Optimization of Fin Spacing of Vertical Plate Fin Heat Sink in Natural Convection

D.D.Palande, A.M.Mahalle, N.C.Ghuge, P.N.Belkhode

Abstract*: Heat sinks are frequently used in the cooling of electrical and electronics devices If the heat sink have very close fin spacing, it increases the surface area but reduces the heat transfer coefficient. On the other hand, if heat sink has wide fin spacing, it reduces the surface area but increases the heat transfer coefficient. Therefore, there is need to optimize the fin spacing that enhanced the heat transfer from the heat sink. A properly selected heat sink may reduced the operating temperature and reduce the risk of failure of components. A steady state natural convective heat transfer from aluminum plate fin heat sink was examined experimentally. The length and thickness of fin was kept constant while height were varied from 5mm to 25mm and spacing varied between 5.5mm to 17mm.After experimentation, it was observed that fin spacing plays important role than any other geometrical parameters. Response surface methodology is used for optimization of fin spacing. It is observed that optimum fin spacing of heat sink is 8.28mm.The error analysis is done with the help of ANN and flow visualization were done using CFD

Keywords: Natural convection, fin spacing, Response Surface Methodology.

I. INTRODUCTION

Many researchers have worked on fin geometry to improve the heat transfer. Still more efforts are needed in order to understand the complete behavior of geometry variation and its effect on heat transfer and fluid flow application. The selection of a particular heat sink depends on the required thermal performance and application. Among the literature, the most common studied heat sink was the rectangular heat sink because of simplicity in manufacture. B.Yazicioglu,H.Yuncu [1] experimentally investigated natural convection heat transfer from vertical fin arrays by changing the fin height ,fin spacing and base to ambient temperature difference. The study shows that fin spacing is playing major role than any other geometrical parameter.Yüncü and Güvenc [2] concluded fin spacing was the most important parameter in the thermal performance of fin arrays and an optimum fin spacing can be found for every fin height, for a given base-to-ambient temperature difference. R. Arularasan and R. Velraj [3] carried out the modeling and simulation of parallel plate heat sink by using computational fluid dynamics package. The result shows that, 20 numbers of fins with 30mm fin height and 7.5mm base Height gives lower thermal resistance and higher heat transfer compared to all other geometries. S. Manivannan, S. Prasanna Devi, et al. [4]Taguchi's design of experiments was performed by using Minitab software. The factors to be considered for optimization as length and width of the heat sink, fin height, base height, number of fins, and fin thickness. They also carried out, ANOVA test for finding out the contribution of various parameters .Ko-Ta Chiang et al.[5] using RSM analyze The results shows that design parameters, such as height and diameter of pin-fin and width of pitch are the significant influence factors to minimize thermal resistance and pressure drop. R.Senthilkumar, et al. [6] analyzed natural convective heat transfer of nanocoated aluminum fins using Taguchi method.They found 5% more fin efficiency for coated aluminum surface. D.D.Palande,A.M.Mahalle[7] has experimentally investigated different heat sink. It is concluded that fin spacing is significant parameter for better heat transfer.

Revised Manuscript Received on October 15, 2019
D.D.Palande Asso. Professor Dept.of Mechanical Engineering Matoshri College of Engineeing Nasik Maharastra
Email:-palande1@rediffmail.com
A.M. Mahalle Professor Govt. College of Engineering, Amaravati, India.
N.C.Ghuge, Asso. Professor Dept.of Mechanical Engineering Matoshri College of Engineeing Nasik Maharastra
P.N.Belkhode, Dept. of General Engineering L.I.T. Nagpur

II. EXPERIMENTAL SETUP AND EXPERIMENTATION

An experimental setup is designed and fabricated to investigate the enhancement in heat transfer in natural convection using plate fin heat sink. To ensure natural convection a large enclosure is required to be made symmetrical about a vertical plane. It is required to heat the plate arrangement to obtain the natural convection effects by using suitable heating arrangement. The experimental evaluation of the results requires temperature measurements at several locations on the heat sink and also temperature of the surrounding. The enclosure is open from top and bottom. A schematic view of the experimental set-up are shown in figure 1

