EXPERIMENTAL ANALYSIS AND VALIDATION OF STAGERRED DROPPED AND CIRCULAR PIN FINS IN 1-DIRECTIONAL AND 2-DIRECTIONAL FORCED CONVECTION

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Abstract : In this experimental analysis of heat transfer variation and its enhancement of the dropped and circular shapes, staggered pin fin heat sink under constant heat flux condition are presented. Conducted experimental comparison between aluminum, stainless steel and Iron materials with circular and dropped shaped pin fins A pin fin is fabricated from heat sink aluminum (Aluminum-Magnesium-Silicon Alloy), Stainless steel and ferrous material with diameter 10 mm. Base plate is also same material and fin are mounted on base plate with the help of thread. Various trials conducted on each material for choosing best materials for more heat transfer. Also, to choose which is best shape of pin fins i.e. circular or dropped for enhancing maximum heat transfer. Also, trial conducted for to find out from forced convection from 2-directional or 1-directional which is more capable to transferring heat transfer and therefore to choose best flow of heat transfer model. The total comparison between circular and dropped shaped pin fins performed in this experimental analysis.

***Index Terms* - Aluminum, Circular, CFD, Dropped, Iron Stainless-Steel.**

I.INTRODUCTION

Extended surfaces are used in heat exchanging devices to increasing the heat transfer between the surface and the surroundings fluid, different types of heat exchangers fins are employed with different shapes such as cylindrical, rectangular, annular, drop shapes tapered, or pin fins, these fins are attached from the rectangular or cylindrical base. One of the most commonly used extended surface heat exchangers is the pin fin, a fin pin is a cylindrical or other shaped element is protruded perpendicular to the wall, and the heat transfer fluid is flowing in cross flow manner, different types of parameters that characterize the pin fins they are shape, diameter, height, positions, in which the fins are placed in flow direction (staggered or inline).
Fins are playing main role to enhance the heat transfer performance; the fins are modified by shape according to our convenience to get maximum heat transfer and fins are used inside and outside the heat exchanger to improve the efficiency.

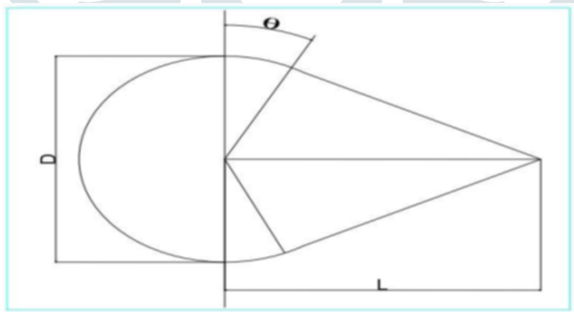


figure 1.1 designed dropped shape[13]

By changing the pin shape from round to drop, there is an increase in the wetted surface area to exchange the heat with the flow, which increases the total heat transfer rate. By having the tail in the drop case, the separation is delayed which leads to decreases in the friction drag and power. By overlapping also creates a nozzle effect due to the angular shape of the pintail causing the flow to accelerate and collide with the subsequent row of pins. The interaction of the pins and the accelerating flow together with the coalescence lead to more turbulence, which help to increase the heat transfer. A through experimental characterization of different possible shapes is a very expensive and time-consuming task, due to the enormous cost of experimental parts and tools.[13]

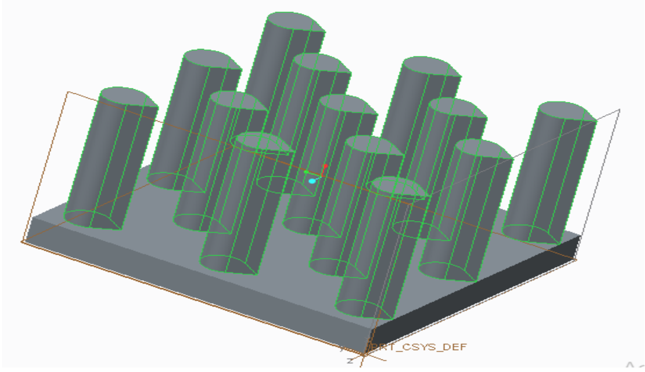


Figure 1.1 dropped shaped fins by using PTC Creo 3.0

2. EXPERIMENTAL SET-UP

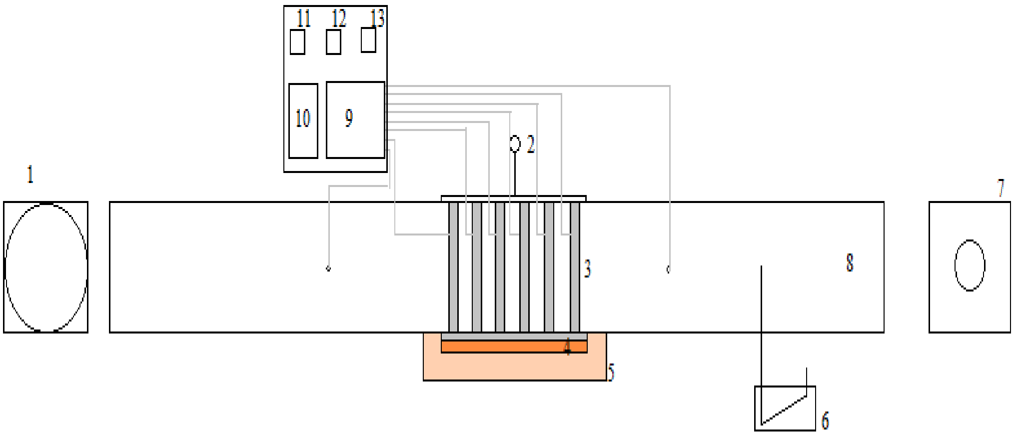


Figure 2.1 Experimental Set-up

1. Blower
2. Small capacity blower
3. Pin fin array
4. Heater
5. Insulating box
6. Manometer
7. Orifice meter
8. Duct
9. Dimmer stat
10. Blower controller
11. Temperature indicator
12. Voltmeter
13. Ammeter

