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Improve heat transfer in sudden expansion canal by using obstacle

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ABSTRACT

The purpose of this investigation is to determine if adding an isolated cylinder to the domain can improve forced convection in the laminar case of the sudden expansion flow in a two-dimensional channel. The range of the Reynolds number (1-200) and the number of prattles 0.71, the impact of different cross-stream locations (x=10.4,10.8 and 11.2) of the circular cylinder on the flow, and thermal properties of the sudden expansion flow have been computationally studied (air). COMSOL Multiphysics is utilized to address the governing continuity, Navier-Stokes, energy equation of energy, and the necessary boundary conditions. Although streamline and isotherm profiles have been used to describe the flow and thermal fields, the temperature dependence of the flow viscosity and thermal conductivity has not been taken into account. The findings presented here demonstrate an improvement in the peak Nusselt value when a circular cylinder is used in comparison to the unobstructed condition.

1. Introduction

The process of heat transmission is significantly influenced by flow separation and subsequent reattachment. They can sometimes have negative effects, anything like uneven heat application in thermal devices, but they can also have positive effects, such improving heat transmission at the flow reattachment point. Understanding the fundamental process of temperature difference in flows that are being detached and rejoined is thus crucial for engineering practice. among the most basic geometry where flow detachment and re-attachment occur take place is a backward-facing step. Engineering uses for flow through a backward-facing step include cooling electrical devices, atomic energy devices, Turbine blade cooling channels, Cooling channels for digital devices, and more devices. Numerous research have been done in regard to this geometry, but most of them solely focused on the flow, and it appears that our understanding of heat transmission is still in its infancy. To learn the fundamentals of the flow split and reconnect events in the laminar flow regime, backward facing step flows under laminar circumstances have been studied both experimentally [7-8] and numerically [9-10]. This study uses an adiabatic circular cylinder in the canal over a wide range of Reynolds numbers when there is a steady two-dimensional fluid motion to investigate the improvement of heat transfer of sudden expansion flows in horizontal canals. However, it is helpful to quickly review the current status of the pertinent literature before beginning a full discussion and presentation of this issue.

2. Problem statement

The physical architecture of a 2-D forced convection research in a sudden expansion channel with a step height (H) and an adiabatic obstacle have

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Nomenclature

Cp	specific heat (J kg^{-1} K^{-1})	*Greek symbols*	
ρ	Density ($kg\ m^{-3}$)	α	thermal diffusivity (m^2 s^{-1})
k	thermal conductivity (W m^{-1} K^{-1})		
x/s	length per inlet height	Θ	dimensionless temperature
H	Step height	Ø	Angle of obstacle
Nuloc	Local value of Nusselt number	μ	dynamic viscosity (kg $m^{-1}s^{-1}$)
Nu avg	average value of Nusselt number		
		Subscripts	
		avg	Value of the Average amount
Pr	Number of prantl	o	obstacle
Ra	number of Rayleigh	Tc	cold temperature
T	Temperature	f	fluid (pure water)
U	dimensionless velocity of flow in X-direction	Th	hot temperature
V	dimensionless velocity of flow in Y-direction		
Ro	dimensionless obstacle radius		
X	dimensionless X-coordinates		
Y	dimensionless Y-coordinates	Tw	Wall temperature

cylindrical shape with a radius (R) at various position dimensions is shown in Figure 1. The basic fluid is air. The backward-facing bottom surface is kept at a high constant temperature (Th), while the extra walls provide thermal insulation. The pace of the step wall varies. The Darcy-Brinkman model is used to simulate channel flow. The expanding area contains an isolated cylinder. The following are the dimensionless parameters that were used in this study: The Reynolds number (Re) 100, 200, and 300, Xc= 10.4, 10.8, and 11.2, and the Prandtl number was 0.71.

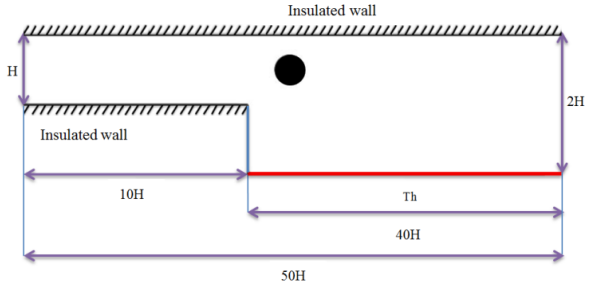


Figure 1 .Boundary conditions and model design for the B.F.S problem with an adiabatic cylindrical obstacle

2.1. Assumption

Avoid hyphenation at the end of a line. Symbols denoting vectors and matrices should be indicated in bold type. Scalar variable names should normally be expressed using italics. Weights and measures should be expressed in SI units. All non-standard abbreviations or symbols must be defined when first mentioned, or a glossary provided. Steady-state.

