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Heat Transfer Enhancement through Inline and Staggered Micro Fin Heat Sink

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Abstract—*All the electronic components release heat during their operation which must be transferred to the surrounding for the its proper and intended operation and to avoid the damage of the equipment. Due to rapid growth in the field of micro electrical mechanical systems in the past decade increased the demand for more compact and small devices. These devices produce large amount of heat but having small area to dissipate them, so heat sinks are used for heat transfer. The present study deals with the numerical study of different arrangement (inline and staggered) of micro fin heat sink and compare them with heat transfer without micro fins. Deionised water is used as a working fluid. The navier-stokes momentum equation, continuity equation and energy equation are solved simultaneously by Ansys fluent version 14.5. The base plate is made up of silicon, cover plate is made up of Pyrex. At the inlet, the Reynolds number of the fluid varies from 100 to 900. Heat supplied from base is 100 W/cm^2. The results show that staggered arrangement of micro-fins is better than the inline arrangement. Staggered arrangement has higher heat transfer rate due to higher turbulence.*

1. INTRODUCTION

Now a day, electronic devices shows the tendency for smaller, faster and denser chips with higher heat transfer rate. As the chip becomes more powerful and smaller, thermal management of the chips becomes more complicated. As the density of the transistor increases the heat flux from the system increases. And without the efficient way of heat dissipation to the environment the temperature of the heat sink will go on increasing and it will stop working. To solve these problems various types of heat sinks has been developed by the researchers over the period of time.

There are three Modes of Heat transfer from a system conduction, convection and radiation. Conduction generally occurs within solid body or two solid bodies in thermal contact. Heat conduction occurs when hot, rapidly moving/vibrating atoms and molecules collides with the neighboring molecules and atoms. Conduction heat transfer mainly dependent on the temperature difference, physical properties of intervening medium, cross-section area of material and length of travel path.

