Energy 95 (2016) 447–458

Contents lists available at ScienceDirect

Energy

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

A utilization of GEP (gene expression programming) metamodel and PSO (particle swarm optimization) tool to predict and optimize the forced convection around a cylinder

Prasenjit Dey*, Ajoy Kumar Das

Department of Mechanical Engineering, National Institute of Technology, Agartala, India

ARTICLE INFO

Article history:
Received 18 August 2015
Received in revised form
5 November 2015
Accepted 6 December 2015
Available online 4 January 2016

Keywords:
Square cylinder
Rounded corner edge
Prandtl number
Enhancement of heat transfer
GEP
PSO

ABSTRACT

An unsteady two-dimensional laminar forced convection heat transfer around a square cylinder with the rounded corner edge is numerically investigated for Pr = 0.01–1000 and non-dimensional corner radius, r = 0.50–0.71 at low Reynolds number (Re = 100). The effect of gradual transformation of a square cylinder into a circular cylinder on heat transfer phenomenon is studied. The FVM (finite volume method) based commercial code Ansys FLUENT is used for numerical simulation. The heat transfer characteristics over the rounded cornered square cylinder are analyzed with the isotherm patterns, local Nusselt number (Nu_{local}), average Nusselt number (Nu_{avg}) at various Prandtl numbers and various corner radii. The heat transfer characteristic is predicted by the GEP (gene expression programming) and the GEP generated explicit equation of Nu_{avg} is utilized in PSO (particle swarm optimization) to optimize the corner radii for maximum heat transfer rate. It is found that the heat transfer rate of a circular cylinder can be enhanced 14.17% by introducing a new cylinder geometry of corner radius r = 0.51.

1. Introduction

The fluid flow and heat transfer over a lean cylindrical bluff body has been the subject of an extreme exploration, mostly owing to the tremendous engineering significance on nuclear reactor, heat exchangers, natural circulation boilers, solar heating systems, electronic cooling, dry cooling towers, flow dividers, probes, vortex flow meters and sensors etc. Although, no such information is presented in the literature about the heat transfer characteristics around the square cylinder of rounded corner edges at low Reynolds number.

The vast majority of the fluid flow and heat transfer studies has been accomplished for the circular cylinder, a square cylinder with sharp edges and triangular cylinder. The square cylinder is the most common sharp-edge body and widely investigated in aerodynamics. The preceding studies are carried out by numerical, theoretical and experimental methods and based on Reynolds number and Prandtl number, various flow regimes are recognized in the available studies [1–12]. Also, there are various available studies associated with circular cylinder accomplished by both numerically and experimentally [13–22].

The effect of buoyancy on vortex shedding and heat transfer characteristics has studied [1,10,11,19–22]. The effect of the Prandtl number on the heat transfer from unconfined and confined square cylinders have been studied [2,3,12] but are limited to the steady flow regime (Re up to 40). An experiment on the heat transfer characteristics from a uniformly heated square cylinder in a channel for two values of Reynolds number 350 and 540 and three different blockage ratios; 1/10, 1/8 and 1/6 have accomplished [4]. The effect of confinement on flow and heat transfer of the forced and mixed convection regimes from a square cylinder placed in a channel has been reported so far [5]. A numerically based study of the effects of the Reynolds and Prandtl numbers on the heat transfer rate from a square cylinder for the range of conditions Re 60 to 160 and Pr 0.7–50 has been done [6]. Some researchers [7,8] investigated the flow and heat transfer characteristics from a square cylinder in the steady and unsteady flow regimes up the Reynolds number values of 160 for isothermal and constant heat flux boundary conditions. Most of the studies are reported for Pr = 0.71.

A numerical analysis of fluid flow and heat transfer features around a circular cylinder in unsteady flow regime ($50 \leq Re \leq 180$)

* Corresponding author.
E-mail address: deyprasenjitnita@gmail.com (P. Dey).

http://dx.doi.org/10.1016/j.energy.2015.12.021
0360-5442/

Nomenclature

B	Blockage ratio (D/H)
Cp	Specific heat of the fluid (J/kg k)
D	Width of the square cylinder (m)
h	Local convective heat transfer coefficient (W/m^2k)
H	Height of the domain (m)
k	Thermal conductivity of the fluid (W/mk)
L_d	Downstream face distance of the inlet from the cylinder center (m)
L_u	Upstream face distance of the inlet from the cylinder center (m)
Re	Reynolds number ($=\rho U_\infty D/\mu$) (dimensionless)
t	Time (dimensionless)
U_∞	Free stream velocity (m/s)
x, y	Cartesian coordinates
p_∞	Free stream pressure (Pa)
R	Radius of the corner (m)
r	Radius of the corner (dimensionless, R/D)
u, v	Velocity components in x and y directions (m/s)

