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Performance Analysis of Heat Sink of Different Drafted Pins with Artificial Roughened Rectangular Shape Fin Wall at Different Velocities for Constant Heat Input

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ABSTRACT:

Heat sink is a device is used to remove the amount of heat which is generated from processor of CPU in a computer system. It is installed above the CPU to extract maximum amount of heat generated on it. The CAD model of heat sink has been developed. There are four types of configurations of pin fin heat sink are used with different profile namely type-1 pin dia. 1,1,1 mm, type-2 pin dia. 1,1,2 mm, type-3 pin dia. 1,2,2 mm, type-4 pin dia. 2,2,2 mm. An optimized model of heat sink with rectangular shaped roughness on fin wall is developed. The pins are drafted by an angle of 20. At constant heat input of 10W, the simulations have been performed, that is the heat flux of fin base of heat sink domain 3665 w/m2 with different air velocities i.e. 6.5, 8, 10, 12.5, 15 m/s. Through the simulation of the optimized model results higher value of pressure drop, less thermal resistance, an increased Nusselt number and profit factor was reduced at moderate pumping power. The results are then validated with the experimental data which shows the configuration of type-4 gives maximum convergence on all parameters amongst all the configurations used.

Keywords: Heat Sink, Pumping Power, Velocity, Temperature Difference, Nusselt Number, Reynolds Number, Profit Factor.

Introduction:

A heat sink is a device that absorbs heat generated on the processor of a computer system and dissipates it into the atmosphere by forced convection process to protect processor from excess amount of temperature. Heat sink acts as in a semiconductor device to transfer maximum amount of heat. So, the thermal conductivity of heat sink should high, so that maximum amount of the heat must be dissipated into atmosphere. The thermal conductivity of heat sink depends on the property of material by which it is manufactured. For example aluminium has better thermal conductivity, so commonly heat sinks are made up of aluminium. It has good manufacturing and economic to assemble or to optimized for better heat transfer during the work of processor to dissipate the heat in maximum amount to atmosphere.

According to the configuration of heat sink, it is classified as follows:

1. rectangular channel heat sink
2. circular fin heat sink
3. zigzag shaped heat sink
4. stamped heat sink
5. annular fin shaped heat sink

Numerical and Experimental Investigation:

Xiang Wanga et. al. 2018 - This study aims to find out the optimized solution for coupled effects of parameters. Different turbulence models were studied and RSM (Response Surface Methodology) was the most appropriate one to deal with optimization of target and investigate interaction of different parameters. In design height and diameter of cylindrical pin-fin was adopted as control parameters, according to numerical simulation the thermal resistance and pressure loss of pin-fin heat sink indicated improving tendency with increasing the both parameters.

E. Siva Reddy et. al. 2019 - Various types of fin geometries with copper and aluminum as heat sink materials have been simulated in both natural convection and forced convection conditions. Various fin arrangements such as inline & staggered arrangements in combination with variation in pin fins geometries have been simulated. Fin geometries such as Rhombus prism and Rhombus pyramid. Heat sink with Rhombus prism pin fins (HS-RPPF) is found to be more effective in dissipating heat compared to other configuration of fins, this is observed mainly due to the higher surface area. Rhombus tapered pins have lower heat transfer rate compared to all the other pin fins which have been simulated, considering the complexity of manufacturing involved, more feasibility study and optimization has to be carried out for these type of fins to be used.

Senthil kumar 2020 - This study reveals that threaded surface pin heat sink is 18.13% higher heat transfer than plain pin heat sink. In terms of specific performance consideration, threaded surface textures pin fins shows impending substitute design to plain circular pin fins. The threaded surface texture pin has decreased aerodynamic consequence compared to plain circular pin. The threaded texture increases surface area, flow turbidity and delays flow separation and these factors enhances the heat transfer.

S.Senthur Prabhu 2021 - In this present study, the systematic review is carried out by critically analyzing the different types of fin profile such as plain rectangular fin, wavy fin, circular pin fin, and rectangular pin fin to increase the fins efficiency. The outcome from this study reveals that the heat transferred by the fins is mainly dependent on the fins profile (type and shape), length, angle, and surface area. Alongside the orientation of the fins, porosity, thermo-geometry also affects the fins’ efficiency.

Ozgur Ozdilli 2021 - This work aims to develop an alternative heatsink to replace a conventional heat sink for cooling a LED. Heat sinks were designed in two different geometries, such as wavy pin-fin (WPF) and square pin-fin (SPF). The heat dissipation performance of each heat sink, which has the same number of fins and weights, was analyzed using computational fluid dynamics software at 5 W, 10 W, and 15 W thermal power.

Yacine Khetib et. al.2021- This study numerically investigates a micro-pin-fin heat sink (MPFHS) to improve cooling capability and productivity of MPFHS. It was assumed that the flow is turbulent, steady, and incompressible. It is found that the RS configuration possessed maximum heat transfer while yielding the maximum pressure drop. Smaller distances between the pins improved heat transfer but enhanced the convective heat transfer coefficient and increased pressure drop.

S Sushma et.al. 2021 - To enhance heat transfer by using different shaped heat sinks.The results from the experimental forced convection are compared for different heat sinks like honeycomb-shaped, radial-shaped, and flared shaped.

Modelling and Analysis

DESIGN PARAMETERS OF HEAT SINK MODEL

Basic Parameters of Heat Sink Model: Four types of plate pin fin heat sink

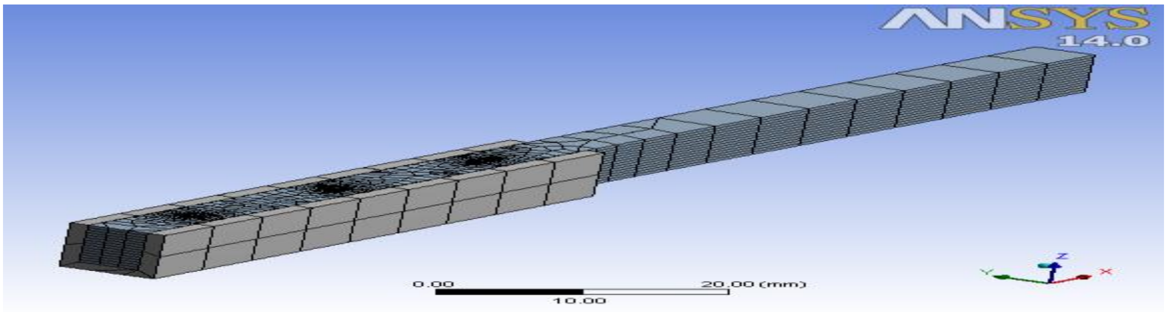
Fin Length, L(mm)	Fin Height, H(mm)	Pin Height, H1(mm)	Fin Number, N	Fin thickness, t(mm)	Fin Spacing, δ(mm)
51	10	10	02	1.5	5

