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Experimental Analysis of Staggered Fin Arrays

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Abstract:—It is proved till today that special surface geometry or special fin pattern may enhance heat transfer coefficients. The area selected for investigation is experimental analysis of one of the special fin pattern i.e. staggered fin arrays. They are compared with continuous fin array. From the literature survey, test section and fin arrays under study are designed. Four sets of 38 mm height and four sets of 48 mm height are designed. For each height 33.33 %, 40% and 50% lengthwise staggering is done. Then by performing an experiment, readings of 11 temperatures were recorded for five different heater inputs. From these readings Nusselt number for each array for given range of heater input is calculated. Conduction and radiation losses are also calculated. The arrays under study are compared. It was predicted that array with staggered fins will have higher values of Nusselt number for all values of heater input and increases when % staggering is increased and the experiment gave the same results. Nusselt number increased up to 3.5 to 25% for 38mm height and 1 to 45% for 48mm height. The non-dimensionalized parameters are also presented by plotting Nu verses Gr.Pr graphs. Thus it is concluded that the staggered arrangement enhances the heat transfer rate. In other words it can be concluded that the staggered arrays may be used for augmentation of heat transfer in vertical fins.

Keywords:—Staggered fin array, heat transfer augmentation, special fin arrangement, higher Nusselt Numbe, efficient cooling techniques.

I. INTRODUCTION

The need for more efficient cooling techniques of devices prompted study into heat transfer and flow characteristics of various configurations of finned surfaces. Literature survey shows various areas where the work is distributed like
(I) Horizontal and vertical fin arrays
(II) Various fin geometries and fin patterns
(III) Various combinations of convection and radiation
(IV) Effects of obstructions that is shrouds.

Many of the earlier investigators have studied the problems concerned with the arrays having vertical fins on horizontal and vertical base surfaces, extensively both theoretically and experimentally.

It is proved that the use of special surface geometries and special fin patterns may allow higher heat transfer coefficients than those given by plain extended surfaces. In this connection, fin surfaces made by staggered plates aligned parallel to flow are employed in compact heat exchanger and electronic equipment cooling, because of their capability of high heat transfer rates per unit volume.

Applications:-

- Air cooled engines, finned heat exchangers.
- Cooling of electronic equipments like transducers, heat sinks.

II. NOMENCLATURE

- T_s = Average Fin Array Temperature (^{0}C)
- T_∞ = Surrounding Temperature (^{0}C)
- A_S = Surface Area (m^2)
- ρ =Density of Fluid (kg/m^3)
- μ =Dynamic Viscosity (kg/m s)
- k =Thermal Conductivity (W/m K)
- υ =Momentum Diffusivity (μ / ρ)
- α =Thermal diffusivity ($k/ \rho C_p$)
- A_b = Area of fin Base (m^2)
- A_a =Average area of fin surface (m^2)
- H =Height of fin (m)
- x_b =Distance between holes in siporex box (m)
- t_w = Thickness of wooden insulation (m)
- ΔT_{cond-b} =Temperature difference across the base (^{0}C)
- $\Delta T_{cond-wr}$ =Temperature difference across the right wooden block (^{0}C)

- $\Delta T_{cond-wl}$ = Temperature difference across the left wooden block(^{0}C)
- q_{cond-b} = Conduction loss through base insulation (W)
- $q_{cond-wr}$ = Conduction loss through right wooden insulation (W)
- $q_{cond-wl}$ = Conduction loss through left wooden insulation (W)
- $q_{cond-total}$ = Total conduction Loss (W)
- q_{rad} = Radiation loss through fin array (W)
- q_{conv} = Heat transfer rate due to convection (W)
- q_{in} =Total Heat input (W)
- ΔT_{conv} = Temperature difference between the array and ambience (^{0}C)
- h_a= Average heat transfer coefficient (W/m^2 K)
- Nu_a= Average Nusselt Number.

III. EXPERIMENTAL SETUP

The schematic view of the experimental apparatus is illustrated in fig.1.The main component consists of the test section, dimmerstat and power supply. The test section includes fin array, having base-plate connected to electric heaters. The fins are attached to the base-plate with aluminium tape to get minimum contact resistance and heat loss. The fin/base-plate assembly is made up of aluminium because of its high thermal conductivity, low emissivity, and easy machinability.

