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Optimum Design Parameters for Heat Transfer from Triangular Fin Array within a Rectangular Enclosure

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Abstract - **This article outlines the evaluation of optimum parametric design for heat transfer analysis through triangular fin array within a vertically oriented rectangular enclosure using general full factorial design approach. This statistical approach has been applied to the conclusions of an experimental analysis conducted to explore the effects of fin height (L), fin spacing (S) and Rayleigh number (Ra) on free heat transfer from triangular fins attached to the heated bas plate within an air filled rectangular enclosure. The analysis of variance (ANOVA) technique has been used to find the significant effect of control parameters on response. The control parametric combination L=37.5 mm; S= 50mm; and Ra=773410 has been reported as the optimum parametric combination yielding maximum heat transfer rate for present study.**

Keywords: **Rectangular Enclosure, Triangular Fin Array, Parametric Optimization, General Full Factorial Design Approach, ANOVA.**

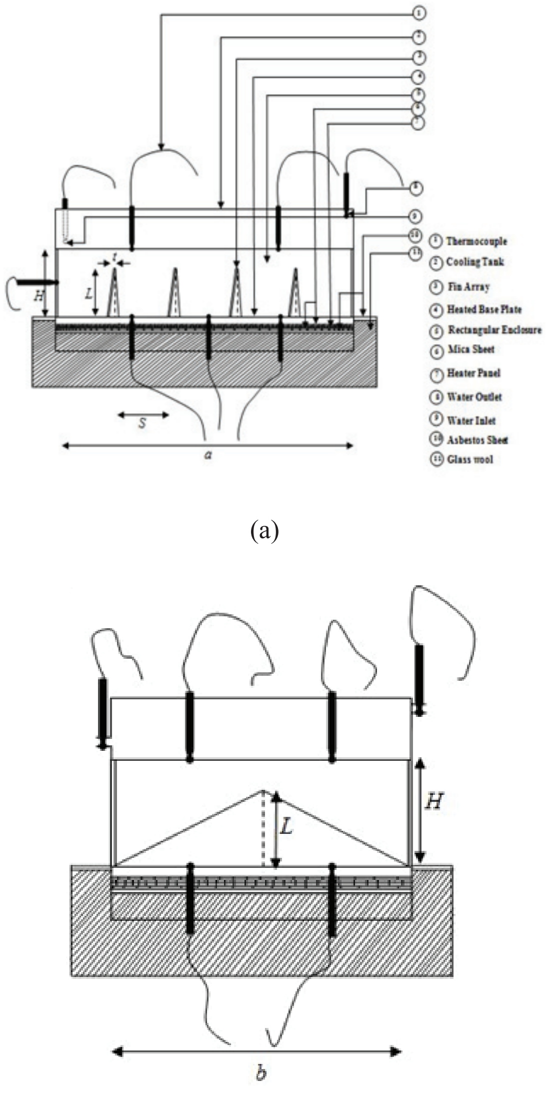
I. INTRODUCTION

The thermal management problems in the equipments, especially in electronic and computing fields, are the common problems in present state of affairs. The general trend of compact designs leads to higher packing density which may cause the increase in temperature of equipments beyond their permissible limit. This fact emphasizes the requirement of effective cooling systems in order to improve the system performance. Use of extended surfaces is the best option for the same as it is often more economical and convenient. Although, the addition of numerous fins results to heat transfer enhancement, but it may also cause the diminished heat transfer rate due to interference of boundary layers [1]. The amount of heat transfer enhancement by finned surface depends upon different fin parameters like fin height, fin spacing, fin thickness and Rayleigh number. Optimum parametric design is the most desired condition for design of any system.

The present investigation outlines the application of general full factorial design methodology to obtain the optimum parametric combination yielding maximum heat transfer enhancement. An experimental analysis regarding natural convection heat transfer from rectangular fin arrays on a horizontal base was conducted by [2]. It was reported that optimum fin spacing does not depend on temperature difference between fin base and surroundings significantly while decreases with increase in fin height. The mixed convection heat transfer from longitudinal fin arrays within a horizontal channel was investigated by [3] for wide ranges of influencing parameters. It was concluded that in order to achieve maximum heat transfer enhancement the fin spacing should achieve an optimum value. As per the conclusion of experimental analysis carried out by [4] regarding natural convection heat transfer through rectangular fin array for every fin height value, optimum fin spacing exists providing maximum heat transfer enhancement. [5] reported Nusselt number as an increasing function of Rayleigh number and decreasing function of fin height and relative conductivity ratio. The heat transfer suppression up to 38% was observed by selecting apropriate fin parameters. [6] investigated experimentally the effects of various influencing parameters on the heat transfer from a surface equipped with rectangular blocks by employing Taguchi method. Fin height, fin width, stream wise span wise distance between fins and flow velocity were analyzed as parameters for the study. [7] carried out an experimental investigation for optimization of design parameters in a rectangular duct with plate-fins heat exchanger by Taguchi method. An optimal parametric design to improve chip cooling for electronic systems was suggested by [8] using two level Taguchi design approach. The effort saving of approximately 50% was reported in performing experiments and simulations using such statistical approaches. Optimum design parameters for a heat exchanger having hexagonal fins were studied by [9] using Taguchi's L18 (21*37) orthogonal array design. The plate-fins were arranged containing periodic diverging and converging channel flow. L25 orthogonal array design was adopted as an experimental plan for design parameter.

