International Journal of Thermal Sciences 124 (2018) 344–355

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

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

Effect of the injection angle on local heat transfer in a showerhead cooling with array impingement jets

Eui Yeop Jung[a], Chan Ung Park[a], Dong Hyun Lee[b], Kyung Min Kim[c], Hyung Hee Cho[a,*]

[a] Department of Mechanical Engineering, Yonsei University, Seoul, 03722, South Korea
[b] Korea Institute of Energy Research, 152 Gajeong-ro, Yuseong-gu, Daejeon, 34129, South Korea
[c] Korea District Heating Corporation, 781 Yangjae-daero, Gangnam-gu, Seoul, 13585, South Korea

ARTICLE INFO

Keywords:
Heat/mass transfer
Staggered array impingement jets
Inclined jet
Showerhead cooling
Gas turbine

ABSTRACT

An experimental study was conducted to investigate the effect of the injection angle for staggered array impingement jets in a showerhead cooling system. We suggested the angled jets array to enhance heat transfer performance, and heat transfer characteristics were compared to that on the normal jets array. The semicircle test section was designed to consider the showerhead configuration, and the Reynolds number was changed from 3000 to 10,000. The naphthalene sublimation method was used to evaluate the heat transfer coefficients on targeted plates, and the numerical simulations were carried out to analyze the characteristics of the flow fields. The averaged heat transfer coefficient increased monotonically with increasing Re_d due to the enhanced flow mixing by increasing mass flow rate. A low heat transfer coefficient was observed among the adjacent impingement jets in the vicinity of the central row of holes due to staggered array pattern and curvature effect. To overcome this disadvantage, the inclined jets were applied in present study. The heat/mass transfer coefficients were larger for the inclined jets for all Re_d because an amount of wall jet is flowed toward the low heat transfer region by flow imbalance. As applied inclined array impingement jets, averaged heat transfer was enhanced about 9% in low Re_d compared to normal array impingement jets.

1. Introduction

The operating temperature of gas turbines has increased in recent years to meet demand for higher thermal efficiencies and larger power outputs. Especially, the turbine blades, which is installed in gas turbine, are exposed directly to hot combustion gases, and the leading edge of the turbine blades are under the high temperature gas. Therefore, the development of advanced cooling techniques is required to protect components of gas turbines from excessively high heat resistance temperature. At the leading edge of the turbine blades, the most popular cooling method is impingement jet cooling, an internal cooling method to protect the hot component.

The heat transfer characteristics of impingement jet cooling are dominated by turbulent transport of jets and vortices, as well as flow interactions due to geometry. Thus, the configuration of the impingement jets is important, and many reports have been published on geometry affecting impingement jet configuration as a variable to improve the cooling performance. Previous researches considered the various shapes of the hole [1–3], the pattern of the array of holes [4–7], and the distance between the hole and plate [2,8,9] to obtain optimized geometric condition. And investigation of the significance of crossflow was progressed in point of heat transfer [10–12]. In addition, the studies on the heat transfer characteristics according to the various shaped rib have been carried out recently [13,14]. In these studies, the fluid flow and heat transfer characteristics were investigated using simplified conditions. The correlations and optimal geometries of jets were evaluated experimentally.

The leading edge of a gas turbine blade has a concave surface, and the fluid flow and heat transfer characteristics are mainly affected by the geometry of the surface [15–18]. Gau and Chung [16], Yang et al. [17], and Poitras et al. [18] investigated the fluid flow and heat transfer characteristics of concave surfaces as a function of the Reynolds number (Re_d), the distance between the hole and the plate, the ratio of the diameter to the slot width and curvature of concave surface. They reported that the heat transfer characteristics was larger for concave surfaces due to an enhancement of the wall jet flow instability by curvature effect. In addition, the heat transfer was enhanced at the large curvature condition in the narrow confined duct. Kumar et al. [19] and Hong et al. [20] reported numerical and experimental analyses of a concave surface using a single row arrangement of

* Corresponding author.
E-mail address: hhcho@yonsei.ac.kr (H.H. Cho).

http://dx.doi.org/10.1016/j.ijthermalsci.2017.10.033
Received 21 March 2017; Received in revised form 26 October 2017; Accepted 26 October 2017