The 8 test fin arrays are used in the experiment with constant spacing but variable % staggering. The base-plate thickness is constant for all the samples. Four arrays with 38 mm height and four arrays with 48 mm height are used. For each height there is a continuous array and then it is staggered lengthwise by 33.3 %, 40%, and 50%.

Total 11 K-thermocouples are used to measure temperatures at different locations. Four K-thermocouples are inserted in four different locations in the fin array to determine the average temperature of it. Two K-thermocouples are inserted in the base insulation that is in the siporex box to find the base conduction loss and two K-thermocouples are inserted in each side of the wood insulation of the array to determine the side conduction losses.

Four rod heaters are inserted in the base frame and it is insulated by siporex box to minimize heat loss from the heater to the environment.

The electric power is supplied to the heaters by a stabilized AC source and is measured with the help of voltmeter and ammeter. The range of heater input is 25W to 125 W with an increment of 25W. For each array about 6 to 8 hours were required to attain the steady-state condition.

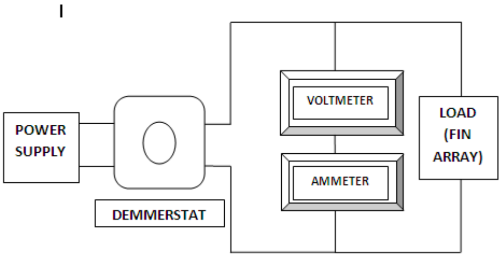

Fig.1 Schematic of the Experimental Setup

Fig.2 Actual Photo of Experimental setup

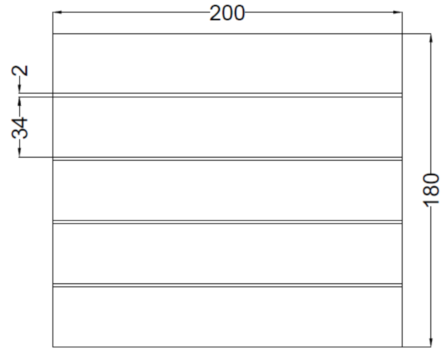

Fig.3 Continuous Array

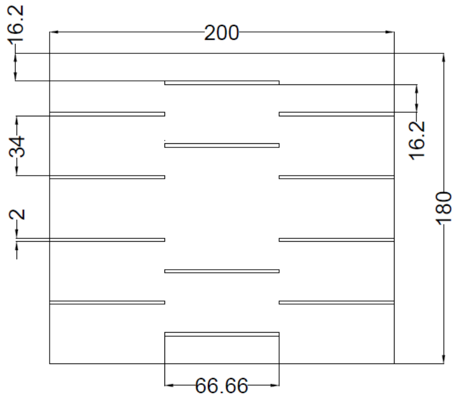

Fig.4 Array with 33.33% staggering

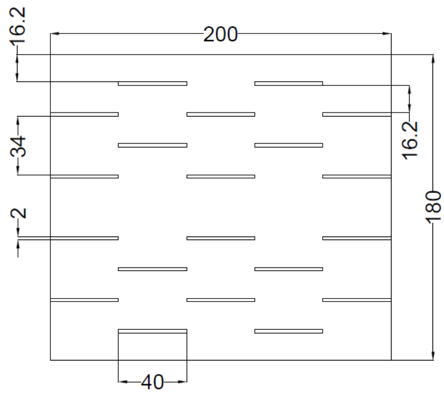

Fig.5 Array with 40% staggering

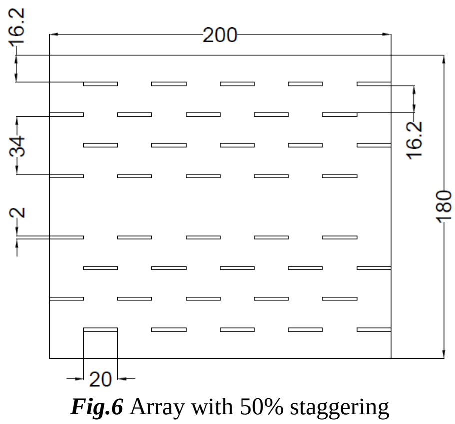

Fig.6 Array with 50% staggering

IV. EXPERIMENTATION

Total 8 sets are observed under experimentation. Out of which 4 sets are of height 38 mm with varying % staggering (33.3 %, 40%, and 50%) and 4 sets of height 48 mm with varying staggering (33.3 %, 40%, and 50%).

