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The Heat Transfer Analysis of Vertical Heated Plate Using Fin Array.

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Abstract

In this paper the investigation is being done on heat transfer rate on vertical heated plate using different fin array by experimental study, the numerical analysis of this technique is done by using Ansys 15.0 Workbench. Fins offer an economical and trouble free solution in many situations demanding natural convection heat transfer. Fin arrays on horizontal, inclined and vertical surfaces are used in variety of engineering applications to dissipate heat to surroundings. Natural convection heat transfer from vertical surfaces with large surface element is encountered in several technological applications like electronic circuit which represents an inherently reliable cooling process. This heat transfer enhancing technique is investigated for natural convection adjacent to a vertical heated plate with a multiple v- type and s-type partition plates (fins) in ambient air surrounding. This V-type partition plate is compact and hence highly economical. As compared to conventional vertical fins, this v-type partition plate works not only as extended surface but also as flow turbulator. The numerical analysis of this technique is done by using Ansys 15.0 Workbench for natural convection adjacent to a vertical heated plate in ambient air surrounding. The experimental studies have been carried out on three geometric orientations viz., a) Vertical base with S-fin array b) Vertical base with short length V fin & c) Vertical base V-fin with bottom spacing. It was observed that among the three different fin array configurations on vertical heated plate, V-type fin with short length design performs better than vertical S fin array and V-fin with bottom spacing design. In this research work the attempts are also made to validates the result using Ansys 15.0 workbench.

Keywords: S fin and V type fins , V-type partition plate, ansys 15.0 workbench analysis, numerical analysis.

Introduction

Natural convection cooling with the help of finned surfaces often offers an economical and trouble free solution in many situation. For effective dissipation of heat, plain horizontal surfaces facing upward are preferred since they provide relatively higher surface heat transfer coefficients than other orientations. The active heat transfer enhancement techniques have not found commercial interest because of the capital and operating cost of the enhancement devices. The majority of passive techniques employ special surface geometry or fluid additives for enhancement i.e. no direct application of external power. Whenever it is difficult to increase the rate of heat transfer either by increasing heat transfer coefficient or by increasing the temperature difference between the surfaces and surrounding fluid, the fins are commonly used. The tall vertical fin array restricts the heat transfer enhancement from tall vertical base plate. This is because of the boundary layer thickening and subsequent interference developed over the height. To obtain an appreciable improvement of the heat transfer in case of the horizontal fin array and Vertical fin array the fin height may be increased .The modes of heat transfer are conduction, convection and radiation. Based upon the cross sectional area type, straight fins are of different types such as rectangular fin, triangular fin, trapezoidal fin, parabolic fin or cylindrical fin. Fin performance can be measured by using the effectiveness of fin, thermal resistance and efficiency. Triangular fins have applications on air cooled cylinders and compressors, outer space radiators and air conditioned systems in space craft. Fins are also extensively used in cooling of generators, motors, transformers, refrigerators, cooling of computer processors and other electronic devices etc. Enhancement of heat transfer is of vital importance in many industrial applications. One of the methods of enhancing heat transfer is the use of extended surfaces or fins. The current trend in the electronic industry is miniaturization, making the overheating problem more acute due to the reductions in surface area available for heat dissipation .Thus heat transfer from fin arrays has been studied extensively, both computationally and experimentally.

1.1 Description and working of fins

Engine life and effectiveness can be improved with effective cooling. The cooling mechanism of the air cooled engine is mostly dependent on the fin size. The heat is conducted through the engine parts and convected to air through the surfaces of the fins. Insufficient removal of heat from engine will lead to high thermal stresses and lower engine efficiency. As air-cooled engine builds heat, the cooling fins allow the wind and air to move the heat away from the engine. On the basis of above advantages of fins they are termed as Extended Surfaces.

I. Extended surfaces

Temperatures Ts and T_0 are fixed by design considerations, as is often the case, there are two ways to increase heat transfer rates:

(1) To increase convection heat transfer coefficient [h] &

(2) To increase the surface area [A_S].

