ANALYSIS OF HEAT TRANSFER IN A HEATED TUBE WITH A DIFFERENT TYPED DISC INSERTION

by

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Heat transfer and fluid flow can be controlled in a tube by inserting different typed passive elements. The main objective of this study is to control heat transfer and fluid flow using cutting edged disc in pipe. Governing equations of laminar, two-dimensional flow is solved via finite volume technique. The disc is adiabatic and its thickness is 5mm. It is located into axial axis of the tube. Three cases were applied based on the type of the disc as inclination angle of the top side is 45^o and 0 ^{o}. Calculations were performed for different Reynolds number in the range of 335 < Re < 845. Three cases were tested based on types of discs. It is observed that each position exhibits different heat transfer ratio according to studied Reynolds number. The highest heat transfer is formed when inlet flow impinges to flat side of the cutting edged baffle.

Keywords: *Heat transfer enhancement, disc, numeric, fluid flow*

1. Introduction

Heat transfer enhancement techniques are very important to save more energy and using of optimal energy sources. Heat transfer enhancement techniques are mainly divided into two clases as passive and active techniques. The passive techniques have been usually preferred by many researchers since no additional external power is required as extended surfaces, rough surfaces and swirl flow devices. Coiled wire insert is one of the passive heat transfer enhancement techniques, which is extensively used in various heat transfer applications such as, air conditioning and refrigeration systems, heat recovery processes, food and dairy processes, chemical process plants. The wire coil is quite simple to manufacture, to insert and remove from the tube which, therefore, justifies its usage in heat transfer enhancement Webb et al., [1], Bergles, [2], Bergles [3], Webb and Kim, [4] and Webb, [5].

A study on heat transfer enhancement is performed tried to enhance heat transfer in a tube with equilateral triangle cross sectioned coiled wire inserts Günes et al. [6]. They made several experiments to do this. They indicated that the highest overall enhancement efficiency of 36.5% is achieved for the wire at Reynolds number of 3858. Consequently, the experimental results reveal that the best operating regime of all coiled wire inserts is detected at low Reynolds number, leading to more compact heat exchanger. In another study, delta-

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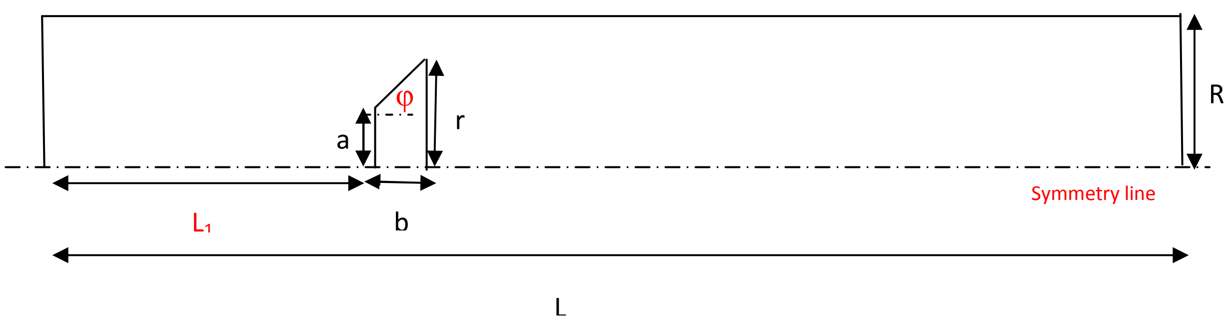
winglet twisted tape inserts was used to enhance heat transfer in a tube [7]. They found that he values of Nusselts number and friction factor in the test tube equipped with delta-winglet twisted tape are noticeably higher than those in the plain tube and also tube equipped with typical twisted tape. Investigation of heat transfer enhancement in a tube with an inner tube insertion was made numerically and experimentally by Fu and Ching [8] and Fu et al. [9], respectively. Both studies indicate that heat enhances by inserting a inner tube. Oztop and Dagtekin [10] studied the effects of contraction-expansion-contraction (CEC) pipe insertion in a pipe. They observed that the fluid deviates the outside pipe wall due to insertion of CEC pipe. Varol [11] numerically analysed the ring like body inserted tubes with different positions and he tried to find optimum position for heat and fluid flow. Nguyen et al. [12] prepared a numerical code to solve conjugate heat transfer and fluid flow in rib roughened tube. They indicated that thermal conductivity value is an important parameter on temperature distribution and heat transfer. Fu and Tong [13] made a numerical work on heat transfer rate of heated walls in a channel with an oscillating cylinder. An arbitrary Lagrangian-Eularian kinematic description method is applied. It is shown that the position and the diameter of the cylinder in the cylinder have great effects on the flow and thermal fields. Other related studies can be found in Promvonge et al. [14] and Yu et al. [15].

The main objective of this study is to present heat transfer and fluid flow in a method sharp edged disc inserted pipes. Based on brief above review and authors' knowledge, the inserted geometry did not studied in earlier works using a numerical technique. Results will be presented in next parts with pressure contours, velocity contours, temperature distribution, heat transfer and temperature and velocity profiles.

2. *Problem Definition*

Physical model of considered problem is depicted in Fig. 1. In this figure, a pipe with 2m length and 40mm diameter are chosen and a sharp edged disc were inserted its center. The location of center of disc is taken as 0.5m from inlet. In Fig. 1 (a), a, b, r and R stand for short side of the disc, thickness of the disc, tall side of the disc and radius of the pipe, respectively. Its thickness is 5mm. and thermal conductivity of disc material is chosen as very low. Physically the disc is fixed using a very thin rope which is not disturbed the flow. Thickness of pipe wall is accepted as very thin. Thus, conduction heat transfer along pipe wall is neglected. Air was chosen as working fluid and its properties are chosen as ρ= 1,225 kg/m3, Cp= 1006,43 J/kgK and ν= 1,78.10-5. Diameter of the pipe is taken as 30mm.



