INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH & DEVELOPMENT

ISSN 2278 – 0211 (Online)

Review of Performance Analysis of Extended Surfaces (Fins) Under Free and Forced Convection Heat Transfer

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Abstract:
This paper reviews previous work done on performance analysis of extended surfaces (fins) under free and forced convection in order to determine the enhancement in the heat transfer rate. The Thermal resistance and pressure drop are considered as the multiple thermal performance characteristics. The effects of geometric parameters, fin height, fin diameter fin material and base-to ambient temperature difference on the heat transfer performance of fin arrays and the optimum fin separation value has been determined. The studies have shown that the convection heat transfer rate from fin arrays depends on all geometric parameter, fin material and base-to-ambient temperature difference..Heat transfer increases with the increase in approach velocity, pin diameter, and number of pins. The effect of fin density on the heat transfer performance is examined Heat transfer also increases with the thermal conductivity of the material and with the pin height. In-line arrangement gives higher heat sink resistance and lower pressure drop than the staggered arrangement. Heat transfer models for in-line and staggered arrangements are suitable in designing pin-fin heat sinks. The effect on Re on the behavior the channel are also studies.

Key words: *Free convection, Forced convection, extended surfaces, Optimal fin spacing, CFD*

1. Introduction

Heat sinks are the most common thermal management hardware used in electronics. They are employed in Microelectronic devices as well as high power electrical components and are considered to be the simplest and the cheapest cooling solution. They improve the thermal control of electronic components, assemblies, and modules by enhancing their surface area through the use of pin fins. Applications utilizing pin fin heat sinks for cooling of electronics have increased significantly during the last few decades due to an increase in heat flux densities and product miniaturization. Today's cutting edge electronic circuits dissipate substantially heavier loads of heat than ever before. At the same time, the premium associated with miniaturized applications has never been greater, and space allocated for cooling purposes is on the decline. These factors have forced design engineers to seek more efficient heat sink technologies. One of the more powerful cooling technologies that have emerged in recent years is the pin fin technology. The unique pin fin design generates significant cooling power and is highly suitable for "hot" devices and applications that have limited space for cooling. Pin fin heat sinks for surface mount devices are available in a variety of configurations, sizes and materials. Pin fin heat sinks, which contain an array of vertically oriented round pins made of copper or aluminium, deliver significantly greater performance than standard heat sinks with flat fins. The aerodynamic nature of the round pins and their unidirectional configuration enable pin fin heat sinks to transfer heat very efficiently from the heat generating device to the ambient environment. As a result, this superior heat sink style is used in a wide range of applications and industries, wherever difficult cooling challenges take place.

2. Experimental and Numerical Investigations

Sparrow EM, Ramsey JW, et al [1980] the study of this paper Heat transfer and pressure drop experiments were performed for in-line pin fin arrays to obtain basic data to complement available information for staggered arrays. The experimental data were utilized as input to analyses aimed at establishing performance relationships between in-line and staggered arrays. In the experiments, mass transfer measurements via the naphthalene sublimation technique were employed to determine the row-by-row distribution of the heat (mass) transfer coefficient. In general, the fully developed heat transfer coefficients for the in-line array are lower than those for the staggered array, but the pressure drop is also lower. The deviations between the two arrays increase with increasing fin height. With regard to performance, the in-line array transfers more heat than the staggered array under conditions of equal pumping power and equal heat transfer area. On the other hand, at a fixed heat load and fixed mass flow rate, the staggered array requires less heat transfer surface than the in-line array.