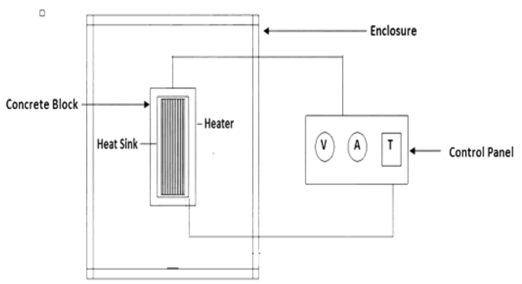

Fig. 1.Experimental setup

For all Aluminum plate heat sink 2.5 mm thickness and 200 mm length and 75 mm width were fixed while the fin height vary from 5mm to 25mm and fin spacing varies from 5.5 to 17mm.

The samples of various plate heat sink is shown in the figure 2

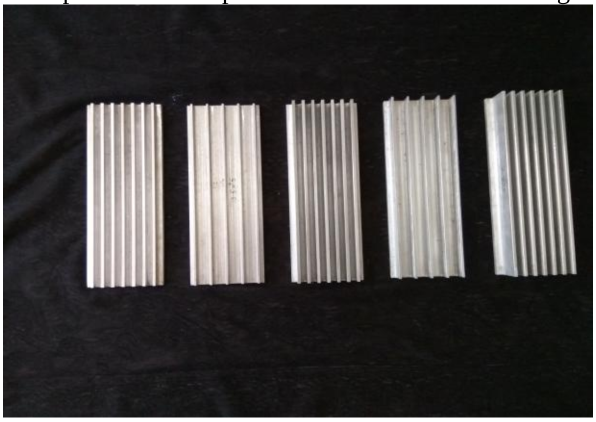

Fig. 2 Finned heat sink

The heater plate is placed on the concrete block and heat sink is placed on heater plate. A unidirectional heat transfer takes place from heater to plate fin heat sink. The control panel consists of dimmer stat, voltmeter, ammeter, and multi point digital temperature indicator. A dimmer stat was used to vary the heat input in steps of 10 watts, starting from 10 watts to 50 watts. A calibrated voltmeter and ammeter is used to measure the heat input. Five thermocouples were used to measure the temperature of the heat sink at various locations. A separate thermocouple was used to measure the ambient temperature in the enclosure. All experiments were carried out with utmost care and many of them were repeated to avoid errors .The final observations were recorded only after reaching the steady state condition

III. RESPONSE SURFACE METHODOLOGY AND ARTIFICIAL NEURAL NETWORK

Response surface methodology (RSM) is a collection of statistical and mathematical techniques useful for developing, improving, and optimizing processes

Response surface methodology (RSM) is used to frame the mathematical models for convective heat transfer rate and average base to ambient temperature difference. Moreover, artificial neural network (ANN) is used to predict the response. Response optimizer is used to optimize fin spacing for minimum temperature difference and maximum heat transfer rate.

Analysis of variance (ANOVA) test is performed to verify the fitness of the model. Residual plots are plotted to confirm the assumptions of the ANOVA.MINITAB 17 is used for mathematical modeling. Response optimizer is used for multi objective optimization

Regression Equation for Convective Heat Transfer Rate

$$Qc = -3.489 + 0.0868\ H + 0.6434\ S + 0.4076\ Q - 0.003539\ H*H\ 0.02881\ S*S - 0.000009\ Q*Q + 0.000667\ H*S + 0.003854\ H*Q + 0.000421\ S*Q \quad \ldots (1)$$

To validate the regression equations, residual plots are plotted for vertical plate fin heat sink for temperature difference i.e.average base to ambient temperature and convective heat transfer rate as shown in figure 3.

