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Experimental Investigation of Heat Transfer from Inverted Notch Fin Arrays (INFA) Under Natural and Forced Convections

S. D. Wankhede[1], S. G. Taji[1], V. M. Suryawanshi[2]
[1](*Department of Mechanical Engineering, P.E.S. Modern College of Engineering, Pune, India)*
[2](*Department of Mechanical Engineering, M. E. Society's College of Engineering, Pune, India)*

ABSTRACT : *Experimental setup is developed to carry out the investigation on horizontal rectangular fin array with and without inverted notch under natural and force convections. The objective of the work is to determine the heat transfer characteristics experimentally, and further to find out the enhancement in heat transfer in the case of notched fin arrays over normal fin arrays, and analyzed the effect of different parameters like length, height, spacing of fins on heat transfer coefficient (h). Hereafter the inverted notched fin arrays are termed as INFAs and without inverted notched fin arrays are termed as normal arrays.*

Keywords: *Fin Array, Heater, Heat transfer, Inverted Notch, INFAs, Thermocouple*

I. INTRODUCTION

Fins are used to enhance convective heat transfer in a wide range of engineering applications, and offer a practical means for achieving a large heat transfer surface area without the use of an excessive amount of primary surface area. Fins are commonly applied for heat management in electrical appliances such as computer power supplies or substation transformers. Other applications include Internal Combustion engine cooling, such as fins in a car radiator. It is important to predict the temperature distribution within the fin in order to choose the configuration that offers maximum effectiveness. Natural convection and Force convection heat transfer is often to increase by provision of rectangular fins on horizontal or vertical surfaces in many electronic applications, motors and transformers. Thus heat transfer from fin arrays has been studied extensively, both analytically and experimentally. The current trend in electronic industry is microminiaturization of electronic packages. The thermal design problem is recognized as one of the factors limiting achievement of higher packaging densities. Because of reduction in surface area available for heat dissipation, optimization of fin surface area and geometry becomes very important in natural convection heat transfer. In lengthwise short array (L/H ~5), where the single chimney flow pattern is present, as shown in Fig. 1, near the central bottom portion of the fin channel, the stagnant zone that is created becomes ineffective because no air stream passes over this part. In this central portion, a rectangular notch is cut, as shown in Fig. 2 and its effect on heat transfer characteristics and flow is studied.

