

DESIGN THE SHELL AND TUBE HEAT EXCHANGER WITH THE HELP OF PROGRAMMING USING MATLAB SOFTWARE

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Abstract: - Heat exchangers are those devices that allow the heat transfer between two fluids at different temperatures. A lot of research is going on for increasing the heat transfer through heat exchangers. In the present paper, research done by various researchers to increase the effectiveness of heat exchanger has been discussed. Through detailed study it has been found that corrugated shell and tube heat exchanger have highest rate of heat transfer.

Key Words: Corrugated plate heat exchanger, MATLAB (Matrix Laboratory) software.

INTRODUCTION

In most of the heat exchangers, there is a solid wall that separates two fluids so that they are not in direct contact with each other. In heat exchangers, usually external heat and work interactions are absent. Typical applications of heat exchangers include refrigeration and air conditioning systems, power systems, food processing systems, chemical reactors and space or aeronautical applications.

In many of the heat exchangers, there is a heat transfer surface that separates the fluids so that they do not mix or leak. These type of heat exchangers are known as direct transfer type or recuperators. On the other hand the heat exchangers in which there is continuous heat exchange between the hot and cold fluids are referred to as indirect transfer type heat exchangers or simply regenerators. These type of heat exchangers have fluid leakage from one fluid stream to the other due to pressure differences. Common examples of heat exchangers include shell and tube heat exchangers, condenser, automobile radiators, evaporators, preheaters and cooling towers. If there is no phase change in any of the fluids in the heat exchanger, it is called sensible heat exchanger. In heat exchangers, there can also be internal thermal energy sources as in case of electric heaters and nuclear fuel elements. Chemical reaction and combustion can also take place within the heat exchanger as in case of boilers, fired heaters, and fluidized bed exchangers. Some heat exchangers make use of mechanical devices such as in case of scraped

surface exchanger, agitated vessels, and stirred tank reactors.

In case of recuperators heat transfer takes place in the separating wall by the process of conduction. However, in a heat pipe heat exchanger, heat pipe facilitates the transfer of heat by condensation, evaporation, and conduction of the working fluid inside the heat pipe in addition to acting as a separating wall. In general, the separating wall may be eliminated if the fluids are immiscible, and the interface between the fluids replaces a heat transfer surface, as in a direct-contact heat exchanger. A heat exchanger consists of heat transfer elements such as a core or matrix containing the heat transfer surface and the fluid distribution elements such as manifolds, headers, tanks, inlet and outer nozzles or pipes. In general, a heat exchanger does not have any moving parts; however, there are also some exceptions such as a rotary regenerative exchanger or a scraped surface heat exchanger.

The heat transfer surface is that surface of the heat exchanger core which is in direct contact with the fluids and through which heat transfer takes place by the process of conduction. That portion of heat transfer surface which is in direct contact with both the fluids is known as the primary or direct surface. In order to increase the heat transfer area, appendages can be intimately connected to the primary surface that provides an extended, secondary or indirect surface which is referred to as fins. Therefore heat is conducted through the fin and convected or radiated from the fin to the surrounding fluid or vice versa depending upon whether the fin is being cooled or heated. Hence the addition of fins to the primary surface increases the total heat transfer from the surface for the same temperature difference. In addition to the applications in the process, power, petroleum, transportation, air-conditioning, refrigeration, cryogenic, heat recovery, alternative fuel, and manufacturing industries, heat exchangers also serve as a key component of many industrial products available in the market today.

LITERATURE REVIEW:

Design is an activity aimed at providing complete descriptions of an engineering system, part of a system, or just of a single system component. These descriptions represent an unambiguous specification of the system/component structure, size, and performance, as well as other characteristics important for subsequent manufacturing and utilization. The design of a new heat exchanger (HE) is referred to as the sizing problem. In a broad sense, it means the determination of exchanger construction type, flow arrangement, tube and shell material, and physical size of an exchanger to meet the specified heat transfer and pressure drop. This sizing problem is also referred to as the design problem. Inputs to the sizing problem are: flow rates, inlet temperatures and one outlet temperature at least, and heat transfer rate.