The heater input was varied as 25, 50, 75, 100, 125 W for each set. Thus total 40 sets of readings were taken. About 6 to8 hours were required to attain the steady state leading to 1 or 2 sets per day.

Observations:

1. Distance between holes in siporex box (x_b) = 0.025 m
2. Thickness of wooden insulation(t_w) =0.018 m
3. Area of base (A_b)= lxb=(0.2 x 0.18)= 0.036 m^2
4. Average area of fin (A_a) = A_b + 5(lxH)x2 m^2
5. For 38 mm height Arrays A_a =0.112 m^2
6. For 38 mm height Arrays A_a =0.132 m^2
7. T_1= Ambient Temperature
8. T_2 &T_3 = Temperatures for measuring conduction loss through base of fin array
9. T_4,T_5= Temperatures for measuring conduction loss through one side of fin array
10. T_6,T_7,T_8,T_9= Temperatures for measuring average temperature of fin array
11. T_{10},T_{11}= Temperatures for measuring conduction loss through other side of fin array

V. RESULTS AND DISCUSSION

Results can be calculated as follows.

1. Temperature difference across the base
   $\Delta T_{cond-b} = T_3 - T_2$
2. Temperature difference across the right wooden block
   $\Delta T_{cond-wr} = T_4 - T_5$
3. Temperature difference across the left wooden block
   $\Delta T_{cond-wl} = T_{10} - T_{11}$
4. Conduction loss through base insulation
   $q_{cond-b} = K_c x A_b x(\Delta T_{cond-b}/x_b)$
5. Conduction loss through left wooden insulation
   $q_{cond-wl} = K_w$x(wood length xH) x($\Delta T_{cond-wl}/t_w$)
6. Conduction loss through right wooden insulation
   $q_{cond-wr} = K_w$x(wood length xH)x($\Delta T_{cond-wr}/t_w$)
7. Total conduction Loss
   $q_{cond-total} = q_{cond-b} + q_{cond-wl} + q_{cond-wr}$
8. Radiation loss through fin array
   $q_{rad} = \sigma x A_a x[(T_s + 273)^4 - (T_1 + 273^4)]$
9. Total Heat input $q_{in} = VxI$
10. Average Fin array Temperature
    $T_s = (T_6 + T_7 + T_8 + T_9)/4$
11. Heat transfer rate due to convection
    $q_{conv} = q_{in} - q_{cond-total} - q_{rad}$
12. Temperature difference between the array and ambience
    $\Delta T_{conv} = T_s - T_1$
13. Average heat transfer coefficient
    $h_a = q_{conv} / (A_a x \Delta T_{conv})$
14. Grashoff Number
    $Gr_H = (gx\ \beta\ x \Delta T_{conv}\ x\ H^3)/\nu^2$
15. Average Nusselt Number
    $Nu_a = (ha*H)/k$

Here, the properties ν (Thermal Diffusivity), k (Thermal Conductivity, β (Temperature Coefficient), Pr (Prandlt Number) are taken from standard tables at the mean film temperature (T_s+T_1)/2.

***Table I**:* Nu_a vs. q values (For H = 38mm)

Heat Input (W)	25	50	75	100	125
SetI	17.734	18.392	21.27	24.63	24.649
SetII	19.023	19.71	23.06	25.109	25.531
SetIII	20.001	21.01	23.4	25.682	26.388
SetIV	22.234	22.52	24.39	26.146	29.062