The alternative is to increase the surface area by attaching to the extended surfaces called fins made of highly conductive materials. The main purpose of extended surfaces is to increase the heat transfer rate. Whenever it is difficult to increase the rate of heat transfer either by increasing heat transfer coefficient or by increasing the temperature difference between the surfaces and surrounding fluid, the fins are commonly used.

II. Materials used for fins

Generally there are two types of materials used for fins aluminium and copper. The thermal conductivity of aluminium is 225 W/m K and that of copper is 385 W/m K. The melting and boiling point of copper are 1084˚ and 2595˚ and that of aluminium are 658˚ and 2057˚.In experimental work the material used for fins is aluminium.

2. Literature review

Literature survey has been done in order to study the research done by various researchers on the heat transfer analysis of heated plates by using fin .The few of the articles chosen for review work are stated below.

Baskaya S, Sivrioglu M., and Ozek M. [1] carried out parametric study of natural convection heat transfer from the horizontal rectangular fin arrays. They investigated the effects of a wide range of geometrical parameters like fin spacing, fin height, fin length and temperature difference between fin and surroundings; to the heat transfer from horizontal fin arrays. However, no clear conclusions were drawn due to the various parameters involved. M.J. Sable, S. J. Jagtap, P.S.Patil, P. R. Baviskar, and S.B.Barve [2] investigated heat transfer enhancing technique for natural convection adjacent to a vertical heated plate with a multiple V- type partition plates (fins) in ambient air surrounding. They concluded that as compared to conventional vertical fins, the V-type partition plates work not only as extended surface but also as flow turbulator.It is further observed that the base heat transfer coefficient (hb) of V-type fin array is better than all other configurations

The work by R.S.Prasolov , Heya, Fujii , Bhavnani and Bergles [3] suggested that the roughness elements whose height is less than the boundary layer thickness will have no appreciable influence on the heat transfer of natural convection and these elements will work as flow retarder rather than the heat transfer promoter.

Misumi and Kitamura [4] have reported an experimental work on enhancement of natural convection heat transfer from vertical plate having a horizontal partition plate and V-plates in the water ambience. They found that the heat transfer in the downstream region of the partition plate is markedly enhanced when the plate height exceeds certain critical values because of the inflow of the low temperature fluid into the separation region. For vertical plate with V-shaped fins, authors obtained 40% higher heat transfer coefficient than the conventional vertical fins. From the results, they observed that the ratio of the heat transfer enhancement exceeds the ratio of the surface enlargement. An extensive review and discussion of work done on the convective heat transfer in electronic equipment cooling was presented by Incropera [5], summarizing various convection cooling options. A great number of analytical and experimental works has been carried out on this problem since Elenbaas first introduced the problem of natural convection between vertical parallel plates. One of the earliest studies of the heat transfer from fin arrays is that of Starner and McManus who presented heat transfer coefficients for four differently dimensioned fin arrays with the base vertical, 45 degrees and horizontal. They showed that in correct application of fins to a surface actually may reduce the total heat transfer to a value below that of the base alone.

Jones and Smith [6] studied the variations of the local heat transfer coefficient for isothermal vertical fin arrays on a horizontal base over a wide range of fin spacing. A simplified correlation, an optimum arrangement for maximum heat transfer and a preliminary design method were suggested.

S.S.Sane, N.K.Sane, and G.V. Parishwad [7] established a match between the experimental results and the results obtained by using CFD software for a horizontal rectangular notched fin arrays dissipating heat by natural convection. Both the flow patterns as well as the trend of heat transfer coefficient are found to be within 5% range. It is observed that total heat flux as well as the heat transfer coefficient increases as the notch depth increases.

Kharche and Farkade [8] used fin with notch and with-out notch of copper as a fin material on vertical heated plate for the experimental work. The shape of the notch was rectangular. They compared the effect of heat transfer coefficient for notch and without notch fins. From the experimental study it was found that the heat transfer rate in notched fins was more than the unnotched fins. The average heat transfer coefficient for without notched fin was 8.3887W/m2K and for 20% notched fins it was 9.8139W/m2K. Also the copper gives more heat transfer rate than aluminium plate.

