Jet Impingement Heat Transfer on Flat and Ribbed Surfaces

Anuj Kumar Shukla and Anupam Dewan
Department of Applied Mechanics, IIT Delhi, Hauz Khas, New Delhi - 110016
Presenting author's email: *anujshukla.iitd@gmail.com*
Other authors' email(s): *adewanphd@gmail.com*

Abstract

A computational study was carried out for turbulent slot jet impingements on flat and ribbed surfaces to investigate heat transfer and flow characteristics using OpenFOAM 4.1. It was observed that the flow and heat transfer properties were significantly affected by the ribbed plate compared to that on a flat plate. The detached rib configuration showed augmentation in the local Nusselt number in the area of clearances between ribs and plate due to a sudden flow acceleration. However, the stagnation point Nusselt number was observed to be the maximum with the flat surface as compared to that on a ribbed surface.

1. Introduction

Jet impingement heat transfer has the highest heat transfer rate among all possible single-phase heat transfer arrangements [1]. Some of its industrial applications are cooling of turbine blades and electronics chips, heating and cooling of food products and rapid cooling or heating in glass manufacturing industries, etc. Jet impingement configuration looks quite simple geometrically but it involves some flow complexities, such as, free jet, free shear-layer, potential core, stagnation point, wall jet region and flow separation with ribbed impingement surface, etc. Two kinds of conventional arrangements are possible for cooling of an impingement surface, i.e., jet impingement on a flat surface or surface with some kind of roughness. The latter represents an appropriate physical situation where this type of cooling is required in actual practice [1, 2]. Recently many researchers [1-3] have considered jet impingement on a flat surface and performed RANS computations. They observed that the computations with the standard *k-ε* turbulence were in close agreement with the experimental data [4]. In the present study we have also considered the standard k-ε model for computation of both the cases.

2. General Specifications

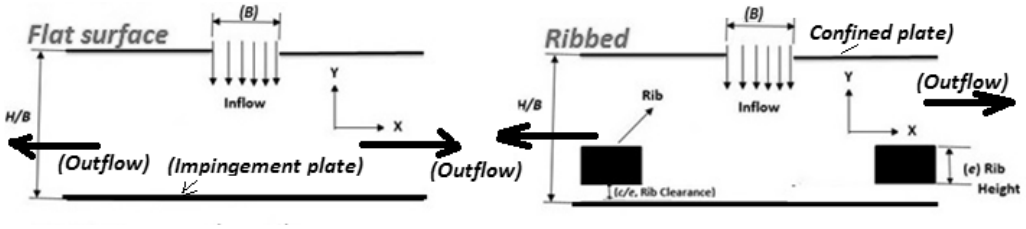


Figure 1. Computational domain and boundary conditions used in the present study.

In the present study, a 2D computational domain (Figure 1) was considered and computations were performed using OpenFOAM 4.1, which is an open source customized CFD solver. No-slip boundary conditions were applied at all walls and the impingement plate was kept at a constant temperature (T = 320 K). However, all the other walls were considered adiabatic. Almost a flat nozzle exit velocity profile (T = 300 K) was specified at the nozzle outlet. Outflow boundary conditions were specified at the outlet. Both the outlets were located at a sufficiently large distance from the nozzle centerline to avoid any reversed flow situation (*x/B* = *+60B*). Grids were made finer at critical locations, such as, near impingement plate, ribbed walls, stagnation region, etc.

3. Equations

The standard *k-ε* model is a most commonly used turbulence model to obtain mean flow characteristics of a turbulent flow. In this model the eddy viscosity is given as $\mu_t = \rho C_\mu (k^2/\varepsilon)$, where C_μ is an empirical constant.

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k \overline{u_i}) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + P_k - \rho\varepsilon \quad (1)$$

$$\frac{\partial}{\partial t}(\rho \varepsilon) + \frac{\partial}{\partial x_i}(\rho \varepsilon \overline{u_i}) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}P_k - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \quad (2)$$

The values of the model constants are [3] $C_{1\varepsilon} = 1.44,\ C_{2\varepsilon} = 1.92,\ C_\mu = 0.09,\ \sigma_k = 1$ and $\sigma_\varepsilon = 1.3$.