Kern [1] provided a simple method for calculating shell-side pressure drop and heat transfer coefficient. However, this method is restricted to a fixed baffle cut (25%) and cannot adequately account for baffle-to-shell and tube-to-baffle leakage. Kern method is not applicable in laminar flow region where shell-side Reynolds number is less than 2000. Although the Kern equation is not particularly accurate, it does allow a very simple and rapid calculation of shell-side heat transfer coefficient and pressure drop to be carried out.

The concept of considering the various streams through the exchanger was originally proposed by Tinker [2]. He suggested a schematic flow pattern, which divided the shell-side flow into a number of individual streams. Tinker's model has been the basis of "stream analysis method", which utilizes a rigorous reiterative approach and is particularly suitable for computer calculations rather than hand calculation.

Tinker's original analysis was quite complex and hard to understand. After an extensive series of experiments was carried out, a new method has emerged, commonly described as the Bell-Delaware method [3]. The Delaware method uses the principles of Tinker's model but more suitable for hand calculation. In this method, correction factors for baffle leakage effects, etc., are introduced based on extensive experimental data. This method is widely used and most recommended. In manual design of an exchanger, the thermal design engineer cannot avoid the trial and error routine. Accordingly there is little interest in hand calculation method. For manual design, Saunders [4] proposed very practical method that simple design factors are provided which enable the method proposed by Bell to be used rapidly for a fixed set of geometrical parameters. In Bell's work, the correction factors for heat transfer and pressure drop correlations are given in graphic form. For computer applications, Taborek [5] gives the correlations for all correction factors involving Bell

methods. Wills and Johnston [6] have developed the stream analysis method that is viable for hand calculation. Hewitt provides a more readily accessible version of Wills and Johnston method [7]. Reppich and Zagermann [8] offer a computer-based design model to determine the optimum dimensions of segmentally baffled shell-and-tube heat exchangers by calculating optimum shell side and tube-side pressure drops from the equations provided in his work. The six optimized dimensional parameters are number of tubes, tube length, shell diameter, number of baffles, baffle cut, and baffle spacing. The proposed model carries out also cost analysis. Gaddis [9] presented a new procedure for calculating shell-side pressure drop, which is based principally on Delaware method. However, instead of using diagrams—as in the Delaware method—to calculate the pressure drop in tube bank, the present authors use equations previously presented in [10,11]. Li and Kottke have carried out series of experimental work on shell-and-tube heat exchangers to analysis shell-side heat transfer coefficient (HTC) and pressure loss. They employed a particular mass transfer measuring technique based on absorption, chemical and color giving reaction in their researches to obtain local shell-side HTC by applying the extended Lewis analogy between heat and mass transfer to mass transfer coefficient. They studied local shell-side HTC in shell-and tube heat exchangers with disc-and-doughnut baffles and segmental baffles [12–14]. They also investigated effect of leakage and baffle spacing on pressure drop and HTC in [15] and [16] respectively.

Although design may be carried out by hand calculation, computer programs are widely employed anymore. These are often proprietary codes produced by design industry, large processing companies, and international research organizations such as Heat Transfer and Fluid Flow Service (HTFS) or Heat Transfer Research Inc. (HTRI) or Tubular Exchanger Manufacturers Association (TEMA). Unfortunately, it is hard to employ them as a heat exchanger subroutine of a computer simulation for any thermal system plant that one of its equipment is heat exchanger. Researchers usually tend to make a mathematical model and a computer simulation of thermal systems for their theoretical analysis and when a heat exchanger exists in the system, a subroutine will be needed to solve thermo-hydraulic performance of heat exchanger.

Some of the work of the researchers in the field of design of heat exchangers using MATLAB or some other software is as follows:

Yusuf Ali Kara and Ozbilen Guraras developed a program using FOTRAN90 software for design of shell and tube heat exchanger. In that work a computer based design model for the preliminary design of shell and tube heat exchanger was developed with single phase fluid

flow on both shell side and tube side. The program developed was employed for segmentally baffled U-tube and fixed tube sheet heat exchangers for one pass and two-pass for tube side flow. The overall dimensions of the shell, the tube bundle, and optimum heat transfer surface area that are required to meet the specified heat transfer duty by calculating minimum or allowable shell-side pressure drop are determined by the program.