R. L. Edlabadkar [9] did their research work on single V-type partition plate with different included angles, in air as ambience in the laminar air flow over a vertical base plate with length 0.3m, width 0.3m, and V shape fin (the fin limb length is 0.15m and width 0.05m) attached to it .Results were numerically tested using Computational Fluid Dynamics (CFD) software of FLUENT with laminar viscous model. Computations were performed for the geometrical configurations with fin included angles 90°, 120° and 60°, for equal base and fin areas dissipating heat under natural convection condition for temperature difference θ, varying from 30°C to 150°C. The results show that the 90° V fin gives least resistance to flow separation in the upstream region and most effective high heat transfer region in the downstream region of the base plate.

T. Aberra, S.W. Armfield [10] studied numerically the stability of the natural convection boundary layer on an evenly heated vertical plate for a Boussinesq fluid with Prandtl numbers of Pr= 0.733 and 6.7, With Ra=1x1010,0<x<1.25 (giving the local Ray-leigh number 0 < Rax < 2.4 x1010. A Boussinesq fluid with Prandtl numbers of Pr= 0.733 (air) and 6.7 (water).

3. Problem definition

Numbers of researchers have worked on V-fin. One of them used single V-fin with water ambience. Another used single V-fin with air ambience for computational work and found that V-fin gives more heat transfer coefficient than horizontal and vertical fin. It is due to the thickness of boundary layer which is more for horizontal fin and vertical fin as compared to V-fin. It was also found that V-fin acts as a flow turbulator. After this one of the researchers have used multiple V-fins for his experimental work and observed that multiple V-fins on base plate give more heat transfer coefficient than horizontal and vertical rectangular fin. So it is decided to work on V-fin array for experimental work, as V-fin gives greater heat transfer coefficient. In the present work it is introspected experimentally and computationally to verify the performance of Vertical Heated plate with S fins and Short length V fin in heat transfer enhancement. For this new geometry S fins and short length V fins is used as a test channel. The intention behind this modification is to actually investigate the heat transfer enhancement over vertical heated plate and its effectiveness on different fin geometry. The Vertical plate with S fin and short length V fin are attached on vertical plate and performance is tested for varying the temperatures.

4. Experimental set up

The setup consists of a square M.S plate box on which rheostat i.e.: Dimmer stat is attached with Digital Temperature Indicators. The test plate of 250*250* 3mm thickness is used for experimentation. Vertical Plate with spring coil is attached on the aluminium plate. Input to heater is controlled through rheostat. Seven thermo couples T1, T2, T3, T4, T5, T6 and T7 are embedded on the heated plate and fins of the test section to measure the change in temperature of base plate and plate is observed after every 20 minutes. Average temperature of plate is evaluated by summation of temperatures from T1 to T4 and fins temperatures are observed by thermocouples T5, T6 and T7. The digital device Digital Temperature Indicator is used to display the temperature measured by thermocouple at various position. The temperature measured by instrument is in 0C. Heated plate is cooled till ambient temperature to measure better heat transfer coefficient from the vertical plate.

4.1 Objectives of setup

The following are the objectives of this Setup:

1. To heat up the outer base plate surface uniformly to 400 0 C.
2. To measure the temperature at different point.
3. To calculate Nusselt Number for laminar and turbulent flow of air.
4. To calculate heat transfer coefficient of Each plate
5. To calculate effectiveness of the fins .

According to the objective the arrangement of block diagram is as shown Fig. 1.

