

Parametric Analysis and Thermal Optimization of Triple Concentric Tube Heat Exchanger Using RSM

Chandrapal Singh¹, Prof. Devendra Singh Sikharwar² & Prof. Ashish Patidar³

^{1,2 &3} Mechanical Dept., PCST, Indore, India

Abstract- In the present study, the thermo-fluid characteristics of the triple concentric-tube heat exchanger focus of those research is especially on conventional three -fluid heat exchangers. Consequently, engaging in an investigation on three-fluid warmth exchangers would be a tremendous attempt. In this examine optimization of the heat switch and pressure drop characteristics of heat from triple concentric tubes exchanger has been completed based totally on CFD effects. **Response surface technique (RSM)** approaches were carried out to develop an optimum response as well as a functional relationship primarily based on the studied variety of design/control parameters. The (Nu) Nusselt number and (F) friction factor were chosen as response variables, whereas Reynolds number and length to hydraulic diameter ratio were employed as design variables. The input variable is used to construct a mathematical model using RSM in this study.

Keywords- CFD, numerical modeling, optimization, thermal hydraulic performance, Response surface methodology, triple concentric-tube.

1. INTRODUCTION

A double tube heat exchanger is the most common heat exchanger kind used in a variety of applications. Its operation is based on the transmission of heat between two pipes containing cold and hot fluids.

It has its significance in freezing, boiling drying, dairy, and pharmaceutical, food, pasteurization and chemical industries. In order to manage high-

temperature differences, the heat exchange area should be increased, which could be possible only by increasing the heat exchanger's length.

It has three concentric tubes, or three compartments, referred to as the inner tube, inner annulus, and outer annulus, respectively. The target fluid, whose temperature changes are of primary relevance for application fulfillment, must flow within the inner annulus in order to maximize the heat exchanger's efficiency.

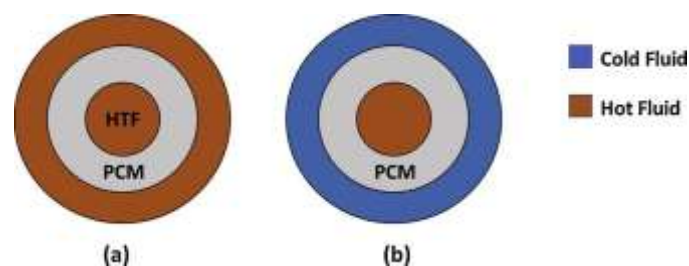


Fig: (a) Charging or discharging mode (b) Sequential charging and discharging mode Diagram of triple concentric tube heat exchanger

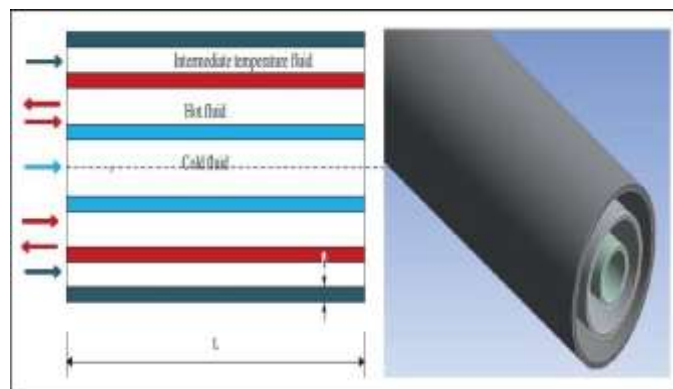


Figure: Schematic representation of Triple Concentric-tube Heat exchanger and its Computational domain

The heat exchanger is a tool permitting to transfer the heat among or more fluids thru walls, without mixing them or they may be in direct contact.

