International Journal of Thermal Sciences 104 (2016) 158–171

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

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

Heat transfer and flow characteristics of a rectangular channel with a small circular cylinder having slit-vent vortex generator

Jiansheng Wang [a], Chen Wang [b, *]

[a] *Key Laboratory of Efficient Utilization of Low and Medium Grade Energy, MOE, School of Mechanical Engineering, Tianjin University, Tianjin 300072, China*
[b] *Department of Mechanics, School of Mechanical Engineering, Tianjin University, Tianjin 300072, China*

ARTICLE INFO

Article history:
Received 8 April 2015
Received in revised form
1 November 2015
Accepted 12 January 2016
Available online xxx

Keywords:
Large eddy simulation
Slit-vent cylinder
Gap ratio
Cylinder wake
Boundary layer

ABSTRACT

The heat transfer and flow characteristics of a rectangular channel with a small scale slit-vent circular cylinder are numerically investigated by Large Eddy Simulation (LES). The small scale circular cylinder is used as vortex generator and located in the boundary layer. The gap ratio G/D (the distance between the lower of the cylinder and the bottom of the channel G to the cylinder diameter D) varies from 0.5 to 6.0. The Reynolds number based on the bulk velocity and half height of the channel is 3745. The influence of gap ratio on cylinder wake and flow structure near the bottom of the channel is probed. Then, the effect of the cylinder wake on the flow and heat transfer features of the channel is revealed. Compared with the result of the rectangular channel without cylinder, it can be found that the interaction between the wake of cylinder and the boundary layer can significantly improve the heat transfer performance of the channel. Compared with the result of the rectangular channel with a reference cylinder whose diameter is the same as the slit-vent cylinder and without slit-vent, it can be found that the impinging jet derived from the slit-vent can further strengthen the interaction between the wake from the lower cylinder and the boundary layer when the gap ratio is less than 2.0. When the gap ratio is more than 2.0, the overall thermal performance of rectangular channel with the slit-vent cylinder is improved, and the constraint of the channel bottom on the wake of the cylinder is gradually weakened. Meantime, the disturbance caused by the wake of the slit-vent cylinder wears off, which leads the synthesis thermal coefficient η lower. The impinging jet has obvious influence on the stability of cylinder wake which related to the features of flow and heat transfer of the channel.

© 2016 Elsevier Masson SAS. All rights reserved.

1. Introduction

Heat transfer enhancement technique is used in many engineering applications. In general, heat transfer enhancement techniques are classified into active, passive and compound categories. The distinction between the passive and active method is that the latter one requires external power to bring about the effect. Compound technique combines passive and active techniques to produce an enhancement. Typical examples of active method include induced pulsation by various artificial methods, the additional magnetic and the electrostatic fields, surface vibration, fluid vibration, suction or injection and jet impingement, which require an external activator or power supply to achieve the enhancement goal [1]. The surface or geometrical modifications achieved by inserts or additional devices are usually applied in passive method. Inserts extra unit, swirl flow devices, treated surface, rough or extended surfaces, coiled tubes, surface tension devices and additives in fluid are typical examples of passive method [2]. As a typical example, vortex generator has been widely used in engineering for its advantages such as without additional power input and less cost. The major function of vortex generator is to induce the vortices, improve fluid mixing and thus efficiently reduce the thickness of the boundary layer to obtain the enhancement of heat transfer.

In 1960s, Schubauer and Spangenberg [3] reported the investigation on boundary layer controlled by vortex generator. Their results indicated that the vortices induced by vortex generator played a fatal role in the evolution of the boundary layer. In the earlier study, the vortex generator was mainly used for delaying the separation of boundary layer in aircraft wing. In 1969, Johnson and Joubert [4] first proposed to achieve the heat transfer enhancement in a channel with the vortex generator. It was found that the heat transfer performance was obviously improved by the vortex generator. The vortices induced by vortex generator augment the turbulence intensity and flow instability which are responsible for

---

* Corresponding author. Tel.: +86 022 27890053.
E-mail address: chenwangme@tju.edu.cn (C. Wang).

http://dx.doi.org/10.1016/j.ijthermalsci.2016.01.006
1290-0729/© 2016 Elsevier Masson SAS. All rights reserved.