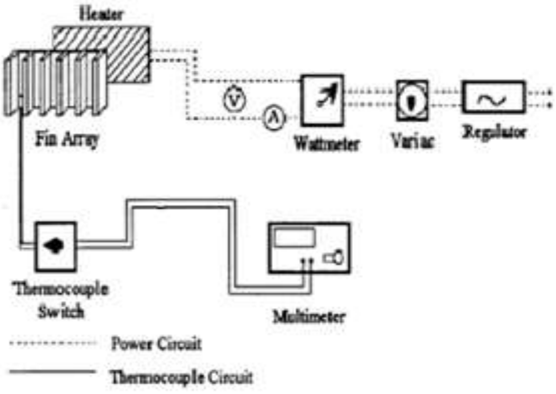

Fig. 1 Block diagram of required set up

Fig.2 Experimental set up

4.2 Components:

Thermocouples:K type Thermocouple is used to measure the surface temperature of the tube, which is having range -200 ^{0}C to 1200 ^{0}C

Digital Temperature Indicator: D.T.I. is used to measure the temperature. Accuracy is about (27 ±) 60 ^{0}C

Rheostat: Heats com model Volt=230, Watt=3000 is used to give a control voltage and amp to give control rate of heating by using heating coil.

Fig. 3 Vertical plate with S fins

Fig.4 Vertical plate with short length V-type fins .

Finally the setup has made by bringing all components together, and what we get is presented in the following picture Fig.2 having components 1. Dimmer stat, 2.Test plate, 3.Heating Coil, 4.Digital Temperature Indicator, 5.T1 to T7 Thermocouples,

The experimental set up is as shown in the fig.2. The base plates used for the experiment were made of 3mm – thick 250mm – high, 250mm – wide aluminium. Aluminium glue was used to stick all the fins as per different combination on plain vertical plate of aluminium. Tapping was done at different suitable locations (5 points) to tie the thermocouples. Aluminium plates of 3 mm thick, 250mm long and 20mm wide were used as a material for generating vertical S fins and different V-type fins. The rated power of 400 Watts, 2 Amp at 230 volts, is supplied to the plate . mica claded, thin plate type, 250 mm long and 250 mm wide square electrical heater wire was sandwiched between the symmetrical vertical base plates.The spread of the sandwiched electrical heater ensured almost uniform surface temperature of the test plates. The heater was supplied with stabilized a/c current through dimmer stat and wattmeter. Multi range wattmeter of 75V/150V/300V/400V and 1A/2A was also used. For the purpose of local temperature measurement of the test plates, seven calibrated constantan thermocouples were put up on the test plates at suitable location. Out of these, four were centrally tapped on the plate and three were put up at fin corners. In case of V-plate fins, one thermocouple was placed below the V corner and another in the V corner. A separate thermocouple was used to measure the ambient temperature in the enclosure. A calibrated digital temperature indicator was used to measure the thermocouple output. Heat inputs of 50, 75, 100, 150, 250, 300, 325 and 400 watt were used. The assembled set up was hung in vertical position; in a box type enclosure under ensured good natural convection conditions. All the readings were recorded under steady state conditions.

4.3 Experimental procedure

Following steps are followed for experimental work

- Switch on the Heater input .
- Using rheostat increase the supplied air heater input.
- Vertical Base plate is our heating source which must be heated till 400 0C.
- Start taking readings once the plate temperature drops down from 400 0C to ambient air temperature.
- The reading were observed after every 15 – 20 minutes for better results
- Heat input was measured as product of Voltage and current.
- Base plate temperature were recorded which is noted as Ts.
- Ambient air temperature is recorded as Ta.

Initially the readings on plain vertical plate were observed then Vertical plate with S fin and V fin were tested. This is to validate and compare the performance of vertical plate with vertical plate with fins. The temperature readings Ti (Initial temperature), T1, T2 to T4 (temperatures at different location in test section) were recorded with the help of Digital Temperature Indicator present with the apparatus.T5, T6 to T7 were recorded for fin base temperature at different locations .