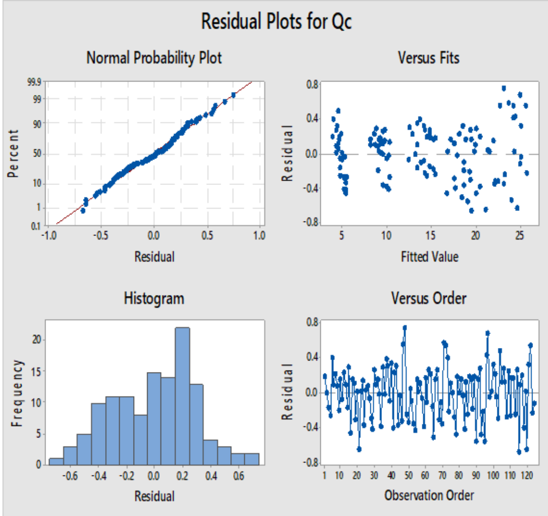

Fig. 3 Residual Plots for Convective Heat Transfer Rate

If the model is adequate, the points on the normal probability plots of the residuals should form a straight line, which means the errors are normally distributed. Normal probability curve shows residual are falling on straight line. It indicates that model is precise and satisfactory.

IV. ERROR ANALYSIS AND VALIDATION

Though all the experiments were carried out with utmost care and many of them were repeated to avoid errors, there is possibility of experimental uncertainty. Property values for air were taken from the data book at the film temperature. Experimental uncertainty in temperature measurements may occur due to variation in atmospheric conditions.

An artificial neural network is a structure that is designed to solve certain types of problems by attempting to emulate the way the human brain would solve the problem. The most common structure involves three layers: the inputs, which are the original predictors, the hidden layer, consisting of a set of constructed variables; and the output layer, made up of the responses. Each variable in a layer is called a node. Artificial Neural Network (ANN) is one of the most common neural networks used in solving the engineering problems.

The regression plots represent the training, validation, and testing data. A neural network will provide a nearly perfect fit to aset of historical or training data The dashed line in figure 4, represents the perfect result – outputs = targets. The solid line represents the best-fit linear regression line between outputs and targets for heat transfer rate. The R-value is an indication of the relationship between the outputs and targets. Figure 4 shows experimental data are in perfect agreement with ANN data. The R-value is 0.9946, approaching to one shows training data indicates a good fit.

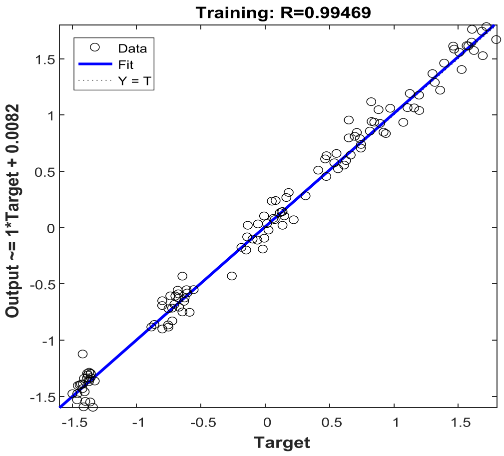

Fig. 4 Regression Plot for Convective Heat Transfer Rate

The error of convective heat transfer rate and temperature difference for RSM and ANN for vertical plate heat sink in natural convection is as shown in figure5.From figure5, it is seen that at experiment number 26,33,54,80 percentages of error increases, this is due to uncertainties in the experimentation. Rest of the number of experiments shows little peak values of error, so we can neglect this type of percentage error

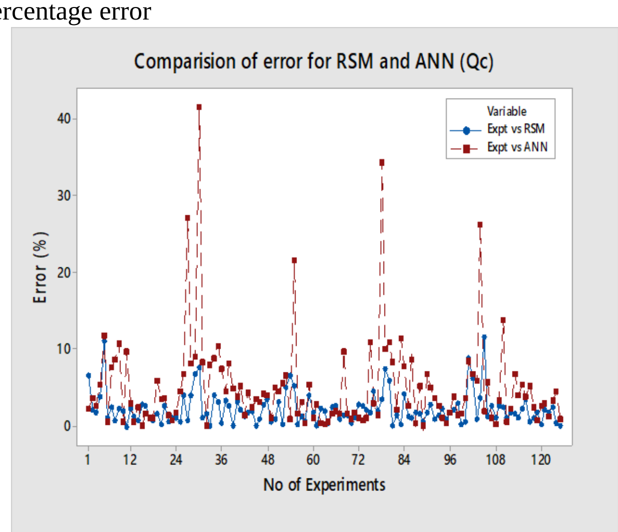

Fig. 5 Validation of Experimental and RSM and ANN Results for convective heat rate

