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Experimental and Cfd Analysis of Heat Transfer Rate in Multi Air Jet Impingement Over A Flat Plate and Pin-Fin Heat Sink

Syed.Unees Babu, Perumalla Vijay Kumar, K. Lakshmi Prasad

***Abstract:** In this paper reports the results of investigation of heat transfer performance of in compression air jet impinging of heated surface over a flat plate & pin-fin heat sink. To mimic the computer processor of flat plate and pin fin dimensions are 120mm*75mm and pin height is 5cm and fin radius is 1cm and L/d ratios are 5,10,15respectively. By using this simulation in Ansys fluent software to perform the turbulent jet impingement on a surface. The bottom surface of the plate is supply constant heat flux and top surface of the plate is cooled by an impingement jet of air. It has two equations are used k-w model and shear stress transport to handle the turbulent jet. The result of flat plate heat sink is compare the Experimental and simulation is higher at 0.89% of experimental to compare numerical and Nusselt is higher at 3.35% of numerical to compare the experimental and heat transfer coefficient is higher at 4.51% of numerical to compare the Experimental and result of pin fin heat sink is compare the Experimental and numerical is higher at 0.23% of experimental to compare the numerical and Nusselt number is higher at 0.71% of numerical to compare the experimental and heat transfer coefficient is higher at 0.88% of numerical to compare the experimental. The effect of L/d ratios of jet impingement over a flat plate and pin fin heat sink on the heat transfer performance of the heated surface of investigated.*

***Keywords:** Impingement of jet, convective heat transfer coefficient (h), target plate, thermal conductivity (k), Reynolds number and temperature range (%).*

Nomenclature

Nu Nusselt number d jet diameter, mm

h heat transfer coefficient, w/m^2k U jet velocity, degree centigrade

Tavg Average Temperature ρ density, m/s

Tmax Maximum Temperature μ dynamic viscosity of air, kg/m-s

Tmin Minimum Temperature To jet temperature,̊c

K thermal conductivity, w/m-k q uniform heat flux, w/m^2

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I.INTRODUCTION

The experimental and numerical studies of the transient heat transfer characteristics of circular air-jet impingement are presented. Circular nozzle has an inner diameter of 6mm and varied from Reynolds number from 14,000 to 53,000. The nozzle exits to target plate varied from 4 to 8. The uncertainty analyses results show that the error of temperature and depth measurement can result in anerms of 11.1 and 1.4 to the local Nusselt number.The local Nusselt number at the stagnation increased from 144 to 175 Qiang Guo et al [1].The impinged by hot air jt coming out of nozzle of different profiles and different materials of target plate that are(acrylic, stainless steel, wrought iron, nickel, aluminium) are used. The nozzle employed in the investigation are single nozzle. For single nozzle varying the I/D ratio that are 2,3,4,5,6,7,8 at Re 5000,10000,15000,20000 and 0.5,1,5,10,20 thickness target plate. on these impinging plate temperature distribution, local and average Nusselt number values are recorded. It is used in cfd analysis software R veeranjaneyulu et al [2].In the confined air jet impinging on a flat plate is considered three jet shapes circular, half circuit, quarter circuit. In this three shapes 1st two shapes give higher heat transfer then compare the third shape. In this three shapes half circuit jet is higher Nusselt number to compare the other two circuits Fifi N.M. Elwekeel et al [3] .In this research work, it can be considered the different types of nozzle and jet to applied their related Reynolds number, spacing of nozzle to nozzle, distance between nozzle to target plate and nozzle diameter. To calculate the Nusselt number Sagar Chirade et al [4]. To study the industrial application, it can be used in electric cooling in size and weight of electric component to reduce the heat for the electric cooling. Rectangular pipe isgiving the better heat transfer to use in industrial application. The Reynolds number are considered by 5000-25000 at constant distance y/d is 8 and fin width w/L IS 0.1 and height h/L IS 0.5. To perform the increasing the Reynolds number then fin efficiency is increases but thermal resistance decreases Md. FarhadIsmail [5]. In this air jet impinging heat transfer it is flowing the compressed air to supply the single nozzle and the nozzle to plate distance is very low spacing. The pressure regular value is used in the air flow to measure the manometer reading. It is used in aluminum bar is used and both ends are connected the tension spring. The Reynolds number in the range of 3600 to 27600 and the gap of nozzle to plate is 0.25.

The nozzle to plate distance is less than heat transfer coefficient increases D. Lytle [6].The focus of this work is a synergistic heat transfer analysis of the jet impinging. It is considered the different exit point to be determined the flow of the air. It takes the rectangle shape and holes are plate the face of the body at different positions. It is the weaker parameter to be arrangement. Then heat transfer increases with increasing Reynolds numbers PerihanCulun et al [7].