- Newtonian fluid.
- Flow is incompressible.
- Flow is laminar.
- whithout energy generation.
- The channel and cylinder walls are considered impermeable.

2.1 The Equation of the conservation

The equation of Continuity:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \quad (1)$$

The equation of Momentum:

x- Component

$$\frac{\partial u}{\partial x}+\frac{\partial u}{\partial y}=\frac{-1}{\rho}\frac{\partial p}{\partial x}+\frac{\mu}{\rho}\left(\frac{\partial u}{\partial x}+\frac{\partial u}{\partial y}\right) \quad (2)$$

y- Component

$$\frac{\partial v}{\partial x}+\frac{\partial v}{\partial y}=\frac{-1}{\rho}\frac{\partial p}{\partial y}+\frac{\mu}{\rho}\left(\frac{\partial v}{\partial x}+\frac{\partial v}{\partial y}\right) \quad (3)$$

Energy equation

$$\frac{\partial T}{\partial x}+\frac{\partial T}{\partial y}=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \quad (4)$$

To simplify and minimize the number of variables in equations, especially big equations with many variables, equations are translated into non-dimensional form. Multiple parameters are created by converting variables. The governing equations in the current study were changed by the non-dimensional formula, and the physical characteristics are determined by the flowing non-dimensional parameters**[2, 3]**:

$$Y=\frac{y}{L},\ X=\frac{x}{L}\ ,\ R=\frac{r}{L},\ Re=\frac{\omega r L}{v},\ u=\frac{uL}{\alpha},\ V=\frac{vL}{\alpha},\ Pr=\frac{v}{\alpha}\ ,\ \theta=\frac{T-T_c}{T_h-T_c}$$

Non-dimensional governing equations are given by[4, 5].

The equation of Continuity

$$\frac{\partial U}{\partial X}+\frac{\partial V}{\partial Y}=0 \quad (5)$$

Momentum equation

x- Component

$$U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}=-\frac{\partial P}{\partial X}+\frac{1}{Re}\left(\frac{\partial U}{\partial X}+\frac{\partial U}{\partial Y}\right) \quad (6)$$

y- Component

$$U\frac{\partial V}{\partial X}+V\frac{\partial V}{\partial Y}=-\frac{\partial P}{\partial Y}+\frac{1}{Re}\left(\frac{\partial V}{\partial X}+\frac{\partial V}{\partial Y}\right) \quad (7)$$

Energy equation

$$U\frac{\partial \theta}{\partial X}+V\frac{\partial \theta}{\partial Y}=\frac{1}{RePr}\left(\frac{\partial^2 \theta}{\partial X^2}+\frac{\partial^2 \theta}{\partial Y^2}\right) \quad (8)$$

2.3. Boundary conditions

The non-dimensional boundary conditions are as follows:

On the intake wall.

$U = 1, V = 0,$ *and* $\theta = 0$

For the exit:

$\frac{\partial U}{\partial X} = 0, \frac{\partial V}{\partial X} = 0,$ *and* $\frac{\partial \theta}{\partial X} = 0$

At the bottom surface after sudden expansion step:

$T = Th = 1$

Other horizontal walls is thermal insulated

$U = 0, V = 0$ *and* $\frac{\partial \theta}{\partial Y} = 0$

2.2 The Nusselt number

The local and average Nusselt values along the channel's heated bottom surface are calculated as shown in **[2, 3, 6]**. The influence of various parameters on these coefficients is investigated.