The program actually selects the optimum exchanger among the three different flow arrangement, namely one-pass, two-pass, and U-tube exchangers. The program is run for both cold and hot fluid as shell-side stream to show which one gives the best result. For instance, considering minimum shell-side pressure drop as constraining criteria for optimum design, circulating cold fluid in shell-side has some advantages on hot fluid as shell stream since the former causes lower shell-side pressure drop and requires smaller heat transfer area than the latter's.

The program selects an optimum exchanger among total number of 240 exchangers. The program is restricted to single-segmental baffle having 25% baffle cut that is most frequently used, triangular-pitch layout that results in greatest tube density. The exchanger type covers only fixed tube sheet with one-pass and two-pass, and U-tube for E-type shell. This program can be extended to different exchanger configurations, such as square pitch, 4or 6 tube-pass, etc. by inserting data from tube counts. Working fluids other than water can also be introduced easily.

Mohammed Rabeeh V and Vysakh S designed shell and tube heat exchanger using MATLAB codes. In their work a standard procedure is followed in design of shell and tube heat exchangers and the parameters required for building a heat exchanger are calculated by numerical method until the dimensions satisfy the condition for maximum overall heat transfer coefficient. A code written in MATLAB is used where the calculations are iterated by varying the TEMA specified values for tube length and tube outer diameter. The effective parameters for the design of shell and tube heat exchanger for given boundary conditions are the output of the above calculation. Energy balance over the heat exchanger for the designed HX was completed using partial differential equations, which was solved using second order Runge-Kutta method. Since Runge- Kutta method is very robust and efficient, so thermal diffusion term is not included in the energy balance equation. By plotting a temperature v/s tube length graph in MATLAB using the energy balance differential equation and analysing the same, time required for the shell and tube heat exchanger to reach a steady state condition is obtained. The present work proposes a standard steps to design and analyse the working and performance of a shell and tube heat exchanger.

Andre L.H. Costa and Eduardo M. Queiroz worked together for design optimization of shell and tube heat exchangers. The formulated problem consists of the minimization of the thermal surface area for a certain service, involving discrete decision variables. Additional constraints represent geometrical features and velocity conditions which must be complied in order to reach a more realistic solution for the process task. The optimization algorithm is based on a search along the tube count table where the established constraints and the investigated design candidates are employed to eliminate non optimal alternatives, thus reducing the number of rating runs executed. The performance of the algorithm and its individual components are explored through two design examples. The obtained results illustrate the capacity of the proposed approach to direct the optimization towards more effective designs, considering important limitations usually ignored in the literature R. Hosseini, A. Hosseini-Ghaffar and, M. Soltani In this paper, the heat transfer coefficient and pressure drop on the shell side of a shell-and-tube heat exchanger have been experimentally obtained for three different types of copper tubes (smooth, corrugated and with micro-fins). Also, experimental data has been compared with theoretical data available. Correlations have been suggested for both pressure drop and Nusselt number for the three tube types. A shell-and-tube heat exchanger of an oil cooler used in a power transformer has been modeled and built for this experimental work in order to investigate the effect of surface configuration on the shell side heat transfer as well as the pressure drop of the three types

of tube bundles. The bundles with the same geometry, configuration, number of baffles and length, but with different external tube surfaces inside the same shell were used for the experiment. Corrugated and micro-fin tubes have shown degradation of performance at a Reynolds number below a certain value ($Re < 400$). At a higher Reynolds number the performance of the heat exchanger greatly improved for micro-finned tubes.

Amin Hadidi*, Ali Nazari Cost minimization of Shell-and-tube heat exchangers is a key objective. Traditional design approach esbesides being time consuming, do not guarantee the reach of an economically optimal solution. So, in this research, a new shell and tube heat exchanger optimization design approach is developed based on biogeography-based optimization (BBO) algorithm. The BBO algorithm has some good features in reaching to the global minimum in comparison to other evolutionary algorithms. In this study BBO technique has been applied to minimize the total cost of the equipment including capital investment and the sum of discounted annual energy expenditures related to pumping of shell and tube heat exchanger by varying various design variables such as tube length, tube outer diameter, pitch size, baffle spacing, etc. Based on proposed method, a full

computer code was developed for optimal design of shell and tube heat exchangers and three different test cases are solved by it to demonstrate the effectiveness and accuracy of the proposed algorithm. Finally the results are compared to those obtained by literature approaches up to the present. The obtained results indicate that the BBO algorithm can be successfully applied for optimal design of shell and tube heat exchangers.

