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Numerical Heat Transfer Analysis for Smooth and Roll-Worked Tube

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Abstract—*The objective of this study is to investigate numerically the behavior of the flow inside smooth and roll-worked tubes. Numerical simulation are performed using a CFD (FLUENT) for 2D configuration with smooth surface tube and roll-worked tube. Simulations were performed using 10 mm diameter and 50 mm long tubes with a constant heat flux (300 W/m^2). The wall temperature, mean temperature of fluid and Nusselt number variation has been studied for both and a comparison has been done between them. Considerable increase in both temperatures has been seen in case of roll-worked tube over smooth tube.*

Nomenclature

Table 1: Nomenclature

ρ	density (kg/m3)
u	velocity (kg/m-s)
p	pressure (Pa)
μ	Viscosity
k	thermal conductivity (W/m-2 K-1)
T	temperature (K)
e	internal energy

1. INTRODUCTION

Fluid flow in circular and non-circular pipes is commonly encountered in practice. Pipes and tubes used in boilers intended to cross through economizers to reduce energy consumption, or to perform useful function such as preheating a fluid. Thermal energy in a hydraulic space heating system is transferred to the circulating water in the boiler, and then it is transported to the desired locations through pipes. So our intention here is to reduce the energy loss to the surrounding and utilizing the complete input. Faghri & Sparrow [1] found that the wall conduction in the axial direction can take suitable amount of heat upstream into the non-directly heated portion of the tube. A little attention has been received for the interaction of wall mass transfer and heat transfer. Yuan and Finkelsten [2] carried out a perturbation solution for small injection rates to show the effect of a step change in tube wall temperature.

Kinney [3] computed the fully developed profiles for flow in a circular tube at constant wall temperature. G.Raithby [4] investigation deals with the problem of the thermal development in a region of fully developed velocity in rectangular and circular tubes for the both constant wall temperature and constant heat flux boundary condition.

Zhen-Hua Liu & Jie Yie [5] found experimentally the low cost roll-worked tube can greatly enhance the falling film evaporation heat transfer capacity as compared to other commercial enhanced tubes.

2. THEORETICAL AND NUMERICAL METHODOLOGIES ADOPTED

Motion of the liquid inside a circular pipe and rolled pipe is simulated in 2D using the FLUENT. Computational domain for smooth tube and rolled tube with boundary conditions is shown in Fig. 1 & Fig. 2.

The boundary conditions for fluid flow through inlet was set as velocity inlet, where fluid flows through tubes with velocity 0.1 m/s and right side boundary is set as pressure outlet. Bottom boundary taken as centerline due to axisymmetric case and top boundary set as heated wall.

Heat flux of 300 W/m^2 is given to the heated wall.

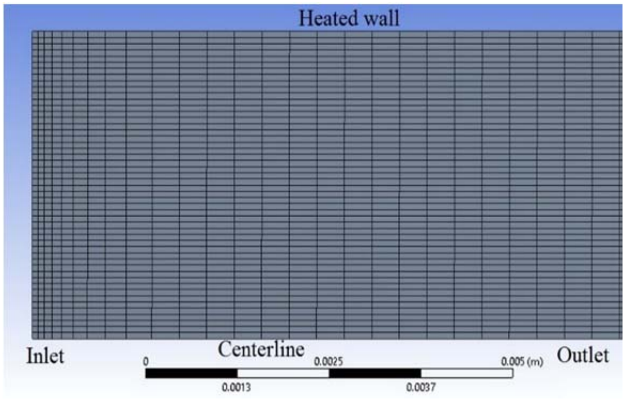

Fig. 1: Smooth tube domain with boundary conditions

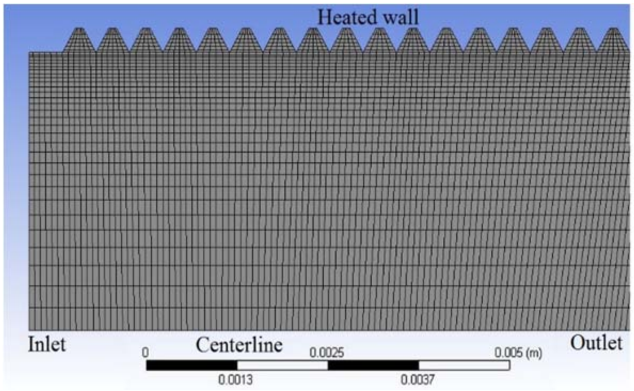

Fig. 2: Rolled tube with boundary conditions

Table 2: The numerical range of physical variable:

Parameter	Ranges
Tube diameter	10 mm
Tube length	50 mm
Fluid	Air
Fluid velocity	0.1 m/s
Heat flux	300 W/m2

2.1 Governing Equations

Following conservation equations for the mass, momentum and energy has been solved by the FLUENT [6].

