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Spatially-resolved heat transfer characteristics in channels with pin fin and pin fin-dimple arrays

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ABSTRACT

A comparative study has been conducted to investigate the spatially-resolved heat transfer characteristics of air turbulent flow in rectangular channels with pin fin and pin fin-dimple arrays. A combined method of experiments and numerical computation was adopted to obtain the spatially-resolved Nusselt numbers on the endwall surface of the pin fin and pin fin-dimple channels. Compared with the pin fin channel, the pin fin-dimple channel shows distinctive local heat transfer characteristics on the endwall beneath the main flow and the wake flow region. Due to the presence of the dimples in the pin fin arrays, extra strong vortex flows are generated near the wall beneath the main flow region downstream the dimples, which distinctively increase the turbulent mixing there and enhance the heat transfer rates; however the turbulent mixing in the wake of the pin fins is reduced appreciably, which leads to decreased heat transfer rates in the wake especially at relatively low Reynolds number. Overall, the dimples in the pin fin arrays increase not only the averaged heat transfer coefficient, but also the heat transfer area on the endwall.

1. Introduction

Short pin fins (pin fin height-to-diameter ratio $H/D = 0.5–4$) are commonly used in the internal cooling passage of gas turbine blades, particularly in the trailing edge where there exist narrow cooling channels [1,2]. In the pin fin channel, the pin fins increase the internal wetted (cooled) surface area. On the other hand, when the fluid flows across the pin fin arrays, the pin fins create accelerated flow between pins, separated highly disturbed wake regions behind each pin, horseshoe vortices from interaction with the endwall, and the unsteady vortical shedding induced from the pin. These mechanisms serve to produce a high turbulence level in the flow and significantly enhance the convective heat transfer performance.

Previously, numerous investigations have been done focusing on the effects of geometrical parameters on the flow friction and heat transfer in the pin fin channel. Zukauskas [3], Van Fossen [4], Metzger et al. [5–7] and Chyu et al. [8,9] revealed that the pin height-to-diameter ratio, array orientation (in-line or staggered) and fin cross-sectional shape, etc. are crucial parameters in determining the heat transfer and friction facto. Lau et al. [10], and McMillin and Lau [11] considered the effects of bleed ejection on heat transfer, and on streamwise pressure variations in a pin fin channel. More recently, Won et al. [12] studied the spatially-resolved Nusselt number and flow structure in a pin fin channel, and their study revealed the underlying mechanisms of heat transfer enhancement in the pin fin channel.

It is noted that, even though the pin fin channel has a significantly improved heat transfer performance, however it pays a penalty of considerably increased flow resistance in the channel. Metzger et al. [5–7] and Chyu et al. [8,9] indicated that, compared to the smooth channel, the channel with pin fin arrays with the streamwise and spanwise spacings of 2.5 can achieve a heat transfer enhancement of 2–4 times, and an increase in the friction factor by 20–30 times in the Reynolds number range of 10,000–100,000.

Dimples on the heat transfer surface can significantly enhance the convective heat transfer, but do not increase the pressure loss appreciably. Chyu et al. [13], Moon et al. [14], Mahmood et al. [15,16] and Ligrani et al. [17] investigated the flow and heat transfer performance in a channel with dimples. Their studies showed that, compared with the smooth channel, the dimpled channel surface can improve the Nusselt number by a factor of 1.8–2.8, with an increase in the friction factor by 1.3–2.9 times. Mahmood et al. [15] stated that the outward shedding or ejection of fluid from the dimples produces the heat transfer augmentation mainly by the periodicity and unsteadiness of the vortical fluid.

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