The rate of heat transfer in the turbulent jet, the Reynolds number range of 5000 to 124000 and the distance of the nozzle to plate from 1.2 to16. to draw the ratio of nusselt number and Reynolds number to the variation of different journals to understanding and compare the better of the performance. It is the levell is give the better cooling effect K. Jambunatha et al [8].In this configuration, it has considered the three different orifice, sharp-edged, standard edge and square edge nozzle. In these three nozzles, the nozzle to plate is L/d = 2 and in this sharp-edged nozzle gives the higher heat transfer 50-75%. In this three nozzles the local and average heat transfer rate gives the sharp-edged nozzle to compare the square edged and standard edged Jungho Lee et al [9].In this investigation, the heat transfer coefficient between the impinging jet from three types of region are used transition region, stagnation region and wall jet region. When we increase the Reynolds number the heat transfer increase. To varied the Reynolds number and L/d ratio and nozzle diameter VadirajKatti et al [10]. It is investigation to the jet-jet spacing, nozzle to plate spacing and spent air exit (Xn/d) is 0.25, 1.0 and 6.0 and Reynolds number is 3500 to 20400. The heat transfer coefficient between the local and average nusselt number are presented in the Reynolds number Aaron M. Humber et al [11]. In this research is carried out in the area of steady air jet impinging over the flat plate by varying geometric as well as the injection parameters. Not only that, plenty amount of research works is also available with pin fin array as the target surface. But the numerical analysis of the current problem in commercial simulating software seems to be done very less Siddique Mohd Umair at el [12]. In this paper investigated the thermal & hydraulic performance of 20 different plates of pin-fin heat sink at different cross-section and different shapes circular, square, elliptic, drop-form and NACA 0050 and different ratios of pin width 0.3, 0.4, 0.5 & 0.6. it is used to solve the Ansys CF software as the 3D Reynolds average and navierstrokes equation. The results of the high pressure drop and heat transfer in the higher order of elliptic and NACA then drop-form then circular and next plate fin heat sink and next square and finally pin fin heat sink feng zhon et al [13]. In this paper work in the cooling channel of thermal resistance to the number of channels, thickness ratio, length of the width ratio of the heat source, fin efficiency, fin thermal conductivity, Prandtl number, maximum pressure drop through the cooling channel and incorporates the maximum cooling pump power to design the calculate the thickness ratio and laminar floe of Goldberg and Tuckerman and Pease for water cooled R.W.Knight et al [14]. In this paper investigated the multi jet impingement at different Reynolds number [5000<Re<20000] and different target to plate distance is [0.5<H/d<4]. In these papers to compare the single jet impingement and multi jet impingement which is give the better results to show. At multi jet impingement gives certain jet was higher than corresponding to other and heat removing of the single jet and multi jet impingement which is give the better results Suresh V. Garimella et al [15]. In this paper study the three-dimensional inverse design problem to calculate the two methods commercial code and Levenberg-Marquardt method. The design operating condition of the Re=5000, Rth can be decrease 12.98% & 4.81% compare the Yang & Peng's. heat sink and the Nusselt number & coefficient of Enhancement is increases by 14.92% & 15% compare to original heat sink. The Rth is decreases by 12.49% and Nu & COE is increases by 14.21% & 14% to compare the original fin. The thermal performance of the heat sink is improved Cheng-Hung huang et al [16]. In this experiment investigated the flow behavior, pressure drop and heat transfer through the pin-fin heat sink. The parameters of the plate thickness are 1.5*2.5mm, height is 12.5*22.5mm, velocity is 2 to 20 and clearance ratio is 0 to 1. The result of increase the Reynolds number pin density and pin diameter and decrease with thermal resistance Johnny S. Issa et al [17]. In this experiment, it has a rectangular horizontal duct set pin-fin heat sink. To flow the one side forced air to measure the magnetic field, mass flow rate & appliedheat flow. To reduce the evaluation of Nusselt number & friction factor and increases the Nusselt number & pressure drop provided in the pin-fin set compare to flow in a plain duct under similar condition. To increase the Nusselt number and decrease the clearance ratio M. G. Mousa et al [18]. In this paper investigation the pin-fin heat sink in the jet impingement cooling in the method of Taguchi method. Here k-w two equation of the turbulence structure & behavior and their parameters are height 35mm, 40mm, 45mm. They have three different inter fin spacing a, b, c and each inter fin spacing is 2mm, 4.2mm, 6.4mm respectively. The result of inter fin spacing Nusselt number & COE is increases and Reynolds Number decreases Y. T. Yang et al [19]. In this paper reported the performance of 3-dimensional, single nozzle on a flat plate of finite thickness. In this flat plate the bottom part is give the constant heat flux and top surface is cooled impinging of jet. It has two equations of shear stress transport and k-w model. It is investigated the local and average heat transfer and expressed by the temperature range & average Nusselt numberPullaraoMuvvala et al [20]. In this paper reported the numerical investigated of single and multi-air jet impingement over a plate dimension is 37mm *37mm at different L/d ratios (5,10,15,17.5,20) and different Reynold's number(2465, 3081, 6161, 9242, 12323). We can increase the L/d distance to increase the Reynolds number is 2465 to 12323 and decrease the Range 7.1 to 2%. In this investigate the L/d =15 is the best solution to increase the Reynold number and Nusselt number increase the 35% to compare the L/d =5 PullaraoMuvvala et al [21].