Mass conservation equation

$$\nabla.\vec{\mathbf{u}} = 0$$

Momentum conservation equation

$$\left(\rho\vec{\mathbf{u}}\cdot\nabla\right)\vec{\mathbf{u}} = -\nabla p + \mu\nabla^2\vec{\mathbf{u}}$$

Energy conservation Equation

$$\nabla\cdot\left(\rho e u\right) = \nabla\cdot\left(k\nabla T\right)$$

2.2 Rolled Tube Surface Structure

Fig. 3 shows the dimension and photograph of the roll-worked tube with surface structure's dimensions. The pitch is taken as 0.6 mm with height 0.4 mm and apex angle 60°.

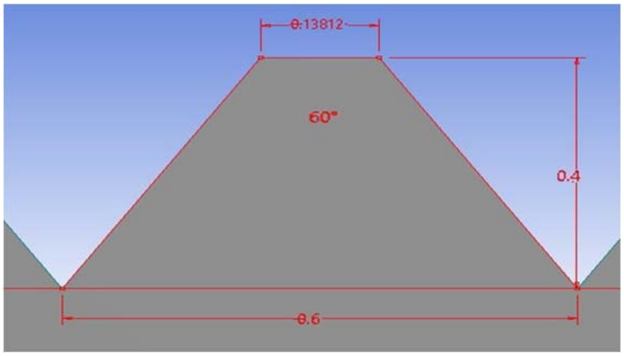

Fig. 3: Photograph and dimension of roll-worked tube (all units are in mm)

3. NUMERICAL RESULTS AND DISCUSSION

3.1 Wall temperature of fluid along the tube length

In case of rolled tube the increase in the wall temperature is more prominent than smooth tube as shown in Fig. 4.

3.2 Effect on mean temperature of fluid

Variation in mean temperature inside the tube due to mixing of the fluid in case of rolled tube has greater change in temperature than smooth tube as shown in Fig. 5.

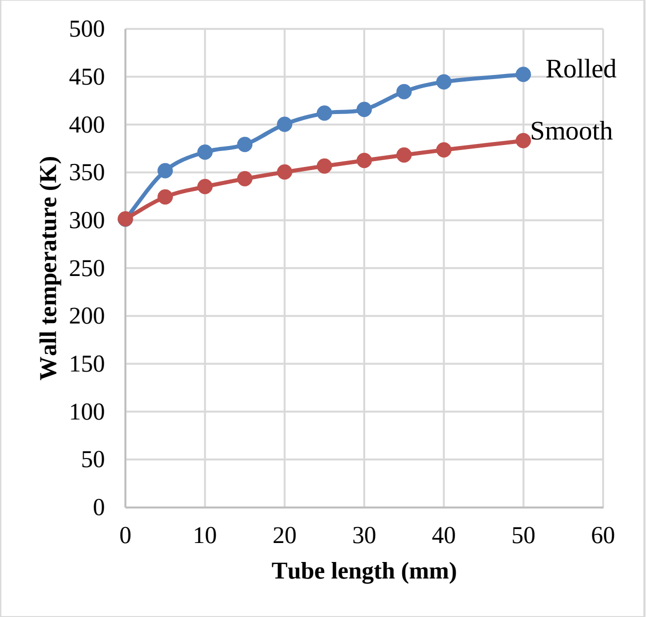

Fig. 4: Wall temperature variation along tube length for rolled and smooth tube

3.3 Effect on Nu along the tube length

Heat transfer coefficient and Nusselt number are supplementary to each other. Hence instead of heat transfer coefficient a non-dimensional number (Nu) is used for further comparison. Fig. 6 shows the variation of Nusselt number along the tube length.

3.4 Temperature contour

Thermal entrance region for both tube has been calculated by Fluent and found to be in good agreement with the expression for laminar flow thermal entry length [7].

$$\left(\frac{x_{fd,t}}{D}\right)_{lam} \approx 0.05\,\mathrm{Re}_D\,\mathrm{Pr}$$

Thermal entry length for rolled and smooth tube are 25.15 mm and 26.56 mm. Temperature change inside both pipes can be understood easily by temperature contour shown Fig.7 and Fig. 8.