To the authors' best knowledge; there is no literature available that deals with parametric optimization yielding maximum natural convection heat transfer through triangular fin array within a rectangular enclosure. The prime objective of the present study is to suggest an optimum parametric design for maximum heat enhancement from a given surface using classical design approach.

II. EXPERIMENTAL SETUP



(a)

(b)

Fig.1 Schematic Diagram for Experimental Test Rig (a) Front View (b) Side View

Figure 1 illustrates the schematic diagram for the experimental setup. There were three main sections of the test rig- heating section, test section and cooling section. Heating section was consisted of nickel chrome wired heater provided with proper insulation with glass wool and mica sheet. The test section was comprised of an air filled rectangular enclosure with heated triangular finned base plate. Aluminum was used as the material for base plate as well as fins because of its high thermal conductivity and low emissivity. A cooling tank facilitated with normal tab water flow circulation was used as the cooling arrangement for the system. The input power was varied using an auto transformer to vary the Rayleigh number. Total thirteen K-type thermocouples were used to measure the temperatures at different points within the system. The output data was recorded using digital multimeter. The uncertainty in Nusselt number measurement was calculated in between 7%-9% using the procedure suggested by [10].

III. RESULTS AND DISCUSSION

In the present investigation the optimum parametric design yielding maximum heat transfer rate has been suggested using full factorial design (classical design) methodology with MINITAB 14. In this technique responses are measured at all combinations of experimental factor levels. There are two types of factorial designs in Minitab 14 software-

- Two level full factorial design
- General full factorial design

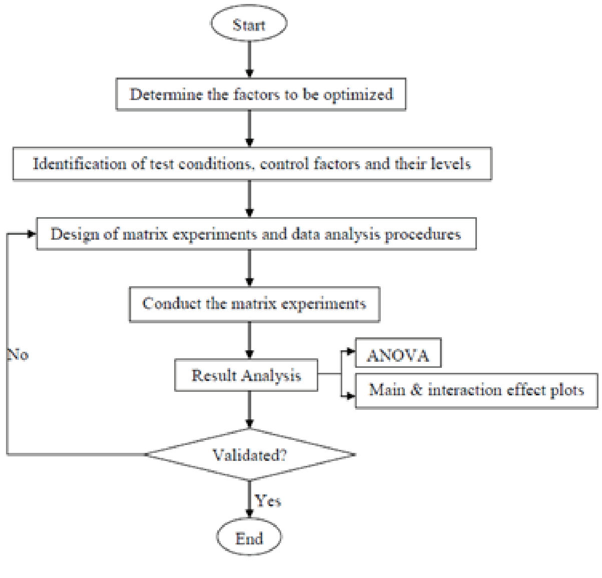


Fig.2 Flowchart for Classical Design Methodology

In the study the general full factorial design is used. In a general full factorial design, the control factors of an experiment can have any number of levels and the experimental runs include all the possible combinations of these factor levels. If ‘p’ represents the number of control factors and ‘q’ are the number of levels for the control factors, then the classical experimental design is denoted by ‘q^p’. A general full factorial design includes following characteristics [11]:

- Sequential experimentation for modelling of process behaviour
- Prediction of future process behaviour
- Investigation and isolation of factors influencing mean and variation independently
- Selection of experimental design from consideration of the trade-off in running a fraction of full factorial design

Various steps involved in the classical design methodology are shown in form of a flowchart in figure 2.

The Analysis of variance (ANOVA) technique has been applied to evaluate the significant effect level of influencing parameters on response. In the ANOVA table, degree of freedom (DF) is the number of terms in sum of squares (SS) that can be assigned randomly. For any sample of ‘r’ observations, the degree of freedom will be ‘r-1’. The basic difference between sequential sum of square (Seq SS) and adjusted sum of square (Adj SS) is that Seq SS measures the reduction in the residual sums of square provided by every additional term in the model while Adj SS measures the reduction in the residual sums of squares provided by each term relative to a model having all the other terms. Mean square (MS) is defined as the ratio of sum of squares to the degree of freedom. F is known as the variance ratio and defined as the ratio of mean square for any term (main or combined effect) to mean square for error term. P is termed as probability of significance and calculated on the basis of calculated F-value. This P-value is compared with the presumed Alpha level depending on the chosen confidence level. For 95% confidence level, if the P-value obtained is less than 0.05, the corresponding factor has significant influence on the response.