Type	Diameter of pin fins (mm)		
	Pin - 1	Pin – 2	Pin - 3
Type – 1	1	1	1
Type – 2	1	1	2
Type – 3	1	2	2
Type – 4	2	2	2

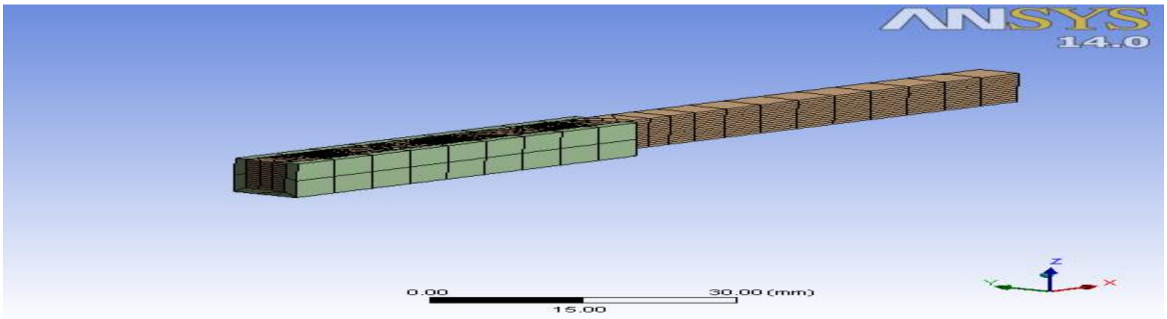
Design Parameters of Optimized Heat Sink Models

Dimensions of Artificially roughened drafted pin fin heat sink models: Four types of optimized plate pin fin heat sink

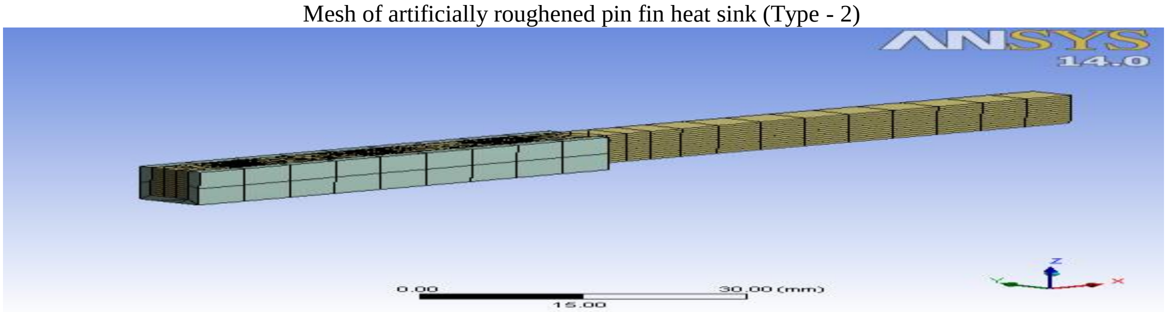
Model	Draft Angle	Roughness on fin wall (Rectangular shaped)	
Type – 1 (1,1,1mm)	2^0	1mm (width)	0.5 (Height)
Type – 2 (1,1,2mm)	2^0	1mm (width)	0.5 (Height)
Type – 3 (1,2,2mm)	2^0	1mm (width)	0.5 (Height)
Type – 4 (2,2,2mm)	2^0	1mm (width)	0.5 (Height)



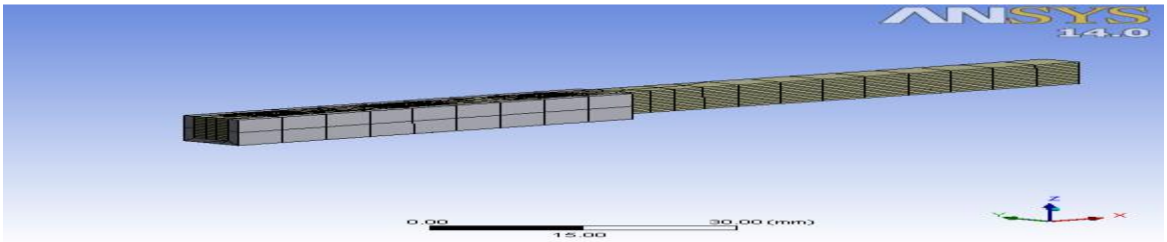
Mesh of artificially roughened pin fin heat sink (Type - 1)



Mesh of artificially roughened pin fin heat sink (Type - 2)



Mesh of artificially roughened pin fin heat sink (Type - 3)



Mesh of artificially roughened pin fin heat sink (Type - 4)

Boundary conditions

Fin Profile	Fin type	Velocity (m/s)					Heating power(W/m^2)	Periodic boundary condition
Artificially Roughened Pin Fin Heat Sink	Type – 1	6.5	8	10	12.2	15	3665	Translate in X direction
	Type – 2	6.5	8	10	12.2	15	3665	Translate in X direction
	Type – 3	6.5	8	10	12.2	15	3665	Translate in X direction
	Type – 4	6.5	8	10	12.2	15	3665	Translate in X direction

Boundary conditions

Result Analysis and Discussion

The validation of the Experimental result is done by carrying out the simulation work on the plate pin fin heat sink by using ANSYS software on Fluent domain 14.0 Work bench. The model proposed by me is validated by some past work that has been already done. For this purpose I have selected the work done by Wuhan Yuan et.al. (2012) and taken all the experimental data of thermal resistance, Reynolds no., nusselt no. , profit factor and pumping power , and compare it with my optimization result.

Optimization Result of various Simulation of Artificially roughened drafted pin fin heat sink Model

The Artificially roughened drafted pin fin heat sink is simulated and the results of temperature contours, velocity vectors, Surface Nusselt number and the effects of heat flux at different roughness of artificially roughened drafted pin fin heat sink are presented.