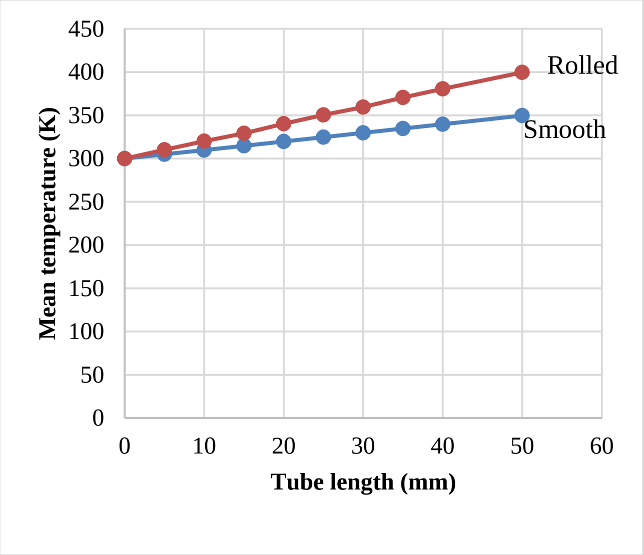

Fig. 5: Mean temperature variation along tube length for rolled and smooth tube

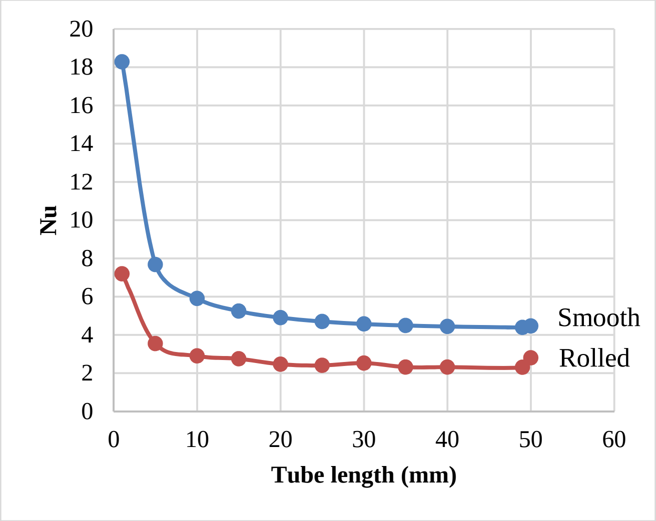

Fig. 6: Nu variation along the tube length for rolled and smooth tube

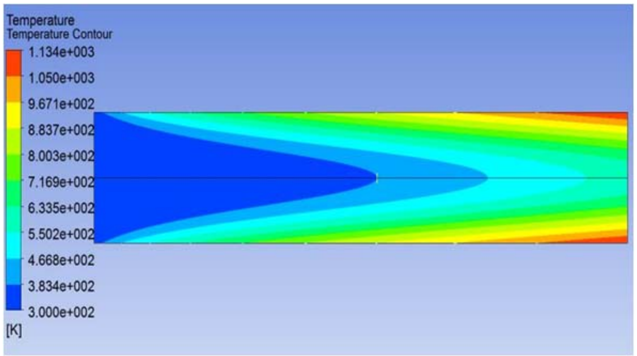

Fig. 7: Temperature contour for smooth tube

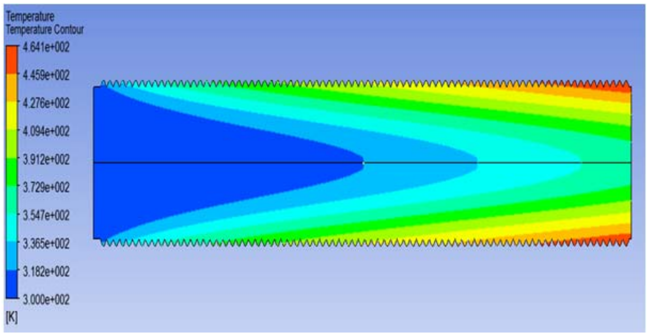

Fig. 8: Temperature contour for rolled tube

4. CONCLUSION

Numerical simulations were performed on smooth and roll-worked tube to study heat transfer characteristics. The analysis suggest the following conclusion:

1. It is concluded that the effect of uniform heat flux on the rate of heat transfer in pipes is most marked near the wall region.
2. Mixing of the fluid in case of rolled worked tube is more hence results in greater mean temperature of the fluid.
3. Thermal entry length for rolled tube is less compared to smooth tube results in more mean temperature and hence small Nusselt number.

5. ACKNOWLEDGEMENTS

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