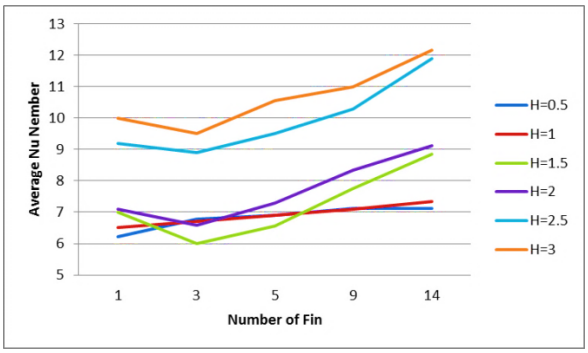
Re=5



Re=500



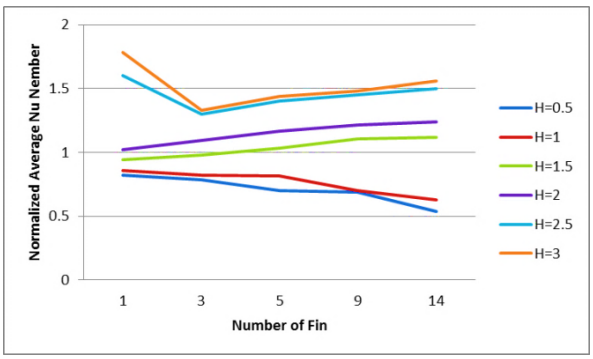
Re=1000



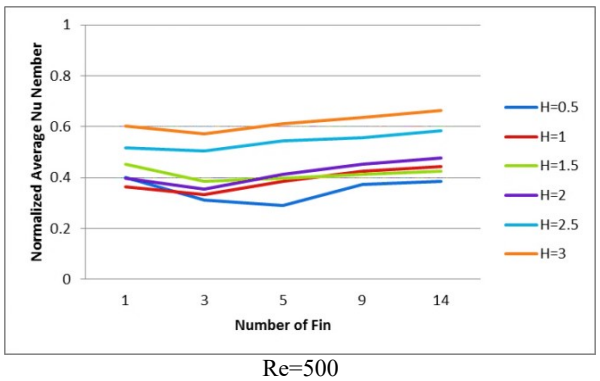
Re=2000

Figure 10. The average of Nusselt number as a function of number of fins in various combinations of fins and Reynolds numbers

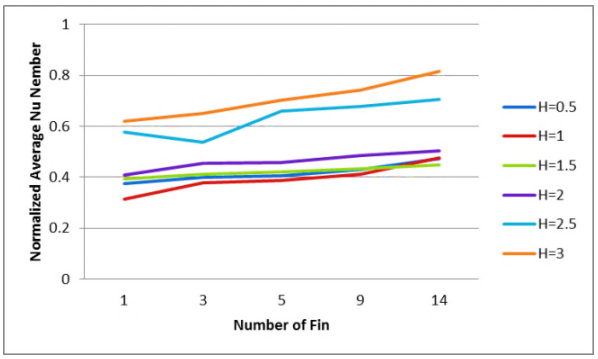
Figure 11 shows that in the same Reynolds number with increasing the number of fins, Nusselt number also has been increased. Also it is clear that long fins have more normilized average Nusselt number.