5. Results and discussion for S fin array :

5.1 Observations

Plate temp 0C Ts = 360

Length L = 250 mm

t_f =(360+28.5)/2 = 194.25 0C

The thermo physical properties of air at 194.25 0C are,

Density of air :(ρa) = 0.7459 kg/m3`

Thermal conductivity of air: (k) = 0.03779W/m K

Kinematic Viscosity of Air (μ) = 3.455 * 10^-5 m2/s

Prandtl No= 0.69

B= 1/ T = 1/(273+360) = 0.00214

$$\mathrm{Gr} = \frac{\rho^2 \beta g \Delta t L^3}{\mu^2} = (0.25)^3 * (0.00214) * 9.81 * (360 - 28.5) \,/\, (3.455 \, * \, 10^{-5})^2$$

= 91.09 *106

Gr * Pr = 91.09 *106 * 0.69

= 62.85 * 106 which is the case for Laminar Flow

For Laminar Flow ,

Nu = 059 * (Gr * Pr)(1/4)

Nu = 52.53

Since ,Nu = h L/k

$$h = \frac{0.03779 \, * \, 52.53}{(0.25)}$$

h= 7.94 W/m2 K

5.2: Observation tables

Table 1. Vertical heated plate with S Fin array

Vertical Plate with S Fin					
Temp.	Mean film temp. Tf oC	Grashloff Number (Gr)	Prandtl Number (Pr)	Nusselt Number (Nu)	Heat transfer Coeff. (h) W/m2 K
360	194.25	91.09 * 10^6	0.69	52.53	7.94
311	169.25	11.09 * 10^6	0.7014	93.92	13.19
205	116.25	10.98 * 10^7	0.7073	55.39	7.16
165	96.25	10.73 * 10^7	0.711	55.14	6.82
110	68.75	92.77 * 10^7	0.71	53.15	6.12

Similarly the readings are taken and calculations are done for short length V fin array and are listed in table below.

Table 2. For Vertical heated plate with short length V fin array

Temp.	Mean film temp. Tf oC	Grashloff Number (Gr)	Prandtl Number (Pr)	Nusselt Number (Nu)	Heat transfer Coeff. (h) W/m2

					K
352	190	10.33 * 10^7	0.6992	54.39	7.95
301	164.25	11.09 * 10^7	0.7014	90.92	14.45
195	111.25	10.31 * 10^7	0.7073	54.59	6.75
130	78.5	91.09 * 10^7	0.7111	52.53	7.94
92	66.75	10.73 *10 ^7	0.7	55.39	7.16

These are the tables of reading for the cases of Vertical Heated plate with S fin array and Vertical heated plate with Short length V fin array. For one case minimum five to six set of readings has been taken, from those all above are approximately best readings has been chosen, and become a base for further calculations. Using these readings for calculating fin Effectiveness all the three cases are taken into account for comparison.

5.3: Observations, results and discussion for effectiveness of S fin array :

To Calculate Effectiveness of S fin :

Q fin = (P h k Acs)^1/2 * Temperature difference

Perimeter P = (2b + 2 y)

= (2*0.2 +2*0.03)

= 0.46 m for one Fin

As we total 8 fins Total Q fin = 0.46 * 8 = 3.68 m

Acs = b * y = 0.2 *0.03

= 6 *10 ^-3 m2

Q fin = (3.68*7.94*225*6*10^-3)^(0.5)*380

= 2386

Q without Fin = 9.6 * 10^-6 *(250*3)*(360-28.5)

= 434 W

Effectiveness fin = $\frac{\text{Q fin}}{\text{Q without fin}}$ =6.04

Table 3. Effectiveness comparison for short length V fin and S fin array

Fin data						
Temperature Vertical Plate 0 C	h W/mm2 K	Q without fin (W)	Q for S fin	ε fin S fin	Q for V fin	ε fin V fin
360	9.6 * 10^-6	434	2622	6.04	5282	12.17
311	8.4 * 10^-6	340	2286.8	6.72	4635	13.63
205	7.1 * 10^-6	241	2001.47	8.3	4056	16.8
165	5.85 * 10^-6	180	1719.72	9.55	3485	19.3
110	5.5 * 10^-6	145	1531.5	10.56	3104	21.4

The results are given here to understand the variations in average heat transfer coefficient (ha) for different set-ups and comparison of the same designs for fin effectiveness for better results .The various equations used for calculating the Parameters under study are given below.

ha =q/As (Ts – Ta) (1)

As=Area of base plate + Area of V-Type Partition Plate.

