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A Review on Optimization of a Shell and Tube Heat Exchanger in Industrial Applications

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Abstract:

This paper presents a study about the 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. Heat transfer rate and cost significantly affect designs of shell and tube heat exchangers. From the viewpoint of engineering, an optimum design is obtained via maximum heat transfer rate and minimum cost. Here, an analysis of a shell and tube heat exchanger is carried out, considering nine design parameters: tube arrangement, tube diameter, tube pitch, tube length, number of tubes, fin height, fin thickness, baffle spacing ratio and number of fins per unit length of tube. The "Delaware modified" technique is used to determine heat transfer coefficients and the shell-side pressure drop. The purpose of this paper is optimization of shell and tube heat exchanger for water heating operation. 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.

Keywords — **Shell-and-tube heat exchanger, Optimization.**

I. Introduction:

Shell-and-tube heat exchangers are the most common type of thermal equipment employed in chemical process industries. This widespread use can be justified by its versatility, robustness and reliability. Despite the technological advances of other exchanger types. Shell and tube type heat exchanger is an indirect contact type heat exchanger as it consists of a series of tubes, through which one of the fluid. Usually, it is cylindrical in shape with a circular cross section, although shells of different shapes are used in specific applications. For this particular study E shell is considered, which a one pass shell is generally. E shell is the most commonly used due to its low cost and simplicity, and has the highest log mean temperature difference (LMTD) correction factor. Shell and tube heat exchangers are important components in energy conversion systems, oil and chemical industries, *etc.* In these industries, the heat transfer rate and the total cost of the shell and tube exchangers significantly affect system designs. Extended surfaces (fins) of the shell and tube heat exchangers are applied to enhance heat transfer rates for gas and liquid heat transfer fluids. Fins can be of various geometrical shapes. Generally, fins increase the internal and external tube heat transfer coefficients. Fins are utilized less frequently to decrease shell-side thermal resistance. A suitable and an optimum design, in terms of both economics and efficiency, is obtained through judicious selection of the design parameters.

The optimum thermal design of a shell and tube heat exchanger involves the considerations of many interacting design parameters which can be summarized as follows;

1) Process Process fluid assignments to shell side or tube side.
2) Selection of stream temperature specifications.
3) Setting shell side and tube side velocities limits.
4) Setting shell side and tube side pressure drop design limits.
5) Selection of heat transfer models and fouling coefficients for shell side and tube side.

Mechanical

1) Selection of heat exchange TEMA layout and number of passes.
2) Specification of tube parameters- size, layout, pitch and material.
3) Setting upper and lower design limits on tube length.
4) Specification of shell side parameters materials baffles cut, baffle spacing and clearances.
5) Setting upper and lower design limits on shell diameter, baffle cut and baffles spacing

II. Objectives:

- To review the different researches made on heat exchangers
- To understand the behaviour of heat exchangers with different industries.
- To improve the heat transfer system size – reduction

III. Literature Review:

Shah and London [1] this paper is concerned with the study of shell & tube type heat exchangers along with its applications and also refers to several scholars who have given the contribution in this regard. Moreover the constructional details, design methods and the reasons for the wide acceptance of shell and tube type heat exchangers has been described in details inside the paper.

Haji-heikh et al [2] in this paper a computer program for economical design of shell and tube heat exchanger using specified pressure drop is established to minimize the cost of the equipment. The design procedure depends on using the acceptable pressure drops in order to minimize the thermal surface area for a certain service, involving discrete decision variables. Also the proposed method takes into account several geometric and operational constraints typically recommended by design codes, and provides global optimum solutions as opposed to local optimum solutions that are typically obtained with many other optimization methods.

Srinivasan and Shah [3] They have presented a shell and tube formulation to relate the shell-side pressure drop with the exchanger area and the film coefficient based on the full Bell–Delaware method. In addition to the derivation of the shell side shell and tube expression, they have developed a shell and tube pressure drop equation for the tube-side stream, which accounts for both straight pressure drops and return losses. They have shown how the shell and tube formulations can be used within an efficient design algorithm. They have found a satisfactory performance of the proposed algorithms over the entire geometry range of single phase, shell and tube heat exchangers

Goering et al [4] studied that techniques were employed according to distinct problem formulations in relation to:
(i) Heat transfer area or total annualized costs,
(ii) constraints: heat transfer and fluid flow equations, pressure drop and velocity bound; and
(iii) Decision variable: selection of different search variables and its characterization as integer or continuous.

