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Numerical study and identification of cooling of heated blocks in pulsating channel flow with a rotating cylinder

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ABSTRACT

A numerical study of pulsating channel flow with heated blocks in the presence of an adiabatic rotating cylinder is performed. The governing equations are solved with a finite volume based commercial solver. The effects of pulsating frequency, Reynolds number and cylinder rotation angle on the fluid flow and heat transfer characteristics from the surface of the heated blocks are numerically studied. It is observed that the flow field and heat transfer rate are influenced by the variations of these parameters. Furthermore, nonlinear models are created to identify the dynamics of the heat transfer for each of the surface of the blocks using system identification.

1. Introduction

Forced convection channel flow with heated blocks is of great importance for various practical engineering applications such as cooling of electronic equipments and design of heat exchangers. The temperature limitation on the electronic equipments in order to maintain their reliability and accuracy has led to consider the problem of thermal management of electronic devices. Due to its importance, a vast amount of literature is dedicated to the study of forced convection flow in a channel with heated blocks. To remove heat from the heat generating blocks effectively, active and passive control methods have been proposed. In one of the methods, vortex generators are installed in the channel to disturb the thermal boundary layer developed along the heated blocks and hence augmentation the convective heat transfer is achieved. Perng et al. [1] have numerically simulated the effect of using a porous vortex-generator on the convective heat transfer in the block-heated channel. Their results indicate that Reynolds number increases the heat transfer enhancement and vortex-induced vibration and the porosity has slight influence on heat transfer enhancement. Luviano-Ortiz et al. [2] have used the curved deflectors to redirect the flow in a block-heated channel flow. They put the deflectors to lead the fluid in the inter-spacing between the blocks since without deflectors this part became a low energy transport stagnant zone. They also pointed out that, insertion of the deflectors also increases the pressure drop in the channel. Fu et al. [3] have numerically studied the effect of an insulated moving block on a heated surface in a channel. They observed a remarkable heat transfer enhancement of the heated surface due to destruction of the thermal boundary layer attached to the heated surface. Fu and Tong [4] have numerically investigated the effects of an oscillating cylinder on the heat transfer removal from the heated blocks in a channel. The effects of Reynolds number, oscillating amplitude and frequency on the heat transfer were studied. They observed that heat transfer is enhanced substantially when the cylinder oscillates in the lock-in region. The unsteadiness of flow and instability mechanism inside the channel have attracted much attention due to the need for efficient design of these systems with maximum heat transfer and minimum power requirements. Ghaddar et al. [5,6] have numerically demonstrated the resonance behavior in a periodic grooved channel flow and showed that heat transfer enhancement was observed when the oscillating frequency was in tune with the frequency of the least stable mode. Korichi and Oufer [7] have numerically studied the convective heat transfer in a channel with three heated obstacles. Their results indicated that transition from steady to unsteady flow occurred at lower values of Reynolds number when one of the obstacles are placed on the upper wall of the channel. They also showed that vortices generated by the upper mounted obstacle can greatly influenced the heat transfer along the

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Nomenclature

A	amplitude of forcing, [−]
D	cylinder diameter, [m]
h	height of the blocks, [m]
H	channel height, [m]
$h_{x,t}$	local heat transfer coefficient, [W m^{-2} K^{-1}]
k	thermal conductivity, [W m^{-1} K^{-1}]
L	channel length, [m]
n	unit normal vector
Nu	local Nusselt number, hH/k ,[−]
p	pressure, [Pa]
Pr	Prandtl number, ν/α, [−]
Re	Reynolds number, u_0H/ν, [−]
St	Strouhal number, fH/u_0, [−]
T	temperature, [K]
u, v	x–y velocity components, [m s^{-1}]
x, y	Cartesian coordinates, [m]
x_c, y_c	cylinder center location, [m]
w	length of the blocks, [m]
W	inter-block spacing, [m]

Greek characters

α	thermal diffusivity, [m^2 s^{-1}]
θ	non-dimensional temperature, $T - T_c/T_h - T_c$, [−]
ν	kinematic viscosity, [m^2 s^{-1}]
ρ	density of the fluid, [kg m^{-3}]
τ	non-dimensional time, u_0t/H, [−]
Ω	cylinder rotation angle, [−]

