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Free convective energy management of an inclined enclosure mounted with triple heating elements: Multiple morphology optimizations with unique global energy supply

Dong-Dong Zhang [a,b,c], Lei Wang [a,b,c], Di Liu [d], Fu-Yun Zhao [a,b,c,*], Han-Qing Wang [e]

[a] *Key Laboratory of Hydraulic Machinery Transients (Wuhan University), Ministry of Education, Wuhan, Hubei Province, China*
[b] *Hubei Key Laboratory of Waterjet Theory and New Technology (Wuhan University), Wuhan, Hubei Province, China*
[c] *School of Power and Mechanical Engineering, Wuhan University, Wuhan, Hubei Province, China*
[d] *College of Pipeline and Civil Engineering, China University of Petroleum, Qingdao, Shandong Province, China*
[e] *School of Civil Engineering, University of South China, Hengyang, Hunan Province, China*

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ABSTRACT

An objective-oriented optimization procedure consisting of a simplified conjugated gradient methodology and a two-dimensional fluid and thermal energy transfer model is implemented to discover optimal morphologies of local heating elements. Direct heat transfer problem and inverse optimization problem are subsequently investigated. Full simulation shows that thermal Rayleigh number, enclosure inclination, heating strength ratio and size ratio of local heating sources have significant effects on the natural convection heat transfer in the inclined enclosure, asymptotically modeling like solar energy collectors or electronic boxes. The fluid flow and energy transfer inside the enclosure are analyzed in some representative situations, by the simultaneous use of streamlines, isotherms and heatlines. Inverse natural convection solutions on the maximization of global conductance are addressed, concerning on the effects of thermal Rayleigh number, inclination angle, heater strength ratio and heater length ratio. Mathematical correlations have been proposed by the multiple linear regressions to identify the role of governing parameters on maximizing global conductance and optimal morphologies of the discrete heat sources, concerning on the unique global heating flux. Present numerical methodology and inverse procedures could benefit free cooling of electronic components and effective solar collection elements.

1. Introduction

Natural convection through a rectangular enclosure with several discrete heating sources is common in many applications, such as environmental control (e.g., indoor buildings, storage), materials processing (e.g., drying), food processing (e.g., baking) and electronics (e.g., cabinets). Particularly, the continuing miniaturization of integrated circuits on a single computer chip and reduced spacing of chips in an array have contributed to significant improvements in the performance of computer systems. However, increased circuit densities corresponding to larger power dissipation rates and complicate thermal control are needed when a principal objective is to maintain components at or below specified maximum temperatures [1–4].

Many researches have been conducted over the last decades, to investigate the enclosed convection of heat transfer with flush-type heating sources. Chu et al. [5] conducted the numerical studies involving laminar natural convection with a single heat source mounted on one vertical wall of an air-filled cavity. As the Rayleigh number increases, the heater location associated with the maximum Nusselt number shifted downward toward the bottom of the cavity. Refai and Yovanovich [6] investigated the influence of discrete heat sources on natural convection heat transfer in a square enclosure filled with air. A relationship between *Nu* and *Ra* was correlated, depending on the scale length obtained from analytical solutions. Chadwick et al. [7] studied the natural convection in a discretely heated enclosure experimentally and theoretically for the single and dual heater configurations. Recently, Liu and Phan-Thien [8] investigated optimum configurations of the three heated elements mounted on a vertical substrate using finite element method. Observing from their results, an optimum thermal performance could be obtained when the center-to-center distances between the chips follow a geometric series, especially

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* Corresponding author at: School of Power and Mechanical Engineering, Wuhan University, Dong-Hu Southern Road, 430072 Wuhan, Hubei Province, China.
E-mail addresses: liudi66@163.com (D. Liu), fyzhao@whu.edu.cn (F.-Y. Zhao).

