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DIFFERENT HEAT SINK GEOMETRIES AND COOLING TECHNIQUES, EXPERIMENTAL STUDY OF PIN FIN HEAT SINK UNDER MULTI JET AIR IMPINGEMENT TECHNIQUE

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Abstract: A variety of heat sinks were used in compact electronic circuits under fan impingent flow for good thermal performance. The following study will examine the effect on overall thermal performance associated with different fin geometries, including, rectangular plates as well as square, circular, elliptical, offstrip, centrifugal heat sinks. The results clearly indicate that the preferred fin profile is very dependent on these parameters. In this paper the different geometries of heat sink, flow configuration, cost, and arrangement of pin fin heat sink studied. The present experiment investigate the effect of circular pin fin heat sink, jet velocity, jet to jet spacing, and nozzle plate to heated surface separation distance in 3×3 square multi jet impinging array on the average nusselts number. The jet Reynolds Number is varied in the range of Re=6000-13000.The thermal performance of 4×4 circular array pin fin heat sink studied with thermal parameters like average Nusselts number, total thermal resistance, average base temperature, Reynolds numbers. The multi jet impingement shows average heat transfer coefficient increases with increases in Reynolds number, total thermal resistance decreases with increases in Reynolds number.

Index Terms - Heat sink geometry, multi jet impingements, electronic cooling

I. INTRODUCTION

Modern portable electronics have seen component heat loads increasing, while the space available for heat dissipation has decreased, both factors working against the thermal designer. This requires that the thermal management system be optimized to attain the highest performance in the given space. While adding fins to the heat sink increases surface area, it also increases the pressure drop. This reduces the volumetric airflow, which also reduces the heat transfer coefficient [1]. There exists a point at which the number of fins in a given area can be optimized to obtain the highest performance for a given fan. While heat sinks are routinely used in most electronics applications, the rationale for selecting a particular design of heat sink or more specifically a particular fin cross sectional profile remains somewhat uncertain [2]. The current trend for dense packaging and high-performance of state-of-the-art electronics has been accompanied with a serious requirement for effective cooling schemes [3]

With increasing power density of electronic chips and devices, interest in effective cooling technologies has been growing both in industry and academia. Today, most research efforts are focused on single phase and flow boiling heat transfer in enhanced compact heat sink geometries such as micro-channels, micro pin fins, and impinging jets. Each of these technologies has its advantages and disadvantages, and the challenge is to find their optimal performance for a given electronics cooling application [4].

I. HEAT SINK TECHNOLOGIES:

1. Plate fin Heat sink:

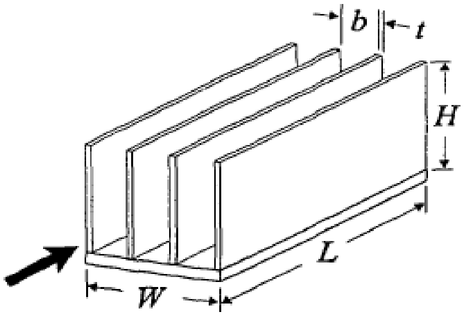

FIG.1 PLATE FIN HEAT SINK

The use of finned heat sinks increases the effective surface area for convective heat transfer, reducing the thermal resistance mid operating temperatures in aircooled electronics. Tlie plate fin heat sink shown in Fig. 1 is one of the most common configurations used in current applications. It consists of a parallel, uniform array of thin, conductive plates of length L, height H and thickness t, mounted on a baseplate of dimensions L x W. Heat is convected from tlie heat sink by fan or blower- driven airflow through tlie channels formed between tlie fins in a direction parallel to tlie base plate[9].The plate- fin heat sinks are designed as an array of 6 × 2 with a cut- off passage in the x-direction. The material of the heat sinks is selected as aluminum alloy 6061 and the surfaces are coated with a flat black paint that has a radiation emissivity of 0.96 to increase the accuracy of temperature measurement. The length and width (L) of the base of the heat sinks are 80 mm and the thickness (b) is 8 mm. The height and width of the fins are varied as experimental parameters. There are 25 heat sink models in this study with 5 fin widths and 5 fin heights[7].

