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Optimization Of Shell And Tube Heat Exchanger Enhenced By Taguchi Method

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Abstract — *In modern day shell and tube heat exchanger is widely used in industries as a chillers plant for transfer waste heat from the injection molding machine to the cooling water for improve the efficiency of the injection molding machine. The transformations of the waste heat from injection molding machine to the cooling water is dependent on the heat exchange capacity of heat exchangers. So in now a day the industries are facing the problem for improving the heat exchange capacity of the heat exchanger by improving the heat exchanger's efficiency for increase production capacity and efficiency of injection molding machine.*

Keywords-*heat exchanger, cfd analysis of shell and tube heat exchanger, shell and tube, experimentation of heat exchanger, analysis of shell and tube type heat exchanger.*

I. INTRODUCTION

A heat exchanger is a device built for efficient heat transfer from one medium to another. The media may be separated by a solid wall, so that they never mix, or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning, power plants, chemical plants, petrochemical plants, petroleum refineries, natural gas processing, cryogenics applications and sewage treatment. One common example of a heat exchanger is the radiator in a car, in which the heat source, being a hot engine-cooling fluid, water, transfers heat to air flowing through the radiator (i.e. the heat transfer medium).

II. OBJECTIVE OF THE PAPER

The objective of work is to increase the efficiency of the shell and tube heat exchanger. The efficiency of the heat exchanger is basically depends on the geometric parameters (tube diameter, pitch length, types of the baffles, angle of the baffles etc.) as well as process parameters (mass flow rate, inlet and outlet temperature of the cooling water etc.) of heat exchangers. So the objective is to optimize some of these parameters (tube diameter, pitch length, mass flow rate) for improve the efficiency of the heat exchanger. The steps needs for perform optimization of parameters are:

- Experimental reading for validation of ANSYS result.
- Optimization of parameters by using Taguchi method.

III. LITERATURE SURVEY

3.1 Effect of geometrical parameters on heat transfer and pressure drop characteristics of plate fin and tube heat exchangers *(Author: Aytunc Erek, Barıs Ozerdem, Levent Bilir , Zafer Ilken & Journal: ScienceDirect)*

Work: In this study, the influences of the changes in fin geometry on heat transfer and pressure drop of a plate fin and tube heat exchanger are investigated, numerically. A computational fluid dynamics (CFD) program called Fluent is used in the analysis. The segment of one tenth of fin is used in the modeling, due to symmetrical condition. The results of heat transfer, static, and total pressure drop values of ten different fins are tabulated and the normalized values of them are, also, given for the comparison of the models.

The distance between fins is found to have a considerable effect on pressure drop. It is observed that placing the fin tube at downstream region affects heat transfer positively. Another important result of the study is that increasing elasticity of the fin tube increases the heat transfer while it, also, results in an important reduction in pressure drop.

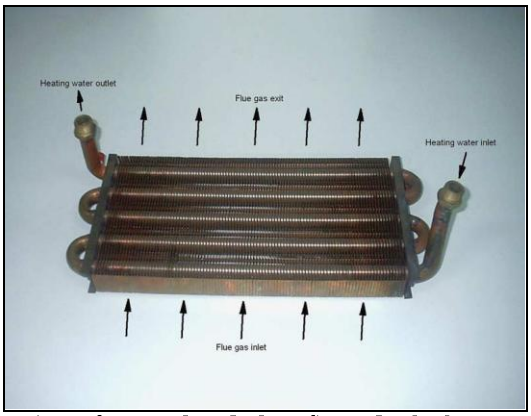

Figure 1. View of an analyzed plate fin and tube heat exchanger.

The effects of fin tube center location, fin height, tube thickness, tube ellipticity, and distance between fins on heat transfer between flue gas and water, and pressure drop of flue gas passing through the fins are investigated, numerically. On the basis of previous results, the following discussions and conclusions are made:

- The distance between fins has an important effect on pressure drop. For the models with ellipticity value of 0.7345, Model (b) has the smallest static and total pressure drops. Since flue gas velocity is decreased, the lower pressure drop value is obtained.
- Placement of the tube in downstream region, as in Model (c), increases the heat transfer between flue gas and water. The reason of this augmentation can be revealed as horseshoe vortex effect. If the fin tube is placed in the upstream region, heat transfer augmentation caused by horseshoe vortex could not be noticed at sufficient level. But, if it is placed in the downstream region which has lower Nusselt number, horseshoe vortex can be noticed strongly.
- In addition to this, recalculating vortices formed behind the tube attenuate negative effect on heat transfer when the fin tube is placed at the downstream region. This effect can be seen for the results of Models (e) and (f), as well.
- Greater heat transfer and pressure drop values are obtained as the fin height is increased, due to the increased heat transfer surface area.
- As the tube thickness is decreased, heat transfer is increased whereas pressure drop is decreased. Because heat resistance between water and flue gas is lower for this case.
- As ellipticity increases in a tube, the heat transferred across a heat exchanger increases. The ellipticity, also, affects pressure drop positively. This result can be revealed that as ellipticity increases, the cross section of flue gas flow, also, increases. Elliptical tube results in a lesser drag than the circular tube, due to its better aerodynamic shape. This shape causes better heat transfer characteristics, as well.

Although the present study has been completed for one row heat exchangers, the results can be applied to heat exchangers with more rows. The results concluded above are in good agreement with previous experimental and numerical studies. Finally, this entire study should have a great value for direct application to heat exchanger design aspect.

3.2 Shell side numerical analysis of a shell and tube heat exchanger considering the effects of baffle inclination angle on fluid flow using CFD *(Author:* Thundil Karuppa Raj, Srikanth Ganne *& Journal: ScienceDirect)*

Work: In this present study, attempts were made to investigate the impacts of various baffle inclination angles on fluid flow and the heat transfer characteristics of a shell-and-tube heat exchanger for three different baffle inclination angles namely 0°, 10° and 20°. The simulation results for various shell and tube heat exchangers, one with segmental baffles perpendicular to fluid flow and two with segmental baffles inclined to the direction of fluid flow are compared for their performance. The shell side design has been investigated numerically by modeling a small shell-and-tube heat exchanger.

The study is concerned with a single shell and single side pass parallel flow heat exchanger. The flow and temperature fields inside the shell are studied using non-commercial CFD software tool ANSYS CFX 12.1. For a given baffle cut of 36 %, the heat exchanger performance is investigated by varying mass flow rate and baffle inclination angle. From the CFD simulation results, the shell side outlet temperature, pressure drop, recirculation near the baffles, optimal mass flow rate and the optimum baffle inclination angle for the given heat exchanger geometry are determined.

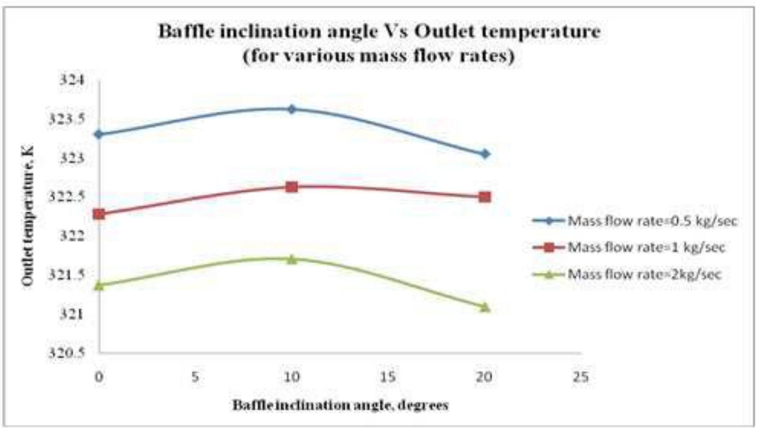

Figure 2. Variation of temperature with baffle inclination angle (for various mass flow rates).