Table 1 . grid size that achieves validation

Predefined mesh	*Grid size*	*Average Nusselt number*
Extra Coarse	5855	1.0068
Coarser	9419	1.0098
Coarse	17925	1.0072
Normal	**27910**	**1.0077**
Fine	49785	1.0086
Finer	118539	1.0103
Extra Fine	279864	1.0110

Local Nusselt number:

$$Nu(X) = -\frac{\partial \theta}{\partial Y} \quad (9)$$

Average Nusselt number on the bottom surface:

$$Nuavg = \frac{1}{L}\int_0^L Nu(X)dX \quad (10)$$

3. Numerical solutions

Because of its successful program for addressing scientific and engineering issues based on partial differential equations, COMSOL Multiphysics CFD Commercial software was employed in the current investigation. COMSOL Multiphysics® version 5.6 software used to resolve the numerical solution. described in this chapter. The P2+P1 Lagrange elements were employed to assure the numerical solution's stability. For finding the local and average Nusselt numbers inside the channel, the governing non-dimensional equations are solved using the finite element method. The CFD solution necessitates the use of a mesh that is appropriate for the computational domain. To achieve great precision, a significant number of cells is required. As a result, as illustrated in **Figure 2**, the triangular mesh element is used to build the computational domain in a 2-D Cartesian coordinate for a backward-facing expanding channel. It is critical for the PC to tackle a specific problem with minimal processing time and great accuracy. Seven successively revised standardized meshes were examined. The average Nusselt number for all preset grid sizes on the bottom hot wall is evaluated to pick the appropriate grid. The grid-independent test settings are as follows: Re=100, yc=1.5, Xc=10.6 and Pr=0.72. As seen in Error! R eference source not found., those varied from such an Extra coarse grid to an Extra fine. Because the percentage error equals (0.0496%), the Normal mesh was chosen for all situations in this investigation.

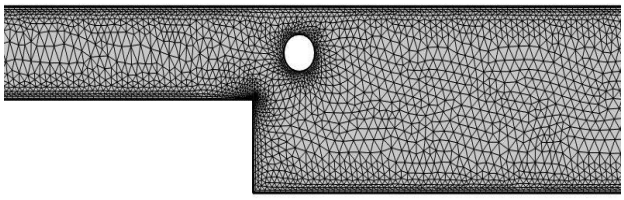
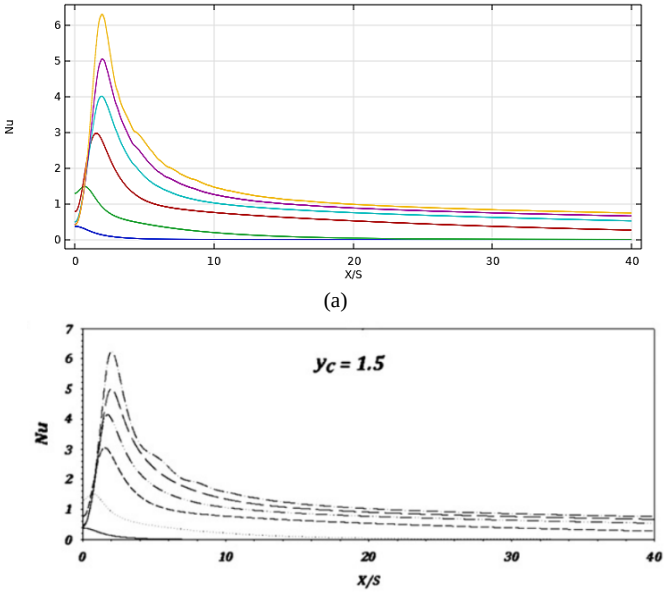


Figure 2 .Shape of element and formation the grid

3.1. Validation

The findings are compared to previous studies to ensure that the COMSOL Multiphysics® software is functional and may be utilized to design and examine the present investigation. Figure 3 illustrates the validation of the local Nusselt number of the present work with Kumar and Dhiman [4]. That investigated the force convection within backward-facing expanding channel with an inner cylindrical obstacle o filled with air at Xc=10.6, Pr=0.72 and yc=1.5.



(a)

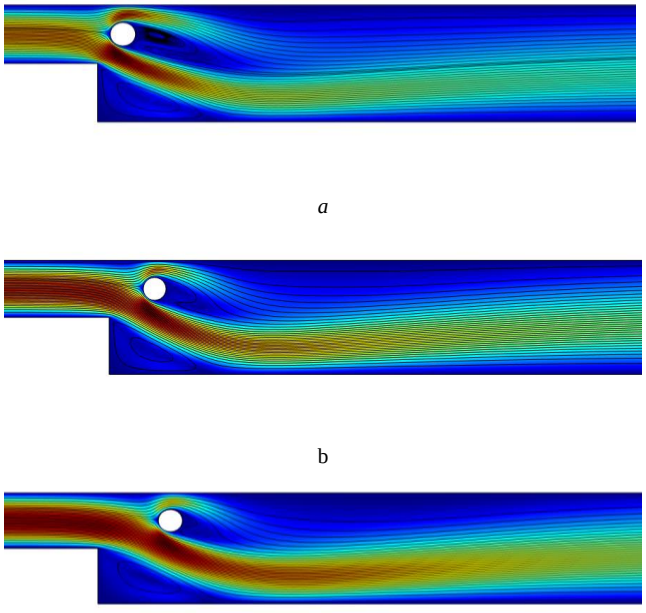
(b)

Figure 3. (a) Present work; (b) Kumar and Dhiman [4].

