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Heat transfer assessment of an alternately active bi-heater undergoing transient natural convection

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ABSTRACT

The effective thermal management of the heat generating components is important for job scheduling in multi core processors used in several electronic devices. In the present paper, natural convection in an enclosure with alternately active heat sources for different switch over time period is studied. Laminar, incompressible 2-D code with Finite Volume Method (FVM) has been used to solve the transient equations of continuity, momentum and energy. The study is limited for the Rayleigh number (Ra) varying from 10^3 to 10^6 and Prandtl number of 0.71. For the range of Rayleigh number and time period studied here, heat transfer is found to be more than that of the steady operation of a single heater for all switchover time periods. Some nonlinear characteristics on hydrodynamics and heat transfer are observed at higher Rayleigh numbers for longer switchover time period. The analysis also shows that the decrease in time period results in increase in heat transfer.

1. Introduction

In electronic processing units performance optimization with temperature constraint (POTC) gives the upper limit of the task scheduling length. Temperature ceiling for maintaining the hardware life often restricts the execution time of the task and consequently degrades the overall system performance [1]. Chips like Intel Core i7 use the on-chip Digital Thermal Sensor (DTS) for obtaining the allowable temperature limit. A multi-functional power management system called "AMD-P" is used in AMD Turion and Six-Core AMD Opteron processor [1]. It is, therefore, necessary to understand and assess the thermal characteristics of the electronic processing unit undergoing a task scheduling for effective thermal management.

The knowledge of time-dependent responses of the thermal systems is essential in the setup and operation of modern electronic devices. To achieve better performance for same power consumption manufacturers of computer hardware distribute total transistors into multiple processing cores [2]. It may be noted that in a multi-core processor switching of jobs from one core to other generates local pulsed heating. However, studies of relevant transient characteristics in enclosure with alternately activated multiple heat sources are relatively scarce. In the present work the cores of a multi core processor are modeled as heaters and the turnaround time can be viewed as the alternating on–off time period (Z) of the heaters. Here, the two heaters are located on the bottom wall of the enclosure. It is also assumed that the supply of power to the heaters is intermittent so that a given heater is active only in the "on" mode and during the "off" mode it is inactive such that heat transfer is not taking place from the wall. The control of heat transfer can be done by varying the time period between the "on" and the "off" modes. Detailed computations are performed to analyze the physical significance of the results.

For reliable cooling of electronic equipments, natural convection becomes the viable option in many situations due to its inherent passive features. To exploit it fully, researchers are interested in heat transfer enhancement during natural convection [3,4]. Electronic equipments are often modeled as discrete heaters during natural convection studies. Literature review indicates the interests of researchers for studying natural convection in bottom heated cavity [5–15]. However, majority of the work was performed by assuming the steady sate situation. For example, Calcagni et al. [11] experimentally and numerically analyzed the effect of discrete heating on the bottom of the enclosure while side walls remained cooled. Roy and Basak [12] studied the effect of non-uniformly heated walls in a square cavity where one vertical wall and the bottom wall were uniformly and non-uniformly heated. Effect of various thermal boundary conditions on top and sidewalls in an air-filled 2D square enclosure heated with a constant source from below and cooled from above was studied

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Nomenclature

A	aspect ratio (=H/L)
g	acceleration due to gravity
H	height of the enclosure
L	width of the enclosure (length scale used in the problem)
Nu_{avg}	average Nusselt number
p^*	effective pressure $p_0 + \rho_0 gy$
P	effective dimensionless pressure
p_0	pressure
Pr	Prandtl number
Ra	Rayleigh number
T	wall temperature
u, v	velocity
U, V	dimensionless velocities
x, y	Cartesian coordinates
X, Y	dimensionless Cartesian coordinates
Z	switchover time period
Z	dimensionless time period $Z = \frac{z\alpha}{L^2}$
α	thermal diffusivity
β	thermal expansion coefficient
ε	length of the heated wall
η	heat transfer parameter
θ	dimensionless temperature
ν	kinematic viscosity
ρ	fluid density
ρ_0	reference density
τ	dimensionless time
ψ	stream function

