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Heat Transfer Enhancement in a Circular Tube Using Ribs with Middle Arm

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ABSTRACT

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Heat transfer enhancement, Turbulent flow, Ribs, Forced convection.

Nomenclature

- A Heat transfer area, m²
- Cp Specific heat of air, J/kg.K
- D_h Hydraulic diameter, m f Frictional factor
- g Acceleration due to gravity $,m/s^2$
- h Heat transfer coefficient, W/m^2 . k
- K Thermal conductivity, w/m.K
- m Mass flow rate, kg/s
- Nu Nusselt number, dimensionless
- p Pitch of rib, m
- Pr Prantdle Number, dimensionless
- Q Heat transfer rate, W
- Re Reynold number, dimensionless
- T Temperature, Kº
- U Overall heat transfer coefficient , $w/m^2.K^o$
- u Velocity of flow, m/s
- b Bulk
- c Center
- i Inlet
- o Outlet
- s Surface
- w Wall
- μ Viscosity of air , N.s/ m^2
- $\rho \quad Density \ of \ air, \ kg/m^3$

Introduction

In the past years, momentous effort has been made to develop heat transfer enhancement techniques to improve the overall performance of heat exchangers. The need to energy saving, materials, and other indispensable costs has stimulated the search for various heat transfer enhancement techniques[1]. To obtain a higher heat transfer with a smaller or reasonable friction loss, there have been a significant amount of investigations in the last two or three decades reflecting this. These investigations, the effects of geometric parameters on both local and overall heat transfer coefficients, such as channel aspect ratio, rib height, rib height to passage hydraulic diameter, rib angle of attack, rib pitch to height ratio and shape, the manner in which the ribs are positioned [2]. Up to now, a variety of tube inserts have been developed by many researchers [3].

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This work presents an experimental and numerical investigation of heat transfer characteristics for horizontal circular pipe of 500mm long fitted with ribs having middle arm with cross section of 5mm width ,5mm length, pitch=80mm, with air as the working fluid. Reynolds number ranged(Re=24253, 26119 and 27984). The steel pipe(ASM4120) was subjected to two constant surface temperatures ($673K^{\circ}$ and $973K^{\circ}$). The experimental data obtained were compared with plain (without ribs). Based on the same coolant flow, the pipe with ribs was found to possess the highest performance factors for turbulent flow. The results show a good agreement between theoretical and experimental bulk temperature by factor 0.9%, 1% for inner wall temperature and 0.8% for average Nusselt number. Using ribs improved the heat transfer in a circular tube. All studies where carried out using workbench program FIUENT14.5 by using K- ε model.

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For instance, the twisted tape is the most widely used due to its steady performance, simple configuration and being easy to install and disassemble. The main mechanism for the heat transfer arrangement by applying a twisted tape is that it can generate swirks which enhance fluid mixing of the near-wall and central regions [4–7]. To improve the overall thermo-hydraulic performance of tubes fitted with twisted tapes, some modifications on the conventional twisted tape have been made. For example, segmented twisted tapes [8,9], broken and serrated twisted tapes[10,11].

In this paper, the effect of fitting ribs with middle arm in a circular pipe with internal air flow and constant wall surface temperature will be investigated.

Mathematical formulation Governing Equations

In our study heat transferred from the hot air (environment) surrounded the test section tube(Tg) to the coolant air (Tc) across the tube wall material. Fig.(1) shows a cross section of the simulated case which includes heat convection from Tg to Ts, heat conduction from Ts to Tw and then heat convection from <u>Tw to Tc</u>



Fig1. Present Case Study

The heat transfer rate can be defined as the amount of heat transferred per unit time. If a hot metal block has a surface temperature of To on one side and Ti on the other side, the basic heat transfer rate due to conduction can be given by:

If a hot wall at a temperature To is exposed to a coolant fluid at a temperature Ti on one side, the convective heattransfer rate can be given by:

The heat transfer coefficient for fully developed turbulent flow in smooth pipes can be calculated using Dittus Boelter relation.