2. Pin fin heat sink: Among existing heat-sink technologies, pin-fin heat sinks represent an efficient cooling solution. They have a large surface area in relation to any other heat-sink volume. Also, the round pins and pin spacing let blown air create a significant amount of turbulence between the pins. This breaks up boundary layers around the pins, creating high convective thermal performance. In addition, pin-fin heat sinks are made of highly thermally conductive aluminum alloys or copper. Pin-fin heat sinks consist of a base and an array of embedded pins. Parameters such as base-plate dimensions (both footprint and thickness), pin length, thickness and density, and material (aluminum, copper, or copper-aluminum. The volumetric efficiency of pin fins is higher than most other heat-sink shapes. As a result, pin-fin heat sinks are significantly smaller and lighter compared to their cooling ability. In one instance, switching to a pin fin heat sink while keeping the same 1 × 1-in. footprint dropped the temperature by 10°C. In some instances, pin fins are two to 10 times more efficient than extrusion-type heat sinks.

The design of elliptical pin heat sinks challenges existing thermal modeling techniques. These simplified terms represent a combination of several factors, such as material conductivity, lateral fin conduction, boundary layer formation, effective surface area, and pressure drop. 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. These results are in correlation with the basis of the elliptical pin fin design considerations; i.e. reduced vortex flow, eliminating boundary layer effects. Another surprising result was that the extruded straight design performed significantly better than either of the other two designs over the flow range examined herein[5].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 [5]. Elliptical pin fin heat sinks were conceived to provide cooling on boards where the direction of the flow may not be known. They also provide a heat sink with large surface areas for heat transfer and minimum vortex formation, and, consequently, flow pressure drop. As their name suggests, these heat sinks utilize an elliptical airfoil cross section for the pin. The elliptical pin fin heat sink used in their study is made of cast aluminum and had a dual grid pattern of pins with an outer grid of 9 by 5 and an inner grid of 8 by 4 pins [8]. There are various shapes of pin fin heat sink are available like square, circular, elliptical rectangular in microelectronic application. But to choose the best solution to it the challenge for the engineers.

FIG2. PIN FIN HEAT SINK

3. **Off strip Heat sink:** Off strip heat sink technology is similar to plate fin heat sinks but channels are cuts at width wise to increase the turbulence. Offset- strip fin heat sink take advantage of boundary layer restarting to enhance heat transfer over that of plain-fin heat sink. Typically, these heat sinks are operated at low Reynolds numbers (Re < 1,000)[12]. At higher Reynolds numbers, vortex shedding and turbulent flow in the array may cause further enhancement of heat transfer, but with an increase in pressure drop.The relatively better performance of the offset strip fin heat sink can be attributed to its ability to enhance the heat transfer coefficients as well as to add surface area. In offset strip fins, the thermal boundary layers are stripped and reestablished; this causes the average heat transfer coefficients to be higher than those of continuous parallel plate fins. Besides interrupting the growth of the thermal boundary layers, offset strip fins may cause vortex shedding , which may increase the heat transfer coefficients . However, this enhancement of the heat transfer coefficients is also associated with higher pressure drop and, consequently, higher pumping power consumption [11].