Table I shows the general linear model for the present investigation showing several control parameters, their levels and corresponding values taken under consideration:

TABLE I GENERAL LINEAR MODEL: NUSSELT NUMBER VS. RAYLEIGH NUMBER, FIN HEIGHT AND FIN SPACING

Factor	Type	Levels	Values
Ra	fixed	4	295214, 461264, 554449, 773410
L	fixed	3	12.5, 25.0, 37.5
S	fixed	3	25, 50, 100

The randomized design table based on classical design has been shown in Table II.

TABLE II DESIGN TABLE FOR CLASSICAL DESIGN METHODTABLE 6.3 SHOWS THE CORRESPONDING ANOVA TABLE.

Run	Blok	A	B	C
1	1	3	1	2
2	1	3	2	2
3	1	1	3	1
4	1	4	1	2
5	1	2	1	2
6	1	4	3	3
7	1	3	3	2
8	1	4	1	3
9	1	3	3	1
10	1	2	3	3
11	1	3	3	3
12	1	3	1	1
13	1	2	1	1
14	1	2	2	3
15	1	1	2	1
16	1	4	3	2
17	1	2	1	3
18	1	2	3	1
19	1	1	1	2
20	1	4	3	1
21	1	4	2	1
22	1	4	1	1
23	1	3	2	1
24	1	3	2	3
25	1	3	1	3
26	1	1	3	2
27	1	1	2	3
28	1	4	2	2
29	1	1	1	3
30	1	2	3	2
31	1	2	2	2
32	1	2	2	1
33	1	1	3	3
34	1	4	2	3
35	1	1	2	2
36	1	1	1	1

TABLE III ANALYSIS OF VARIANCE TABLE FOR NUSSELT NUMBER, USING ADJUSTED SS FOR TESTS (HORIZONTAL ARRANGEMENT)

Source	DF	Seq SS	Adj SS	Adj MS	*F*	*P*
Ra	3	5.18188	5.18188	1.72729	169.91	0.000
L	2	1.52273	1.52273	0.76136	74.90	0.000
S	2	0.28561	0.28561	0.14281	14.05	0.000
Error	28	0.28464	0.28464	0.01017		
Total	35	7.27486				

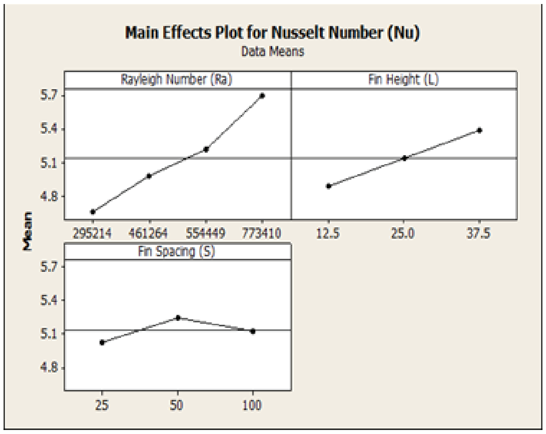


Fig.3 Main Effects Plot for Nusselt Number

The main effect and interaction plots for the influencing factors Rayleigh number, fin height and fin spacing on Nusselt number are illustrated in figures 3 and 4 respectively. It can be clearly observed from the main effect plots that Nusselt number increases continuously with increase in Rayleigh number and Fin height. These results can be attributed to the increased effective surface area and buoyancy effects with increase in fin height and Rayleigh number. The Nusselt number increases firstly up to maximum value then decreases with decrease in fin spacing. This effect can be attributed to the fact that decrease in fin spacing results to two effects- increase of heat transfer due to increased effective surface area and reduced heat transfer due to increased hindrance to convection cells (because of interaction of boundary layers). So initially, with decrease in fin spacing, the net effect is the heat transfer enhancement as increased effective surface area effect dominates increased hindrance effect then tends to decrease as increased hindrance effect dominates increased effective surface area effect. The optimum parametric design combination yielding maximum Nusselt number becomes Ra= 773410, L= 37.5 mm and S= 50 mm which is found in complete agreement with the experimental results.

