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Numerical Investigation of Heat Transfer Enhancement in a Circular Tube with Rectangular Opened Rings

Arkan Altaie*[1], Moayed R. Hasan[2], Farhan Lafta Rashid[3]
University of Technology-Iraq
*Corresponding author, email: arkanaltaie@yahoo.com[1], uotmed_deputy@yahoo.com[2], engfarhan71@gmail.com[3]

Abstract

Turbulent forced convection of coolant air flow (10 m/s velocity) in a steel tube of 50 cm long having outside diameter of 60 mm and inside diameter of 30 mm with constant outside surface temperature of 1000, 1200 and 1400 K^o is numerically analyzed. The renormalization group k-ε model is used to simulate turbulence in ANSYS - FLUENT 14.5. An opened ring of rectangular cross section (5x7 mm) is fitted in the tube and separated by 8cm pitch. Results of temperature and velocity distribution along the tube center line for the case of tube with internal ribs were compared with that of plain tube , these results show that the use of internal ribs enhance the heat transfer rate and found to possess the highest performance factors for turbulent flow.

Keywords*: heat transfer enhancement, cooling enhancement, internal ribs, turbulators and turbulent flow*

1. Introduction

Shell-and-tube heat-exchangers are extensively used in various industrial fields such as petrochemical industry, power generation, air-conditioning, etc. In those devices, heat is transferred from the hot side to the cold side via the tube walls. In cases of low heat transfer rate, additional approaches are necessary to intensify the heat transfer process. Scientists and engineers around the world have made great contributions to heat transfer augmentation techniques [1].

Heat transfer enhancement (HTE) techniques can be classified as [2]: 1) reducing thermal boundary layer thickness; 2) increasing disturbance between fluid and surface; 3) extending heat transfer surface; and 4) treating heat transfer surface. Those techniques are all based on heat transfer surfaces or fluid near the surfaces, therefore, they are called boundary or surface enhancement techniques [3].

Heat transfer enhancement techniques play a vital role for laminar flow heat transfer since the heat transfer coefficients are generally low for laminar flow in plain tubes [5, 9, 31, 32, 42]. The heat transfer rate can be improved by introducing a disturbance in the fluid flow, which can be achieved by with the twisted tape/turbulator insert in circular tube. Insertion of turbulators in the flow passage is one of the favourable Passive heat transfer augmentation techniques due to their advantages of easy fabrication, operation as well as low maintenance [4].

V. Kongkaitpaiboon et al. [5] reported an experimental investigation of heat transfer and turbulent flow friction in a tube fitted with perforated conical-rings.

M.R. Salimpour and S. Yarmohammadi [6] have been conducted an experimental investigation to find the influence of twisted tape inserts on the pressure drop during forced convective condensation of R- 404A vapor in a horizontal tube. The tube set 5 with twist ratio of 4 has the highest pressure drop. Reduction in twist ratio induces higher turbulence intensity in liquid film and vapor core.

Piroz Zamankhan [7] has been developed a 3D mathematical model to investigate the heat transfer augmentation in a circular tube with a helical turbulator.

A. Durmus et al. [8] investigated the effect of propeller type turbulators which were located in the laminar pipe of co axial heat exchanger.

Smith Eiamsa-ard and Pongjet Promvonge [9] have been conducted the experiments to investigate the heat transfer and friction factor characteristics of the fully developed turbulent

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airflow through a uniform heat flux tube fitted with diamond-shaped turbulators in tandem arrangements.

Shashank S. Choudhari and S.G. Taji [10] have been studied the experimental investigation of the heat transfer and friction factor characteristics of a double pipe heat exchanger fitted with coil wire insert made up of three different material as copper, aluminum and stainless steel and different pitches for Reynolds number in range of 4000-13000.

In this paper, a new design of ribs (opened rings with rectangular cross section) fitted in a pipe with internal cooling air flow and constant wall surface temperature.

2. Theoretical Model and Numerical Solution

The computational fluid dynamics (CFD) becomes one of the most useful tools for complex phenomena without resorting to expensive prototype and difficult experimental measurement. Numerical prediction using **FLUENT** can be performed to determine the temperature distribution and for better understanding the losses of heat transfer. The flow may be considered incompressible as velocity tends to be constant. Like many common fluids such as water, air is a Newtonian fluid, displaying a linear relationship between shear and strain.