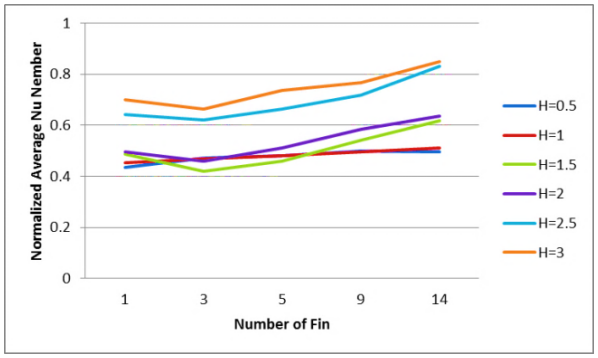
Re=5



Re=500



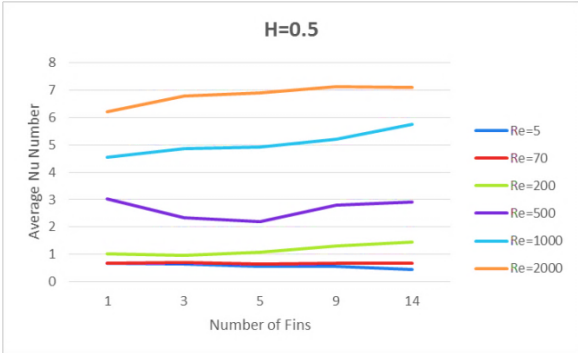
Re=1000

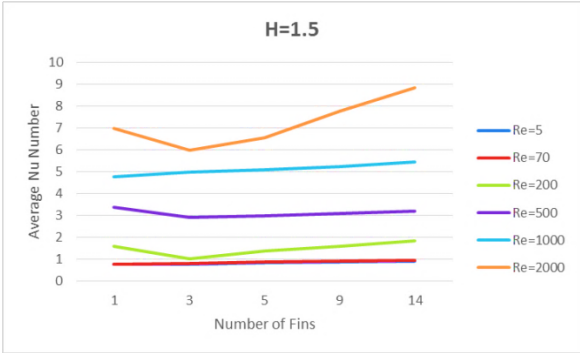


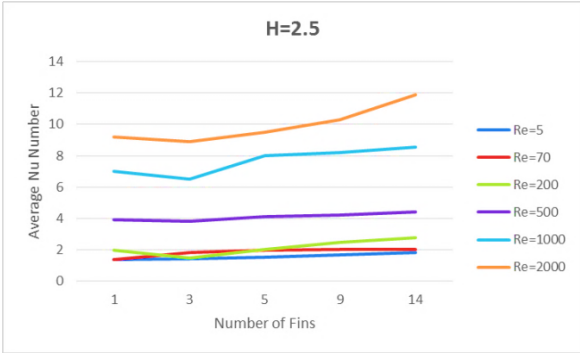
Re=2000

Figure 11. The average Nusselt number compared to the case of finless as a function of the number of fins in various combinations of fins and Reynolds numbers

Figure 12 shows that the average Nusslet number has increased with increasing the number of fins with respect to different Reynolds numbers at a specific height. Another significant results is that the increasing trend of average Nusselt number is more in high reylonds number.







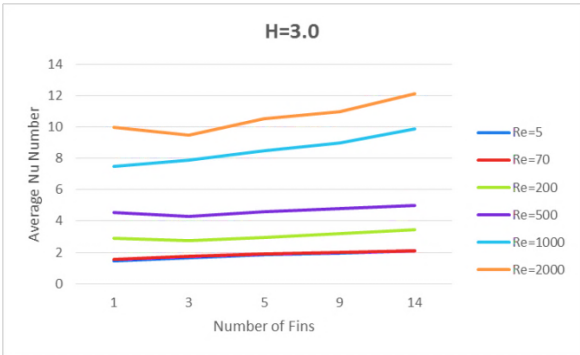


Figure 12. The average Nusselt number as a function of height of fins in various combinations of fins and Reynolds numbers

5. Conclusion

In this study, the effect of fins on the forced convective heat transfer of flow over a horizontal isothermal cylinder was studied for several combinations of number of fins (F =0-14), the height of fins (H=0.5-3) and Reynolds number (Re_D= 5-2000). Changes in the average Nusselt number for a given value of Reynolds number due to increased number of fins, the average Nusselt number at the same Reynolds number by the Nusselt number of finless cylinder was normalized and it was conducted because of the focus on the

relatively effect of the increased fins. Changes in the value of average Nusselt number depend on the number and the height of fins which is used at appropriate Reynolds number. A small number of short fins were tended to reduce heat transfer from the cylinder. Adding the fins caused to reduce air flow velocity around the cylinder near the fins which reduces heat transfer from the cylinder surface. Not only adding small fins did not compensate the loss of heat transfer from the surface of the cylinder but also it caused to loss more heat transfer from more surfaces and caused a reduction in the normalized average Nusselt number from the cylinder. When long fins are employed, more heat transfer from the excess surface area for compensating the reduction in heat transfer from the cylinder surface caused an increase in the normalized average Nusselt number.