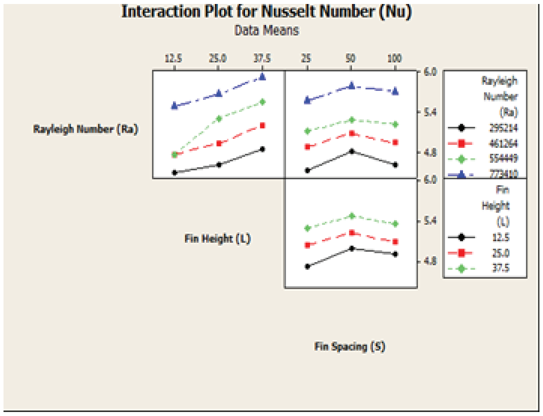


Fig.4 Interaction Plots for Nusselt Number

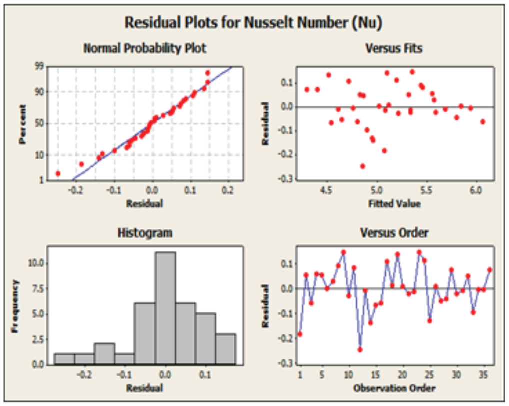


Fig.5 Residual Plots for Nusselt Number

Figure 5 illustrates different residual plots for Nusselt number using classical design technique that includes normal probability, residual histogram plot, and residual variations respect to fitted values and observation order. The difference between observed and fitted response values is known as residuals. In the normal probability plot, the points on the plot appear close to the residual line which indicates the data to be normally distributed. Residual histogram is an exploratory tool to learn about typical values, spread or variation and unusual values of data. In the residual versus fitted value plot the residuals appear to be scattered randomly about zero line which indicate the constant variance. Also, the residuals seem to be fluctuating in a random manner about the centre line and that's why no evidence appears to exist that the error terms are correlated to each other.

IV. CONCLUSIONS

In the present article, a detailed methodology of the Classical optimization design method has been discussed and applied to evaluate optimum design parameter combinations yielding maximum heat transfer. The effect of varying influencing parameters on the response has been reported by the mean of main effect plot. The influencing parametric combination Ra= 773410, L= 37.5 mm and S= 50 mm has been determined as the optimum factor combination for the present study. One of the next attempts by the present authors would be to investigate and analyze the effect of enclosure orientations on the heat transfer enhancement from triangular fin array within the rectangular enclosure.

REFERENCES

[1] C.W. Leung, S.D. Probert, M.J. Shilston, 'Heat Exchanger: Optimal Separation for Vertical Rectangular Enclosure Fins Protruding from a Vertical Rectangular Base', *Applied Energy,* 1985, Vol. 19, pp. 77-85.

[2] H. Yüncü and G. Anbar, 'An Experimental Investigation on Performance of Rectangular Fins on a Horizontal Base in Free Convection Heat Transfer', *Heat Mass Transfer,* 1998, Vol. 33, pp. 507-514.

[3] M. Dogan and M. Sivrioglu, 'Experimental Investigation of Mixed Convection Heat Transfer from Longitudinal Fins in a Horizontal Rectangular Channel: In Natural Convection Dominated Flow Regimes', *Energy Conversion and Management,* 2009, Vol.50, pp. 2513-2521.

[4] B. Yazicioğlu and H. Yüncü, 'Optimum Fin Spacing of Rectangular Fins on a Vertical Base in Free Convection Heat Transfer', *Heat Mass Transfer,* 2007, Vol. 44, pp. 11-21.

[5] E. Bilgen, 'Natural Convection in Cavities with a Thin Fin on the Hot Wall', *Int J Heat Mass Transfer,* 2005, Vol. 48, pp. 3493-3505.

[6] Kadir Bilen, Sinan Yapici, Cafer Celik, 'A Taguchi Approach for Investigation of Heat Transfer from a Surface Equipped with Rectangular Blocks', *Energy Conversion and Management,* 2001, Vol. 42(8), pp. 951-961.

[7] Isak Kotcioglu, Ahmet Cansiz, Mansour Nasiri Khalaji, 'Experimental Investigation for Optimization of Design Parameters in a Rectangular Duct with Plate Fins Heat Exchange by Taguchi Method', Applied *Thermal Engineering,* 2013, Vol.50(1), pp. 604-613.

[8] Yung-Shin Tseng,, Hwai-Hui Fu, Tzu-Chen Hung, Bau-Shei Pei, 'An Optimal Parametric Design to Improve Chip Cooling', Applied *Thermal Engineering,* 2007, Vol. 27, pp. 1823-1831.

[9] Kenan Yakut, Nihal Alemdaroglu, Bayram Sahin, Cafer Celik, 'Optimum Design Parameters of a Heat Exchanger having Hexagonal Fins', *Applied Energy,* 2006, Vol. 83(2), pp.82-98.

[10] J.P. Holman, 'Experimental methods for engineers', McGraw-Hill, Singapore, 1989.

[11] D.C. Montgomery, 'Design and Analysis of Experiments', Wiley, New York, 1991.