This study solves the interaction of coolant air with configuration of ribs. To demonstrate the effect of the turbulence model that involves the solution of two transport equation (***K*-ε**) model is used, thus the numerical techniques will solve these Cartesian coordinate system. Three dimensional geometries are generated and the effects of ribs shape are to be studied. **FLUENT** version (14.5), **GAMBIT** software will be used to create, grid for the system geometry and then simulate the heat transfer outlet from the pipes for the seven geometry model.

Geometry of the Test Section

The test section shown in figure (1) is steel tube with outside diameter of 60 mm and inside diameter of 30 mm at which the coolant air flow in , and having steel opened ring (Ribs) of rectangular cross section (4mm width by 7mm height). The test section was drawn using AUTO CAD 2013.

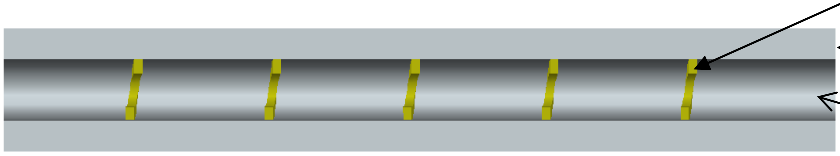


Figure 1. Geometry of the Test Section

3. Results and Discussion

Figures (2), (3), (4) show the contours of temperature distribution along the whole test section geometry at constant surface temperatures of 1000, 1200 and 1400 K^O, respectively.

Figure (5) shows the temperature distribution along the pipe center line for two cases, one without ribs and the other with ribs at surrounding surface temperature of 1000K^o. It shows that the pipe with ribs has highest outlet air temperature. This means that the pipe with ribs, has highest surface area resulted in enhancing the heat transfer. So an opened ring will generate swirls (more turbulent) that enhancing the heat transfer rate.

Figure (6) shows the temperature distribution along the pipe center line for two cases, one without ribs and the other with ribs at surrounding surface temperature of 1200K^o. It shows that the pipe with ribs has highest outlet air temperature. This means that the pipe with ribs, has highest surface area resulted in enhancing the heat transfer. So an opened ring will generate swirls (more turbulent) that enhancing the heat transfer rate.

Figure (7) shows the temperature distribution along the pipe center line for two cases, one without ribs and the other with ribs at surrounding surface temperature of 1400K^o. It shows that the pipe with ribs has highest outlet air temperature. This means that the pipe with ribs, has highest surface area resulted in enhancing the heat transfer. So an opened ring will generate swirls (more turbulent) that enhancing the heat transfer rate.

Figure (8) shows the velocity distribution along the pipe center line for two cases, one without ribs and the other with ribs at surrounding surface temperature of 1000 K^o. It shows that the pipe with internal ribs having more velocity distribution than the case of plain pipe. This because of the swirls generated from the use of ribs (opened rings).

Figure (9) shows the velocity distribution along the pipe center line for two cases, one without ribs and the other with ribs at surrounding surface temperature of 1200 K^o. It shows that the pipe with internal ribs having more velocity distribution than the case of plain pipe. This because of the swirls generated from the use of ribs (opened rings).

Figure (10) shows the velocity distribution along the pipe center line for two cases, one without ribs and the other with ribs at surrounding surface temperature of 1400 K^o. It shows that the pipe with internal ribs having more velocity distribution than the case of plain pipe. This because of the swirls generated from the use of ribs (opened rings).

4. Conclusions

In the present work, a numerical study was performed, with the aim to assess the effect of using ribs on temperature and velocity distributions along the pipe center line. The main conclusions are:

1. CFD predictions were shown to reproduce the enhancement in heat transfer for the use of internal ribs, with respect to the plain tube.
2. Pipe with ribs gave more velocity distribution than the plain pipe.
3. The temperature of the plain pipe was found to be approximately un affected for cases of 1000, 1200 and 1400 K^o. While when ribs are used, the effect was to increase the temperature by 455, 459, and 463 K for the cases above, respectively.