Pin Fin Model	Air Velocity (m/s)	Pressure Drop (Pa)	Heat flux (w/m^2)	Temperature Drop (k)	Thermal Resistance (k/w)	Nusselt Number (Nu)	Profit Factor (J)
Type-1	6.5	55.8	3665	425	0.115	1721.099	0.02
	8	87.3	3665	410	0.111	1739.981	0.01
	10	134.0	3665	394	0.107	1871.148	0.005
	12.2	196.8	3665	382	0.104	2127.703	0.003
	15	291.8	3665	370	0.1	2444.658	0.001
Type-2	6.5	55.2	3665	432	0.117	1700.922	0.02
	8	88.7	3665	415	0.113	1879.18	0.01
	10	136.3	3665	398	0.108	2255.63	0.005
	12.2	199.7	3665	384	0.104	2575.64	0.003
	15	300.0	3665	372	0.101	2946.167	0.001
Type-3	6.5	60.4	3665	432	0.117	1787.571	0.018
	8	93.3	3665	416	0.113	2151.558	0.009
	10	143.9	3665	397	0.108	2500.494	0.005
	12.2	211.8	3665	384	0.104	2848.405	0.002
	15	317.1	3665	372	0.101	3246.719	0.001
Type-4	6.5	59.5	3665	433	0.118	1620.421	0.018
	8	90.4	3665	415	0.113	1720.687	0.01
	10	137.9	3665	396	0.108	1901.901	0.005
	12.2	202.5	3665	382	0.104	2236.06	0.002
	15	292.5	3665	371	0.101	2557.929	0.001

The Profit factor of the artificially roughened drafted pin fin heat sink. J, can be defined by-

$$J = \frac{Q}{E}$$

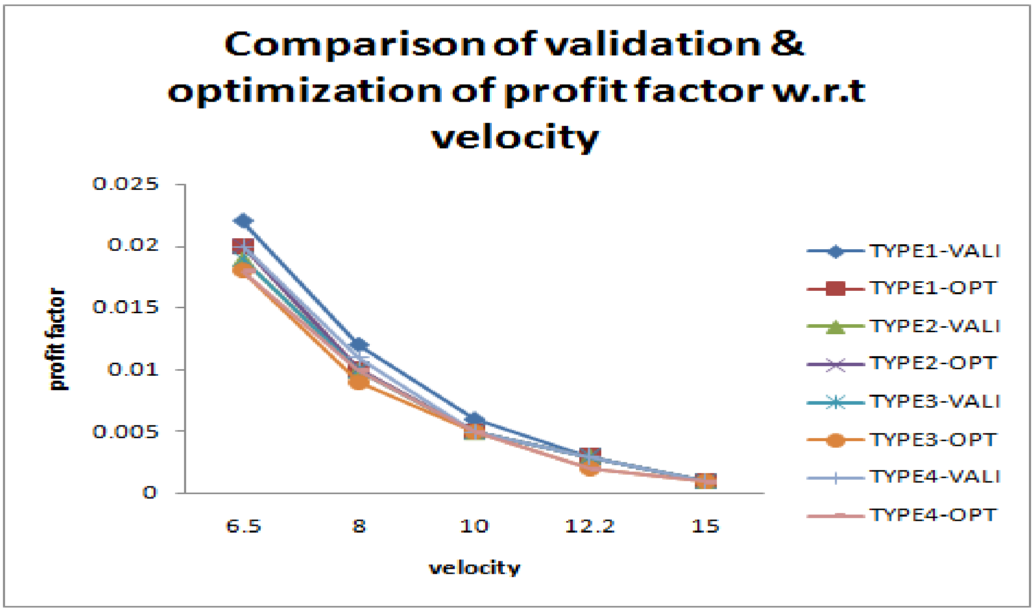
Where Q is Heat flux (3665 w/m^2) and E is pumping power this relation justify the further optimization in heat sink and also to predict the difference between the best configuration of heat sink model and Wuhan Yuan (author of base paper) experimental results for thermal resistance, Reynolds no. and NUSSELT number of the pin fin heat sink and Artificially roughened drafted pin fin heat sink are plotted in respectively, As can be seen in these figures below.

Observation Tables-

(a) Profit Factor :-

This table shows experimental and simulation results of Profit Factor for the pin fin heat sink

Comparative Result									
Velocity	Profit Factor (validation)				Velocity	Profit Factor (optimization)			
	Type-1	Type-2	Type-3	Type-4		Type-1	Type-2	Type-3	Type-4
6.5	0.022	0.019	0.019	0.02	6.5	0.02	0.02	0.018	0.018
8	0.012	0.01	0.01	0.011	8	0.01	0.01	0.009	0.01
10	0.006	0.005	0.005	0.005	10	0.005	0.005	0.005	0.005
12.2	0.003	0.003	0.003	0.003	12.2	0.003	0.003	0.002	0.002
15	0.001	0.001	0.001	0.001	15	0.001	0.001	0.001	0.001



Experimental and Simulation results for the pin fin heat sink: Profit Factor & Velocity.

The above figure shows the experimental and simulation result of pin fin heat sink for profit factor. The results are slightly below than experimental values, the deviation almost constant. From this we found that due to increase velocity profit factor decreases, this is due to increased pumping power according to the relation,

$$J = \frac{Q}{E}$$

Where J = profit factor of a heat sink

Q = heat flux of a heat sink

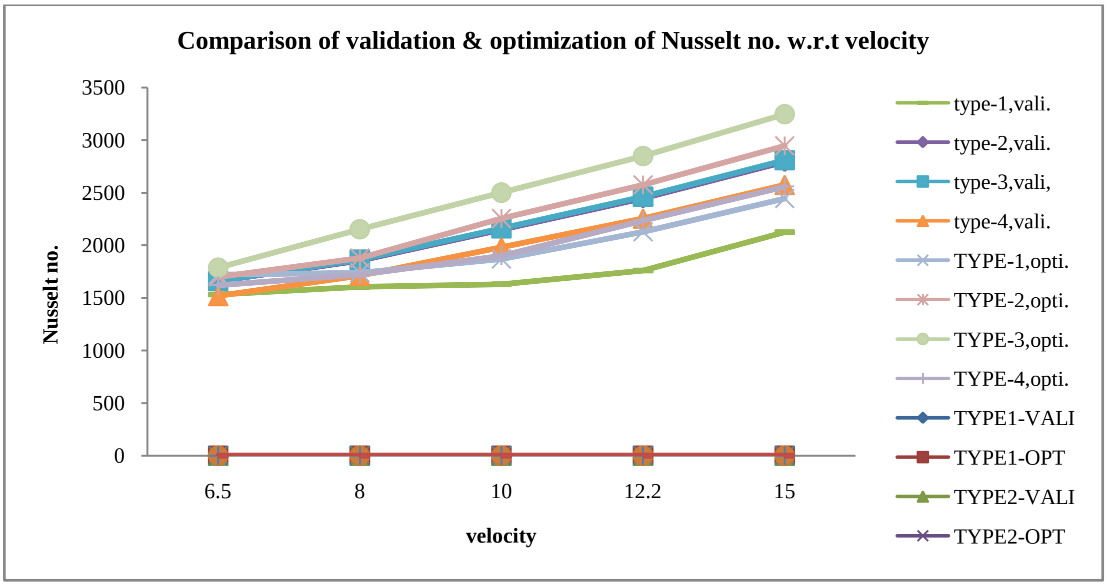
E = pumping power

From the above relation we found that type-3 modeled heat sink have lesser profit factor it concludes that it have good pumping power.

