ISSN PRINT 2319 1775 Online 2320 7876

Research paper UGC CARE Listed (Group -I) Journal Volume 8, Issue 2, 2019

Identification of Optimal Design Parameters for Wire Mesh Fin Arrays

G R Sanjay Krishna[1]

[1]Department of Mechanical Engineering, Koneru Lakshmaiah Educational Foundation, Vaddeswaram, Andhra Pradesh, Email: grskrishna@gmail.com

Abstract

This paper presents experimental results for tracing optimal design parameters to enhance the heat transfer through wire mesh fin arrays equipped with horizontal base plate. The performance analysis has been carried out on the mild steel for different heat inputs varying wire mesh diameter, fin height and spacing between two fin arrays. Taguchi's L9 orthogonal array is adopted for obtaining the optimal design parameters to improve the heat transfer coefficient. It is observed that the influence of wire mesh diameter and fin height on the heat transfer coefficient is high when compared to spacing between two fin arrays. These studies will be useful to industries to enhance heat transfer in the extended surface or with different geometries such as square, circular pin-fins, plate fins, perforated fins etc.

Keywords: Heat transfer, Finned surface, Wire mesh diameter

Introduction

Heat Transfer is the transmission of thermal energy due to a gradient in temperature. In the following, different heat transfer modes are described as conduction, convection, radiation. The removal of excessive heat from system components is essential to avoid the damaging effects of burning or overheating. The heat transfer from a surface is enhanced by increasing the heat transfer coefficient between the surface and its surrounding or by increasing the heat transfer area of the surface. To enhance heat transfer in several industries the extended surface or fins are used. For both natural and forced convection heat transfer, fins with different geometries such as square, circular pin-fins, plate fins, perforated fins etc. are used. Pin-fin arrays are

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a common geometry used to increase the internal heat transfer in the trailing edge region of a turbine vane [1]. A pin-fin array is a series of short cylinders which span the cooling flow passage. They increase the internal surface area and the flow passage turbulence. Sabale et al[2] worked on worked experimentally on the micro fin geometry made up of copper material forvarying fin height and fin spacing by natural convection heat transfer and experimental on multiple V-fin arrays with vertical heated plate by natural convection heat transfer. It was noted that the enhancement in the heat transfer of perforated fins is better than that of the solid fins for heat inputs, for tested range of Reynolds number and for sizes of perforations. They also experimentally investigated the optimum design parameters such as Reynolds number, porosity and thickness of fin and their level for lateral circular perforated fin arrays under forced convection. From the literature survey, it has been observed that many investigators worked onthe plate fin as well as perforated fins [3]. They studied parameters affecting the heat transfer enhancement. But none emphasized the experimental investigation on wire mesh as heat sink because it requires a vast number of experiments which enormously increase the experimentalcost and time [4-13]. For many practical applications, it is necessary to determine the economic benefits for the heat transfer enhancement. Thus, the aim of this study is to minimize the experimental trials using Taguchi experimental design for determining the heat transfer characteristics of the wire mesh fin arrays as a heat sink, and to determine new design parameters and their levels.

Nomenclature

AT Total surface area, m2
Af Area of all horizontal wire, m2
Af Area of all vertical wire, m2
Af Total area of fin, m2
Ab Base surface area, m2
D Diameter of wire mesh, m
H Height of fin, m
L Length of fin, m
W Width of fin, m
Kb Thermal conductivity of insulation brick, W/mK
Ka Thermal conductivity of air, W/mK
Ts Average surface temperature, ° C
Ta Ambient temperature, ° C
Tmf Mean film temperature, ° C
Tf Fins temperature, ° C
Pr Prandalt number
Ra Rayleigh number
Nuwf Nusselt number without fin
β 1/Tmf Coefficient of volumetric thermal expansion (1/K)

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LITERATURE SURVEY

For this project we have taken various journals of Taguchi method as suggested by our guide. From them we have chosen the topic "Selection of Optimal Design Parameters for Wire MeshFin Arrays". In this process wire diameter, height of fin, fin spacing parameters were taken. The output responses are heat transfer coefficient, prediction, range, sum of squares percentage of contribution etc., we have identified the 9 test runs data by using Taguchi approach and all the calculations are displayed in the next pages. We have identified that using Taguchi approach we can reduce the experimental cost and calculate the high testing procedure very easily and effectively

Methodology:

Table-1: Control parameters and their levels

Parameter / Level	**Symbol**	**vel-1**	**vel-2**	**vel-3**
Wire mesh diameter	A (D)	1 mm	1.2 mm	1.6 mm
Height offin	B (H)	50 mm	45 mm	40 mm
Fin spacing	C (S)	16.5 mm	21.5 mm	30 mm

No of experiments to be performed in Full Factorial

No of experiments to be performed in Full Factorial

DoE = $L^P = 3^3 = 27$

$N_{Taguchi}$ = 1+No of factors * Degree of freedom = 1+No of factors *(No of Levls-1) = **1+3*(3-1) = 7**

Grand Mean $(\emptyset_{mean}) = \frac{1}{9}\sum_{i=1}^{9} \emptyset_i$

Mean values of Output response (Total sum of squares,

$$(SOS)_T = \sum_{i=1}^{9} (\Delta\emptyset)^2 = \sum_{i=1}^{9} (\emptyset_i - \emptyset_{mean})^2$$

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GEOMETRY OF FIN ARRAYS AS PER TAGUCHI MTEHOD

Table-2

EXP. NO.	Orthogonal Array				Levels of Process Parameters		HEAT TRANSFER COEFFICIENT
	A	B	C	D	HEIGHT OF FIN	FIN SPACING	
1	1	1	1	1	50	16.5	20.55
2	1	2	2	2	45	21.5	19.05
3	1	3	3	3	40	30	18.03
4	2	1	2	3	45	21.5	19.94
5	2	2	3	1	40	30	18.53
6	2	3	1	2	50	16.5	17.50
7	3	1	3	2	40	30	18.27
8	3	2	1	3	50	16.5	17.50
9	3	3	2	1	45	21.5	16.01
						GRAND MEAN	18.375

- Let ϕ_i (I = 1, 2…9) be the output response of the i^{th} test run.
- The overall mean or the gross mean of the total test runs,

$$\phi_{mean} = \frac{1}{9}\sum_{i-1}^{9} \phi_I = 3.253\ \mu m.$$

- The mean values of the output response for i^{th}, j^{th}, k^{th} and l^{th} levels of the process parameters A, B, C and D are designated by ϕA_i, ϕB_j, ϕC_k, ϕD_l respectively.

ϕA1 = ⅓ (ϕ1 +ϕ2 + ϕ3) = ⅓ (20.55 + 19.05 + 18.03) = **19.21**

ϕA2 = ⅓ (ϕ4 +ϕ5 + ϕ6) = ⅓ (19.94 + 18.53 + 17.50) = **18.65 ϕA3 = ⅓ (ϕ7 +ϕ8 + ϕ9)** = ⅓ (18.27 + 17.50 + 16.01) = **17.26**

ϕB1 = ⅓ (ϕ1 + ϕ4+ ϕ7) = ⅓ (20.55 + 19.94 + 18.27) = **19.58 ϕB2 = ⅓ (ϕ2 +ϕ5 + ϕ8)** = ⅓ (19.05 + 18.53 + 17.50) = **18.36 ϕB3 = ⅓ (ϕ3 + ϕ6 + ϕ9)** = ⅓ (18.03 +17.50 + 16.01) = **17.18**

ϕC1 = ⅓ (ϕ1 + ϕ6+ ϕ8) = ⅓ (20.55 + 17.50 + 17.50) = **18.36 ϕC2 = ⅓ (ϕ2+ ϕ4 + ϕ9)** = ⅓ (19.05 +19.94 + 16.01) = **18.33 ϕC3 = ⅓ (ϕ3 + ϕ5 + ϕ7)** = ⅓ (18.03 + 18.53+ 18.27) = **18.27**

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ϕD1 = ⅓ (ϕ1 +ϕ5 + ϕ9) = ⅓ (20.55 + 18.53 + 17.50) = **18.36 ϕD2 = ⅓ (ϕ2 +ϕ6 + ϕ7)** = ⅓ (19.05 + 17.50 + 18.27) = **18.27 ϕD3 = ⅓ (ϕ3 +ϕ4 + ϕ8)** = ⅓ (18.03 + 19.94 + 17.50) = **18.49**

Total sum of squares: $(SOS)_T = \sum_{i-1}^{9} (\Delta \phi_i - \phi_{mean}) = 14.7945$

The differential responses to the process parameters A, B, C and D for i th, j th, kth and l th levels are designated by ϕAi, ϕBj , ϕCk , ϕDl respectively.