Tuckerman and pease [1] were first to investigate experimentally microchannel heat sink. They varied length and width of the channel to get the higher heat transfer rate. They used deionized water as a working fluid. The base plate is made up of silicon. To make silicon channel, plate is etched with the KOH solution. The cover plate is made up of Pyrex glass. Results shows dramatic increase in heat transfer rate which is nearly forty times. And heat transfer coefficient varies inversely with channel width. the minimum practical width of the channel is determined by viscosity of coolant. Jeung sang go [3] experimentally investigated the effect of flow induced vibration on heat transfer from micro-fin heat sink. For the experimental evaluation, thermal performance of micro fin array heat sink is compared with the plain wall heat sink for different air velocity.it was seen that micro fin vibrates with fundamental natural frequency irrespective of the air velocity and the vibration displacement of micro-fin increases and then saturated over a certain range velocity of air. Results shows an increase of 5.5% and 11.5% in heat transfer rate for air velocity 4.4 m/s and 5.5 m/s respectively. Pales et al. [4] investigated experimentally heat transfer and pressure drop in micro pin fin heat sink. a simplified expression for the total thermal resistance is derived, discussed and validated experimentally. They also discussed the thermos-hydraulic parameter affecting the total thermal resistance. They suggested to avoid very low tube diameter (below 50μm) but thermal resistance is nearly independent on larger tube diameters. The results show that heat transfer co-efficient for micro scale pin fins are high due to which fin efficiency decreases. Height of micro fins should be small, to increase fin efficiency. Olivier et al. [5] studied experimentally flow regimes, heat transfer and pressure drop during condensation of refrigerant in smooth tube, helical micro fin and herringbone tube. They carried experiments on R-22, R-134a, R-407C at an average surface temperature of 40°C with mass flux range from 400 to 800 Kg/m^{-2}s^{-1} with vapour qualities 0.85 to 0.95 at condenser inlet and 0.05 to 0.15 at condenser outlet. Results show that transition from annular flow to intermittent flow occurs, on an average for three refrigerants at vapour quality 0.49 for smooth tube, 0.29 for helical micro-fin tube and 0.26 for herringbone tube. John et al. [6] studied the thermal and hydraulic performance of square and circular pin fins operating under similar conditions. They studied thermal resistance and pressure drop of micro fins by varying axial and transverse pitch, aspect ratio, hydraulic diameter of micro fins and flow rate of liquid. The characteristic study was done with constant Reynolds number of fluid flow at the entrance of channel. Water is used as working fluid. for Re < 300 circular pin micro fin is better and for Re > 300 square pin micro fin is better one. Results also shows that, for circular pin fin thermal resistance decreases with the decrease in axial pitch at the cost of the pressure drop. Deiz et al. [8] done thermal analysis of the effect of the random and isometric surface roughness on micro fin of variable diameter by truncated power series method. Behrami et al. model is followed which considers geometric effect of surface roughness and also increases the intricacy of fin equation. So, adequate number of terms is considered for approximate solution based on the convergence to the exact solution. 3 fin profile hyperbolic, trapezoidal and concave parabolic is observed. Effect of surface roughness is evaluated over a wide range of heat transfer. Results shows that effect of roughness on heat transfer is highest in hyperbolic pin fins and lowest in concave pin fins. Mahmoud et al. [9] investigated experimentally effect of micro fin height and spacing on heat transfer coefficient horizontally mounted heat sink operated under steady state natural convection. micro fins are manufactured of copper, with height ranging from 0.25 -1.00 mm and fin spacing varying from 0.15-1.00 mm respectively. Results shows that heat transfer co-efficient increases with increase in fin spacing and decrease in fin height. Highest value of heat transfer co-efficient 8 W/m^2K at lowest fin height and fin spacing 1.00 mm. Liu et al. [11] investigated the fluid flow and heat transfer characteristics micro square pin fin heat sink with total chip area 20×20 mm^2. 625 staggered micro square pin fins with cross- section area 559×559 μm^2 or 445×445 μm^2 with height 3 mm were fabricated with copper test section. deionized water is used as coolant fluid. Reynolds number is varied from 60 to 800.results shows that the pressure drop and average nusselt number increases with Reynolds number. Thermal resistance decreases with pressure drop. Shafeie et al. [12] investigated forced convection heat transfer from micro pin fin heat sink. Water cooled heat sink of dimension 1×1 cm^2 has been studied. The distribution pattern of pin fins is either staggered or oblique. Navier- stokes equation and energy equation for fluid region and energy equation for solid are solved simultaneously. Micro channel heat sink with fabricated pin fins performs better than pin fin heat sink for same pumping power. The non-dimensional entropy generation is lower for the heat sink with a higher heat removal in a specified pumping power. Naphon and Nakharintr [13] studied experimentally heat transfer characteristics of mini rectangular heat sinks with different channel heights fabricated with aluminum by wire electric discharge machining with length, width and thickness 110,60 and 2 mm respectively. The nanoscale TiO_2 particles mixed with the de-ionized water to make nanofluids. They recorded effect of inlet temperature of nanofluid, nanofluid Reynolds number and heat flux on heat transfer from rectangular fin heat sink. The results show that average heat transfer rate increased with the use of nanofluids. Fan et al. [14] studied experimentally fluid flow and heat transfer from cylindrical oblique-finned heat sink. The hydraulic boundary layer reinitiates at leading edge of next downstream fin due to periodic cylindrical oblique fins. Which results in the in decrease in the average hydrodynamic boundary layer thickness, increase rate of heat transfer and lower pressure drop due to combined effect of redevelopment of thermal boundary layer and flow mixing. Results shows an increase in heat transfer rate upto 75.6% and lower thermal resistance upto 59.10% compared to conventional minichannel heat sink. Hasan [15] investigated numerically fluid flow and heat transfer from micro pin fin heat sink with nanofluid. Two nanofluids diamond -water and Al_2O_3-water are used for three different fin geometries (square, triangular and circular) in addition to unfinned micro-channel heat sink. The volumetric concentration of nanofluid varies from 1% to 4%. To ensure laminar flow, Reynolds number is varying from 100-900. Results shows that with the use of nanofluids heat transfer rate and pressure drop both increases. The diamond- water nanofluids are better than the other because it has higher heat transfer rate. Xu et al. [16] investigated experimentally the heat transfer characteristics of liquefied natural gas during flow boiling in a vertical micro-fin tube. And analyzed the effect of heat flux, mass flux, inlet pressure on flow boiling heat transfer coefficient. Results shows that local heat transfer co-efficient increases with heat flux, mass flux but decreases with the inlet pressure. Lee et al. [18] studied fluid flow and heat transfer from microchannel heat sink using oblique fins. The re-initiation of thermal boundary layer at the leading edge of next oblique fin which causes breakage of continuous fins into oblique sections and due to oblique cuts secondary flow occurs which results in better heat loss. Experiments carried out with hydraulic diameters 100 mm and 200 mm with deionized water as working fluid. Results shows 47% increase in heat transfer rate when Re = 680. For optimum performance microchannel width should be 100 µm with 27^0 oblique angle. Zhang et al. [19] investigated experimentally fluid flow and heat transfer from multiport minichannel flat tube with micro fins. Fourteen types of micro-fin structures are used as test section and water is used as working fluid. The Reynolds number ranging from 128 to 5645. Results shows that heat transfer coefficient and friction factor (f) both increases with increase in fin height and number of fins. Bin and Yumei [20] Investigated experimentally pressure drop during flow boiling of liquefied natural gas in a vertical micro-fin tube. And studied the effect of heat flux, mass flux and inlet pressure on the frictional pressure drop during two phase flow of gas. Results shows that two phase flow pressure drop increases with increases in heat flux and mass flux but decreases with increase in inlet pressure. Rajabifar [21] et al. studied fluid flow and heat transfer in micro pin fin heat sink with Nano-encapsulated phase change material. The volume fraction of