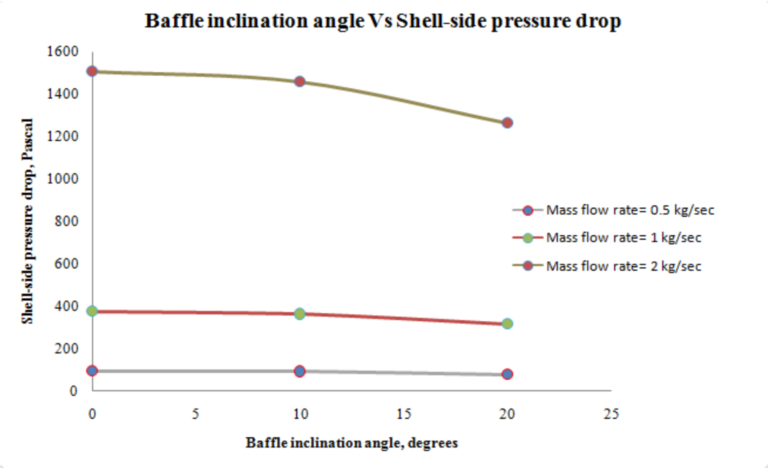

Figure 3. Variation of pressure drop with baffle inclination angle (for 0.5 kg/s, 1 kg/s, 2 kg/s mass flow rates)

The shell side of a small shell-and-tube heat exchanger is modelled with sufficient detail to resolve the flow and temperature fields.

- The shell side of a small shell-and-tube heat exchanger is modelled with sufficient detail to resolve the flow and temperature fields.
- For the given geometry the mass flow rate must be below 2 kg/s, if it is increased beyond 2 kg/s the pressure drop increases rapidly with little variation in outlet temperature.
- The pressure drop is decreased by 4 %, for heat exchanger with 10° baffle inclination angle and by 16 %, for heat exchanger with 20° baffle inclination angle.
- The maximum baffle inclination angle can be 20°, if the angle is beyond 20°, the centre row of tubes are not supported. Hence the baffle cannot be used effectively.
- Hence it can be concluded shell and tube heat exchanger with 20° baffle inclination angle results in better performance compared to 10° and 0° inclination angles.

3.3 CFD analysis of a shell and finned tube heat exchanger for waste heat Recovery applications
(Author: Apu Roy, D.H.Das & Journal: ScienceDirect)

Work:-The energy available in the exit stream of many energy conversion devices such as I.C engine gas turbine etc goes as waste, if not utilized properly. The present work has been carried out with a view to predicting the performance of a shell and finned tube heat exchanger in the light of waste heat recovery application. The performance of the heat exchanger has been evaluated by using the CFD package fluent 6.3.16 and has been compared with the available experimental values.

An attempt has also been made to predict the performance of the above heat exchanger by considering different heat transfer fluid and the result so obtained have been compared. The performance parameters pertaining to heat exchanger such as effectiveness, overall heat transfer coefficient, energy extraction rate etc, have been reported in this work.

An investigation was carried out to study the shell and finned tube heat exchanger computationally. The analysis has done and pressure drop and temperature rise along the tube surfaces has been investigated. Based on the obtained result it can be concluded as follows,

- Temperature variation with same velocity of castor oil and water is greatly noticeable. This is due to better thermal properties of castor oil than the water.
- All dimensionless parameters are changes for their own properties such as specific heat, viscosity, density, and thermal conductivity properties.
- Better effectiveness can be achieved by using castor oil as heat transfer fluid whereas water gives the traditional effectiveness.
- The effectiveness of the finned tube heat exchanger is quite comparable with other conventional heat exchanger.
- The results from the computational analysis appear to be in good agreement with the available experimental results.
- Energy extraction rate is also quite significant .That means a sufficient amount of heat can be recovered by the using of finned tube heat exchanger.

3.4 CFD and experimental studies on heat transfer enhancement in an air cooler equipped with different tube inserts *(Author: S.R. Shabanian, M. Rahimi, M. Shahhosseini, A.A. Alsairafi S.R. Shabanian, M. Rahimi, M. Shahhosseini, A.A. Alsairafi & Journal: ScienceDirect)*

Work: This paper reports the experimental and Computational Fluid Dynamics (CFD) modelling studies on heat transfer, friction factor and thermal performance of an air cooled heat exchanger equipped with three types of tube insert including butterfly, classic and jagged twisted tape. In the studied range of Reynolds number the maximum thermal performance factor was obtained by the butterfly insert with an inclined angle of 90°.

The results have also revealed that the difference between the heat transfer rates obtained from employing the classic and jagged inserts reduces by decreasing the twist ratio. The CFD predicted results were used to explain the observed results in terms of turbulence intensity. In addition, good agreements between the predicted and measured Nu number as well as friction factor values were obtained.

In the present study the thermal performance factor of an insert called butterfly has been compared with that of classic and jagged twisted tape tube inserts. The studied tube inserts including the butterfly inserts with inclined angles of 45°, 90° and 135°, and the jagged and classic twisted tape inserts with twist ratios of 1.76, 2.35, 2.94 and 3.53, were placed in a bent tube of the air cooled heat exchanger.

The enhancement percentages of Nu/Nu0 of all studied inserts have been calculated. The ratio of Nu/Nu0 values for the jagged inserts with various twist ratios with respect to the classic ones have been measured. The average value of 17.24%, 22%, 26.02% and 28.11% were found for twist ratios of 1.76, 2.35, 2.94 and 3.53, respectively. From these results it has been concluded that the effect of edging of the classic insert on heat transfer rate reduces by decreasing the twist ratio.

In addition, in comparison between the jagged inserts and butterfly inserts, it was found that there were higher performances by the butterfly inserts in terms of thermal performance factor. In the studied range of Reynolds number, the thermal performance factor of butterfly insert varied between 1.28 and 1.62, while it was between 1 and 1.23 for the jagged inserts.

The CFD modeling was employed to explain the experimental observations. In the modeling, the MFR method was used to model the fan rotation and the RNG $\kappa-\varepsilon$ turbulence model was employed to predict the turbulence effects. The three dimensional CFD modeling results showed that an increase in turbulence intensity could be one of the reasons for higher performance of butterfly compared with the jagged and classic ones.

3.5 CFD application in various heat exchanger designs *(Author: Muhammad Mahmood Aslam Bhutta, Nasir Hayat, Muhammad Hassan Bashir, Ahmer Rais Khan, Kanwar Naveed Ahmad, Sarfaraz Khan & Journal: ScienceDirect)*

Work: Nasir hayat present the research paper on CFD application in various heat exchanger designs. The main objective of this research paper is that CFD is employed for the following areas of study in various type of heat exchanger, fluid flow maldistribution, fouling and pressure drop and thermal analysis in the design and optimization phase. Finally he concluded that conventional methods are used for the design and development of the heat exchangers are largely tedious and expensive in today’s market.

CFD has emerged as cost effective alternative and it provides speedy solution to heat exchanger design and optimization.

3.6 Analysis on flow and heat transfer characteristics of EGR helical baffled cooler with spiral corrugated tubes *(Author:* lin liu *& Journal: ScienceDirect)*

Work: lin liu present the research paper on analysis on flow and heat transfer characteristics of EGR (exhaust gas recirculation) helical baffled cooler with spiral corrugated tubes .the main objective for this work is that exhaust gas recirculation which reduces the exhaust gas temperature for reduction of NO_x.

He used helical baffled tube cooler with spiral corrugated tubes. Finally he concluded that heat performance of spiral corrugated tube is significantly higher than that of smooth tube.

IV. INTRODUCTION OF DESIGN OF EXPERIMENT

The word experiment is used in a quite precise sense to mean an investigation where the system under study is under the control of the investigator. This means that experiment is the process in which purposeful changes are made to the input variables of process or systems so that we may observe and identify the reasons for changes that may be observed in the output response. For investigate or discovers something about any process there are number of experiments are required for finding response of desire output in condition of large input. Therefore to reduce the number of Experiments and to obtain good quality of investigation the term named Design of experiments (DOE) is highly useable method in all over the world.

Design of Experiments (DOE), is one of the most important statistical tools of TQM for designing high quality experiment at reduced cost. Design of Experiments (DOE) methods provides an efficient and systematic way to optimize designs for performance, quality, and cost. This method was developed in the early 1920s by Sir Ronald Fisher at the Rothamsted Agricultural Field Research Station in London, England. He was implementing this method for determining the effect of various fertilizers on different plots of land.

The purpose of Design of experiment is to plan, design and analyze the experiment so that the valid and objective conclusions can be drawn effectively and efficiently.