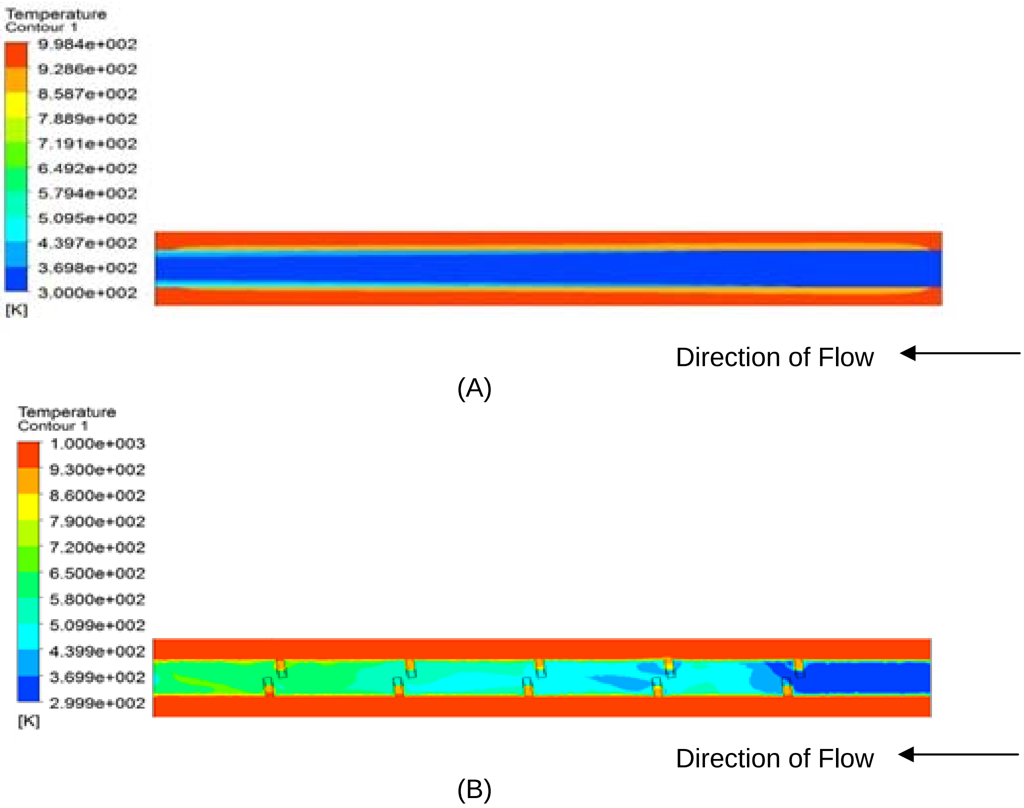
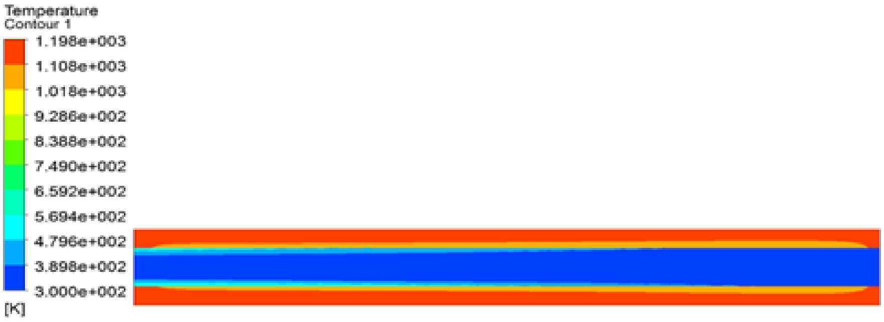
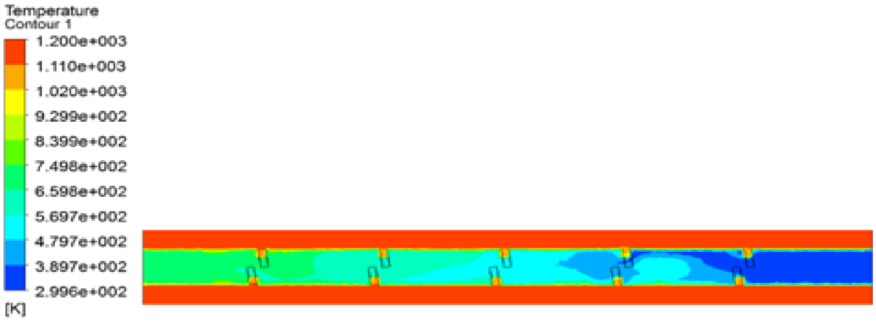


