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ORIGINAL ARTICLE

Experimental investigation of thermal loading of a horizontal thin plate using infrared camera

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Abstract This study reports the results of experimental investigations of the characteristics of thermal loading of a thin plate by discrete radiative heat sources. The carbon–steel thin plate is horizontally located above the heat sources. Temperature distribution of the plate is measured using an infrared camera. The effects of various parameters, such as the Rayleigh number, from 10^7 to 10^{11}, the aspect ratio, from 0.05 to 0.2, the distance ratio, from 0.05 to 0.2, the number of heaters, from 1 to 24, the thickness ratio, from 0.003 to 0.005, and the thermal radiative emissivity, from 0.567 to 0.889 on the maximum temperature and the length of uniform temperature region on a thin plate are explored. The results indicate that the most effective parameters on the order of impact on the maximum temperature is Rayleigh number, the number of heat sources, the distance ratio, the aspect ratio, the surface emissivity, and the plate thickness ratio. Finally, the results demonstrated that there is an optimal distance ratio to maximize the region of uniform temperature on the plate.

1. Introduction

Interaction of natural convection, thermal conduction in solid and surface radiation is of practical interest. Conjugate heat transfer occurs in various engineering applications, such as cooling of electronic equipment (Etemoglu, 2007), distribution transformers (Hajidavalloo and Mohamadianfard, 2010), solid oxide fuel cells (Liu et al., 2008), fibrous insulations (Zhang et al., 2008), and solar chimney (Chen et al., 2003). In the field of conjugate heat transfer there are some experimental investigations concentrated on the temperature and flow field (Dubovsky et al., 2001; Ebert et al., 2008; Manca and Nardini, 2009; Mokhtarzadeh-Dehghan, 2011; Pigeonneau and Flesselles, 2012; Malik et al., 2012; Tang et al., 2012), some of them are focused on solid temperature (Campo and Blotter, 2000; Abraham and Sparrow, 2002; Langebach et al., 2007; Yang et al., 2012) and others are emphasized on heat transfer in solids (Causone et al., 2009; Rahimi and Sabernaeemi, 2010; Ramesh and Venkateshan, 2001; Ramesh and Merzkirch, 2001).

An important industrial application of uniform heating takes place in material processing (Balakrishnan and Edgar, 2000). In thermal loading by discrete heat sources, uniformity of required temperature can be achieved by controlling the power and the arrangement of the heat sources. Such process

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Nomenclature

Symbol	Description unit
A	aspect ratio, = H/L
d	distance between heat sources, m
D	diameter of heat sources, m
g	acceleration due to gravity, m/s^2
h	heat transfer coefficient, W/m^2 K
H	distance between plate and heat sources, m
k	thermal conductivity, W/m K
L	thin plate width, m
L_0	heat sources length, m
L_u	uniform temperature length, m
N	number of heat source
Q	heat source power, W
q"	heat source heat flux, $= Q/(\pi D\ L_0)$, W/m^2
Ra	Rayleigh number, $= g\beta q\text{"}H^4/(k_f\alpha\upsilon)$
T	temperature, K
t	plate thickness, m

Greek symbols

α	thermal diffusivity, m^2/s
β	volumetric coefficient of thermal expansion, 1/K
γ	length ratio, $= L_u/(Nd)$
δ	distance ratio, $= d/H$
ε	surface emissivity
θ	dimensionless temperature, $= T/T_\infty$
τ	thickness ratio, $= t/H$
λ	length ratio, $= L_u/H$
v	kinematic viscosity, m^2/s
ρ	fluid density, kg/m^3

Subscript

max	maximum
∞	ambient value

at high temperature cannot be performed on the enclosed system because of compressibility of air and the hazard of bursting. So it occurs at open cavities or in environments. To increase the absorption of thermal radiative energy, it is suitable to use low emissivity coating for all surfaces other than desired surface for heating and perform heating process in a vacuum or radiatively non-participating medium such as air.

Recently the effect of thermal radiation in an enclosure with discrete heaters is investigated numerically (Abdollahzadeh Jamalabadi et al., 2012; Abdollahzadeh Jamalabadi et al., 2013). Although there are some numerical works (Porter et al., 2006) on the optimization of discrete heaters to uniform heating, there are few experimental studies (Radhakrishnan et al., 2010; Radhakrishnan et al., 2007).

A review of the above available literature provides enough evidence that uniform thermal loading of a thin plate in natural convection environment and the effect of geometrical parameters on uniform heating are not performed experimentally. The aim of current study is to explore, in detail, the effect of heat sources power, arrangement, surface radiation, and plate thickness on temperature field on a thin plate.

2. Experimental rig

Fig. 1 shows the sectional view of the experimental set-up. As shown, a thin plate made of carbon–steel (dimensions: 1 m × 1 m × 3 mm) is mounted horizontally on the four supports at its corners above the quartz lamps (BLV Licht – und Vakuumtechnik GmbH, halogen flood light lamps, 2000 W, 230 V, 44000 lm, 3000 K, 29 cm length 1 cm diameter). The relatively long dimension (1 m length 1 m width) of the plate compared to its thickness (3 mm) guaranteed one-dimensional conditions inside the plate. Each Quartz lamp is energized using stabilized electric ac supply through an industrial dimmer (TD30 Tesla company, 1500VA, 15A). The distance between the heater and the plate is varied by the supports. In addition, the plate emissivity changes by black painting (Dupli-color Supertherm, exhaust paint spray, temperature resistant until 800 °C). The range of the heater powers, distances from the plate and their emissivity are given in Table 1. An infrared camera (ThermoPro-TM-TP8, produced by AMETEK Company, 8 μm –14 μm bandwidth, Optional Lenses Field of View/Focus: 7.7° × 5.8°/100 mm;

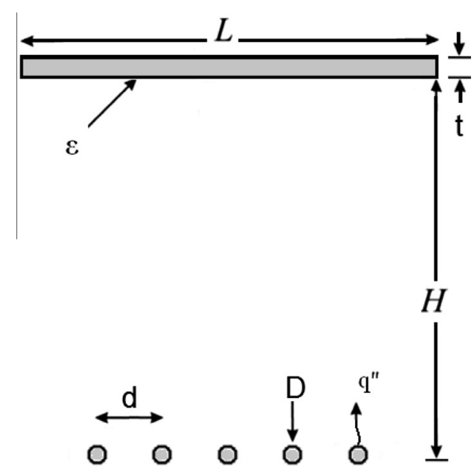

Figure 1 Schematic of the experiment: discrete heaters ($N = 5$) and geometrical parameters.

Table 1 Computation of the error estimation of parameters.

Parameter	Experiment range	Maximum error	Maximum relative error
Q	200–2000 (W)	1 (W)	0.005
T_∞	300 (K)*	1 (K)	0.003
H	2–20 (cm)	0.1 (cm)	0.05
D	1 (cm)	0.01 (cm)	0.01
d	1–20 (cm)	0.01 (cm)	0.01
ε	0.576–0.889	0.001	0.0017
N	1–25	0	0

* Fixed by air-conditioning of the test room.