Nano fluid in working fluid is 0.1,0.2,0.3. the inlet velocity and wall temperature are 0.015, 0.030, 0.045 m/s and 299.15, 303.15, 315.15, 350.15 K respectively. The results indicate significant increase in the heat transfer while using Nano encapsulated phase change material. The nusselt number becomes 2.27,1.81,1.56 times of the base fluid with volume fraction of Nano-encapsulated phase change material 0.3 and at velocities 0.015,0.030,0.045 m/s respectively. Zhao [22] et al. proposed a geometry optimizing method changing fin porosity and pin fin located angle for enhancing the cooling performance of micro square pin fin heat sink. Results reveals that pin fin geometry porosity and located angle both are important for cooing capacity and thermal performance of micro square pin fin heat sink. For better performance, the optimal porosity and located angle are 0.75 and 30^0 respectively. Micheli et al. [23] compares the thermal performance of plate micro fins and pin micro fin arrays under natural convection condition. Results indicate that thermal performance of pin micro fins are better than plate micro fins due to higher heat transfer coefficients and pin fin shows the ability of optimizing material usage compared to flat plate fins. Yu et al. [24] studied experimentally and numerically piranha pin fin micro scale heat sink. These fins enhance the thermal performance by manipulating the flow field and adding surface area. the hydraulic and thermal performance of piranha fin is studied for Reynolds number ranging from 508 to 2114 based on the channel hydraulic diameter. Piranha pin fins enhances heat transfer rate in many ways like it disturbs the velocity field along with separation and mixing of fluid, which further increases heat transfer rate. Micheli et al. [25] investigated thermal performance of horizontal micro-pin fins under natural convection using different sink metrics. Results reveals that micro fins can enhance the heat transfer rate of a flat plate and can achieve an individual effectiveness higher than 3. Also found increase in overall heat transfer rate by 14%.

2. PROBLEM FORMULATION

2.1 Physical model

The model studied the three dimensional fluid flow and heat transfer from different arrangement of micro fin heat sink to enhance the heat flux. The length of heat sink is 11.5 mm and width 11.5 mm. the height of fin axial pitch, lateral pitch is same and equal to one side of square cross-section fin. The dimensions of fins in the staggered and inline micro-fin heat sink is same. Deionized water Is used as working fluid. The figure of staggered and inline micro fin heat sink is shown below. Height of heat sink is 1 mm.

2.2 Assumptions

1. Steady and laminar flow

2. No thermo-physical properties variation with temperature;

3. Fluid is incompressible, Newtonian and viscous;

4. No velocity-slip at the walls.

2.3 Governing equation

Based on the above assumptions, the following governing differential equations are used to describe the fluid flow and the heat transfer in the unit cell. Governing equation for fluid:

$$\nabla . V = 0$$

$$\rho_f C_p (V.\nabla V) = -\nabla P + \nabla .(\mu_f \nabla V)$$

$$\rho_f C_p (V.\nabla T) = k_f \nabla^2 T$$

Governing equation for solid region:

$$\nabla^2 T = 0$$

2.4 Boundary condition:

For the flow boundary condition, uniform velocity was imposed at the inlet. At the outlet pressure is atmospheric. And velocity is computed based on the Reynolds number. Governing equation of fluid and solid is solved in Ansys 14.5 using upwind scheme. Heat flux 100 W/cm^2 is supplied from bottom and all other walls are adiabatic. The inlet temperature of fluid is 293 K. base plate is made of silicon. The convergence criteria for energy equation is 10^{-6} and for momentum, continuity 10^{-3}.

