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DEVELOPMENT OF AN IMPROVED COMPUTER-AIDED ANALYSIS FOR THE THERMAL AND MECHANICAL DESIGN OF SHELL AND TUBE HEAT EXCHANGERS

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Abstract: The last past few decades have witnessed a considerable number of different attempts to design the Shell-and-tube heat exchangers have been developed. However, most of these designs focused on the thermal analysis of the heat exchanger without much consideration of the effects of the mechanical parts of the systems. Moreover, such complete designs have never been an easy “straight forward” task since it involves a lot of mathematical models, which are not easily and directly related to each other. A consequence of this is that, at the present time, there is no assurance of complete design of the equipment, but with the aid of Computer Aided Design which takes both Thermal and Mechanical design of the E type shell of the equipment into a deep consideration. Therefore this project aims at presenting a complete design with effective considerations of welding and analysis of stress of Shell-and-tube heat exchangers for different types of passes, flows, shapes and working fluids using Computer-Aided design with the aid of Visual Basic.Net. The computer-aided analysis and theoretical analysis are in agreement. It can be said that the developed computer program has some advantages to its credit which includes less skill requirement, high precision and accuracy of the design. It must be mentioned that the computer program can accept a design that satisfies the temperature correction factor, fouling factor, pressure drop and velocity of the fluid on both tube and shell side without investigating other options that may be more better, since the design parameters are been supplied. This programme will serve as a handy tool for designers who want to simulate various working process, conditions parameters and shape geometry.
Keywords: Shell and tube heat Exchanger, thermal and mechanical design

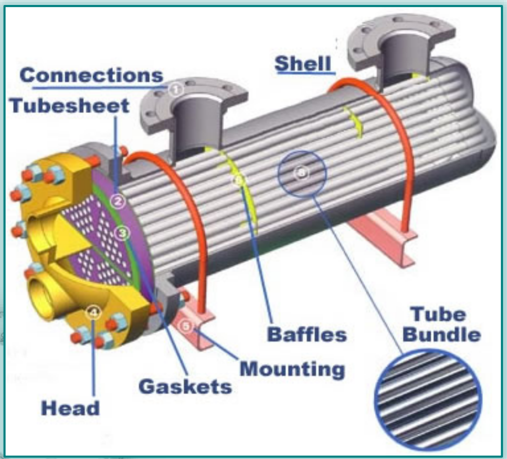
INTRODUCTION

The shell and tube heat exchangers are the most versatile type of heat exchangers. It provides relatively large ratios of heat transfer area to volume and weight and can be easily maintained. They offer great flexibility to meet any service requirement. Shell and tube heat exchangers are designed for high pressure relative to the environment and high pressure differences between the fluid streams. They find useful applications in process industries, in conventional and nuclear power station and are also used in air conditioning and refrigeration system.