II.EXPERIMENTAL SET-UP & PROCEDUR

In the schematic diagram of air jet impingement used in the experimental procedure as shown in fig. A blower is used in the flow of air in the capacity of 1.5 m^3/min. It is varying the speed also. To connect the blower pipe to settling chamber. In the settling chamber the air is flow through the nozzle into the target plate.

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In the settling chamber prepare the 30.5cm*30.5cm square wooden sheet and 1.5cm thickness of wooden sheet. In this wooden sheet we can take each sides 5cm distance mark and vertically 30.5cm height glass wall and horizontally 21cm length form a rectangular box. In this box top of the settling chamber mark 3.5cm radius and cut it hole. In the middle of the wooden sheet mark 6 hole to flow the air into the target plate. In the bottom of the wooden sheet we can take same length of top box to build another box. In the nozzle inlet diameter is 10mm radius & outer diameter is 6mm radius and each nozzle to nozzle distance is 2cm in bottom of the wooden sheet we can place the aluminium plate at the distance of 5cm, 10cm & 15cm respectively. The parameters of flat plate are 75mm*120mm length &thickness is 0.05mm and another one is pin-fin length is 75mm*120mm and pin height is 5cm and pin diameter is 1cm radius. We can insulate the plate 4 sides and bottom of the plate is applied the heat flux and topside of the plate is placed 6 thermocouples. In these 6 thermocouples, 3 thermocouplesare placed plate top it takes the surface temperature and other 3 thermocouples placed the sides of the glass wall to take the ambient temperature in this process to run the pin-fin heat sink also. The heat sinks are preparing the aluminium material. The experiment procedure to conduct the flat plate we can apply the bottom heat flux in the range of 45w/m^2 and top of the settling chamber to flow the air in the velocity of 10m/s and pin-fin heat sink is also same velocity 10m/s in the flow of air through blower . we can take the velocity readings through the flow of air flowing to the settling chamber to place the vacuum meter. We can supply the voltage through dimmer stat in this dimmer-stat to supply the power through the heater in the capacity of heater to supply. The capacity dimmer-stat is zero to 270v ACin single phase AC circuit and 3 phase AC is 415v AC. We can apply the voltage in this experiment is 45w/m^2 source is applied to perform the experiment. It has some heat loss is also done in the experiment.
The schematic diagram of the experiment is shown in fig

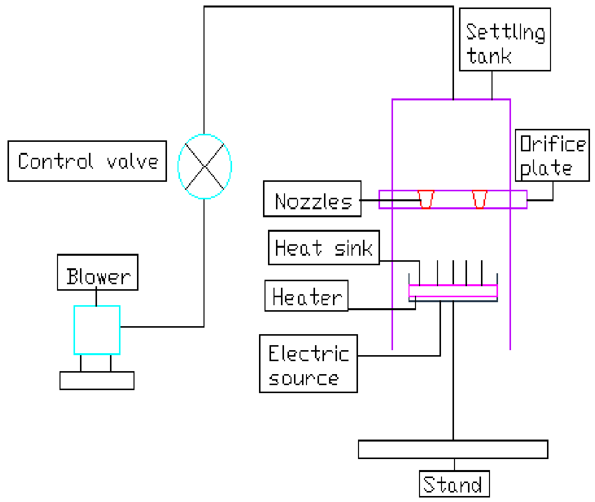

Fig.1 line diagram of air jet impingement

Table 1:Experimental Readings for flat plate Heat Sink

S.No	Velocity(m/sec)	L/D	T(ambient)^{0}C			T(surface)°C			Avg Surface Temp
			T1	T2	T3	T4	T5	T6	
1	10	5	305	306	308	358	333	378	356
2		10	307	309	311	363	339	383	361
3		15	305	311	308	370	345	391	368

Table 2: Experimental Results for flat plate Heat Sink

L/d	Tmax, K	Tmin, K	Tavg, K	Range, K	% Range	Nu	h(w/m^2-K)
5	378	305	341.5	73	21.37	122.316	120.481
10	383	307	345	76	22.02	223.56	111.10
15	391	305	348	86	24.71	311.824	104.166

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Table 3:Experimental Readings for pin fin Heat Sink

s.no	Velocity	L/D	T (ambient) ˚C			T (surface) ˚C			Avg Surface temp
	10		T1	T2	T3	T4	T5	T6	
1		5	306	308	309	349	314	353	339
2		10	308	310	313	351	318	359	342
3		15	311	313	314	358	329	364	349

Table 4: Experimental Results for pin-fin Heat sink

L/d	Tmax, K	Tmin, K	Tavg, K	Range, K	% Range	Nu	h(w/m^2-k)
5	353	306	329.5	47	14.26	177.10	169.48
10	359	308	333.5	51	15.29	308.90	149.25
15	364	311	337.5	53	15.70	409.97	133.331

Table 5: Simulation Results for flat plate Heat sink

L/d	Tmax, K	Tmin, K	Tavg, K	Range, K	% Range	Nu	h(w/m^2-K)
5	373.418	306	339.709	67.418	19.84	128.398	125.915
10	377.112	304	340.556	73.112	21.46	250.921	123.285
15	389.237	304	346.618	85.237	24.59	322.301	107.254