Christopher L. Chapman et al [1994] Study of these papers comparative thermal tests has been carried out using aluminium heat sinks made with extruded fin, cross-cut rectangular pins, and elliptical shaped pins in low air flow environments. The elliptical pin heat sink was designed to minimize the pressure loss across the heat sink by reducing the vortex effects and to enhance the thermal performance by maintaining the large exposed surface area available for heat transfer. The performance of the elliptical pin heat sink was compared with those of extruded straight and crosscut fin heat sinks, all designed for an ASIC chip. The results of the straight fin were also compared with those obtained by using Sauna TM, a commercially available heat sink modelling program developed based on empirical expressions. In addition to the thermal measurements, the effect of air flow bypass characteristics in open duct configuration was investigated. As expected, the straight fin experienced the lowest amount of flow bypass over the heat sink. For this particular application, where the heat source is localized in the centre of the heat sink base plate, the overall thermal resistance of the straight fin was lower than the other two designs mainly due to the combined effect of enhanced lateral conduction along the fins and the lower flow bypass characteristics. The elliptical pin heat sink tested represents only one set of design parameters relating pin spacing and shape based upon minor and major axes. There may exist other designs which produce better results in overall thermal performance. A study looking at reduced spacing, pin alignment, pin staggering, and an array of ellipse axis ratios would be advantageous to the heat sink industry.

W. Leonard, P. Teertstra, et al. [2002] in this report Experimental testing has been performed on two plate fin heat sinks in order to examine flow bypass phenomenon. The present study examines the pressure drop and thermal resistance as well as flow velocities within the heat sinks. Tests are performed for bypass channel/fin height ratios of 0.25, 0.5, 0.75 and 1 with approach velocities from 2 to 8 m/s. By examining flow behaviour within the heat sinks and the bypass channel, a model for predicting flow bypass is presented that incorporates only the significant pressure drop mechanisms that affect the flow path. This model allows for a simple prediction of flow bypass for plate fin heat sinks based solely on the geometry. For all of the heat sinks tested the agreement between model and experimental data is ±8%.

Sukhvinder Kang et al [2003] this paper presents physics based analytical model to predict the thermal behaviour of pin fin heat sinks in transverse forced flow. The key feature of the model is the recognition that unlike plate fins, stream wise conduction does not occur in pin fin heat sinks. Thus, the heat transfer from each fin depends on its local air temperature or adiabatic temperature and the local adiabatic heat transfer coefficient. Both experimental data and simplified CFD simulations are used to develop the two building blocks of the model, the thermal wake function and the adiabatic heat transfer coefficient. These building blocks are then used to include the effect of the thermal wake from upstream fins on the adiabatic temperature of downstream fins in determining the fin-by-fin heat transfer within the pin fin array. This approach captures the essential physics of the flow and heat transport within the fin array and yields an accurate model for predicting the thermal resistance of pin fin heat sinks. Model predictions are compared with existing experimental data and CFD simulations. The model is expected to provide a sound basis for a consistent performance comparison with plate fin heat sinks.

(4–10). Ellison (1) and Kraus and Bar-Cohen (5) has presented the fundamentals of heat transfer and hydrodynamics characteristics of heat sinks including the fin efficiency, forced convective correlations, applications in heat sinks, etc.. Iyengar and Bar-Cohen (6) determined the least-energy optimization of plate fin heat sinks in the status of forced convection. Park et al. (7, 8) performed an investigation of numerical shape optimization for high performance of a heat sink with pin-fins. Park and Moon (9) proposed the progressive quadratic response surface model to obtain the optimal values of design variables for a plate-fin type heat sink. Sahin et al. (10) Investigated the effect of design parameters on the heat transfer and pressure drop characteristics of a heat exchanger using the Taguchi experimental design method. From the above descriptive analysis, the optimal design and selection of effective heat sink modules is becoming one of the primary challenges of the computer science and technology industry. In this study, the optimal values of designing parameters of a pin-fin type heat sink (PFHS) are numerically acquired using the quadratic model of response surface methodology (RSM), associated with a sequential approximation optimization (SAO) method to reach the high thermal performance (or cooling efficiency). The RSM relates to the regression analysis and the statistical design of experiments for constructing the global optimization (11) and is one of the most widely used methods to solve the optimization problem in the manufacturing environments (12–14). To achieve the high thermal performance (or cooling efficiency) under the given design constraint, the predictive model for thermal performance characteristics will be created using the RSM. (15) Sukhvinder Kang, Maurice Holahan presents a physics based analytical model to predict the thermal behaviour of pin fin heat sinks in transverse forced flow. The key feature of the model is the recognition that unlike plate fins, stream wise conduction does not occur in pin fin heat sinks. Thus, the heat transfer from each fin depends on its local air temperature or adiabatic temperature and the local adiabatic heat transfer coefficient.(16).ko-Ta chiangand Fu Ping Chang has developed an effective procedure of response surface methodology (RSM) for finding optimal values of designing parameters ofa pin fin type heat sink (PFHS) under constrains of mass and space limitations to achieve the high thermal performance (or cooling efficiency).various design parameters such as height and diameter of pin fin and width of pitch between fins are explored by experiment. The Thermal resistance and pressure drop are considered as the multiple thermal performance characteristics.