This paper approaches the optimization of the design of shell and tube heat exchangers. The formulation of the problem seeks the minimization of the thermal surfaces of the equipment, for certain minimum excess area and maximum pressure drops, considering discrete decision variables. Important additional constraints, usually ignored in previous optimization schemes, are included in order to approximate the solution to the design practice**.**

Beecher and Fagan [5] carried out an experimental system for investigation on performance of shell-and-tube heat exchangers, and limited experimental data is obtained. The ANN is applied to predict temperature differences and heat transfer rate for heat exchangers. BP algorithm is used to train and test the network. It is shown that the predicted results are close to experimental data by ANN approach. Comparison with correlation for prediction heat transfer rate shows ANN is superior to correlation, indicating that ANN technique is a suitable tool for use in the prediction of heat transfer rates than empirical correlations. It is recommended that ANNs can be applied to simulate thermal systems, especially for engineers to model the complicated heat exchangers in engineering applications**.**

B.V. Babu, S.A. Munawarb [6] 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.

Panchal and Rabas [7] Applied genetic algorithms (GA) for the optimal design of shell-and-tube heat exchanger by varying the design variables: outer tube diameter, tube layout, number of tube passes, outer shell diameter, baffle spacing and baffle cut. From this study it was concluded that the combinatorial algorithms such as GA provide significant improvement in the optimal designs compared to the traditional designs. GA application for determining the global minimum heat exchanger cost is significantly faster and has an advantage over other methods in obtaining multiple solutions of same quality.

Zahid H. Ayub[8] A new chart method is presented to calculate single-phase shell side heat transfer coefficient in a typical TEMA style single segmental shell and tube heat exchanger. A case study of rating water-to-water exchanger is shown to indicate the result from this method with the more established procedures and software available in the market. The results show that this new method is reliable and comparable to the most widely known HTRI software**.**

Gray and Webb [9] prepared a computer based design model for preliminary design of shell and tube heat exchangers with single phase fluid flow both on shell and tube side. The program determines 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. He concluded that 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 and thus it is better to put the stream with lower mass flow rate on the shell side because of the baffled space.

Volker Kott Ke [10] In this paper data is evaluated for heat transfer area and pressure drop and checking whether the assumed design satisfies all requirement or not. The primary aim of this design is to obtain a high heat transfer rate without exceeding the allowable pressure drop.

Qiao He and Wennan Zhang [11] presented a theoretical analysis and an experimental test on a shell and tube latent heat storage exchanger. The prediction by the mathematical model on the performance of the heat storage exchanger is reasonable and in agreement with experimental measurements

Selbas et al. [12] optimized a shell and tube heat exchanger economically using a genetic algorithm that considers as the objective function heat transfer area and shows the relationship between heat transfer area and total cost: heat transfer area increases as total cost increases.

Vahdat Azad and Amidpour [13] optimized shell and tube heat exchangers based on constructed theory, with the objective of reducing the total cost of the heat exchanger. They use a genetic algorithm to optimize the objective function, which is a mathematical model for the cost of the shell and tube heat exchanger and is based on constructed theory.

Rozzi et al [14] worked on convective heat transfer and friction losses in helically enhanced tubes for both Newtonian and nonNewtonian fluids. Four fluid foods, namely, whole milk, cloudy orange juice, apricot and apple puree, are tested in a shell and tube heat exchanger. Both fluid heating and cooling conditions are considered. The experimental outcome confirms that helically corrugated tubes are particularly effective in enhancing convective heat transfer for generalized Reynolds number ranging from about 800 to the limit of the transitional flow regime

Hosseini et al [15], they experimentally obtained the heat transfer coefficient and pressure drop on the shell side of a shell and tube heat exchanger for three different types of copper tubes (smooth, corrugated and with micro-fins). Corrugated and microfin tubes have shown degradation of performance at a Reynolds number below a certain value ($NRe < 400$). At a higher Reynolds number the performance of the heat exchanger greatly improved for micro finned tubes.

Zubair et al [16] presents a simple probabilistic approach to characterize various fouling models that are commonly encountered in many industrial processes. These random fouling growth models are then used to investigate the impact on risk based thermal effectiveness, overall heat transfer coefficient and the hot and cold fluid outlet temperatures of a shell and tube heat exchanger. Probabilistic approach is used to characterize various fouling growth models in terms of the risk level p and scatter in growth rate of the process. These random fouling growth models are then considered in the performance evaluation of a shell and tube heat exchanger in a crude oil preheat train to demonstrate the influence of risk level and scatter parameter on important thermal parameters of the heat exchangers. Although the analysis presented in the paper is applicable to shell-and-tube heat exchangers, the procedure can easily be modified to include other types of heat exchanger such as double pipe, plate and frame and other shell and tube heat exchangers

Tan and Fok [17] developed an educational computer aided design tool for shell and tube heat exchanger that integrates thermo hydraulics analysis with mechanical design.