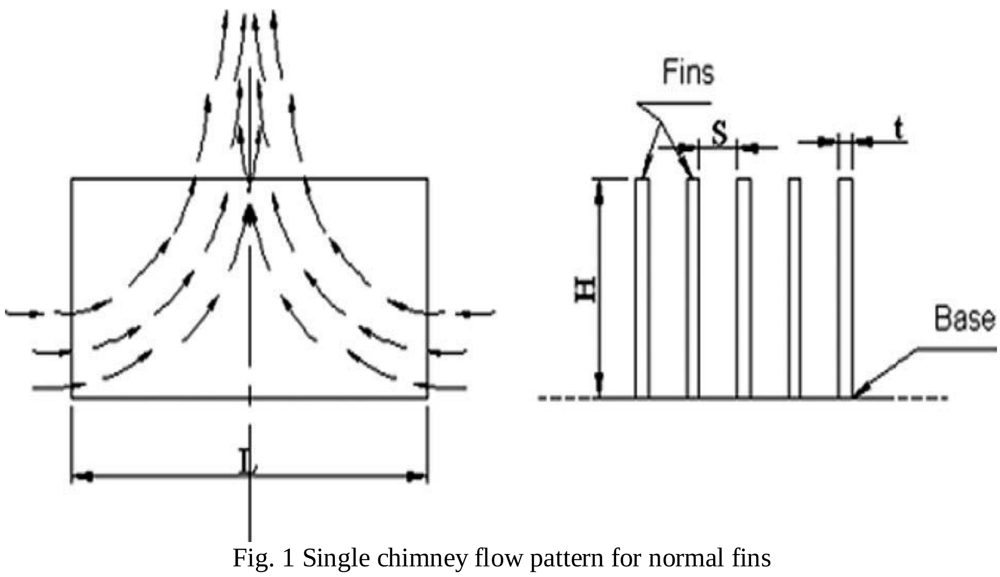

Fig. 1 Single chimney flow pattern for normal fins

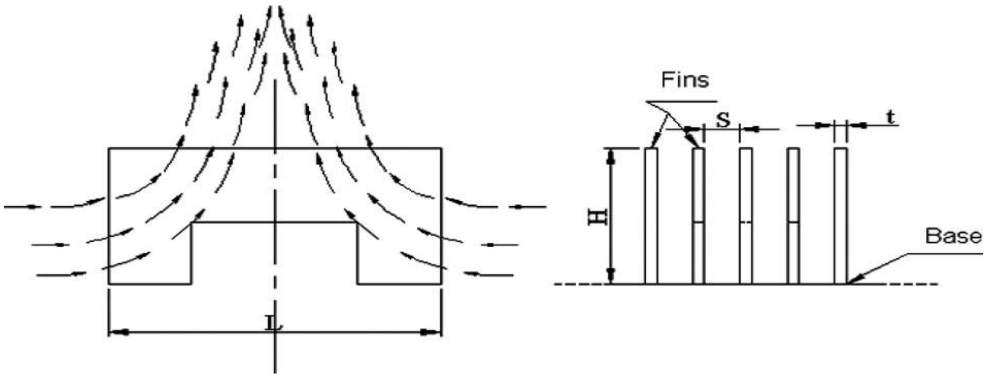

Fig. 2: Single chimney flow pattern for INFA

II. OBJECTIVES OF WORK

Experimental setup is developed to carry out the investigation on horizontal rectangular fin array with and without inverted notch. The objective of the work is to determine the heat transfer characteristics experimentally, and further to find out the enhancement in heat transfer in the case of notched fin arrays over normal fin arrays. In the lengthwise short arrays where single chimney flow pattern is present, the central portion of the fin flat near the base becomes ineffective. This is due to relatively hot air coming in contact with the fin portion. The air entering from the two sides, flow lengthwise gets heated up and hence has a tendency to go up forming flow pattern of single chimney. For conducting experiment, fin arrays were formed by assembling fin flats and separate spacers and tied together by tie bolts and nuts. Fin flats are separated by spacers forming fin channels. Insulating bricks are used to guard the leakage of heat from bottom and sides of the fin array. From the preliminary work it is found out that the insulating bricks are quite effective in preventing the leakage of heat and hence it was decided not to go for additional guard heaters. However the side and bottom heat loss was measured and accounted.

III. METHODOLOGY OF WORK

Requirement of test facility:
Test facility was developed by using following parts,
Fins:
Fins were cut from rolled aluminum plates of 3mm thickness on a shearing machine (press). Four holes were drilled for inserting 12.7mm diameter cartridge heaters and two holes for inserting tie bolts of 6mm diameter. Then all fin flats were finally finished to achieve the exact size on milling machine. As per requirement of inverted notch marking was made, afterwards four drills were drilled at corner of rectangular notch, after cutting by hacksaw final finishing was carried out by filing. Fig. 3 to 7 shows the sketches of rectangular fin flat with and without inverted notch with all pertinent dimensions. Two holes near corners on two fin flats were made with tapping for attaching thermocouple wires with the help of screws to fin flats.
Spacers:
Spacers of required size were cut out from rolled aluminum sheets of thickness 1 and 3mm on shearing machine. Holes were drilled for heaters and tie bolts similar to fin flats. Fig. 9 shows sketch of a specimen spacer plates with all pertinent dimensions.
Tie bolts, Nuts, Washers and Screws:
Tie bolts of 6mm diameter and of length 125mm are directly purchased from market with nuts and washers. They are used for assembling fin arrays, shown in Fig. 10.
Heaters:
Cylindrical cartridge heaters of 12.7mm diameter and 100mm in length were used for heating purpose. Heaters have nichrome flat wire as a heating element, with mica as electrical insulation and brass as cladding material Fig. 8 shows details of cartridge heaters. Four numbers of such heaters were used at a time.