Xiaoling Yu , Jianmei Feng [2005] ,These Paper Based on plate fin heat sinks (PFHSs), a new type of plate-pin fin heat sink (PPFHS) is constructed, which is composed of a PFHS and some columnar pins staggered between plate fins. Numerical simulations and some experiments were performed to compare thermal performances of these two types of heat sinks. The simulation results showed that the thermal resistance of a PPFHS was about 30% lower than that of a PFHS used to construct the PPFHS under the condition of equal wind velocity. Another obvious advantage of PPFHSs is that users can change an existing unsuitable PFHS into a required PPFHS by themselves to achieve better air-cooling results. This paper proposed a special solution for improving heat transfer performance of a PFHS by planting some columnar into flow passages of the PFHS to disturb airflows passing through the heat sink. So a PPFHS was constructed. Numerical simulation and experimental results show that the thermal resistance of a PPFHS is 30% lower than that of a PFHS used to construct the PPFHS with the same blowing velocity, and the profit factor of the former is about 20% higher than that of the latter with the same pumping power.

Mohammad Mashud, Md. IliasInam, Zinat Rahman Arani and AfsanulTanveer [14] research, a solid cylindrical fin and two other cylindrical fins with circular grooves and threads on their outside surface are investigated experimentally. The heat input to the fin is varied such that the base temperature is maintained constant under steady state. Based on a study of effect of pressure reduction, using available resources, the chamber is designed for a vacuum of 680 mm Hg. The experimental result shows that for cylindrical fin with circular grooves (depth 3.5mm) heat loss is a maximum. The grooved cylindrical fin loses approximately1.23 times greater heat per unit area, compared to the threaded cylindrical fin, and 2.17 times greater heat per unit area, respectively compared to the solid pin fin at a pressure lower than atmospheric pressure. As pressure decreases heat loss reduces and contribution of radiation heat transfer on total heat loss increases.

W. A. Khan, J. R. Culham et al [2005] Analytical models are presented for determining heat transfer from in-line and staggered pin-fin heat sinks used in electronic packaging applications. The heat transfer coefficient for the heat sink and the average temperature for the fluid inside the heat sink are obtained from an energy balance over a control volume. In addition, friction coefficient models for both arrangements are developed from published data. The effects of thermal conductivity on the thermal performance are also examined. All models can be applied over a wide range of heat sink parameters and are suitable for use in the design of pin-fin heat sinks. The present models are in good agreement with existing experimental/ numerical data. Finally result is heat transfer from and pressure drop across the heat sink increases with the increase in approach velocity, pin diameter, and number of pins. Heat transfer also increases with the thermal conductivity of the material and with the pin height. In-line arrangement gives higher heat sink resistance and lower pressure drop than the staggered arrangement. Heat transfer models for in-line and staggered arrangements are suitable in designing pin-fin heat sinks.