V. CFD FOR FLOW VISUALIZATION

It seems from previous research work, CFD is better for air-flow visualization. In CFD, temperature distribution along the fin length is studied. The temperature values at a particular node can be easily obtained in this diagram, and also study velocity profile diagram, for examining the nature of flow.

Figures 6 shows temperature distribution. The heated base images which has red colour shows the highest temperature. Away from the base the colour becomes yellow first and then blue which shows reduction in temperature. The difference in flow structure affects the convective heat transfer rate.

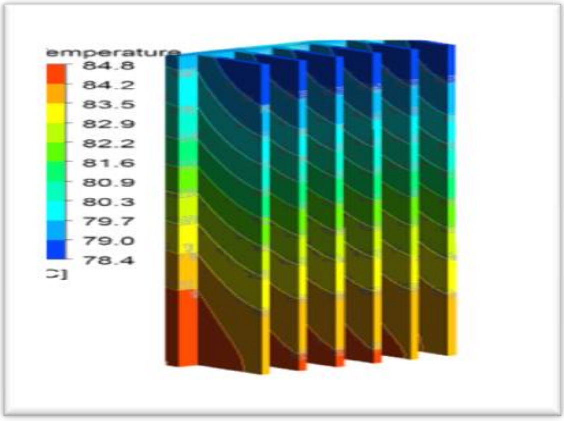

Fig.6 Temperature and Velocity Images for Vertical Plate Heat Sink

VI. RESULT AND DISCUSSION

On the basis of observations recorded from total twenty five different heat sink were presented. The results are useful to identify the effect of fin spacing, fin height and temperature difference on heat transfer rates from the plate fin heat sink.

The figure 7 to 11shows the variation in convective hat transfer rate with the change in fin spacing at different fin heights. The heat input is varied from 10 W to 50 W.

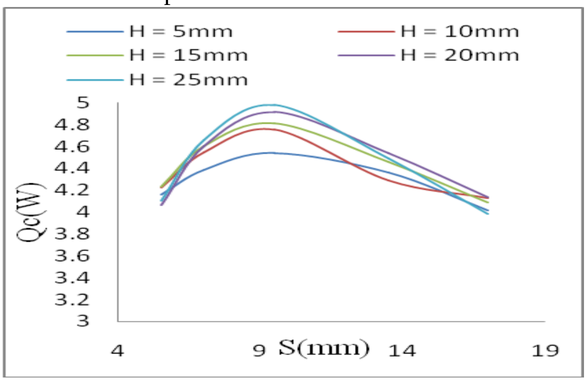

Figure.7 Variation of Convection Heat Transfer Rate with Fin Spacing for Different Height at 10W

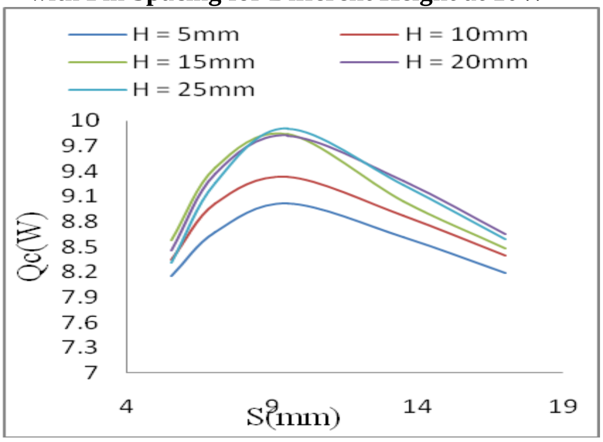

Figure.8 Variation of Convection Heat Transfer Rate with Fin Spacing for Different Height at 20W