Ajib [18] developed new software for calculation, simulation and optimization of shell and tube heat exchangers. This program is able to predict the effects of baffle spacing, baffle cut, tube size, shell pass number, shell size, etc., on the average heat transfer coefficient, thermal performance and thermal efficiency of the shell and tube heat exchangers

Ghoshal [19] considered an optimum design problem for the different constraints involved in the designing of a shell-and-tube heat exchanger consisting of longitudinally finned tubes. A Mat lab simulation has been employed using the Kern's method of design of extended surface heat exchanger to determine the behavior on varying the values of the constraints and studying the overall behavior of the heat exchanger with their variation for both cases of triangular and square pitch arrangements, along with the values of pressure drop. Simulations were performed to analyze the effect of tube pitch on the heat transfer.

Srinivasan and Shah [20] examined condensation phenomena occurring in shell and tube heat exchangers. Other attempts to analyze transport phenomena in the air-side, within the fin-tube passages

IV. Results and discussions

References	**Year**	**Study**	**Results**
Srinivasan and Shah	**(2017)**	In design of shell and tube exchangers, passive techniques of heat transfer enhancement	Heat exchangers in automobile applications boundary layers and results in better heat transfer enhancement.
Tan and Fok	**(2017)**	Performance of shell and tube heat exchangers with different configurations is presented.	heat exchangers role became important because to enhance of heat transfer rate and for better performance
Ghoshal	**(2016)**	heat exchangers is a thrust area as it is an eco-design model	to the heat exchangers and modifications made to improve the efficiencies.
Zubair et al	**(2015)**	Shell & Tube Heat Exchanger Thermal Design	how to design the shell and tube heat exchanger which is the majority type of

		With Optimization Of Mass Flow Rate And Baffle	liquid –to- liquid heat exchanger
Hosseini et al	**(2012)**	Design optimization of shell-and-tube heat exchangers	The performance of the algorithm and its individualcomponents are explored through two design examples.
Vahdat Azad and Amidpour	**(2010)**	Optimization of a Finned Shell and Tube Heat Exchanger Using a Multi-Objective Optimization Genetic Algorithm	an analysis of a radial, finned, shell and tube heat exchanger is carried out, considering nine design parameters: tube arrangement, tube diameter, tube pitch, tube length, number of tubes, fin height, fin thickness, baffle spacing ratio and number of fins per unit length of tube

V. Discussions:

The previous studies exhibit some shortcomings. First, there are no studies on finned shell and tube heat exchangers in the context of this article. Second, most prior optimization have single objectives, permitting the use of single-objective optimization and the identification of designs with single solutions. Here, we use two-objective optimization and a set of solutions is obtained. Third, most prior optimizations use the Kern method for calculating the heat transfer coefficient and the shell-side pressure drop, but we used a Simplified Delaware method which has better accuracy than the Kern method. There is increase in pressure drop with increase in fluid flow rate in shell and tube heat exchanger which increases pumping power. The results obtained, corresponding to the different objective functions, are also discussed. The results of these methods are then used to demonstrate how the optimum baffle spacing ratio is affected by the varying values of the heat exchanger geometrical parameters. Calculation of fluid water outlet temperature is 351K which is nearer to the value mentioned in output temperature of COMSOL result. As we change, the tube material from the aluminum to copper and steel had been varied.

VI. CONCLUSIONS:

In order to further accelerate the use of shell and tube heat exchangers for phase change duties heat exchanger passages, especially for cross corrugated channels of plate heat exchangers. This information would be useful for developing flow pattern specific models for shell and tube heat exchangers further; the usage of various nanoparticles in the base fluid for the heat transfer enhancement along with these configurations had been studied. A review on the shell and tube heat exchangers had been also done to extract some useful facts regarding heat transfer. This innovative technique can be implemented in micro-channel heat exchanger especially in the inferior heat transfer side to Enhance overall thermal performance of the heat exchanger. Jet position influence overall performance of the heat exchanger and need to optimize for a specific condition and geometry. Jet velocity can be controlled with the constriction that induced jet and with the increase of jet velocity local heat transfer rate increases.

VII. Future scope:

Heat exchanger optimization is an important field and full of challenges. The task of optimization may be considered as a design process, in which any possible candidates will be evaluated based on requirements. Savings of materials or energy, as well as capital cost and operating cost, are common objectives for industrial applications of heat exchangers.

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