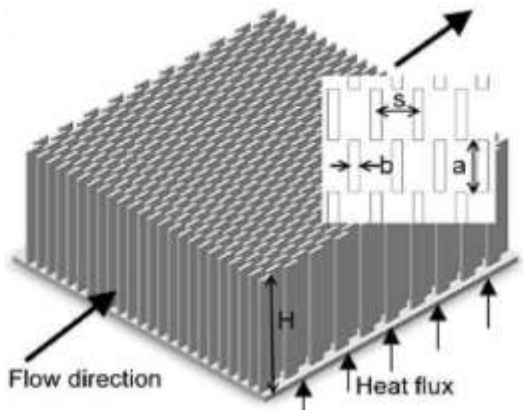

FIG 3. OFF STRIP HEAT SINK

4. **Centrifugal Heat sink:** A novel heat sink, called a centrifugal heat sink, into which the blades of a fan are integrated between the fins, is proposed. The fan blades, based on design principles of centrifugal turbomachinery, are arranged to be placed between the fins of the circular heat sink. The rotary motion of the blades causes nearby coolant to be sucked into and pass through channels formed by adjacent fins. Due to the integration of the blades into the space between the fins, additional space for the blades of the fan is no longer required for the centrifugal heat sinks. Consequently, this centrifugal heat sink makes efficient use of available cooling space. To evaluate the thermal performance of the centrifugal heat sink under constant heat flux conditions, the maximum temperature at the heat sink base is measured. Experimental data show that the fluid flow characteristics of the centrifugal heat sink are identical to those of a typical centrifugal fan. The average velocity at the inlet and the exit is linearly proportional to the rotating speed of the blades. The thermal resistance of the heat sink was also measured. The measured thermal resistance decreases as the rotating speed or the pumping power of the fan increases. As result, the minimum thermal resistance of the centrifugal heat sink is found to be 0.47 K/W[10].

FIG.4 CENTRIFUGAL HEAT SINK

The cross sections for rectangular plate fin (RPF), circular pin fin (CPF), square pin fin (SPF), and elliptical pin fin (EPF) are shown in Fig. 5

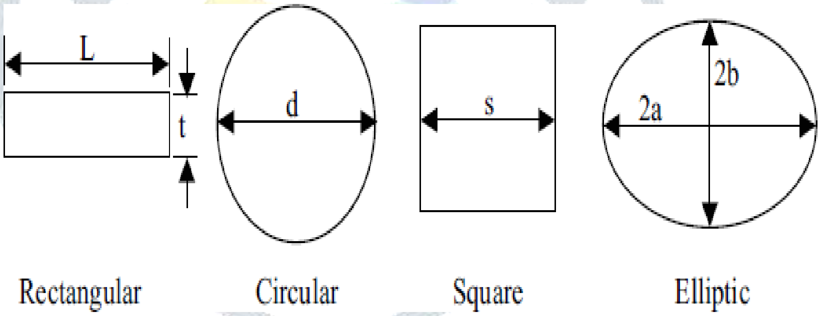

FIG 5. PIN HEAT SINK SHAPES

Computer cooling is required to remove the waste heat produced by computer components, to keep components within permissible operating temperature limits. Components that are susceptible to temporary malfunction or permanent failure if overheated include integrated circuits such as CPUs, chipset, graphics cards, and hard disk drives. The following methods are used for computer cooling.

II.Methods of Cooling:

1. Fan Cooling: Fans are used when natural convection is insufficient to remove heat. Fans may be fitted to the computer case or attached to CPUs, GPUs, chipset, PSU, hard drives, or as cards plugged into an expansion slot. Common fan sizes include 40, 60, 80, 92, 120,and 140 mm. 200, 230, and 250 mm fans are sometimes used in high-performance personal computers. A computer has a certain resistance to air flowing through the chassis and components. This is the sum of all the smaller impediments to air flow, such as the inlet and outlet openings, air filters, internal chassis, and electronic components. Fans are simple air pumps which provide pressure to the air of the inlet side relative to the output side. That pressure difference moves air through the chassis, with air flowing to areas of lower pressure. Fans generally have two published specifications: free air flow and maximum differential pressure. Free air flow is the amount of air a fan will move with zero back-pressure. Maximum differential pressure is the amount of pressure a fan can generate when completely blocked.

2.Jet Impingement cooling: A jet impingement device can produce a flow field that can achieve relatively high local heat transfer rates over a surface to be cooled or heated. Jet impingement is an attractive cooling mechanism due to the capability of achieving high heat transfer rate. Impinging jets are used in many engineering applications to enhance heat transfer for cooling or heating purposes or mass transfer for vapour deposition. Typical heat transfer applications include electronics cooling, paper drying, metal annealing and sheet metal treatment. In most of these applications, arrays of jets are used in a range of configurations and shapes with the objective on optimizing heat transfer rates.Jet impingement cooling in CPU cooling can be achieved by air or liquid as fluid such as FC72, distilled water etc. Convective heat transfer to impinging jets is known to yield high local and area averaged heat transfer coefficients. Impingement jets are of particular interest in the cooling of electronic components where advancement relies on the ability to dissipate extremely large heat fluxes. Effective Jet impingement cooling can be achieved by Single jet,multijet, multijet with spent air exit with either cross flow arrangement or impingement on target surface.