Retrieval Number: A9467109119/2019©BEIESP
DOI: 10.35940/ijeat.A9467.109119

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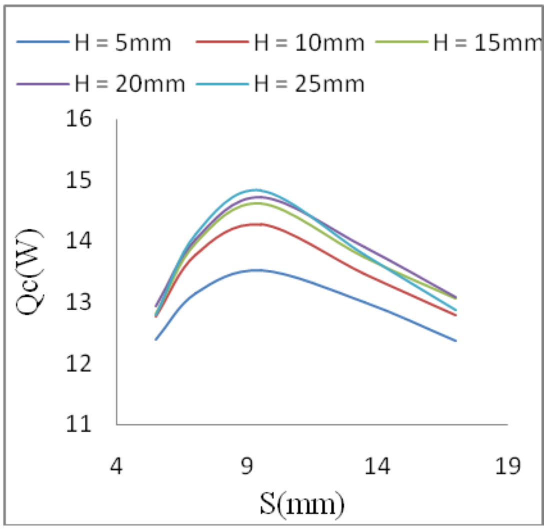

Figure.9 Variation of Convection Heat Transfer Rate with Fin Spacing for Different Height at 30W

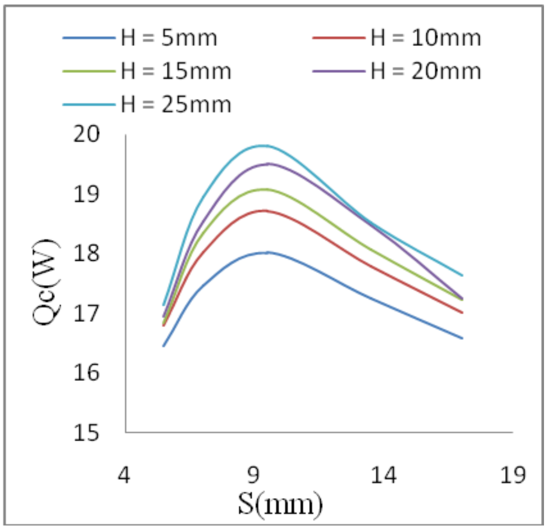

Figure.10 Variation of Convection Heat Transfer Rate with Fin Spacing for Different Height at 40W

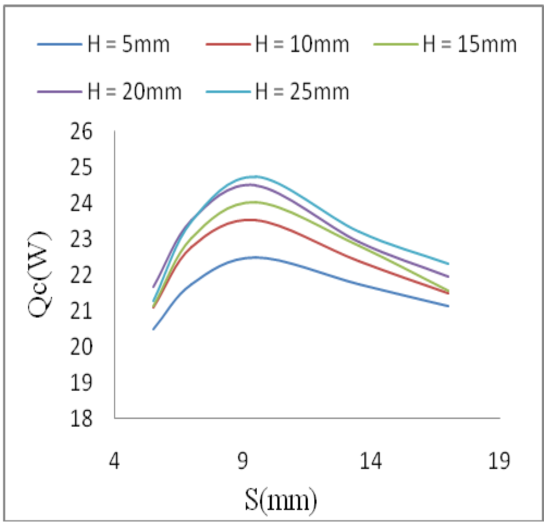

Figure.11 Variation of Convection Heat Transfer Rate with Fin Spacing for Different Height at 50W

It is observed that the convection heat transfer rate is maximum in between the fin spacing, 7 mm to 9.5mm.So it is optimum fin spacing. Figure7 reveals that when the fin spacing is increased from optimum value, the convective heat transfer rate decreases. Moreover if the fin spacing decreases from optimum value, the convective heat transfer rate also decreases as shown in figure 8. Figure 9 reveals that for values of fin height viz. H=5mm to H=25mm, the nature of these plots is almost similar to those in figure 7 To find an optimum spacing that maximizes the natural convection heat transfer from the heat sink for a given base area which is shown in figure 10 and figure 11. It would be appropriate to manufacture the heat sink with aforementioned fin height and spacing. It is observed that the convection heat transfer rate is maximum in between the fin spacing, 7 mm to 9.5mm.So it is optimum fin spacing