Nomenclature

D	cylinder diameter
H	channel half height
Nu	$Nu = hH/\lambda$, Nusselt number
f	friction coefficient
p	pressure
Pr	Prandtl number
x, y, z	coordinate direction
u_i	velocity components
Greek symbol	
α	thermal diffusion
η	synthesis performance coefficient
λ	thermal conductivity
ν	kinematic viscosity
ρ	density
τ_w	shear stress
S	slit width
G	distance from cylinder to channel bottom
T	temperature
h	heat transfer coefficient
u_m	average bulk velocity
u_τ	frictional velocity
u, v, w	x, y, z velocity components
t	time
Superscript	
“–”	the filtered spatial variable
“/”	fluctuation components
Subscript	
i, j, k	different direction
0	the rectangular channel without cylinder
w	the channel bottom

improving the local heat transfer [5]. Chen et al. [6] investigated the frictional pressure drop and heat transfer performance of rectangular micro-channels with longitudinal vortex generators. It was found that heat transfer performance was improved while the augment of pressure losses were larger than that of heat transfer performance and the critical Reynolds numbers of channel decreased. Zhou and Feng [7] performed experimental investigations on the performance of plane and curved winglet vortex generators with and without punched holes. It was found that the punched holes improve the thermohydraulic performance of vortex generator and decrease the flow resistance. Promvonge et al. [8] conducted an experimental investigation on thermal performance enhancement in a constant heat-fluxed square duct fitted with combined twisted-tape and winglet vortex generators. The results indicated that the Nusselt number and friction factor presented different trend while winglet blockage ratio and winglet pitch ratio varying. A mesh cylinder suspended in the tube was used to enhance convective heat transfer in tubes [9]. The flow field modulation was achieved when the fluid flowed over the mesh screen, which resulted in increase of velocity gradient near the wall and significant heat transfer enhancement. Aris et al. [10] studied the convective heat transfer enhancement of heated surfaces by vortex generators made from shape memory alloys. The vortex generators can change shape to intrude further into the flow at high temperatures, while maintaining a low profile at low temperatures to minimize flow pressure losses. Mikielewicz et al. [11] studied the air flow in the wind tunnel featuring transverse and inclined vortex generators. It was found that the heat transfer performance presented a nearly periodicity and strongly related to the rib pitch-to-height ratio and the spanwise coordinate. The heat transfer performance of the rib roughened passages was effectively improved in comparison to the smooth channel and suffered increased pressure loss. Caliskan [12] experimentally studied the features of triangular and rectangular vortex generators. The vortex generators showed a more significant increase in heat transfer coefficient for channel flows. He et al. [13] numerically investigated the characteristics of punched winglet type vortex generator arrays which were used to enhance air-side heat transfer of finned tube heat exchanger. The results indicated that the main vortex didn't play dominant role while the corner vortex had significant influence on the heat transfer performance for the punched vortex generator. It was found that the augmentation of pressure drop exceed that of heat transfer performance as well. Cheraghi et al. [14] numerically investigated the heat-transfer enhancement in a uniformly heated slot mini-channel with an adiabatic circular cylinder. The result indicated that the maximum heat transfer enhancement can be achieved when the obstacle was located in the middle of the duct. When the circular cylinder was located near the bottom, the vortex shedding can be suppressed, which leaded flow and thermal fields gradually become steady and pressure drop decreased. The various vortex generators have been proved to be an effective method for enhancing the convective heat transfer. But the improvement of heat transfer is obtained with the penalty of the augment in flow drag (pressures drop) generally. The heat transfer performance can be improved by changing the velocity distribution. For example, Cao et al. [15] proposed flow field modulation concept and applied it in a tube by mesh cylinder, an annular region and a core region were formed within the tube cross section. The results showed double-peak velocity distribution over tube cross section. The larger velocity and velocity gradient near wall region were responsible for the heat transfer enhancement. Furthermore, Cao and Xu [16] modulated flow and temperature distribution by mesh pores. The results showed the excellent heat transfer enhancement performance at low flow rate pumping cost, which derived from an attached hydraulic boundary layer, a weak circulating flow region upstream of the mesh insert and a weakly positive flow region downstream of the mesh insert. In most cases, the augment of pressures drop is larger than that of the heat transfer [14], which means that in order to achieve the heat transfer enhancement, more pump power will be expended. So, it's necessary to find a method which is effective in both heat transfer improvement and suppression of flow drag augment.

The geometric scale of most vortex generator is equivalent to that of enhanced surface, which means that larger scale vortices can be induced by the vortex generator. The larger scale vortices enlarge the disturbance of flow field, which is responsible for the substantial increase of the flow drag. It can be predicted that less scale vortices is benefit for the suppression of the flow drag. For this reason, the wake of small scale blunt body is attempted to achieve the goal in present work.

The flow past a circular cylinder immersed in fluid can be considered as a typical example of flow past a blunt body.

For the unbounded circular cylinder immersed in fluid, when the Reynolds number exceeds the critical value, the periodic

Download English Version:

https://daneshyari.com/en/article/667875

Download Persian Version:

https://daneshyari.com/article/667875

Daneshyari.com