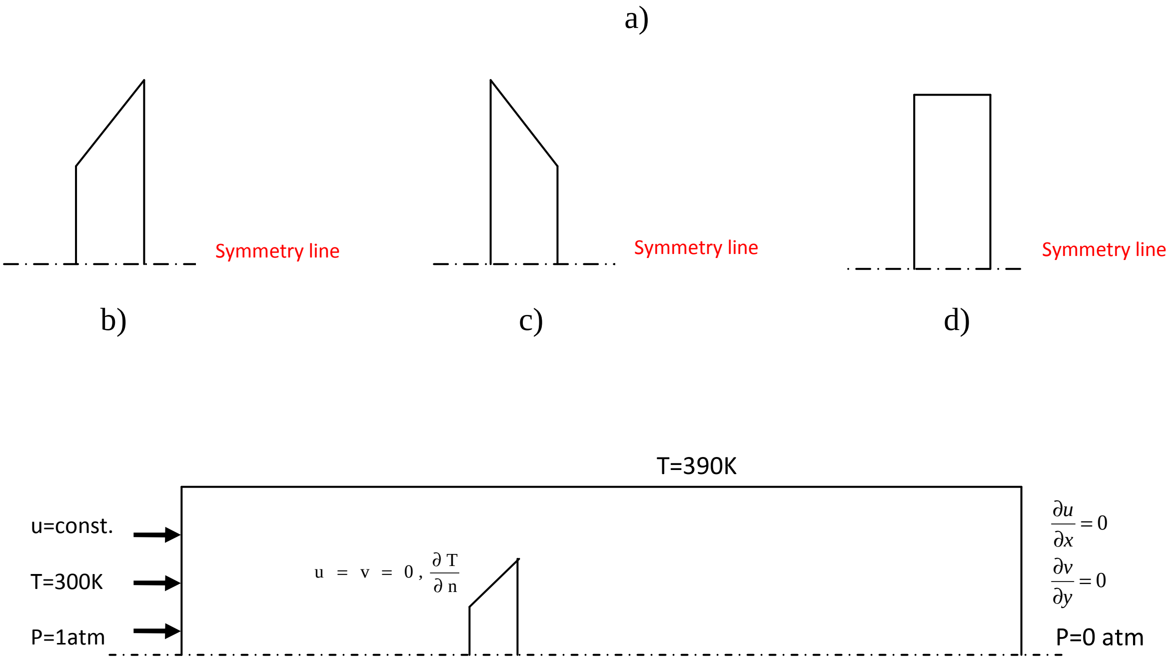


Fig. 1. Physical model, a) Pipe with inner body, b) Case I, c) Case II, d) Case III, e) boundary conditions

3. *Governing Equations and solution*

Governing equations as continuity, x and y momentum and energy are written in cylindrical coordinates by considering incompressible flow, neglecting of radiation of heat transfer and buoyancy forces, steady-state and laminar flow conditions. Thus, equations are,

$$\frac{\partial u}{\partial x}+\frac{1}{r}\frac{\partial}{\partial r}(rv)=0 \tag{1}$$

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial r}\right)=-\frac{\partial P}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial r^2}+\frac{1}{r}\frac{\partial u}{\partial r}\right) \tag{2}$$

$$\rho\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial r}\right)=-\frac{\partial P}{\partial r}\,\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial r^2}+\frac{1}{r}\frac{\partial v}{\partial r}-\frac{v}{r^2}\right) \tag{3}$$

$$\rho C_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial r}\right)=k\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}\right) \tag{4}$$

The boundary conditions assume no-slip conditions for velocity on the surfaces and the passive element. Symmetrical solution is adopted. Velocity and temperature is uniform at the inlet and temperature boundary condition is also constant on the pipe wall. The physical properties of the air have been assumed to remain constant at average bulk temperature. Thus, Prandtl number is taken as 0.72 for whole cases. Velocity is hydrodynamically developed at the pipe exit. Disc is assumed as adiabatic for all cases. Boundary conditions can be defined mathematically as

At the inlet $u = const, T = const.$ and $P = const.$ (5)

At the block $u=v=0, \frac{\partial T}{\partial n}=0$ (6)

At the exit $\frac{\partial u}{\partial x}=\frac{\partial v}{\partial y}=0, P=0$ (7)

At the top wall $u=v=0, T = const.$ (8)

Governing equations were solved by Finite volume method of Patankar [17]. SIMPLE solution algorithm was applied. Fluent Commercial Code [18] was used to solve governing equations and simulate the results. The discretization scheme used is hybrid for the convective terms in the momentum and energy equations, and the SIMPLE algorithm for pressure-velocity coupling. The mesh for considered model is generated in the Gambit 2.1.6 preprocessor [19]. Thus, a grid independent solution was performed for 10000 nodes. Convergence criteria is taken as 10^{-6} and 10^{-3} for energy and other parameters, respectively. Convergence is obtained after 200 iterations. Local and average Nusselt numbers are calculated as

$$Nu_l = \frac{h_l L}{k}, \quad Nu = Nu_l \, dy \tag{9}$$

4. Results and Discussion

A numerical work has been performed to investigate the effects of sharp edged disc insertion in a pipe on heat transfer and fluid flow. Three different discs were used to make this analysis. The study was performed for different Reynolds number as Re = 335, 590 and 845. Pressure contours, velocity contours, isotherms, velocity and temperature profiles will be presented in next part of the study. Validation of computers code was made with literature. Trend is similar between two works but they are little difference near the inlet due to different acceptations.

Fig. 3 (a) to (c) illustrates the velocity contours for the same Reynolds number and compares the effects of used types of discs. The flow is maximum near the center of the body and it is almost zero near the impinged region to the disc. Thus, a stagnation point is occurred at the middle but it is difficult to see it on Fig. 3 (a). The flow goes from top inclined part of the disc and it impinges to the top wall of the pipe. Due to acceleration of the fluid between disc and pipe wall a maximum flow velocity is occurred. Results are shown for sharp edged disc is located as in Fig. 3 (b), the maximum velocity is occurred only at the edge of the disc. Isotherms are presented in Fig. 4 for the same case with velocity contours (Fig. 3). It is noted that the fluid inlets to the duct with lower temperature than that of heated boundary. The boundary is heated under constant temperature and the disc is taken as adiabatic. As seen from the figure, the fluid is heated after the disc depends of the types of the inner disc. The disc types affect the temperature at the upstream of the channel. Fig. 5 presents the isotherms for three different case at Re = 590. Temperature distribution for different cases are presented for Re = 845 in Fig. 6. Both of these figures indicate that thinner temperature boundary layer is obtained with the presence of baffle. The thermal boundary layer becomes thinner with further increasing of Reynolds number. For Re = 845, the flow in front of baffle becomes cold then, a dome typed temperature layer is observed around the baffle. Velocity and temperature profiles for Case I are shown in Fig. 7 (a), (b) and (c) for Re = 335, 590 and 845, respectively. Flow is developed at the exit of the duct. The profile is seen around L = 0.8m. For Re = 845, higher velocity values are obtained for Re = 845. Variation of velocity becomes almost constant at L = 0.4m with increasing of Reynolds number. Similarly, Fig. 8 is plotted to give temperature profiles for Case II at different location of pipe length directions and Reynolds number. Temperature values are almost constant at the exit for the lowest value of Reynolds number. Flow is heated along the duct. There is huge difference on temperature between L = 0.4 and L = 0.8. In a similar manner, Fig. 9 gives the profiles for Case III. The trend is almost same with earlier profiles but values are different from each other depends on the pipe length. Fig. 10 presents the variation of local Nusselt numbers along the pipe. Heat transfer increases around the inserted baffle and this increment becomes higher with increasing of Reynolds number. Higher increment is formed at Case III.