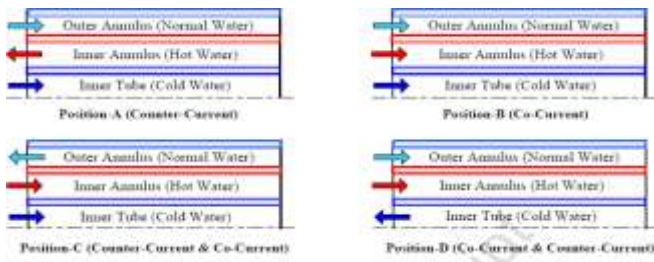


Figure: Flow patterns for the triple tube heat exchanger

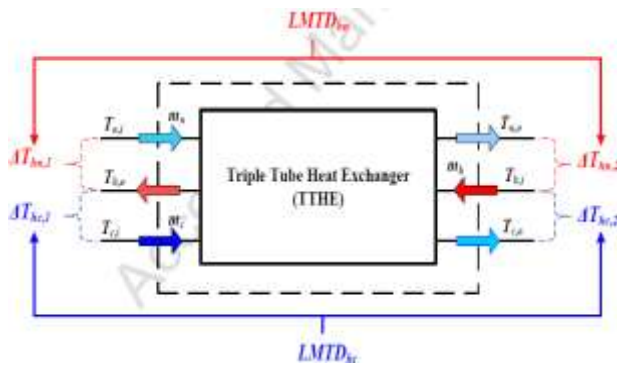


Figure: The approached method of the average LMTD

The simplest model of heat exchanger that you may conceive is a simple tubular warmth exchanger; it is difficult with this type of exchanger to gain important change surfaces without result in very cumbersome gadgets. It's far one of the motives that caused broaden different change geometries which include triple concentric-tube heat exchanger (TTHE).

The TTHE improves heat exchange by adding a second flow route and a large surface area that is roughly double that of a double concentric-tube heat exchanger (DTHE).

In TTHE, we can transfer the heat between three different fluids such as: the refrigerant, the lubricant and the cooling source in a refrigeration machine.

II. LITERATURE REVIEW

[2023] Carlos A. Zuritz et al. [1] a set of mathematical calculations were used to calculate the fluid temperatures of a triple concentric-tube heat

exchanger.

[2023] Ahmet Unal et al. [2] produced a case study for the counter-current arrangement based on a simplified physical model with a completely analytical statement for the fluctuations of the three fluid streams' bulk temperatures along the triple tube heat exchanger. According to a collection of case studies for counter-current setups, the performance or size of the heat exchanger is dependent on the relative sizes of the three tubes. A fully analytical equation for the effectiveness of triple concentric-tube heat exchangers with both counter current and co-current configurations has been added to the previously mentioned temperature distribution formulas.

[2022] O. García-Valladares et al. [3] developed one-dimensional stable and transient numerical modeling criteria to simulate the thermal and fluid-dynamic behaviour of a triple concentric-tube heat exchanger in both transient and steady condition.

CONCLUSIONS OF LITERATURE REVIEW: The majority of research on triple tube heat exchangers has been carried out utilizing water as a heat transfer medium, according to published studies. Furthermore, all research papers show that flow rate and heat transfer rate are precisely proportional, and none of the publications use any other heat transfer fluid than water. Due to its practical uses, work on triple tube heat exchangers (TTHE) is limited as compared to double tube heat exchangers (DTHE). Alternate heat transfer fluids among the three fluids can be used for further research.

III. Objectives

For effective RSM implementation, selecting the right design of experiments (DOE) is critical. The matrix has two elements with un-coded values, Re with five levels and L/Dh with four levels, resulting in a total of 20 runs. The equivalent CFD- predicted responses (Nu and f)

have also been published in the literature [19]. Later, a central composite design (CCD) with a face-centered technique was used to analyses with fewer data points while maintaining the accuracy of the forecast.