(1) Nu = ha L/K (2)

(2) $Pr = Cp\ \mu / K$ (3)

(3) $Gr = g.\ ß\ (Ts - T\infty)\ L3 / \mu 2$ (4)

(4) The air properties at mean film temperature were used. For the purpose of comparison, the Test Plate area including area of the partition plates (if any) was kept same in all the cases. The variations of the average heat transfer coefficient (ha) with temperature difference (Δt) for vertical plate with S fin, vertical plate with Short length V fins are shown in the graph no.1

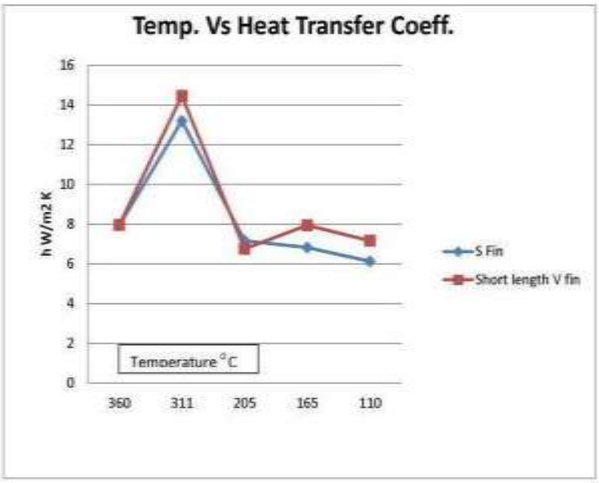

Fig. 5 Variation of (ha) Vs $(\Delta t)^0$ C for S fin and short length V fin array

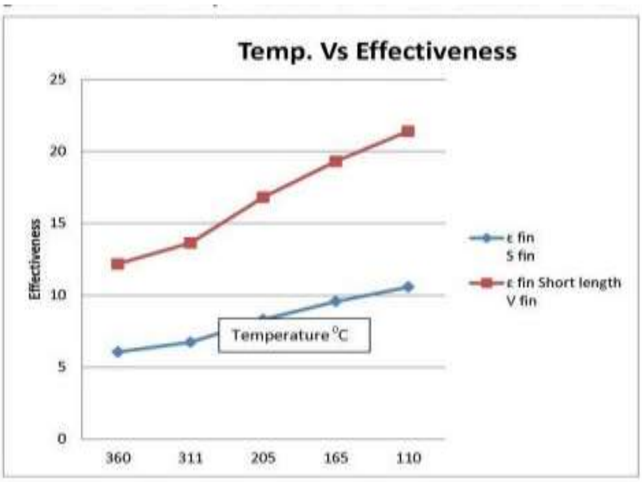

Fig.6 Variation of (ε fin) Vs $(\Delta t)^0$ C for S fin and short length V fin array

Fig. 5 Shows the Variation in Average Heat transfer coefficient, the increase in the average heat transfer coefficient (ha) is steep in the initial stage and tapers down later. From the graph average heat transfer coefficient for vertical heated plate with short length V fin is greater than S-fin array because of no flow obstruction to flow of the fluid.

Fig. 6 shows variation in effectiveness of S fin and short length V fin .Effectiveness for Short length V fin is better as compared to S fin base.

