Parametric Study and Optimization of H-Type Finned Tube Heat Exchangers using Taguchi Method

M.Tech. Scholar Himanshu Shekhar
School of mechanical Engineering,
MPU, Bhopal, MP, India

Asst. Prof. Sujeet Kumar Singh
School of mechanical Engineering,
MPU, Bhopal, MP, India

***Abstract* - Fin and- tube heat exchangers are the typical equipment with extended surface and widely used in many engineering applications, such as air conditioning units, compressor intercoolers, boiler economizers, etc. Heat exchangers are widely used in various industries, such as space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries and waste heat recovery process. A heat exchanger is a device used to transfer heat between one or more fluids, which may be separated by a wall to prevent mixing or may be in direct contact. In this study, a parametric study is performed to investigate the effects of geometric parameters on the heat transfer characteristic and the flow friction characteristic of H-type finned tube heat exchangers. The effectiveness of various parameters on the objectives is evaluated and the geometric structure of the H-type finned tube is optimized for the best performance using Taguchi method. The results show that fin height, transversal tube spacing and longitudinal tube spacing is statistically significant to the flow performance characteristics of the H-type finned tube. Hence, these three parameters must be firstly considered and paid more attention during the design and optimization of H-type finned tube heat exchangers. Analysis of variance also further validates that intuitive analysis is correct.**

***Keyword-*: fine efficiency, CFD, Taguchi method.**

I. INTRODUCTION

In order to improve the thermal performance of heat exchangers, it is necessary to enhance heat transfer on the side of heat exchanger where the thermal resistance is dominant in the overall heat transfer process. The extended surface has been proved to be an effective method for enhancing gas-side heat transfer. Fin and- tube heat exchangers are the typical equipment with extended surface and widely used in many engineering applications, such as air conditioning units, compressor intercoolers, boiler economizers, etc.

Otherwise, in order to solve the problem of energy shortage and environment pollution, plenty of research has been focused on the waste heat recovery. Although the low temperature waste heat in exhaust gas stream has lower capacity to do work as compared to the original hot gas according to the second law of thermodynamics, the amount of such low-utility waste heat is enormous in various industries.

Hence the waste heat recovery is necessary in order to save energy and increase the efficiency of the system. Because of the advantages of anti-wear and anti-fouling, H-type finned tube heat exchangers have been widely used in boilers and waste heat recovery units to enhance the gas-side convection heat transfer. In recent years, a number of experimental and numerical studies have been reported on the air side heat transfer and flow friction characteristics of H-type finned tube H-type finned tube heat exchanger elements maintain a high capacity for heat transfer, possess superior self-cleaning properties and retain the ability to affect flue gas waste heat recovery in boiler renovations.

II. METHODOLOGY

1. Model Description

1.1Physical model

The structure of the H-type finned tube and tube bank is shown in Figure 3.1. Twenty seven H-type finned tubes banks with different geometric parameters were tested, as shown in Table 3.1.

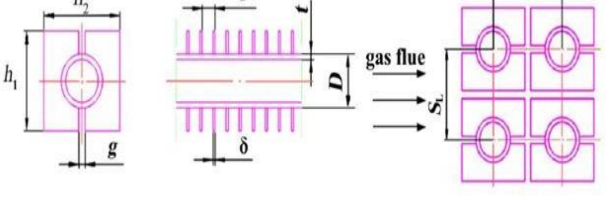

Fig.1. Geometric schematic of H-type finned tube and tube ban.

1.2 Taguchi Method

The Taguchi method is being extensively used in industrial and engineering problems due to its wide range of applications. The Taguchi method is the commonly adopted approach for optimizing design parameters. The method was originally proposed as a means of improving the quality of products using the application of statistical and engineering concepts. This methodology is based on two fundamentals concepts: First, the quality losses must be defined as deviations from the targets, not conformance to arbitrary specifications, and the second, achieving high system quality levels economically requires quality to be designed into the product. To achieve desirable product quality by design, Taguchi suggests a three-stage process: system design, parameter design and tolerance design.