4.1 Advantages of DOE

DOE eliminates the 'confounding of effects' whereby the effects of design variables are mixed up. Confounding of effects means we can't correlate product changes with product characteristics.

- DOE helps us handle experimental error.
- DOE helps us determine the important variables that need to be controlled.
- DOE helps us find the unimportant variables that may not need to be controlled.
- DOE helps us measure interactions, which is very important.

The optimization methods available in Minitab 16 include Taguchi designs, general full factorial designs (designs with more than two-levels), and response surface designs.

4.2 Analysis Methodology for Experimental Result

A. Taguchi Method for Single Objective Optimization

Taguchi's methods of experimental design provide a simple, efficient, and systematic approach for the optimization of experimental designs for performance quality and cost. The main purpose of Taguchi method is reducing the variation in a process through robust design of experiments. It was developed by Dr. Genichi Taguchi of Japan. He developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied; it allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. Analysis of variance on the collected data from the Taguchi design of experiments can be used to select new parameter values to optimize the performance characteristic.

B. Process Steps Of Taguchi Method

1. Define the process objective.
2. Identify test conditions.
3. Identify the control factors and their alternative levels.
4. Create orthogonal arrays for the parameter design.
5. Conduct the experiments indicated in the completed array to collect data on the effect on the performance measure.
6. Complete data analysis to determine the effect of the different parameters on the performance measure.
7. Predict the performance at these levels.
8. Confirmation experiments.

C. Signal -to- Noise (S/N) Ratio

The objective of problem statement is to obtain maximum value or minimum value of desired response. Taguchi method chooses to calculate the signal-to-noise ratio for finding effective parameter for desire response value. To calculate the S/N ratio, experiments are conducted in a systematic manner. Taguchi's idea is to recognize controllable and noise factors and to treat them separately as a design parameter matrix and a noise factor matrix, respectively. Experiments are organized according to orthogonal arrays (OAs). Noise factors are changed in a balanced fashion during experiments.

The characteristics of S/N ratio can be divided into three categories smaller is better, Higher is better and nominal is best when the characteristic is continuous. These characteristics are selected as per objective of problem. They are calculated by following equation.

(a) Nominal is the best characteristic

$$SNi = 10log\frac{\bar{y}_i^2}{s_i^2} \tag{4.1}$$

(b) Smaller is batter

$$SNi = -10\log\left(\sum_{u=1}^{Ni}\frac{y_u^2}{N_i}\right) \tag{4.2}$$

(c) Larger the better characteristics

$$SNi = -10\log\left[\frac{1}{N_i}\sum_{u=1}^{Ni}\frac{1}{y_u^2}\right] \tag{4.3}$$

Where

$$\bar{y}_i = \frac{1}{N_i}\sum_{u=1}^{N_i} y_{i,u} \tag{4.4}$$

$$s_i^2 = \frac{1}{N_i - 1}\sum_{u=1}^{N_i}(y_{i,u} - \bar{y}_i) \tag{4.5}$$

i = Experiment number
u = Trial number
Ni = Number of trials for experiment i.

The effect of many different parameters on the performance characteristic in a condensed set of experiments can be examined by using the orthogonal array. Once the parameters affecting a process that can be controlled have been determined, the levels at which these parameters should be varied must be determined. Determining what levels of a variable to test requires an in-depth understanding of the process, including the minimum, maximum, and current value of the parameter. If the difference between the minimum and maximum value of a parameter is large, the values being tested can be further apart or more values can be tested. If the range of a parameter is small, then less value can be tested or the values tested can be closer together

A matrix has a number of columns equal to the number of factors (parameters) to be considered, each column representing a specific factor. Within each column we specify the levels (parameter setting) at which the factors are kept for experiments. The number of rows in a matrix represents the number of experiments that are to be performed. As the name suggests, the columns or orthogonal array are mutually orthogonal. Here, orthogonal is interpreted in the combinatory sense that is for any pair of columns, all combinations of factor levels appear equal number of times. An orthogonal array design gives more reliable estimates of factor effects with fewer experiments that are needed in traditional methods.

Taguchi has tabulated 18 basis orthogonal arrays. An arrays name indicates the number of rows and columns it has and also the number of levels in each columns. For example L12 (211) has 12 rows and 11 columns each at 2 levels. The array can be directly used in many cases or modified to suit a specific problem. The number of rows of an orthogonal array represents the number of experiments. For an array to be a viable choice, the number of rows must be at least equal to the degrees of freedom required for the case study. The number of columns of an array represents the maximum number of factors that can be studied using that array. Usually, it is expensive to conduct experiments of the case study. The selection orthogonal arrays for number of process parameter with respect to levels of variation of parameter are listed in the table given below table no. 4.1 Analysis of variance techniques provides a mathematical basis for organizing and interpreting the experimental results. For each performance requirement, signal-to-noise (S/N) ratio is used.

D. Advantages Of Taguchi Method

- Taguchi method is that it emphasizes a mean performance characteristic value close to the target value rather than a value within certain specification limits, thus improving the product quality.
- Taguchi's method for experimental design is straightforward and easy to apply to many engineering situations, making it a powerful yet simple tool.

- It can be used to quickly narrow down the scope of a research project or to identify problems in a manufacturing process from data already in existence.
- The Taguchi method allows for the analysis of many different parameters without a prohibitively high amount of experimentation.

E. Disadvantages Of Taguchi Method

- The Taguchi method is that the results obtained are only relative and do not exactly indicate what parameter has the highest effect on the performance characteristic value.
- Since orthogonal arrays do not test all variable combinations, this method should not be used with all relationships between all variables are needed. The Taguchi method has been criticized in the literature for difficulty in accounting for interactions between parameters.
- The Taguchi methods are offline, and therefore inappropriate for a dynamically changing process such as a simulation study. Taguchi methods deal with designing quality in rather than correcting for poor quality, they are applied most effectively at early stages of process development. After design variables are specified, use of experimental design may be less cost effective.

Orthogonal array	Number of rows	Maximum number of	Maximum number of columns at this level			
			2	3	4	5
L_4	4	3	3	-	-	-
L_8	8	7	7	-	-	-
L_9	9	4	-	4	-	-
L_{12}	12	11	11	-	-	-
L_{16}	16	15	15	-	-	-
L_{16}	16	5	-	-	5	-
L_{18}	18	8	1	7	-	-
L_{25}	25	6	-	-	-	6
L_{27}	27	13	-	13	-	-
L_{32}	32	31	31	-	-	-
L_{32}	32	10	1	-	9	-
L_{36}	36	23	1	12	-	-
L_{36}	36	16	3	13	-	-
L_{50}	50	12	1	-	-	11
L_{54}	54	26	1	25	-	-
L_{64}	64	63	63	-	21	-
L_{64}	64	21	-	-	-	-
L_{81}	81	40	-	40		-

Table 1. Selection of Orthogonal Arrays

Experiment	**P1**	**P2**	**P3**	**P4**
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 2. L-9 ARREY TABLE

Sr. No	Tube Outer Dia.(mm)	Pitch of tube(mm)	Mass Flow Rate(kg/s)
1	8.525	23	1.2
2	8.525	25	1.5
3	8.525	27	1.8
4	9.525	23	1.5
5	9.525	25	1.8
6	9.525	27	1.2
7	10.525	23	1.8
8	10.525	25	1.2
9	10.525	27	1.5

Table 3. Selection of Orthogonal Arrays

4.3 Optimization Geometrical Data

CASE 1: pitch length = 23 mm, tube diameter= 8.525 mm, mass flow rate: 1.2 kg/s.