The entrance length of duct is 595 mm, test section 250 mm and downstream exit is 595 mm. The internal height and width of channel is 110mm and 160mm respectively. The front side of duct is constructed with acrylic material sheet for visibility of temperature sensor and all other side of duct is constructed with MS material sheet. The joints of MS sheet duct are sealed with rubber gasket.

There are two blowers named as primary and secondary blower is used with controllable speed. Primary blower is used to blow the air in ‘x’ direction and it is act as main blower for duct assembly. The secondary blower is fitted perpendicular direction to the primary blower exactly on test plate section for blowing air in ‘y’ direction on test plate.

The staggered pin fin array is installed in test section. All fins are fitted on base plate by thread fitting and gap between threads is sealed by thermal grease. Three K-type thermocouple (Pencil shape) are installed on entrance length and exit length of duct to measure the average inlet and outlet air temperature respectively. Also, Six K-type thermocouple are installed on test plate to measure the temperature at various locations. A 1200-Watt plate type heater is mounted below the base plate. The gap between plate and heater is sealed by thermal grease. The inlet and outlet temperature are measured by six K-type thermocouples. [15]

3. Problem identification

1. The heat transfer rate is less in 1-directional heat flow model as well as in natural convection.
2. The surface area of circular pin fin is less comparing to dropped shape of pin fin.
3. Heat Transfer rate is not uniform in 1-directional flow of fluid.
4. Due to circular shape of pin fins more materials are required which result in more cost.

4. Literature reviews

[1] Manoj Dange et al, In the present study, experimental analysis of heat transfer variation and its enhancement of the cylindrical, staggered pin fin heat sink under constant heat flux condition are presented. A pin fin is fabricated from heat sink cylindrical aluminium (Aluminium-Magnesium-Silicon Alloy) material with diameter 10 mm. Base plate is also same material and fin are mounted on base plate with the help of thread. Three trials were conducted for the calculating suitable height of pin fin. Again, two trials are conducted on model for calculating the suitable value of Sx and Sy. Last trial is conducted on design pin fin array at different mass flow rate of air for obtaining objective. The result shown that 2-directional air impingement gives higher heat transfer rate as compare to1D air flow impingement. 2-directional air impingement gives equal heat rate on pin fin heat sink array as in 1D air flow impingement the heat transfer is not equal.

[2] Manikandan C et al, in this paper simulation of temperature and pressure drop in a perforated drop-shaped pin fin heat sink is considered and heat transfer is increased by changing the circular pin fin arrangement into a perforated Drop-shaped pin fin in the staggered arrangement also constant heat flux is given for a better solution. The process has been tested by using ANSYS-15.0 (CFD), the perforated drop-shape with same cross-sectional area is delaying the air passes through them, thereby increasing the heat transfer. The transient condition is used here to obtain a better result. Finally, perforated Drop shaped pin fins results are compared with Circular and Rectangular Shapes to justify the Drop shaped pin fin will give the better heat transfer.

[3] R Muthukumarn et al, an experimental investigation was performed to study the heat transfer and pressure loss characteristics in a horizontal rectangular wind tunnel having attachment of cylindrical, grooved cylindrical and perforated pin fins over a horizontal based pin fin assembly. The experiments covered the rates from 2000-25,000 and the clearance ratio (C/H) = 0.0. In-line Pin fin arrangements were studied for one constant span wise pitch (Sx /d=1.2) and three different stream wise pitch (Sy /d = 1.2, 2.4 and 3.6) distance. Nusselt number and pressure drop were considered as performance parameters. The performance of all the pin fins compared to each other. The maximum enhancement in Nusselt number corresponds to the grooved cylindrical fin and the results were matching with previous reports.

[4] Lei Chai et al, three drop-shaped micro pin-fin heat sinks with different tail angles were designed based on the optimization of traditional round micro pin-fin heat sink. The flow resistance and heat transfer characteristics of the heat sinks were experimentally investigated using demonized water as working fluid. The results show that the micro pin-fin with tail angle of 60° has the lowest flow resistance among the heat sinks. The streamlined structure of drop-shaped micro pin-fins improves the distribution of flow and delays the conversion from laminar to turbulent flow. The smaller the angle, the more obvious the effect. The optimal angle of drop-shaped micro pin-fin is different under different flow rates. The heat sink with tail angle of 60° has the strongest heat transfer coefficient at the corresponding Reynolds number in this experiment (Reynolds number is equal to 200-1 000). When the tail angle decreases to 30°, the heat transfer is also enhanced in the tail section of micro pin-fin. However, the flow is affected by the micro pin-fin behind, so the heat resistance is higher than other heat sinks under the same pump power.