These heat exchangers are capable of handling a quite high load at moderate size with good thermal and hydraulic efficiency in the moderate range of industrial applications. Consequently, this type of heat exchangers occupied a large area of research and investigation to establish the more easily and efficient procedure of design with optimization in its characteristics and cost. Lord et al. [1] pointed out the important of design details. These design considerations include pressure drop, mean temperature difference, types of flow, fluid properties, location, tube size and arrangement, flow-induced vibration, baffles in the shell, flow distribution and bypass prevention. Madson [2] designed Heat Exchangers for liquids in Laminar Flow. Butterworth [3] outlined a general procedure for the design of shell and tube heat exchangers where the overall heat transfer coefficient varies along the heat exchanger. Also, few years later, the same author presented a detailed procedure for the calculation of equation [4]. In another paper, Bell [5] submitted a procedure for the global thermal and hydraulic design of the shell and tube bundle heat exchanger. There is no available complete approach for the thermal-hydraulic design of the shell and tube heat exchanger where enhanced surfaces are used in the open literature. However, there are comprehensive correlations for the prediction of the heat transfer coefficient on finned tube surface. For predicting heat exchanger performances, it is necessary to calculate the overall heat transfer coefficient, and pressure drop for both fluids in tube and shell side. Fluid flow in the tube side is relatively simple. Many correlations for calculating heat transfer coefficients and pressure drops in the tube side are available, including Colburn correlation and Dittus-Boelter correlation [6] for obtaining heat transfer coefficients, and plain tube pressure drop method [18] for calculating pressure drop. However, fluid flow in the shell-side is more complex. Bell-Delaware method [7] can be used for calculating heat transfer coefficients and pressure drop. Furthermore, developed Delaware method [8] and Chart method [9] are proposed for heat transfer coefficients, while for pressure drop using simplified Delaware method [10]. Although these methods had been claimed to be effective for calculating shell-side heat transfer coefficients and pressure drops, they always give significantly different results in most cases. Leong [11] developed a shell and tube heat exchanger design software for education applications which is suitable for teaching the thermal and hydraulic design of shell and tube heat exchangers to senior undergraduate student in mechanical and chemical engineering and train new graduate engineers in thermal design. In the recent past, some experts studied on the design, performance analysis and simulation studies on heat exchangers. Mohammed [12] investigated experimentally and theoretically the thermal-hydraulic designs of shell and tube heat exchanger using the step by step technique for a single tube pass. Ramanathan [13] presented a novel technique to design shell and tube heat exchangers based on the cell method. This technique defines a cell to comprise of only one tube row. Adelaja [14] developed a computer-aided analysis of the thermal and mechanical design of the shell and tube heat exchanger. The developed Heat Exchanger Simulator software was done in order to complement the teaching of the thermal and mechanical properties of the shell and tube heat exchangers, bringing to the student knowledge of the applications of these exchangers. Although, in the earlier work, Mukhareej [15] also presented work on effective design of shell and tube heat exchanger, most of these designs approaches in the literatures are focused on the thermal-hydraulic analysis of the heat exchanger without much consideration of mechanical design of the systems. Moreover, such complete designs (with effective considerations of welding and analysis of stress in the equipment) have never been an easy "straight forward" task since it involves a lot of mathematical models, which are not easily and directly related to each other. Therefore there is no assurance of complete design of the equipment. Therefore, this work presents a complete design (Thermal, hydraulic and Mechanical design with effective considerations of welding and analysis of stress in the equipment) of Shell-and-tube heat exchangers of different types of passes , E type shell, and working fluids with the aid of Visual Basic.Net computational tool.

DESCRIPTION OF SHELL AND TUBE HEAT EXCHANGER

The principal components of the shell and tube heat exchangers are: shell, shell cover, tubes, channel, channel cover, tube sheet, baffles and nozzles. Others include tie rods, spacer, pass partition plates, impingement plates and longitudinal baffles, sealing strips, support and foundation.



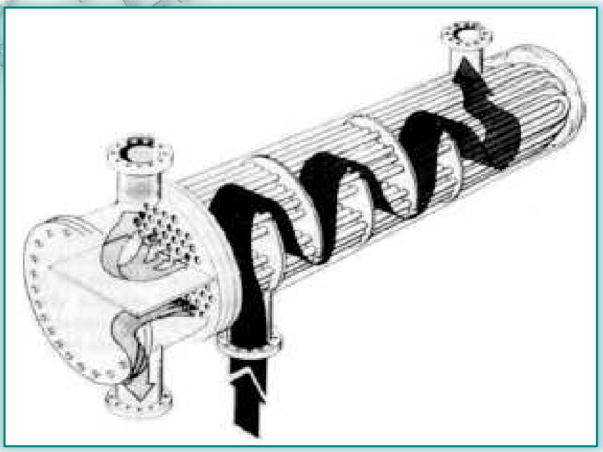


Figure 1. Conceptual diagram and fluid flow pattern of a Shell and Tube heat exchanger [22]

The basic sizes of shell available include 8, 10, 12 inches, we find 2 inches of increment step start from 13 to 25 inches. From 25 to 39 inches, there is a 2-inches increment and from 39 to 72 inches we find 3-inches increment in shell tube size. Basically during service the heat exchanger may function as single phase (such as cooling or heating of a liquid or gas) or two phase such as vaporization or condensing or a combination of several services. The tube side design includes the tube layout and the tube pitch. There are four tube layout patterns which include the triangular 30°, rotated triangular pattern 90°, square pattern 90°, and rotated square 45°. A rotated triangular pattern accommodates more tubes than a square or rotated square pattern. Furthermore a triangular pattern produces more turbulence and a high heat transfer coefficient.

However a typical tube pitch is 1.25 times the tube outer diameter and does not permit mechanical cleaning of the tube since access is not available. Consequently a triangular layout is limited to cleaning of shell side service. For services that require mechanical cleaning on the shell side square pattern must be used. The tube pitch defined as the shortest distance between adjacent tubes for a triangular pattern TEMA (Tubular Exchangers Manufacturers Association) specifies a minimum tube pitch of 1.25 times the tube outer diameter while for square pattern TEMA recommends a minimum clearing lane of 4 inches between adjacent tubes. Shell configuration patterns as classified by TEMA is based on the shell side fluid flow and there are E, F, G, H, J, K and X.