(b) NUSSELT number :-

This table shows experimental and simulation results of nusselt number for the pin fin heat sink

Comparative Result									
Velocity	NUSSELT number (validation)				Velocity	NUSSELT number (optimization)			
	Type-1	Type-2	Type-3	Type-4		Type-1	Type-2	Type-3	Type-4
6.5	1531.57	1661.493	1661.308	1518.896	6.5	1721.099	1787.571	1700.922	1620.421
8	1603.427	1856.667	1865.263	1711.944	8	1739.981	2151.558	1879.18	1720.687
10	1628.496	2150.363	2162.969	1982.047	10	1871.148	2500.494	2255.63	1901.901
12.2	1760.142	2446.162	2462.831	2255.124	12.2	2127.703	2848.405	2575.64	2236.06
15	2125.21	2792.763	2809.994	2573.894	15	2444.658	3246.719	2946.167	2557.929



Experimental and Simulation results for the pin fin heat sink: Nusselt number & Velocity

The above figure shows the experimental and simulation result of pin fin heat sink for Nusselt number. The results are slightly above than experimental values, the deviation almost constant.

From the above results we determine that our simulation results give better nusselt number by following relation,

$$N_u = \frac{hD}{k}$$

Where h = heat transfer coefficient

D = pin diameter

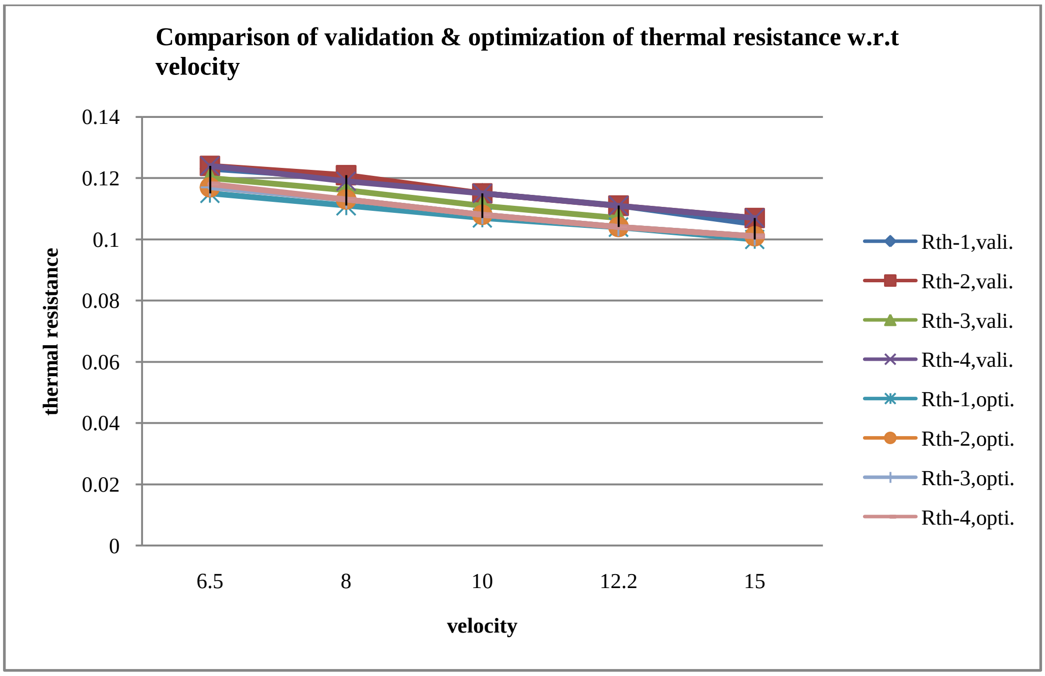
k = thermal conductivity

From the above relation we found that type-3 modeled heat sink have greater nusselt number it concludes that it have good pumping power.

(c) Thermal resistance:

This table shows experimental and simulation results of Thermal Resistance for the pin fin heat sink

Validation Result									
Velocity	Thermal Resistance (validation)				Velocity	Thermal resistance (optimization)			
	Type-1	Type-2	Type-3	Type-4		Type-1	Type-2	Type-3	Type-4
6.5	0.123	0.124	0.12	0.124	6.5	0.115	0.117	0.117	0.118
8	0.12	0.121	0.116	0.119	8	0.111	0.113	0.113	0.113
10	0.115	0.115	0.111	0.115	10	0.107	0.108	0.108	0.108
12.2	0.111	0.111	0.107	0.111	12.2	0.104	0.104	0.104	0.104
15	0.105	0.107	0.103	0.107	15	0.1	0.101	0.101	0.101



Experimental and Simulation results for the pin fin heat sink: Thermal Resistance & Velocity.

The above figure shows the Thermal resistance for pin fin heat sink with experimental and simulation gives a constant deviation but in similar manner, from the above results we determine that thermal resistance due to temperature difference

$$R_{th} = \frac{\Delta T}{Q}$$

Where R_{th} = thermal resistance

ΔT = temperature difference

$\Delta T = T_{in} - T_{out}$

T_{in} = temperature at inlet

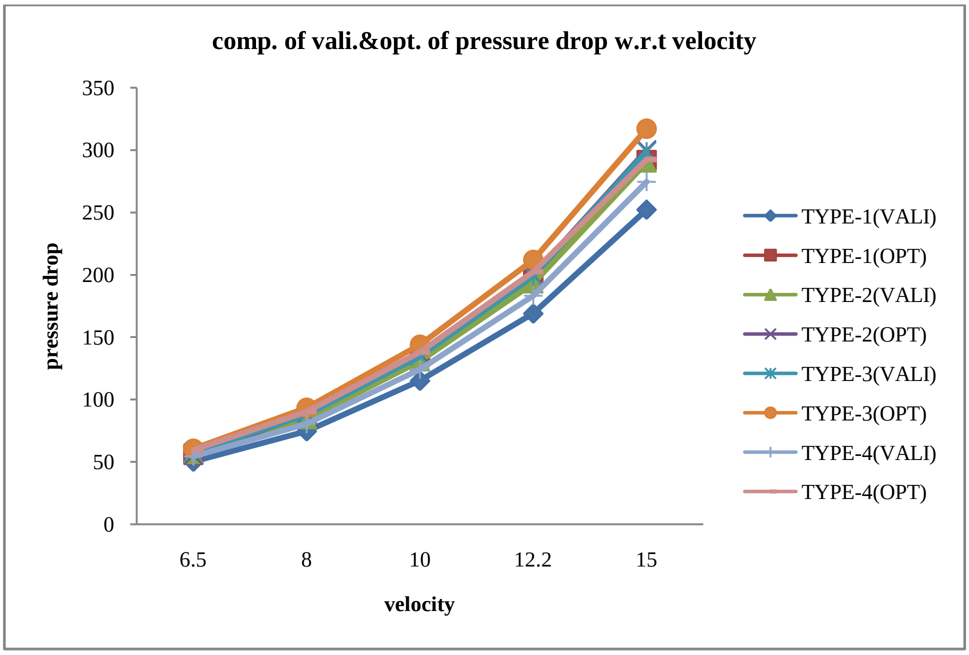
T_{out} = temperature at outlet

Q = constant heat flux (3665 W/m^2)