[5] M.M. Sahu et al**,** in this study experimental based model for pin fin heat sinks in forced convection has been developed. Key empirical data and correlations for thermal resistance and heat transfer in inline arrays of circular pin fin arrays were validated through CFD simulations. With same design parameters, such as height diameter and spacing of pin-fin are validate by CFD analysis. The thermal resistance and heat transfer are considered as the multiple thermal performance characteristics. Pin fin heat sink having 6×8 array of circular pin. Total number of pin fin is restricted to be 48 and velocity of air flow is set to 2.5 m/s. The heat sinks were constructed of aluminium (thermal conductivity of 209 W/mK) and consisted of an array of staggered pin fins The base of Pin fin heat sink is subjected to a heat load of 40 W. Heat sinks had constant fin height of 60mm,pin diameter of 6 mm and the longitudinal pitch was 10 mm, varied transverse pitch was 8,12 mm. Heat flux was applied to the wall using heaters.

5. Material selection

The selected materials for experimentation have thermo physical properties which are given in tabular form

Table No.5.1 thermo physical properties of materials

Sr No	Properties	Aluminium	Stainless-steel	Iron
1	Thermal conductivity (W/mk)	237	15.1	80.2
2	Specific heat, C_p (J/KgK)	903	480	447
3	Density, ρ (Kg/m^3)	2702	8055	7870
4	Melting points (K)	933	1670	1810

6. Design and Analysis

The design modeled pin fins for experimentation are as shown in figure.4.1 In this experimentation three materials are chosen i.e. Aluminum, stainless-steel and Iron with circular and dropped shaped geometries respectively

		
Aluminium circular	Aluminium Dropped	Stainless-steel circular
		
Stainless-Steel Dropped	Iron circular	Iron dropped shaped

Figure 4.1 different geometries of fins

7. Data Reductions

7.1 Heat transfer rate (Q) calculation

$Q=h^{*}A_s^{*}(\Delta T)$ (1)

Where,

Q - Heat transfer rate, KJ/s or watt

h_s – Convective heat transfer coefficient, $W/m^2\,{}^0c$

A - Area m^2

ΔT - Temperature difference, K

C_p -Specific heat, KJ/Kg * K

m - Mass flow rate, Kg/s

7.2 Discharge of air through orifice (Q_a) Calculation

$$Q_a= C_d*\frac{\pi}{4}*d^2*\sqrt{2*g*\frac{H}{1000}*\frac{\rho_w}{\rho_a}} \quad (2)$$

Where,

C_d- Coefficient of discharge = 0.64

d - Diameter of orifice = 60mm = 0.06 m

ρ_w- Density of manometric liquid = 810 Kg/m^3

ρ_a- Density of manometric air = 1.225 Kg/m^3

H_m- Manometric reading=5mm

$$Q_a= 0.64*\frac{\pi}{4}*0.06^2*\sqrt{2*9.81*\frac{5}{1000}*\frac{810}{1.225}}$$

= 0.0145 Kg/m^3

7.3 Mass flow rate (m) calculation

$m=\frac{Q_a}{V_a}$ (3)

V_a – Volume flow rate, Kg/m^3

From psychometric chart, At DBT=37^{0}C and WBT=29^{0}C the values of volume flow rate V_a=0.923 m^3/s

$m=\frac{0.0145}{0.923}= 0.0157$ kg/s

7.4 Coefficient of convective heat transfer (h) calculation

$h= m*C_p\{(T_{out}-T_{in})/A_s*[T_b-(T_{out}-T_{in})/2]\}$ (4)

Where,

m - Mass flow rate =0.0157 Kg/s

C_p - Specific heat=1.005 KJ/Kg0K

T_{in} = Inlet temperature
T_{out} = Outlet temperature
T_b= Average temperature of base plate ^{0}C

7.5 Surface Area (A_s) Calculation

A_s= (b*L) + (π*r^2*h) * N (For circular shape pin fin) (5)
= (0.15*0.25) + (π*0.01*0.07) * 20
= 0.0376 m^2

A_s=(b*L) + ((π*d*H/2) +(L*b*H/2)) *N (For drop shaped pin fin)
= (015*0.25) + ((π*0.1*0.07/2) +(0.010*0.010*0.07/2))*20
= 0.0592 m^2

Where,
b= Width of base plate=150mm=0.15m
d= diameter of pin fin = 10mm=0.1m
L= Length of base plate = 250mm=0.25m
H=Height of pin fin =70mm=0.07m
N= Number of pin fins = 20
From Equation number (4)
h=85.641 W/m^{2}k
From Equation number (1)
Q=85.41*0.0376*(29.8-29.3) =1.61W

7.6 Nusselt Number Calculation (Nu)

Nu= h.L/K (6)
= 85.41*0.1875/0.025
= 642.30

Where,
h= Convective heat transfer coefficient (W/m^{20}c)
L= Characteristic length (m)
= For Rectangular Duct L=4(a*b)/2(a+b)=0.1875m
K= Thermal conductivity (W/m^{0}c)=0.025(W/m^{0}c)

8. RESULT AND DISCUSSION

8.1 Result Table

8.1.1 for Aluminium

Sr No	Material	Aluminium							
	Type of flow	1D				2D			
	Shape of fins	Circular		Dropped		Circular		Dropped	
	Dimmer stat	50W	100W	50W	100W	50W	100W	50W	100W
1	Actuacl heat transfer rate, Q	1.61	2.25	4.86	5.89	2.18	3.34	10.43	11.36
2	Convective heat transfer coefficient, h	85.641	119.897	97.908	126.918	96.840	148.108	117.453	159.917
3	Nusselt Number, Nu	642.30	899.227	734.31	951.885	726.3	1110.81	880.897	1199.37