Table 6: Simulation Results for pin-fin Heat sink

L/d	Tmax, K	Tmin, K	Tavg, K	Range, K	% Range	Nu	h(w/m^2-K)
5	329.478	301.635	315.656	27.843	8.82	345.385	319.365
10	331.034	301.713	316.373	29.321	9.26	659.332	305.380
15	342.992	302.388	322.69	40.604	12.58	702.533	220.361

III.NUMERICAL METHODOLOGY

A.Geometry

To considered the computational fluid problem under the consideration of the schematic diagram as shown in fig. The cold air enters the room temperature To and uniform velocity U is entering the nozzle comes out through turbulent jet and impinging the heated flat plate and its finite thickness. The plate top side is coming the air & bottom side is applied constant heat flux and other 4 sides insulated. The size of the impinging plate is 75mm*120mm*5mm respectively. The ambient pressure and temperature are 1*10^5 Pa and 300K respectively. The flow of air is incompressible & steady state with constant fluid properties. To neglected the surface radiation & buoyancy.

B.Meshing

When we complete the design modular in ANSYS 2020R. then we start the meshing option in this option Tetrahedral meshing for fluid domain and Hexahedral meshing for impingement plate. We can give the naming for flow of the air entering and leaving and apply the plate bottom heat flux. Then we apply the fine meshing with 15 inflation layers is adopted.

C.Boundary Conditions

The boundary conditions are applied this problem are shown in fig

1. Velocity inlet: uniform velocity U= 10 m/s & uniform Temperature T = 300K.
2. Heat flux: constant heat flux is applied q = 5000w/m^2.
3. Pressure outlet: the flow variable & temperature are corresponding to Zero.
4. Wall: it is an adiabatic condition & No slip.
5. Interface: it is a fluid – solid interface & heat transfer boundary condition is imposed.

D.Numerical Scheme

The 3-Dimesional steady state governing equations of mass, momentum & energy equation flow based on Reynolds number & energy equation is solid region is solved using the Ansys fluid software. The two equation of turbulence is shear stress & k-w model is acceptability. Pressure and velocity are solved the single algorithms. The three equations are convergence by the continuity, momentum and energy is 1*10^-5, 1*10^-9 & 1*10^-4.

IV.RESULT AND DISCUSSION

A.Design Parameter

The jet Reynolds number flow the air above the 2000 is called as turbulent flow jet and it is below the 2000 is called laminar flow jet as shown in equation [1]

$$Re = \frac{\rho U d}{\mu} \quad [1]$$

B.Performance Parameter

Since, in the view of performance of jet impingement cooling at the local temperature range & average heat transfer performance on the heated surface. At that maximum, minimum & average temperature i.e; Tmax, Tmin&Tavg respectively. From these values distribution of local temperature and its parameter is called as temperature range as shown in equation [2].

$$TR = \frac{Tmax - Tmin}{Tavg} \times 100 \quad [2]$$

At this heat transfer performance of impingement jet over a flat plate and pin-fin heat sinks are uniformly distributed. At this distributed to calculate the Range and % Range in the equation of 3 & 4. To also calculate the localized thermal stress and fatigue failure of the component over a flat plate and pin-fin heat sinks to calculate the Nusselt number in the equation of 5.

Range = Tmax-Tmin [3]

$$\% \text{ Range} = \frac{Range}{Tavg} \times 100 \quad [4]$$

$$Nu = \frac{hl}{k} = \frac{q}{(Tavg - To)} \times \frac{l}{k} \quad [5]$$

C.Effect of jet-to-plate heat sink separation on the impingement cooling performance

