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Effect of inclination in heat transfer between impinging circular air jet and flat plate

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ABSTRACT

There are some industrial applications like spray formed billet cooling by impinging jets where the target and the jet are not orthogonal but the oblique.Therefore, study of inclination of target plate on heat transfer between impinging jet and flat plate is important. In the present work, inclination effect is studied for the oblique angles of 45^{o}, 60^{o}and 75^{o} at a given *Z/D* of 6 and Reynolds number of 23000. The fins used are in the form of cubes of 2 *mm* size spaced at a pitch of 5 *mm* on the target plate. It is observed that there is augmentation in heat transfer rate .

Keywords: Impinging air jet, heat transfer augmentation, finned surface.

INTRODUCTION

Impinging jets have received considerable attention due to their inherent characteristics of high rates of heat transfer besides having simple geometry. Various industrial processes involving high heat transfer rates apply impinging jets. Heat transfer rates in case of impinging jets are affected by various parameters like Reynolds number, nozzle plate spacing, radial distance from stagnation point, Prandtl number, target plate inclination, confinement of the jet, nozzle geometry, curvature of target plate, roughness of the target plate, low scale turbulence intensity i.e., turbulence intensity at the nozzle exit. Gardon and Cobonpue[1] have reported the heat transfer distribution between circular jet and flat plate for the nozzle plate spacings greater than 2 times the diameter of jet, both for single jet and array of jets. They have used specially designed heat flux gauge for the measurement of local heat transfer rates from a constant wall temperature plate. Gardon and Akfirat[2] studied the effect of turbulence on the heat transfer between two dimensional jet and flat plate. They also studied effect of multiple two-dimensional jets on the heat transfer distribution[3]. Baughn and Shimizu[4] and Hrycak[5] have conducted experiments of heat transfer between round jet and flat plate employing different methods of surface temperature measurement. Lyttle and Webb[6] have studied the effect of very low nozzle plate spacing ($Z/D < 1$) on the local heat transfer distribution on a flat plate impinged by a circular air jet and found that in the acceleration range of the nozzle plate spacing ($Z/D < 0.25$), maximum Nusselt number shifts from the stagnation point to the point of secondary peak with the effect being more pronounced at higher Reynolds number. Review of the experimental work on impinging jets is done by Martine[7], Jambunathan *et. al.*[8] and Viskanta[9]. Hansen and Webb[10] have studied the effect of the modified surface on the heat transfer between impinging circular nozzle and the flat plate. In the present work, inclination effect is studied for the oblique angles of 45°, 60°and 75° and at a given *Z/D* of 6 and Reynolds number of 23000. The fins used are in the form of cubes of 2 *mm* size spaced at a pitch of 5 *mm* on the target plate. It is observed that there is augmentation in heat transfer rate .