4. Results and Discussion

We have validated our code for jet impingement on a flat plate and observed that the standard *k-ε* showed good agreement with the reported experimental data [4] similar to that of other reported computational results [1, 3]. From Figures 2, 3 and 4 it can be observed that the flow and heat transfer characteristics are different for jet impingement on flat and ribbed surfaces. Flow acceleration and good mixing can be seen in clearances between rib and plate (Figures 2 and 3). The stagnation point *Nu* is lower for a detached rib configuration compared to the flat plate for the same values of *H/B* and *Re* (Figure 4a), but in the region of rib clearances, a heat transfer enhancement can be observed due to a sudden flow acceleration in these regions. It can also be observed (Figure 4) that there is a drop in *Nu* between the ribs due to the formation of counter-rotating vortices and hence flow cannot effectively impinge at the heated plate.

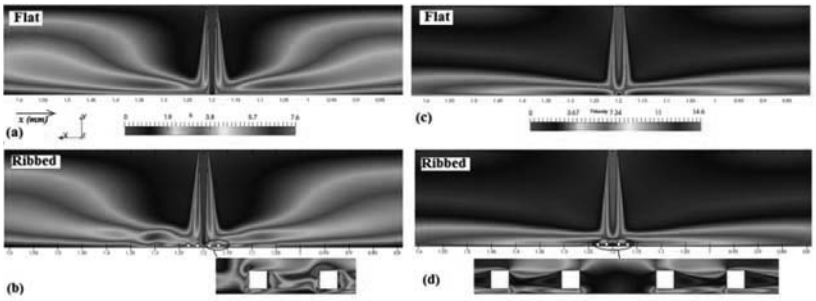


Figure 2. Contours of (a, b) TKE and (c, d) velocity for flat and ribbed surfaces.

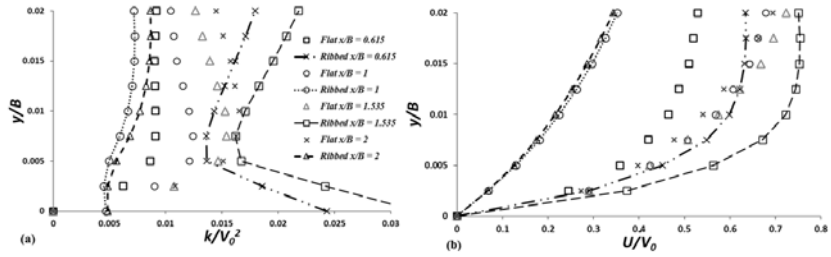


Figure 3. (a, b) Profiles of TKE and streamwise velocity close to flat and ribbed surfaces.

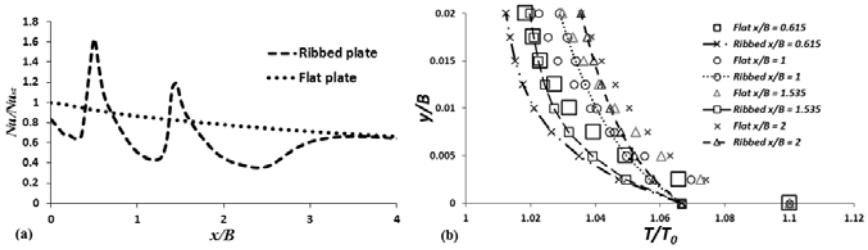


Figure 4. (a, b) Profiles of Nu and temperature for flat and ribbed surfaces.

5. Summary

Significant differences in heat and fluid flow behaviours were observed with the placement of ribs on a plate. Augmentation of heat transfer was observed in the regions of rib to plate clearances due to a good flow mixing and flow acceleration.

6. References

[1] Shukla A K, Dewan A, 2017, Flow and thermal characteristics of jet impingement: comprehensive review, Int. J. of Heat and Tech., 35, 153-166.
[2] Shukla A K, Dewan A, 2017, Convective heat transfer enhancement using slot jet impingement on a detached rib surface, J. of Applied Fluid Mechanics, 10 (6), 117-126.
[3] Dutta R, Dewan A, Srinivasan B, 2013, Comparison of various integration to wall (ITW) RANS models for predicting turbulent slot jet impingement heat transfer, Int. J. of Heat and Mass Transf., 65, 750-764.
[4] Ashforth-Frost S, Jambunathan K, Whitney CF, 1997, Velocity and turbulence characteristics of a semiconfined orthogonally impinging slot jet, Experimental Thermal and Fluid Science, 14, 60–67.