The nusselt number is calculated by given formula:

Nu = hD / k

Where h = heat transfer coefficient

D = hydraulic diameter

K = thermal conductivity of fluid

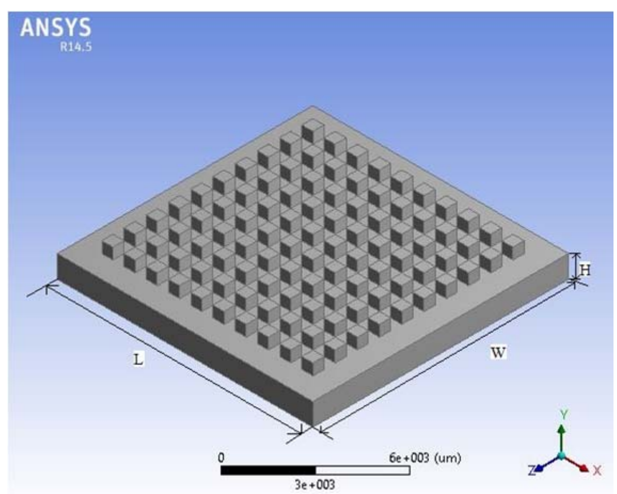

Fig. 1: Inline arrangement of micro-fins heat sink.

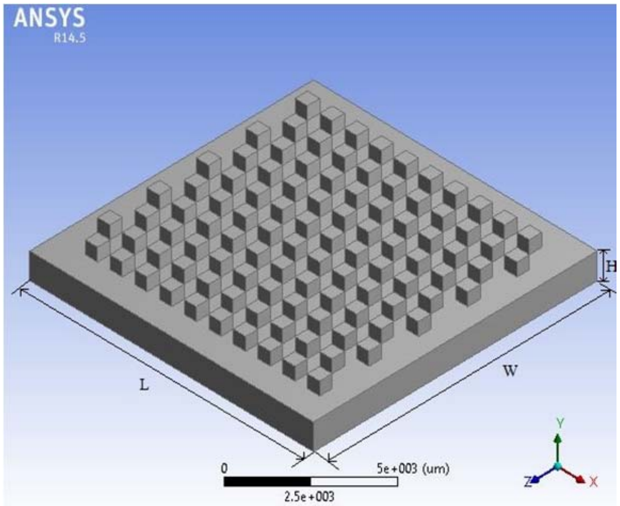

Fig. 2: Staggered arrangement of micro- fins heat sink.

3. RESULTS AND DISCUSSIONS

3.1 heat transfer

The heat transfer coefficient for different velocities of fluid are used for both inline and staggered fin heat sink. As we can see from the graph as the Reynolds number increases, the nusselt number also increases. Which imply that by increasing velocity of fluid heat transfer can be increased. So force convection should higher heat transfer rate than natural convection heat transfer. Also for the fixed Reynolds number the staggered fin heat sink has higher nusselt number, this imply that staggered fin arrangement is better heat dissipation capacity than the inline.

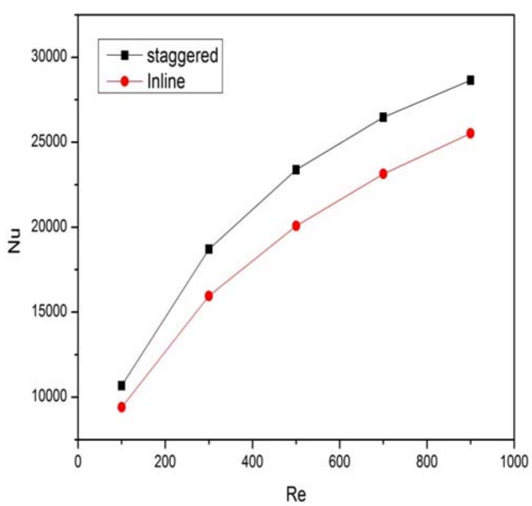

Fig. 3 :Variation nusselt number of staggered and inline micro-fin heta sink.