Table 1. Variation of mean Nusselt number with Reynolds number

Re	Case I	Case II	Case III
335	12.71057	12.69113	12.73672
590	21.49988	21.63115	21.66167
845	30.94855	31.46152	31.40339

5. Conclusions

A numerical study has been performed to examine the heat transfer and fluid flow in a sharp-edged disc inserted channel with different Reynolds numbers. Three types of disc are studied to see the effects of discs on temperature distribution, flow field and heat transfer. It is found that both flow and heat transfer can exhibit different behavior at the same value of Reynolds number. Case II presents the best results on heat transfer at the highest Reynolds number. For low Reynolds number, Case III gives the better results. A sharp-edged disc can be a good control element for heat transfer and fluid flow.

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Nomenclature

A - actual flow area [m^2]

a - short side of the disc

b - disc thickness

C_p - spesific heat capacity of air [J/kgK]

D - diameter of pipe [m]

h - convection coefficient [W/m^2K]

k - thermal conductivity [W/(mK)]

L - length of pipe [m]

Nu - Nusselt number (hL/k) [-]

n - any coordinate

P - pressure [N/m^2]

Pr - Prandtl number (=ν/α) [-]

L_1 - location of disc distance from inlet [m]

r - tall side of the disc, radial coordinate

R - disc radius

Re - Reynolds number (uD/ν) [-]

T - temperature [K]

u, v - velocities [m/s]

Greek letters

μ - dynamic viscosity [kg/ms]

ρ - fluid density [kg/m^3]

φ - Inclination angle of the disc [°]

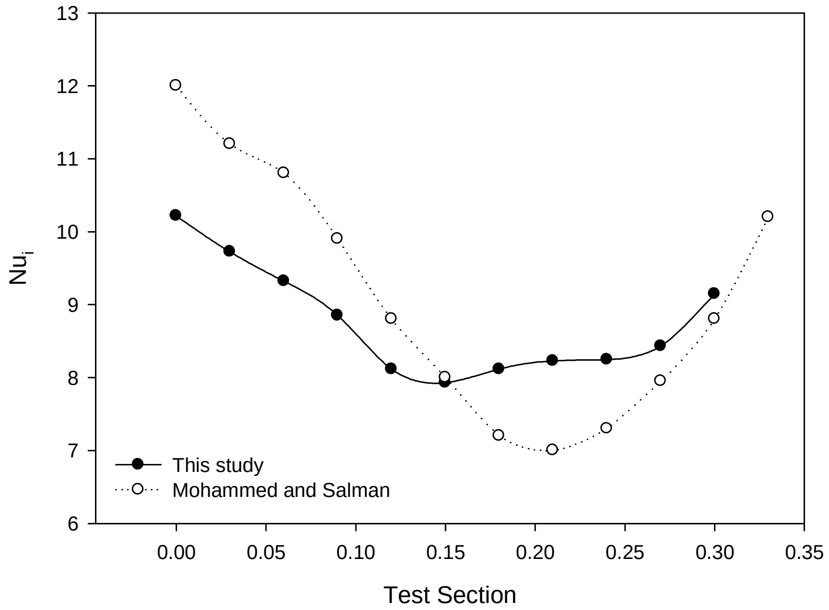


Fig. 2. Comparison of local Nusselt number with literature [20].

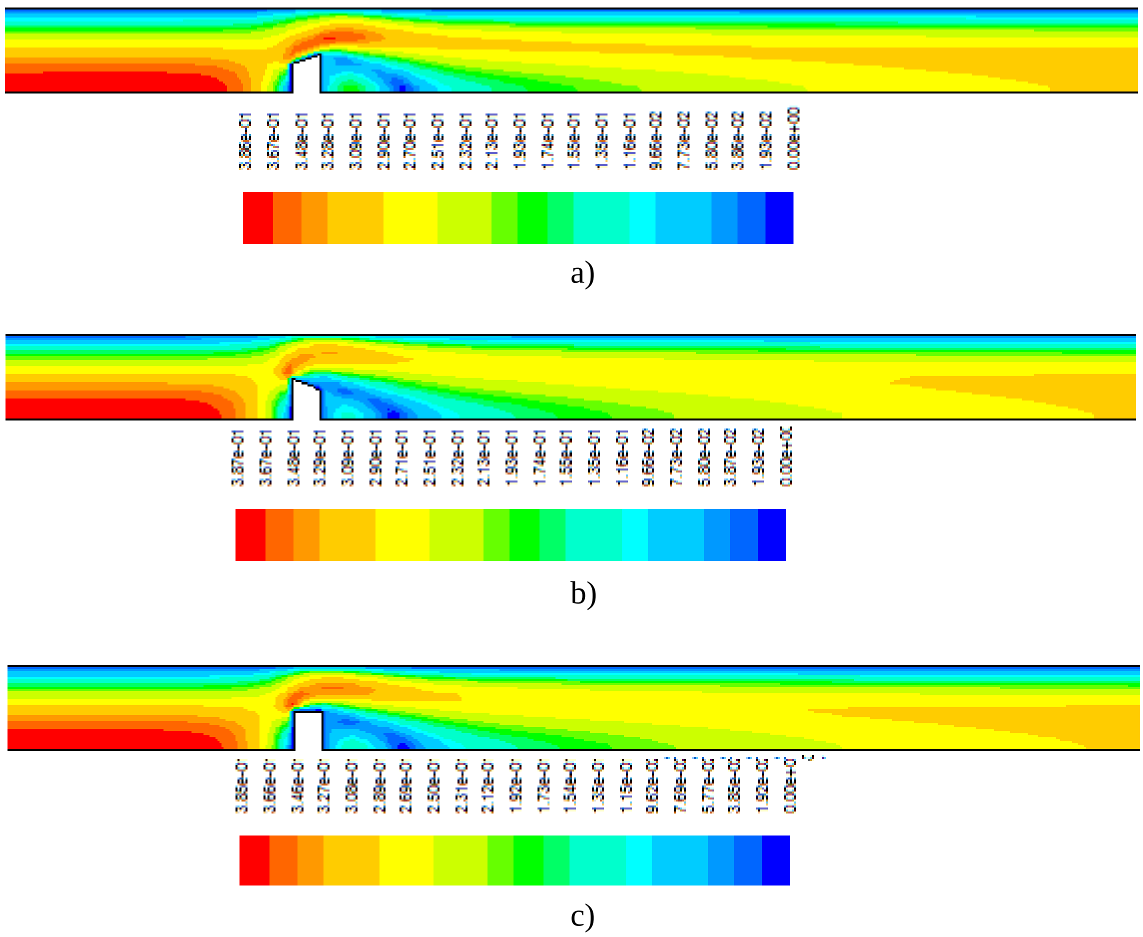
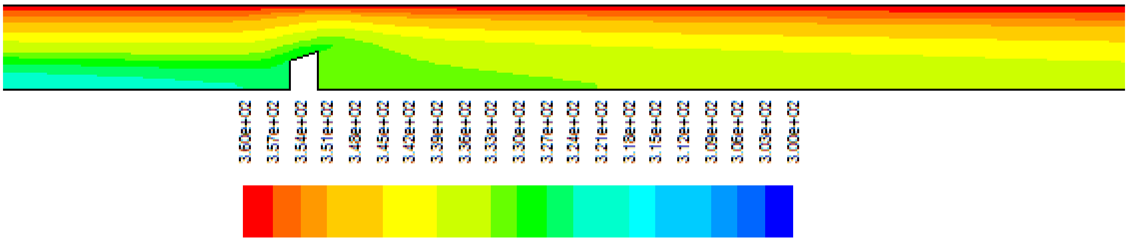