Insulating Bricks:
To avoid the thermal losses, the assembly of fin array is placed in insulating bricks cavity. These insulating bricks are made from ceramic material alumna. Reason behind using these bricks is that alumna bricks are soft and it can cut to required shape easily.

Enclosure:
Array was placed in sufficiently large enclosure to provide natural convection condition. It is made up of mild steel angle section and plywood sheets are attached on four sides, one side having window for observation at center as shown in photograph 11 Observation window was prepared by cutting plywood sheet and inserting a transparent acrylic sheet.

Assembly:
The assembled fin array after placed in enclosure as shown in photograph 11

Instrumentation

Input power measurement:
Heaters were connected to AC mains via dimmer stat so that input power can be varied, as shown in figure 12 The input was measured with help of a calibrated wattmeter, multi range wattmeter of 75V/150V/300V and 1A/2A was used.

Temperature measurement:
Four thermocouples were used for average temperature of the fin array. Two for measuring heat lost by conduction through base of the array through insulating bricks, which were, placed 1.5cm apart. Two at sides of array 1.5cm apart, for measuring heat lost by conduction through sides of insulating bricks and one for measuring ambient temperature. Calibrated copper constantan thermocouples were used. 4.5 digit temperature indicators was used for temperature measurement

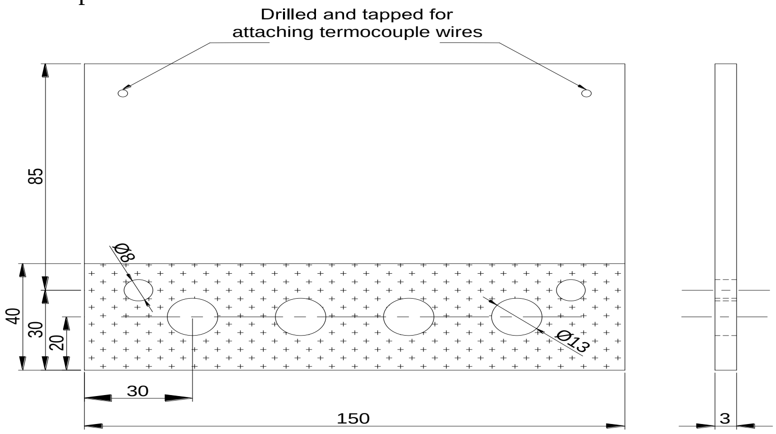

Fig. 3 Fin flat without notch

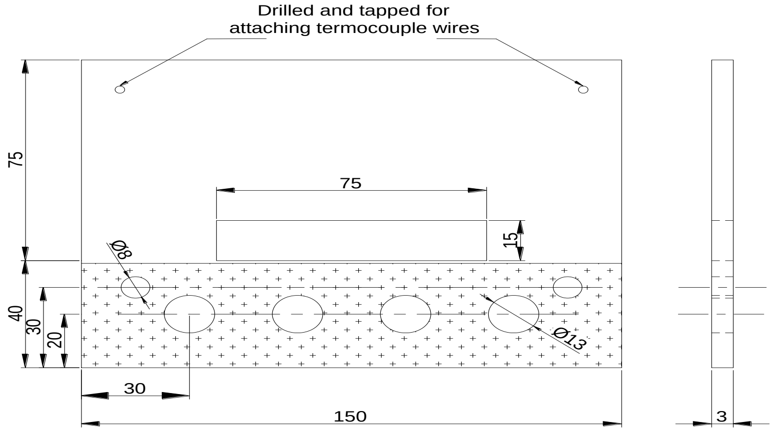

Fig. 4 Fin flat with inverted notch (10%)