VII. OPTIMIZATION

Optimization is method of finding the best result under given circumstances. It can be defined as the process of finding the conditions that give the maximum or minimum value of a function. Desirability is used to verify the feasibility of optimization process. Value of desirability approaching one, which specifies that optimization process is realistic and reasonable. Response Optimizer is used to find the optimized values of the input parameter. The optimal plot for vertical plate fin heat sink is shown in figure 12

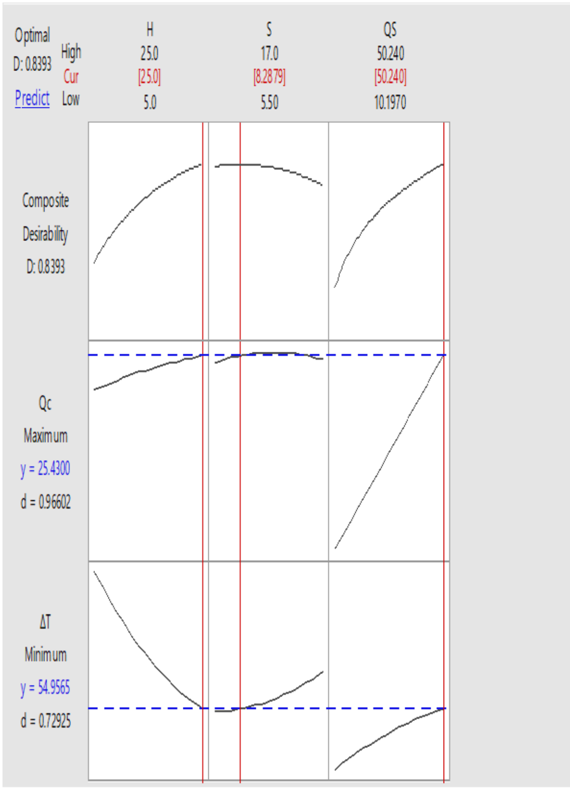

Fig. 12 Optimal Plots for Vertical Plate Heat Sink

The optimized values obtained for minimum temperature difference and maximum heat transfer rate for vertical orientation plate heat sink are -height-25 mm, Spacing-8.28mm and heat supplied-50W.

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DOI: 10.35940/ijeat.A9467.109119

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VIII. CONCLUSIONS

Conclusions based on the studies are as follows.

- It is observed that fin spacing is the major parameter to enhance the convective heat transfer rate. The value of fin spacing, at which the heat transfer rate is highest is called the optimum fin spacing. The effect of other parameter is not affecting significantly.
- In order to validate the response surface methodology (RSM) based regression model, artificial neural network (ANN) is used to predict the responses. The results of these methodologies were compared for their predictive capability. It is noticed that the results of ANN model showed close matching between RSM model output and experimental results. It has been confirmed numerically that the results from the derived modeling equation are consistent with the experimental results
- Enhanced convective heat transfer rate can be achieved at optimized geometrical parameters. It is concluded from the experimentation that the optimum fin spacing's is found in between 7 mm to 9.5mm for all heat sink for maximum convective heat transfer rate. RSM based desirability approach was used to optimize the fin spacing. The optimized value found from RSM is 8.28 mm for vertical plate heat sink.

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AUTHOR PROFILE

D.D.Palande, Asso. Professor Dept. of Mechanical Engineering Matoshri College of Engineeing Nasik Maharastra
Email:-palande1@rediffmail.com

A.M. Mahalle, Professor, Govt. College of Engineering, Amaravati ,India
.

N.C.Ghuge, Asso. Professor Dept. of Mechanical Engineering Matoshri College of Engineeing Nasik Maharastra

P.N.Belkhode, Dept. of General Engineering, L.I.T.Nagpur