Fig. 3. Velocity contours for three different cases, (Re = 335), a) Case I, b) Case II, c)

Case III



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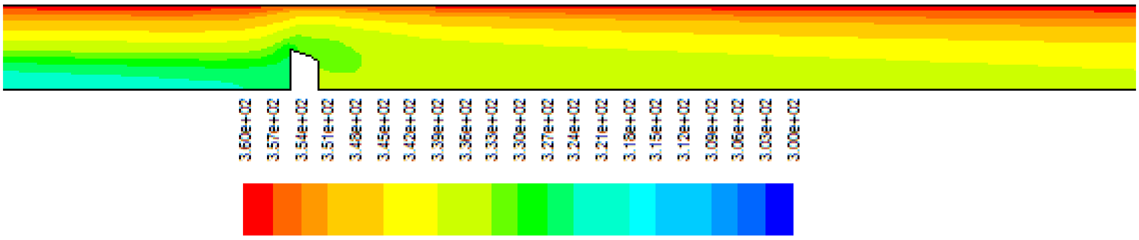

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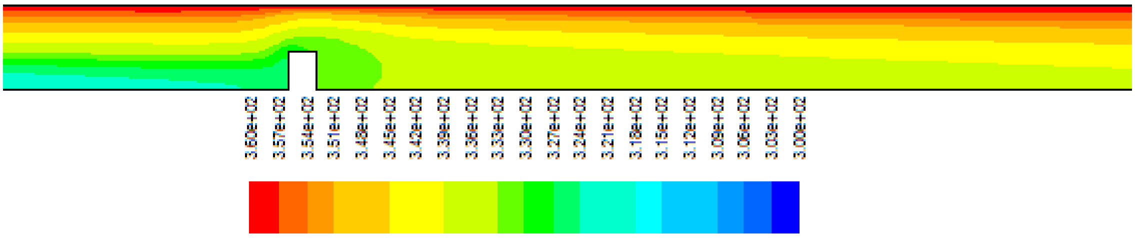

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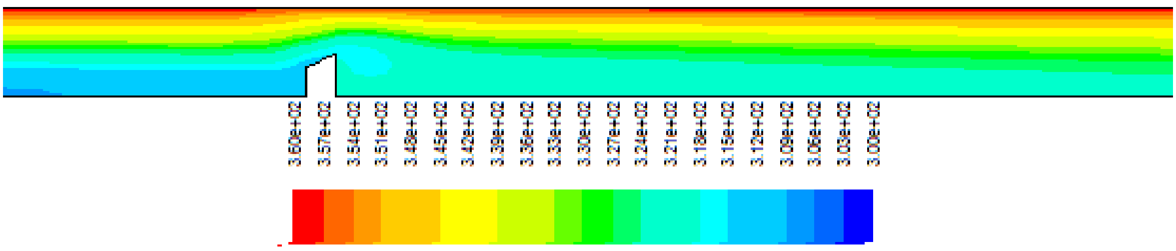
Fig.4. Isotherms for three different cases, (Re =335), a) Case I, b) Case II, c) Case III



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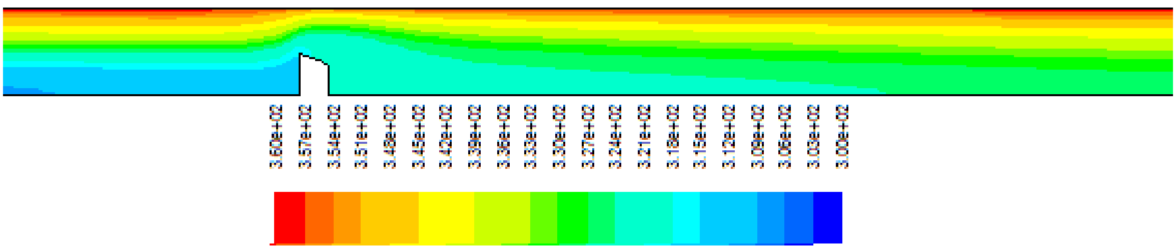

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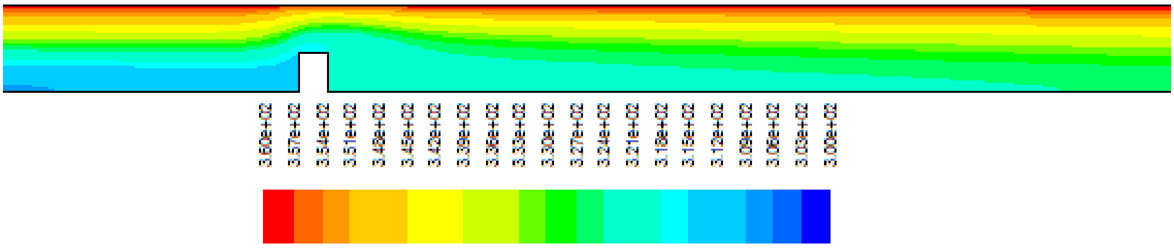