8.1.2 for Stainless Steel

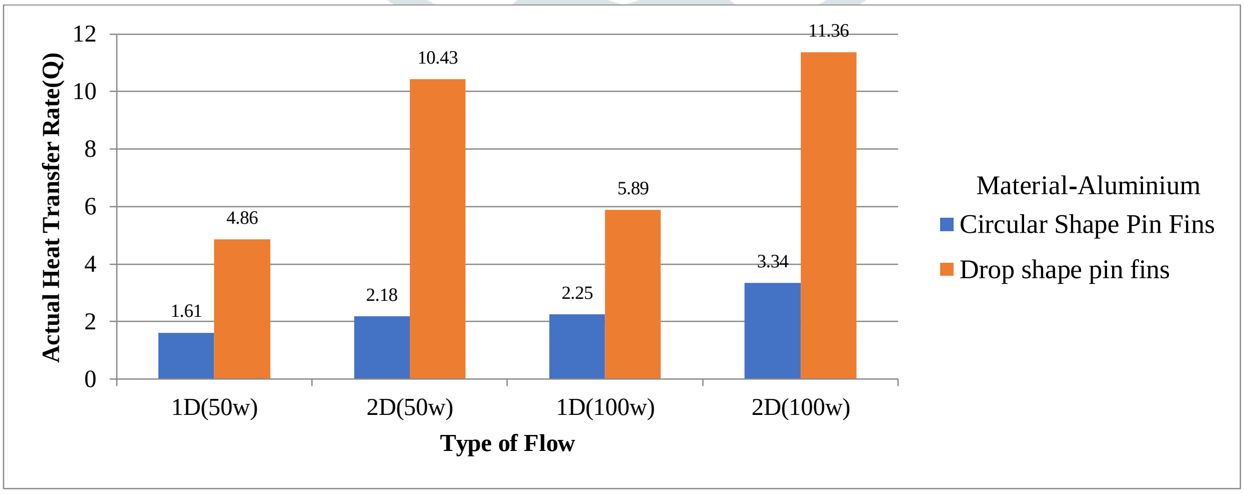
Sr No	Material	Stainless Steel							
	Type of flow	1D				2D			
	Shape of fins	Circular		Dropped		Circular		Dropped	
	Dimmer stat	50W	100W	50W	100W	50W	100W	50W	100W
1	Actual heat transfer rate, Q	1.274	1.485	1.692	1.901	1.579	2.146	2.103	2.277
2	Convective heat transfer coefficient, h	36.490	64.560	39.004	76.151	51.384	96.199	59.228	104.910
3	Nusselt Number, Nu	273.67	484.2	292.53	571.13	385.38	721.49	444.21	786.825

8.1.3 for Iron

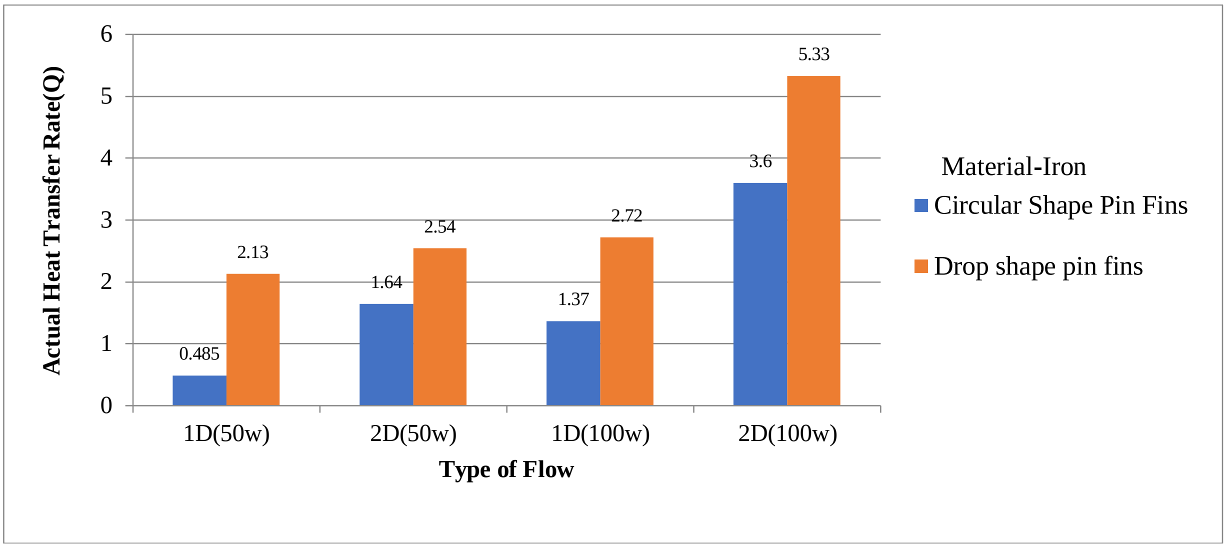
Sr No	Material	Iron							
	Type of flow	1D				2D			
	Shape of fins	Circular		Dropped		Circular		Dropped	
	Dimmer stat	50W	100W	50W	100W	50W	100W	50W	100W
1	Actual heat transfer rate, Q	0.485	1.37	2.132	2.720	1.48	3.60	2.54	5.33
2	Convective heat transfer coefficient, h	64.560	81.220	72.034	91.906	79.177	119.897	85.977	128.669
3	Nusselt Number, Nu	484.2	609.15	540.25	689.29	593.82	899.22	644.82	965.01