3.Phase change Material: Phase-change cooling is an extremely effective way to cool the processor. A vapor compression phase-change cooler is a unit which usually sits underneath the PC, with a tube leading to the processor. Inside the unit is a compressor of the same type as in a window air conditioner. The compressor compresses a gas (or mixture of gases) into a liquid. Then, the liquid is pumped up to the processor, where it passes through a condenser (heat dissipation device) and then an expansion device to vaporize the fluid; the expansion device used can be a simple capillary tube to a more elaborate thermal expansion valve. The liquid evaporates (changing phase), absorbing the heat from the processor as it draws extra energy from its environment to accommodate this change (see latent heat). The evaporation can produce temperatures reaching around −15 to −150 ^{o}c. The gas flows down to the compressor and the cycle begins over again. This way, the processor can be cooled to temperatures ranging from −15 to −150 ^{o}c, depending on the load, wattage of the processor, the refrigeration system (see refrigeration) and the gas mixture used. This type of system suffers from a number of issues but, mainly, one must be concerned with dew point and the proper insulation of all sub-ambient surfaces that must be done (the pipes will sweat, dripping water on sensitive electronics).

4.Liquid cooling: Liquid cooling is a highly effective method of removing excess heat, with the most common heat transfer fluid in desktop PCs being (distilled) water. The advantages of water cooling over air cooling include water's higher specific heat capacity and thermal conductivity. The principle used in a typical (active) liquid cooling system for computers is identical to that used in an automobile's internal combustion engine, with the water being circulated by a water pump through a water block mounted on the CPU (and sometimes additional components as GPU and north bridge and out to a heat exchanger, typically a radiator. The radiator is itself sometimes cooled additionally by means of a fan. Besides a fan, it could possibly also be cooled by other means, such as by means of a Peltier cooler (although Peltier elements are most commonly placed directly on top of the hardware to be cooled, and the coolant is used to conduct the heat away from the hot side of the Peltier element).Also, a coolant reservoir is often also connected to the system.Heat Pipe: A heat pipe is a hollow tube containing a heat transfer liquid. The liquid absorbs heat and evaporates at one end of the pipe. The vapor travels to the other (cooler) end of the tube, where it condenses, giving up its latent heat. The liquid returns to the hot end of the tube by gravity or capillary action and repeats the cycle. Heat pipes have a much higher effective thermal conductivity than solid materials. For use in computers, the heat sink on the CPU is attached to a larger radiator heat sink. Both heat sinks are hollow, as is the attachment between them, creating one large heat pipe that transfers heat from the CPU to the radiator, which is then cooled using some conventional method. This method is expensive and usually used when space is tight, as in small form-factor PCs and laptops, or where no fan noise can be tolerated, as in audio production. Because of the efficiency of this method of cooling, many desktop CPUs and GPUs, as well as high end chipsets, use heat pipes in addition to active fan- based cooling to remain within safe operating temperatures.

III.PROBLEM DESCRIPTION

To solve the overheating problem of heat sink we Study different research papers on heat sink geometry and methods of cooling we decided to work on Multi jet impingement pin fin Heat sink using same forced convection principle. The objectives of this study are to develop Geometrical optimization of pin fin heat sink for effective heat transfer rate under multi jet impingement forced cooling. To increase heat transfer rate, reduce total thermal resistance for different Reynolds numbers, spacing between nozzle jet plates to the target surface (Z/D ratios).i.e. to find heat transfer coefficient. There are a number of parameters to be considered in the design of such systems: These are jet-to- target surface distance (Z/D ratios), flow rate, Jet diameter,overall geometry heat sink, Reynolds Number. The air flow rate, the diameter of the jet, their spacing and their distance to the target surface are the main variables, which can be chosen to solve our heat transfer problem [16][17][18]. The schematic of a multi jet impinging on a pin fin heat sink which is to be analyzed is shown in Fig.1. The air jet is discharged through the round nozzle having length l and diameter d is directed normally towards the pin finned target plate with base 60 x 60 x 6mm, the pin fin are provided on top of plate on 50 x 50mm area, the sink is subjected to constant heat input (30W) from bottom and except top surface all other walls are adiabatic. The material of the heat sink is Aluminum. The jet after impingement spent air will exit from opening provided in top confinement plate in opposite to impinging direction as shown in Fig. 6.

