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Heat transfer due to double laminar slot jets impingement onto an isothermal wall within one side closed long duct☆

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Abstract

In this study, heat transfer due to double impinging vertical slot jets onto an isothermal wall was investigated numerically for laminar flow regime. Navier–Stokes and energy equations were discretized with a finite volume procedure on a non-staggered grid arrangement using SIMPLEM (SIMPLE-Modified) algorithm. The effect of the jet Reynolds number, the jet-isothermal bottom wall spacing, and the distance between two jets on heat transfer and flow field was examined. Air was chosen as the working fluid (Pr = 0.71). It is found that multi-cellular flow is formed in the impingement region due to interaction between two jets and entrainment effects in the duct. The mean Nusselt number increases almost linearly with increasing of Reynolds number at isothermal surface. When Reynolds number of the first jet is higher than second one the heat transfer is enhanced significantly.

Keywords: Jet impingement; Non-staggered grid; Laminar flow; SIMPLEM algorithm; Forced convection; Slot jet

1. Introduction

Jet impingement cooling is an effective method in engineering such as tempering of glass, cooling of turbine blades, drying of some industrial goods and cooling of electronic chips because of the high heat transfer coefficients which occur in the impingement region. In laser or plasma cutting processes, the application of jet impingement cooling can reduce thermal deformation of products. Jet flows can be classified according to their jet number in construction such as single, double or multiple jets. The nozzle geometry of jets may be rectangular or circular. From previous related studies it can be seen that some of the researchers investigated single impinging jet [1–11] and the others have studied with double or multiple [12–13] jets. Most of the authors studied on the jet impingement subject experimentally or numerically owing to requirement of high velocity flow and for single jet flow.

Liu et al [1] made an experimental study to investigate convective heat transfer by using impingement of circular liquid jets in laminar and turbulent flow conditions for different Prandtl numbers. They obtained empirical correlations for laminar and turbulent heat transfer in terms of Prandtl number and jet-plate spacing for stagnation point Nusselt number. To investigate the effect of these parameters, Lytle and Webb [2] made an experimental study. They found

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Nomenclature

Re	Reynolds number
Re_1	Reynolds number of the first jet ($\mathrm{Re}_1 = w_1\ v_1/v$)
Re_2	Reynolds number of the second jet ($\mathrm{Re}_2 = w_2\ v_2/v$)
Pr	Prandtl number
P	pressure pressure, (Nm^{-2})
u, v	longitudinal and transverse velocity components (ms^{-1})
U, V	dimensionless longitudinal and transverse velocity components (ms^{-1})
x, y	longitudinal and transverse coordinates
X, Y	dimensionless longitudinal and transverse coordinates
Nu	Nusselt number
H	height of the duct or the jet-bottom wall spacing (m)
w_1,w_2	width of the first and second jet (m)
W	characteristic length ($=w_1+w_2$) (m)
L	length of the duct (m)
D	spacing between two jets (m)
V_0	characteristic inlet mean velocity ($=v_1+v_2$) (ms^{-1})
v_1	mean velocity of the left jet (ms^{-1})
v_2	mean velocity of the right jet (ms^{-1})
R	the ratio of jet velocities ($=\mathrm{Re}_2/\mathrm{Re}_1$)
C_f	skin friction coefficient

Greek symbols

θ	dimensionless temperature K
v	kinematic viscosity ($\mathrm{m}^2\mathrm{s}^{-1}$)
ρ	density (kgm^{-3})
α	thermal diffusivity, ($\mathrm{m}^2\mathrm{s}^{-1}$)
ψ	stream function
φ	general dependent variable

Subcripts

c, h	cold, hot
x	local
o	inlet
m	mean

significant increases in both mean velocity and RMS turbulence fluctuations nozzle-plate spacing. Also, these parameters affected the heat transfer especially in the stagnation point. Heat transfer and fluid flow for impinging jets were studied by Baughn et al. [3]. In their study, entrainment effects of jets were investigated experimentally for circular jet. Wang et al. [4] made an analytical study to solve heat transfer between an axisymmetrical free impinging jet and a solid flat surface with non-uniform wall temperature or wall heat flux. They found that non-uniformity of wall temperature or wall heat flux has a considerable effect on the stagnation point Nusselt number. Shi et al. [5–6] performed a numerical study to show the effect of Prandtl number on semi-confined turbulent slot jet and laminar slot jet heat transfer. They obtained empirical correlations for Nusselt numbers for different fluids. Jambunathan et al. [7] made a numerical analysis to investigate impingement circular jet behavior between two parallel plates with different surface to surface spacing of two jet diameter, exit velocity profile and with different Reynolds number by using PHOENICS code. They found that the characteristics of an impinging circular laminar jet in a confined region were sensitive to the inlet jet velocity profile. Lee et al. [8] performed an experimental study to examine effects of fully developed axisymmetric impinging jet on heat transfer. They made a comparison between uniform velocity profile and