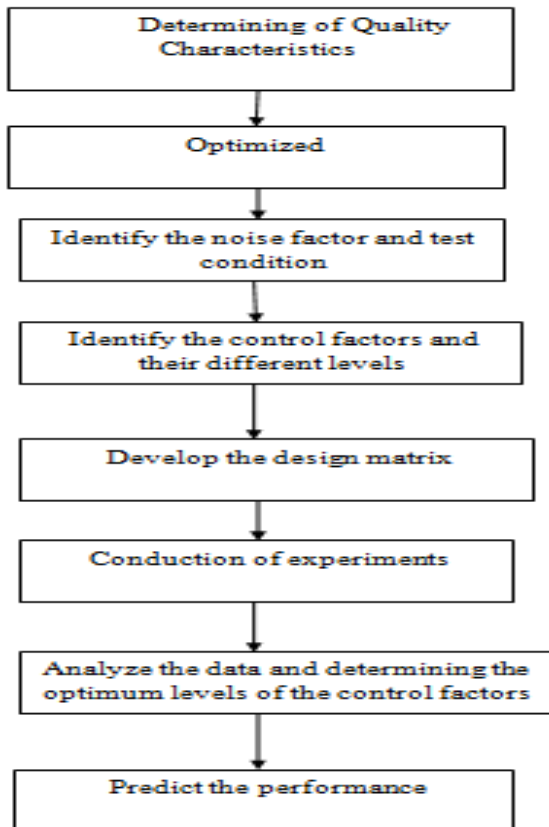


Figure: Flow chart of Taguchi method

Analysis of variance (ANOVA): The analysis of variance (ANOVA) is a statistical approach for detecting whether or not there are differences among multiple population means. While the goal of ANOVA is to find differences between the means of numerous populations, the technique necessitates the analysis of various kinds of variation associated with the random samples under investigation—hence the name analysis of variance.

S/N Ratio Analysis: Signal-to-noise is compares the level of a desired signal to the extent of background signal. It's the magnitude relation of signal power to the noise power, typically expressed

in decibels. The Taguchi methodology uses a loss perform to work out the standard characteristics. Loss function values also are regenerate to a signal-to-noise(S/N) signal-to-noise magnitude relation signal/noise ratio signal/noise(S/N ratio) (S/N) ratio (η).

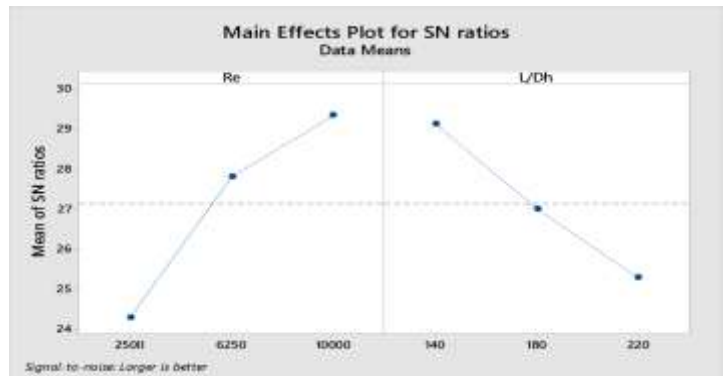


Figure: The S/N response graphs for heat transfer

The following performance objectives, as well as a set of operational limitations and conditions, are frequently addressed for maximizing the utilization of a heat exchanger in most practical applications of enhancement approaches.

1. To observe the effectiveness of parallel flow arrangement of the triple tube heat exchanger.
2. The optimum values, as well as the functional relationship between the design factors (Re and L/Dh) and response variables (Nu and f), have also been developed.
3. In the present study, optimization of heat transfer and pressure drop characteristics in a triple concentric tube heat exchanger has been done using the results of numerical simulation.

IV. RESULTS

The (statistical) design of experiments (DOE) is an efficient procedure for planning experiments, so that the data obtained can be analyzed to yield valid and objective conclusions guarantees the accuracy and efficiency of the experiments [30]. The task starts with identifying the input variables and the response (output) that is to be measured. For each input variable, a number of levels are defined that represent the effect range that is desired to be known. DOE is commonly used in

complex real world experiments; however, it is also applicable for simulation-based experiments, which only requires a single repetition for each experiment. Simulated experiments are obviously not affected by the errors commonly encountered in real experiments.