Subscripts

c	cold
h	hot

obstacle surfaces. In another study, Korichi et al. [8] numerically studied the effects of oblique plates as vortex generators in a channel flow with periodic mounted obstacles. They reported heat transfer enhancement of 200 percent at Reynolds number of 600 and for a given geometric configuration of the oblique plate. Forced pulsation of incoming flow is an active method which increases the flow mixing by affecting the hydrodynamic instability and hence enhances the convective heat transfer of the heated blocks in the channel. Moon et al. [9] have experimentally studied the convective heat transfer from periodically spaced blocks in tandem in pulsating channel flow. The effects of inter-block spacing, forcing amplitude and frequency on the heat transfer removal from the heated protruding block were investigated. They observed that resonance frequency for which heat transfer attains a maximum coincides with the inverse of traveling time of a fluid particle. Huang and Yang [10] have numerically studied the forced pulsating flow in a channel with two porous-block-attached strip heat sources at the bottom wall. They examined the mixing enhanced convection due to porous block and enhanced convection due to pulsating flow. They showed that for some choices of the parameters such as size or permeability of porous block, the frequency and amplitude of pulsation, heated enhancement can be greatly effected. Young and Vafai [11] have numerically investigated the effects of obstacle dimensions, spacing, and number, along with the obstacle thermal conductivity on the forced convection in a channel with an array of heated obstacles attached to one wall. Velazquez et al. [12] have investigated the pulsating flow of 2D laminar flow in a heated rectangle for Reynolds number of 100 and Strouhal numbers between 0 and 0.4. They showed that the prescribed pulsation enhances heat transfer in the cavity due to the periodic change in the recirculation flow pattern generated by the pulsation.

In this article, we have used a rotating cylinder suspended in the channel to create vortex shedding and interact with the flow pulsation which could enhance the convective heat transfer from the heated blocks for a specific combination of parameters. Several studies have been conducted to investigate the effects of rotating or stationary cylinders in enclosures or in channels on the fluid flow and heat transfer. Costa and Raimundo [13] have numerically studied the mixed convection in a differentially heated square enclosure with an active rotating circular cylinder. They observed that depending on the rotation, the free and forced convection can be combined or opposite. The effects of the radius, rotation velocity and thermal conductivity and thermal capacity of the cylinder on the mixed convection problem were studied. Hussain and Hussein [14] have numerically investigated the mixed convection in an enclosure with a rotating cylinder using a finite volume method. Their result showed that rotating cylinder locations have an important effect in enhancing convection heat transfer in the square enclosure. Paramane and Sharma [15] have studied the forced convection heat transfer across a circular cylinder rotating with a constant non-dimensional rotation rate for Reynolds number between 20 and 160. They reported that rotation can be used as a drag reduction and heat transfer suppression technique. Phutthavong and Hassan [16] have studied the forced flow of circular rotating cylinder located eccentrically inside a micro-channel. The study in Ref. [17] is related to the heat transfer in electric machinery. Rehimi et al. [18] studied experimentally the flow past a circular cylinder located between parallel walls for Reynolds number between 30 and 277. They reported differences between the unconfined cylinder case. They observed that von-Karman instability is shifted to a higher Reynolds number for the confined cylinder case. Sahin and Owens [19] have used a finite volume method to investigate the flow field around a circular cylinder placed in a channel. The effect of the lateral wall proximity on the stability, wake structure behind the cylinder is investigated for a range of blockage ratio at Reynolds up to 280. They observed different bifurcations and transition region from symmetric vortex shedding to asymmetric vortex shedding with increasing blockage ratio. Singha and Sinhamahapatra [20] have numerically investigated the flow about a circular cylinder placed in a channel using a finite volume based method. They performed simulations up to $Re = 250$ and the blockage ratio is varied chancing the channel height. They observed that due to the interaction between the cylinder wake and channel wall, transition to vortex shedding regime is delayed.

The aim of the present investigation is to numerically study the combined effects of flow pulsation and rotating cylinder on the heat transfer removal form the heated blocks mounted on the bottom wall of the channel. The effects of Reynolds number, pulsation frequency, cylinder rotation angle on the flow structure and heat transfer characteristic for each of the heated blocks are investigated.

2. Numerical simulation

The physical problem considered in this study is depicted in Fig. 1. Pulsating flow in a channel with two heated blocks held at constant temperature are considered. A rotating adiabatic cylinder (cylinder center is located at (x_0, y_0)) is placed centrally within the channel and inter-block spacing. The distance from the inlet to the