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Thermal Analysis on Pin-Fins With Hexagonal & Threaded Geometry In Natural and Forced Convection

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Abstract: *In the present work of heat transfer for hexagonal fins (1mm & 2mm) grooves on surface and threaded fin is addressed. The test has been performed on three different fin geometries having hexagonal (1mm)groove, hexagonal(2mm)groove, threaded fin(0.5mm)pitch and test performed by using a centrifugal blower, test section, heater and test panel and Results are obtained for temperature distribution, effectiveness, efficiencies at a same flow rate of air as it was conducted in forced convection and the same parameters considered for different values are obtained for natural convection with different fins as well. In this experiment for forced convection, the airflow rate is constant i.e, 2.3371 m/sec throughout the experiment. In natural convection, efficiency for the threaded fin is high with 93.89% and effectiveness of hexagonal(2mm)depth fin is 28.11. In forced convection, the efficiency of the threaded fin is high with 81.83% and effectiveness of hexagonal(1mm)depth fin is high with 23.51 was recorded. The heat transfer rate is higher in natural convection is hexagonal(2mm)depth fin with 11.41 watts and 21.75 watts in forced convection with hexagonal(1mm)depth fin.*

Keywords*:Pin-fins, Hexagonal fin, Threaded fin, Efficiency, Effectiveness.*

I. Introduction

Convective Heat Transfer:

The process of heat transfer between the surface and surrounding fluid is known as convective heat transfer. In this process, the flow of energy is primarily due to the moment of fluid molecules.

They are two types of convective heat transfer:

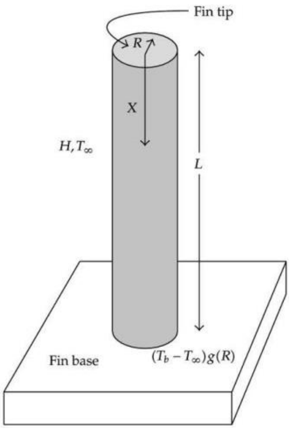
1. Forced convection 2. Natural convection

Forced convection: In this type, the molecules of fluid are forced to move over the surface with the help of some external force. We can get a higher rate of heat transfer.

Natural convection: In this type, the fluid motion is caused by buoyancy forces that result from the density variations due to variations of temperature in the fluid.

Pin Fin:

Extended surfaces (fins) are frequently used in heat exchanging devices for the purpose of increasing the heat transfer between a primary surface and the surrounding fluid. Various types of fins, ranging from relatively simple shapes such as rectangular, square, cylindrical, annular, tapered or pin fins, to a combination of different geometries has been used.



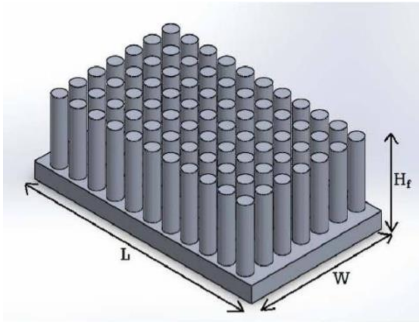


Fig a: Cylindrical fin

Fig b: Heat Sink

Dimensionless numbers:

1. Prandtl number: Is the ratio of kinematic viscosity to thermal diffusivity.

$$P_r = \text{kinematic viscosity/thermal diffusivity}$$
$$P_r = (\mu\, c\square)/K$$
$$_r = (\mu/\rho) / (K/\rho.\ C\square)$$
$$= \nu/\alpha$$

2. Reynold's Number: It may be physically interpreted as the ratio of inertia of force to viscous force in the velocity boundary layer. Large values of Re denotes high viscous forces.

$$Re = \text{Inertia of force / viscous force}$$
$$Re = \rho\, VD / \nu$$

3. Grashof's number: Grashof number (G_r) is a dimensional number used in heat transfer studies involving free or natural convection.

$$G_r = (\beta\ \Delta\ TD^3) / \nu^2$$
$$= (g\ \beta\ d^3\ \Delta T) / \nu^2$$
$$= (\text{Inertia force} \times \text{Buoyancy force})/(\text{viscous force})^2$$

4. Nusselt number: It is the ratio of convection heat transfer rate to the conduction heat transfer rate. Consider an internal flow in a channel of length L and the temperature at the lower and upper surfaces are T1 and T2 respectively.