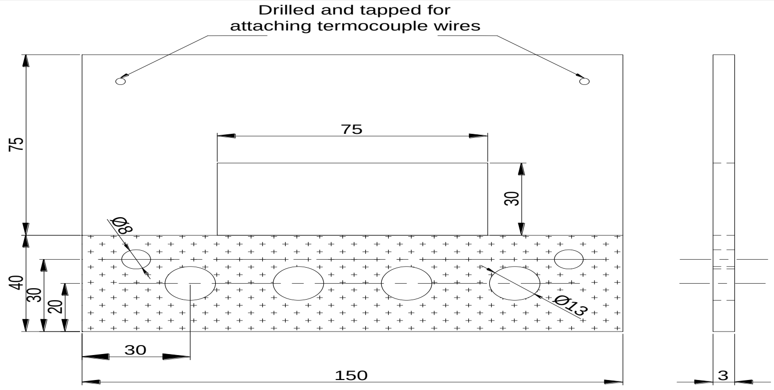

Fig. 5 Fin flat with inverted notch (20%)

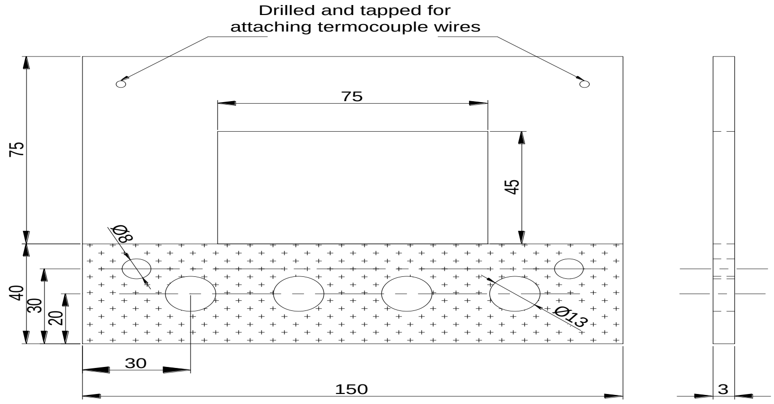

Fig. 6 Fin flat with inverted notch (30%)

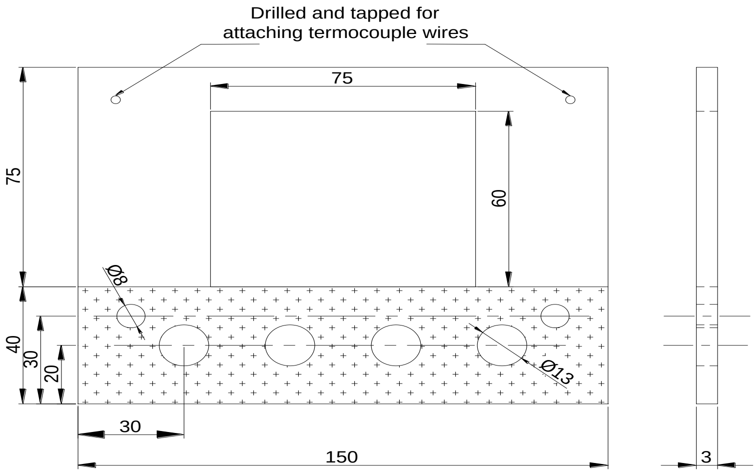

Fig. 7 Fin flat with inverted notch (40%)