(d) Pressure drop:

This table shows experimental and simulation results of pressure drop for the pin fin heat sink

Validation Result									
Velocity	Pressure Drop (validation)				Velocity	Pressure Drop (optimization)			
	Type-1	Type-2	Type-3	Type-4		Type-1	Type-2	Type-3	Type-4
6.5	501	565	575	543	6.5	558	552	604	595
8	745	844	879	805	8	873	887	933	904
10	1150	1308	1348	1241	10	1340	1363	1439	1379
12.2	1689	1933	1991	1832	12.2	1968	1997	2118	2025
15	2522	2902	2989	2744	15	2918	3000	3171	2925

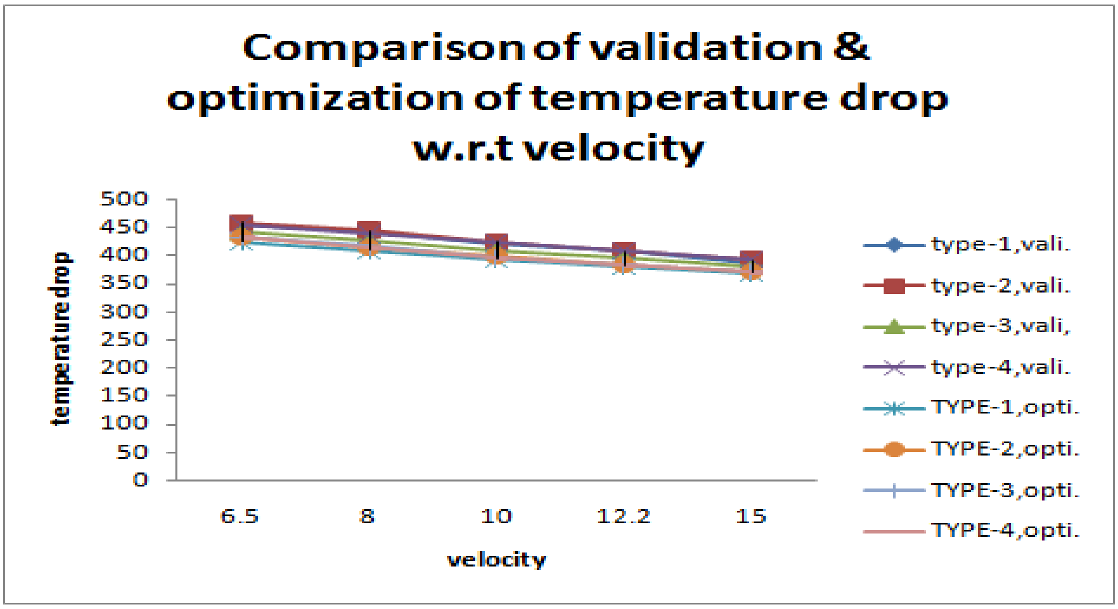


Experimental and Simulation results for the Solar: Pressure drop vs. Velocity

The above figure shows the experimental and simulation result of pin fin heat sink. This gives a slightly large deviation but in similar manner. From the above result pressure drop increase w.r.t velocity due to pressure difference, we found that due to decreased pressure w.r.t pressure difference at inlet and outlet velocity increases

(e) Temperature drop

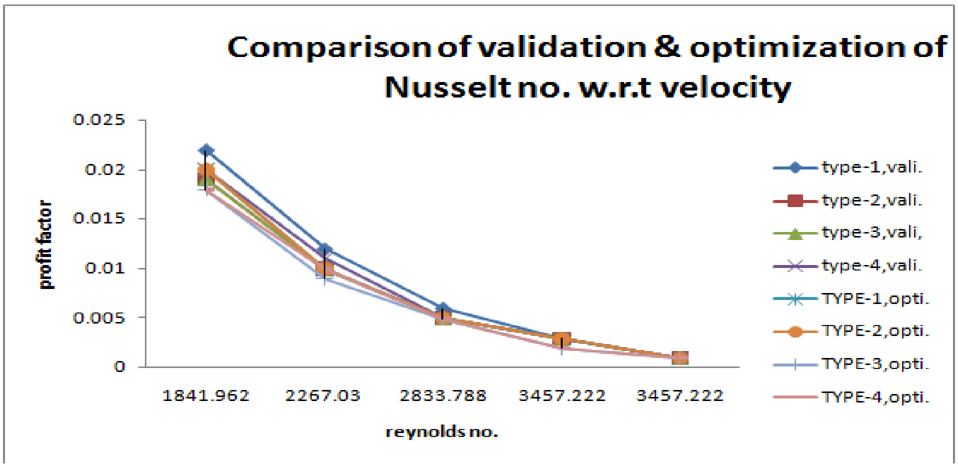
Comparative Result									
velocity	Temperature drop(Experimental)				velocity	Temperature drop (Simulation)			
	Type-1	Type-2	Type-3	Type-4		Type-1	Type-2	Type-3	Type-4
6.5	454	458	441	455	6.5	425	432	432	433
8	441	445	427	438	8	410	415	416	415
10	422	425	409	423	10	394	398	397	396
12.2	407	408	395	408	12.2	382	384	384	382
15	387	393	381	393	15	370	372	372	371



