Optics and Lasers in Engineering 67 (2015) 205–211

Contents lists available at ScienceDirect

Optics and Lasers in Engineering

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

Optical interferometry to investigate the heat transfer from a vertical cone under air jet impingement

E. Borjian [a], T. Yousefi [b,c,*], M. Ashjaee [d]

[a] Department of Mechanical Engineering, Science and Research Branch, Islamic Azad University, Arak, Iran
[b] Department of Mechanical Engineering, Razi University, Kermanshah, Iran
[c] Department of Mechanical and Industrial Engineering, Ryerson University, Toronto, ON, Canada
[d] Department of Mechanical Engineering, University of Tehran, Tehran, Iran

ARTICLE INFO

Article history:
Received 23 June 2014
Received in revised form
23 September 2014
Accepted 1 December 2014

Keywords:
Jet flow
Vertical cone
Mach–Zehnder interferometer

ABSTRACT

The laminar forced convection heat transfer from an isothermal vertical cone under impingement of air jet was investigated experimentally. In the experiment a Mach–Zehnder interferometer was used to obtain the local heat transfer coefficients. The cone with tip angle of 45° has been suspended from its base vertically. The round jet impinged to the tip of the cone from an orifice with 6 mm diameter. The Reynolds number based on the orifice diameter was varied from 1570 to 3040. Furthermore, the ratio of orifice-cone tip distance to orifice diameter, H/d, was varied from 1 to 6. The results show that the average Nusselt number increases by increasing the Reynolds number and by decreasing the distance between the jet exit and cone tip. Based on the experimental results, a correlation is proposed for average Nusselt number in terms of Reynolds number and jet exit spacing from the cone tip. In addition, from the local Nusselt number it can be seen that for low Reynolds numbers there is an increase in the local heat transfer at the base of the cone.

1. Introduction

Because of high heat transfer rate of air jet impingement, it is used in many industrial applications. In addition, the industrial applications of convection heat transfer from cones can be found in civil engineering, chemical industry (bottom of tanks), and electronics (transistors, resistors, diodes, lamps).

The problem of laminar free-convection flow along a vertical faced up or faced down cone has been investigated theoretically and experimentally by many researchers since 1953. Merk and Prins [1] found the similarity solution for the case of an isothermal cone whereas Hering and Grosh [2] have obtained a number of similarity solutions for cones with prescribed wall temperatures being a power function of the distance from the apex along the generator. Further results have been obtained by Hering [3], Sparrow and Guinle [4] for small values of Prandtl number (Pr) and by Roy [5] for large values of Prandtl number, respectively. Alamgir [6] has investigated the overall heat transfer from vertical cones using the integral method. Pop and Takhar [7] have studied the compressibility effects in laminar free convection from a vertical cone, while Hossain and Paul [8] have considered the effect of suction and injection when the cone surface is permeable. In all these analytical papers, the boundary-layer thickness is small compared to the local radius of the cone. Also, Lewandowski et al. [9] studied the problem of laminar free convection from an upward cone theoretically. Their work also includes experimental results for the average heat transfer rates from the cones with different tip angles, and the two limiting cases of vertical cylinder and circular disc as special cases. Recently Ashjaee et al. [10] reported the results of their experimental and numerical study on an isothermal downward cone.

In addition to natural convection heat transfer, some studies have been done on the mixed convection flow along a vertical cone. Kumari et al. [11] investigated the steady mixed convection flow over a vertical cone for two values of Prandtl numbers, namely $Pr=0.733$ (air) and $Pr=6.7$ (water). Pop et al. [12] have investigated steady laminar mixed convection boundary layer flow along a vertical cone of constant wall temperature for fluids of any Prandtl number. Moreover some mixed convection studies from rotating cones and cones with suction and injection have been done by other researchers.

A literature search reveals that no experimental and numerical studies have been done on the forced convection heat transfer from a cone under impingement of air jet. The objective of the current study was to investigate the forced convection heat transfer from a vertical downward cone with uniform surface temperature under impingement of a round jet. The Reynolds number based on the orifice diameter ranged from 1570 to 3040. The ratio of the orifice-cone tip

* Corresponding author. Tel.: +1 416 979 5000x4520.
E-mail address: tooraj.yousefi@ryerson.ca (T. Yousefi).

http://dx.doi.org/10.1016/j.optlaseng.2014.12.002
0143-8166/

Nomenclature

A	parameter in Eq. (6) equal to KR/λ
B_i	coefficient of t^i in expansion of $d/t^{0.5}$ $i=0, 1, 2, \ldots$
D	base diameter of the cone (m)
G	Gladstone–Dale constant
$\bar{h}$	average heat transfer coefficient $(W/m^2\,\mathrm{K})$
k	thermal conductivity of air $(\mathrm{W/m\,K})$
K	specific refractivity of air, Gladstone–Dale constant $(\mathrm{m^3/kg})$
L	slant length, characteristic length of the cone (m)
n	refractive index of the fluid
$\overline{Nu}_d$	average Nusselt number $(\overline{h_L}d/k)$
P	pressure (Pa)
r	radial position (m)
R	radius of axisymmetric disturbance (m)
R_o	gas constant $(J/\mathrm{kg\,K})$
R_i	Richardson number Gr_L/Re_L^2
Ra_D	Rayleigh number $\left[(g\beta(T_w-T_\infty)D^3)/\upsilon\alpha\right]$
Re	Reynolds number (Ud/ν)
T	temperature (K)
t	parameter equal to $t=1-y^2/R^2$
U	average jet exit velocity (m/s)
x, y, z	coordinate axes