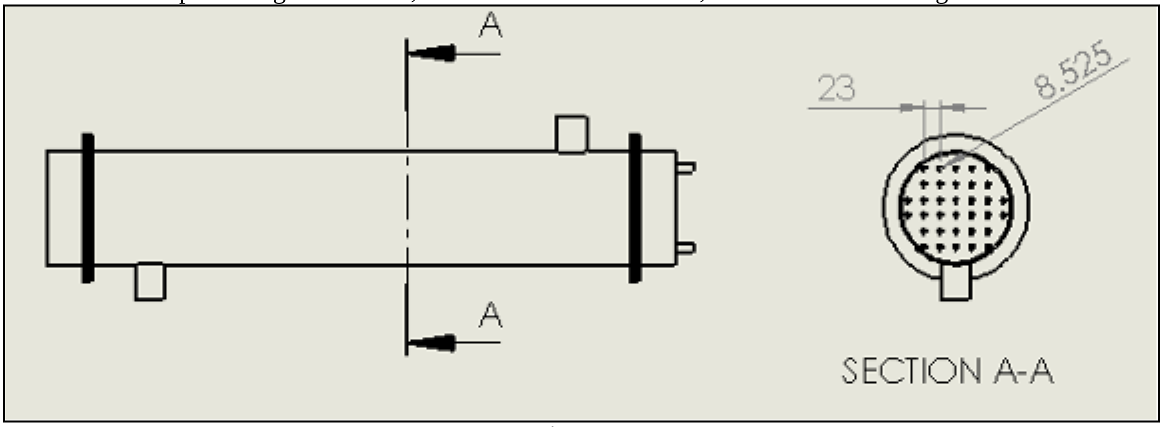

Figure 4.

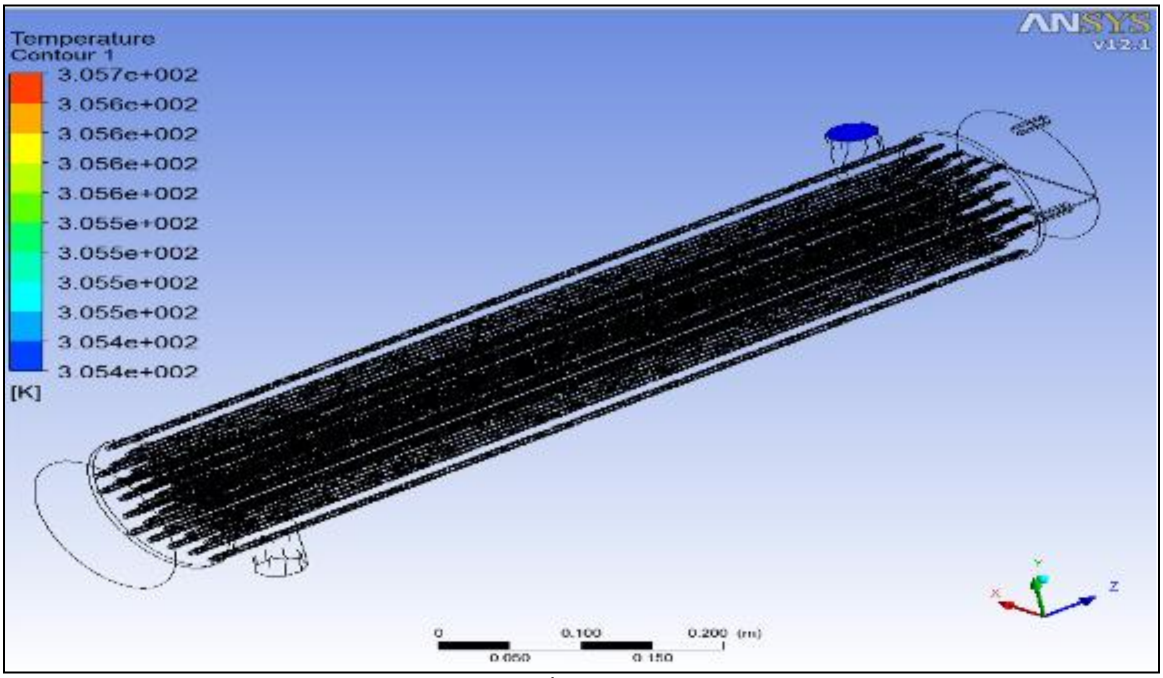

Figure 5.

CASE 2: pitch length: 25mm, tube diameter: 8.525 mm, tube diameter: 1.5 kg/s.

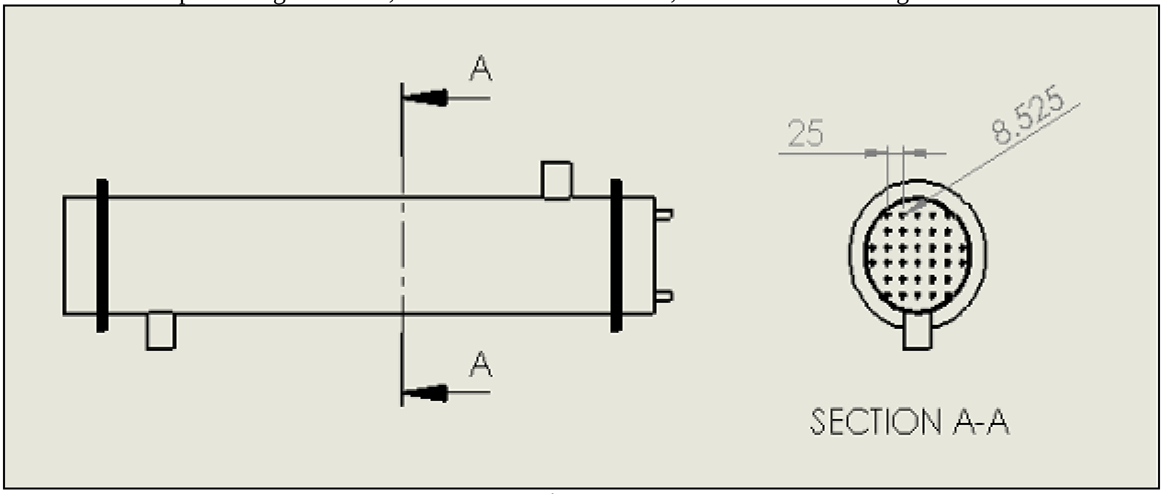

Figure 6.

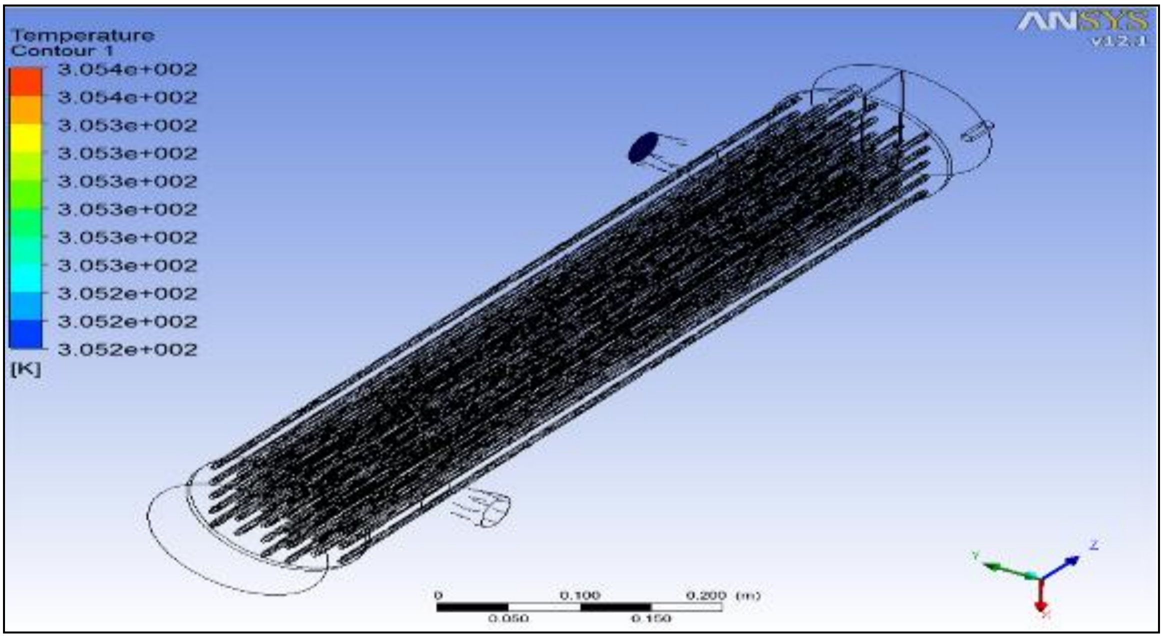

Figure 7.