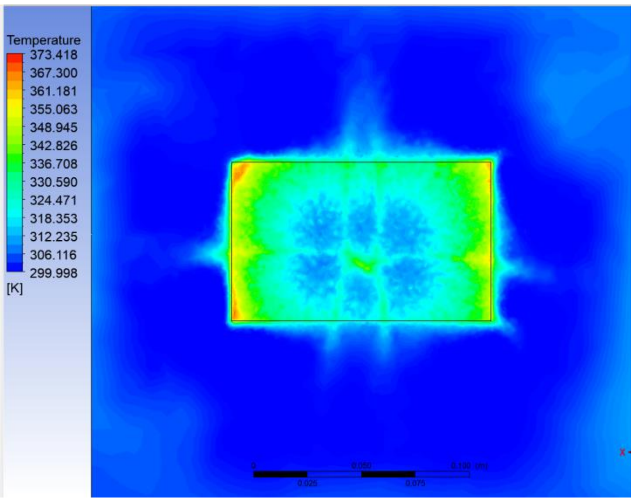

Fig.2 L/d = 5

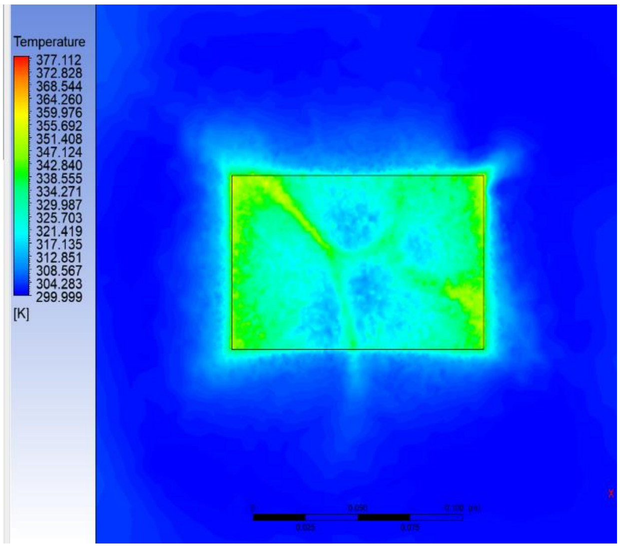

Fig.3 L/d = 10

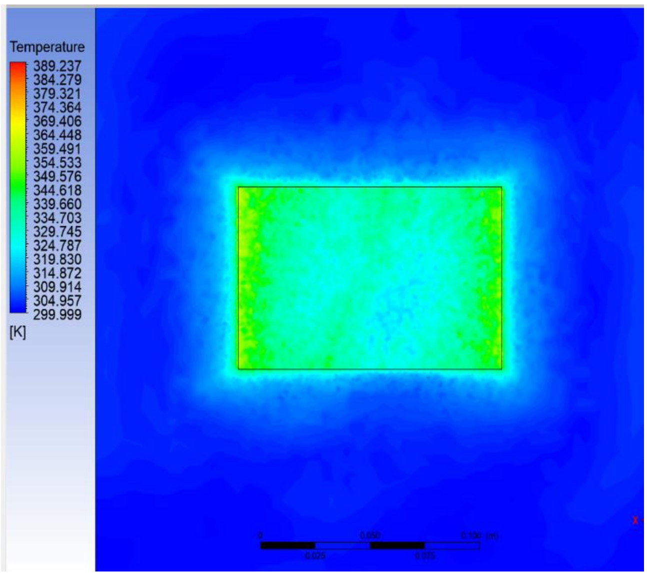

Fig.4 L/d = 15

The effect of impingement plate variation of L/d values on the temperature distribution over a flat plate heated surface of Aluminium at different L/d ratios is 5, 10, 15 respectively. It is the evidence of temperature contours that the range of temperature increase when increase the L/d values. When we increase the L/d values the temperature is also increases. In L/d distance is less the heat transfer is low and the L/d distance is increasing the heat transfer is also increases. When the nozzles hit the target plate in that area have low temperature indicated and remaining area have some more heat is having. We can apply the same temperature in all L/d values. The result of Experimental and simulation of Nusselt number, Range of temperature and heat transfer coefficientat different L/d ratio 5, 10 and 15 in above tables.The results of the different L/d ratios are 5, 10, 15 in maximum temperature indicate the 373.418, 377.112 & 389.237 respectively.

D.Effect of jet-to-pin fin heat sink separation on the impingement cooling performance