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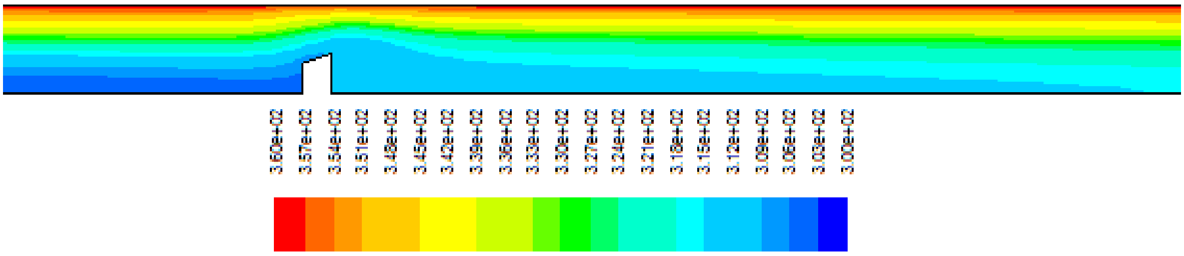
Fig.5. Isotherms for three different cases, (Re =590) a) Case I, b) Case II, c) Case III



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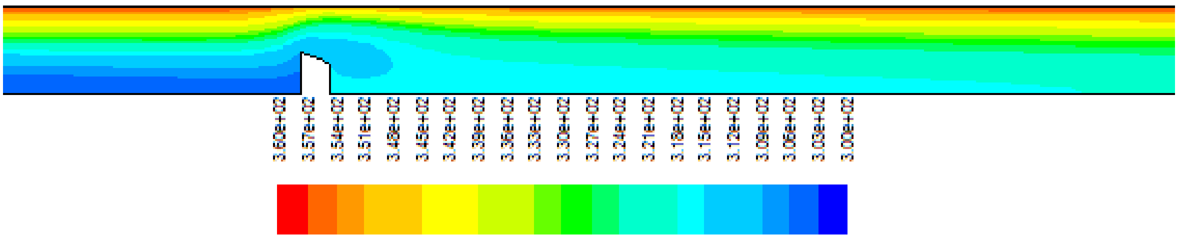

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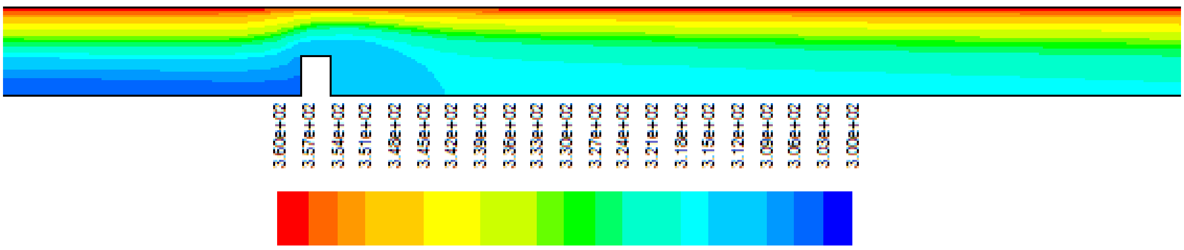
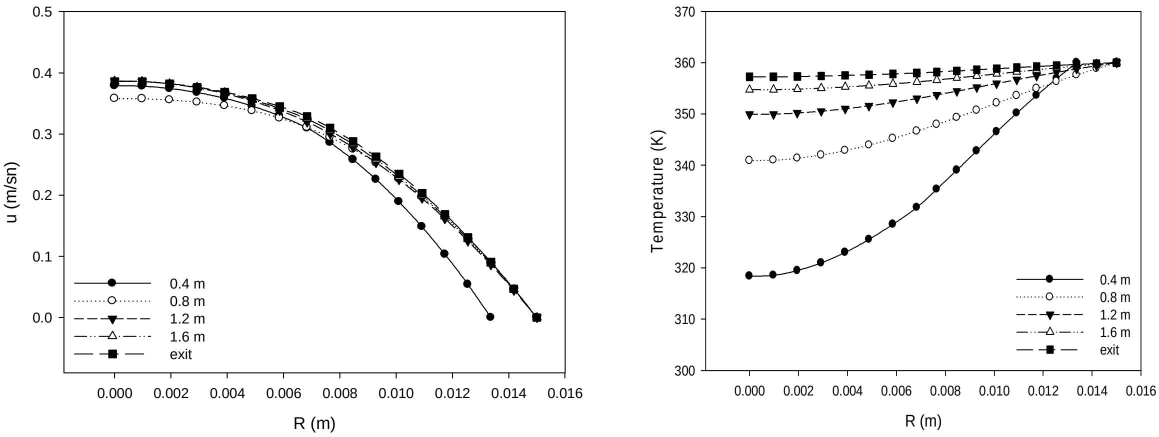


c)

Fig.6. Isotherms for three different cases, (Re =845) a) Case I, b) Case II, c) Case III



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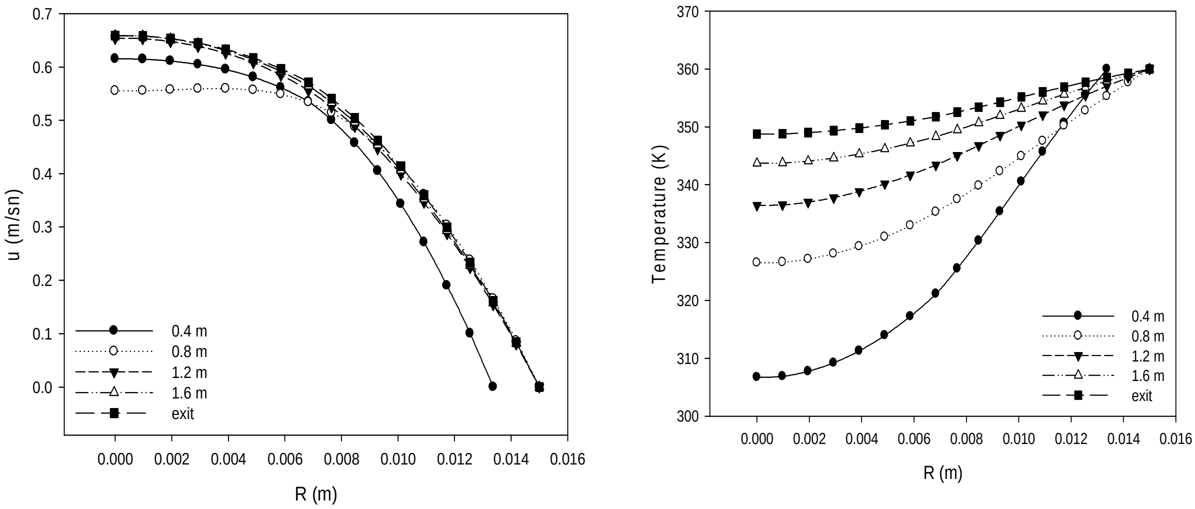