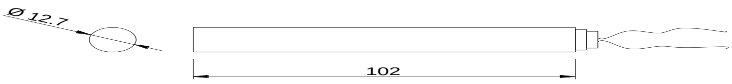

Fig. 8 Cartridge heater

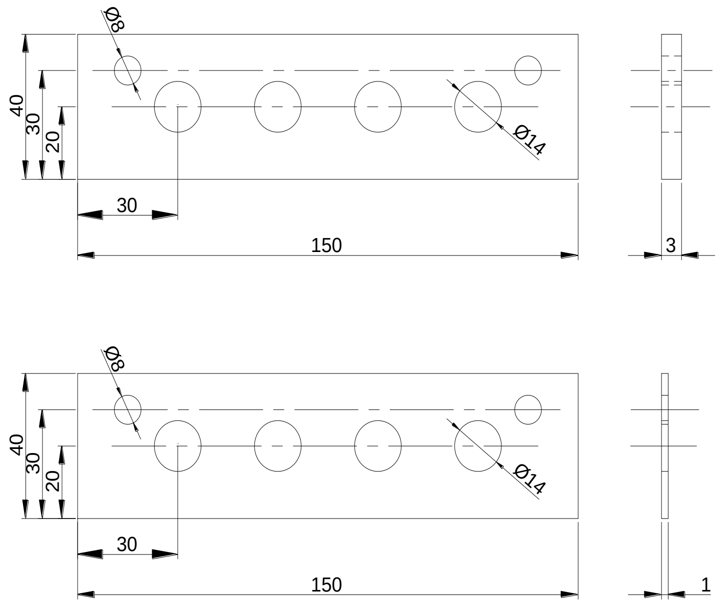

Fig. 9 Spacers

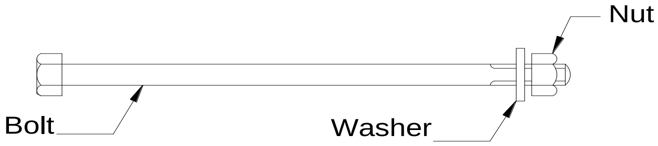

Fig. 10 Tie bolt with nut and washer
(All dimensions are in mm)

IV. EXPERIMENTATION

Experimental setup:
The assembled fin arrays with and without inverted notched fin flats are used to carry out the experimental work. Fig.12 shows the electrical circuit diagram of experimental setup. It was decided to compare the performance of inverted notched and normal fin arrays. Hence careful experimentation was necessary to evaluate heat transfer characteristics. For this purpose various fin arrays with different spacing and notched fin flats were assembled. The outmost without notched fin flats avoids cross flow to retain the desired single chimney flow. Normal array and INFAs having inverted notch of 10 %, 20 %, 30 % and 40 % area removal were tested keeping height and length constant. Five different spacing were tried from a large spacing of 13mm to closely spaced fin array with spacing of 4mm. The numbers of fin channels were varying from 6 to 14. This was done so as to cover the entire length of cartridge heater of 100mm within accuracy of ± 2 mm. Four different power input ranging from 50 to 200 watt in steps of 50 watt were used in this work.

Experimental procedure:

1. Fin array was assembled and placed in the position, with thermocouples and heaters connected as per requirement.
2. The predetermined heater input was adjusted with the help of dimmer stat.
3. The temperatures of assembled fin array at different positions and ambient temperature were recorded at the time intervals of 30 min. up to steady condition. Generally it took 3 to 4 hours to attain steady state conditions.
4. The heater input was kept constant by adjusting the dimmer stat for voltage fluctuations if any.

