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Research Article

Heat Transfer Augmentation by Multijet Air Impingement on Dimpled Heat Sink

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Abstract

Experimental investigation of heat transfer by multiple jets of air on the dimpled surface has been carried out. The experiment is performed by using 4x4 array of nozzle. Three different types of heat sinks of Al with dimensions 80x80x5 mm are used by varying dimple depths of spherical diameters 6mm and 8mm.Various iterations are performed using Reynolds numbers from 6000,8000,10000 and 12000 and varying Z/D ratios from 5 to 6. After doing various iterations using Nusselt number, Reynolds number and Z/D ratios it was found that various parameters which gives heat transfer augmentation to spherical cavity dimples with 6 mm diameter gives maximum heat transfer with all three different heat sinks. Jet impingement cooling technique is utilized when high rate of heat transfer are required. Compared to all other surfaces dimples has simple geometry easy to manufacture and gives more turbulence with low pressure penalty.

Keywords: *Jet impingement, dimple surface, turbulenence.*

I. Introduction

The rapidly miniaturization of electronic components has resulted in need for thermal management in electronic products (Hani A. El-Sheikh *et al*, 2000) to increase their life. So thermoelectric cooling of equipments has been investigated and heat sink designs of electronic equipments using dimples has been analyzed with various parameters.

The advantages of larger surface to volume ratio for pin fin heat sink with dimpled plate design has been investigated in this project, heat transfer enhancement using different parameters like heat transfer coefficient (N. K. Chougule *et al*, 2012) nozzle to target plate space, thermal resistance, cooling rate and performance.

Jet impingement is a mature technique (Yuen-Tzu Yang *et al*, 2009), which has been examined by many researchers as a method of heat transfer enhancement in a variety of applications. There have been a number of attempts to complement jet impingement with other enhancing techniques such as cross flow, ribs and tabulators. Attempts have been made to optimize each method in order to obtain effective heat transfer (Luis A. Brignoni *et al*, 1999) with low pressure loss. In order to augment the heat transfer, the boundary layer has to be thinned or be partially broken and restarted. Protruding ribs have been used widely to enhance the heat transfer. However, the higher pressure loss, high maintenance and weight are the problems the application of ribs has. Dimpled surface has become into the consideration due to its potential in heat transfer augmentation, light weight, low pressure penalty.

To further increase the levels of heat transfer enhancement, the surfaces are modified to include pin fins or cavities (Lakshmi Prasad K. *et al*, 2013). In this study, the target surface has dimples machined on the surface with certain pitch. It is expected that adding dimples to the target surface that has jets impinging on it will further enhance heat transfer. Surface dimples are expected to affect the jet impingement structures and promote turbulent mixing and thus enhance heat transfer.

The effects of Reynolds number and jet-to-plate spacing are investigated by many previous researchers (Sidy Ndao *et al* 2013) that determine the turbulence intensity of the jets for fully developed turbulent jet.
In order to generate more coherent vortices and detach and restart the boundary layer more often, hence higher heat transfer, there have been numerous (Koonlaya Kanokjaruvijit *et al*, 2005) developments in surface protrusions, such as rib-roughness or tabulators, pin-banks or pin-fins.

An alternative method of vortex generation is the use of concavity, which is defined as an indentation on the surface forming a recess rather than the protrusion. A dimple is one kind of concavity, and has a

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drag reduction characteristic in external flow over bodies such as is demonstrated by golf balls.

2. Experimental Work

The air was supplied by a fan, and heated up by a 100W heater. The complete experiment has been performed on the setup as shown in the figure 1. The centrifugal type blower is used to supply ambient air at various velocities. The air from blower reaches the nozzle assembly via the pipes. Air passes through an Orifice meter before reaching the nozzle assembly. U-tube water manometer has been connected across the orifice to measure the pressure drop in terms of mm of water column difference and thus maintain the desired velocities. The flow control knob helps varying the velocity. This way Reynolds number is varied from 6000 to 12000 by delivering air at corresponding velocities. The nozzle assembly consists of a 4 x 4 nozzle array of diameter 6mm providing multiple jets over the Aluminum heat sink geometry.

Fig.1 Experimental Setup

Heater is connected to the supply via a dimmer stat which helps maintain the heat input at 20W. The entire path from blower to nozzle assembly was carefully sealed to ensure no leakages occurred. T-type thermocouples have been used to detect temperatures at various points on the heat sink. These thermocouples are connected to the Digital temperature indicator having several channels to display temperatures at different points. The heat sink position is varied with the help of suitable provisions to maintain Z/D ratio of 5 to 6.

The heater is turned on and dimmer stat value is kept constant at 20W. It takes 30-45 minutes to attain steady state. The first iteration is performed at Reynolds number 6000. Air velocity required to maintain Re 6000 is calculated along with the corresponding water column difference in the U-tube manometer. The blower is turned on and flow is varied using flow control knob to match the water column difference in the manometer. Readings of temperatures at different points are noted at intervals of 5 min till 30 minutes after which it is observed to achieve steady states. The procedure is repeated for Re 6000, 8000, 10000 and 12000. The Z/D ratio is changed to 5, 5.5 and 6 and readings for Re 6000, 8000, 10000 and 12000 are noted.