Kai-Shing Yang , Wei-Hsin Chu[2007] This study performs an experimental study of pin fin heat sinks having circular, elliptic, and square cross-section. A total of twelve pin fin heat sinks with inline and staggered arrangements were made and tested. The effect of fin density on the heat transfer performance is examined. For an inline arrangement, the circular pin fin shows an appreciable influence of fin density whereas no effect of fin density is seen for square fin geometry. This is associated with the unique deflection flow pattern accompanied with the inline circular fin configuration. For the staggered arrangement, the heat transfer coefficient increases with the rise of fin density for all the three configurations. The elliptic pin fin shows the lowest pressure drops. For the same surface area at a fixed pumping power, the elliptic pin fin possesses the smallest thermal resistance for the staggered arrangement. One of the reasons for superior performance of circular pin fin under inline arrangement is associated with the unique deflection flow. For a staggered arrangement where deflection flow pattern vanishes, the elliptic pin fin yields slightly better performance than circular pin fin surface.

Anuradha, Sanyal and Pradip, et al [2008] the work reported in this paper is an attempt to enhance heat transfer in electronic devices with the use of impinging air jets on pin-finned heat sinks. The cooling performance of electronic devices has attracted increased attention owing to the demand of compact size, higher power densities and demands on system performance and re-liability. The problem arises due to restriction of space and also due to high heat dissipation rates, which have increased from a fraction of a W/cm2to 100s of W/cm2. As a result, efficient cooling of electronic chip remains a challenge in thermal engineering. Heat transfer can be enhanced by several ways like air cooling, liquid cooling, phase change cooling etc.The heat transfer can be increased by two ways. First, increasing the heat transfer coefficient (forced convection), and second, increasing the surface area of heat transfer (finned heat sinks). A steady jet often stabilizes the boundary layer on the surface to be cooled. Enhancement in the convective heat transfer can be achieved if the boundary layer is broken. In the present study the combined effect of pin-finned heat sink and impinging slot jet, both steady and unsteady, has been investigated for both laminar and turbulent flows. The effect of fin height and height of impingement has been studied. From the studies carried out it was found that: a) beyond a certain height of the fin the rate of enhancement of heat transfer becomes very low with further increase in height, b) the heat transfer enhancement is much more sensitive to any changes at low Reynolds number than compared to high Reynolds number, c) for a given total height of impingement the use of fins and pulsated jet, increases the effective heat transfer coefficient by almost 200% for the same average Reynolds number, d) for all the cases it was observed that the optimum frequency of impingement is around 50 − 100 Hz and optimum duty cycle around 25-33.33%, e) in the case of turbulent jets the enhancement in heat transfer due to pulsations is very less compared to the enhancement in case of laminar jets.

Yue-Tzu Yang, Huan-Sen Peng [2009] the present study carries out numerical computations of the plate-circular pin-fin heat sink and provides physical insight into the flow and heat transfer characteristics. The governing equations are solved by adopting a control-volume-based finite-difference method with a power-law scheme on an orthogonal non-uniform staggered grid. The plate-circular pin-fin heat sink is composed of a plate fin heat sink and some circular pins between plate fins. The purpose of this study is to examine the effects of the configurations of the pin-fins design. The results show that the plate-circular pin-fin heat sinks has better synthetically performance than the plate fin heat sink. In this study, the numerical simulations of PCPFHS at various wind velocity and the configurations of pin fins design are proposed. The objective of this study is to examine the thermal and hydraulic performance of the PFHS and the PCPFHS. The results show that increasing wind velocity could reduce the thermal resistance and increase the pressure drop simultaneously. The thermal resistance of the PCPFHS is lower than that of the PFHS at the same wind velocity and the pressure drop of the PCPFHS is much higher than that of the PFHS.

