International Communications in Heat and Mass Transfer 95 (2018) 139–146

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Cross-buoyancy mixed convection from a heated cylinder placed asymmetrically in a channel

Amit Dhiman[a], Rishabh Gupta[a], László Baranyi[b,*]

[a] Department of Chemical Engineering, Indian Institute of Technology Roorkee, Roorkee 247 667, India
[b] Department of Fluid and Heat Engineering, Institute of Energy Engineering and Chemical Machinery, University of Miskolc, 3515 Miskolc-Egyetemváros, Hungary

ARTICLE INFO

Keywords:
Asymmetry
Confined cylinder
Gap ratio
Mixed convection
Wall confinement

ABSTRACT

Mixed convection heat transfer from a heated circular cylinder asymmetrically placed in a horizontal channel was studied for incompressible Newtonian fluid. A systematic investigation using two-dimensional numerical simulation (Ansys Fluent) was performed for the following control parameters: Reynolds number $Re = 50$, 100, 150, Richardson number $Ri = 0$, 1, 2, blockage ratio $\beta = 0.2$, 0.3, 0.4, gap ratio $\gamma = 0.25$, 0.5, 1 and Prandtl number of air $Pr = 0.7$. Upon changing these parameters, steady and time periodic regimes were identified. The strongest influence on heat transfer (average Nusselt number) was identified when changing the Reynolds number (a 94% increase between the minimum and maximum *Re* investigated, with other parameters held constant), followed by Richardson number (+18%) and blockage ratio (+16%); the effect of asymmetric placement (γ) was almost negligible (+1%). The time-mean of the drag coefficient was most influenced by blockage ratio (a 150% increase), followed by Richardson number (+91%), gap ratio (+19%), and *Re* (+10%).

1. Introduction

The study of fluid dynamics and heat transfer characteristics around various bluff bodies in an enclosure has been given a great deal of attention by researchers in recent times because of its pragmatic relevance. While many studies are available on forced convection flow alone, in real life there is always a combination of free and forced convection. In most situations, free convection is always present, though sometimes small, and this leads to heat transfer through mixed convection. This mixed convection has numerous real world applications such as heat exchangers, transport of fluid in pipelines, cooling towers, etc. Although it is more difficult to analyse and study mixed convection as compared to forced convection alone, both forced convection and mixed convection from an unconfined circular cylinder have been fairly widely studied. In contrast, there are few studies available on mixed convection heat transfer from a cylinder in a confined channel, and to the best knowledge of the authors no results have been published on mixed convection from a confined heated cylinder placed asymmetrically. In this study, cross-buoyancy mixed convection is investigated for incompressible Newtonian fluid from a heated circular cylinder placed in a channel in symmetrical and asymmetrical positions.

2. Current status of literature

Following is a summary of previous studies related to the flow of fluids past and heat transfer from a circular cylinder placed at various positions in a confined two-dimensional (2-D) channel. It is presented in the following manner: studies on flow around and forces acting on a cylinder in a confined channel, forced convection studies for a symmetrically and then an asymmetrically placed cylinder, and mixed convection studies for a symmetrically placed cylinder.

Experimental and numerical research is now accessible in the literature on the fluid flow in the symmetrical placement of a circular cylinder between the walls of a channel (confined domain) [1–8]. Likewise, adequate research on three-dimensional effects in laminar flow around a circular cylinder in the channel can be found in [9–13]. On the other hand, Zovatto and Pedrizzetti [14] studied the effects of wall confinement (blockage ratio $\beta = b/(2H)$) and the flow separation from the cylinder surface. It was reported that the transition from steady state flow to the vortex shedding regime was delayed for higher blockage ratios, where the walls are placed nearer to the cylinder, because of the stability provided by the confining walls to the wake that formed behind the cylinder. Thus, blockage ratio above a certain value led to inhibition of the vortex shedding phenomenon.

In [15–18] a heated circular cylinder is symmetrically placed (gap ratio $\gamma = 1$) in a channel and forced convection (Richardson number

* Corresponding author.
E-mail addresses: amitdfch@iitr.ac.in (A. Dhiman), arambl@uni-miskolc.hu (L. Baranyi).

https://doi.org/10.1016/j.icheatmasstransfer.2018.05.007

Nomenclature

C_D	total drag coefficient, $= \frac{F_D}{(1/2)\rho U_\infty^2 d}$
c_p	heat capacity, J/(kg K)
d	diameter of cylinder, length scale, m
F_D	drag force per unit length of the cylinder, N/m
g	acceleration due to gravity, m/s^2
Gr	Grashof number, $= \frac{g\beta_v(T_w - T_0)d^3\rho^2}{\mu^2}$
H	half channel height, m
h	local heat transfer coefficient, W/(m^2 K)
$\bar{h}$	average heat transfer coefficient, W/(m^2 K)
k	thermal conductivity of fluid, W/(m K)
L	dimensionless length of the computational domain in x-direction, $=L^*/d$
L_d	dimensionless downstream length, $=L_d{}^*/d$
L_u	dimensionless upstream length, $=L_u{}^*/d$
Nu_L	local Nusselt number, $= hd/k$
Nu	average Nusselt number, $= \bar{h}d/k$
P	dimensionless pressure, $= P^*/(\rho U_\infty{}^2)$
Pr	Prandtl number, $= \mu c_p/k$
Re	Reynolds number, $= \rho d U_\infty/\mu$
Ri	Richardson number, $= Gr/Re^2$
t	dimensionless time, $=t^*/(d/U_\infty)$
T	temperature of fluid, K
T_0	fluid temperature at inlet, K
T_w	cylinder temperature, K
U_∞	average inlet velocity, velocity scale, m/s
V_x, V_y	dimensionless x and y velocity components, $=V_x{}^*/U_\infty$, $=V_y{}^*/U_\infty$
x	dimensionless x-coordinate, $=x^*/d$
y	dimensionless y-coordinate, $=y^*/d$
β	blockage ratio, $= d/(2H)$
β_v	volumetric expansion coefficient, 1/K
γ	gap ratio or eccentricity, $= \delta/(H - d/2)$
δ	gap between lower channel wall and cylinder, m
θ	non-dimensional temperature, $= \frac{T - T_0}{T_w - T_0}$
μ	dynamic viscosity of fluid, Pa s
ρ	fluid density, kg/m^3