CASE 3: pitch length: 27 mm, tube diameter: 8.525 mm; mass flow rate: 1.8 kg/s.

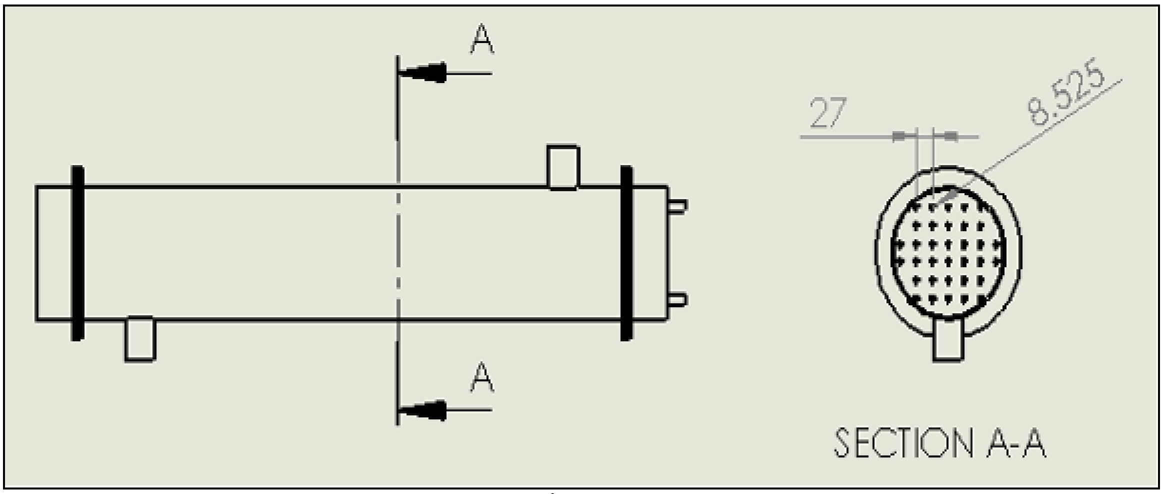

Figure 8.

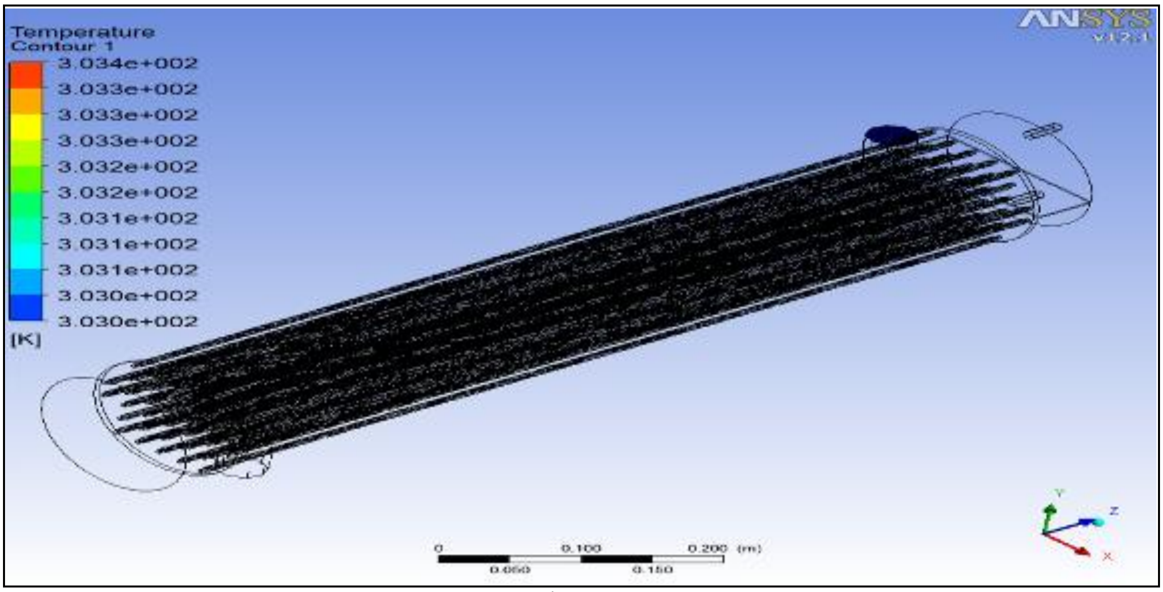

Figure 9.

CASE 4: pitch length: 23 mm, tube diameter: 9.525 mm, mass flow rate: 1.5 kg/s

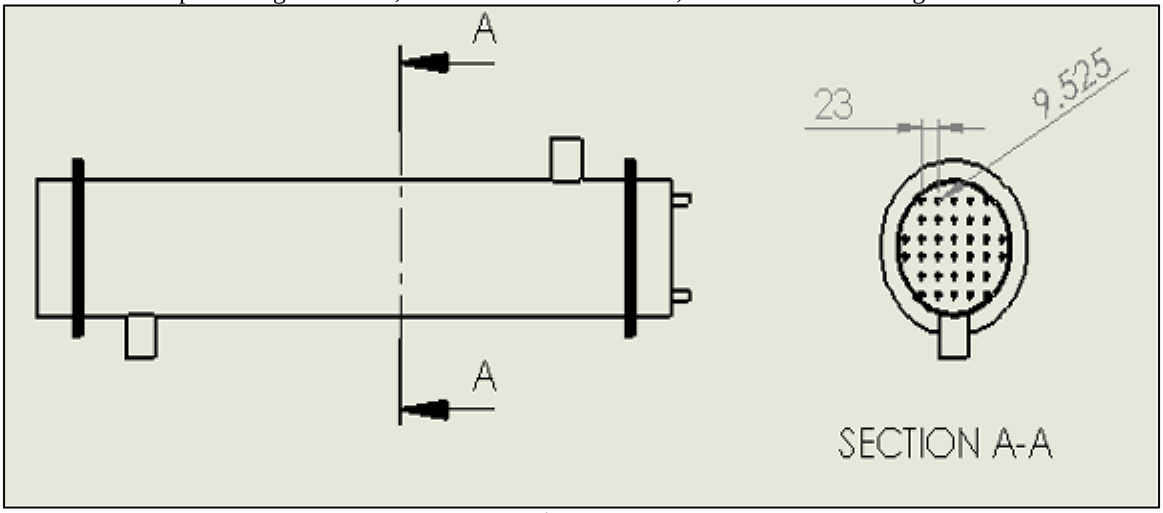

Figure 10.

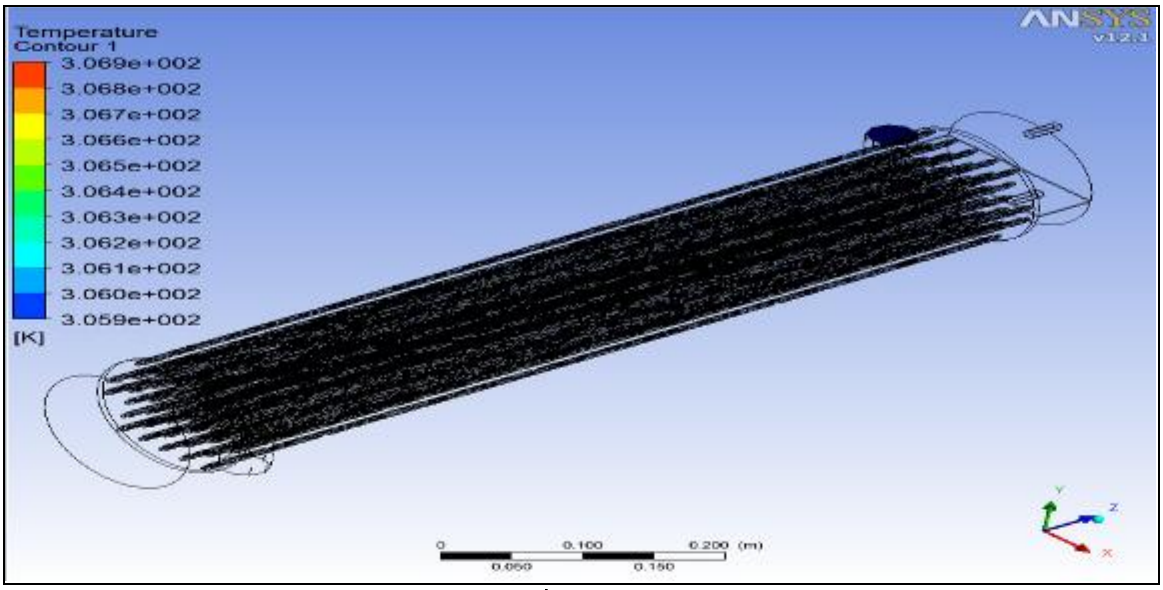

Figure 11.