4. Result and discussion

Force convection analysis in a backward facing step with and with insulated cylindrical obstruction. The bottom surface is kept at a high temperature after the stretching step (Th), while the remaining walls are thermally insulated. For this investigation, the study's parameters were Re, Xo, yo, and Pr. Parameters values (Re= 100, 200, and 300), (Xo= 10.4, 10.8, and 11.2), (yo=1.5), and (Pr= 0.71). Figure 4-6 show how the streamlines are affected by the position of a cylinder obstruction for Re = 100, 200, and 300, respectively. When the barrier is located near the step for the location at yo = 1.5S, the flow coming from the inlet of the canal and hits the obstacle and divided into two amount some pass on obstacle this amount not effect on the separation volume and not effect on heat transfer but anther amount of flow that pass from the way between the obstacle and step height and decrease the separation volume. To ensure a comparative investigation of the impact of the circular cylinder's cross-stream position on flow characteristics, all three cases (Xo = 10.4, Xo = 10.8, and Xo = 11.2) have been described over the entire Reynolds number range considered. When Xo= 10.4 and the cylinder was mounted in the closest position. In this instance, a substantial volume of fluid passes through the space between the cylinder and the step's upper corner. Figures 4(A), 5(A), and 6(A) show the typical fluid flow patterns. for Re =100, 200, and 300, respectively. In the last two cases (Xo= 10.8, and Xo= 11.2), it was found that the flow is similar to the first case (Xo= 10.4), except that the vortices that formed behind the circular cylinder are of a smaller size.

Flow splits from the rear of the cylinder-shaped obstruction as the Reynolds number rises, creating two slightly downward-directed vortices behind the cylinder. For 100<Re<300, the size of these vortices increases as the Reynolds number increases. It is also observed that as the Reynolds number increases, second separation forms on the upper wall of the step geometry.

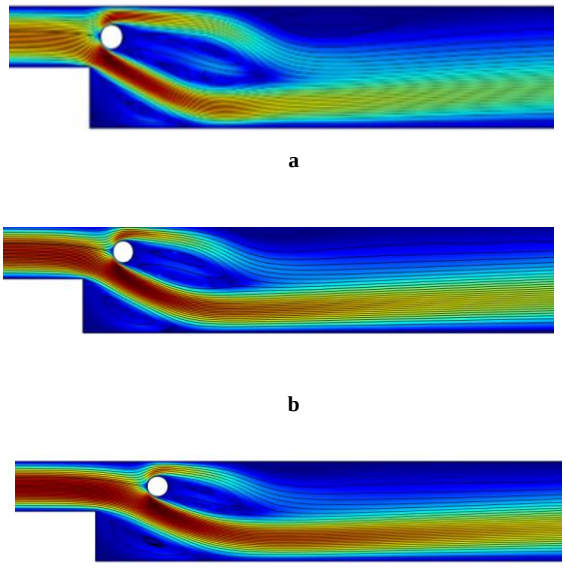


a

b

c

Figure 4. Streamline profiles at Re =100: A) Xo=10.4, B) Xo=10.8, and C) Xo=11.2.



