Quality Improvement in Design Process of Shell & Tube Type Heat Exchanger by Computer Integrated 3D Modeling

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Abstract: Heat exchanger design is task of imagination, knowledge, experience and judgment to define an end product. It involves tough design calculations which are combined with manufacturing activities that can be completed in a short period of time. The heat exchanger design calculations require assumed data. Iterative procedure is used to correct the assumed data to get optimum solution. But it needs lot of calculation work which is time consuming. Again the drafting of heat exchanger is time consuming and complicated task and requires skilled person. So there is large scope to improve the features of present softwares. Design and development of new software of shell and tube type heat exchanger gives design, graphical representation and 3D modeling of shell and tube type heat exchanger. The validity of the software is checked by comparison between the software results and 'Alfa Laval' results. 'Alfa Laval' is well established industry in design of shell and tube type heat exchanger. The results obtained from our developed software were found accurate with 'HTRI' software results of Alfa Laval industry. The 3D modeling feature of software makes it different from the existing commercial software. It is expected that the software will be playing significant role in the heat exchanger industries to meet their requirements.

Keywords- Shell and Tube Type Heat Exchanger; Design Software; Visual Basic; CATIA; Computer Integrated Design; 3D Modeling.

1) Introduction:

A heat exchanger is a piece of equipment 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. The basic concept of a heat exchanger is based on the premise that the loss of heat on the high temperature side is exactly the same as the heat gained in the low temperature side after the heat and mass flows through the heat exchanger. For efficiency, heat exchangers are designed to maximize the surface area of the wall between the two fluids, while minimizing resistance to fluid flow through the exchanger. The exchanger's performance can also be affected by the addition of fins or corrugations in one or both directions, which increase surface area and may channel fluid flow or induce turbulence. Various quantitative design aspects, their interaction and interdependence are important to arrive at an optimum heat exchanger design. Most of these considerations are dependent on each other and should be considered simultaneously to arrive iteratively at the optimum exchanger design.

The computer software will play important role to eliminate the problem of iterative calculations and 3D modeling of heat exchangers. Presently in heat exchanger industries, design is done by using softwares. These softwares gives dimension of the parts but do not give results in terms of graphs and drawings. Graphical results are important for checking the performance of the heat exchanger and to find out optimum solution. Our developed software also gives design results and 3D model within very short time. This new design tool will allow engineers to make design changes and determine their effect on thermal performance of heat exchanger.

2) Shell and Tube Type Heat Exchanger:

A variety of heat exchangers are used in industry and in their products. Heat exchangers are classified according to transfer processes, number of fluids, and degree of surface compactness, construction features, flow arrangements, and heat transfer mechanisms. The most commonly used heat exchanger is the shell and tube type. It has many applications in the power generation, chemical, and process industries. Though the application of other types of heat exchangers is increasing, the shell and tube heat exchanger will continue its popularity for a long time, largely because of its versatility. This type of heat exchangers are generally built of a bundle of round tubes mounted in a cylindrical shell with the tube axis parallel to that of the shell. One fluid flows inside the tubes, the other flows across and along the tubes. The major components of this exchanger are tubes (or tube bundle), shell, front-end head, rear-end head, baffles, and tube sheets. A variety of different internal constructions are used in shell-and-tube exchangers, depending on the desired heat transfer and pressure drop performance and the methods employed to reduce thermal stresses, to prevent leakages, to provide for ease of cleaning, to contain operating pressures and temperatures, to control corrosion, to accommodate highly asymmetric flows, and so on.

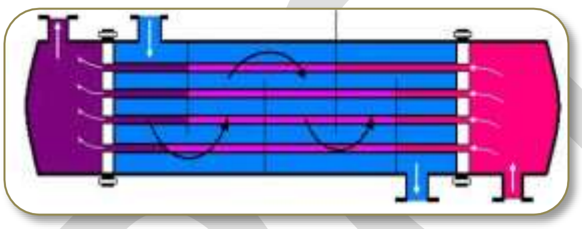


Figure 1: Shell and Tube Type Heat Exchanger

Shell and tube heat exchangers are used extensively throughout the process industry and as such a basic understanding of their design, construction and performance is important to the practicing engineer. Thermal design of shell-and-tube heat exchangers is done by sophisticated computer software. However, a good understanding of the underlying principles of exchanger design is needed to use this software effectively. The optimum thermal design of a shell and tube heat exchanger involves the consideration of many interacting design parameters.