CASE 5: pitch length: 25 mm, tube diameter: 9.525 mm, mass flow rate: 1.8 kg/s

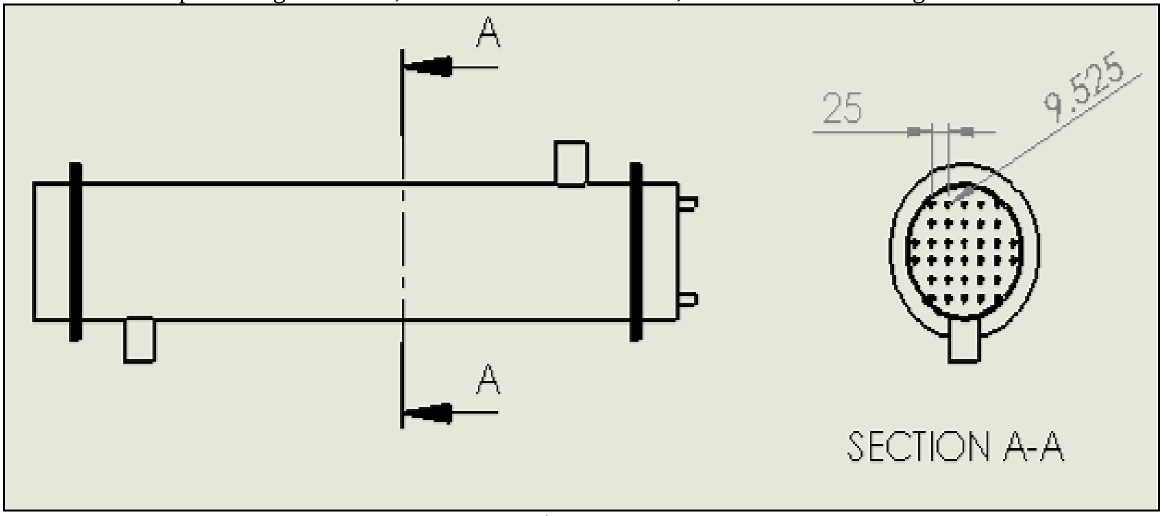

Figure 12.

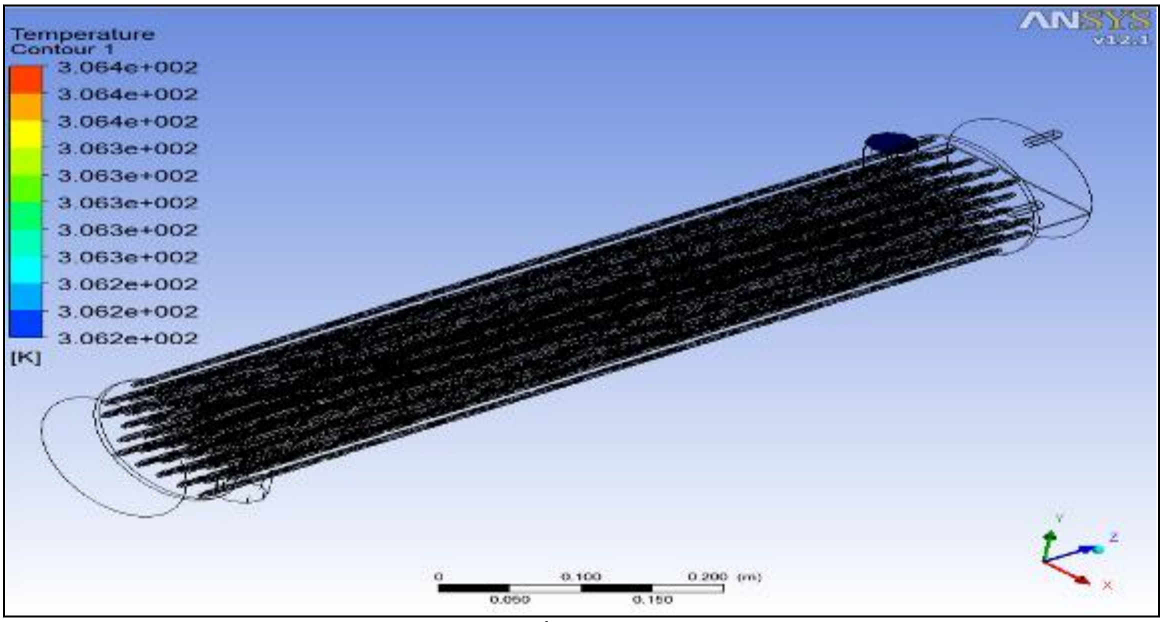

Figure 14.

CASE 6: pitch length: 27 mm, tube diameter: 9.525 mm, mass flow rate: 1.2 kg/s.

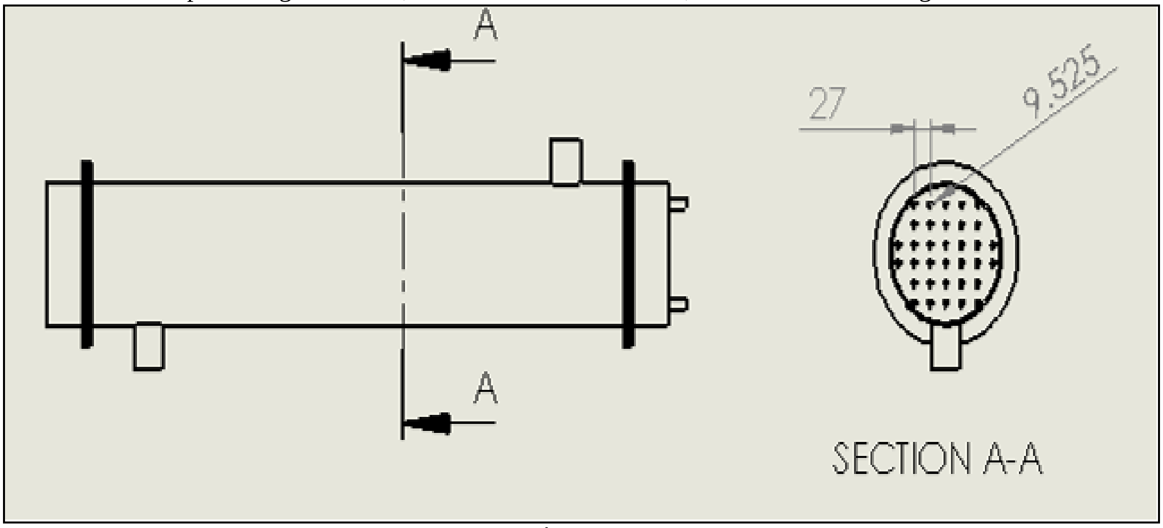

Figure 15.