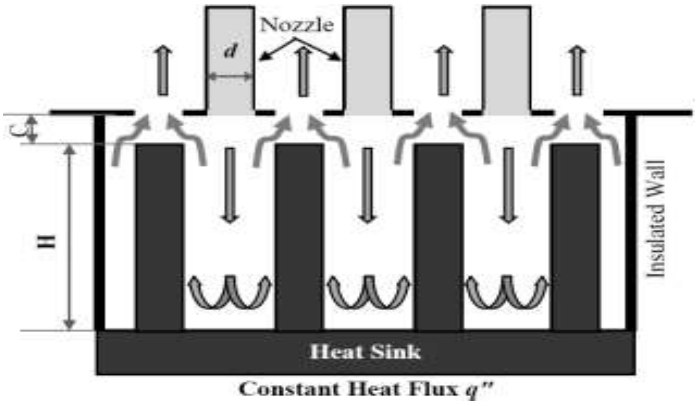

FIG. 6 SCHEMATIC OF MULTI JET IMPINGEMENT ON PIN FIN HEAT SINK

flow configurations unconfined , semi confined ,all side confined at constant heat flux supply 30 W[2].

The average heat transfer coefficient for the heat sinks was calculated according to Newton's laws of cooling,

$h_{avg} = Q_{total} / A_t (T_{bavg} - T_a)$---------------------------- (1),

Total thermal resistances (˚C/W) may be calculated from these definitions using:

$R_{th} = (T_{bavg} - T_a)/Tt_{otal}$ --------------------------------(2)

Temperature measurement on the heat sink was at 6 different locations at the base and one at the pin fin tip. Due to use of 3×3 multi jet air impinging along the fin base temperature distribution is same due to the symmetry of the heat sink area, nozzle spacing, and constant heat flux supply from the base The thermocouples mounted at one corner of the heat sink equally spaced. For measurement of the temperature K-type thermocouple were used.

Pin-fin heat sinks provide a large surface area for the dissipation of heat and effectively reduce the thermal resistance of the package at the cost of higher pumping power. They often take less space and contribute less to the weight and cost of the product.

IV. EXPERIMENTAL SET UP AND APPARATUS:

The experimental apparatus used to measure the performance of pin fin heat sink or unpinned heat sink was vertical air flow bench. The experimental set up consists of pin fin heat sink, 100W capacity electric heater, 3×3 arrays nozzle jets assembly. The experimental set up includes the 4×4 array circular pin fin aluminum heat sink of size 60×60×6 mm base of dimension pin fin heat sink. One 3 mm thickness, 100 W Capacity 60×60mm square electric heater was used to heat pin fin base. Due to the same base dimensions of the heat sink and electric heater same heat distribution at the base of the heat sink. Back side and 4 edges of the heater and pin fin heat sink covered with the asbestos 7 mm thickness insulator at the base and 3 mm at each edge of the heat sink and heater to less heat loss at the bottom side and edges. Air at ambient condition drawn into the variable speed generating blower. The air flow measured by the use of pitot tube manometer difference. Air from the air box flow through air strengthener comes out to through the 3×3 nozzle exit. Air impinging on fin base (target plate) which contains heat source assembly. The nozzle to the target plate or fin base Spacing is maintained by use plastic spacers. Experiments Carried out for 3 different Z/D ratios says 6,8,10 for 3 different