Th ratio is,

$$Nu = Q_{conv} / Q_{cond}$$
$$= [h\ A_C(T1-T2)] / [(k\ A_C / L)\ (T1-T2)]$$
$$= (h\ L) / k$$

II. Materials And Methods

Fin parameters:

Material - Aluminium alloy

Thermal conductivity (k) - 167 w/mk

For Hexagonal fin

L= 15.7cm

D = 2.5cm, S = 1.2cm

Depth-1mm, 2mm

For Threaded fin

L = 15.7cm

D = 2.5cm

Pitch = 0.5mm

Fig a: Cylindrical fin

Fig b: Heat Sink

Fins are fabricated in CNC machines and K-type thermocouple are used to measure temperature. Total fin length is 23.7cm, the thermocouple is placed on fins at a certain distance.

a. Experimental set-up:

Methodology: A pin fin with different geometry (Hexagon, Threaded) cross-section is fitted across a long rectangular duct. The other end of the duct is connected to the suction side of a blower and the air flows pass through the fin perpendicular to the axis. One end of the projects outside of the duct and is heated by a heater. The temperature at 5 points along the length of the fin are measured by K-type thermocouples connected along the length of fin the area flow rate is measured by an orifice meter fitted on the delivery side of the blower. This is for forced convection. For natural convection, it removes the duct and off the blower connects the fin with the heater and notes the temperature readings.

b. Specifications of apparatus:

1Duct size = 150×100mm

2.Diameter of orifice = 20mm

3.Diameter of delivery pipe = 50mm

4Number of thermocouples on fin = 5

5Thermocouple (6) reads ambient temperature inside the duct

6.Temperature indicator = 0-300^{o}

7Dimmer stat for heat input control = 230v,2Amp

8Fluid used in manometer-Mercury (Density-13600kg/ m^3)

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a. Forced convection set-up

b.Natural convection set-up

Cross Section Area Values:

For hexagonal fin(1mm),

Ac = 3.711×10^{-4} m^2

For hexagonal fin(2mm),

Ac = 3.681×10^{-4} m^2

For threaded fin,

Ac = 4.9087×10^{-4} m^2

Surface Area Values:

For hexagonal fin(1mm),

As = 0.01204 m^2

For hexagonal fin(2mm),

As = 0.01203 m^2

For threaded fin,

As = 0.01233 m^2

Perimeter:

For hexagonal fins,

P= 0.072m

For threaded fin,

P= 0.0785m

For, irregular shapes we use hydrodynamic diameter

Dh = 4Ac/P

For hexagonal fin,

For,1mm

Dh=0.02061m

For hexagonal fin,

For,2mm

Dh=0.02045m

In case of the threaded fin, Dh = diameter of fin.

Dh=Dfin

Dh=0.025m

III. Results and Discussion

The models of hexagonal & threaded fins are tested under different voltages of the same diameter and same material. It is observed that heat transfer rates and temperatures have varied with varying geometries. By the depth of the groove increases the heat transfer rate also changes in hexagonal fins. By comparison of threaded and hexagonal two different depths of the groove, the heat transfer rate is higher in hexagonal fin.
Here are the observations of different pin fins taken during experimentation

For Natural convection

Table 3.1: Observations during experimentation for Hexagon fin (1.0mm)

S.No	Power input (W)		Fin Temperatures(^{O}C)					Duct Fluid Temperatures (^{O}C)
	V	A	T_1	T_2	T_3	T_4	T_5	T_6
1	80	0.45	121.3	119.3	116.3	114.5	111.2	54.2
2	90	0.50	180.2	178.2	176.7	174.2	172.3	55.4