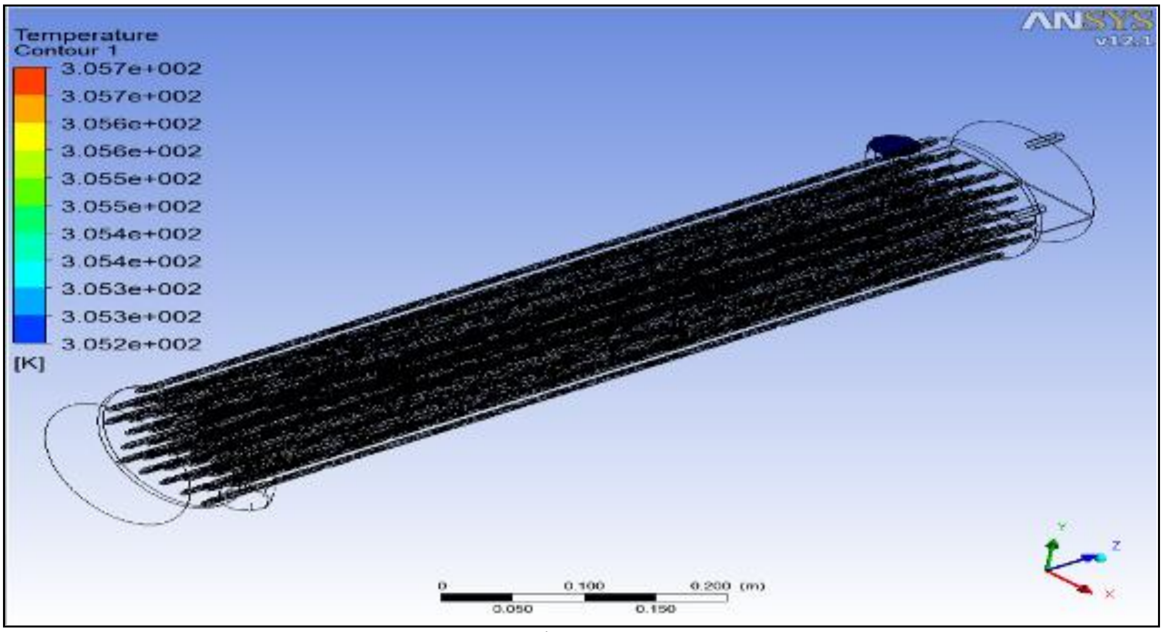

Figure 16.

CASE 7: pitch length: 23 mm, tube diameter: 10.525 mm, mass flow rate: 1.8 kg/s

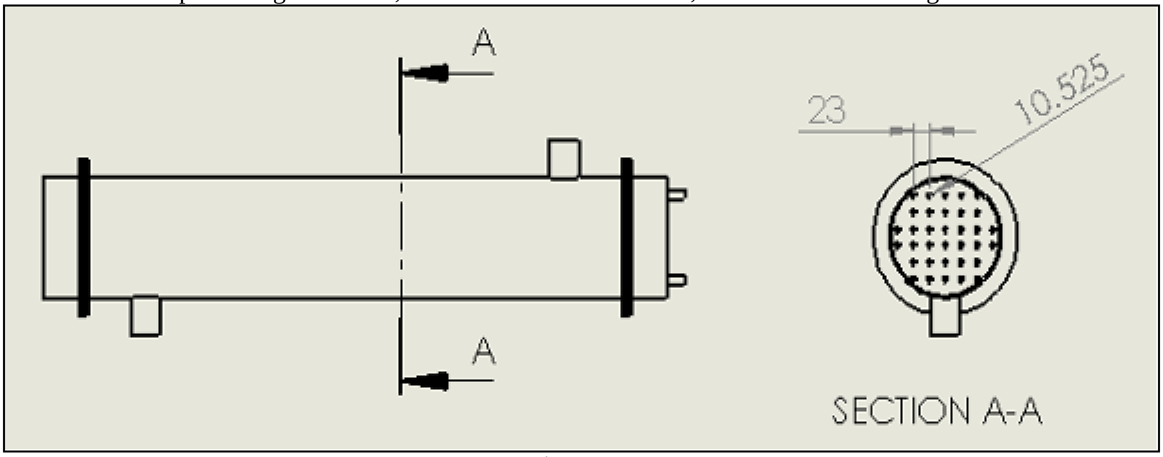

Figure 17.

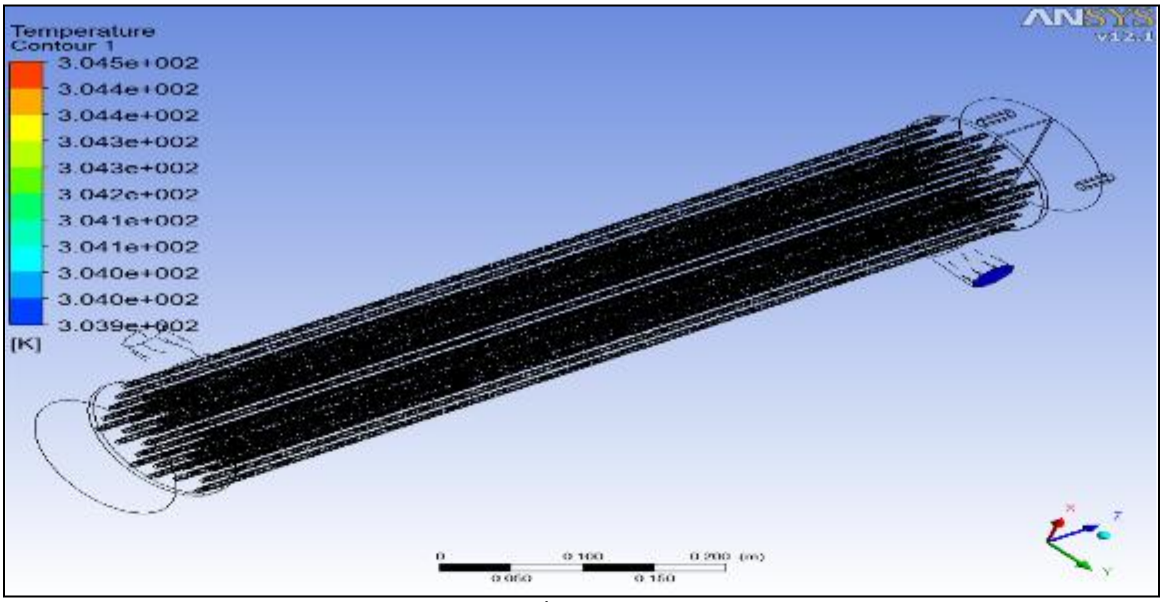

Figure 18.

CASE 8: pitch length: 25 mm, tube diameter: 10.525 mm, mass flow rate: 1.2 kg/s.

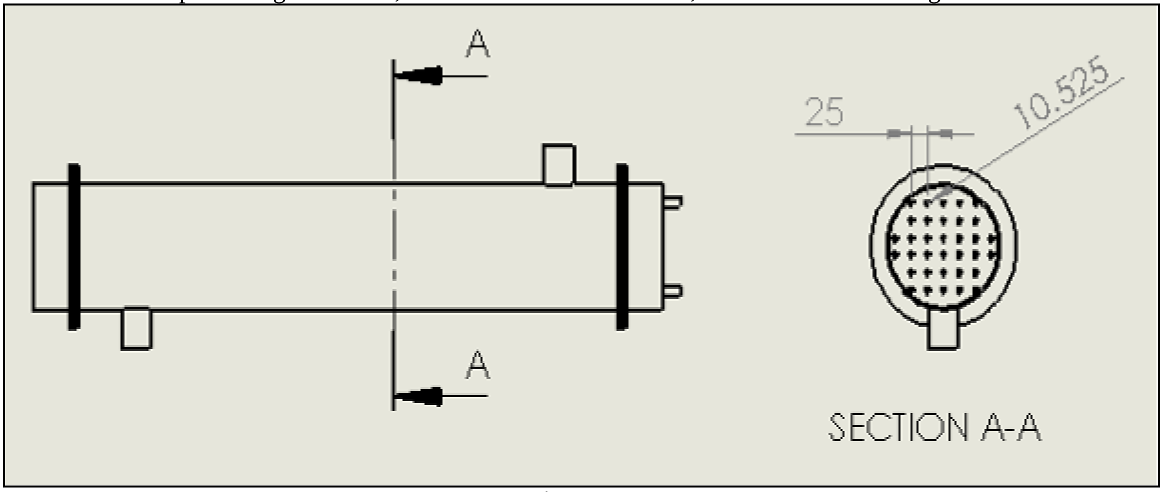

Figure 19.