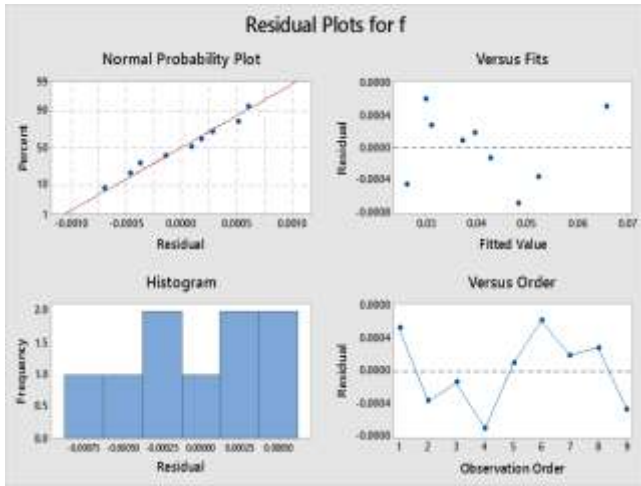


Figure: Residual plots for friction factor

The plots of residuals for friction factor are shown in Figure 4.1. As can be seen in the normal probability plots in both figures, the residuals are distributed equally on both sides of the straight line, indicating that the distribution of residuals for the friction factor is normal and so gives a good fit to the data.