Yue-Tzu Yang , Huan-Sen Peng, [2009] In this paper the numerical study of the thermal performances of the heat sink with un-uniform fin width designs with an impingement cooling were investigated numerically. The coupling of the velocity and the pressure terms of momentum equations are solved by the SIMPLEC algorithm. The well-known k –e two equation turbulence model is employed to describe the turbulent structure and behaviour. The parameters include the five Reynolds number (Re = 5000–25000), three fin heights (H = 35, 40, 45 mm), and five fin width designs (Type-1–Type-5). The objective of this study is to examine the effects of the fin shape of the heat sink on the thermal performance. The results show that the Nusselt number increases with the Reynolds number. The increment of the Nusselt number decreases gradually with the increasing Reynolds number. The numerical simulation of the heat sink with an impingement cooling at various Reynolds numbers and fin dimensions are proposed. The purpose of this study is to evaluate the possibility of improving the thermal performance by utilizing the un-uniform fin width design of the heat sink

N. Nagarani et al [2010] In their present work extended surfaces (fins) are one of the heat exchanging devices that are employed extensively to increase heat transfer rates. The rate of heat transfer depends on the surface area of the fin. Radial or annular fins are one of the most popular choices for exchanging the heat transfer rate from the primary surface of cylindrical shape. In this paper the heat transfer rate and efficiency for circular and elliptical annular fins were analyzed for different environmental conditions. Elliptical fin efficiency is more than circular fin. If space restriction is there along one particular direction while the perpendicular direction is relatively unrestricted elliptical fins could be a good choice.

Hamid Reza Seyf and Mod. Layeghi [2010] A numerical analysis of forced convective heat transfer from an elliptical pin fin heat sink with and without metal foam inserts is conducted using three-dimensional conjugate heat transfer model. The pin fin heat sink model consists of six elliptical pin rows with 3 mm major diameter, 2 mm minor diameter, and 20 mm height. The Darcy–Brinkman–Forchheimer and classical N–S equations, together with corresponding energy equations are used in the numerical analysis of flow field and heat transfer in the heat sink with and without metal foam inserts, respectively. A finite volume code with point implicit Gauss–Seidel solver in conjunction with algebraic multi grid method is used to solve the governing equations. The code is validated by comparing the numerical results with available experimental results for a pin fin heat sink without porous metal foam insert. Different metallic foams with various porosities and permeability are used in the numerical analysis. The effects of air flow Reynolds number and metal foam porosity and permeability on the overall Nusselt number, pressure drop, and the efficiency of heat sink are investigated. The results indicate that structural properties of metal foam insert can significantly influence on both flow and heat transfer in a pin fin heat sink. The Nusselt number is shown to increase more than 400% in some cases with a decrease in porosity and an increase in Reynolds number. However, the pressure drop increases with decreasing permeability and increasing Reynolds number.

Ashish Kumar Pandey [2011] A theoretical study of single phase micro channel heat exchanger has been carried out. The computational fluid dynamics (CFD) model equations are solved to predict the hydrodynamic and thermal behaviour of the exchanger. The utility of nonmaterial as a heat enhancer has been justified by studying a circular micro channel thermal behaviour. Water and its nano fluids with alumina (Al_2O_3) are used as the coolant fluid in the micro channel heat sink. The present CFD calculated heat transfer coefficient values have compared with the analytical values and very close agreement is observed. The result shows
that nano fluids help to increase the heat transfer coefficient by 15% and 12% respectively in laminar and turbulent zone. Thus use of nano fluids has been found beneficial both in laminar and turbulent zone. The hydrodynamic and thermal

behaviour of the system have been studied in terms of velocity, pressure and temperature contours. The velocity contours at the exit show that wall effect penetrates more towards the centre and the thickness of the zone with maximum velocity shrinks with increase in Re. The pressure drop across the channel increases with increase in Re. The effect of Re on the behaviour the channel are also studied. Its behaviour also have been analysed with the help of temperature, pressure and velocity contours. The change of temperature from inlet to outlet was found increasing with decreasing Reynolds number. Pressure drop increases with increase in Reynolds number.