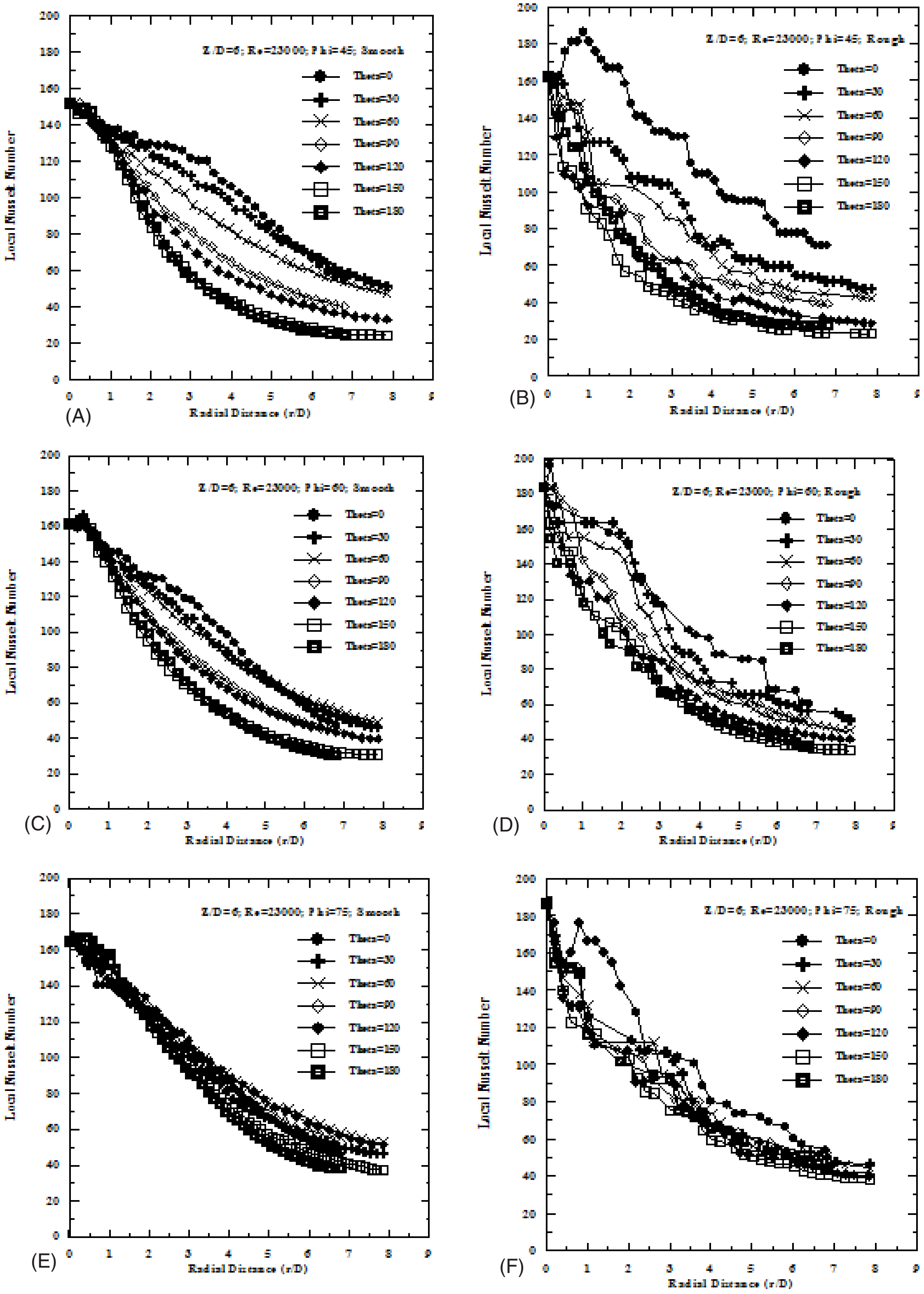

Fig. 1: Effect of Inclination on the Nusselt number for Smooth and Rough surface at *Z/D* of 6

EXPERIMENTAL

Air jet is supplied by a three-cylinder two-stage air compressor through a calibrated orifice flow meter. Air filter and Pressure regulator are installed upstream of the orifice flow meter to filter the air and to maintain the downstream pressure at a value of 4 ± 0.05 bar. The flow rate is controlled by two needle valves, one on each side of the orifice flow meter. The nozzle, which directs the air until it impinges upon a heated target plate, is constructed with a 7.35 mm inner diameter aluminum pipe of length to diameter ratio of 83. The impinging plate is constructed using 1*mm* thick stainless steel plate of size120mm×120mm. Nichrome heater of size100mm×100m is packed between impinging plate and a Bakelite support plate with mica sheets in between to isolate the impinging plate from the heater, electrically.

Electric power is supplied to the heater through variac. The voltage and the current are measured by digital panel meters. A K-type Chromel-Alumel thermocouple junction is soldered on the target plate at its extreme end to know about the steady state. Similarly,thermocouples are attached on cooled surface along the flow direction from the stagnation point with an interval of 5 mm between each thermocouple to measure wall temperature distribution.

RESULTS AND DISCUSSION

Fig. 1 shows the effect of inclination on the heat transfer from smooth and rough surfaces at different oblique angles of 45°, 60° and 75° at given *Z/D* of 6 and Reynolds number of 23000. It can be observed that when the target plate is kept inclined to the axis of the jet; acceleration side (Uphill side,*q* = 0°) exhibits higher heat transfer than that on the downhill side (*q* = 180°). For the smooth surface Fig.1 (a), (b) and (c)), near the stagnation point, the heat transfer data shows more or less axisymetric nature up to *r/D* of 1 to 1.5 for all oblique angles studied. At an oblique angle of 45°, the scattering in the heat transfer data on uphill and downhill side is maximum. For rough surfaces, Fig.1 (d), (e) and (f) show that the scattering in the heat transfer data for uphill and downhill sides is more that the corresponding case of the smooth surface. Further, the shift in the point of the maximum heat transfer from the geometric impinging point toward the uphill side is observed for the oblique angles of 45° and 60° as shown in Fig.1 (d) and (e). The heat transfer on the rough surface is observed to be higher than that on the smooth surface.

CONCLUSION

The inclination of the target plate with the axis of the jet causes the scattering of the heat transfer coefficient between the impinging jet and the flat plate on the acceleration side and the compression side. The acceleration side exhibits higher heat transfer than the compression side, particularly, away from the stagnation point (*r/D* > 1.5) for the smooth surface. For the rough surface, scattering in the heat transfer data is observed also in the stagnation region. There exists the shift in the point of maximum heat transfer from the geometric stagnation point toward the acceleration side for the rough surface. No such shift is observed for the smooth surface.

Nomenclature

D	Diameter of the nozzle exit (m)
h	Heat transfer coefficient ($W/m^2.K$)
Nu	Nusselt number (Dimensionless)
r	Radial distance from the stagnation point (m)
Re	Reynolds number based on nozzle exit condition (Dimensionless)
Z	Nozzle plate spacing (m)

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