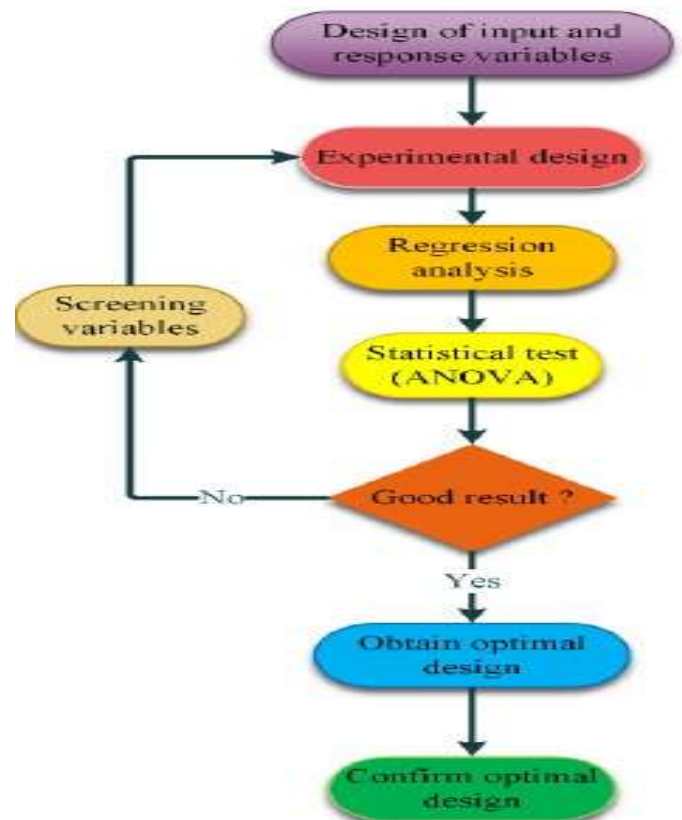


Fig: Response surface methodology

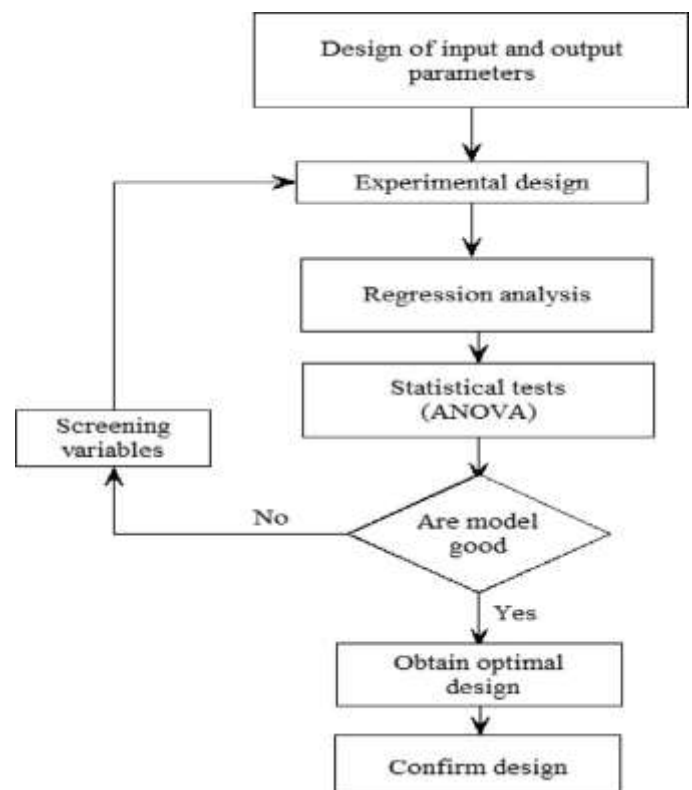


Fig: Flow chart of the RSM modeling approach for optimal design

VIII. Conclusion

Numerical simulation of triple concentric tube heat exchanger and thermal hydraulic performance using CFD and optimization using RSM and Taguchi method: After the numerical approach was validated, optimization was carried out to build a functional relationship between design elements and response variables, as well as to determine the best values for a variety of design variables. Reynolds number (Re: 2500–10,000) and length to hydraulic diameter ratio (L/Dh: 100–220) are the design parameters evaluated.

The response variables have been chosen as Nusselt number (Nu) and friction factor (f). The basic conclusions of this work have been summarized as follows-

- i. Based on the results of numerical simulation and multi-objective optimization. From Figure, that the first Level provides maximum value of Nusselt number.
 - (a) Reynolds number A1 2500
 - (b) Length to hydraulic diameter ratio B2 180
- ii. From Figure, that the first Level provides minimum value of pressure drop (friction factor)
 - (a) Reynolds number A1 2500
 - (b) Length to hydraulic diameter ratio B2 180.
- iii. Table shows the ANOVA result for friction factor. It is observed that the Reynolds number (P=0.000) (54.08 %) is most influences the friction factor followed by

hydraulic diameter ratio (P= 0.000) (40.33%)

- iv. The F-test determines whether the parameters are significantly different statistically. The greater the impact on the friction factor performance characteristics, the higher the F value [15]. For Reynolds number (P=0.000), larger F values are found (58.57 %)
- v. Table 4.3 shows the ANOVA result for Nusselt number. It is observed that the Reynolds number (P=0.000) (54.08 %) is most influences the friction factor followed by hydraulic diameter ratio (P= 0.000) (37.53%)
- vi. The predicted value of the response variables is precisely closer to the numerical results and hence, it has helped in reducing the size of the required data as the RSM provides useful interaction between the various parameters of the system.

IX. References

- [1] J. Y. Long, D. S. Zhu, “Numerical and experimental study on heat pump water heater with PCM for thermal storage”, Energy Build. 40 (2023) 666-672, <https://doi.org/10.1016/j.enbuild.2007.05.001>.
- [2] Carlos A. Zuritz, On the design of triple concentric-tube heat exchanger, Journal of Food Process Engineering 21 (2023) 113-130.
- [3] Ahmet Ünal, Theoretical analysis of triple concentric-tube heat exchangers part-1: mathematical modeling, International Communications in Heat and Mass Transfer 25 (2022) 949-958.