3) Heat Exchanger Design:

Effectiveness of shell and tube type heat exchangers mainly depends on overall heat transfer coefficient which is function of fluid properties, velocity of flow, surface area, Reynolds number etc. The design of heat exchanger includes calculations to determine heat transfer area, shell length, shell diameter, Number of tubes, Diameter of tube, Length of tubes, tube bundle diameter, Number of baffles, baffle spacing, Material of tubes etc. In addition to these, convective heat transfer coefficient for the tube side (hi) and shell side (hs) are required to determine the overall heat transfer coefficient (Uo). Uo requires the huge calculations, but it is essential parameter to decide the thermal performance.

This provides challenging design analysis which is combined with a simple form of construction that can be built in a short space of time. The complicated heat exchanger design and thermodynamics performance calculations are tedious task. There is large scope to improve the features of present software. The remedial causes encourages designing and developing new software of shell and tube type heat exchangers which gives design as well as 3D modeling. It is done by interfacing design software and suitable 3D modeling software. This methodology is the most excellent way to show output results along with 3D modeling of shell and tube type heat exchanger. Hence it is useful design tool for heat exchanger industries.

Our software is developed by using Visual Basic (6.0) language. For executing design of Shell and Tube type Heat Exchanger, code is developed. By utilizing this code different input parameters such as type of flow, material used, diameter of tube, inlet and outlet temperature of tube side and shell side fluid etc. are given and output parameters such as Reynolds no., overall heat transfer coefficient, shell diameter, length of tube etc. are calculated. Some forms are used for interfacing with the user through which user can enter the desired values, these forms are start form, menu form, input form, material form, tube side / shell side fluid form etc.

Figure 2: Input form of software

Entering data in to these forms user can give their requirement and get desired output from result form. Although this software also give graphical representation of some parameters such as number of baffles vs overall heat transfer coefficient, outer diameter of tube vs overall heat transfer coefficient, outer diameter of tube vs tube side pressure drop etc. MSchart is used for this purpose and codes developed give accurate representation of the parameters. While design of heat exchanger it is necessary to consider which inputs are required, which outputs are required to find out and steps required for the programs. These steps are given in the following flow chart:

Flow chart for Computer Program:

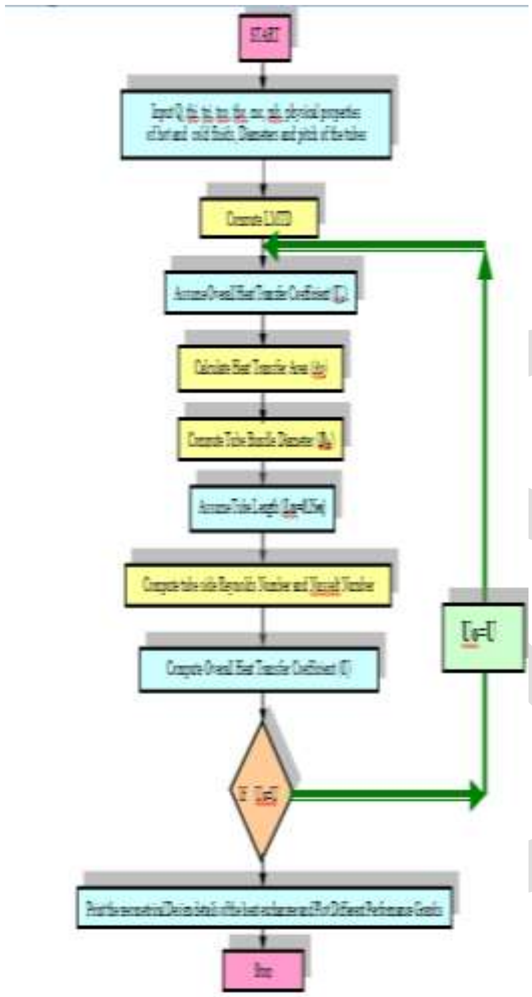


Figure 3: Flow chart for design and thermal analysis

By development of software codes design of shell and tube heat exchanger will be done. 3-D modeling of heat exchanger is done by using output results of Visual Basic software. So it is necessary to transfer data to Microsoft Excel sheet. Output data is transferred to Excel sheet by giving proper path in the program. Program is made in such a way that, it can open, save and close the Microsoft Excel sheet. Since it is not necessary to open the excel sheet or save the excel sheet for 3D modeling purpose. When file of assembly will open in CATIA software, and if it will be updated then changes made according to the output results of Visual Basic software. Most important phase for this is synchronization of Visual Basic with CATIA. It is achieved by Microsoft Excel. Design data of heat exchanger available from Visual Basic is transferred in Excel sheet. The parameters transferred from Visual Basic software are outer diameter of tube, inner diameter of tube, pitch of tube, number of baffles. This data is taken from input form of Visual Basic software which is provided by the user. Also shell diameter, length of tube and number of tubes on horizontal line are transferred from result form. By using these parameters, in Microsoft Excel sheet some relations and formulae are developed to give required data to CATIA software. It can create fully associative 3D solid models, with or without constraints, while using automatic or user derived relations to capture the design intent.