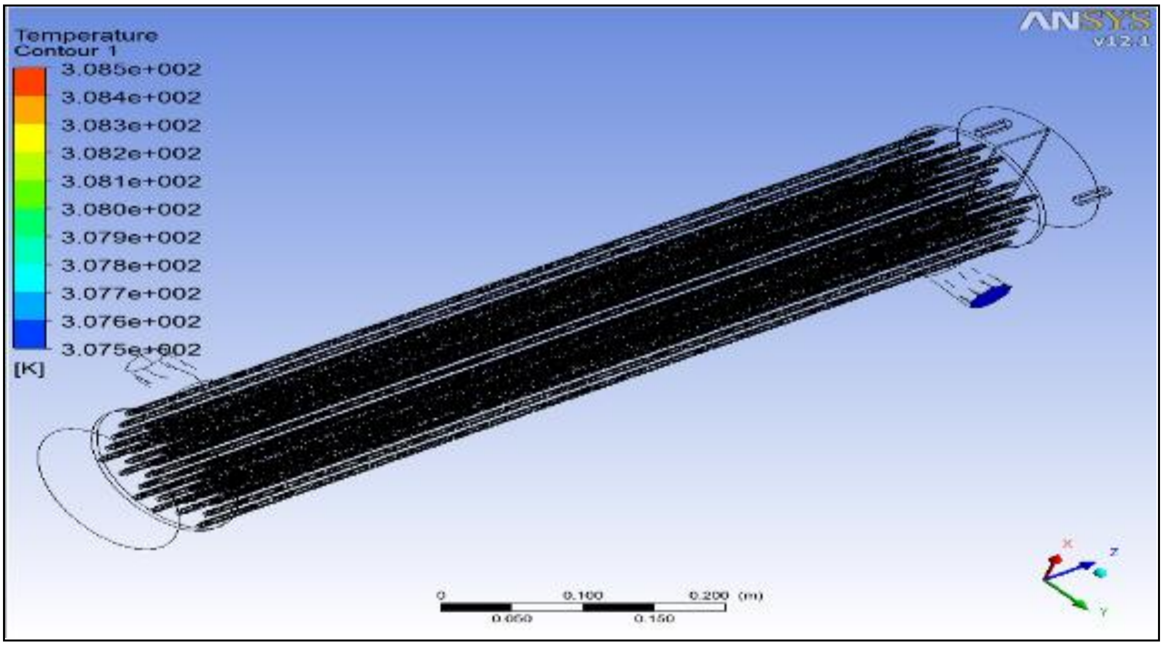

Figure 20.

CASE 9: pitch length: 27 mm, tube diameter: 10.525 mm, mass flow rate: 1.5 kg/s.

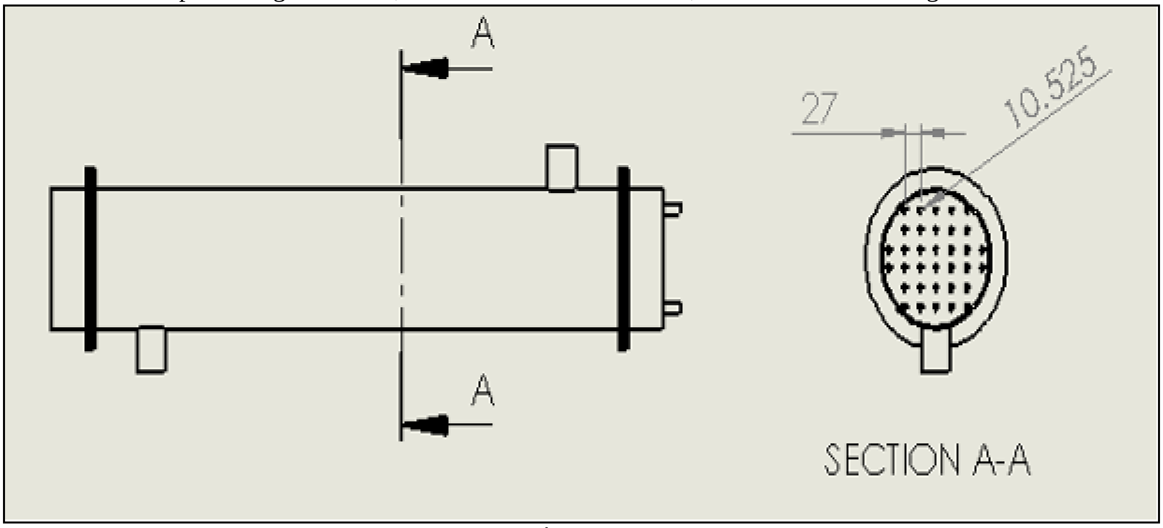

Figure 21.

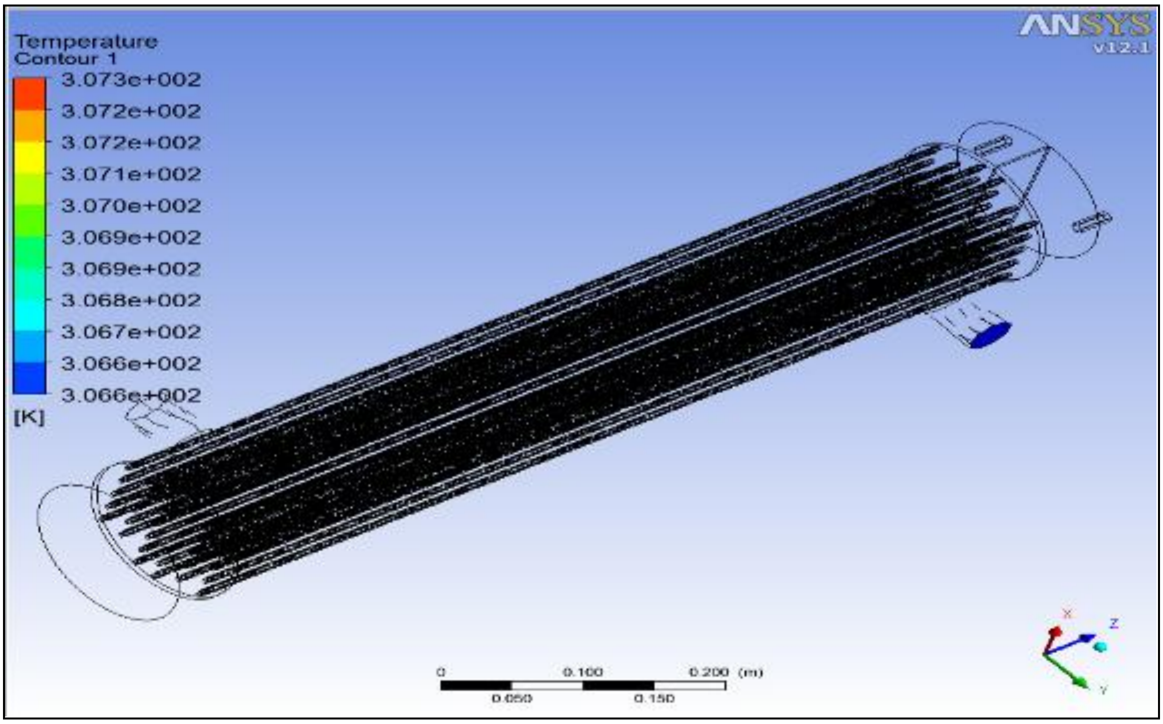

Figure 22.

V. RESULTS

- Shell and tube heat exchanger is widely used in industries. Today the main problem of industries is effectiveness of the heat exchanger.
- There are various heat exchanger performance parameters like tube diameter, mass flow rate, pitch length, longitudinal pitch, tube material, shell material, types of baffles, baffles angles etc. here to improve its effectiveness, heat exchanger parameters done successfully using Taguchi approach with L4 array.
- Taguchi has proven to be a major tool in discovering, which parameters and interactions are significant to improve the effectiveness of shell and tube heat exchanger.
- Based on the practical and ANSYS results, it is found that the mass flow rate is the Primary parameter and pitch length is the secondary element that has an effect of improvement of effectiveness of heat exchanger.
- Also from results of Taguchi analysis it can be concluded hat optimum parameter to increase the effectiveness of the heat exchanger are tube diameter are 8.52 mm, pitch length of tube 27 mm and mass flow rate 1.8 kg/s.
- ANSYS and experimental result are compared and found in good agreement, thus proving the strength of model. After completing CFD Analysis Results, we can say that CFD Analysis is a good tool to avoid costly and time consuming Experimental Work.

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