Applied Thermal Engineering 51 (2013) 723–733

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

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

Effect of nozzle geometry on heat transfer characteristics from a single circular air jet

M. Attalla [a,*], M. Salem [b,1]

[a] Mechanical Power and Energy Department, Faculty of Engineering, South Valley University, Qena – El Mabar Str., Qena 83523, Egypt
[b] Mechanical Department, Faculty of Industrial Education, Sohag University, Sohag, Egypt

HIGHLIGHTS

- ► The chamfered edge nozzle has no effect of local Nusselt number.
- ► The square edge nozzle yields a higher average Nusselt number.
- ► New correlations of impinging jets on the average Nusselt number were obtained.

ARTICLE INFO

Article history:
Received 19 February 2012
Accepted 24 September 2012
Available online 11 October 2012

Keywords:
Impingement heat transfer
Chamfered edge
Nusselt number
Turbulence intensity

ABSTRACT

The paper reports results on the effects of nozzle geometry on local and average heat transfer distribution in unconfined air jet impingement on a flat plate. An infrared thermography camera is used to record the temperature distribution from isotherms on a uniformly heated impingement surface. Experiments have been conducted with variation of exit Reynolds number, *Re*, in the range of $6000 \leq Re \leq 40{,}000$ and plate surface spacing to nozzle diameter, H/d, in the range of $1 \leq H/d \leq 6$ for single nozzle with square edge (non-chamfered) and chamfered nozzles of the same diameter, 5 mm. The chamfered length, L_c is varied from 1 mm to 3.65 mm with constant chamfered angle, $\theta = 60$ and length to diameter ratio of 50 is chosen for each nozzle configuration. It is observed that the local and average Nusselt numbers have the highest value for square edge inlet nozzle when compared with other nozzle configurations. The average Nusselt number was correlated for the nozzle Reynolds number as $\overline{Nu} \propto Re^{0.75}(H/d)^{-0.016}$ for square edge. For chamfered edge nozzles, the value of average Nusselt number is depend on jet Reynolds number, separation distance and chamfered length, L_c, $\overline{Nu} \propto Re^{0.76}(H/d)^{-0.015}(L_c/d)^{-0.01}$.

Published by Elsevier Ltd.

1. Introduction

Impinging jet has been widely used for applications where high heat and mass transfer rates are required. A variety of nozzle geometries ranging from slots to square edged (from profited plate) and round jet [1]. Previous studies have demonstrated the dependence of heat transfer on a number of parameters, including the Reynolds number of jet, nozzle to plate spacing, the presence of a confining wall, the ambient air temperature relative to the jet temperature, and jet diameter [2,3]. The geometry of the nozzle has considerable effect on the heat transfer between the impinging jet and the plate. The nozzle geometry parameters such as orifice shape and diameters, as well as the orifice inlet and outlet shapes have been found to play a determined role in heat transfer rate. The heat transfer rate depends also on the thickness of the nozzle orifice [1–4]. The orifice geometry can be designed to improve the heat transfer between the impinging jet and plate because it affects the development of the jet before it impinges on the plate, principally in the case of confined jets [5]. The orifice design is also important because it affects the pressure drop across the nozzle and the velocity profile along the target surface [1]. Stevens et al. [6,7] showed that the turbulent levels from square edged nozzle are higher than for contoured nozzles causing higher hest transfer rate.

A few prior studies have investigated the effects of nozzle configuration on impinging jet heat transfer. Brignoni and

---

* Corresponding author. Tel.: +20 96 533 0248; fax: +20 96 533 9479.
E-mail addresses: moha_attalla@yahoo.com (M. Attalla), mahmoudsalem.ahmed@yahoo.com (M. Salem).

[1] Tel.: +20 93 4600 058.

1359-4311/$ – see front matter Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.applthermaleng.2012.09.032

Nomenclature

A	plate area, m^2
d	inner nozzle diameter, m
H	distance from jet exit to impingement plate, m
k	thermal conductivity of air, W/m K
I	current, A
L	equivalent tube length, m
L_c	chamfered length, m
Nu	local Nusselt number, (−)
$\overline{Nu}$	average Nusselt number, (−)
q	heat flux, W/m^2
Re	jet Reynolds number, (−)
R	radial distance from stagnation point of jet, m
T_o	heated wall temperature, °C
T_j	jet exit temperature, °C
ΔT	temperature differences, °C
V	voltage, V
X	streamwise distance, from stagnation point of jet measured along the plate (in horizontal direction), m

Greek symbols

α	convective heat transfer coefficient, W/m^2 K
θ	chamfered angle

Subscripts

conv	convection heat flux
ele	electrical heat flux
lo	local value
loss	loss heat flux
st	stagnation point
nat	natural convection heat flux
rad	radiation heat flux