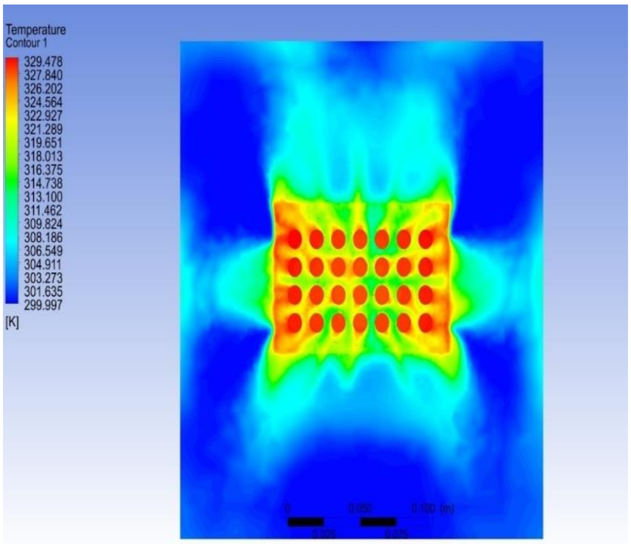

Fig.5 L/d = 5

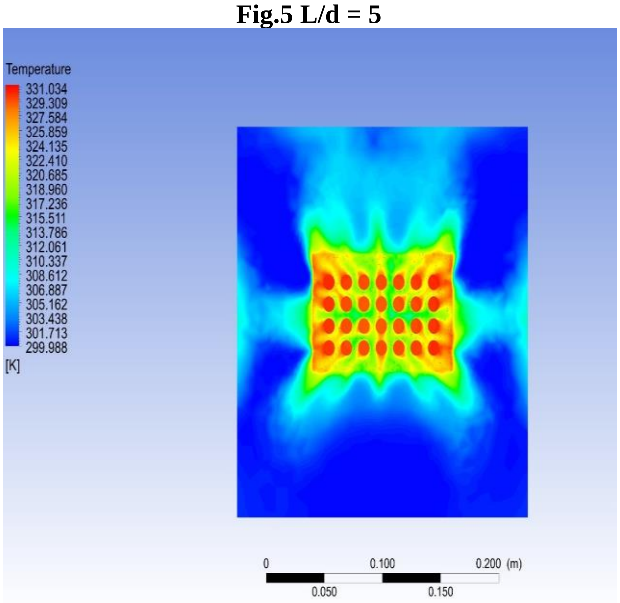

Fig.6 L/d = 10

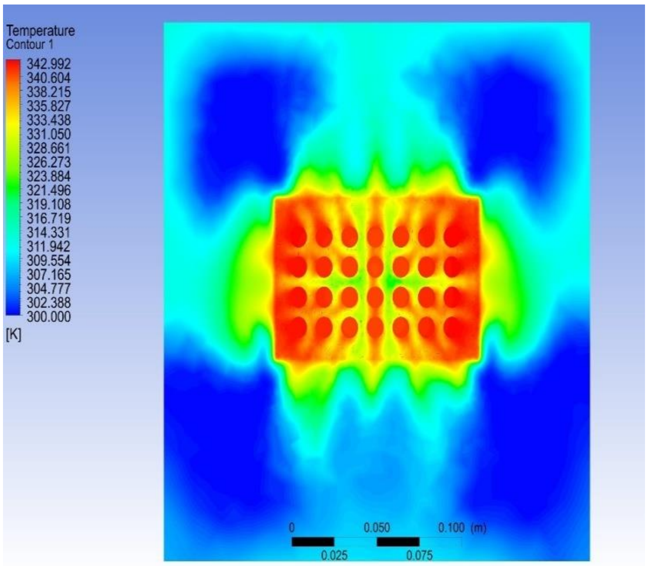

Fig.7 L/d = 15

The effect of impingement over a pin-fin heat sink variation of L/d values on the temperature distribution over a pin-fin heated surface of aluminium at different L/d values is 5, 10, 15 respectively. When we increase the L/d values the temperature is also increases. In L/d distance is less the heat transfer is low and the L/d distance is increasing the heat transfer is also increases. When the nozzles hit the target plate in that area have low temperature indicated and remaining area have some more heat is having. We can apply the same temperature in all L/d values. In this pin -fin heat sink the temperature flow through the bottom of the heat sink to transfer the fin top it takes the sometime it has consider the some length so temperature is low but flat plate it has less length it cover the less time the heat transfer occur the fast and the temperature is more. The results of the different L/d ratios are 5, 10, 15 in maximum temperature indicate the 329.478, 331.034 & 342.992 respectively. To compare the flat plate and pin-fin heat sink the best heat sink is flat plate to transfer the heat.

E. The graphs between different L/d and Range of temperature, Nusselt number and heat transfer coefficient by flat plate heat sink.

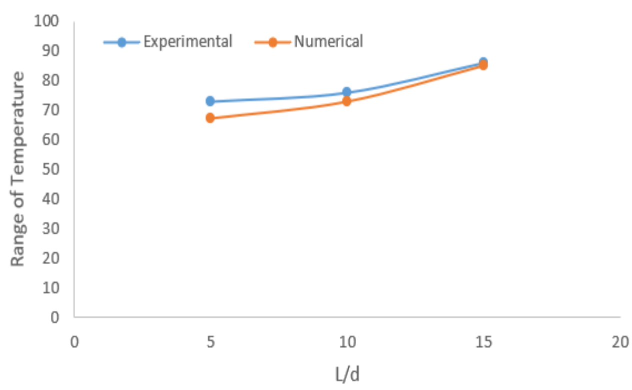

Fig.8 variation of Range of temperature vs L/d ratio on flat plate

We can observe in this figure 8 to vary the different L/d ratios 5, 10, 15 in the Experimental and Numerical values to compare. In this graph the higher values are indicated in the distance of L/d = 15. The Experimental value is 86 & numerical value is 85.237. So, we can conclude the Range of temperature is best for Experimental to compare the numerical.

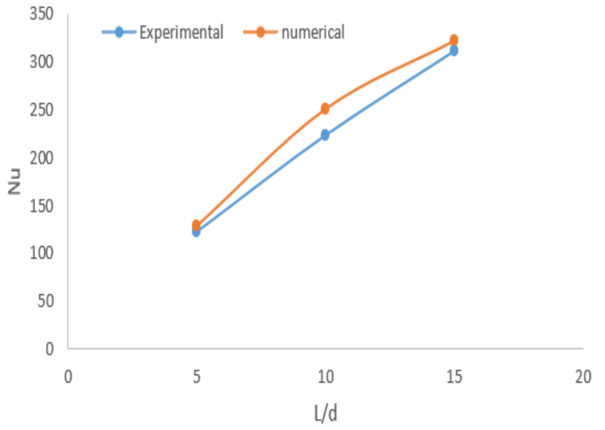

Fig.9 variation of Nusselt number vs L/d ratio on flat plate

The flow resistance is the main importance of the heat transfer performance due to minimum pumping the pressure drop for various flow rate of friction factor.we can explain the Nusselt number is higher for numerical value to compare the Experimental value. The numerical value is 322.301 and experimental value is 311.824. because some leakage for experimental work so the experimental is less than the numerical.