System design is the conceptualization and synthesis of a product or process to be used. To achieve an increase in quality at this level requires innovation, and therefore improvements are not always made. In parameter design the system variables are experimentally analyzed to determine how the product or process reacts to uncontrollable “noise” in the system; parameter design is the main thrust of Taguchi's approach. Parameter design is related to finding the appropriate design factor levels to make the system less sensitive to variations in uncontrollable noise factors, i.e., to make the system robust. In this way the product performs better, reducing the loss to the customer.

The final step in Taguchi's robust design approach is tolerance design; tolerance design occurs when the tolerances for the products or process are established to minimize the sum of the manufacturing and lifetime costs of the product or process. In the tolerance design stage, tolerances of factors that have the largest influence on variation are adjusted only if after the parameter design stage, the target values of quality have not yet been achieved. Since the experimental procedures are generally expensive and time consuming, the need to satisfy the design objectives with least number of tests is clearly an important requirement. Once the levels are taken with careful understanding four parameters with three levels are used for the established experiments. Table 3.1 shows the factors to be studied and the assignment of the corresponding levels.

III. RESULT

1. Fin Efficiency

Temperatures of the H-type fins were measured in this work. Then the relationship between fin efficiency and air velocity and the experimental correlation of fin efficiency was used according to Chen et al., 2014.

$$\eta_f = 7.41 v^{-0.12} \left(\frac{h_1}{d}\right)^{-2.32} \left(\frac{h_2}{d}\right)^{-0.198}$$

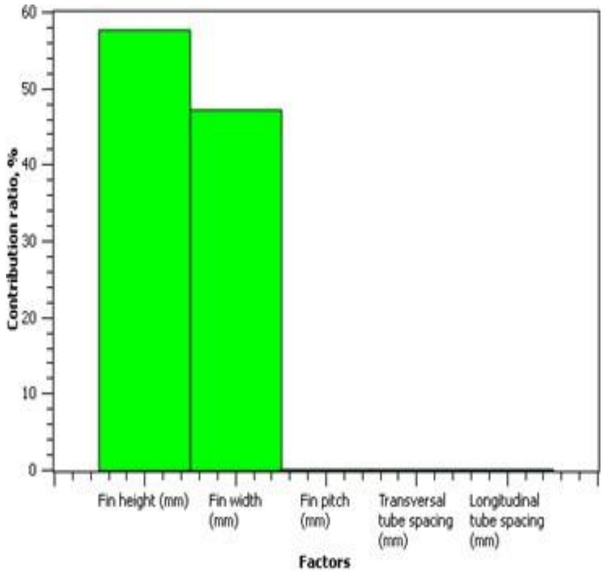

Fig.2. Contribution ratio of each factor for SNR- Fin efficiency, ηf.

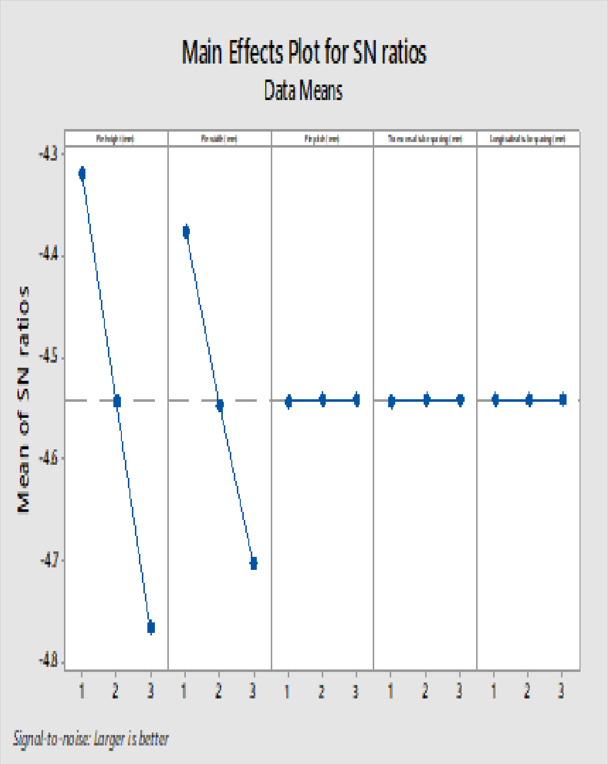

Fig.3. Main-effect plots for SNR- Fin efficiency, ηf.