Garimella [1] started experimentally the effect of change the nozzle geometry from square edge to chamfered on pressure drop and heat transfer rate. They concluded that chamfering the nozzle inlets reduced pressure drop without affecting much the heat transfer characteristics. Puneet et al. [8] investigated the effect of nozzle shape on local heat transfer distribution for three-different nozzle cross sections, circular, square and rectangular. Pertrand et al. [9] proved a better understanding of the mean flow characteristics and heat transfer of jet array with cross-flow, using different jet orifice geometries, circular and cusped ellipse. Whelan and Robinson [10] studied the effect of nozzle geometry on pressure drop and heat transfer on the free surface and submerged liquid jet arrays. They found that the heat transfer coefficient in confined submerged test was greater than that for their free jet counterparts. In addition, the inlet/outlet chamfered and contoured inlet nozzles were best in terms of the obtained heat transfer rate for a given pumping power. Lee and Lee [11] studied the effect of nozzle configuration with three different types of profiles of nozzle exit, namely square and standard edges and sharp edge orifice. They showed that the heat transfer rate for sharp edge orifice is better at the stagnation region. Garimella and Nenaydykh [12] investigated the effect of nozzle length to diameter ratio on heat transfer rates to confined submerged liquid jet. The effect of nozzle geometry on heat transfer rate and pressure drop to confined submerged jet arrays over Reynolds number range of $1000 \leq Re \leq 7700$ were investigated by Royne and Dey [13]. Four different nozzle geometries was investigated with the countersunk nozzle experiencing the lowest pressure drop, whilst the sharp edged nozzle experienced the greatest pressure drop. The heat transfer and fluid flow characteristics of a sharp edged rectangular nozzle of aspect ratio of 4.0 was studied by Zhou and Lee [14]. The flow structure of an impinging jet produced by an orifice or a nozzle can be highly complex, because of the generation of vortex, ambient air fluid, separation and interaction with impingement or confining walls [4]. The flow is developed as a wall jet after impinging until it interacts with a confining wall. Therefore, the flow structures and heat transfer at the impingement's plate can be predicted by solving the Navier–Stokes and energy equations for turbulent flow [4,15]. The heat transfer performance of square, elliptic, and rectangular jets was studied numerically by using RNG $k-\varepsilon$ turbulent model [15]. It showed that the separation distance to equivalent diameter ratio of 5–6 give the highest heat transfer for a circular jet.

The objective of the present paper is to investigate experimentally the effect of the nozzle geometry of square edge (non-chamfered) and with chamfered edge on local and average heat transfer distribution in free single circular air jet. The experimental parameters include nozzle chamfered length (L_c), Reynolds number Re, and nozzle to plate separation distance. The specific goal is to identify condition under which nozzle shape may be reduced or enhance heat transfer rate by using the free single nozzle. The local and average heat transfer are presented as a function of separation distance, H/d, Reynolds number, Re, and chamfered length, L_c.

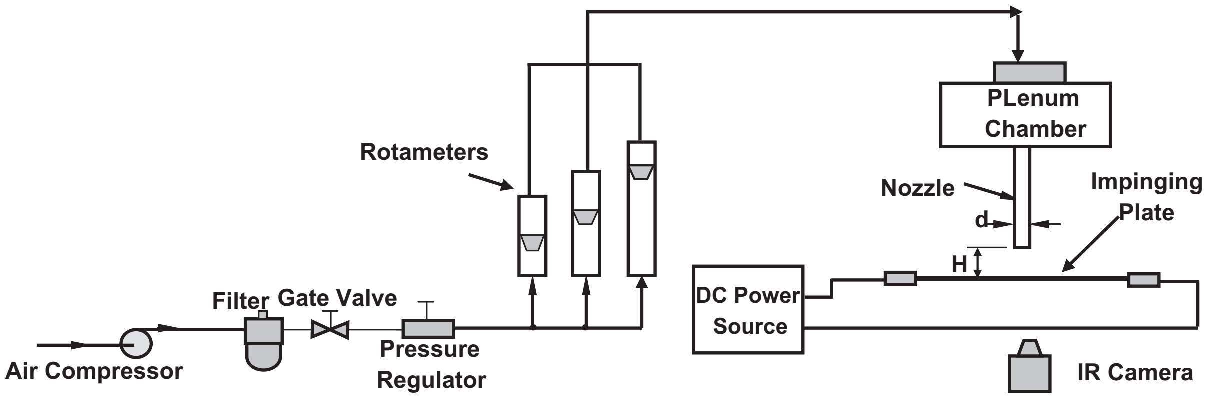

Fig. 1. Layout of experimental set-up.