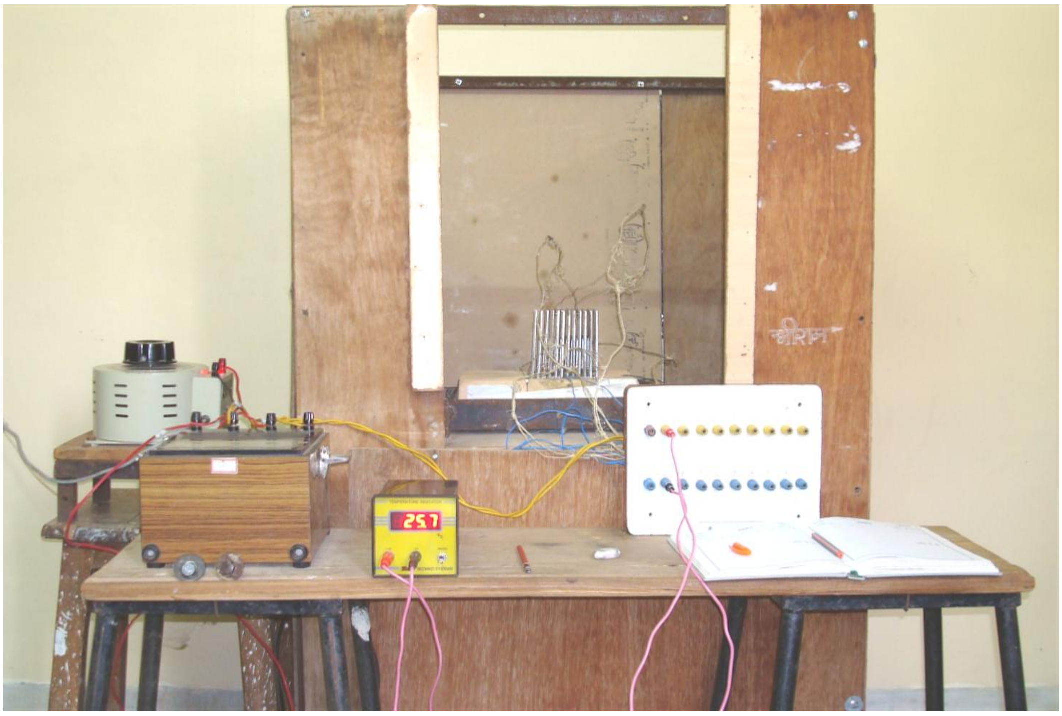

Fig. 11 Photograph showing fin array assembly with experimental setup

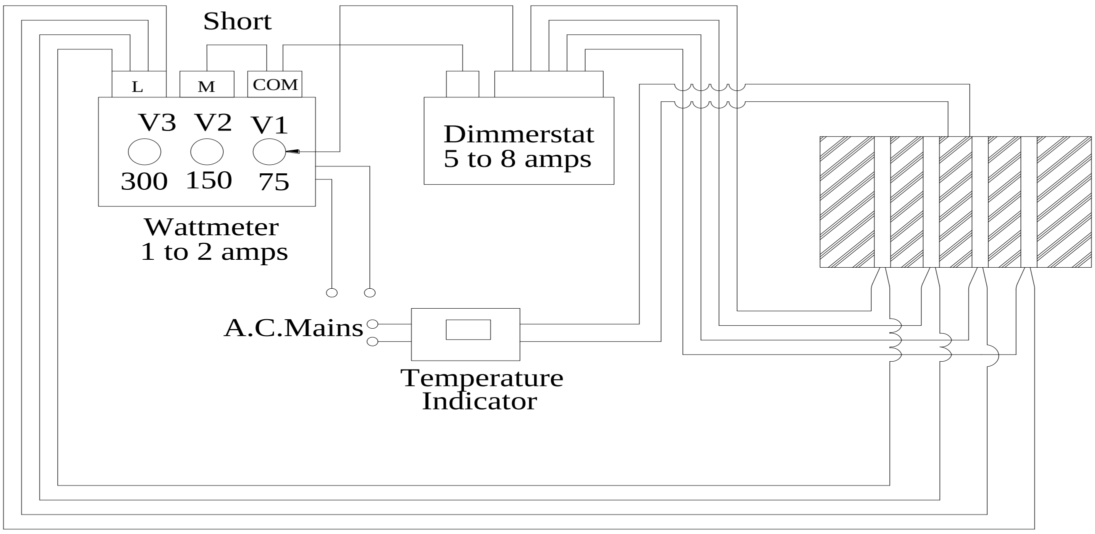

Fig. 12 Circuit diagram for experimental setup

For experimental setup, fin flats and spacers are cut from 3 mm and 1 mm thick rolled aluminum sheet and assembled together to form the required fin array. Fig. 10 shows the arrangement of assembled horizontal fin array (Photograph). Four cartridge heaters are placed in the base portion of the fin array. An assembled array is placed in an insulating brick cavity up to base portion to minimize heat loss by conduction through base and sides of the fin array. The array is placed in a sufficiently large enclosure to provide natural convection condition. Calibrated thermocouples with temperature indicator are used to measure temperatures at various locations of fin array. A calibrated wattmeter is connected to measure heater input.

Table1 Configuration table for experimentation

Length L = 150 mm   Height H = 75 mm   Width = 100 mm

Set No	Fin flat geometry	Spacing in mm	No. of fins	No. of channels	Base area (A_b) m2	Exposed (A_e) area m^2
I	Without notch (normal fin)	4	15	14	0.015	0.3594
		5	13	12	0.015	0.3132
		6	12	11	0.015	0.2907
		9	9	8	0.015	0.2214
		13	7	6	0.015	0.1755
II	With notch 10% area removed	4	15	14	0.015	0.3371
		5	13	12	0.015	0.2943
		6	12	11	0.015	0.2736
		9	9	8	0.015	0.2094