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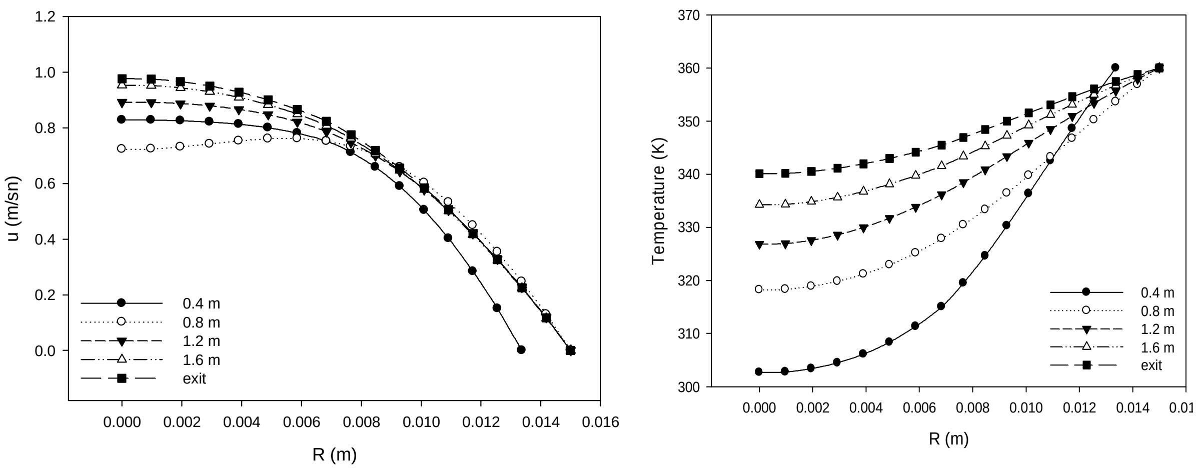
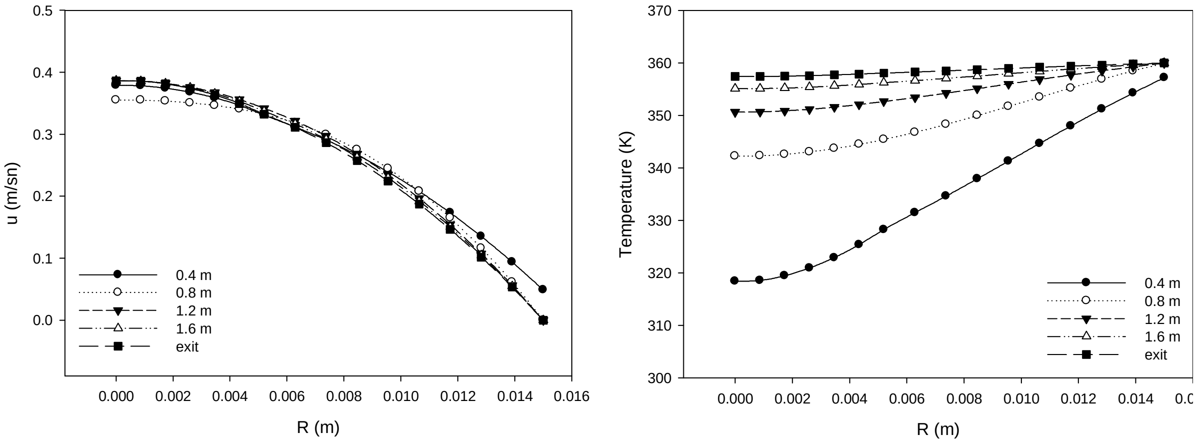


c)

Fig. 7. Velocity profiles (on the left) and temperature profiles (on the right) along pipe at different stations for Case I, a) Re = 335, b) Re = 590, c) Re = 845



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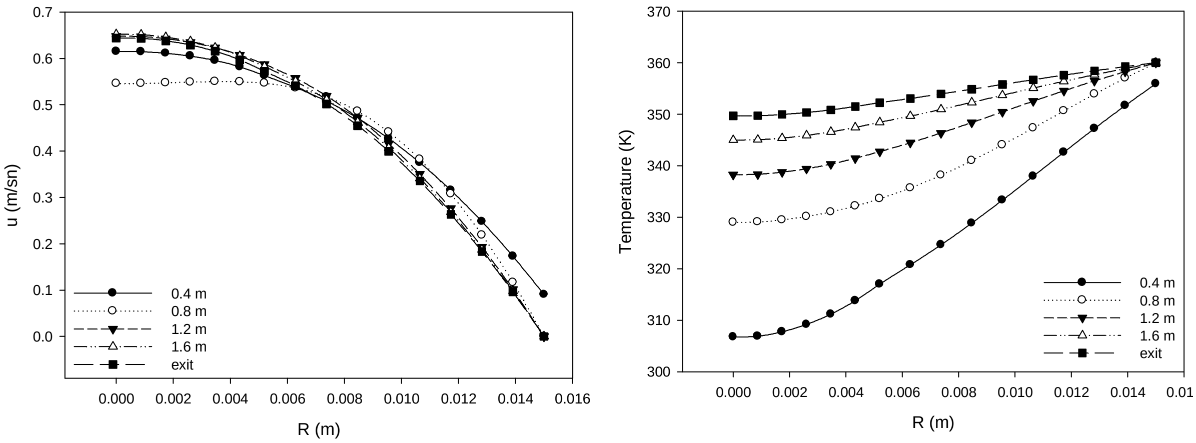