Table 3.2: Observation during experimentation for Hexagon fin (2.0mm)

S.No	Power input(W)		Fin Temperatures(^{O}C)					Duct Fluid Temperatures (^{O}C)
	V	A	T_1	T_2	T_3	T_4	T_5	T_6
1	80	0.45	130.2	123.7	120.3	118.5	117.5	57.1
2	90	0.50	187.9	179.2	175.0	170.6	171.0	58.1

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Table 3.3: Observations during Experimentation for Threaded Fin

S.No	Power input (W)		Fin Temperatures (^{O}C)					uct Fluid Temperatures (^{O}C)
	V	A	T_1	T_2	T_3	T_4	T_5	T_6
1	80	0.45	100.1	101.2	92.3	96.7	94.0	53.5
2	90	0.50	143.1	130.2	117.3	126.7	122.4	55.6

It shows the values of surface temperatures(C°) of different fins i.e, hexagonal (1mm)depth, hexagonal (2mm)depth, threaded fin in natural convection. V is the voltage given as heat input. T1, T2, T3, T4, T5 are the surface temperatures of the fin at different lengths. T6 is the ambient temperature (or) temperature of the air surrounding to fin during experimentation.

For Forced convection

Table 3.4: Observations during experimentation for Hexagon fin (1.0mm)

S.No	Power input (W)		h(mm)	Fin Temperatures(^{O}C)					Duct Fluid Temperatures (^{O}C)
	V	A		T_1	T_2	T_3	T_4	T_5	T_6
1	80	0.45	8	119.0	116.4	111.8	109.4	106.5	58.0
2	90	0.45	8	148.1	144.7	139.1	136.1	131.5	60.5

Table 3.5: Observation during experimentation for Hexagon fin (2.0mm)

S.No	Power input(W)		h(m m)	Fin Temperatures(^{O}C)					Duct Fluid Temperatures (^{O}C)
	V	A		T_1	T_2	T_3	T_4	T_5	T_6
1	80	0.45	8	109.5	106.2	105.2	103.6	98.3	57.0
2	90	0.50	8	134.3	130.3	127.9	126.6	118.6	60.6

Table 3.6: Observations during Experimentation for Threaded Fin

S.No	Power input (W)		h(mm)	Fin Temperatures (^{O}C)					uct Fluid Temperatures (^{O}C)
	V	A		T_1	T_2	T_3	T_4	T_5	T_6
1	80	0.45	8	90.5	91.8	96.1	98.8	108.9	57.8
2	90	0.50	8	109.1	110.3	115.7	119.2	131.8	60.2

It shows the values of surface temperatures(C°) of different fins i.e, hexagonal (1mm)depth, hexagonal (2mm)depth, threaded fin in forced convection. V is the voltage given as heat input. T_1, T_2, T_3, T_4, T_5 are the surface temperatures of the fin at different lengths. T6 is the ambient temperature (or) temperature of the air surrounding to fin during experimentation. h(mm) is the manometric reading. Mercury is used as a manometric fluid.

Table 3.7: Values for dimensionless numbers in natural convection

V	β	Gr	Ra	Nu	h (w/m²k)	m	Fin type
80	2.79×10^{-3}	3.35×10^{4}	2.32×10^{4}	6.543	9.673	3.352	Hexagon(1mm)
80	2.73×10^{-3}	3.045×10^{4}	2.10×10^{4}	6.381	9.76	3.381	Hexagon(2mm)
80	2.86×10^{-3}	4.961×10^{4}	3.44×10^{4}	7.21	8.56	2.86	Threaded
90	2.57×10^{-3}	4.991×10^{4}	3.434×10^{4}	7.216	11.23	3.613	Hexagon(1mm)
90	2.56×10^{-3}	4.762×10^{4}	3.27×10^{4}	7.13	11.19	3.620	Hexagon(2mm)
90	2.74×10^{-3}	6.22×10^{4}	4.29×10^{4}	7.628	9.59	3.023	Threaded

It shows the values of some dimensionless numbers in natural convection. V is the voltage given as heat input, **β** is the volumetric coefficient of thermal expansion, Gr is the grashof number, Ra is the rayleigh number, Nu is the nusselt number, h is the heat transfer coefficient, m is the fin property.