Steinar Hauan and Ignacio E. Grossmann developed mathematical programming model for heat exchanger network synthesis including detailed heat exchanger design. This paper addresses the optimal design of shell-and-tube heat exchangers via a mathematical programming approach. It is shown that it is possible to develop a design model for shell-and tube heat exchangers that takes into account some important construction variables: number of tubes, number of passes, internal and external tube diameters, tube arrangement pattern, number of baffles, head type, and fluid allocation (i.e., the allocation of the fluid streams to the shell or tubes). The model is based on generalized disjunctive programming and is optimized with a mixed-integer nonlinear programming reformulation to determine the heat-exchanger design that minimizes the total annual cost accounting for area and pumping expenses. Examples are presented to illustrate the model performance.

In this paper, an optimization model has been proposed for the design of a shell-and-tube heat exchanger. The main contribution of this work is an optimization model that includes correlations from the Bell-Delaware method in order to calculate the heat-transfer coefficient and the pressure drop in the shell-side flow. Therefore, design options are included in the model with the aim of determining the best design configuration.

The model is based on generalized disjunctive programming and is optimized with a MINLP formulation to determine the heat-exchanger design that minimizes the total annual cost accounting for area and pumping expenses. The application and usefulness of the proposed method have been shown in three example problems. The results indicate that the methodology can properly account for the trade offs between area and pumping costs. Finally, different design options such as flexible target temperatures or mass flow rates can be easily included in the model by using heat balances and logarithm mean temperature equations as constraints.

V.K. Patel, R.V. Rao Shell-and-tube heat exchangers (STHEs) are the most common type of heat exchangers that find widespread use in numerous industrial applications. Cost minimization of these heat exchangers is a key objective for both designer and users. Heat exchanger design involves complex processes, including selection of geometrical parameters and operating parameters. The traditional design approach for shell

and-tube heat exchangers involves rating a large number of different exchanger geometries to identify those that satisfy a given heat duty and a set of geometric and operational constraints. However, this approach is time-consuming and does not assure an optimal solution. Hence the present study explores the use of a non-traditional optimization technique; called particle swarm optimization (PSO), for design optimization of shell-and-tube heat exchangers from economic view point. Minimization of total annual cost is considered as an objective function. Three design variables such as shell internal diameter, outer tube diameter and baffle spacing are considered for optimization. Two tube layouts viz. triangle and square are also considered for optimization. Four different case studies are presented to demonstrate the effectiveness and accuracy of the proposed algorithm. The results of optimization using PSO technique are compared with those obtained by using genetic algorithm (GA). Heat exchangers are an integral component of all thermal systems. Their designs should be adapted well to the applications in which they are used; otherwise their performances will be deceiving and their costs excessive. Heat exchanger design can be a complex task, and advanced optimization tools are useful to identify the best and cheapest heat exchanger for a specific duty. The present study has demonstrated successful application of PSO technique for the optimal design of a shell-and-tube heat exchanger from economic view point. The presented PSO technique is simple in concept, few in parameters and easy for implementation. These features boost the applicability of the PSO particularly in thermal system design, where the problems are usually complex and have a large number of variables and discontinuity in the objective function. The presented PSO technique's ability is demonstrated using different literature case studies and the performance results are compared with those obtained by the previous researchers. PSO converges to optimum value of the objective function within quite few generations and this feature signifies the importance of PSO for heat exchanger optimization. The PSO technique can be easily modified to suit optimization of various thermal systems.

