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Neuro-genetic optimization of laminar slot jets impinging on a moving surface[☆]

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ABSTRACT

In this work, heat transfer from a moving surface due to series of impinging slot jets under laminar conditions has been optimized. For this study numerical investigations were carried out initially using Ansys Fluent 14 and these results were used to train an artificial neural network (ANN). This trained network was integrated into Micro-Genetic Algorithm to get the optimum parameters for better heat transfer from the surface, an optimization procedure proposed by Madadi and Balaji. Pitch of the jets (P), height of the jets (H) and the non-dimensional surface velocity (V_s) were chosen as dependent variables for optimum heat transfer. 99 simulations were performed by changing above parameters for each Reynolds number, Re of 100 and 200 were used for case study. Imposition of surface velocity strongly affects the heat transfer magnitude and distribution following a change in flow structure. The performance of Micro-Genetic Algorithm (μGA) was also compared with standard Genetic Algorithm (GA); it shows that μGA reaches optimum in less than half the time of standard GA. The optimum results show that the pitch of the jets, height of the jets and surface velocity should be as low as possible.

1. Introduction

Heat transfer from a moving surface due to jet impingement is of considerable interest due to high heat transfer rates, which makes it applicable for cooling turbine blades, metal processing and many other cooling and drying applications [1–8]. In recent years, turbulent heat transfer studies were reported on effect of moving surface on slot jets [2–8], while these studies on heat transfer from moving surface impinged with laminar slot jets were also reported [1].

Chattopadhyay and Saha [1] have investigated heat transfer from slot jets on a moving surface under laminar conditions. Axial and knife jet types were considered and have found that axial jets are always preferred over knife jets. Chattopadhyay et al. [2] studied heat transfer from a moving surface due to impinging slot jets using the large eddy simulation technique in the range of Reynolds between 500 and 3000. The surface velocity has been varied from 0 up to twice the jet velocity. By increasing surface velocity Nu distribution becomes more uniform and it also reduces heat transfer. Different types of jets namely annular jet [3] and circular jet [4] were investigated by Chattopadhyay. It was found that heat transfer from annular jet was about 20% less than that of a circular jet [3]. The surface velocity largely influences the heat transfer from the moving surface in the case of circular jet [4]. The large Eddy Simulation technique was extensively used for analyzing heat transfer from moving surface due to slot jets under turbulent conditions [2,6,8]. Whereas realizable K-ε model was used effectively by Chattopadhyay and Benim [4,7] for high Reynolds number.

By combining optimization techniques with Computational Fluid Dynamics, long computer time can be saved compared to extensive search [9–11]. Artificial Neural Networks (ANNs) were integrated into Genetic Algorithms (GAs) to obtain more efficient results [9,10]. Micro-GA is an alternative to standard GA which is adopted to achieve optimum quickly with population size less than 10 [11]. Madadi and Balaji [9] used a back propagation ANN as an objective function which was fed to Micro-GA. A similar approach was employed with standard GA applied to a natural convection problem by Kadiyala and Chattopadhyay [10]. Lee et al. [12] have optimized effectiveness of micro-heat exchanger using the standard GA combined with ANN and named as neuro-genetic optimization.

In the present work the computational domain is adopted from [1] as shown in Fig. 1. Periodic interfaces have been taken on the left and right sides of the domain so as to consider a series of jets. Pressure outlets were imposed at the front and back faces for escaping of incoming fluid. After getting sufficient amount of results from CFD simulations an ANN is trained to integrate with μGA to get optimum results. The variables that are optimized are pitch of the jets (P), height of the jet (H) and horizontal velocity of moving surface in x direction (V_s). Performance of μGA is also compared with standard GA for the present problem.

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Nomenclature

B	Width of the slot jet, m
H	Height of the jet from moving surface, m
p	Pressure, N/m^2
P	Pitch of the slot jets, m
T	Temperature, k
u,v,w	Components of velocity, m/s
V	Velocity of the fluid from jet, m/s
V_s	Nondimensional surface velocity in x-direction
L_x,L_y,L_z	Dimensions of computational domain in x, y, z directions, m
Re	Reynolds number of jet based on 2B
Nu	Nusselt number of moving surface
MRE	mean relative error
n	number of nodes

Greek symbols

α	Thermal diffusivity, m^2/s
μ	Dynamic viscosity, kg/m-s
ρ	Density, kg/m^3

2. Model and governing equations

2.1. Model

The flow is assumed to be incompressible with constant properties and without viscous dissipation. The width of the moving surface is 10 times the jet width. The heights of the jet considered are B, 2B and 3B, whereas the pitch of the jets are 6B, 8B and 10B. The jet delivers the fluid with same properties as the ambient conditions. The transport phenomena is considered to be in laminar regime. Uniform wall temperature boundary condition is considered for the moving surface. Uniform velocity profile was imposed at the jet entrance.

2.2. Governing equations

The simplified form of continuity, momentum and energy equations for a three dimensional, steady state, incompressible flow and laminar forced convection heat transfer without viscous dissipation are given below.

Continuity equation:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0. \tag{1}$$

Momentum equations:

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial x}+w\frac{\partial u}{\partial x}\right)=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right) \tag{2}$$

$$\rho\left(u\frac{\partial v}{\partial y}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial y}\right)=-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right). \tag{3}$$

$$\rho\left(u\frac{\partial w}{\partial z}+v\frac{\partial w}{\partial z}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right). \tag{4}$$

Energy equation:

$$\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\right)=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right). \tag{5}$$

3. Numerical solution procedure

Structured mesh was generated with fine mesh at the exit of the jet and near the moving surface, to generate accurate results with less number of nodes. Different grid sizes were tested as part of grid independence study. By following Richardson extrapolation, error for different grid sizes was calculated. By compromising between computational

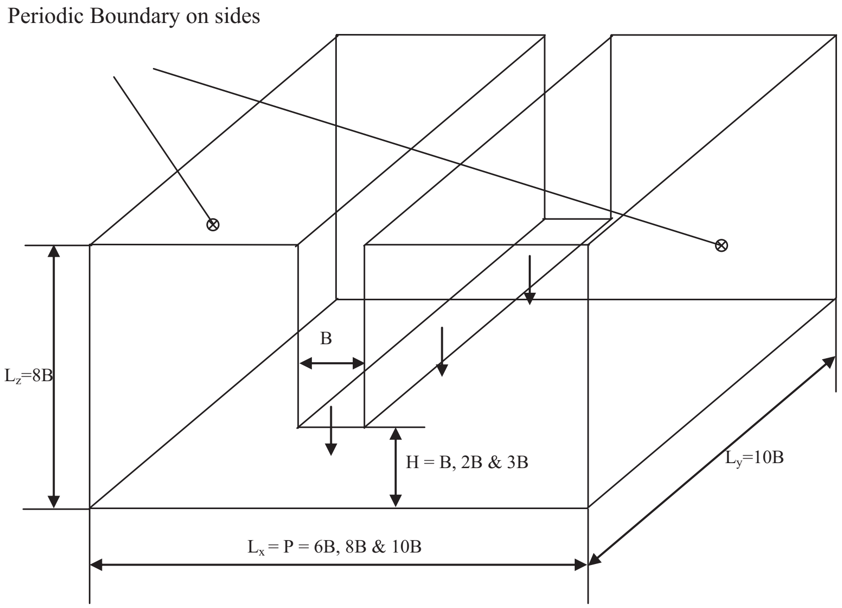

Fig. 1. Computational domain.