N. Nagarani et al. [2012] The study of this paper presents numerical and experimental comparative study of elliptical and circular fins which are made up of same kind of metal with same surface area and fed with constant heat inputs under free convection.
The numerical result show more distribution of isotherms and elevated rate of temperature distribution along the major axis of elliptical fin than those of circular fin. The experimental result proved that the surface temperature of elliptical fin decreased with increase in fin length along major axis. For elliptical fin made up of AISI SS304steel, the shaped tube efficiency is better with Biot number up to 0.13 and fin effectiveness is greater with Biot number up to 0.151 than that of circular fin. The aforementioned limit of Biot number for the shaped tube efficiency and the effectiveness of elliptical fins is an optimized range beyond which there will be a reduction in heat transfer rate in spite of adding metal to the base tube. In this research work, the heat transfer of elliptical and circular fins which are made up of same kind of metal with same surface area has been analyzed experimentally by feeding constant heat inputs under free convection. In elliptical fin, the surface temperature goes on decreasing gradually and continuously. The experimental results that the performances of elliptical fins are better in respect of isotherms, temperature distribution, shaped tube efficiency and effectiveness when compared to those of circular fins.

2. Conclusion

In this study, previous work done on performance analysis of extended surfaces (fins) under free and forced convection has been discussed in order to determine the enhancement in the heat transfer rate. The free and forced convection heat transfer from the fins of different shapes & geometries protruding from a surface has been discussed that have been investigated both experimentally & numerically. The effects of geometric parameters, fin height, fin length, and fin material; thermal conductivity on the heat transfer performance of fin arrays has been discussed. A relation for the optimum fin height that maximizes the heat transfer rate has obtained. Experimental results showed that the larger fin height results in higher convection heat transfer rates from the fin arrays The experimental result shows that for cylindrical fin with circular grooves (depth 3.5mm) heat loss is a maximum. The grooved cylindrical fin loses approximately 1.23 times greater heat per unit area, compared to the threaded cylindrical fin, and 2.17 times greater heat per unit area, respectively compared to the solid pin fin at a pressure lower than atmospheric pressure. As pressure decreases heat loss reduces and contribution of radiation heat transfer on total heat loss increases.
In comparing the elliptical pin heat sink with the rectangular pin heat sink, the air foil benefits are visible. There was 40% more air flowing through the rectangular pin design, yet the thermal resistances was virtually equal. The elliptical pin enhances heat transfer. For pin fin heat transfer from and pressure drop across the heat sink increases with the increase in approach velocity, pin diameter, and number of pins. Heat transfer also increases with the thermal conductivity of the material and with the pin height. In-line arrangement gives higher heat sink resistance and lower pressure drop than the staggered arrangement. Heat transfer models for in line and staggered arrangements are suitable in designing pin-fin heat sinks. The effect of fin density on the heat transfer performance is examined. For an inline arrangement, the circular pin fin shows an appreciable influence of fin density whereas no effect of fin density is seen for square fin geometry. This is associated with the unique deflection flow pattern accompanied with the inline circular fin configuration. For the staggered arrangement, the heat transfer coefficient increases with the rise of fin density for all the three configurations. The elliptic pin fin shows the lowest pressure drops. For the same surface area at a fixed pumping power, the elliptic pin fin possesses the smallest thermal resistance for the staggered arrangement. One of the reasons for superior performance of circular pin fin under inline arrangement is associated with the unique deflection flow. For a staggered arrangement where deflection flow pattern vanishes, the elliptic pin fin yields slightly better performance than circular pin fin surface. The rate of heat transfer depends on the surface area of the fin. Radial or annular fins are one of the most popular choices for exchanging the heat transfer rate from the primary surface of cylindrical shape. Elliptical fin efficiency is more than circular fin. If space restriction is there along one particular direction while the perpendicular direction is relatively unrestricted elliptical fins could be a good choice.

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