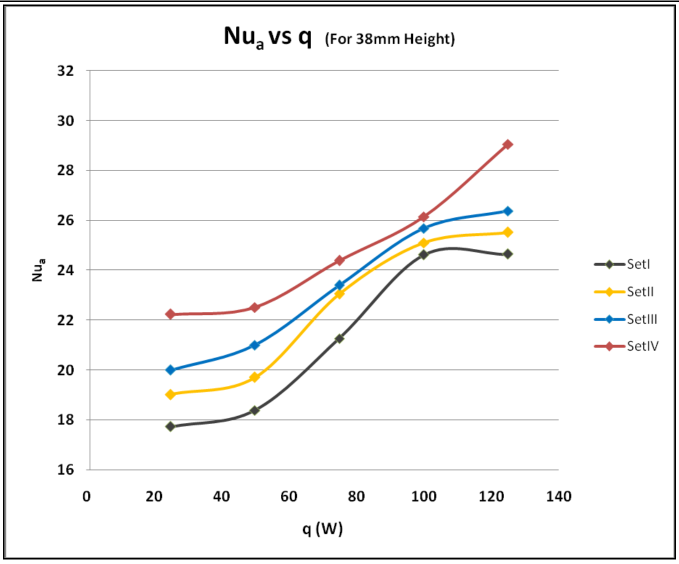

Fig.7 Nu_a vs q

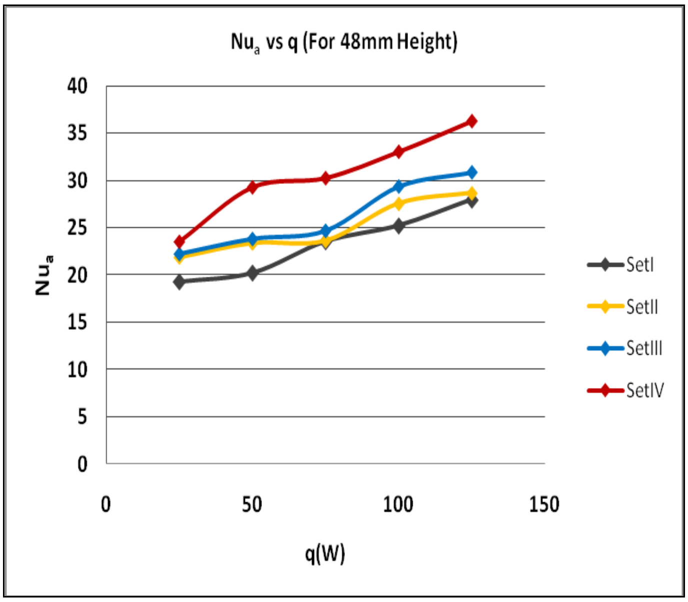

Fig.8 Nu_a vs q

Table II: Nu_a vs q values (For H = 48mm)

Heat Input (W)	25	50	75	100	125
SetI	19.299	20.235	23.546	25.22	27.95
SetII	21.88	23.368	23.635	27.57	28.68
SetIII	22.248	23.83	24.688	29.35	30.84
SetIV	23.55	29.29	30.264	33.04	36.26

From figure 7 and 8 it is clear that the trend of Nusselt number is increasing with increasing heater inputs and % lengthwise staggering. This trend in non-dimensionalized form is presented in figures 9 and 10 in the graphs Nu_a vs Gr.Pr.

The reason is the enhancement in flow pattern due to which the wetted surface of the fins is increased leading to higher effective fin surface in staggered arrangement than the continuous array.

Table III: Nu_a vs Gr.Pr values(For H = 38mm)

SetI	Gr.Pr	73065.69	143059.1	189216.6	234649.8	269032.9
	Nu_a	17.734	18.392	21.27	24.63	24.649
SetII	Gr.Pr	71044.39	135874.1	177562.6	216688.7	261434.2
	Nu_a	19.023	19.71	23.06	25.109	25.531
SetIII	Gr.Pr	67766.72	128644	176043	216446.9	253891.7
	Nu_a	20.001	21.01	23.4	25.682	26.388
SetIV	Gr.Pr	61815.65	119989.7	162339.9	213383.3	243697.6
	Nu_a	22.234	22.52	24.39	26.146	29.062

Table IV: Nu_a vs GR.Pr values (For H = 48mm)

SetI	Gr.Pr	63418.85	120544.5	151592.6	196046.8	213,429.40
	Nu_a	19.299	20.235	23.546	25.22	27.95
SetII	Gr.Pr	56818.11	106192.5	153294.7	184896.8	217,475.47
	Nu_a	21.88	23.368	23.635	27.57	28.68
SetIII	Gr.Pr	55949.49	100549.2	147438	171258.1	198,308.28
	Nu_a	22.248	23.83	24.688	29.35	30.84
SetIV	Gr.Pr	53323.6	84541.28	123277.9	153167.4	187,236.69
	Nu_a	23.55	29.29	30.264	33.04	36.26

The % increase in Nusselt number for each array is tabulated in the tables V and VI.