		13	7	6	0.015	0.1669
III	With notch 20% area removed	4	15	14	0.015	0.3090
		5	13	12	0.015	0.2706
		6	12	11	0.015	0.2520
		9	9	8	0.015	0.1943
		13	7	6	0.015	0.1561
IV	With notch 30% area removed	4	15	14	0.015	0.2810
		5	13	12	0.015	0.2468
		6	12	11	0.015	0.2304
		9	9	8	0.015	0.1791
		13	7	6	0.015	0.1453
V	With notch 40% area removed	4	15	14	0.015	0.2529
		5	13	12	0.015	0.2231
		6	12	11	0.015	0.2088
		9	9	8	0.015	0.1640
		13	7	6	0.015	0.1345

V. RESULTS AND DISCUSSION

In this section, the results are presented followed by relevant discussion. The results are obtained from the observations taken during experimentation and followed by detailed calculation procedure. The detailed observation tables were not given to avoid unnecessary increase of the thesis volume. Relevant part of observations was used to obtain the results as given in sample calculations. The notched configurations yield 50–55% higher values of heat transfer and coefficient of heat transfer compared with the unnotched fin for natural convection. For force convection, the notched configurations yield 60–65% higher values predicted for heat transfer and coefficient of heat transfer compared with the unnotched fin. This is mainly because of the removal of surface area from the stagnant zone of fin channel, thus indicating superiority of INFAs. It is also observed that the values of h_a are higher at higher heater input as expected.