a

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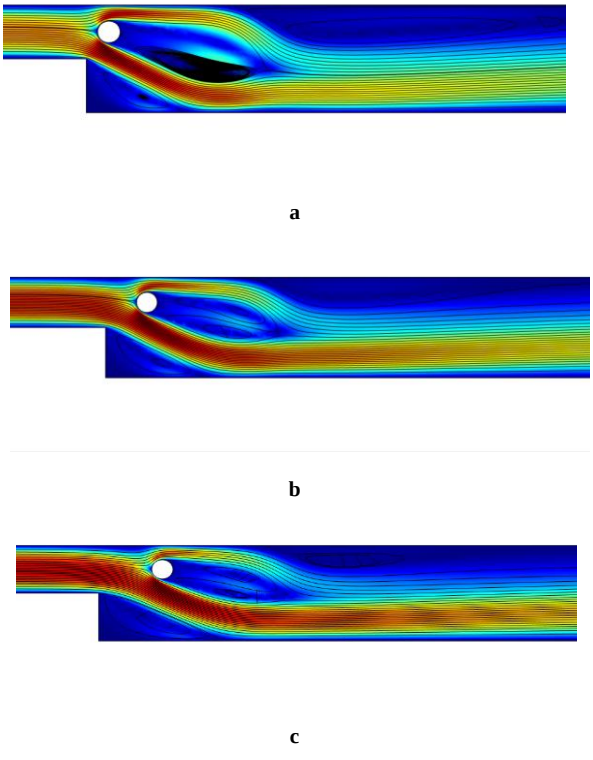
Figure 5. Streamline profiles at Re =200: A) Xo=10.4, B) Xo=10.8, and C) Xo=11.2.



a

b

c

Figure6. Streamline profiles at Re =300: A) Xo=10.4, B) Xo=10.8, and C) Xo=11.2.

4.1. Local Nusselt number

Figure 7 depicts the local Nu on the bottom wall for the three different flow configuration positions considered at different Reynolds numbers. According to these figures, with rising Reynolds numbers, the local Nu numbers rise and are at the same distance from step height. Due to the cylindrical obstacle located near the separation area, the streamlines intersect and the separation volume decreases, which leads to an increase in heat exchange between the high-temperature wall and the passing fluid. This figure depicts the variation local Nu for Xo=10.4S, and the graph shows that there is a maximum value in Nu. The nature of the local number Nusselt plots in both cases Xo =10.8S, and Xo=11.2S does not differ significantly from flow at Xo=10.4S. However, in the first case (Xo=10.4S), with highest Reynolds number value (Re=300) the highest Nusselt number.

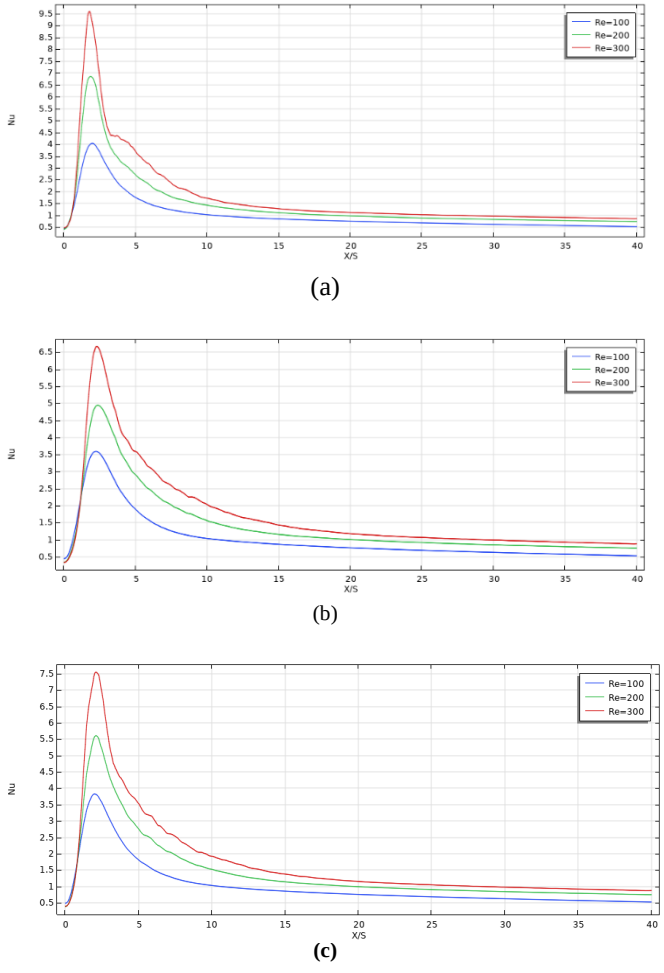


Figure 7. Describes the effect of obstacle location on the Nusselt number at Xo=10.4 , Xo=10.8, and Xo=11.2.

5. Conclusion

The adding an isolated cylinder to the domain of the sudden expansion flow in a two-dimensional channel was investigated numerically. Although streamline of the flow was described as an function of the flow and the temperature, viscosity. The findings presented here demonstrate an improvement in the peak Nusselt value when a circular cylinder is used in comparison to the unobstructed condition.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

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