Alexandria Engineering Journal (2015) 54, 281–293

HOSTED BY

ELSEVIER

Alexandria University

Alexandria Engineering Journal

www.elsevier.com/locate/aej
www.sciencedirect.com

ORIGINAL ARTICLE

Heat transfer due to impinging double free circular jets

Mohamed A. Teamah [a,*,1], **Mohamed M. Khairat** [b]

[a] Faculty of Engineering and Technology, Arab Academy for Science and Technology and Maritime Transport, Alexandria, Egypt
[b] Faculty of Engineering, Suez Canal University, Ismailia, Egypt

Received 27 March 2015; revised 10 May 2015; accepted 18 May 2015
Available online 9 June 2015

KEYWORDS

Heat transfer;
Free impingement jets;
Hydraulic jump;
Super cooling

Abstract The heat transfer and fluid flow between a horizontal heated plate and impinging circular double jets were studied experimentally. The parameters investigated are the Reynolds number of each jet and jet-to-jet spacing. Experiments are carried out covering a range for Reynolds number from 7100 to 30,800 for each jet, the dimensionless jet-to-jet spacing from 22.73 to 90.1. During experimental phases, the right jet Reynolds number was higher than the left jet Reynolds number. The isothermal contours were plotted for different cases as well as the distribution of water film thickness over the heated plate. The results indicated that increasing the Reynolds number of one jet than the other increases both local and average Nusselt numbers. In addition, increasing the jet-to-jet spacing at the same Reynolds number increases the average Nusselt number.

1. Introduction

Impinging cooling is an effective way to generate super cooling rate in many engineering applications such as steel, glass, quenching and paper industries. Impinging jets are used to cool down the products after rolling. Also, it is used in laser or plasma cutting processes and cooling of electronic equipment. Firstly, in 1964 Watson [1] studied analytically the motion of the thin layer formed when a smooth jet of water falls vertically on a horizontal plane and spread out radially. In the same year Chaudhury [2] studied the heat transfer to Watson's analysis in a similar manner. In 1981 Craik et al. [3] measured the liquid depth using a light absorption technique in which a laser shone through water containing a strong dye. Liquid depths ahead and behind the jump were determined as well as the depth profiles of the jump in the stable regime. In 1991 Vader et al. [4] measured the heat flux distribution and the surface temperature on a flat, upward facing, constant heat flux surface cooled by a planar, impinging water jet. Jet velocities were between 1.8 and 4.5 m/s, fluid temperatures of 30, 40 and 50 °C and heat fluxes between 0.25 and 1.00 MW/m^2. In 1988 Zeiton [5] studied the fluid flow and the heat transfer between a horizontal plate and a single liquid circular jet impinging. A theoretical analysis was performed and the flow pattern was obtained. The results included the film thickness distribution at both sides of hydraulic jump and the determination of the position of the hydraulic jump and the velocity distribution within the film. Experiments were also conducted for comparing with the results of theoretical analysis. To visualize the jet nature, it divides the area near-

* Corresponding author.
1 On leave "Mechanical Engineering Department, Faculty of Engineering, Alexandria University, Egypt".

Peer review under responsibility of Faculty of Engineering, Alexandria University.

http://dx.doi.org/10.1016/j.aej.2015.05.010
1110-0168

Nomenclature

A	area of segments, m^2
CNC	computerized numerical control
Cp	specific heat, J/kg K
d_j	jet diameter, m
h	local heat transfer coefficient, W/m^2 K
h_{avr}	local average heat transfer coefficient, W/m^2 K
$\bar{h}$	average heat transfer coefficient, W/m^2 K
H	thickness of water film, m
k	fluid thermal conductivity, W/m K
Nu	local Nusselt number, hd_j/k
Nu_{avr}	average local Nusselt number, $h_{avr}d_j/k$
$\overline{Nu}$	average Nusselt number, $\bar{h}d_j/k$
m	water mass flow rate (kg/s)
Re	Reynolds number, Vd_j/v
Re_L	Reynolds number of the left jet, Vd_j/v
Re_R	Reynolds number of the right jet, Vd_j/v
R	radial coordinate, m
Pr	Prandtl number, $\mu Cp/k$
PVC	polyvinyl chloride
T_s	wall temperature, K
T_w	water temperature, K
V	jet velocity, m/s
X	distance between two jets, m

Greek symbols

v	kinetic fluid viscosity, m^2/s
ρ	fluid density, kg/m^3
μ	dynamic fluid viscosity, kg/m s
σ	surface tension, N/m

Subscripts

n	number of segment

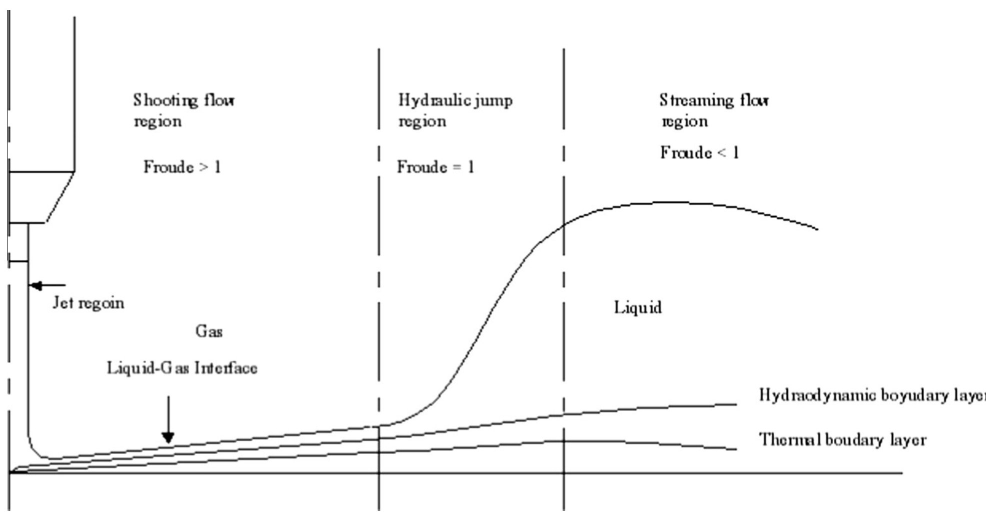

Figure 1 Hydraulic jet nature.

Figure 2 Experimental test rig details.

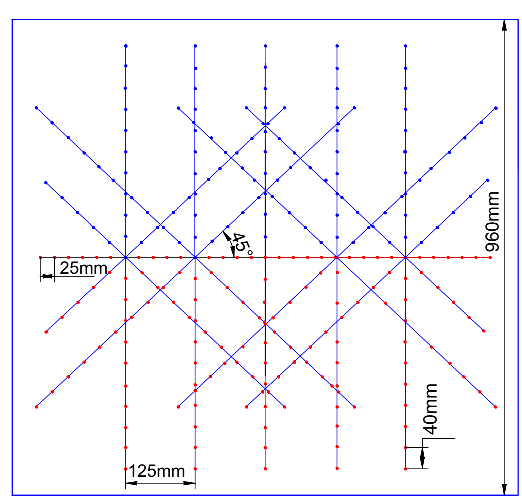

Figure 3 Distribution for thermocouple over the heated plate.