8.2 Graphs for Actual Heat Transfer Rate

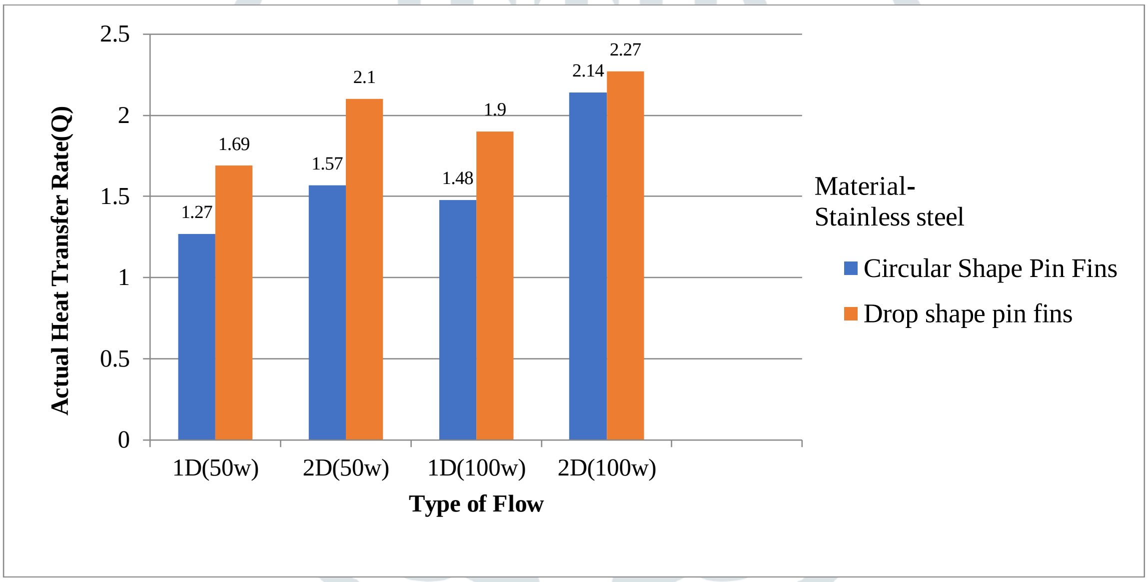
8.2.1 for Aluminium



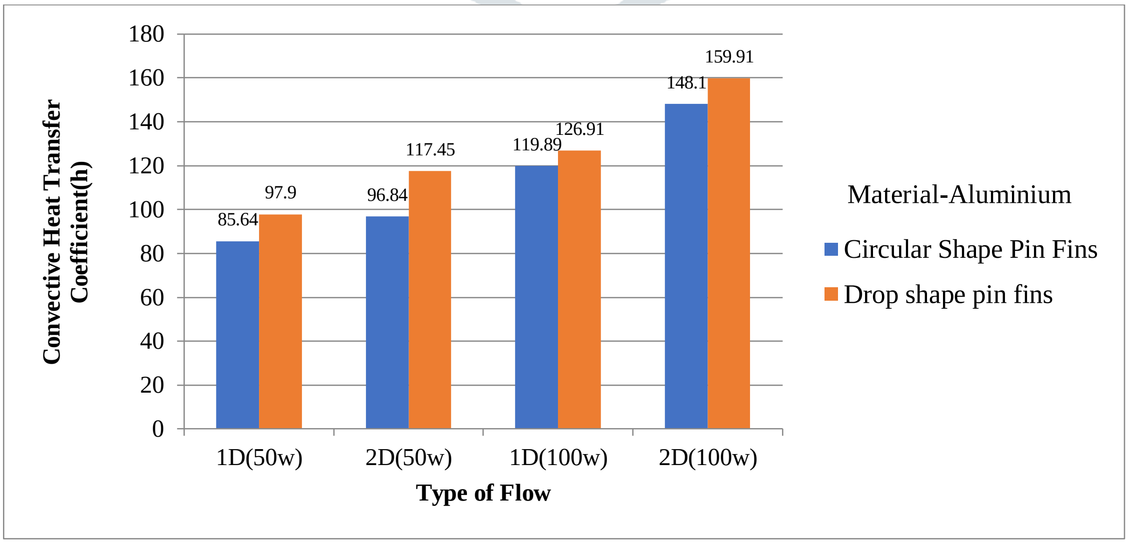
8.2.2 for Iron