Experimental and Simulation results for the Solar: Temperature drop vs. Velocity

(i) Reynolds no. with profit factor

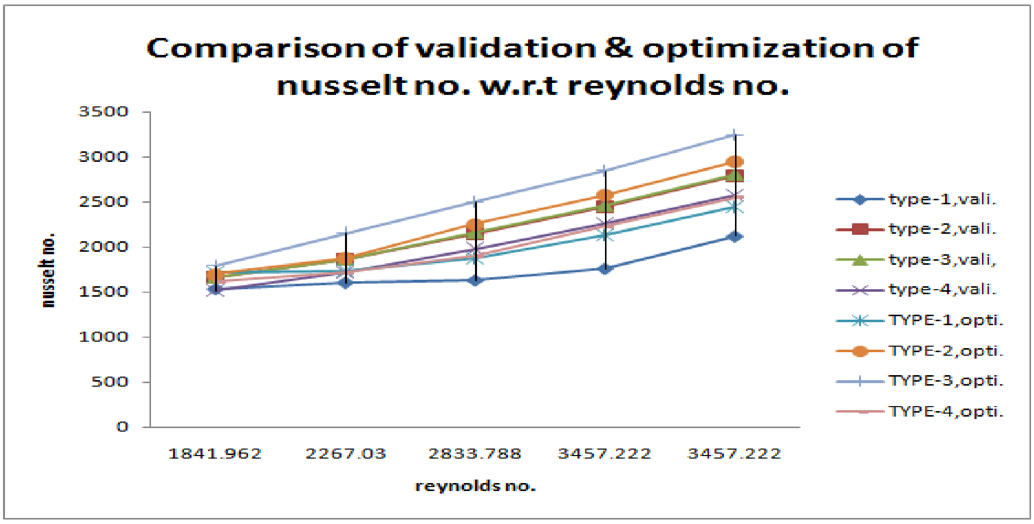
Comparative Result									
Reynolds no.	Profit Factor (validation)				Reynolds no.	Profit Factor (optimization)			
	Type-1	Type-2	Type-3	Type-4		Type-1	Type-2	Type-3	Type-4
1841.962	0.022	0.019	0.019	0.02	1841.962	0.02	0.02	0.018	0.018
2267.03	0.012	0.01	0.01	0.011	2267.03	0.01	0.01	0.009	0.01
2833.788	0.006	0.005	0.005	0.005	2833.788	0.005	0.005	0.005	0.005
3457.222	0.003	0.003	0.003	0.003	3457.222	0.003	0.003	0.002	0.002
3457.222	0.001	0.001	0.001	0.001	3457.222	0.001	0.001	0.001	0.001



Experimental and Simulation results for the Solar: Profit factor vs. Reynolds no.

(f) Reynolds no. with nusselt no.

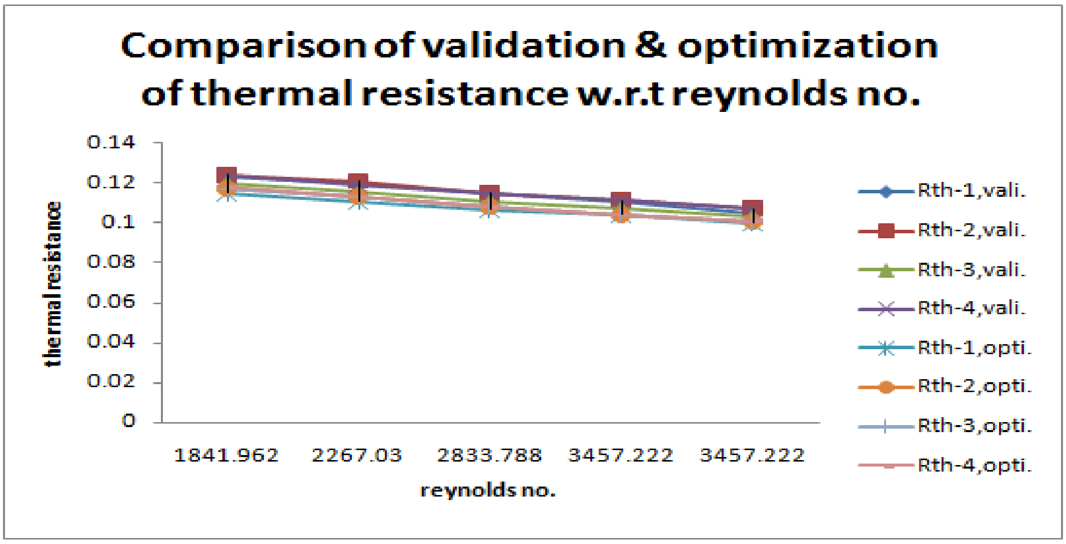
Comparative Result									
Reynolds no.	Nusselt no. (validation)				Reynolds no.	Nusselt no. (optimization)			
	Type-1	Type-2	Type-3	Type-4		TYPE-1	TYPE-2	TYPE-3	TYPE-4
1841.962	1531.57	1661.493	1661.308	1518.896	1841.962	1721.099	1787.571	1700.922	1620.421
2267.03	1603.427	1856.667	1865.263	1711.944	2267.03	1739.981	2151.558	1879.18	1720.687
2833.788	1628.496	2150.363	2162.969	1982.047	2833.788	1871.148	2500.494	2255.63	1901.901
3457.222	1760.142	2446.162	2462.831	2255.124	3457.222	2127.703	2848.405	2575.64	2236.06
3457.222	2125.21	2792.763	2809.994	2573.894	3457.222	2444.658	3246.719	2946.167	2557.929



Experimental and Simulation results for the Solar: Nusselt no. vs. Reynolds no.

(g) Reynolds no. with Thermal resistance

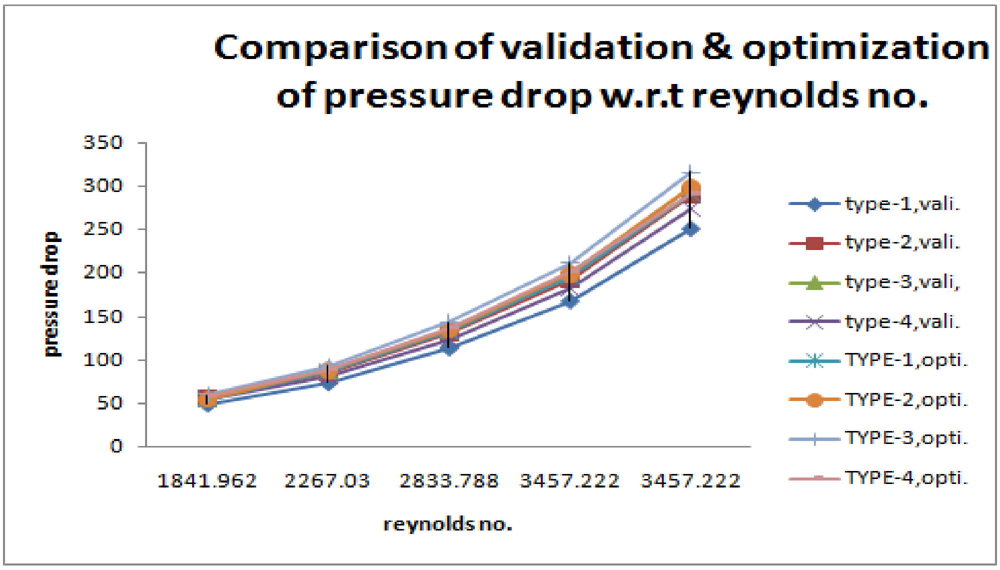
Comparative Result									
Reynolds no.	Thermal resistance (validation)				Reynolds no.	Thermal resistance (optimization)			
	Rth-1	Rth-2	Rth-3	Rth-4		Rth-1	Rth-2	Rth-3	Rth-4
1841.962	0.123	0.124	0.12	0.124	1841.962	0.115	0.117	0.117	0.118
2267.03	0.12	0.121	0.116	0.119	2267.03	0.111	0.113	0.113	0.113
2833.788	0.115	0.115	0.111	0.115	2833.788	0.107	0.108	0.108	0.108
3457.222	0.111	0.111	0.107	0.111	3457.222	0.104	0.104	0.104	0.104
3457.222	0.105	0.107	0.103	0.107	3457.222	0.1	0.101	0.101	0.101



Experimental and Simulation results for the Solar: Thermal resistance vs. Reynolds no.