DESCRIPTION OF THE COMPUTER PROGRAMME

The graphic user interface developed for the thermal, hydraulic and mechanical design of the shell and tube heat exchanger using Visual Basic.Net computational tool is designed and primarily developed for the simulation of industrial operating conditions, for simulating practical application of shell and heat exchangers. Also for enhancing the understanding of functional operation of the equipment by beginner due to it step by step guide of algorithm. The computational programme compatible with any Microsoft Windows-based Personal Computer of at least a 4MB of RAM and 7MB of free hard disk space.

COMPONENTS OF THE SOFTWARE

The computational programme consists of four modules which are the thermal section and mechanical section, design section and the help section as shown in the figures (2-5) below.

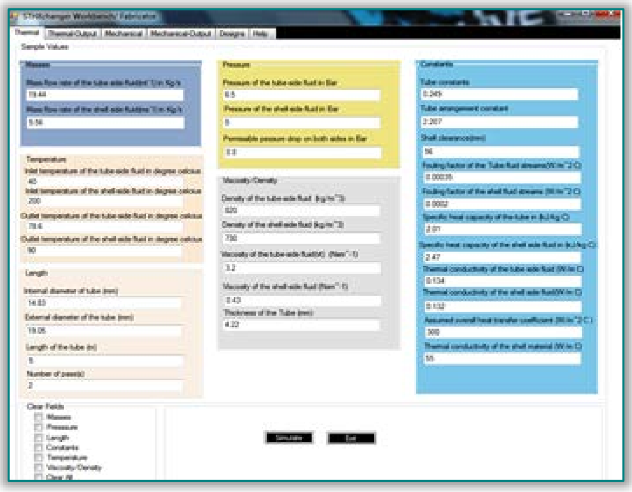


Figure 2. Input for the Thermal- Hydraulic Design

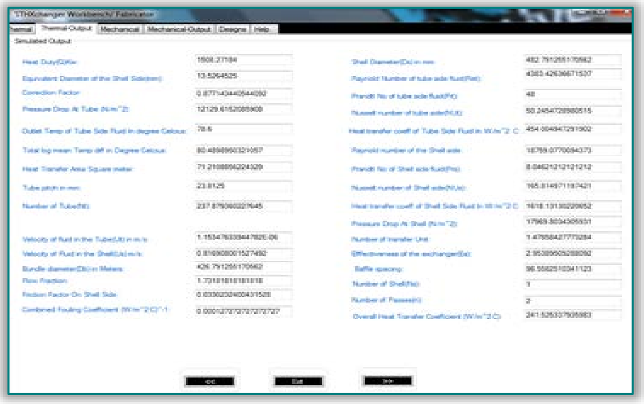


Figure 3. Output for the thermal hydraulic design

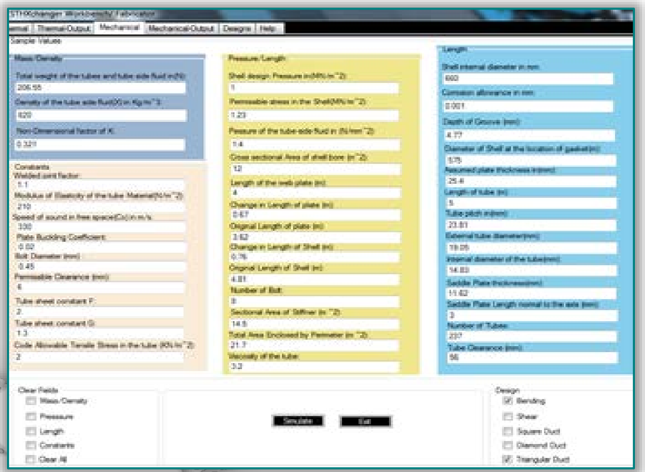


Figure 4. Inputs for Mechanical Design

Figure 5. Output for Mechanical Design

The thermal design provides detail of the heat duty, velocity of the fluid in tube and shell, heat transfer area square meter, number of tube, tube pitch, pressure drop at tube and shell side, shell equivalent diameter, correction factor, outlet temperature of the tube side fluid, bundle diameter, flow fraction, friction factor on shell side, combined fouling coefficient, shell diameter, Reynolds number on tube and shell side, Prandtl number on tube and shell side, Nusselt Number on tube and shell side, baffle spacing, number of shell and overall heat transfer coefficient, heat transfer coefficient on the tube and shell side fluid, effectiveness of the exchanger, total log mean temperature difference.

