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Numerical heat transfer in a rectangular channel with mounted obstacles on upper and lower walls

Abdelkader Korichi [a], Lounes Oufer [b,*]

[a] Centre Universitaire de Médéa, Quartier Ain D'heb Médéa 26000, Algeria
[b] Université des Sciences et de la Technologie Houari Boumediene, Faculté de Génie Mécanique et de Génie des Procédés, Département de Génie des Procédés, B.P. 32, El-Alia, Bab-Ezzouar, Algiers, Algeria

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Abstract

A numerical investigation of convective heat transfer between a fluid and three physical obstacles (blocks) mounted on the lower wall (2 blocks) and on the upper wall (1 block) of a rectangular channel was conducted. Laminar flow of the fluid circulating through the channel was assumed. The effect of the Reynolds number, block spacing and dimensions and solid to fluid thermal conductivity ratio were studied. A uniform heat flux through the blocks was assumed. The results showed that transition from steady to unsteady flows occurred at lower values of the Reynolds number when an obstacle is placed on the upper wall of the channel. The isotherms around the blocks were presented and the heat transfer evaluated through the Nusselt number. As expected, the results obtained showed that as the value of the Reynolds number was increased, the heat removed from the obstacles increased sensibly with a maximum heat removal around the obstacle corners. Moreover, the temperature difference between the three obstacles decreased as the Reynolds number was increased. Some disagreement in the results was observed when compared with those reported in the literature.

Keywords: Convective heat transfer; Laminar flow; Channel; Obstacle; Numerical solution

1. Introduction

Convective cooling of electronic components mounted on circuit boards has been the subject of a large number of scientific papers in the last decade. This interest was motivated by the rapid advances in electronic technology with the trends of the electronic industry being oriented toward the development of more and more compact and powerful computers. In all circumstances, such an objective may never be attained without an effective removal of the heat released by electronic components under operation.

Literature in that area is quite diverse as many experimental and theoretical studies have been reported. Ortega et al. [1] studied experimentally the conjugate convective and conductive heat transfer for laminar, transitional and turbulent boundary layer flow over a flush-mounted. The authors reported that substrate conduction decreased monotonically with increased Reynolds number. Moreover, heat transfer was found to depend not only on the maximum fluctuating velocity but also on the geometry of the grooved surface. Young and Vafai [2] investigated the forced convective heat transfer of individual and array of multiple two-dimensional obstacles for a Reynolds number ranging from 800 to 1300. The effect of a change in the channel height and input heat power was investigated and an empirical correlation established. In another study, Wang and Vafai [3] studied the mixed convection and pressure losses in a channel with discrete flush-mounted and protruding heat sources. In the same work, the effect of obstacle geometry and flow rate was considered. An empirical correlation for both pressure drop and Nusselt number was presented.

* Corresponding author. Tel./Fax: (+213)21 24 71 69.
E-mail addresses: a_korichi@hotmail.com (A. Korichi), lounesoufer@yahoo.com, loufer@usthb.dz (L. Oufer).

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Nomenclature

D_h	hydraulic diameter, $= 2H$	m
h	dimensionless obstacle height, $= h^*/H$	
h^*	obstacle height	m
H	channel height	m
K	thermal conductivity	$W \cdot m^{-1} \cdot K^{-1}$
L	dimensionless outlet length	
L^*	outlet length	m
L_0	dimensionless inlet length	
L_0^*	inlet length	m
Nu_x	local Nusselt number, $= \frac{-1}{\theta_m} \frac{\partial \theta}{\partial n}\vert_{\text{block surface}}$	
$\overline{Nu_x}$	time averaged local Nusselt number, $= \frac{1}{\tau_p} \int_0^{\tau_p} Nu_X \, d\tau$	
P	dimensionless pressure, $= p^*/\rho u_{0m}^2$	
p^*	pressure	Pa
Pe	Peclet number	
Pr	Prandtl number	
q''	heat flux	$W \cdot m^{-2}$
Re	Reynolds number	
s	dimensionless obstacle spacing, $= s^*/H$	
s^*	obstacle spacing	m
T	temperature	K
T	time	s
u, v	dimensionless velocity components, $= \frac{u^*}{u_{0m}}, = \frac{v^*}{u_{0m}}$	
u^*, v^*	velocity components	$m \cdot s^{-1}$
w	dimensionless obstacle width, $= w^*/H$	
w^*	obstacle width	m
x, y	dimensionless coordinates, $= x^*/H, = y^*/H$	
x^*, y^*	physical coordinates	m

Greek symbols

α	thermal diffusivity, $= k/\rho C_p$	$m^2 \cdot s^{-1}$
θ	dimensionless temperature, $= \frac{T - T_0}{q'' H/k}$	
ρ	density	$kg \cdot m^{-3}$
ν	kinematic viscosity	$m^2 \cdot s^{-1}$
τ	dimensionless time, $= t u_{0m}/H$	

Subscripts

cr	critical
f	fluid
m	mean
s	solid
0	inlet
1, 2, 3	refer to obstacle number

Superscript

$*$	dimensional

Garimella and Schiltz [4] studied heat transfer enhancement of cooling by using a protruding heat source and an array of roughness elements and ribs on the opposite wall of a narrow rectangular channel. A Nusselt number correlation was proposed. Jubran et al. [5] carried out an investigation of heat transfer and pressure drop in rectangular channels containing monocubical obstacles. The factors of interest were obstacle dimensions and their shapes. Garimella and Eibeck [6] examined the effect of spanwise spacing on heat transfer from an array of protruding heat sources in forced convection. They concluded that the upper limit of heat transfer was obtained at a ratio of 2.2 of the obstacle height to spanwise spacing. In another study [7], the same authors found that the Nusselt number decreased with an increase in the ratio of channel height to obstacle height, and approached an asymptotic value at the fourth row. Very recently, Meinders and Hanjalic' [8] presented an investigation on the effect of arrangement type of two wall-mounted cubes exposed to turbulent flow. Their results showed a large variation in the distribution of the local convective heat transfer for the various in-line and staggered configurations utilized. Furthermore, the cube-averaged heat transfer coefficients were found to be independent of cube placement.

Numerical studies in that area of research consisting of enhancement of cooling of electronic devices are becoming more and more numerous. Davalath and Bayazitoglu [9], using finite volume formulation, studied forced convection over three block heat sources attached to the lower wall of a channel. They developed a model for prediction of the Nusselt number as a function of the Reynolds and the Prandtl numbers. Using the Gherkin-finite-element formulation, an important work was carried out by Young and Vafai [10,11] who investigated the flow and heat transfer in a rectangular channel containing many heated obstacles mounted on its lower wall. The dependence of the flow and temperature fields on parametric changes such as the Reynolds number, solid thermal conductivity, geometric parameters and heating method was studied. The results were presented in the form of correlations established for one and for arrays of multiple heated obstacles.

Moreover, in much of the recently reported work, researchers showed a strong interest in enhancement of heat transfer from electronic components by passive cooling. For instance, Wu and Perng [12] investigated the effect of installing an oblique plate on heat transfer over an array of five obstacles mounted in a horizontal channel. They observed an enhancement of heat transfer represented by an increase in the value of the Nusselt number of up to 39.5%. Sultan [13] carried out an experimental study on the effect of open holes ratio on the mean heat transfer coefficient from three protruding mounted blocks simulating electronic components. The results showed an increase in the amount of heat trans-