B.V. Babu and S.A. Munawar Differential evolution (DE) and its various strategies are applied for the optimal design of shell-and-tube heat exchangers in this study. The main objective in any heat exchanger design is the estimation of the minimum heat transfer area required for a given heat duty, as it governs the overall cost of the heat exchanger. Lakhs of configurations are possible with various design variables such as outer diameter, pitch, and length of the tubes, tube passes, baffle spacing, baffle cut, etc. Hence the design engineer needs an efficient strategy in searching for the global minimum. In the present study for the first time DE, an improved version of genetic algorithms (GAs), has been successfully applied with different strategies for

1,61,280 design configurations using Bell's method to find the heat transfer area. In the application of DE, 9680 combinations of the key parameters are considered. For comparison, GAs are also applied for the same case study with 1080 combinations of its parameters. For this optimal design problem, it is found that DE, an exceptionally simple evolution strategy, is significantly faster compared to GA and yields the global optimum for a wide range of the key parameters. This paper demonstrates the first successful application of DE for the optimal design of shell-and-tube HEs. A generalized procedure has been developed to run the DE algorithm coupled with a function that uses Bell's method of HED, to find the global minimum HE area. For the case study taken up, application of all the 10 different working strategies of DE are explored. The performance of DE and GA is compared. From this study we conclude that the population-based algorithms such as GAs and DE provide significant improvement in the optimal designs, by achieving the global optimum, compared to the traditional designs. For the given optimal shell-and-tube HED problem the best population size, using both DE and GA, is about seven times the number of design variables. From 'more likeliness' as well as 'speed' point of view, DE/best/1/... strategy is found to be the best out of the presently available 10 strategies of DE. DE, a simple evolution strategy, is significantly faster compared to GA and it achieves the global minimum over a wide range of its key parameters—indicating the 'likeliness' of achieving the true global optimum. DE proves to be a potential source for accurate and faster optimization.

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There is no precise criterion to determine baffle spacing in the presented procedure for condenser design in the Heat Exchanger Design Handbook (HEDH). To consider suitable baffle spacing in the design process, a computer program has been developed which enables designers to determine the optimum baffle spacing for segmentally baffled shell and tube condensers. Total costs of heat transfer area and pumping power are involved to perform objective function, using a weight factor, which depends on the economical conditions of the desired location. As a result, a set of correlation is presented to determine the optimum baffle spacing, which could be considered as a complementary to HEDH recommendations. Throughout the research, a wide range of design input data specifications for E and J types shell and tube condensers have been considered and their corresponding optimum designs for different values of W_1 have been evaluated. This evaluation has led to some correlation for determining the optimum baffle spacing. The steps of guideline are included, and its usefulness and accuracy has been validated.

R. Hosseini, A. Hosseini-Ghaffar, M. Soltani: In this paper, the heat transfer coefficient and pressure drop on the shell side of a shell-and-tube heat exchanger have been

experimentally obtained for three different types of copper tubes (smooth, corrugated and with micro-fins). Also, experimental data has been compared with theoretical data available. Correlations have been suggested for both pressure drop and Nusselt number for the three tube types. A shell-and-tube heat exchanger of an oil cooler used in a power transformer has been modeled and built for this experimental work in order to investigate the effect of surface configuration on the shell side heat transfer as well as the pressure drop of the three types of tube bundles. The bundles with the same geometry, configuration, number of baffles and length, but with different external tube surfaces inside the same shell were used for the experiment. Corrugated and micro-fin tubes have shown degradation of performance at a Reynolds number below a certain value ($Re < 400$). At a higher Reynolds number the performance of the heat exchanger greatly improved for micro-finned tubes. Nusselt and Euler numbers for three different types of tubes in the shell side of a shell-and-tube heat exchanger have been experimentally obtained and presented. Micro-finned tubes show higher Nusselt numbers and higher pressure drops as well. The higher Nu number for micro-finned tube is attributed to the larger surface area. Corrugated tubes at the range of experimental work show lower Nu, but similar pressure drops in comparison to smooth tubes. A simple correlation was presented for the determination of pressure drops and Nusselt number for the shell side of the heat exchanger with different tube types. Micro-finned tubes and corrugated tubes show a lower Nusselt number at lower $Re \propto Pr$. Considering the larger area of micro-finned tubes, favor their use at $Re \propto Pr > 200000$. Experimental results are closer to the theoretical values at higher $Re \propto Pr$. Euler number for micro-finned tubes decreases rapidly with $Re \propto Pr$ increase. Therefore, micro-fin tubes should be used when $Re \propto Pr$ exceeds 200000. Experimental work shows higher Nusselt number and pressure drops with respect to theoretical correlation based on Bell's method. The optimum condition for flow rate (for the lowest increase of pressure drop) in replacing the existing smooth tube with similar micro-finned tube bundle was obtained for the oil cooler of the transformer under investigation.