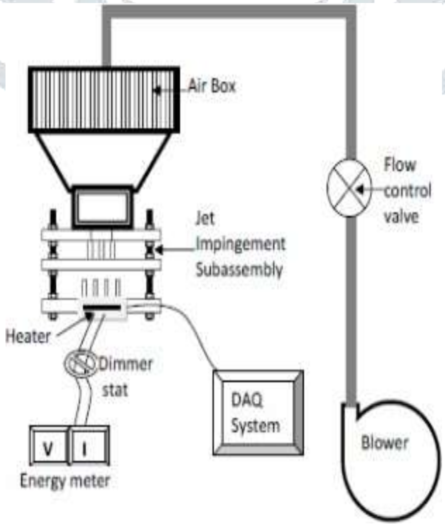

Fig 7 Experimental Set up

V RESULTS AND DISSCUSSIONS

Experiments were performed for the Reynolds number range 6000-13000 for the impingement flow configuration Semi confined cross flow arrangements with 3 Z/D ratios 6,8,10 fixed With constant heat flux supply 30 W[2,3]. The effects on the results of varying this spacing (Z/D Ratios) as well as the Reynolds Numbers were studied with the heat sink clamped on to the heat source. The 3×3 nozzle array with diameter of nozzle d=5mm used for experimentations. Pin fin heat sink used were 4×4 array with diameter of pin fin D= 5 mm height of fin H_p = 25mm, pitch X_p=Y_p=15 mm [2,3].Experiments were performed for Reynolds numbers ranging from 6000 to 12 000 with the nozzle-to- target plate spacing fixed at H_p= 25 mm.

SEMICOMFINED CROSS FLOW ARRANGMENT

Fig.8.shows that total thermal resistance R_{th} ˚C/W for Pin fin heat sink was decreased from 0.41 to 0.27 ˚C/W. compared with unpinned heat sink total thermal resistance of pin fin heat sink is decreased 52% for same base dimensions of flat plate, Re, Z/D Ratios and cross flow arrangement. For the good design of heat sink, it should have less thermal resistance and moderate heat transfer rate, heat dissipation rate is more to the surrounding air so that heat sink temperature should be nearly equal to the atmosphere.

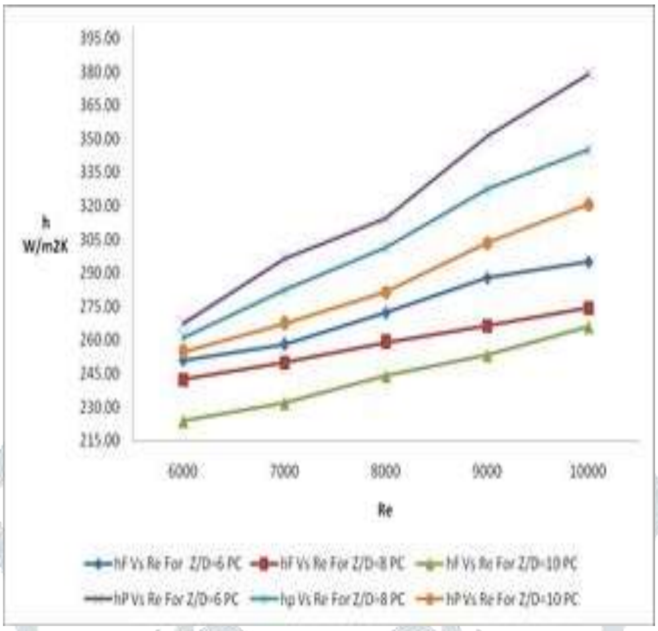

Fig.8. Effect of nozzle plate-to-heated surface separation distance on heat sink average heat transfer coefficient h W/m^{2}K for multiple nozzles jets at Re = 6000 to10 000

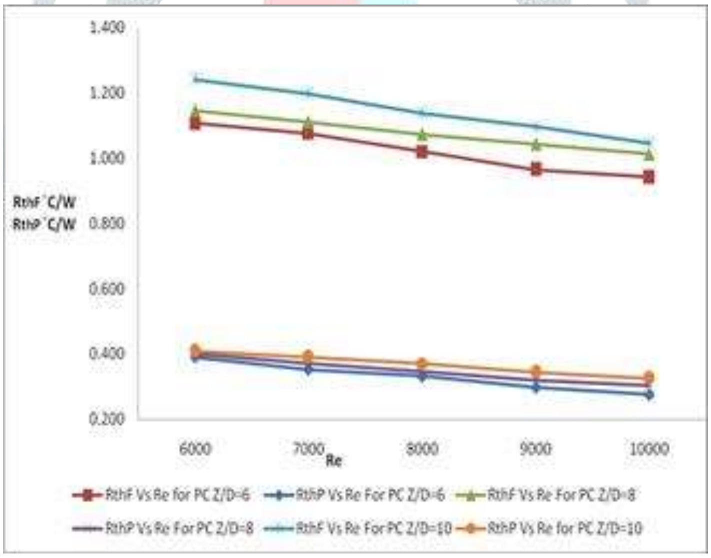

Fig.9. Effect of nozzle plate-to-heated surface separation distance on heat sink total average thermal Resistance for multiple nozzles at Re = 6000 to10 000.