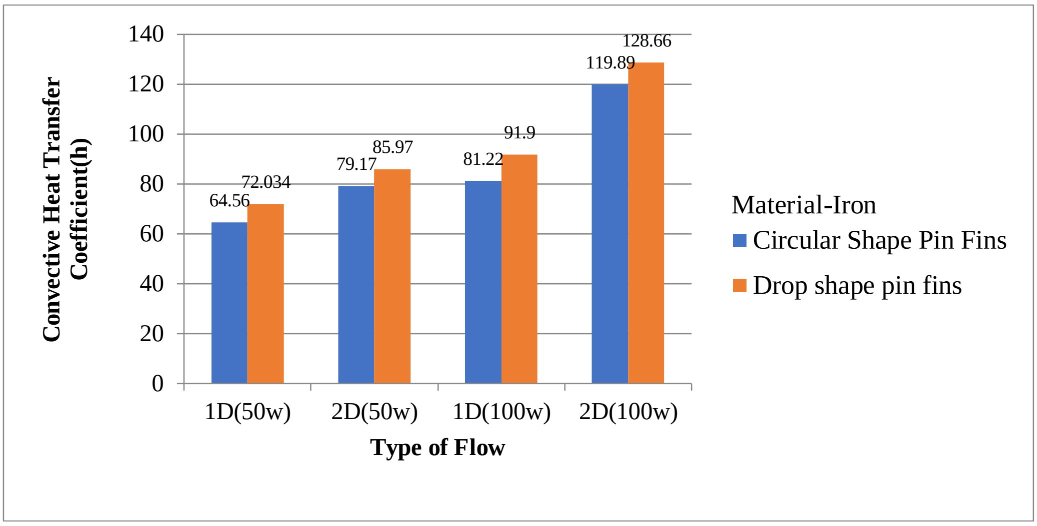
8.2.3 For Stainless-Steel



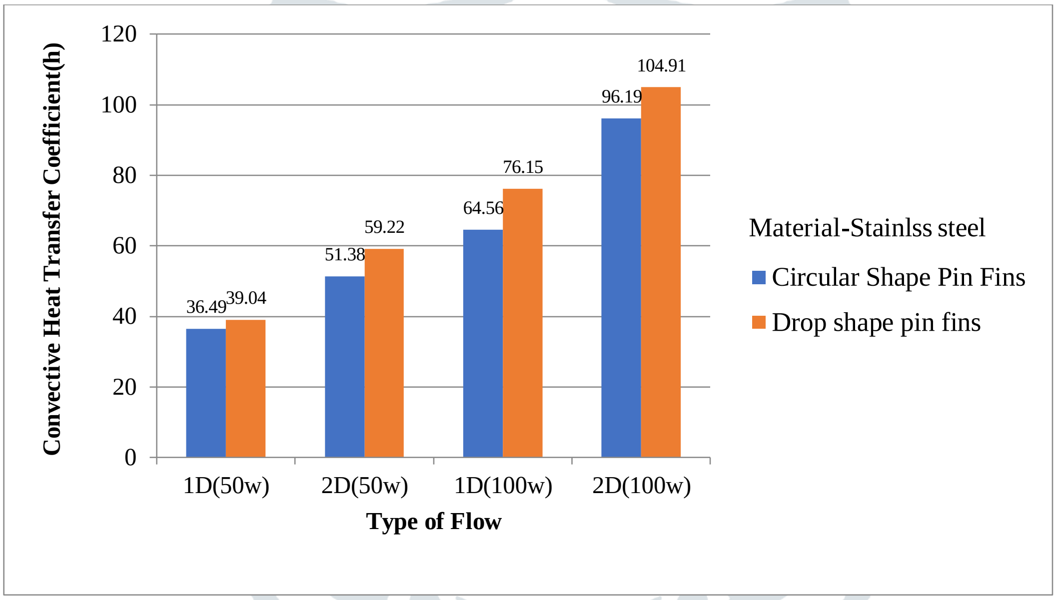
8.3 Graphs for Convective Heat Transfer Coefficient (h)
8.3.1 for Aluminium