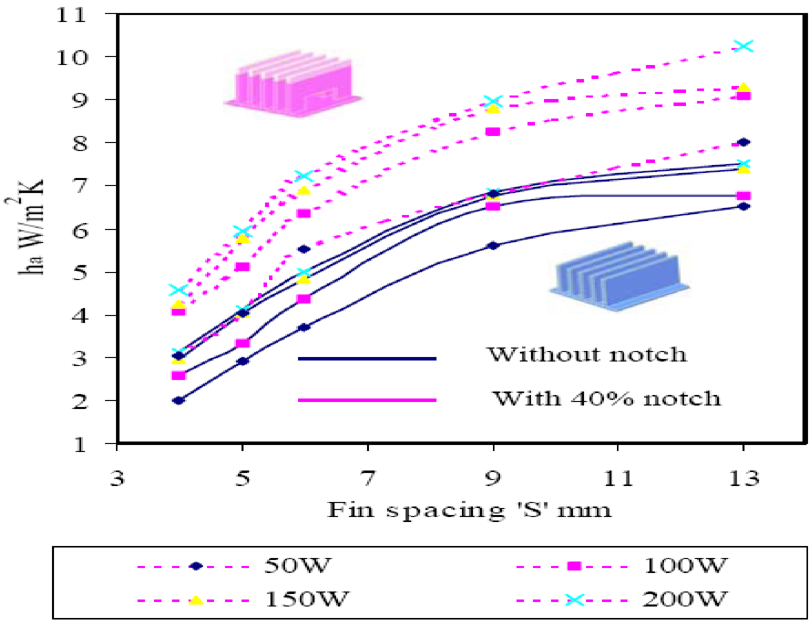

Fig. 13 Variation of average heat transfer coefficient h_a with fin spacing 'S' in mm

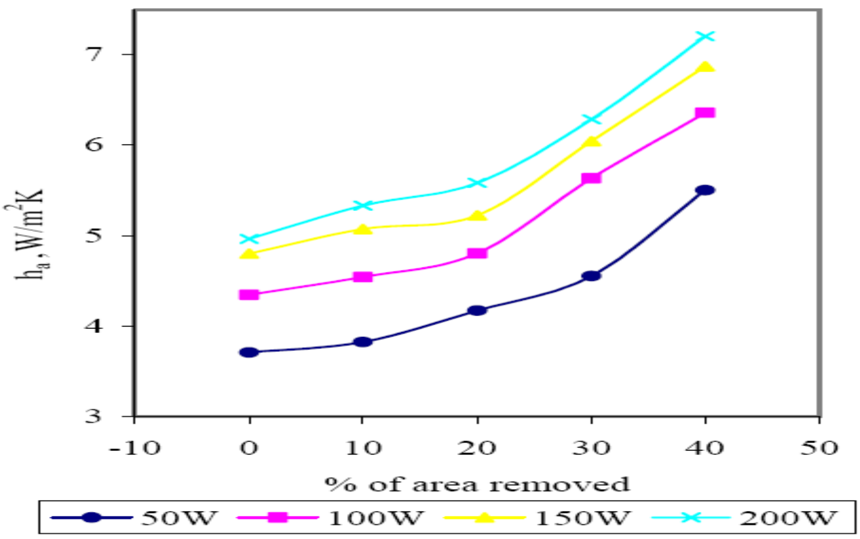

Fig. 14 Variation of average heat transfer coefficient h_a with % area removed for 6mm fin spacing

Effect of fin spacing on h_a:

Fig. 13 shows the effect of fin spacing on h_a with heater input as the parameter for normal and 40% INFA without area compensation. From figure it is clear that as the fin spacing increases h_a increases as expected, near about 65 to 75% rise is achieved. The increasing trend is steep up to spacing about 9mm. After that there is a gradual rise, thus indicating superiority of INFA. It is also concluded that the values of h_a are higher at higher heater input

Effect of % area removed on h_a:

Fig. 14 shows variation of h_a against percentage of area removed for 6mm fin spacing with heater input as the parameter. It is concluded that values of h_a for INFA are more than normal arrays as expected, the notched configurations yield 25 to 55% higher values. This is mainly because of removal of surface area from the inferior area of fin flat from heat transfer viewpoint. It is also concluded that h_a increases as the percentage of area removed increases. At higher heater input values of h_a are higher.

VI. CONCLUSION

Results were obtained and presented in the form of various heat transfer parameters. It is concluded that, the values of average heat transfer coefficient h_a increases as percentage of area removed increases near about 30 to 70% rise is achieved as compared to normal fin array. The value of h_b increases as fin spacing decreases, reaches its maximum, giving optimum spacing and again decreases. For very less fin spacing the values of both h_a and h_b are significantly less. The value of Nu_a increases with increase in fin spacing. The value of Nu_b increases as fin spacing decreases; it reaches to its maximum and again decreases. The average surface temperatures of INFA are less than normal fin arrays. Though surface area of INFA decreases its ΔT decreases, indicates its superiority.

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