Figure 2. Contour of Temperature Distribution at Constant Surface Temperature (1000 k^o)
A: Without Ribs (Smooth) B: With Ribs



Direction of Flow ←

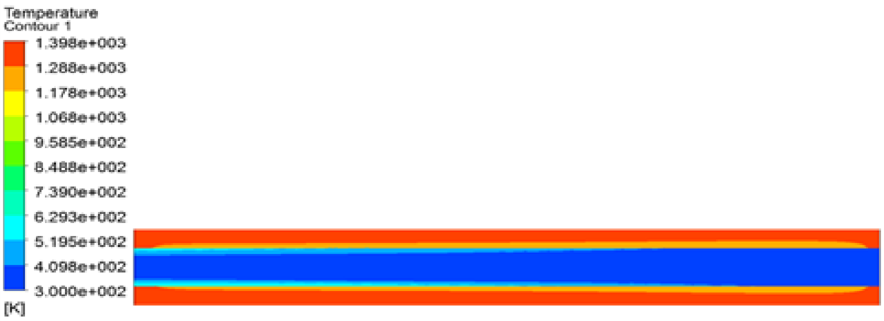
(A)



Direction of Flow ←

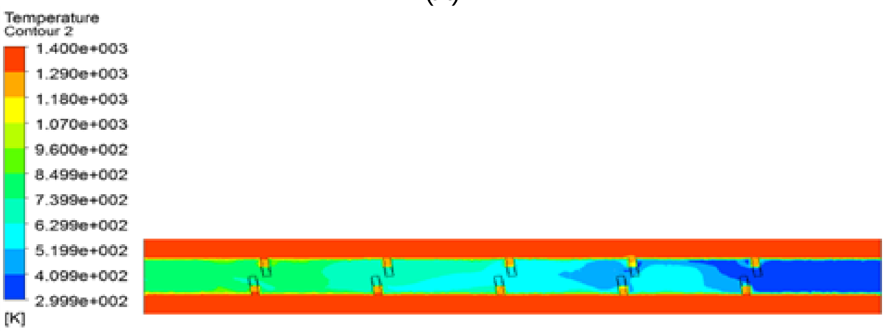
(B)

Figure 3. Contour of Temperature Distribution at Constant Surface Temperature (1200 k^{o})
A: Without Ribs (Smooth) B: With Ribs



Direction of Flow ←

(A)



Direction of Flow ←

(B)

Figure 4. Contour of Temperature Distribution at Constant Surface Temperature (1400 k^{o})
A: Without Ribs (Smooth) B: With Ribs