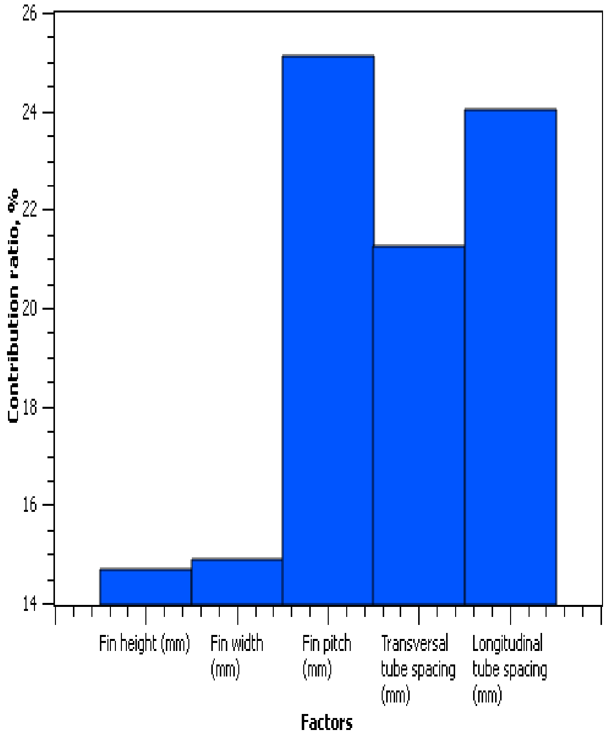

Fig.4. Contribution ratio of each factor for SNR- j.

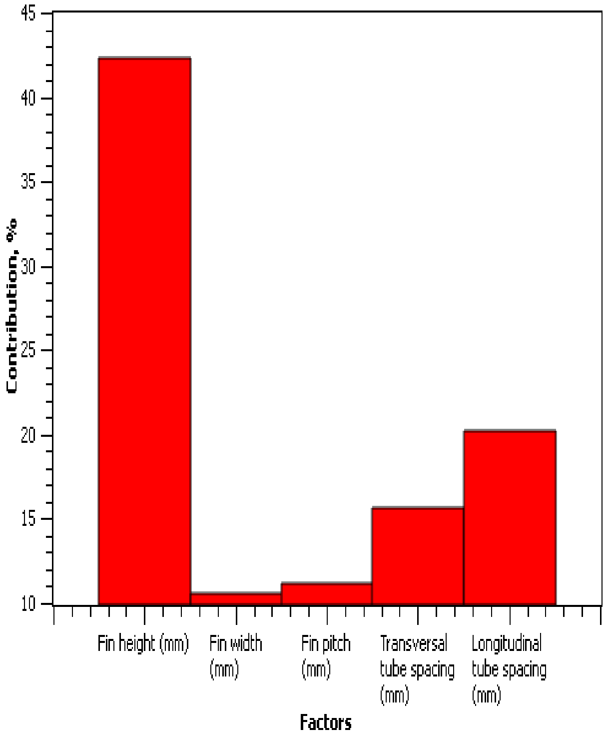

Fig.6. Contribution ratio of each factor for SNR- f.