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Table 3.8: Values for dimensionless numbers in forced convection

V	**β**	**h (m)**	**Va (m/sec)**	**Re**	**Nu**	**h (w/m²k)**	**m**	**Fin type**
80	0.4	0.08	2.3371	2284.10	22.22	32.85	6.178	Hexagon(1 mm)
80	0.4	0.08	2.3371	2266.17	22.14	32.99	6.21	Hexagon(2 mm)
80	0.4	0.08	2.3371	2918.45	24.93	29.58	5.32	Threaded
90	0.4	0.08	2.3371	2082.47	21.24	33.09	6.20	Hexagon(1 mm)
90	0.4	0.08	2.3371	2162.61	21.64	33.10	6.22	Hexagon(2 mm)
90	0.4	0.08	2.3371	2770.38	24.31	29.63	5.35	Threaded

It shows the values of some dimensionless numbers in forced convection. V is the voltage given as heat input, is the volumetric coefficient of thermal expansion, h is the manometric reading, Va is the velocity of air passes on the fin, Re is the Reynolds number, Nu is the nusselt number, h is the heat transfer coefficient, m is the fin property.

Table 3.9: Observation for Hexagon(1.0mm), Hexagon(2.0 mm), Threaded fin's efficiencies and effectiveness in natural convection

S. No	Voltage(V)	Surface(°C)	η (%)	□	Fin type
1	80	116.52	91.6	27.92	Hexagon(1.0mm)
2	80	122.04	91.56	28.11	Hexagon(2.0mm)
3	80	98.86	93.89	23.52	Threaded
4	90	176.32	90.50	27.56	Hexagon(1.0mm)
5	90	176.74	90.47	27.77	Hexagon(2.0mm)
6	90	127.94	93.11	23.38	Threaded

It shows the values of efficiencies and effectiveness of different fins in natural convection. V is the voltage given as heat input, surface (C°) is the surface temperature of a fin, η is the efficiency of the fin, □ is the effectiveness of fin.

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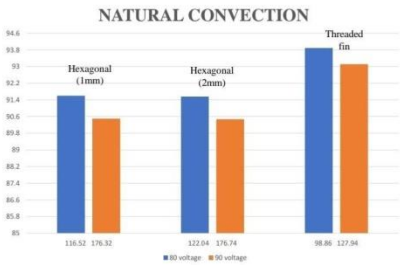
Table 3.10: Observation for Hexagon(1.0mm), Hexagon(2.0 mm), Threaded fin's efficiencies and effectiveness in forced convection

S.No	Voltage(v)	Surface(°C)	η (%)	□	Fin type
1	80	112.62	77.18	23.51	Hexagon(1.0mm)
2	80	104.56	76.98	23.29	Hexagon(2.0mm)
3	80	97.22	81.83	20.53	Threaded
4	90	139.94	77.07	23.47	Hexagon(1.0mm)
5	90	127.54	77.0	23.60	Hexagon(2.0mm)
6	90	117.22	81.73	20.58	Threaded

It shows the values of efficiencies and effectiveness of different fins in forced convection. V is the voltage given as heat input, surface (C°) is the surface temperature of a fin, η is the efficiency of the fin, □ is the effectiveness of fin.

a. GRAPHS:

Efficiency vs surface temperature (°c) -



From the graph, it can be observed that in natural convection the surface temperature is low and the efficiency is high in all fins. For threaded fins, the efficiency is higher among other fins.