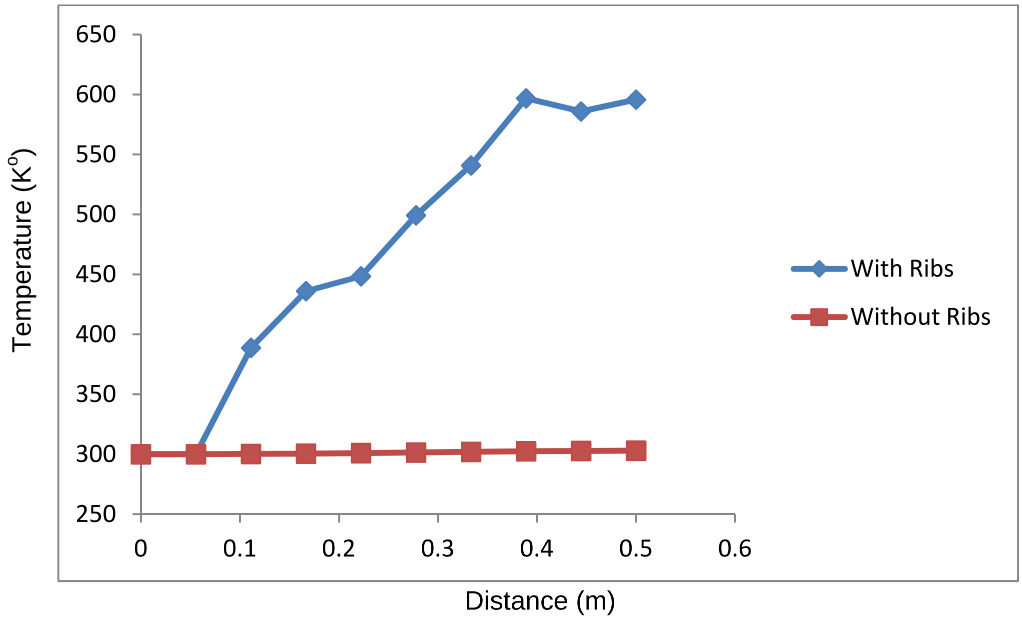


Figure 5. Variation of Temperature Along the Center line of Tube at Constant Surface Temperature (1000 K°)

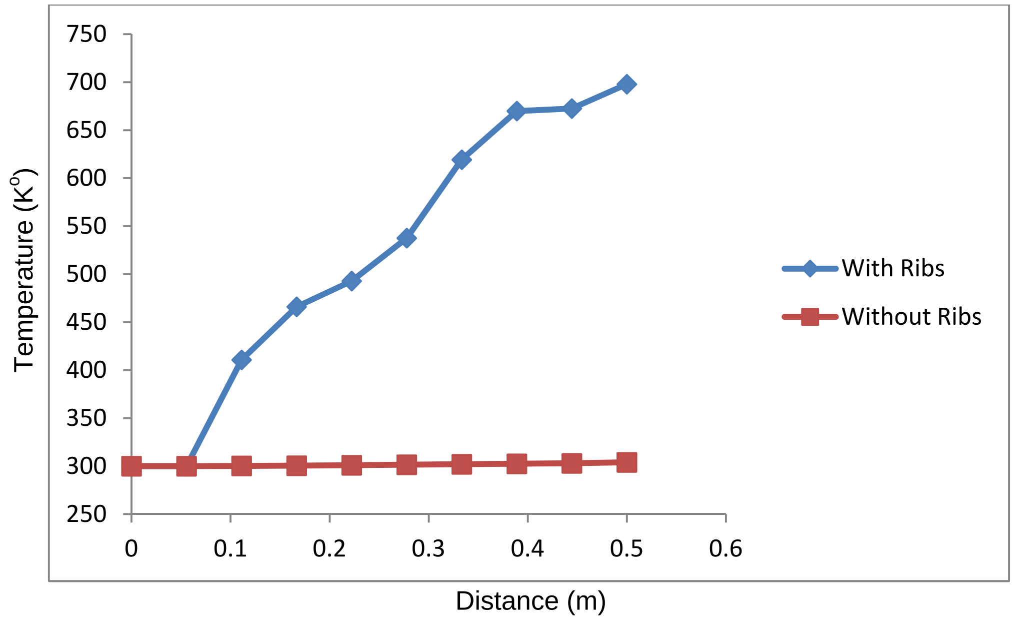


Figure 6. Variation of Temperature Along the Center line of Tube at Constant Surface Temperature (1200 K°)