References

[1] V.T. Morgan, The overall convective heat transfer from smooth circular cylinders. Advances in heat transfer 11 (1975) 199–264.

[2] R.M. Fand, J. Brucker, A correlation for heat transfer by natural convection from horizontal cylinders that accounts for viscous dissipation, International Journal of Heat and Mass Transfer 26 (1983) 709–716.

[3] W.A. Khan, J.R. Culham, M.M. Yovanovich, Fluid flow around and heat transfer from an infinite circular cylinder, Journal of Heat transfer 127 (2005) 785–790.

[4] W.A. Khan, J.R. Culham, M.M. Yovanovich, Fluid flow and heat transfer in power-law fluids across circular cylinders: analytical study. Journal of heat transfer 128 (2006): 870-878.

[5] A.A. Soares, N.D. Couto, M.D. Naia, N.J. Gonçalves, A. Rouboa, Numerical investigation of effects of buoyancy around a heated circular cylinder in parallel and contra flow, Journal of mechanical science and technology 26 (2012) 1501–1513.

[6] A. Campo, C. Cortés, Substantial reduction of the heat losses to ambient air by natural convection from horizontal in-tube flows: impact of an axial bundle of passive baffles, Heat and mass transfer 36 (2000) 361–369.

[7] O. Reymond, D.B. Murray, T.S. O'Donovan, Natural convection heat transfer from two horizontal cylinders, Experimental Thermal and Fluid Science 32 (2008) 1702–1709.

[8] K. Vafai, P.C. Huang, Analysis of heat transfer regulation and modification employing intermittently emplaced porous cavities, Transactions-American Society of Mechanical Engineers Journal of Heat Transfer 116 (1994) 604–604.

[9] M.A. Al-Nimr, M. K. Alkam, A modified tubeless solar collector partially filled with porous substrate. Renewable Energy 13 (1998) 165–173.

[10] B.A. Abu-Hijleh, Natural convection heat transfer from a cylinder covered with an orthotropic porous layer, Numerical Heat Transfer: Part A: Applications 40 (2001) 767–782.

[11] M. Neagu, Natural Convection Heat Transfer from a Horizontal Circular Cylinder with Constant Surface Heat Flux. In ASME 2009 Heat Transfer Summer Conference collocated with the InterPACK09 and 3rd Energy Sustainability Conferences. American Society of Mechanical Engineers, January (2009) 627–632.

[12] R. Nazar, N. Amin, I. Pop, Mixed convection boundary-layer flow from a horizontal circular cylinder with a constant surface heat flux, Heat and mass transfer 40 (2004) 219–227.

[13] H.M. Badr, A theoretical study of laminar mixed convection from a horizontal cylinder in a cross stream, International Journal of Heat and Mass Transfer 26 (1983) 639–653.

[14] T. Saitoh, T. Sajiki, K. Maruhara, Bench mark solutions to natural convection heat transfer problem around a horizontal circular cylinder, International Journal of Heat and Mass Transfer 36 (1993) 1251–1259.

[15] B. A/K Abu-Hijleh, Numerical simulation of forced convection heat transfer from a cylinder with high conductivity radial fins in cross-flow, International journal of thermal sciences 42 (2003) 741–748.

[16] R.A. Ahmad, Steady-state numerical solution of the Navier-Stokes and energy equations around a horizontal cylinder at moderate Reynolds numbers from 100 to 500, Heat Transfer Engineering 17 (1996) 31–81.

[17] A. Bassam, K. Abu-Hijleh, Laminar mixed convection correlations for an isothermal cylinder in cross flow at different angles of attack. International journal of heat and mass transfer 42 (1999) 1383–1388.