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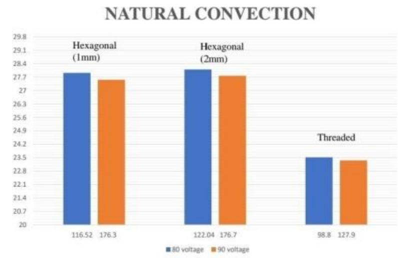
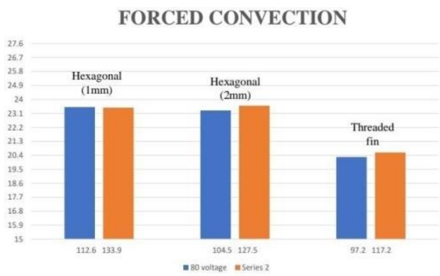
Effectiveness vs surface temperature (°c)-



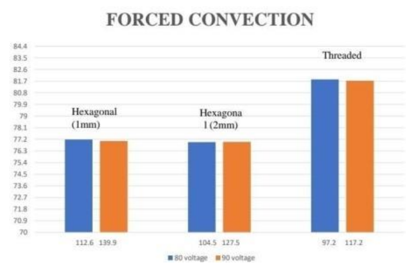
From the graph, it can be observed that in natural convection the surface temperature is low and the effectiveness is high in all fins. For, hexagonal fin(2mm) has high effectiveness among two other fins.

Effectiveness vs surface temperature (°c) -



From the graph, it can be observed that in forced convection the surface temperature is high and the effectiveness is high in all fins. For, hexagonal fin(2mm) has high effectiveness among two other fins.

Efficiency vs surface temperature (°c) -



From the graph, it can be observed that in forced convection the surface temperature is low, the efficiency is high but in hexagonal fin (2mm) the surface temperature is high and efficiency also high.

IV. Conclusion

Heat transfer rates depend not only on the heat transfer coefficient but also the surface area changes and different geometries. By changing the different geometries of fins, the heat transfer rates can be enhanced and are compared to those of the normal cylindrical fins at the same base temperatures. It is concluded that two types of convections natural and forced, give different heat transfer values.

For natural convection, the surface temperature is higher in hexagonal fin (2mm)depth. By comparing the efficiencies threaded fin has maximum and hexagonal fin(2mm)depth has a minimum. By comparing the effectiveness hexagonal fin(2mm)depth has maximum and threaded fin has a minimum. Hexagonal fin(2mm)depth has a high heat transfer rate among two fins.

For forced convection, the surface temperature is higher in hexagonal fin(1mm)depth. By comparing the efficiencies threaded fin has maximum and hexagonal fin (1mm)depth has a minimum. By comparing the effectiveness hexagonal fin (2mm)depth has maximum and threaded fin has a minimum. Hexagonal fin(2mm)depth has a high heat transfer rate in natural convection and hexagonal fin (1mm)depth has a high heat transfer rate in forced convection.

By comparing the experimental and theoretical calculations the percentage of error (%) is below 5 i.e, around 3.75.

V. Future Scope

In this study, only one design parameter is taken i.e, same diameter and same material. In forced convection, the airflow rate is constant 2.3371 m/sec in all types of fins. In future by changing the depths of the groove and by varying airflow rates and changing material it can also be performed.

Nomenclature:

- D = Diameter of pin fin (m)
- D_h = Hydrodynamic diameter of pin fin(m)
- A_s = Surface area of fin(m^2)
- A_c = Cross section area of fin(m^2)
- v = Kinematic viscosity(m^2/sec)
- k = Thermal conductivity(w/mk)
- h = Heat transfer coefficient (w/ m^2k)
- p = Perimeter of fin (m)
- L = Length of pin (m)
- L_c = Characteristics length of fin(m)
- T_s = Surface temperature of fin (^{o}c)
- T_a = Ambient temperature of air (^{o}c)

- T_m = Mean temperature (^{o}c)
- C_d = Coefficient of discharge (0.64)
- h = Difference of level in manometer
- ɳ = Efficiency of fin
- Σ = Effectiveness of fin

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