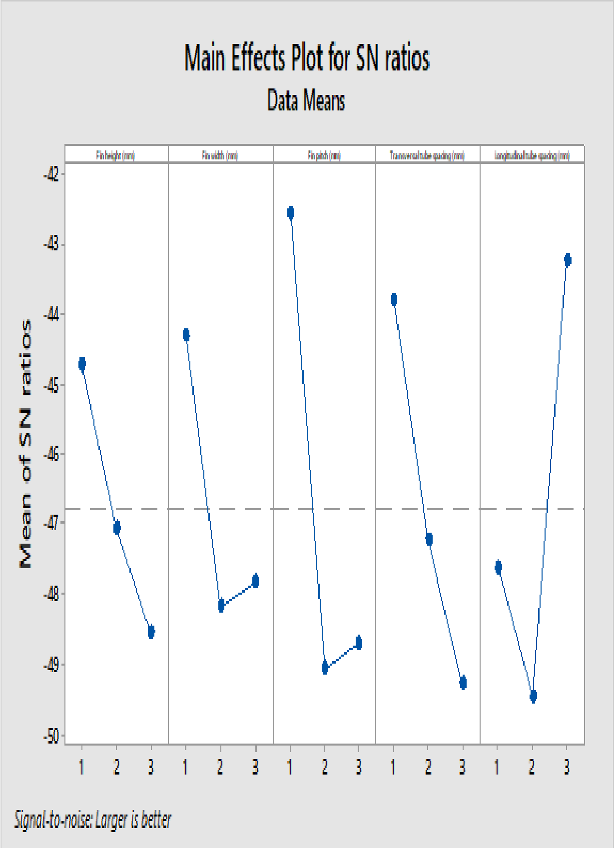

Fig.5. Main-effect plots for SNR- j.

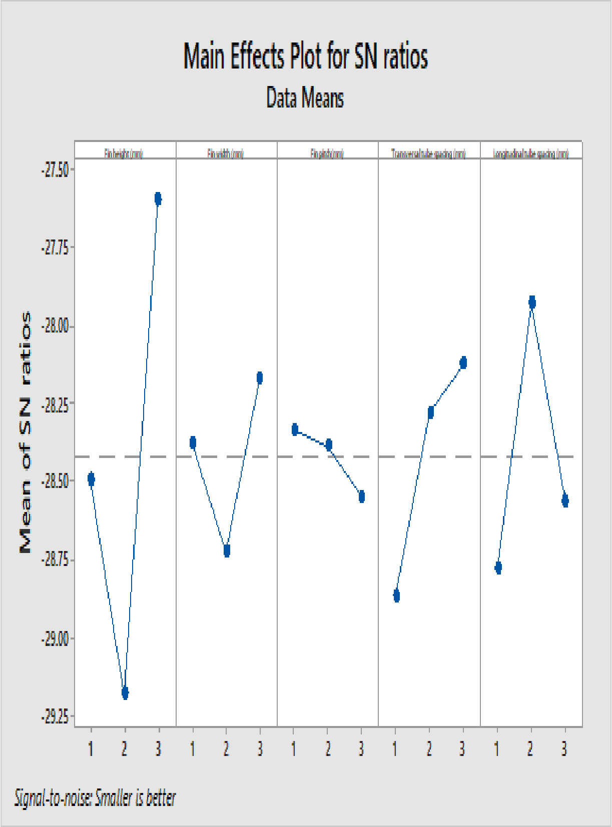

Fig.7. Main-effect plots for SNR- f.

IV. CONCLUSION

In this study, a parametric study is performed to investigate the effects of geometric parameters on the heat transfer characteristic and the flow friction characteristic of H-type finned tube heat exchangers. The effectiveness of various parameters on the objectives is evaluated and the geometric structure of the H-type finned tube is optimized for the best performance using Taguchi method. The main conclusions are drawn as follows:

- It is evident that fin pitch, transversal and longitudinal tube spacing has little effect on fin efficiency. So fin efficiency is primarily associated with fin height and fin width. The optimal combination for SNR- ɳf is determined as A1B1C1D1E1.
- It can be seen that the order of the parametric effectiveness for j is C>E>D>B>A. Fin pitch, transversal tube spacing and longitudinal tube spacing have dominant influence on j with contribution ratios of 25.10%, 24.02% and 21.23% respectively. The reason is that the local heat transfer characteristic of each tube decreases along the flow direction, which contributes to a major decrease of average heat transfer characteristic of the whole H-type finned tube heat exchanger. The optimal combination for SNR-j is determined as A1B1C1D1E3.
- It can be seen that the order of the parametric effectiveness for „f‟ is A>E>D>B>C. Fin height, transversal tube spacing and longitudinal tube spacing have dominant influence on „f‟ with contribution ratios of 42.31%, 20.27% and 15.62% respectively. The optimal combination for SNR-f is determined as A3B3C1D3E2.
- The results show that fin height, transversal tube spacing and longitudinal tube spacing is statistically significant to the flow performance characteristics of the H-type finned tube. Hence, these three parameters must be firstly considered and paid more attention during the design and optimization of H-type finned tube heat exchangers. Analysis of variance also further validates that intuitive analysis is correct.

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