Jie Yang a, Sun-Ryung Oh, Wei Liu A general optimization design method motivated by constructal theory is proposed for heat exchanger design in the present paper. The simplified version of this design approach is suggested and the optimization problem formulations are given. In this method, a global heat exchanger is divided into several sub heat exchangers in series-and-parallel arrangement. The shell-and-tube heat exchanger is utilized for the method application, and the Tubular Exchanger Manufacturers Association (TEMA) standards are rigorously followed for all design parameters, e.g. tube diameter, arrangement, thickness and number. The fitness function is the total cost of the shell-and-tube

heat exchangers, including the investment cost for initial manufacture and the operational cost involving the power consumption to overcome the frictional pressure loss. A genetic algorithm is applied to minimize the objective function by adjusting parameters. Three case studies are considered to demonstrate that the new design approach can significantly reduce the total cost compared to the methods of original design, traditional genetic algorithm design, and old constructal design. In this paper, an optimization design method based on constructal theory is proposed for heat exchanger application. The novel design adopts the perception that divides a whole heat exchanger into several sub heat exchangers, arranges sub-HEs in a certain pattern, and then optimizes sub-HEs simultaneously. A genetic algorithm is used to optimize the parameters of each sub-HE. The total cost minimization of all sub shell-and-tube exchangers is set as the objective function. A heat exchanger design approach motivated by constructal theory is proposed and simplified. The problem formulations for both non-simplified and simplified methods are given. The successful applications of shell-and-tube heat exchangers demonstrate potential applicability in other engineering fields. Three cases studies with the TEMA standards imposing a discrete parameter space were considered to compare the results obtained by the original, the conventional GA, the old constructal, and the new constructal values. The results demonstrated that the novel design approach has a great advantage in solving the MDNLP problem and reduces total cost compared to the other methods.

M. REPPICH and J. KOHOUTEK A new method allowing the optimal design of baffled shell-and-tube heat exchangers was discussed in this paper. The known commercial design tools do not consist optimization strategies. There are presented as simplified expressions describing interaction between heat transfer and pressure drop that can be used for optimal design of heat exchangers from economic view point. The developed program system HEATDESIGN is realizing a general computer-supported design on the basis of estimation of optimal pressure drops determined by consideration of economic conditions and process data. Examples show the influence of changed economic parameters or process data on the design and costs by means of optimization. In addition the program gives the possibility to optimize components of apparatus. The developed method enables to find the optimal pressure drop and flow velocities from the view point of economic conditions. It is applicable for liquid and gaseous streams. The influence of changed economic parameters, process data or fluid properties on the design and costs can be estimated rapidly. The program system HEATDESIGN is a design tool that realizes the derived new concept allowing a computer-supported optimal design of baffled shell-and-tube heat exchangers.

HEATDESIGN gives in addition the possibility to optimize the flange joints of the apparatus.

PROBLEM FORMULATION AND METHODOLOGY

After going through the various works done by different authors in the field of design of heat exchangers which is presented in the literature review, the problem is formulated. The objectives of the work are presented below:

1. To design the shell and tube heat exchanger with the help of programming using MATLAB (Matrix Laboratory) software.
2. To calculate the overall dimensions of the shell, the tube bundle, and optimum heat transfer surface area required to meet the specified heat transfer duty by calculating minimum or allowable shell-side pressure drop.
3. To compare a number of heat exchangers given in the tube count for three different type of flow arrangements.
4. To find out the optimum heat exchanger based on above calculation that is associated with the minimum pressure drop so that the running cost would be minimised.

CONCLUSION

A lot of research work has been done in the field of heat exchangers. Conventional methods are found to be very expensive and time consuming. MATLAB has emerged as boon for researchers. With the help of MATLAB, one can determine effectiveness, heat transfer rate detailed parameters easily. Among all types of heat exchangers corrugated heat exchangers are found to have highest rate of heat transfer.

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