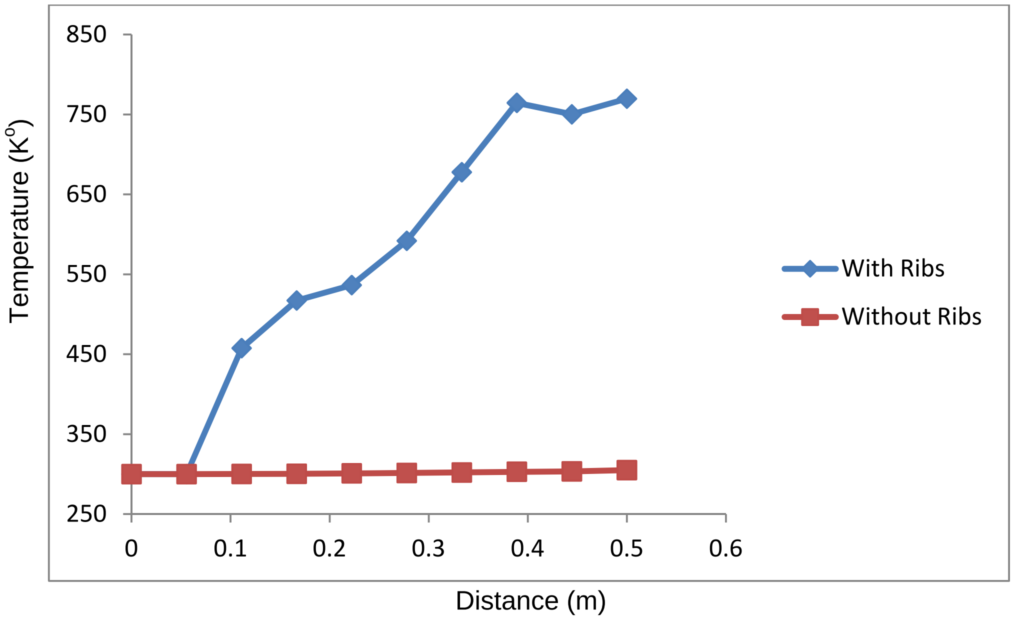


Figure 7. Variation of Temperature Along the Center line of Tube at Constant Surface Temperature (1400 K^o)

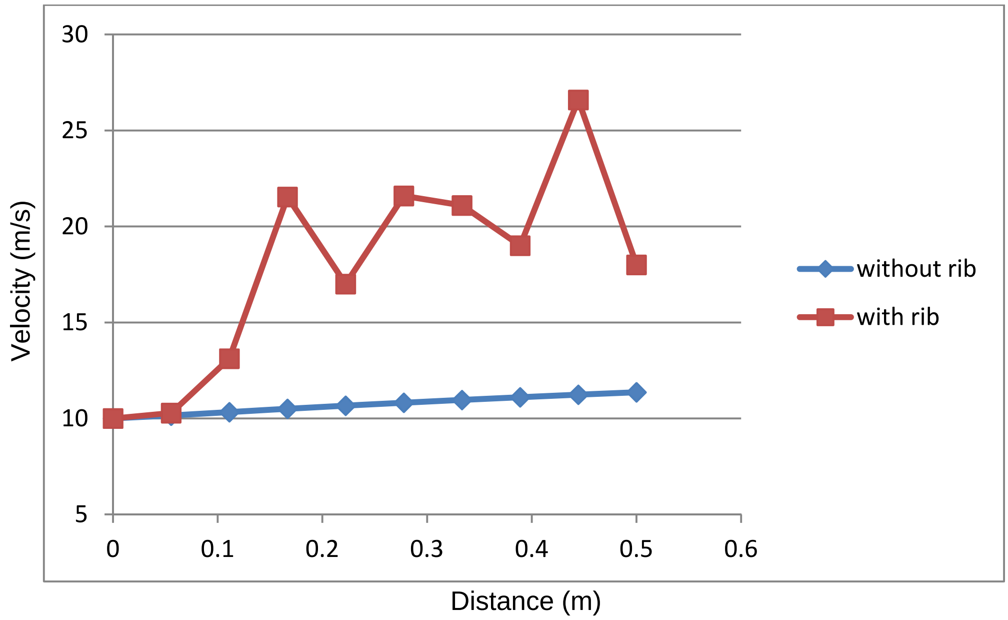


Figure 8. Variation of Air Velocity Along the Center line of Tube at Constant Surface Temperature (1000 K^o)