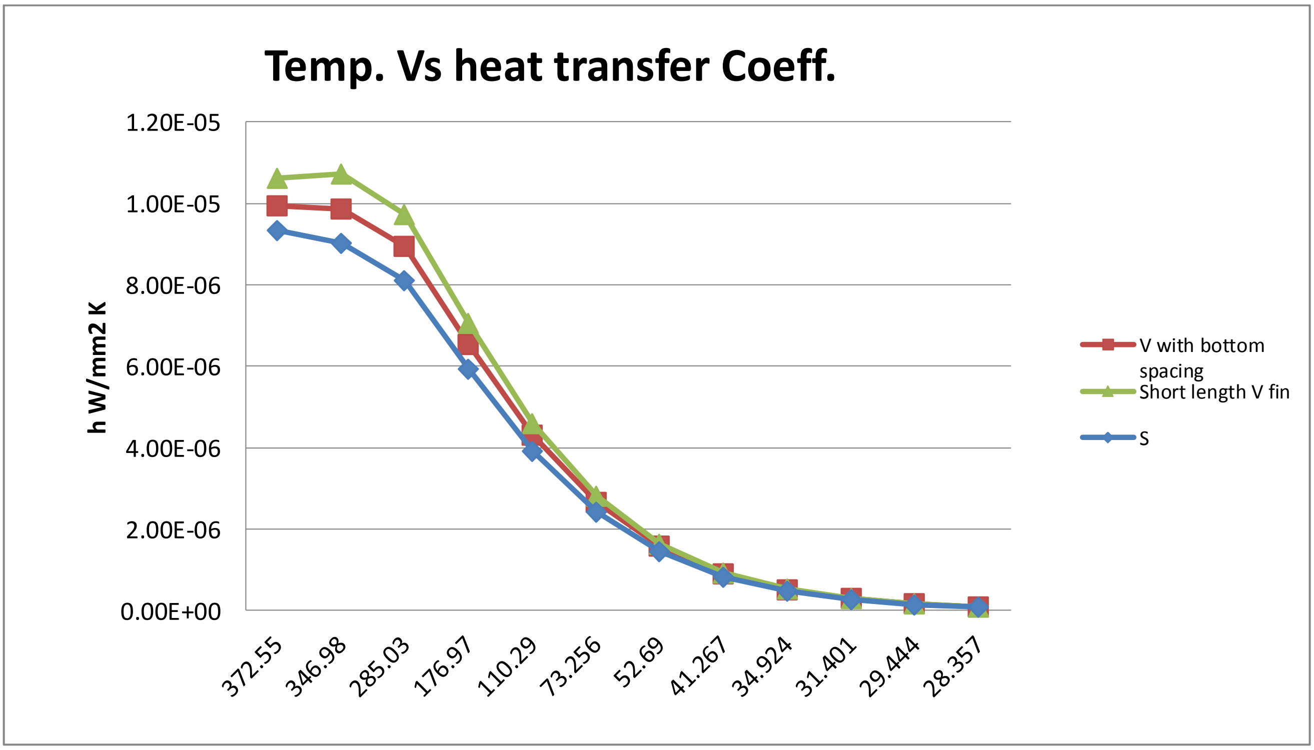

Fig. 7 Ansys graph variation of (ha) Vs $(\Delta t)^0$ C for different fin arrays

The above discussion on experimental work indicates that the highest heat transfer coefficient for short length V fin is better. Hence the models for the same Vertical Plate with three different orientations are designed and are Analyzed using Ansys 15.0 .The graph is plotted for heat transfer coefficient in W/mm2K versus various temperatures in 0 C. From the graph it is clear that the average heat transfer coefficient is maximum, for short length V fin . The value of the heat transfer coefficient goes on increasing, reaches a maxi-mum value at 10 W/mm2 K and slowly decreases.

6. Conclusion

In this investigation work a totally new heat transfer technique is found out to increase the rate of natural convection heat transfer on vertical heated plate. For the same surface areas the Short length V-type partition plates gave better heat transfer performance than S fin array. Better fin effectiveness for short length V fin array is observed as compared to S fin array. Ansys 15.0 workbench and experimental setup showed the similar trend. Ansys computational results show 20% more heat transfer coefficient than experimental results. During experimental reading and evaluations more heat loss may take place from bottom, top and end corners of fins and due to this heat loss the value of experimental heat transfer coefficient is less than computational heat transfer coefficient. It is anticipated that a low pressure suction region is created in the nose region on the downstream side of each short length V-fin which eventually admits the low temperature ambient fluid from surrounding. This immensely helps to allow the inflow of the low temperature fluid into the separation region and increases the heat transfer rate.

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