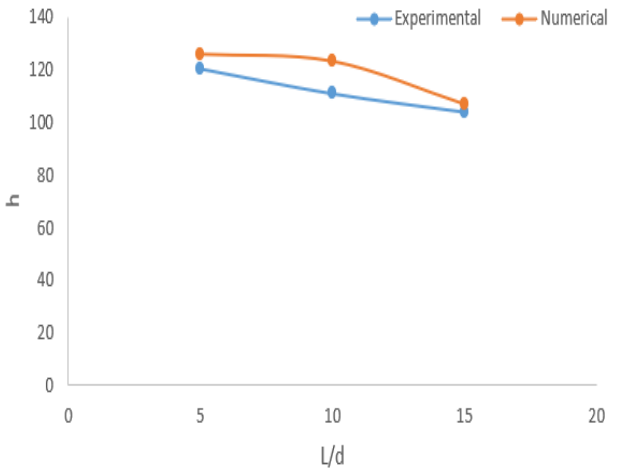

Fig.10 variation of heat transfer coefficient vs L/d ratio on flat plate

For this heat transfer coefficient, the performance of Reynolds number for different L/d ratios to flow the incompressible air through the jet to hit the target plate at different L/d ratios in this L/d = 5 is give the best result for numerical. The numerical value is 125.915 to compare the experimental value is 120.481 respectively.

F. The graphs between different L/d and Range of temperature, Nusselt number and heat transfer coefficient by flat plate heat sink.

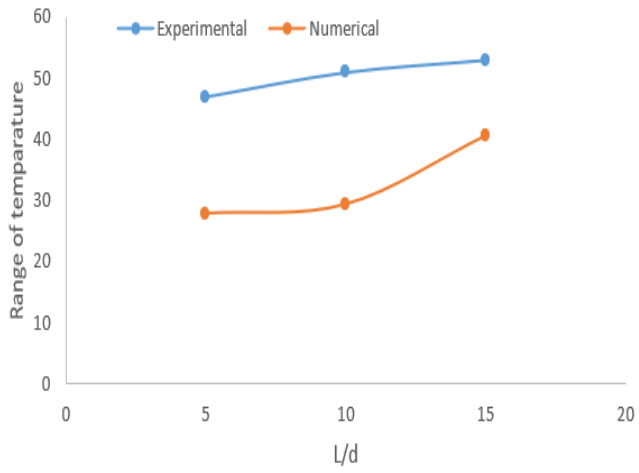

Fig.11 variation of Range of temperature vs L/d ratio on pin fin

We can observe in this figure 11 to vary the different L/d ratios 5, 10, 15 in the Experimental and Numerical values to compare. In this graph the higher values are indicated in the distance of L/d = 15. The Experimental value is 53& numerical value is 40.604. So, we can conclude the Range of temperature is best for Experimental to compare the numerical.

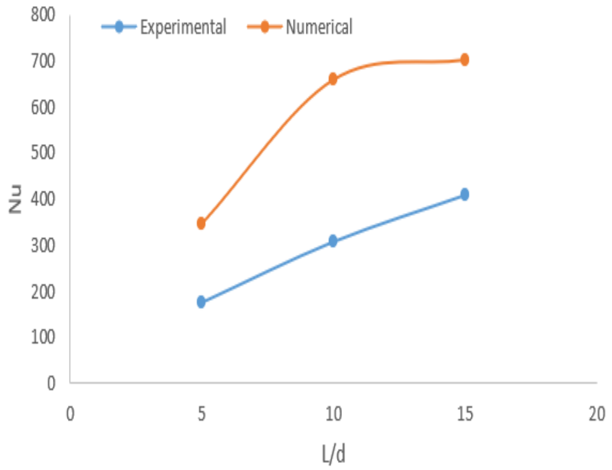

Fig.12 variation of Nusselt number vs L/d ratio on pin fin

The flow resistance is the main importance of the heat transfer performance due to minimum pumping the pressure drop for various flow rate of friction factor. we can explain the Nusselt number is higher for numerical value to compare the Experimental value. The numerical value is 702.533 and experimental value is 409.97. because some leakage for experimental work so the experimental is less than the numerical.

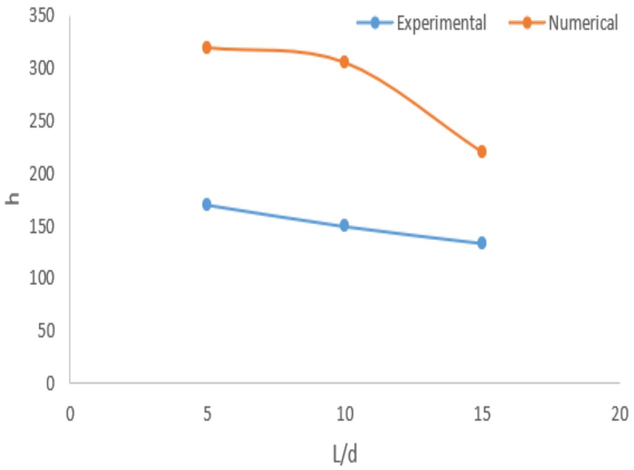

Fig.13 variation of heat transfer coefficient vs L/d ratio on pin fin

For this heat transfer coefficient, the performance of Reynolds number for different L/d ratios to flow the incompressible air through the jet to hit the target plate at different L/d ratios in this L/d = 5 is give the best result for numerical. The numerical value is 319.365 to compare the experimental value is 169.48 respectively.