The mechanical design of the exchangers involves the determination of the thickness of the shell, channel, shell cover, tube plate, floating head cover, nominal diameter of bolt, radial stress in tube, numbers of bolt required, number of web plate, maximum permissible stress of the tube plate, baffle spacing, critical velocity of the tube side fluid, speed of sound perpendicular to axis, natural frequency of the tube, buckling load under comprehensive load, sound induced velocity, critical buckling stress for plate, effective saddle width, critical velocity of flow of pipe buckling a complete design is relevant for both the optimisation of the fluid flow process of the shell and tube heat exchanger as well as the cost optimization during construction and maintenance. The computational tool for the computer aided analysis is tested to evaluate its performance using the physical properties of crude oil and kerosene, standard parameters from Mechanical Engineers handbook were supplied to test the mechanical designed and the results are shown.

CONCLUSION

In this work, a complete design with effective considerations of welding and analysis of stress of Shell-and-tube heat exchangers for different types of passes, flows, shapes and working fluids using Computer-Aided design with the aid of Visual Basic.Net has been presented. Since the computer aided analysis and theoretical analysis are in agreement, it can be said that the computer program has some advantages to its credit which includes less skill requirement, high precision and accuracy of the design. It must be mentioned that the computer program can accept a design that satisfies the temperature correction factor, fouling factor, pressure drop and velocity of the fluid on both tube and shell side without investigating other options that may be more better, since the design parameters are been supplied. This programme will serve as a handy tool for designers who want to simulate various working process, conditions parameters and shape geometry.

References

[1.] Lord R.C., Minto P.E., Slusser R.P. Design of Heat Exchanger, Mcgraw Hill, New York, 1970.
[2.] Madson N., Design of Heat Exchanger for Liquid Laminar Flow, University of Rhode Island, 1974.
[3.] Butterworth, D. A Calculation Method For Shell And Tube Heat Exchanger in Which The Overall Coefficient Varies Along The Length", Conference on Advances in Thermal And Mechanical Design of Shell And Tube Heat Exchangers, 1973.
[4.] Butterworth, D. and Cousins, L. B. "Use of Computer Programs in Heat Exchangers Design", Chemical Engineering, McGraw-Hill, 1979.
[5.] Bell K. J. "Preliminary Design of Shell and Tube Heat Exchanger", Heat Exchange Thermal-Hydraulic Fundamentals and Design, McGraw-Hill., New York. 1980.
[6.] Bhatti, M. S., and Shah R.K. Turbulent and transition convective heat transfer in ducts, Handbook of Single-Phase Convective Heat Transfer, Wiley, New York, 1987.
[7.] Taborek, J., Shell and tube heat exchangers, Heat Exchanger Design Handbook, Hemisphere Publishing Corp., New York, 1988.
[8.] Gnielinski, A., Zukauskas A. andSkrinska A., Banks of plain and finned tubes, in Heat Exchanger Design Handbook, Hemisphere Publishing Corp., New York, Vol. 2, 1988.
[9.] Ayub Z. H. A new chart method for evaluating single-phase shell side heat transfer coefficient in a single segmental shell and tube heat exchanger. Applied Thermal Engineering, vol. 25, pp. 2412-2420, 2005.
[10.] Kern, D. Q. and Kraus A.D. Extended Surface Heat Transfer, McGraw-Hill, New York, 1972.
[11.] Leong K.C. and Toh K.C. Shell and tube heat exchanger design Software for educational applications, International Journal of Engineering, vol. 14, No. 3, p. 217-224, 1998.
[12.] Mohammed A. G. "Experimental And Theoretical Studies of Shell And Tube Heat Exchanger Using Step By Step Method", M.Sc. Thesis, Mech. Eng. Dept., Al-Mustansiriy Univ., Baghdad, Iraq, 2005.
[13.] Ramanathan V.G., Ketan A.N., and Nayak A. A novel way to design shell-and-tube heat exchangers based on the cell method, 2009.
[14.] Adelaja A.O., Ojolo S.J. and Sobamowo M.G., "Computer Aided Analysis of Thermal and Mechanical Design of Shell and Tube Heat Exchanger" Advanced Materials Research, vol 367, pp.731-737, 2012.
[15.] Mukharej R. Effectively Design Shell and tube Heat exchangers, Chemical Engineering Progress, 1998.

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