(h) Reynolds no. with Pressure drop

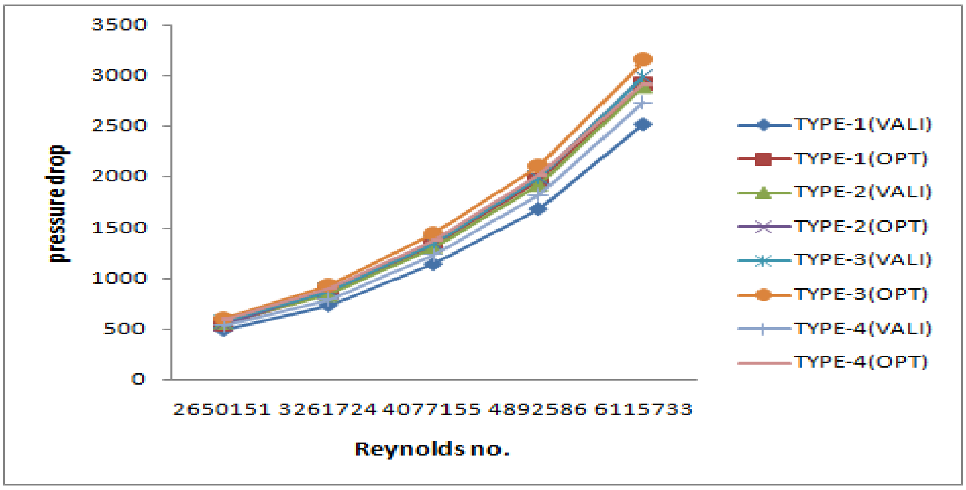
Comparative Result									
Reynolds no.	Pressure drop (validation)				Reynolds no.	Pressure drop (optimization)			
	Type-1	Type-2	Type-3	Type-4		Type-1	Type-2	Type-3	Type-4
1841.962	501	565	575	543	1841.962	558	552	604	595
2267.03	745	844	879	805	2267.03	873	887	933	904
2833.788	1150	1308	1348	1241	2833.788	1340	1363	1439	1379
3457.222	1689	1933	1991	1832	3457.222	1968	1997	2118	2025
3457.222	2522	2902	2989	2744	3457.222	2918	3000	3171	2925



Experimental and Simulation results for the Solar: Pressure drop vs. Reynolds no.

Validation				Optimization				
Type-1	Type-2	Type-3	Type-4	Type-1	Type-2	Type-3	Type-4	
Pressure Drop								Reynolds No.
501	565	575	543	558	552	604	595	1841.962
745	844	879	805	873	887	933	904	2267.030
1150	1308	1348	1241	1340	1363	1439	1379	2833.788
1689	1933	1991	1832	1968	1997	2118	2025	3457.222
2522	2902	2989	2744	2918	3000	3171	2925	4250.683

Optimized comparative result of Pressure drop with artificially roughened drafted pin fin heat sink

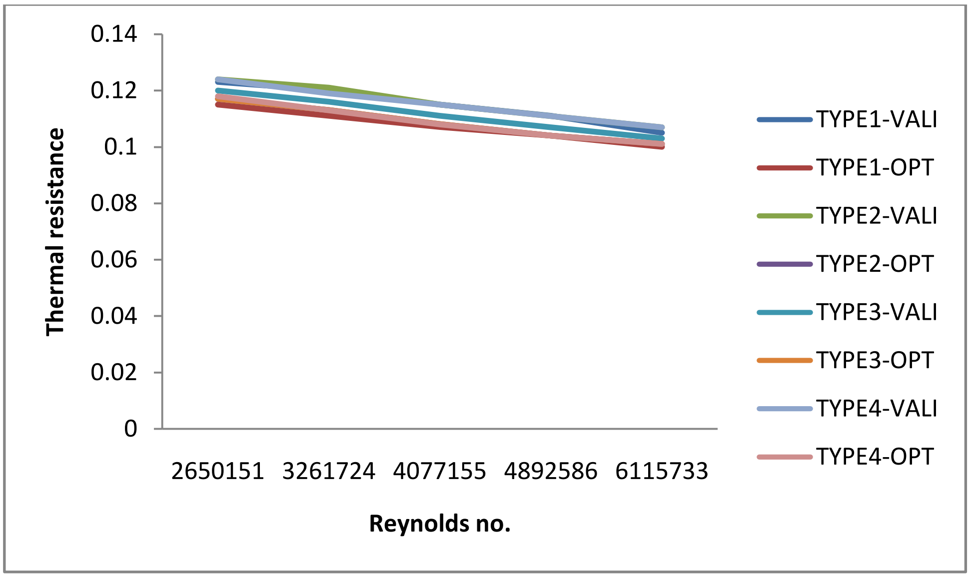


Nusselt no. Variations for Different Profile of Artificially roughened drafted pin fin heat sink of Artificially roughened drafted pin fin heat sink with Reynolds no.

The above figure shows the Pressure drop variations for different Artificially roughened drafted pin fin heat sink with compare them with Reynolds no. gives a constant deviation but in similar manner. This figure shows the increase in the pressure drop with increase in the Reynolds no.

Optimization				Validation				
Rth-1	Rth-2	Rth-3	Rth-4	Rth-1	Rth-2	Rth-3	Rth-4	Reynolds No.
0.123	0.124	0.12	0.124	0.115	0.117	0.117	0.118	1841.962
0.12	0.121	0.116	0.119	0.111	0.113	0.113	0.113	2267.030
0.115	0.115	0.111	0.115	0.107	0.108	0.108	0.108	2833.788
0.111	0.111	0.107	0.111	0.104	0.104	0.104	0.104	3457.222
0.105	0.107	0.103	0.107	0.1	0.101	0.101	0.101	4250.683

Optimized comparative result of Thermal resistance with artificially roughened drafted pin fin heat sink