Superscript

*	dimensional quantity

Ri = 0) is assumed. Progress in research on the forced convection can also be found for the asymmetrical placement of a circular cylinder in the confined domain [19–23]. Mettu et al. [19] explored flow around and forced convection from a circular cylinder placed asymmetrically in a planar channel for Reynolds number Re ranging from 10 to 500, blockage ratio β from 0.1 to 0.4, gap ratio γ from 0.125 to 1 and Prandtl number $Pr = 0.744$. A critical Reynolds number that represents the shift from steady flow regime to unsteady periodic flow regime was determined. Drag coefficient was found to increase with a decrease in the gap ratio. The oscillation amplitude of the lift signal was found to have an inverse relationship with blockage ratio.

Champmartin and Ambari [20] studied the effect of disturbances which break the symmetry of the system on heat transfer. An asymmetrical configuration of a single cylinder moving in a horizontal confined channel with Dirichlet and Neumann boundary conditions was investigated numerically. The heat transfer was observed to increase with the blockage ratio when Dirichlet condition was used, while an inverse relation was obtained for the Neumann condition. Investigating symmetrical versus asymmetrical confinement, Nirmalkar and Chhabra [21] studied the momentum and heat transfer characteristics from the power-law fluid flow past a heated cylinder in asymmetric confinement for Re ranging from 0.1 to 100, Pr from 1 to 100, β from 0.2 to 0.4 and γ from 0.25 to 1. They found that Nusselt number did not follow any trend with respect to the asymmetry in the placement of the cylinder. As the cylinder was placed away from the centre of the channel, there was an imbalance of force acting on the cylinder in the vertical direction because of both confining walls, with the wall closer to the cylinder exerting more repellent force than the wall further away from the cylinder, thus leading to some positive value of lift coefficient. However, the drag coefficient and Nusselt number were far more influenced by other parameters like Re and β than by γ. In a recent investigation, Bijjam et al. [23] studied the forced convection from an asymmetrically confined cylinder for $Re = 1$–40, $\gamma = 0.375$–1, $\beta = 0.2$–0.5 and $Pr = 1$–50. They found that asymmetrical configuration reduces overall drag, and that the Nusselt number is higher for symmetric cylinder placement than for asymmetric placement.

In contrast, mixed convection ($Ri \neq 0$) effects around a symmetrically placed circular cylinder in a channel have not been paid the same attention. Few investigations can be found for a confined symmetrically placed circular cylinder [24–28]. Farouk and Güçeri [24] dealt with mixed convection (aiding buoyancy) from a confined circular cylinder in the steady state at $\beta = 0.1667$. Singh et al. [25] examined the mixed convection (aiding/opposing buoyancy) from a confined cylinder for $Re = 100$, $Pr = 0.7$ and $Ri = -1$ to 1 at $\beta = 0.25$. Vortex

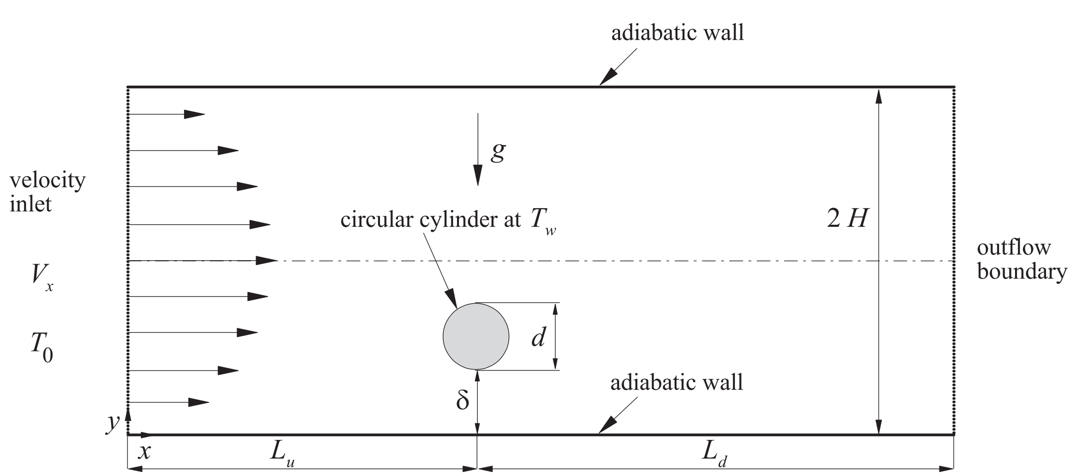

Fig. 1. Schematic of the flow situation.