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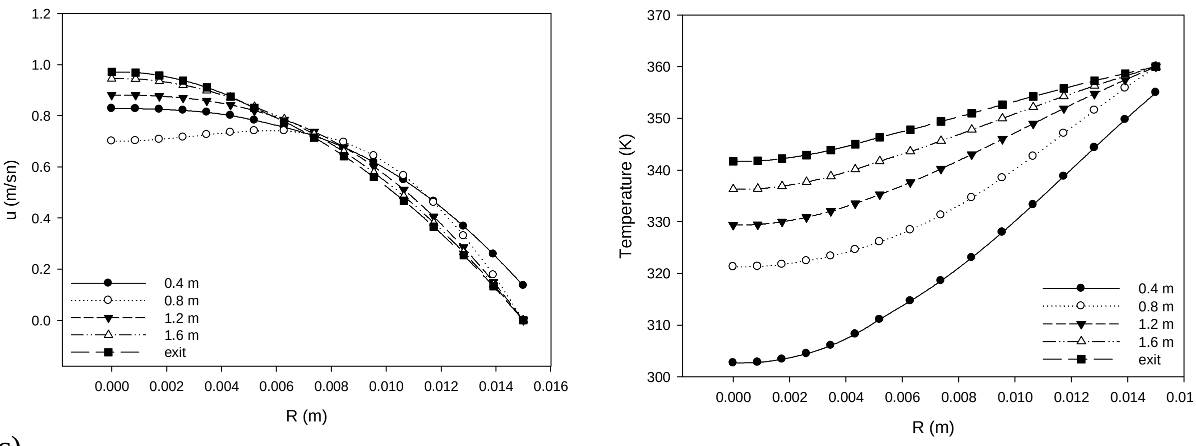

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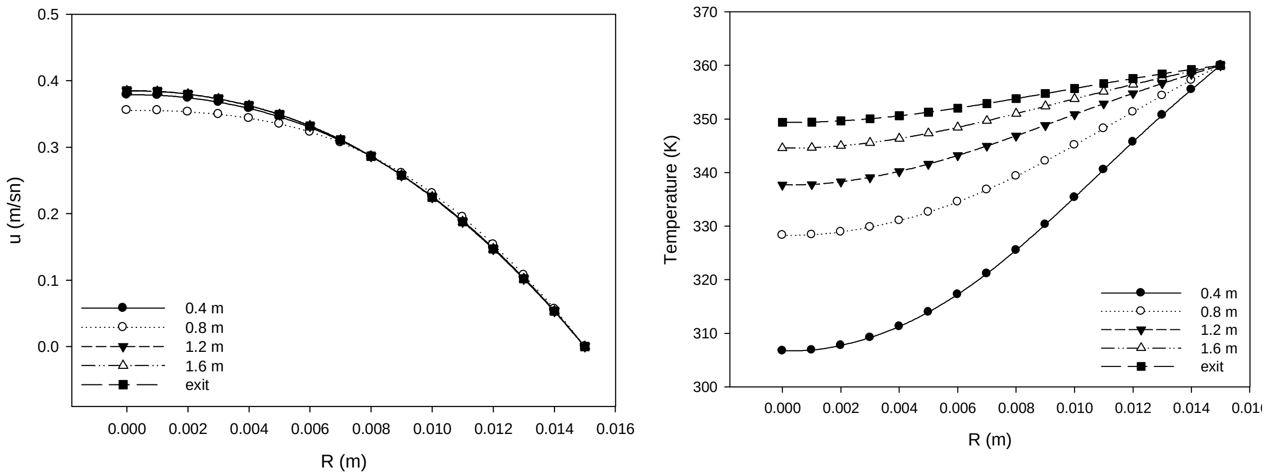
Fig. 8. Velocity profiles (on the left) and Temperature profiles (on the right) along pipe at different stations for Case II, a) Re = 335, b) Re = 590, c) Re = 845



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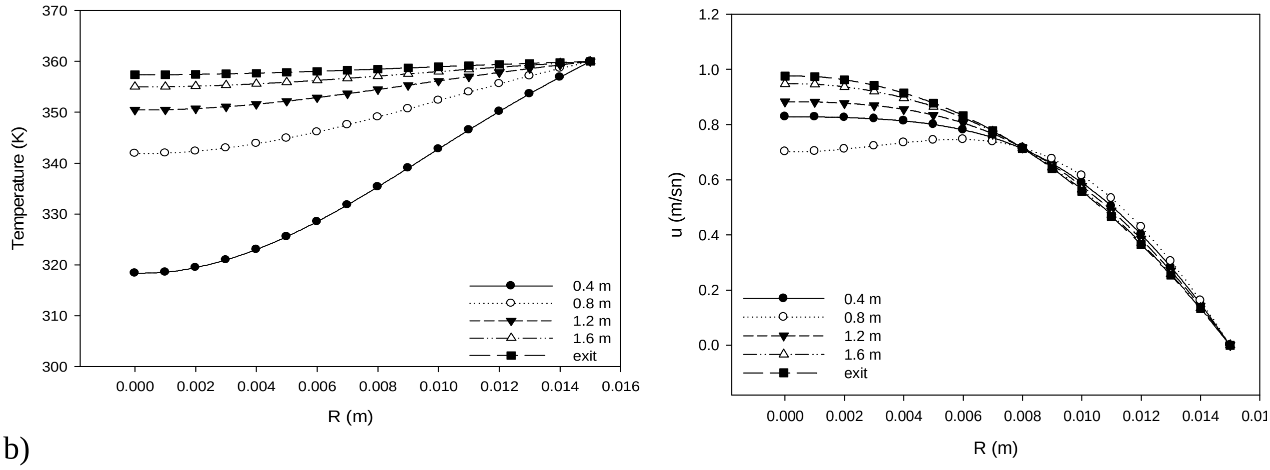