Greek symbols

α	thermal diffusivity $(\mathrm{m^2}/s)$
β	volumetric expansion coefficient $(1/K)$
δ	fringe shift
$\Delta\delta$	error in fringe shift
ρ	density (kg/m^3)
λ	laser wave length (m)
θ	tip angle of the cone (degree)
ν	kinematic viscosity (m^2/s)
ξ	characteristic length, measured from cone tip (m)

Subscripts

ref	ambient or reference condition
f	film condition
w	at the surface
ξ	local position

spacing to orifice diameter was varied from $H/d=1$ to $H/d=6$, while the cone surface temperature and jet nozzle diameter were kept constant at 120 °C and 6 mm, respectively. Experiments have been done on a cone with apex angle of 45° using a Mach–Zehnder interferometer. The schematic of the model is shown in Fig. 1.

2. Experimental setup

2.1. Interferometer

In addition to non-intrusive measurement of temperature field with no thermal inertia, optical technique has been known as an accurate method in the measurement of temperature fields. In this investigation a Mach–Zehnder interferometer (MZI) was used as the optical technique. Fig. 2 shows a schematic of the interferometer, which is used in this experiment.

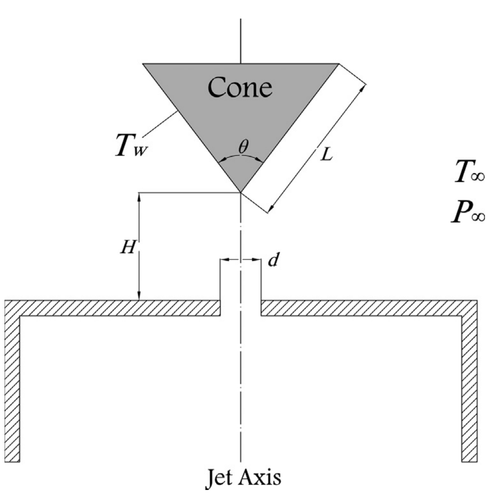

Fig. 1. Scheme of the studied geometry.

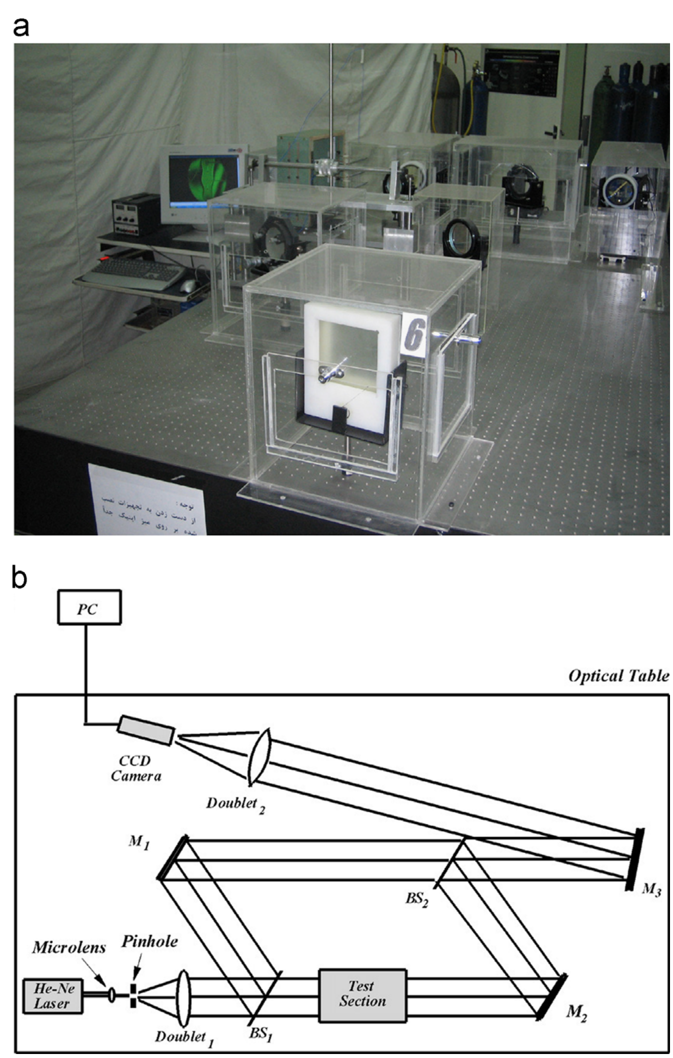

Fig. 2. (a) Mach–Zehnder set up. (b) Plane view of Mach–Zehnder interferometer.