Nomenclature

d	injection hole diameter
D_c	diameter of semicircle in concave test duct
D_{naph}	mass diffusion coefficient of naphthalene vapor in air
h_m	local mass transfer coefficient
$\dot{m}$	local naphthalene mass transfer per unit area and time
ρ_s	density of solid naphthalene
$\rho_{v,w}$	naphthalene vapor density on the surface
dy	local sublimation depth of naphthalene
$d\tau$	runtime of experiment
H	gap distance between injection hole and target surface
θ	circumferential angle
x	coordinate in test section
s	coordinate in test section
Nu	Nusselt number
Pr	Prandtl number
Sc	Schmidt number
Sh	Sherwood number based on the hole diameter
$\overline{\overline{\text{Sh}}}$	averaged Sherwood number
Re_d	Reynolds number based on hole diameter and the average velocity in the hole

impingement jets. The heat transfer coefficient was larger for the concave surface and increased with increasing distance in a spanwise direction. The average heat transfer coefficient increased as the ratio of the height to the plate spacing decreased. Patil et al. [21] showed experimental analysis of a concave surface using the confined singe row impingement jet, and they obtained correlation for overall averaged *Nu* with various geometric variables. However, a single row arrangement of impingement jets exhibits a low heat transfer region between the impingement jets and the outer region ($s/d > 2$), and crossflow leads to a reduction in the heat transfer coefficient [22–24]. Therefore, it is necessary to change the arrangement of the impingement jets to improve the low heat transfer of a sing row arrangement of impingement

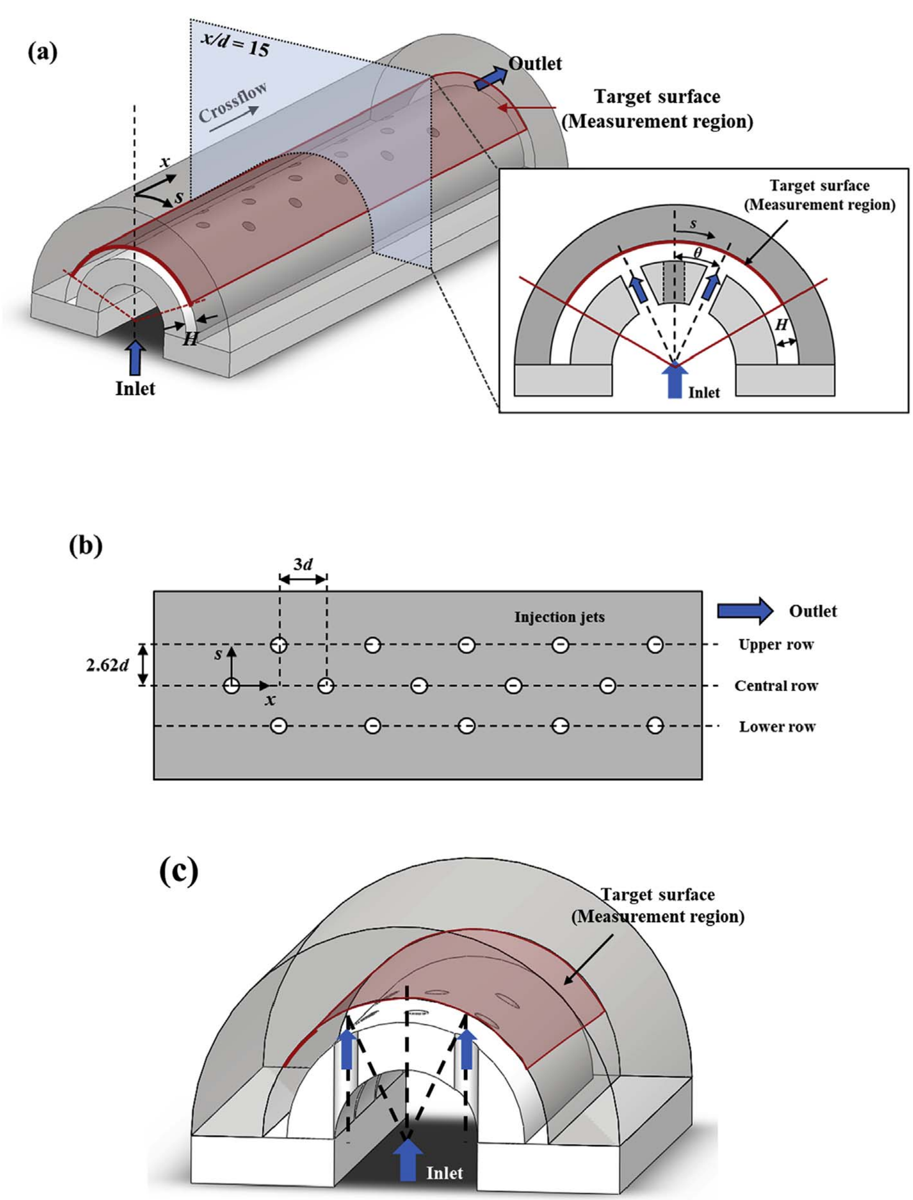

Fig. 1. Schematic 3-D view of concave surface; (a) test section and cross-section of normal jet, (b) hole arrangement, (c) cross-section of inclined jet.