CONCLUSIONS:

From above study we can conclude the different fin geometries and methods of cooling having the same wetted surface area are compared from the point of views of heat transfer, thermal resistance, velocity of flow Z/D ratio, and flow arrangement. It is observed that, for low approach velocities and smaller aspect ratios, the circular, elliptical geometry gives better results from the point of view of heat transfer, thermal resistance. With increasing in Reynolds number total thermal resistance decreases for various flow cross, jet impingement configurations. Multi jet impingement method is most effective cooling method. By using multi jet impingement cooling techniques on 60×60×6mm pin fin heat sink with nozzle diameter 5mm heat sink will be studied for Re range 6000 to 13000.

The results for the multiple jets were compared with flat plate heat sink with pin fin heat sink, both at a fixed nozzle diameter (5 mm). The most important parameters affecting the thermal resistance are fin height, fin width and fluid velocity. Thermal resistance can be successfully improved by controlling these parameters. The minimum thermal resistance was observed at 25 mm fin height, 5 mm fin width and Re=12000,nozzle plate to heated surface target distance Z/D=6 for semi confined flow arrangement. The

Reynolds number of the impinging jet plays an important role in the thermal resistance. Increasing the Reynolds number consistently diminishes the thermal resistance.

FUTURE SCOPE: Conventional technology to cool desktop computers and servers is that of the ‘‘direct heat removal’’ heat sink, which consists of a heat sink/fan mounted on the CPU. Although this is a very cost effective solution, it is nearing its end of life. This is because future higher power CPUs will require a lower R-value than can be provided by this technology, within current size and fan limits.

1) Hot source heat removal by two-phase impingement flow in micro channels/spray cooling can achieved low R value.
2) Multi jet impingement technologies with spent air exist by using air or dielectric liquids.
3) Geometry of pin fin heat can be changed like elliptical circular or centrifugal heat sink.
4) Fanless heat sink with Phase change material.

NOMENCLATURE

A_t	Total heat transfer area m^2.
d	Nozzle diameter for the multi-jet impingement mm.
D	Pin fin diameter for the multi-jet impingement mm
Z/D	Nozzle plate-to-heated surface separation distance
H_p	Fin height mm.
Xn	Center to center distance between nozzles mm
n	Numbers of pin fin,
N	Number of nozzles
Z	Vertical distance from nozzle outlet to flat plate m
Q	Heat input to the heater W
h_{av}	Averaged convective heat transfer coefficient W/m^2K
Ka	Thermal conductivity of air W/m K.
K	Thermal conductivity of aluminum W/m K.
W or L	Width or Length of heat sink mm..
Nu	Nusselt number
UC	Unconfined Cross Flow Arrangement
PC	Semi Confined(Partially Cross Flow Arrangement.
Nu_F	Nusselts number for Flat Plate heat sink.
Nup	Nusselts number for pin fin heat sink.
Re	Nozzle Jet Reynolds number
T_{bavg}	Base average temperature for pin fin & Flat plate ˚C.
Ta	Supply air temperature at the nozzle ˚C

Subscripts:

F	Flat plate heat sink or unpinned heat sink,
P	Pin fin Heat sink,
bavg	Base average thermal,
C	Cross Section,
a	air.

REFERENCES:

[1] Waqar A. Khan,” The Role Of Fin Geometry In Heat Sink Performance”, International Electronic Packaging Technical Conference and Exhibition July 6-11, 2003, Maui, Hawaii, USA.

[2] Optimization of Heat Sink Design and Fan Selection in Portable Electronics Environment-article.