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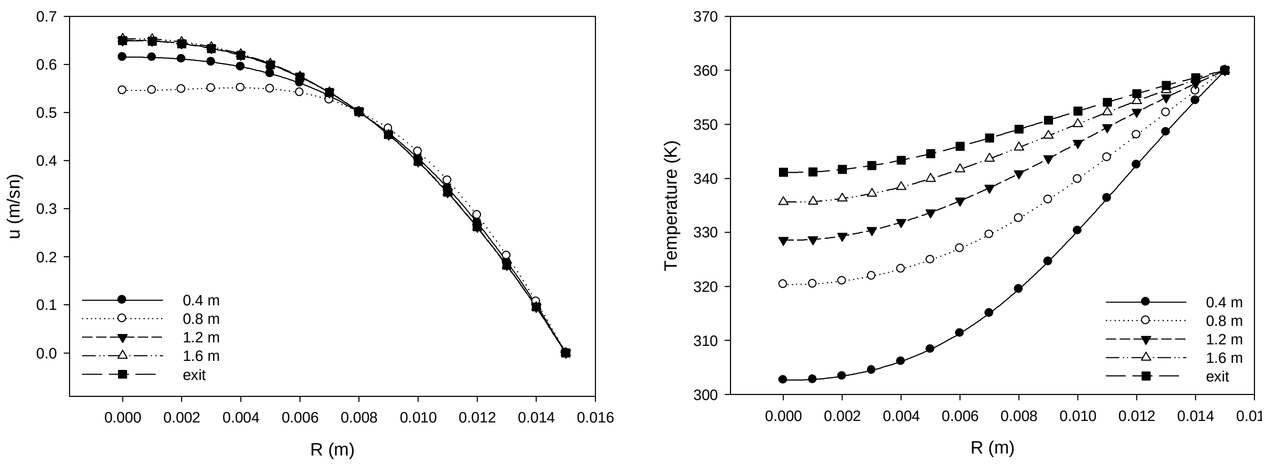

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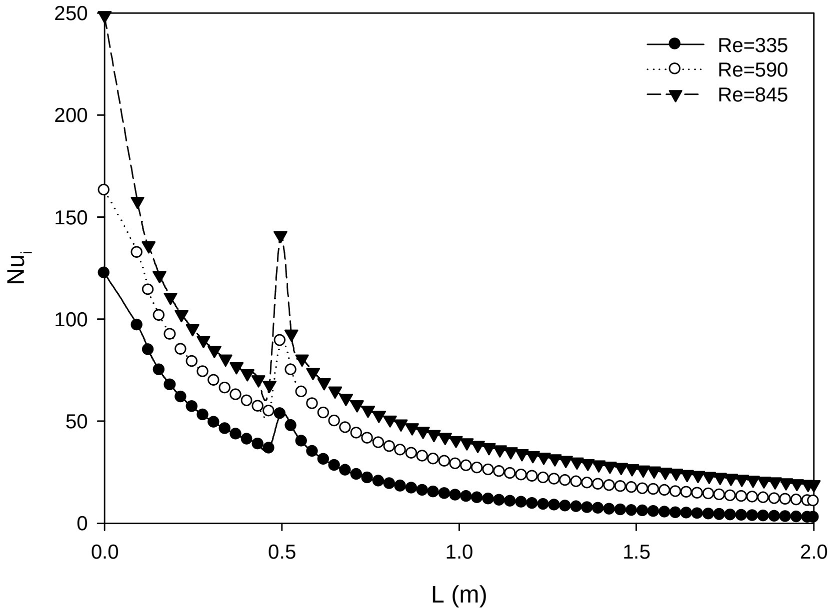
Fig. 9. Velocity profiles (on the left) and temperature profiles (on the right) along pipe at different stations for Case III, a) Re = 335, b) Re = 590, c) Re = 845


250
200
150
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Nu_i
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1.5
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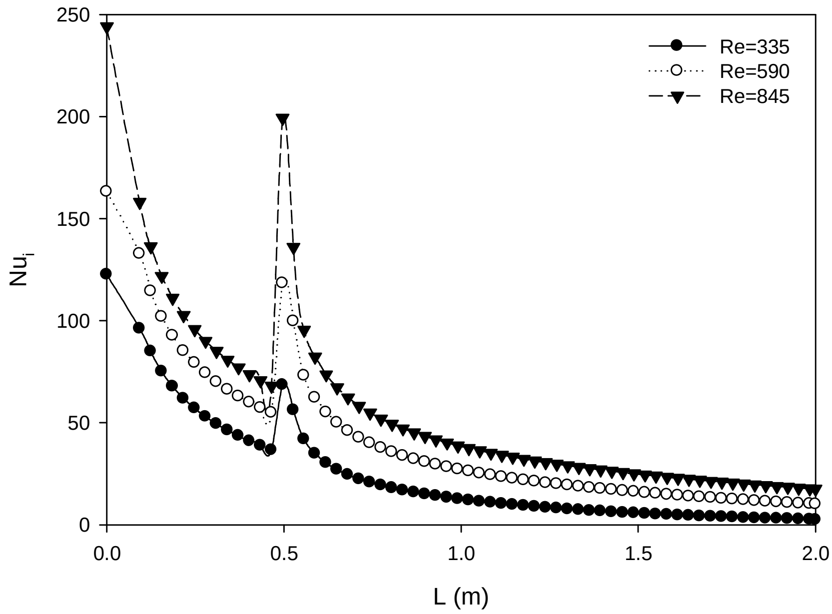
L (m)
Re=335
Re=590
Re=845

a)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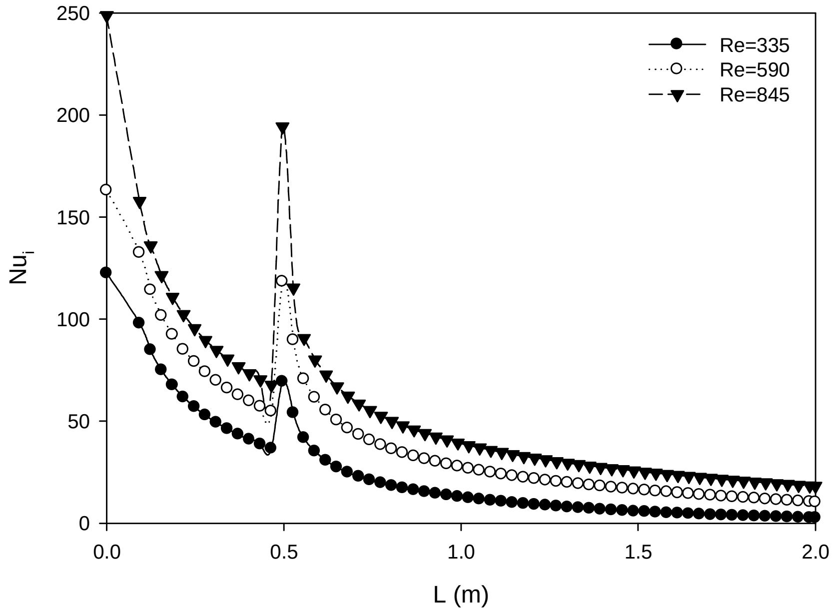

c)

Fig. 10. Variation of local Nusselt number along the pipe for different Reynolds number , a) CaseI, b) Case II, c) Case III