G. The numerical graphs between the different L/d ratios and Range of temperature, Nusselt number, Heat transfer coefficient by compare the flat plate & pin-fin heat sink.

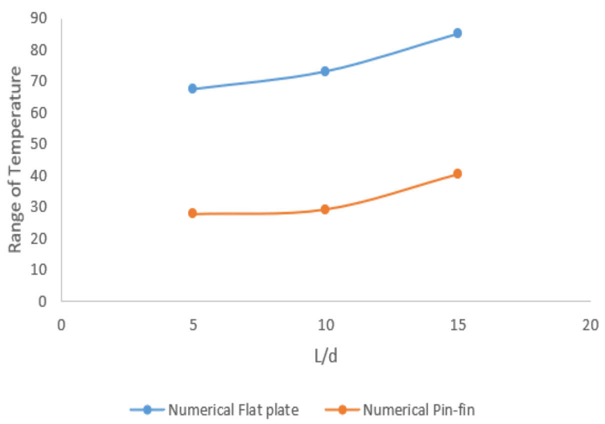

Fig.14 variation of Range of temperature vs L/d ratio

In this numerical to vary the Flat plate and pin fin heat sink by different L/d ratio to Range of temperature. In the flat plate easily, the heat distributed but pin fin the heat passes the plate to fin tip take some time but pin fin heat sink gives the best result in this graph the Range of temperature give the best result for flat plate to compare the pin fin heat sink. At the L/d =15 gives the maximum value for flat plate is 85.237 and pin fin is 40.604 respectively.

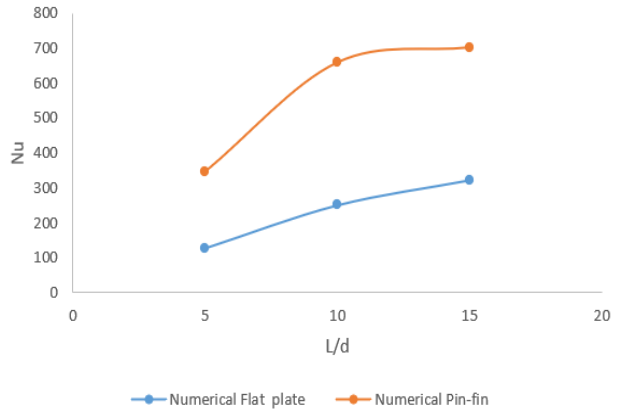

Fig.15 variation of Nusselt number vs L/d ratio

In this graph pin fin heat sink give the best to compare the flat plate because the flow of incompressible air through nozzle in the target plate & pin fin heat sink. At the L/d= 15 is the maximum value to compare the other ratios. In this graph the Nusselt number is higher for pin fin heat sink to compare the flat plate heat sink because the flow of air due to pressure drop of friction factor. In this the Nusselt number for pin fin is 702.533 and flat plate is 322.301 respectively.

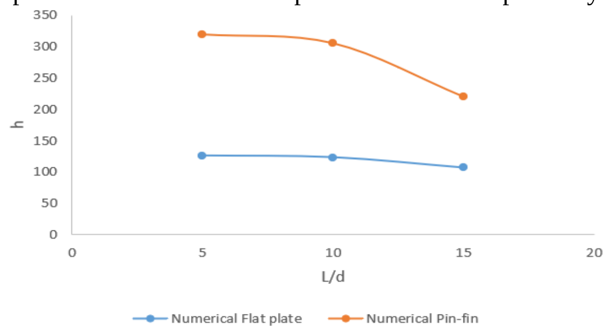

Fig.16 Variation of heat transfer coefficient vs L/d ratio

For this heat transfer coefficient, the performance of flat plate and pin fin heat sink. We can observe the her the L/d = 5 is give best result for pin fin to compare the flat plate heat sink. At this flow of air & Reynolds number through the jet to hit the target plate in this process the more het transfer rate in the pin fin heat sink to compare the flat plate. The result of pin fin heat sink is 319.365 and flat plate is 125.915 respectively. In this graph the variation of different L/d ratio with Range of temperature, Nusselt number and heat transfer coefficient.

V.CONCLUSION

AnExperimental and numerical investigated on the flow of fluid and heat transfer study on multi air jet impingement over a flat plate and pin fin heat sink. To vary the different L/d ratios in flat plate and pin fink heat sink with a constant heat flux over a heated surface. To conclude the study are as follows. The nozzle to the target flat plate and pin fin heat sink spacing by L/d ratio significant of heat transfer on an observed from the graph. Range of temperature is 0.89% and 0.23% is higher at experimental to compare the numerical over a flat plate and pin fin heat sink.

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Nusselt number is 3.35% and 0.71% is higher at numerical to compare the experimental over a flat plate and pin fin heat sink. Heat transfer coefficient is 4.51% and 0.88% is higher at numerical to compare the experimental over a flat plate and pin fin heat sink.
Finally, Pin fin heat sink is giving the best heat transfer performance to compare the flat plate heat sink.

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