For modeling of shell and tube type heat exchanger from CATIA, user pattern, circular pattern, rectangular pattern and reuse patterns are mostly used. By using these patterns time of constructing the model tremendously minimized. Dimensions of model changes case to case and it is not possible to construct a model for every case. But it is possible in this model to draw models for each case with the help of formulae and design table associations. We can vary number of tubes, ID, OD, pitch of tube, shell diameter, length of tube, number of baffles etc. in this model.

4) Design Results from Program of heat exchanger:

The comparison between theoretical design results with our software results and 'Alfa Laval' results with our software results is studied. At the beginning, assumed value of overall heat transfer coefficient is 1000 W/m^{2}K which is with maximum error. This error reduces in second and third iterations, become 44.84 W/m^{2}k and 44.91 W/m^{2}k respectively. We proceed with an iterations process to improve the accuracy. The developed software does forty iterations to give more accurate results which is not possible within short period of time. In Final iteration (40th iteration) value of tube side heat transfer coefficient is 101.205 W/m^{2}k and shell side heat transfer coefficient is 315.453 W/m^{2}k. These values give overall heat transfer coefficient (U_o) is 65.36 W/m^{2}k with negligible error (0.00001). When the conditions are given to the program as input, it gives result values in result form. The design data calculated by software are summarized in the table 1. This data is obtained after forty iterations. Hence accuracy of this result is more than results obtained by manual calculations also by using software time required to find out accurate results decreases. The results obtained by the software give optimum values of design parameters.

Sr. No.	Design Parameters	Iteration 1	Iteration 2	Iteration 3	Software Results
1	Log Mean Temp. Difference	4.5670	4.5670	4.5670	4.5670
2	Heat Transfer Coeff. In. W/m^2 k	134.98	44.84	44.91	65.3628
3	Cross flow area in m^2	0.00204	0.00503	0.00938	0.0068
4	Heat transfer area in m^2	0.6384	4.877	14.75	10.0732
5	Tube bundle diameter in m	0.118	0.208	0.30	0.2638
6	Shell diameter in m	0.1604	0.2324	0.344	0.3019
7	Length of tube in m	0.678	1.5861	2.3	1.8846
8	Number of tubes	19	61	127	127

Table 1 Results obtained manually and with design software

For validation of software, results are compared with 'Alfa Laval' industries results. These industries use 'HTRI' softwares for design of shell and tube type heat exchanger. There, one case study was taken for comparison of two softwares. We have selected liquid – liquid (Water – Water), counter flow single pass heat exchanger. Comparative study is given as follows:

Sr. No.	Design Parameters	Developed Software Results	Alfa Laval 'HTRI' Results
1	Outside diameter of tube in mm	15.88	15.875
2	Pitch of tube in mm	22.22	22.22
3	Heat transfer rate in Watt	3007	3200
4	Log Mean Temp. Difference	4.5670	4.200
5	Overall Heat Transfer Coeff. W/m^2 k	65.3628	65.250
6	Heat transfer area in m^2	10.0732	11.937
7	Shell diameter in m	0.3019	0.301
8	Length of tube in m	1.8846	1.883
9	Number of tubes	127	127

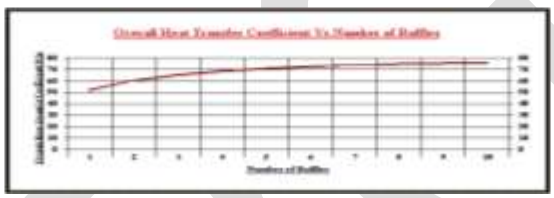
Table 2 Comparison between developed software and 'Alfa Laval' software

From above table, it is found that the results obtained by developed software are to be matching with that of the 'HTRI' software results. Thus developed software is valid which provides accurate design data which is useful to manufacture well economical heat exchanger. This developed software has the advantage of calculating performance and design with graphical representation with greater accuracy and within short period.

5) Performance Graphs obtained from the software:

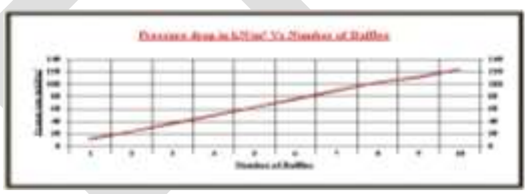
For the same case study graphical representation of designed parameters is shown. There are number of parameters influence the performance of heat exchanger such as baffles number, inner diameter, pitch layout, number of passage etc. This software provides graphical representation for effect of these parameters on overall heat transfer coefficient and pressure drop, which gives useful information to the design engineers.