8.3.2 for Iron

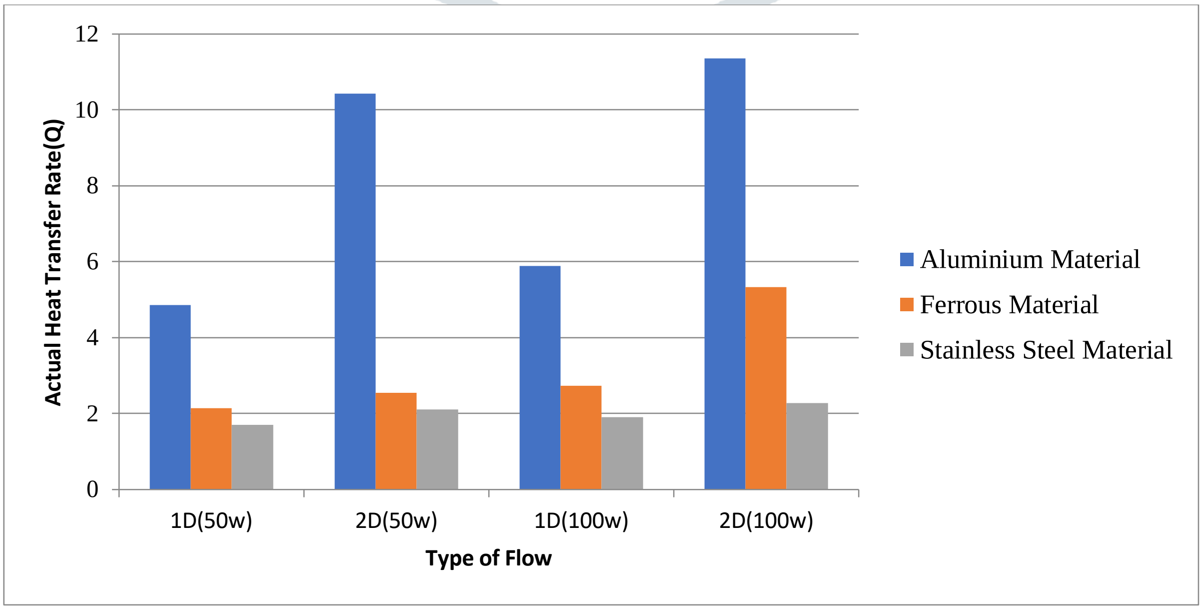


8.3.3 For Stainless-Steel

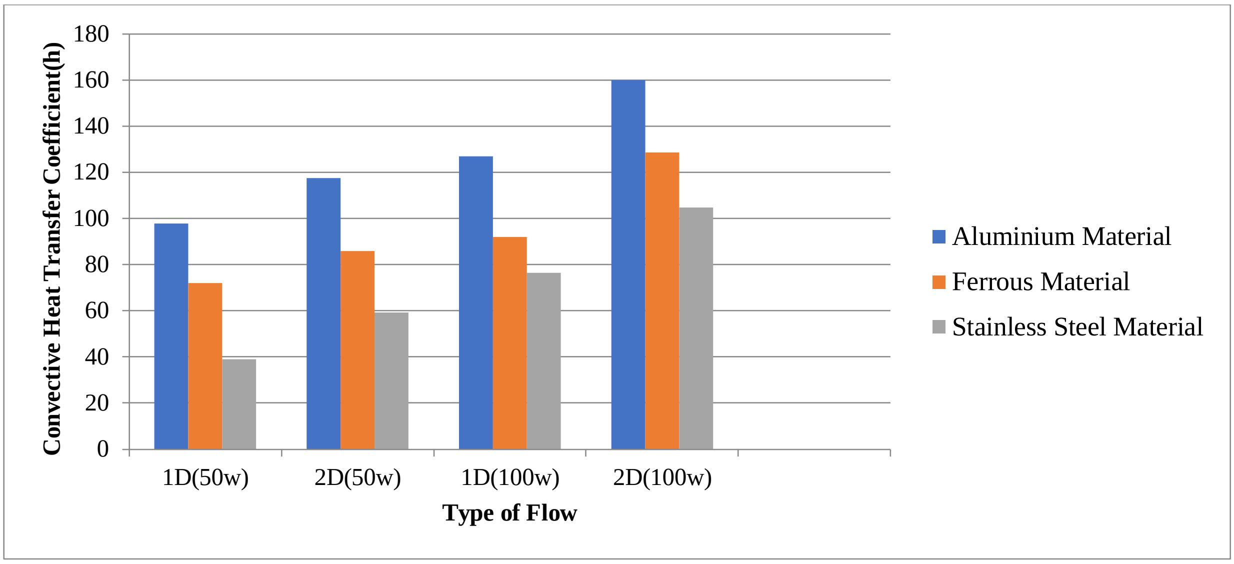


8.4 Graphs for Dropped Shape pin fin

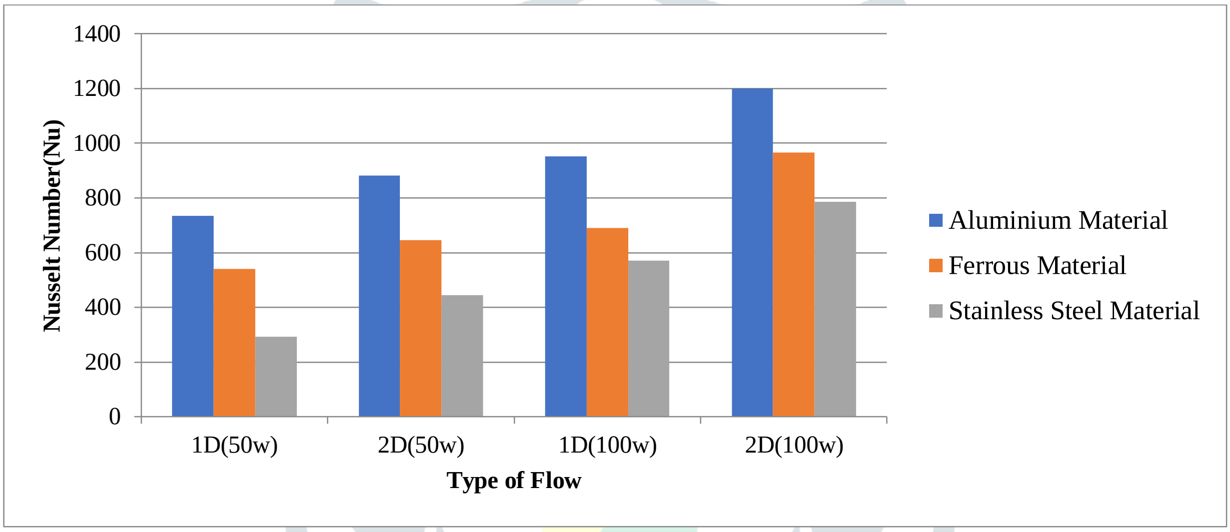
6.4.1 Actual Heat Transfer Rate Vs Type of Flow for various materials