3. Data Reduction

Reynolds number was calculated from the formula as

$R_e = (V_a * D_h)/\gamma_a$

Mass flow rate of air coming out from nozzle plate can be calculated from the formula as

$m_a = \rho_a * V_a * A_{pipe}$

& $m_a = C_d * (\pi/4) * d_0^2 * \rho_a * ((2 * g * h_a)/(1-\beta^4))^{1/2}$

Height in the water column which is to be maintained for above Reynolds number can be calculated by

$h_w = h_a/\rho_w$

Bulk mean temperature can be calculated as

$T_m = T_{av}/4$

Heat consumed

$Q_s = h * A_s * (T_m - T_a)$, W

$Q_s = Q - (Q_r + Q_c)$, W

Radiation heat loss = $Q_r = A_1 * 5.67 * 0.6 * (((T_m+273)^4) - ((T_a+273)^4)) * 10^{-8}$, W

Convection heat loss = $Q_c = (K * A_2 * (T_5 - T_6)) / 0.005$, W

Heat transfer coefficient

$h = Q_s/[A_s * (T_m - T_a), W]$

Nusselt Number, $N_u = h * D_h/K_a$

Experimental Parameters

The following table gives one sample for readings of dimple surface parameters measured during experimentation out of three test pieces.

Table 1 Experimental procedure parameters for Heat sink 2, d= 6 mm, Z/D =5, Q=20 W and Re =6000.

Time\Temp.	T1	T2	T3	T4	T5	T6
0	42	38	38	34	37	35
5	41	39	38	37	37	35
10	41	38	36	35	37	35
15	41	38	36	35	37	35

4. Result and Discussions

The following graph gives detailed information from dimple heat sink.

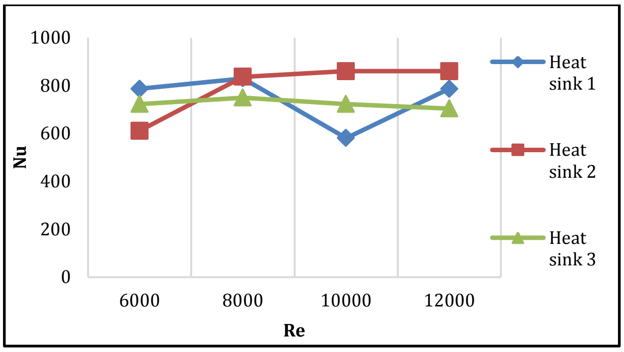

Fig 3.1 Nu Vs Re for Z/D = 5

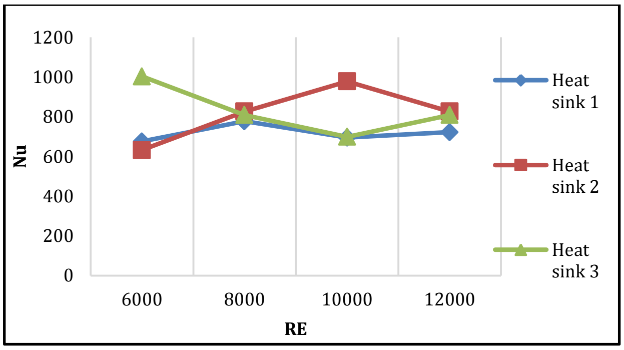

Fig 3.2 Nu Vs Re for Z/D = 5.5

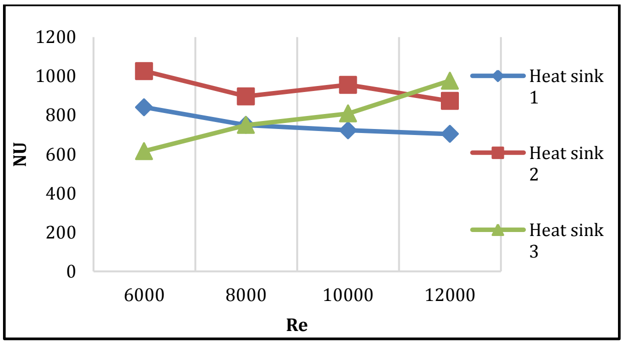

Fig 3.3 Nu Vs Re for Z/D =6

From detailed analysis of Nusselt number and Reynolds number with various Z/d ratios, it gives highest heat transfer augmentation at Z/D ratio 6 and with Reynolds number 6000.

Heat sink two with 6 mm dimple diameter zigzag arrangement gives maximum heat transfer with multiple air jet impingements for all Z/D ratios.

Conclusion

This experiment was performed for investigating effects of different cavities on heat transfer with jet impingement on dimples. Main conclusions are summarized as

i) Use of dimples increase heat transfer compared to flat plate
ii) Heat transfer enhancement increases with increase in Reynolds number.
iii) Nusselt number is maximum for dimpled surface with 6000 Reynolds number.
iv) It was found to be Nu higher for heat sink with dimple of 6 mm zigzag spacing with Z/D =6.
v) Z/D ratio affects heat transfer augmentation.

Nomenclature

A_{plate} Area of Test plate (Al plate), m^2
D Nozzle diameter, m
Z Nozzle to target surface spacing, m
C_d Discharge Coefficient of air
C_p Specific heat of air at constant pressure, J/Kg K
d_o Diameter of Orifice, m
g Acceleration due to gravity, m/s^2
h Convective heat transfer Coefficient of air, W/m^{2}K
Ka Thermal Conductivity of air, W/m K
h_{air} Height of air column, m
h_w Height of water column, m
M_a Mass flow rate of air, kg/s
Q_c Convective heat transfer to air, W
T_m Mean Temperature, °C
T_{12} Ambient temperature

Dimensionless Parameter

N_u Nusselt Number
R_e Reynolds Number
P_r Prantle Number

Symbols

ρ_a Air Density, kg/m^3
ρ_w Water Density, kg/m^3
μ Coefficient of Viscosity, N-s/m^2

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