Greek symbols

μ	Viscosity of the fluid (Pa s)
ρ	Density (Kg/m^3)
θ	Dimensionless temperature ($=\overline{T}-T_\infty/T_W-T_\infty$)

Subscript

∞	Free stream
w	Cylinder surface

Superscript

—	Dimensional variable

have been investigated by Golani et al. [15] and for numerical simulation they have utilized CFD commercial software FLUENT. Another numerical study of the heat transfer around the two circular cylinders in the tandem arrangement has been accomplished by Mahir et al. [16] for Re = 100 and 200. A two dimensional numerical simulation of the flow around the cylinder for Re = 5 to 250 by using the spectral element method has been investigated [17]. The effect of different density of air and the temperature dependent viscosity on heat transfer and fluid flow over a circular cylinder was investigated by Shi et al. [18] in the range of Reynolds number, $10^{-3} \le Re \le 170$. Whereas, the drag force and the vortex shedding over a square cylinder can be minimized by rounding the corners [23–25]. The studies were accomplished by experimentally. Also, some studies about the fluid–structure interaction of a square cylinder with the rounded corners were accomplished recently [26–28].

In the course of the most recent couple of years, the forecast of diverse attributes of heat exchange and aerodynamic conduct is turning into a territory of exploration in different designing applications because of its less time intense strategies. There are different strategies are utilized as a part of forecast; between them ANN (artificial neural network) and GEP (gene expression programming) are the foremost using strategies. In order to avoid the solution methods which are time-consuming and needs high numbers of iterations; hence, ANN and GEP has been increasingly preferred by researchers. GEP (gene expression programming) is an another framework having the upsides of both GP (genetic programming) & GA (genetic algorithm) to assess more mind boggling capacity to display a declaration of the connection between input & output [29]. GEP is more productive to foresee the output as contrasted an ANN; examined as of late [30,31]. The GEP model has also been successfully employed to predict various engineering parameters [32–34].

Latterly, different optimization techniques i.e. GA, PSO (particle swarm optimization), etc. has been successfully applied for optimizing heat transfer. The GA has been used by different researchers to optimize the convective thermal performance of the fin & plate fin heat exchanger. For the moment, PSO has been applied to thermodynamic optimization of cross-flow plate fin heat exchanger and in a natural convection model [35,36]. A comparison study of GA and PSO have been studied recently [37] and found that PSO is more efficient than GA for optimizing the geometry of a longitudinal fin.

Therefore, it is pertinent to make a conclusion by evaluating the foregoing studies that there is no information is available on the effects of corner radius of a square cylinder for the heat transfer characteristics at various Pr. It is also valuable to remark that in petroleum, chemical and other industries that are related to oil, the different value of Pr is often perceived, mostly in the treating of organic liquids such as glycerols, olive oil, glycols and other [2,3,38]. Accordingly, the present study aims to investigate the effect of r and Pr on heat transfer characteristics over a cylinder as frequently encountered in various engineering and industrial applications. This present study aims to fill the gap in the literature that how a square cylinder behaves on heat transfer phenomenon when it is converted gradually to a circular cylinder. Further, the corner radius is optimized for maximum heat transfer by using PSO followed by a GEP modeled objective function.

2. Geometrical configuration and mathematical formulation

The schematic representation of the present numerical problem is depicted in Fig. 1(a). A square cylinder with the sharp and rounded corner is placed in a channel exposed to a two-dimensional incompressible flow. The square cylinder is having the depth as D and non-dimensional radius of the corner, r (R/

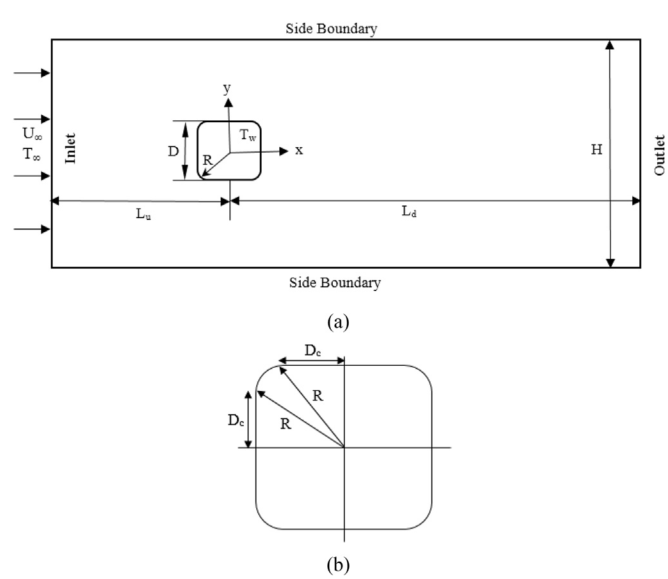

Fig. 1. A schematic diagram of the (a) present problem description and (b) explanation of the corner radius.