$$(SOS)_A = 3\sum_{i-1}^{9} (\Delta \phi_{Ai} - \phi_{mean})^2 = 6.045$$

$$(SOS)_B = 3\sum_{i-1}^{9} (\Delta \phi_{Bi} - \phi_{mean})^2 = 8.6409$$

$$(SOS)_C = 3\sum_{i-1}^{9} (\Delta \phi_{Ci} - \phi_{mean})^2 = 0.0351$$

$$(SOS)_D = 3\sum_{i-1}^{9} (\Delta \phi_{Di} - \phi_{mean})^2 = 0.0735$$

% Of contribution of the process parameters to the total variation can be obtained from:

$$P_A = 100 \text{ X } \frac{(SOS)\ A}{(SOS)\ T} = \frac{6.045}{14.7945} \text{ X } 100 = 40.8\ \%$$

$$P_B = 100 \text{ X } \frac{(SOS)\ B}{(SOS)\ T} = \frac{8.6409}{14.7945} \text{ X } 100 = 58.4\ \%$$

$$P_C = 100 \text{ X } \frac{(SOS)\ C}{(SOS)\ T} = \frac{0.0351}{14.7945} \text{ X } 100 = 0.2\ \%$$

$$P_D = 100 \text{ X } \frac{(SOS)\ D}{(SOS)\ T} = \frac{0.0735}{14.7945} \text{ X } 100 = 0.5\ \%$$

% Of contribution **99.97 %**

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Process Parameter	Output Response 1				
	1-Mean	2-Mean	3-Mean	Grand mean	% Of Contribution
A	19.21	18.65	17.26	18.37	2.881
B	19.58	18.36	17.18	18.37	24.039
C	18.36	18.33	18.27	18.37	63.955
D	18.36	18.27	18.49	18.37	9.125
			(SOS)T	73.48	100

ESTIMATE OF THE OUTPUT RESPONSE: -

It is possible to estimate SR using a simple superposition (additive method):

$$\phi_e = \phi\,(A_i, B_j, C_k, D_l) = \phi_{mean} + \Delta\phi_{A_i} + \Delta\phi_{B_j} + \Delta\phi_{C_k} + \Delta\phi_{D_l}$$

$$= \Delta\phi_{mean} + (\phi_{A_i} - \phi_{mean}) + (\phi_{B_i} - \phi_{mean}) + (\phi_{C_i} - \phi_{mean}) + (\phi_{D_i} - \phi_{mean})$$

$$= \phi_{A_i} + \phi_{B_j} + \phi_{C_k} + \phi_{D_l} - 3\phi_{mean}$$

Table-4

NO OF TESTS	OUTPUT VALUES	PREDICTION VALUES
1	20.55	20.41
2	19.05	19.19
3	18.03	17.92
4	19.94	19.82
5	18.53	18.54
6	17.5	17.54
7	18.27	18.37
8	17.5	17.24
9	16.01	16.03

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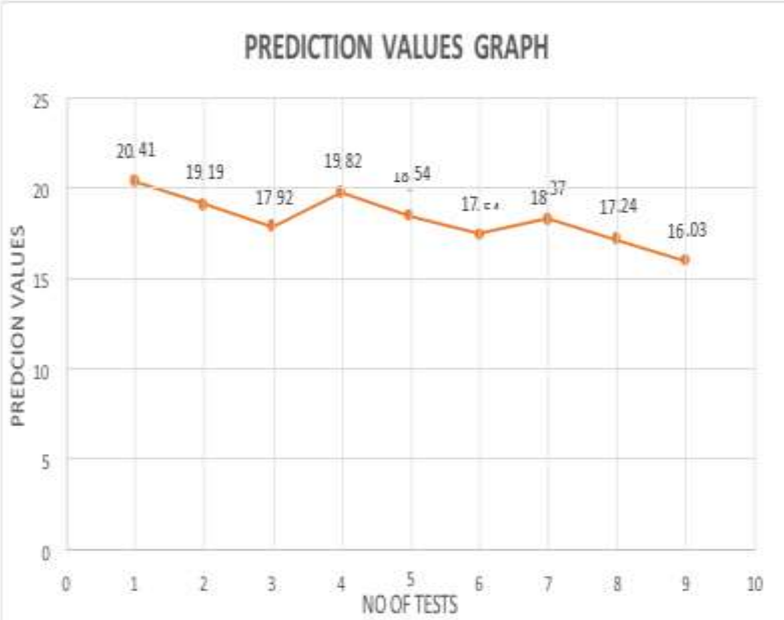