3.2 Pressure drop

As we can see from fig. 4 The friction factor for inline fin heat sink is higher than the staggered below the reynolds number 450. The inline fin heat sink is not beneficial below reynolds number 450. High friction factor, causes higher pressure drop which in turn needs higher pumping power. Above reynolds 450 staggered fin heta sink has higher pressuer loss but also has higher heat transfer rate.

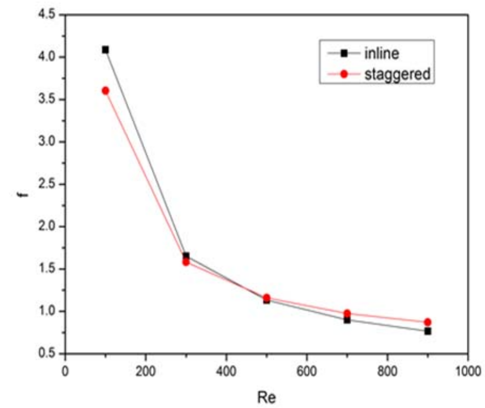

Fig. 4: Variation of friction factor of staggered and inline fin heat sink with Reynolds number.

Friction factor can be calculated by

f = $(2 \times \Delta p)/(N_x \rho v^2)$

where;

f = friction factor

N_x = number of row of fins

ρ = density of fluid (Kg/m^3)

v = velocity of fluid (m/s)

$\nabla p =$ pressure drop (Pascal)

4. CONCLUSION

1. Heat transfer from both heat sink increases with increases in reynolds number.
2. Staggered fin heat sink has higher heat transfer rate than the inline pin fin heat sink.
3. Staggered fin heat sink has higher heat transfer rate but also has higher pressure drop above reynolds number 450, which means fluid fluid s needs higher power.
4. Below the Reynolds number 450, inline fin heat sink has higher pressure loss with lower heat transfer rate.
5. Above Reynolds number 450, inline fin heat sink has lower pressure loss with lower heat transfer rate.

1. Future scope

1. Heat transfer from piranha fins with nano encapsulated phase change material.
2. Heat transfer enhancement from piranha fins by vibration due to the flow of fluid through it.
3. Effect of variation of fin height on heat transfer from piranha fins.
4. Effect of variation of lateral and longitudinal pitch on heat transfer.
5. Inverse design of square, circular and elliptical fins.

REFERENCES

[1] D. B. Tuckerman and R. F. W. Pease "high-performance heat sinking for VLSI", IEEE electron device letters, vol. Edl-2, no. 5, may 1981.

[2] K. Seo, Y. Kim "Evaporation heat transfer and pressure drop of R-22 in 7 and 9.52 mm smooth/micro-fin tubes", International Journal of Heat and Mass Transfer 43 (2000) 2869-2882.

[3] Jeung Sang Go "ADesign of a micro-fin array heat sink using flow-induced vibration to enhance the heat transfer in the laminar flow regime", Sensors and Actuators A 105 (2003) 201–210.

[4] Yoav Peles, Ali Kosar, Chandan Mishra, Chih-Jung Kuo, Brandon Schneider "Forced convective heat transfer across a pin fin micro heat sink", International Journal of Heat and Mass Transfer 48 (2005) 3615–3627.

[5] Jonathan A. Oliviera, Leon Liebenberga, John R. Thomeb, Josua P. Meyer "Heat transfer, pressure drop, and flow pattern recognition during condensation inside smooth, helical micro-fin, and herringbone tubes", International Journal of Refrigeration 30 (2007) 609-623.

[6] T.J. John, B. Mathew, H. Hegab "Parametric study on the combined thermal and hydraulic performance of single phase micro pin-fin heat sinks part I: Square and circle geometries", International Journal of Thermal Sciences 49 (2010) 2177-2190.

[7] Robert Pastuszko "Pool boiling on micro-fin array with wire mesh structures", International Journal of Thermal Sciences 49 (2010) 2289-2298.

[8] Luis I. Dıez, Sergio Espatolero, Cristobal Cortes, Antonio Campo "Thermal analysis of rough micro-fins of variable cross-section by the power series method", International Journal of Thermal Sciences 49 (2010) 23–35.