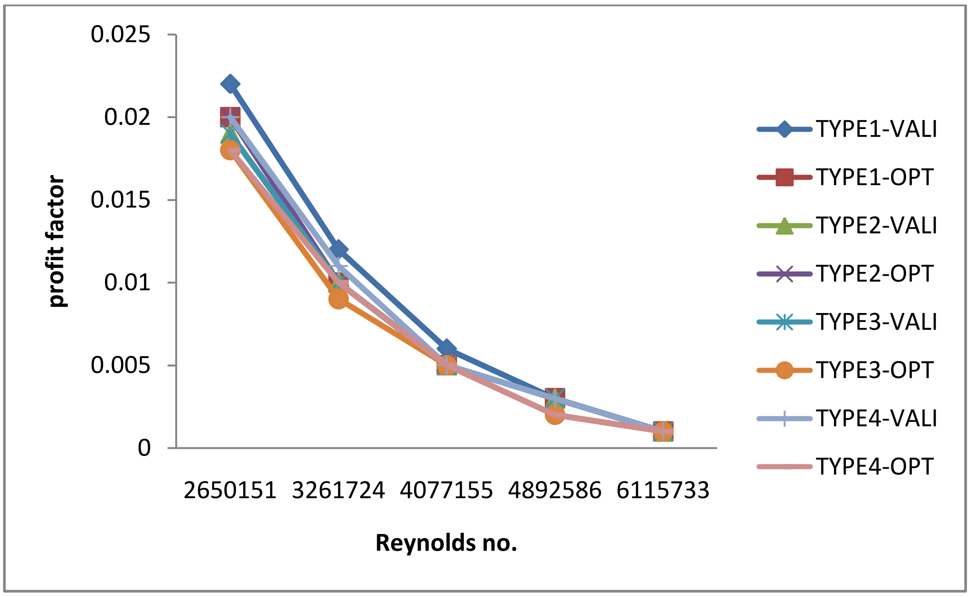


Thermal Resistance Variations for Different Profile of Artificially roughened drafted pin fin heat sink of Artificially roughened drafted pin fin heat sink with Reynolds no.

The above figure 5.20 shows the Thermal Resistance variations for different profile of artificially roughened pin fin heat sink with compare the Reynolds no. gives a constant deviation in Heat sink optimized model but in similar manner of experimental results. This figure shows the decrease in the thermal resistance with increase in the Reynolds no.

Validation				Optimization				
J-1	J-2	J-3	J-4	J-1	J-2	J-3	J-4	Reynolds No.
0.022	0.019	0.019	0.02	0.02	0.02	0.018	0.018	1841.962
0.012	0.01	0.01	0.011	0.01	0.01	0.009	0.01	2267.030
0.006	0.005	0.005	0.005	0.005	0.005	0.005	0.005	2833.788
0.003	0.003	0.003	0.003	0.003	0.003	0.002	0.002	3457.222
0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	4250.683

Optimized comparative result of Profit factor with artificially roughened drafted pin fin heat sink

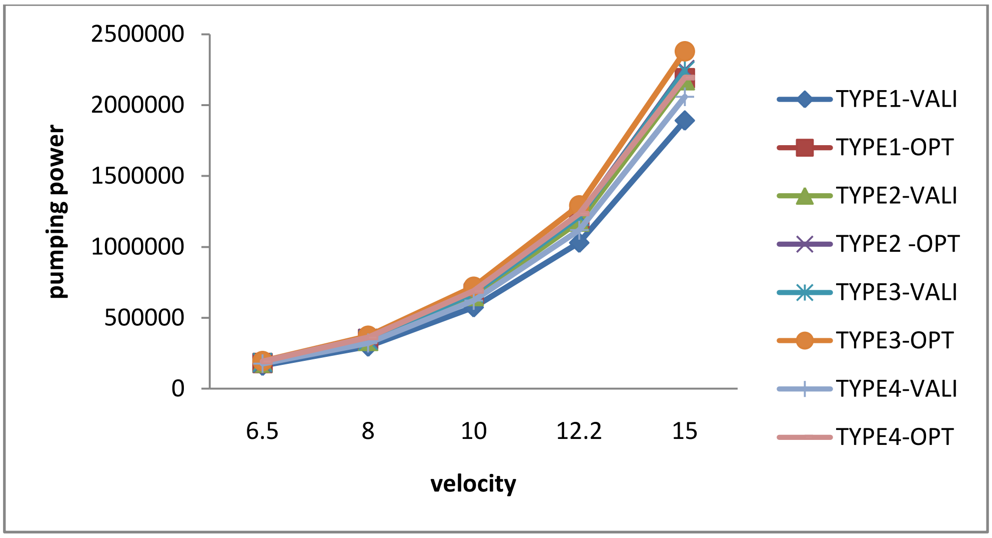


Profit Factor Variations for Different Profile of Artificially roughened drafted pin fin heat sink of Artificially roughened drafted pin fin heat sink with Reynolds no.

Above results shows comparison result between Profit factor and Reynolds no. with different configurations of artificially roughened drafted pin fin heat sink the results shows that type – 3 configured heat sink shows lesser profit factor results with respect to reynolds no.

Validation				Optimization				
E-1	E-2	E-3	E-4	E-1	E-2	E-3	E-4	Reynolds No.
162825	183625	186875	176475	181350	179400	196300	193375	1841.962
298000	337600	343600	321600	349200	354800	373200	361600	2267.030
575000	654000	674000	620500	670000	681500	719500	689500	2833.788
1030290	1179130	1214510	1117520	1200480	1218170	1291980	1235250	3457.222
1891500	2176500	2241750	2058000	2188500	2250000	2378250	2193750	4250.683

Optimized comparative result of Pumping power with artificially roughened drafted pin fin heat sink.



Pumping Power Variations for Different Profile of Artificially roughened drafted pin fin heat sink of artificially roughened drafted pin fin heat sink with Velocity.

Above results shows comparison result between pumping power and velocity with different configurations of artificially roughened drafted pin fin heat sink the results shows that type – 3 configured heat sink shows better pumping power results with respect to velocity.

Conclusion

1. The CFD model was developed on Unigraphics-8.0 and analysis was done by Ansys.
2. The prediction of CFD model show good relation with experimental result present in literature.
4. Simulated the artificially roughened pin fin heat sink having different constant draft angle at pin and roughness at fin wall velocity of (6.5,8,10,12.2,15m/s) and at constant heat input of 3665(W/m^2).
5. From the above result we have least profit factor in artificially roughened pin fin heat sink of Type - 3 i.e. 0.001
6. From the above result we have best Nusselt no. in artificially roughened pin fin heat sink of type - 3 of velocity 15m/s i.e. 2946.167
7. So, from the above we can conclude that the Type - 3 at constant velocity having better heat transfer rate due increase in nusselt no. and decrease in profit factor with compared experimental result.

Scope for Future Work

For the future works in this area the following outlines are -

1. Simulate the Heat sink of artificially roughened drafted pin fin heat sink profiles by varying the pin profiles.
2. Simulate the Heat sink of artificially roughened drafted pin fin heat sink profiles by varying heat input.
3. Simulate the Heat sink of artificially roughened drafted pin fin heat sink profiles by varying fin profile.

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