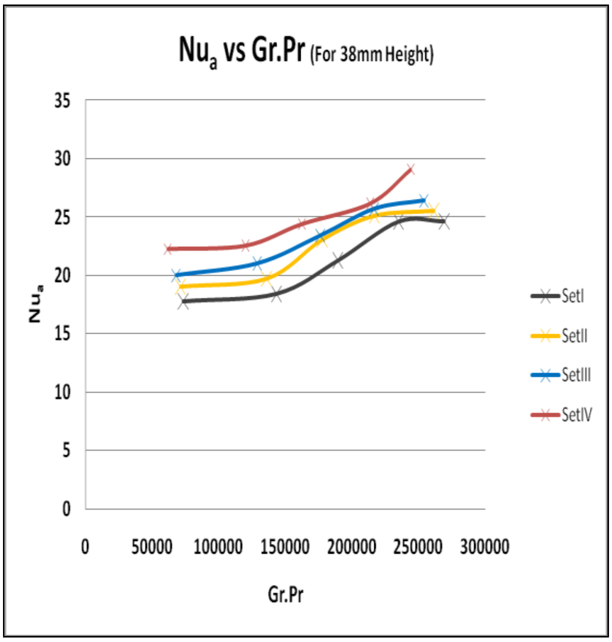

Fig.9 Nu_a vs Gr.Pr

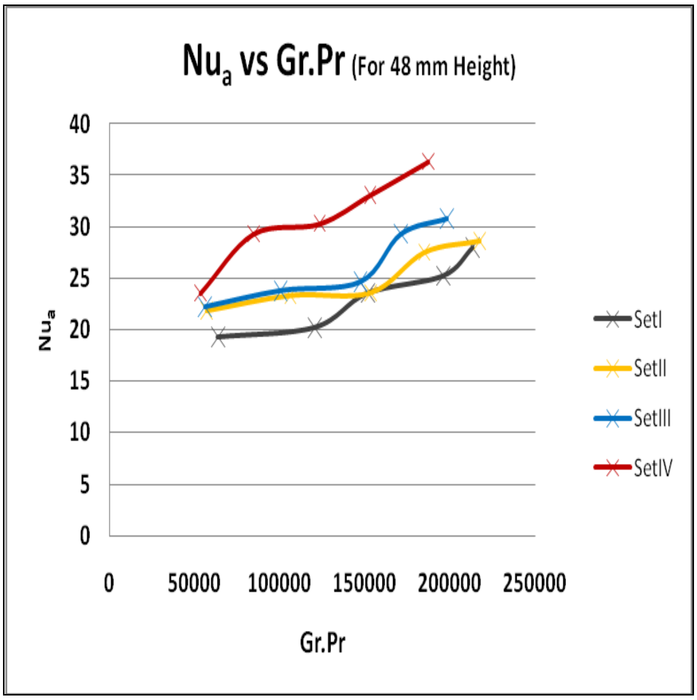

Fig.10 Nu_a vs Gr.Pr

Table V: % increase in Nusselt Number (For H = 38mm)

Heater Input		25	50	75	100	125
% increase in Nu_a (38 mm Height)	33.33% Staggering	7.26	7.16	8.42	7.89	3.57
	40% Staggering	12.7	14.34	10.01	4.27	7.055
	50% Staggering	25.37	22.44	14.66	8.33	17.90

Table VI: % increase in Nusselt Number (For H = 48mm)

Heater Input		25	50	75	100	125
% increase in Nu_a (48 mm Height)	33.33% Staggering	13.37	15.48	0.8	9.31	2.6
	40% Staggering	15.28	17.76	4.85	16.37	10.33
	50% Staggering	22.02	44.74	28.5	31	29.73

VI. CONCLUSIONS

Arrays with staggered fins have higher values of average Nusselt number for all heater inputs, and hence it can be concluded that the staggered arrangement enhances the heat transfer rate. The experimental results lead to the following conclusions:

***Table VII**:* Conclusions

38 mm Fin Height			
	Lengthwise Staggering		
Range of % increase in Nusselt Number	33.33%	40%	50%
	3.5 to 8	4 to 14	8 to 25
48 mm Fin Height			
Range of % increase in Nusselt Number	1 to15	5 to 18	22 to 45

In other words it can be concluded that the staggered arrangement with some optimum spacing (which needs to be found out from the experimental study) can be used for augmentation of heat transfer in vertical fins. It can also be concluded that each arrangement has higher value of Nusselt number for higher height. This is due to increased heat transfer area.

The use of special fin patterns may allow higher heat transfer coefficients than those given by plain extended surfaces. In this connection, fin surfaces made by staggered plates aligned parallel to flow are employed in compact heat exchanger and electronic equipment cooling, because of their capability to remove heat with high heat transfer rates per unit volume.

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