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Thermal design and optimization of vertical convergent channels in natural convection

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Abstract

In this study, design charts for the evaluation of thermal and geometrical parameters, when some of these are known, are proposed for natural convection in air, in vertical convergent channels.

A simple procedure to obtain thermal design charts is presented. The optimal spacing and convergence angle, in terms of thermal performance, is obtained from composite correlations of average Nusselt number and dimensionless maximum wall temperature as a function of Rayleigh numbers.

Results are carried out for symmetrically heated channels with walls at uniform heat flux. The proposed charts are obtained starting from data of numerical investigation in the following parameter ranges: surface emissivity from 0.10 to 0.90, convergence angle from 0° to 10°, $2.0 \leqslant L/b_{\max} \leqslant 60$, $0.048 \leqslant b_{\min}/b_{\max} \leqslant 1.0$ and $3.0 < Ra'^{*}_{b,av} < 1.2 \times 10^{7}$.

Keywords: Thermal design; Natural convection; Vertical convergent channel

1. Introduction

The design of natural convection thermal control systems by using simple relations is certainly appealing. Particular interest has been devoted to the channel configuration and several contributions have dealt with this geometry, as recently reviewed in [1]. An interesting problem is the heat transfer in a convergent channel with two uniformly heated flat plates. The determination of the thermal performance of these configurations is rather difficult, due to the large number of thermal and geometric variables [2–8].

The first numerical and experimental study of natural convection in water in a convergent vertical channel was carried out in [2]. Natural convection in air, in a convergent vertical channel with uniform wall temperature was investigated numerically in [3]. A numerical study on natural convection in vertical converging channels, with uniform wall temperature, for different angles of convergence was carried out in [4]. A numerical simulation and optimization for a vertical diverging and converging channel with laminar natural convection was accomplished in [5]. The configuration of a vertical convergent channel was studied numerically in [6]. The two principal flat plates at uniform heat flux were considered with finite thickness and thermal conductivity. For laminar natural convection in air in channels, the radiative effects may be significant, as first shown by Carpenter et al. [7]. This is particularly interesting in convergent

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Nomenclature

b	channel spacing, m
d	wall thickness, m
g	gravitational acceleration, m s^{-2}
Gr	Grashof number, Eq. (2)
h	heat transfer coefficient, W m^{-2} K^{-1}
k	thermal conductivity, W m^{-1} K^{-1}
L	wall length, m
$\dot{m}'$	mass flow rate for unity of width, Eq. (8), kg m^{-1} s^{-1}
Nu	average Nusselt number, Eq. (3)
Pr	Prandtl number
q	heat flux, W m^{-2}
Q_T	total heat transfer rate, W
S	wall surface, m^2
Ra'	average Rayleigh number, Eq. (2)
Re	average Reynolds number, ub/v
T	temperature, K
T^+	dimensionless temperature, Eq. (1)
u	mean velocity, m s^{-1}
x, y	coordinates, m
W	total width of the stack, m

Greek symbols

β	volumetric coefficient of expansion, K^{-1}
ε	emissivity
θ	angle between the single plate and the vertical, half convergence angle, °
μ	dynamic viscosity, kg m^{-1} s^{-1}
v	kinematic viscosity, m^2 s^{-1}
ρ	air density, kg m^{-3}

Superscript

*	convective and radiative

Subscripts

av	average
b	channel gap
c	convective
max	maximum
min	minimum
o	ambient air
r	radiative
ref	reference value
x	x coordinate
w	wall
Ω	ohmic dissipation
0	fully developed flow
∞	single plate

channels, due to the large view factor toward the surrounding [8].

The design of natural convection thermal control systems using simple relations is appealing and attention has been devoted to the vertical channel configuration [1,9,10]. For channels, a simplified design procedure was proposed in [9]. A graphical procedure for the design of a channel-chimney system was carried out in [1].

Following the analysis accomplished in [1], a graphical procedure for the design of vertical convergent channel in natural convection in air is proposed by assuming a two-dimensional steady state regime and uniform surface heat flux. A method for calculating the optimal channel spacing and optimal value of the convergence angle, in terms of thermal performance, is developed.

2. Analysis and numerical procedure

The parameters that play important role in natural convection in convergent channels are: heat flux, wall temperatures, channel height, the channel sections at the entrance and exit. One of the aims of the thermal control of electronic equipments is to estimate the maximum wall temperature. The investigated configuration is shown in Fig. 1. The elaborated results were obtained numerically by FLUENT 6.0 and the numerical model is reported in [6,8]. The geometry under consideration consists of two non-parallel plates that form a vertical convergent channel. A two-dimensional model was considered. The channels walls were thermally

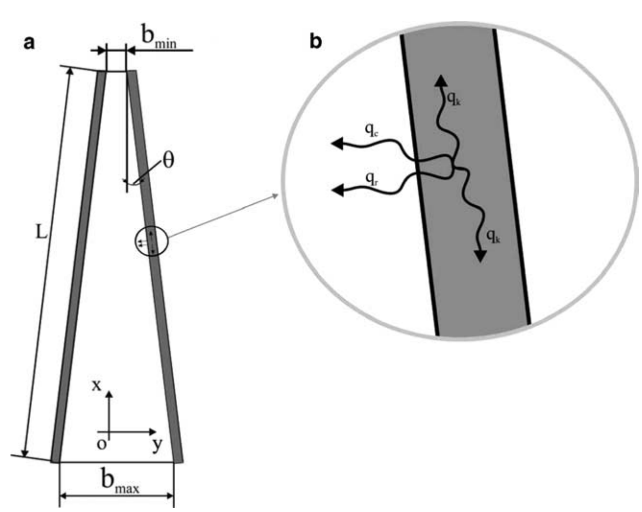

Fig. 1. (a) Sketch of investigated configuration; (b) detail of the conductive wall.