Subscripts

C	cold
H	hot
max	maximum

numerically by Cheikh et al. [13]. The variation of Rayleigh number considered in the study was from 10^3 to 10^7. Banerjee et al. [14] reported steady state natural convection in a square cavity with two flush-mounted discrete heat sources on the bottom wall. The heaters were modeled as constant-flux heat sources while the side-walls were isothermal heat sinks. To maintain the safe operative temperature a criteria was specified using the ratio of heater length and strength. An optimum distribution of the inputs through individual heaters was determined keeping the total power input from the two heaters constant. Recently, Cianfrini et al. [15] studied laminar natural convection in a bottom heated cavity for Rayleigh number ranging from 10^3 to 10^6 and cavity aspect ratio within the range of 0.25–4.

In contrast, very little work is available on the unsteady effect of localized pulsed heating. A review of such works was presented in [16]. Periodic heating of the walls with a sinusoidal variation of temperature in an enclosure was studied for various flow and temperature fields [12,17–22]. Lage and Bejan [23] reported the resonance effect between enclosed natural convection and pulsating wall heating. The critical resonant frequency was pointed out for a wide range of Rayleigh and Prandtl numbers. Bae and Hyun [24] represented electronic equipments as discrete heaters mounted on the side walls of a rectangular enclosure. Here, the thermal condition of heater at the lowest position changed between "on" and "off" state. After studying the effect of different Rayleigh numbers, the authors concluded that the transient stage temperatures at the heaters could exceed the corresponding steady state values. However, the quantification of the change on heat transfer was not performed.

The purpose of this work is to study the pulsating heating in an enclosure that simulates the scheduling of job from one core to another in a duel core processor. The work estimates the suitable range of the switchover frequency for which the heat transfer can be augmented. This knowledge enables the designer to determine the cooling rate of the electronic equipment with an aim to estimate the effective switchover time for maximum possible heat transfer. Now a days, scheduling of jobs on the basis of maximum allowable temperature considering heat dissipation capabilities of the system has already been implemented in Intel i7 like processors [1]. The results of this analysis would provide the necessary information for optimum scheduling of jobs on a multi-core processor to ensure maximum heat transfer within the permissible temperature limit utilizing job-scheduling itself to augment the heat transfer rate. In addition to the heat transfer assessment, the effect of switchover time period on parameters like stream functions and energy flux vectors are also analyzed. Energy flux vectors, as explained by Hooman [25], are used to visualize the flow of energy as in this kind of transient problem heatline is not a suitable tool of energy flow visualization.

2. Problem definition

The cores of the dual core system are viewed as heaters and the corresponding heat and fluid flow domain is shown in Fig. 1a. The corresponding grid distribution of the computational domain is shown in Fig. 1b with 100 × 100 grid points. Here, two isothermal heaters (temperature T_H) are mounted on the lower surface of the enclosure. The heaters are alternately active, i.e., at any given point of time only one heater is active. When the heater is not active, adiabatic condition is assumed. The switching "on" and "off" of the heaters are shown in the form of a pulse graph in Fig. 1c. In the context of electronic cooling the assumption of constant temperature of the heat source is made by many authors e.g., [26]. In the context of thermal management of electronic components, the temperature specified at the bottom heater represents the allowable temperature of the electronic component. The heat flux calculated at the isothermal heat sources can be viewed as the achievable heat flux at the design temperature. The geometric configuration with details of boundary conditions under consideration is shown in Fig. 1. The top wall and non-heated bottom wall of the enclosure are adiabatic while the side walls are maintained at constant temperature T_C, such that $T_H > T_C$.

3. Governing equations

It is assumed that fluid is laminar and incompressible, thermophysical properties of the fluid are constant everywhere, radiation effects and viscous dissipation are negligible in energy balance [27,28], Boussinesq approximation is valid and the flow is two-dimensional. The walls are rigid and impermeable and no-slip boundary conditions are imposed on all the enclosure boundaries. The dimensionless temperature on all active heater surfaces is set to 1. The dimensionless switchover time period (Z) is the time interval between successive switching on of a particular heater. The definition of Z can be found from Fig. 1c.

The dimensionless governing equations for conservation of mass, momentum and energy are given by