5.1 Baffles and Overall heat transfer Coefficient (U_o): The influence of baffles number on U_o is shown in graph 1. It shows that the *Uo* increases with increase in baffles number, the rate of overall heat transfer increases more rapidly as number of baffles increases and at less number of baffles it decreases. This is because to as number of baffles increases, it causes to change in the flow pattern of the shell fluid creating parallel or cross flow to the tube bundle thus increasing turbulence and therefore, the heat transfer coefficient U_o



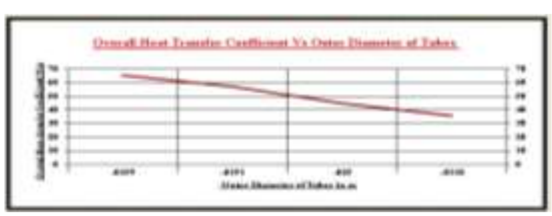
Graph 1: Number of baffles vs. overall heat transfer rate

5.2 Number of Baffles and Pressure Drop: Following graph shows that as number of baffles increases pressure drop at shell side increases. Baffles causes to change direction of flowing fluid, since velocities of fluid stream decreases near the baffles. As a result pressure drop increases and as we increase number of baffles there will be more pressure drop takes place at shell side.



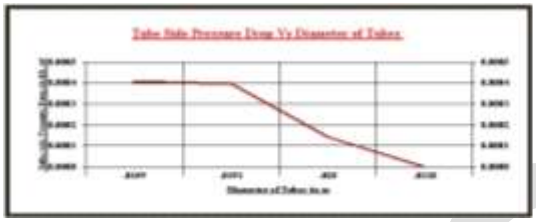
Graph 2: Number of baffles vs. shell side pressure drop

5.3 Outer Diameter of tube and Overall Heat Transfer Coefficient: This graph shows that as outer diameter of tube increases overall heat transfer coefficient decreases. Heat transfer coefficient depends on circumference of tube and fluid in contact with surface of the tube. As diameter of tube increases contact area between inside fluid and surface of tube decreases since overall heat transfer area also decreases which is shown by following graph.



Graph 3: Outer diameter of tube vs. overall heat transfer coefficient

5.4 Diameter of tube and tube side pressure drop: Pressure drop at tube side basically depends on cross flow area of tube. As diameter of tube increases tube side pressure drop decreases. Suitable value of tube diameter for minimum pressure drop is 31.8 mm is shown by following graph.



Graph 4: Diameter of tube vs. tube side pressure drop

6) 3D Modeling of Heat Exchanger:

Heat exchanger data is transferred to the excel sheet and through excel sheet it is transferred to the CATIA modeling software. For this case study the software can give 3D model and 2D model with designed parameters with negligible error and within very short time. The 3D and 2D model of above heat exchanger is drawn by the software is shown below:

Figure 4: Verification of design parameters in 3D model

After visiting many companies in which design and manufacturing of shell and tube of were done, it is found that in these companies for design of heat exchangers 'HTRI' software used and some companies calculations were done manually. Also it is found that drawing of heat exchanger was done by using 'AUTOCAD' software after checking output results from software. This method is time consuming and required skilled person.

There is no software which gives directly 3D and 2D model of heat exchanger after giving input parameters to the design software. With our developed software, it is possible to draw 3D model of required heat exchanger within very less time. This 3D model is used to show detailed drawing and also used for 3D printing machine and CFD analysis of heat exchanger model.

Conclusion:

For design of shell and tube type heat exchanger lot of calculation work is required which is time consuming. Same time the drafting of heat exchanger is another complicated task. This problem is eliminated by our developed software. The software based on established theory of heat exchanger. The code is developed in Visual Basic language which is user friendly and gives accurate results in very short time. Thermal design of heat exchanger is done by developed software and gives graphical representation of designed parameters, which gives useful information to the design engineers.

Dimensions of model changes case to case and it is not possible to construct a model for every case within very short period of time. Also, it was found that the heat exchanger industries use some basic software to design shell and tube heat exchanger, but there is no feature on 2D and 3D modeling in it. But developed software gives directly 3D and 2D model of heat exchanger within very short time.

To check validity of our software, comparison of program results with theoretical results was done. In addition to this, the comparison between our software results and 'Alfa Laval' results was carried out. It is found that program results and 'HTRI' software results of Alfa Laval are matching with each other. So the developed software has an ability to predict the thermal performance and shows reliability in results.

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