Because of the many factors that affect the convection heattransfer coefficient (h), coefficient calculation is complex. However, dimensionless numbers are used to calculate (h) for both free convection and forced convection. For forced convection, the formula expressing the relationship between the various dimensionless groups may generally be written in the following form [12]:

$Nu = C \operatorname{Re}^{a}$	\Pr^{b}	 5)
And		

$$Nu = \frac{hL_c}{k} \qquad (4)$$

Nusselt number for a smooth channel is calculated using the Dittus-Boelter equation :

Nu = 0.023Re0.8 Pr0.4(5)

To generalize heat transfer correlations, it is common to use non-dimensional parameters. The heat transfer coefficient is often made non-dimensional by the Nusselt number, defined as:

$h = \frac{Nuk}{m}$	• • •	(6)	
L_c			

Where Lc is the characteristic length (known as hydraulic diameter, Dh, in non-cylindrical pipe) which is:

$D = \frac{4A}{4}$		(7)
$\mathcal{D}_h = P_W$		
Prandtl num	ber is expressed as:	
$\Pr = \frac{\mu c_p}{\mu c_p}$		(8)

Λ	
Reynolds number is	expressed as:

$Re = \frac{\rho u D}{\rho u D}$	
μ	

Also, the flow Reynolds number is:

$\operatorname{Re} = \frac{4\dot{m}}{2}$	(10)
$\pi D \mu$	(-)
Mass flow rate is defined by:	

 $\dot{m} = \rho u A$ (11) Mesh Conception

Mesh Generation

There are two types of approaches in volume meshing, structured and unstructured meshing. FLUENT can use grids comprising of tetrahedron or hexahedron cells in three dimensions. The type of mesh selection depends on the application, for the present case using ribs of middle arm(fig.2), the mesh generated can be shown in fig.(3).



Fig 2. Ribs with middle arm



Fig 3. Mesh Generation

Experimental Work Experimental Rig

Figure (4) illustrates the basic components of the experimental rig, which is depicted in figure (5). This rig consists of :

1. Air Blower.

- 2. U-Manometer.
- 3. Control Circuit.
- 4. Digital Thermocouple.

5. Heating System.

6. Test Section.



Fig 4. Schematic Diagram of the Experimental Setup



Fig 5. Photographic View of Experimental Rig

A blower unit fitted with a pipe, which is connected to the test section located in horizontal orientation. A heat input of 1000 W was given to the Ni-chrome heating wire on the test tube. The test section was insulated in order to avoid the loss of heat energy to the surrounding. The readings of the thermocouples were observed every (30 minutes) until the steady state condition was achieved. The blower consists a plate, which controls the air flow rate through the pipe and an orifice meter to find the volume flow rate of air through the system.

Test Section

The test section is divided into two parts ,the first (fig.6) is box of dimensions ($300 \times 300 \times 500$ mm). This box is contained in another box of dimensions ($405 \times 405 \times 610$ mm) the gap between the two boxes filled with air as insulator.



Figure 6. Part One

The second part is a tube, shown in fig.(7), which is photographed in fig.(8), is a steel tube (ASM4120) of 500mm long , outside diameter of 60 mm and inside diameter of 40 mm, was fitted in the boxes through two opposite holes. Ribs are fitted through the pipe test section at equal distance (pitch) of 80 mm.



Figure 7. Part Two

Figure 8.Tube with Rings having Middle Arm Results and Discussion Temperature Distribution

Figure (9), shows contour of temperature distribution for smooth tube at surrounding air temperature (673Ko) and coolant air flow velocity (Re=24253). It was shown that cooling air temperature at tube center line remains un effected to the tube



Figure (10), shows contour of temperature distribution for tube ribbed with ribs having middle arm. It was shown that air bulk temperature at the tube center line seems to be un effected until (0.584) then suddenly increased to be (336Ko) and be maximum value at the tube end (400Ko). Air temperature distribution is to be uniform elevated at last segment (beginning at 0.88 to the exit). Rings of middle arm generate disturbance then circulation will occur to enhance the heat transfer rate.



Fig 10. Contour of Temperature Distribution for Tube with Middle Arm

Fig.(11), represents variation of cooling air temperature at tube centerline with distance for tube supplied with ribs having middle arm. Cooling air temperature with the presence of ribs be larger than the case of smooth tube, the difference between the inlet and outlet temperature for smooth tube be (0.296Ko) and (100.318Ko) for using ribs.