8.4.2 Convective Heat Transfer Coefficient (h) Vs Type of Flow for various materials



8.4.3 Nusselt Number (Nu) Vs Type of Flow for various materials



9. CFD VALIDATION

9.1 Temperature contour for iron material in circular and dropped shape

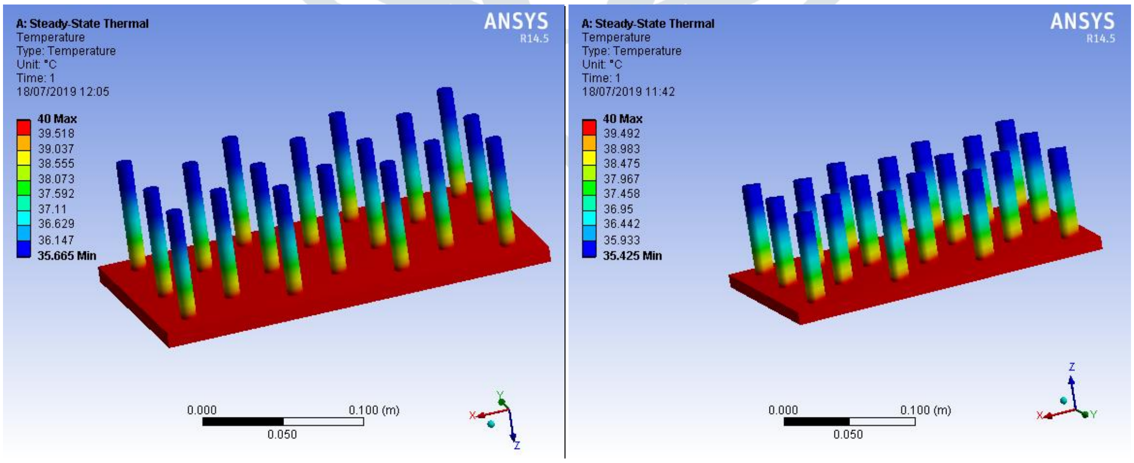


Figure No.9.1 Temperature contour (a) Circular shaped fins (b) Dropped shaped fins

The above figure are the static temperature contours of the Circular, and Drop-shaped pin fin of iron material, the figure itself tells that the heat transfer in Drop-shaped pin fin array is somewhat higher than the circular shaped pin fin arrays. The heat transfer is higher in the fin base and it is decreased to the fin tip. The temperature induced is increases in the pin fin array will causes the serious damages into the pin fin array it must be dissipated as early as possible to avoid the melting and other problems the above temperature contour will clearly tell that the temperature induced in the Drop-shaped pin fin array is somewhat lesser than the other two shaped pin fin array we are considered.

The Drop-shaped pin fin will increases the contact between the air flow medium and pin fin arrays this will increase the heat transfer when compared to the Circular fins. From figure it is shown that the maximum static temperature is 40^0C and minimum temperature is 35.665^0C for circular fins while in case of drop shaped it is 40^0C and $35.425y^0$C respectively.

9.2 Validation of Data

In this division outcomes from experiment and numerically are presented and compared. Results are obtained for temperature of 40^0C and for constant mass flow rates of air. Thermocouples were used to measure temperature of fins at inlet, outlet and base plate. Computation results are obtained using ANSYS – CFD Post. The temperature contours are shown in above figures clearly indicated that dropped shape fins of any material gives more heat transfer as compared to circular shape.

The variation in the experimental values may be caused due to many factors. Some of them are fabrication errors, leakage of air from duct, uneven base heating etc. The experimental results with comparison of CFD results are shown in the following tables

The below table is 2- Directional flow and for 22^0C atmospheric air temperature, base plate temperature at 40^0C.

Sr. No	Dimmer stat reading, W	Aluminium				Iron				Stainless Steel			
		Circular		Dropped		Circular		Dropped		Circular		Dropped	
		Exp. T_{out}	CFD T_{out}	Exp. T_{out}	CFD T_{out}	Exp. T_{out}	CFD T_{out}	Exp. T_{out}	CFD T_{out}	Exp. T_{out}	CFD T_{out}	Exp. T_{out}	CFD T_{out}
1	50	32.12	37.33	32.71	37.52	29.86	33.52	27.2	33.21	25.23	26.67	24.20	26.42
2	100	32.90	38.33	35.6	38.22	31.21	35.66	30.11	35.43	26.11	27.48	25.88	27.14

0. CONCLUSION

After conducting trial on pin fin array at different constant heat flux following points will investigated

1) During 1-directional air flow impingement temperature of pin fin goes on increasing on downstream side. The heat dissipation on downstream side goes on reducing row by row due to pin fin surrounding air temperature goes on increasing due to this temperature variation the heat transfer rate of first few rows is higher as compare to downstream rows.
2) In 2-directional air flow impingement the temperature of all pin fin tip is nearly same due to turbulence created by two perpendicular air streams. The heat transfer rate is nearly same on pin fin array. Also, heat transfer rate in 2-directional air flow impingement is more as compare to 1-directional air flow impingement.
3) The Heat transfer rate is increased depend on shape of surface area provided.
4) The Heat transfer rate and effectiveness of dropped shaped pin fins in more than circular pin fin in all types of material.
5) The Heat transfer rate is more in 2-directional impairment as compared to 1-directional flow.
6) Due to drop shaped of three materials more turbulence created hence more heat transfer. Convective heat transfer coefficient and Nusselt number occurs more as compared to circular shape.
7) In each material Nusselt number is more than 100 hence flow type is turbulence.

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