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Nomenclature

c_p	heat generation rate
g	gravitational acceleration
H	height of the enclosure
i	refer to the heat source
J	objective function
k	number of iterations
K_L	heater length ratio
Kq	heater strength ratio
L_i	length of local heat source
C_{max}	maximum global conductance
P	dimensionless pressure
q	heat flux
Pr	Prandtl number
T	dimensionless temperature
Ra	thermal Rayleigh number
S_i	location of heat source
T	dimensionless temperature
U	dimensionless horizontal velocity
V	dimensionless vertical velocity
X	horizontal Cartesian coordinate
Y	vertical Cartesian coordinate

Greek symbols

α	thermal diffusivity
ν	momentum diffusivity of fluid
ρ	density of the fluid
τ	dimensionless time
Γ	boundary of enclosure
π	step size
ξ	conjugate direction
γ	conjugate gradient coefficient
κ	thermal conductivity
χ	the constant
Ψ	streamfunction
Θ	heatfunction
Δ	difference value
Ω	domain of the partitions

Subscripts

low	of low level
N	heat source index
r	ratio

Superscript

$*$	dimensional variable

when the geometric ratio is maintained at the golden mean (1.618).

Although discrete heat sources on a wall have been addressed in the past decades, few were aimed to identify their optimal positions and sizes for maximizing their heat dissipation potentials. Analytical calculations were carried out by Da Silva et al. [9,13] and Hajmohammadi et al. [10–12,14–16] for heat transfer performance enhancement. Representatively, Da Silva et al. [9] determined the optimal distribution of discrete heat sources in a laminar natural convection enclosure, by the use of constructal theory. They have reported that the optimal distribution is not uniform and the heat sources placed near the tip of a boundary layer should have zero spacing as thermal Rayleigh number promotes to critical values. Later, Da Silva et al. [13] carried out the similar

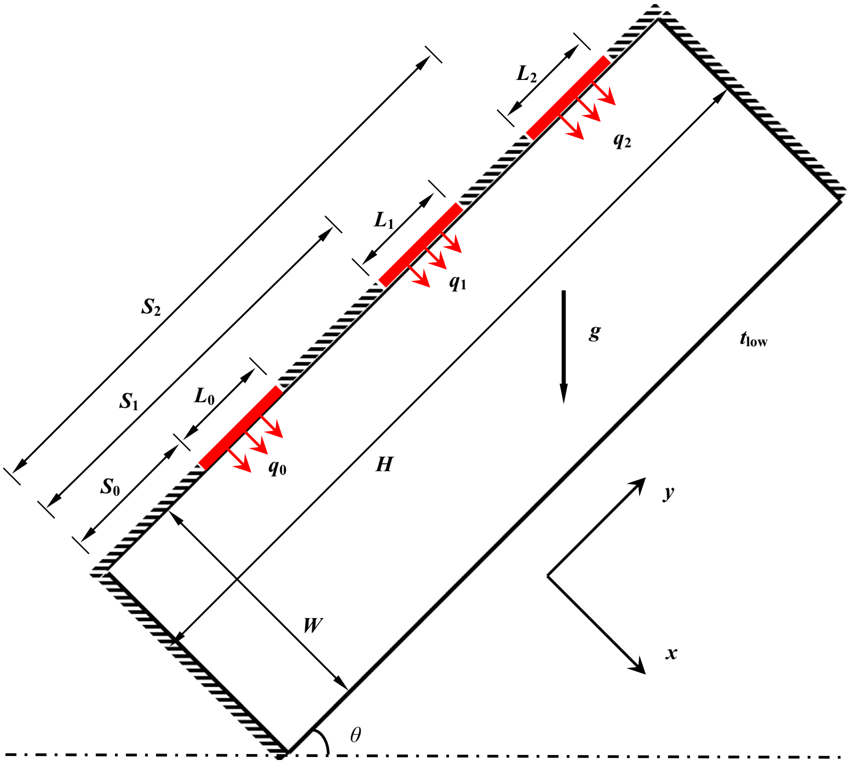

Fig. 1. Schematic of the inclined enclosure with flush-type discrete heat sources.