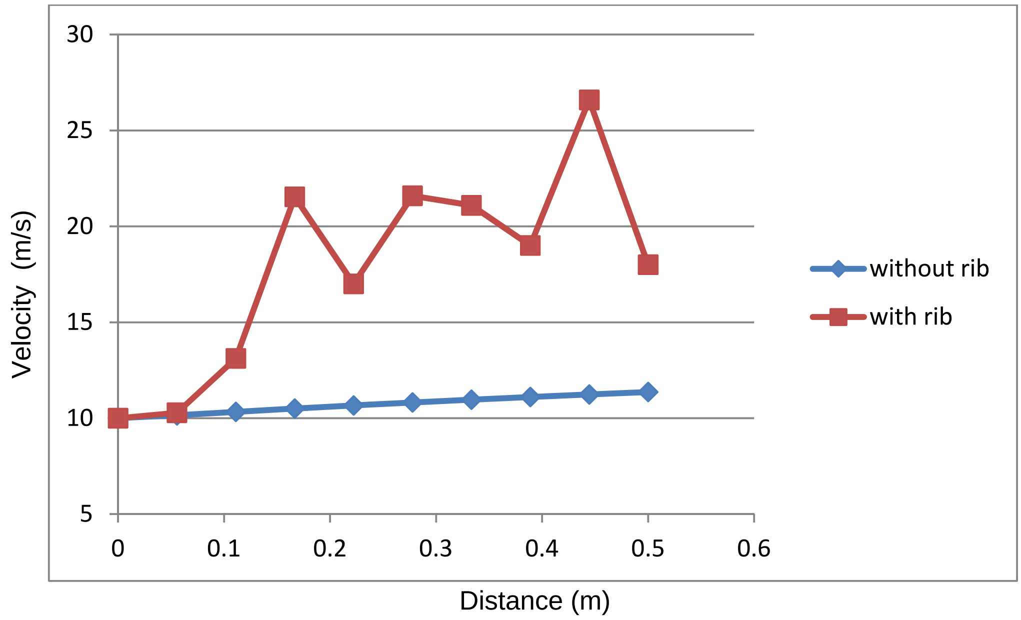


Figure 9. Variation of Air Velocity Along the Center line of Tube at Constant Surface Temperature (1200 K^o)

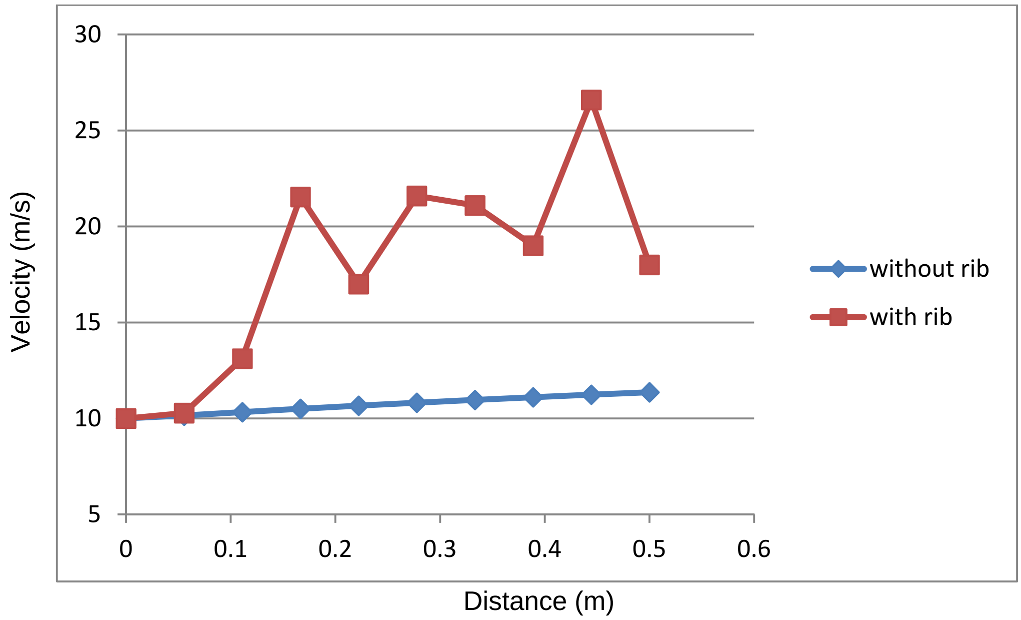


Figure 10. Variation of Air Velocity Along the Center line of Tube at Constant Surface Temperature (1400 K^o)

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