[3] Seo Young Kim, Myung Ho Lee, and Kwan-Soo Lee,” Heat Removal by Aluminum-Foam Heat Sinks in a Multi-Air Jet Impingement” 2005 IEEE Transactions on Components and Packaging Technologies.

[4] Sidy Ndao, Yoav Peles, Michael K. Jensen,” Multi- objective thermal design optimization and comparative analysis of electronics cooling technologies” International Journal of Heat and Mass Transfer 52 (2009) 4317–4326

[5] Seok Pil Jang, Sung Jin Kim,” Fluid Flow and Thermal Characteristics of a Micro channel Heat Sink Subject to an Impinging Air Jet”, Journal of Heat Transfer,ASME July 2005.

[6] Christopher L. Chapman, and Seri Lee,” Thermal Performance of an Elliptical Pin Fin Heat Sink”,Tenth IEEE SEMI-THEFNP

[7] Hung-Yi Li , Kuan-Ying Chen,” Thermal performance of plate-fin heat sinks under confined impinging jet conditions” International Journal of Heat and Mass Transfer 50 (2007) PP 1963–1970.

[8] Fariborz Forghan,” Experimental and Theoretical Investigation of Thermal Performance of Heat Sinks”

[9] P. Teertstra, M.M. Yovanovich and J.R. Culham,” Analytical Forced Convection Modeling of Plate Fin Heat Sinks”, Fifteenth IEEE SEMI- THERMTMSymposium,1999.

[10] Juwan Kim, Sung Jin Kim,” Heat transfer characteristics of a centrifugal heat sink”, International Journal of Heat and Mass Transfer 56 (2013) 188–196.

[11] Sidy Ndao, Yoav Peles, Michael K. Jensen," Multi- objective thermal design optimization and comparative analysis of electronics cooling technologies", International Journal of Heat and Mass Transfer 52 (2009) 4317–4326.

[12] Gregory J. Michn, Anthony M. Jacobi," Friction Factor and Heat Transfer Performance of an Offset- Strip Fin Array at Air-Side Reynolds Numbers to 100,000" International Refrigeration and Air Conditioning Conference at Purdue, July 17-20, 2006.

[13] N. ZUCKERMAN," Jet Impingement Heat Transfer:Physics, Correlations, and Numerical Modeling", Advances In Heat Transfer VOL. 39,2006.

[14] B.S., Louisiana ," Eric Ian Esposito, Jet Impingement Cooling Configurations", State University, August 2006.

[15] Akın Burak Etemoglu, "A brief survey and economical analysis of air cooling for electronic equipments" International Communications in Heat and Mass Transfer 34 (2007) 103–113.

[16] H. H. Jung and J. *G.* Maveety,"Pin-Fin Heat Sink Modeling and Characterization "2000 IEEE.

[17] Jim G. Maveety, Henry H. Jung, "Heat Transfer From Square Pin-Fin Heat Sinks Using Air Impingement Cooling "Vol. 25, NO. 3, September 2002.

[18] Zeinab S. Abdel-Rehim, "Optimization and Thermal Performance Assessment of Pin-fin Heat Sinks"**,** Journal of Applied Sciences Research, 3(3): 227-235, 2007.

[19] Waqar Ahmed Khan, "Modeling of Fluid Flow and Heat Transfer for Optimization of Pin-Fin Heat Sinks", ASME,2004.

[20] N. K. Chougule G. V. Parishwad A. R. Nadgire ,Numerical Investigation of Multijet Air Impingement on Pin Fin Heat Sink with Effusion Slots, WCECS 2013, 23-25 October, 2013, San Francisco, USA

[21] N. K. Chougule, G.V. Parishwad, C.M. Sewatkar ,Numerical Analysis of Pin Fin Heat Sink with a Single and Multi Air Jet Impingement Condition, ISSN: 2277-3754 (IJEIT)Volume 1, Issue 3, March 2012.

[22] Y. Kondo,H. Matsushima, "Optimization of Pin-Fin Heat Sinks for Impingement Cooling of Electronic Packages",240-246, Vol. 122, September 2000 by ASME.

[23] Dae Hee Lee, Heat transfer enhancement by the perforated plate installed between an impinging jet and the target plate. International Communications in Heat and Mass Transfer 45(2002)213-217.