Fig 11. Temperature Distribution Along the Tube Center line for Tube Having Middle Arm

Figure (12), shows temperature distribution in the inner wall tube surface for tube with ribs having middle arm obtained from FLUENT, at constant surrounding air temperature of (673Ko) and coolant air flow velocity (Re=24253). It was shown that using ribs lead to reduce the inner wall tube surface.



Fig 12. Temperature Distribution in the Inner Tube Surface

Velocity Distribution

Figure (13), shows contour of Velocity distribution for smooth case at surrounding air temperature (673Ko) and coolant air flow velocity (Re=24253). It was shown that cooling air velocity at tube center line remains un effected to the tube exit.



Fig 13. Contour of Velocity Distribution for Smooth Case

Figure (14), represents contour of velocity distribution through a tube fitted with ribs having middle arm, for coolant air velocity (Re=24253), inlet coolant air temperature (300 Ko) and surrounding air temperature (673 Ko), the coolant air flow velocity was accelerated and decelerated through the tube, due to contraction and expansion for using these ribs. The coolant air fluid flow seems to be spiral flow.



Fig 14. Contour of Velocity Distribution

Figure (15), represents variation of velocity distribution along the tube centerline, it was shown that using ribs with middle arms lead to enhance the velocity distribution.



Fig 15. Velocity Distribution Along the Tube centerline Figure (16), shows velocity vector for smooth tube at coolant air flow velocity (Re=24253) and surrounding air





Figure (17), shows velocity vector through a tube fitted with ribs having middle, for coolant air velocity (Re=24253), inlet coolant air temperature (300 Ko) and surrounding air temperature (673 Ko). The presence of ribs caused in flow separation and reattachment. The boundary layer is disturbed and the turbulence of flow increases due to separation and reattachment. This mixes the fluid parts near the wall with the cooler ones in the middle of flow. The two fluid phenomena causes enhancement in heat transfer [13].



Fig 17. Velocity Vector Through the Tube with Ribs Having Middle Arm

Comparison Between Experimental and Numerical Results

Figures(18), represents comparison between numerical and experimental temperature distribution along the tube center line for tube with ribs having middle arm at constant surrounding air temperature (673Ko) and coolant air flow velocity (Re=24253). A good agreement between numerical and experimental bulk temperature distribution.



Fig 18. Temperature Distribution Along the Tube Center line for Case6

Figure (19), represents comparison between numerical and experimental temperature distribution in the inner tube surface for tube with ribs having middle arm at constant surrounding air temperature (673Ko) and coolant air flow velocity (Re=24253). A good agreement between numerical and experimental temperature distribution.



Fig 19. Temperature Distribution in the Inner Wall Surface for Tube with Ribs Having Middle Arm

Figure (20), shows comparison between numerical and experimental values of the average Nusselt number with the presence of ribs to the Dittus-Boelter correlation as a function of Reynolds number at environment condition of constant surrounding temperature of (973Ko). A good agreement between numerical and experimental results of the average Nusselt number to the correlation as a function of Reynolds number.



Fig 20. Average Nusselt Numbers Normalized with Dittus-Boelter Correlation for Tube with Ribs Having Middle Arm Conclusions

In the present work, an experimental and numerical study was performed, with the aim to assess the effect of using special ribs on temperature distributions along a horizontal pipe. The main conclusions are: 1. Heat transfer was enhanced by geometrical modification for ribs with middle arm, at constant environment air temperature of 673Ko and coolant air flow of Re=24253, to be ΔT = 79.994Ko.

2. Using ribs gave more heat transfer enhancement than the plain tube (without ribs) due to turbulence caused by flow separation behind the ribs and the formation of vortices in the air flow between the ribs and the pipe wall.

3. Average Nusselt Number is increased with increasing Reynolds Number.

4. The theoretical results for bulk temperature distribution were compared with experimental and showed a good agreement by factor of 0.9% as shown in fig.(18).

5. The theoretical results for inner wall temperature distribution were compared with experimental and showed a good agreement by factor of 1% as shown in fig.(19).

6. The theoretical results for average Nusselt number were compared with experimental and showed a good agreement by factor of 0.8% as shown in fig.(20).

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