[9] S. Mahmouda, R. Al-Dadah, D.K. Aspinwall, S.L. Soo, H. Hemida "Effect of micro fin geometry on natural convection heat transfer of horizontal microstructures", Applied Thermal Engineering 31 (2011) 627-633.

[10] Mustafa Koz, Mehmed Rafet Ozdemir, Ali Kosar "Parametric study on the effect of end walls on heat transfer and fluid flow across a micro pin-fin", International Journal of Thermal Sciences 50 (2011) 1073-1084.

[11] Minghou Liu, Dong Liu, Sheng Xu, Yiliang Chen "Experimental study on liquid flow and heat transfer in micro square pin fin heat sink", International Journal of Heat and Mass Transfer 54 (2011) 5602–5611.

[12] Haleh Shafeie, Omid Abouali, Khosrow Jafarpur, Goodarz Ahmadi "Numerical study of heat transfer performance of single-phase heat sinks with micro pin-fin structures", Applied Thermal Engineering 58 (2013) 68-76.

[13] Paisarn Naphon, Lursukd Nakharintr "Heat transfer of nanofluids in the mini-rectangular fin heat sinks", International Communications in Heat and Mass Transfer 40 (2013) 25–31.

[14] Yan Fan, Poh Seng Lee, Li-Wen Jin, Beng Wah Chua "A simulation and experimental study of fluid flow and heat transfer on cylindrical oblique-finned heat sink", International Journal of Heat and Mass Transfer 61 (2013) 62–72.

[15] Mushtaq Ismael Hasan "Investigation of flow and heat transfer characteristics in micro pin fin heat sink with nanofluid", Applied Thermal Engineering 63 (2014) 598-607.

[16] Bin Xu, Yumei Shi, Dongsheng Chen "Investigation on the heat transfer characteristics during flow boiling of liquefied natural gas in a vertical micro-fin tube", Cryogenics 60 (2014) 68–75.

[17] Weerapun Duangthongsuk, Somchai Wongwises "A comparison of the heat transfer performance and pressure drop of nanofluid-cooled heat sinks with different miniature pin fin configurations", Experimental Thermal and Fluid Science 69 (2015) 111–118.

[18] Yong Jiun Lee, Pawan K. Singh, Poh Seng Lee "Fluid flow and heat transfer investigations on enhanced microchannel heat sink using oblique fins with parametric study", International Journal of Heat and Mass Transfer 81 (2015) 325–336.

[19] Ji Zhang, Yaohua Zhao, Yanhua Diao, Yanni Zhang "An experimental study on fluid flow and heat transfer in a multiport minichannel flat tube with micro-fin structures", International Journal of Heat and Mass Transfer 84 (2015) 511–520.

[20] Xu Bin, Shi Yumei "Investigation on the pressure drop during flow boiling of liquefied

[21] natural gas in a vertical micro-fin tube", International Journal of Heat and Mass Transfer 90 (2015) 159–166.

[22] Bahram Rajabifar, Hamid Reza Seyf, Yuwen Zhang, Sanjeev K. Khanna "Flow and Heat Transfer in Micro Pin Fin Heat Sinks with Nano-Encapsulated Phase Change Materials", Journal of Heat Transfer JUNE 2016, Vol. 138 / 062401-1.

[23] Jin Zhao, Shanbo Huang, Liang Gong, Zhaoqin Huang "Numerical study and optimizing on micro square pin-fin heat sink for electronic cooling", Applied Thermal Engineering 93 (2016) 1347–1359.

[24] Leonardo Micheli, K.S. Reddy, Tapas K. Mallick "Experimental comparison of micro-scaled plate-fins and pin-fins under natural convection", International Communications in Heat and Mass Transfer 75 (2016) 59–66.

[25] X. Yu, C. Woodcock, J. Plawsky, Y. Peles "An investigation of convective heat transfer in microchannel with Piranha Pin Fin", International Journal of Heat and Mass Transfer 103 (2016) 1125–1132.

[26] Leonardo Micheli, K.S. Reddy, Tapas K. Mallick "Thermal effectiveness and mass usage of horizontal micro-fins under natural convection", Applied Thermal Engineering 97 (2016) 39–47.