Figure1

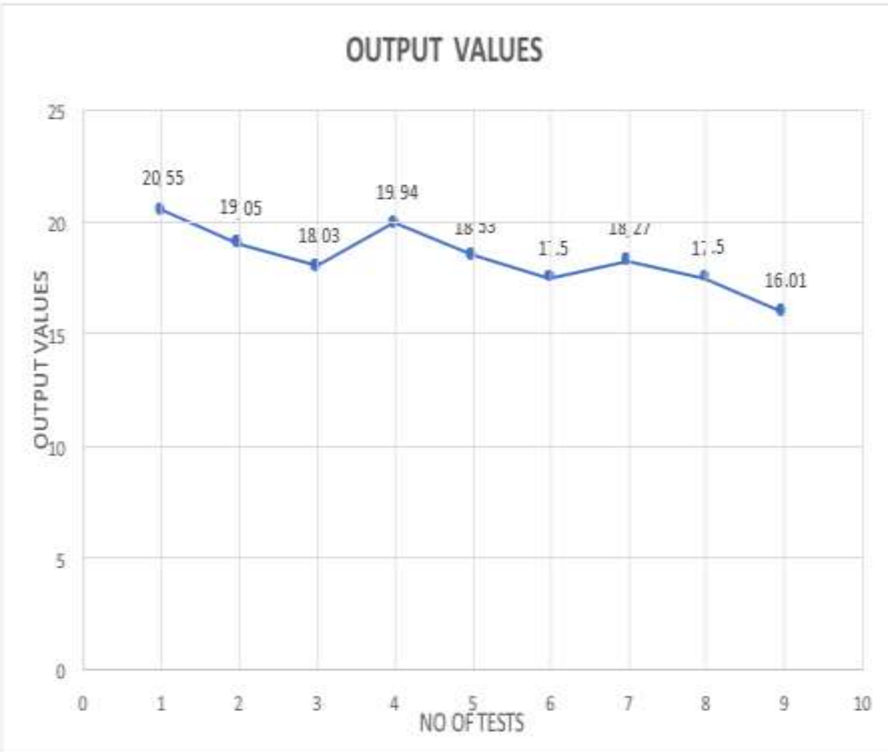

Figure2

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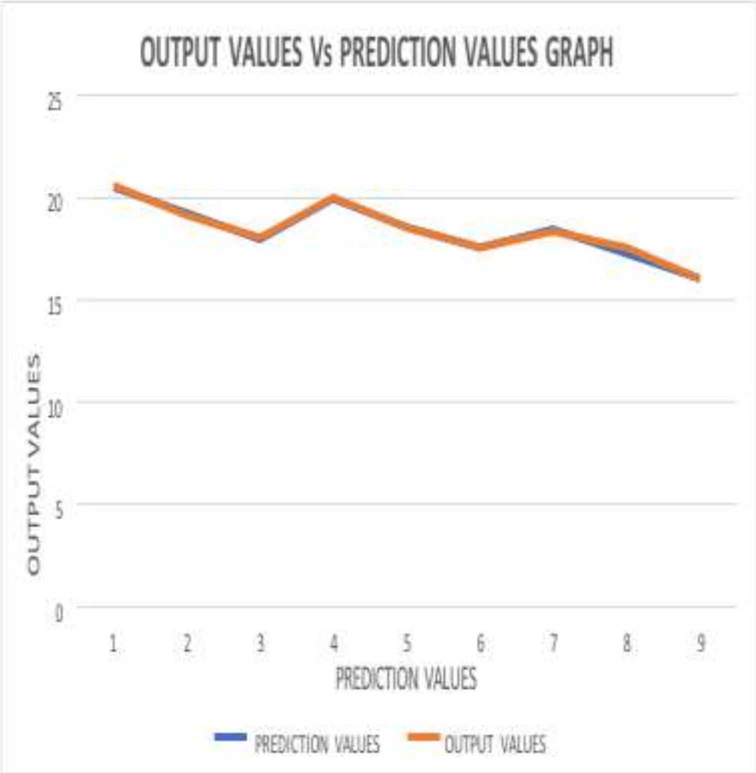

Figure3

Conclusions:

In this study, by completing this project we got maximum values for each parameter by calculating mean values individual parameters at 3 different levels. As per the above data which we have calculated, we obtain very minute difference of prediction values versus output values that which can be negligible. But if we consider the individual observations of prediction values and output values they are fluctuating, they are not at all being constant at any test region.

Author statement

All authors have equal contribution.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ISSN PRINT 2319 1775 Online 2320 7876

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