An Integrated Algorithm for The Thermal Design of a Heat Exchanger

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ABSTRACT: The thermal design of a shell and tube heat exchanger is executed basically by the procedure developed by Kern. However, physical properties, tube sizes and estimation of the other design parameters like heat transformer coefficients, pressure drops on tube side and shell side etc., require reference to tables and plots.

With the advent of computers and their very fast development, very powerful and low cost computers with huge memory are available in the market. Hence, all the tables and data from plots can be stored in the computer (or the data can be correlated by using linear or non-linear equations by the method of least squares 'fit) and for varied industrially important systems, the thermal design can be executed with considerable ease.

It should be noted that if it is necessary to execute the thermal design for a number of exchangers for a chemical plant with varying flow rates and temperatures, it could be done by using matrices to develop the computer program and also store the short-cut equations related with physical properties, tables, graphs etc. the heat exchanger can be accurately designed if the exchanger is divided into numerous sections. This is done so as to get precise values of all the output design variables affecting the cost of the exchanger.

It is concluded that the concept of designing heat exchangers by dividing into sessions has been found to be compatible with the results obtained by conventional methods. Further, extensive information in the form of output variables are obtained and simple shortcut equations obtained are quite accurate (fro plant practice) and compact. More importantly, if the systems used in the different exchanger are similar, then in one stroke the short-cut equations give adequate results sufficient for the design of a number of exchangers without actually going through the sequence of conventional thermal design. It should be noted that the principle of dividing equipment into thermal sections can be used extensively for varied unit operations best process equipment.

Introduction

The design of a heat exchanger can be executed in sequential steps which has been standardize and typically the thermal design of a shell and tube heat exchangers very well established. The authors have developed an integrated algorithm for a liquid-liquid shell and tube heat exchanger. However, the conventional design is modified mainly with an idea to exploit the advantage of the computer's phenomenal capacity and its great speed in performing related calculations. Notably the excellent book by Kern [Kern, 1950] adequately fulfilled the gap between theory and practical and the book is virtually self contained in that the numerous plots. Special design tables like tube counts, dirt factors, design overall and other design data are sufficient to guide the designer to execute the thermal design confidently.

However, since the thermal design requires reference to numerous plots and tables, it would be difficult to solve the problem on computer. There are two possibilities in circumventing this difficulty Firstly, the whole tables and charts can be stored in the computer and design data required may be read out from the plot or table. This method consumes a lot of memory and clearly not desirable although it is obvious that phenomenally large memory is available with the present day powerful personal computers. The other alternative is to use the least squares curve fit which can be developed between any two variables by reading the values from the plots and generating a linear or non-linear fit. Several types of fits are tried. However, a linear or non-linear fit was found to be accurate enough for the design purpose with maximum error of < 5 %. Thus, the exchanger is divided into a number of temperature sections and each section is assumed to be a heat exchanger and the area is computed (for each section) and the total area of the exchanger is obtained by summing up the sectional areas. This method of computation is very accurate and realistic especially when the number of section is large.

Further, for the given input data variables, a number of output design variables are obtained at every sectional point in the heat exchanger. Some typical output design variables computed are mass velocity. Reynolds number, heat transfer, coefficient etc. on shell side and tube side respectively. A linear or non linear least squares fit is developed and the output variables obtained are taken in pairs and short-cut equations relating them have been developed.

Thus, physical properties of the shell side and tube side fluids were computed in terms of linear fits. (it does not give good results for viscosity versus temperature). Also plots of J-H factor and Fanning friction factors are also converted into linear fits.

Plan of Computation

A typical thermal design of liquid-liquid heat exchanger is developed in BASIC language on a personal computer, also, a least squares' fit is developed for fitting a linear or non-linear equation to any set of data. The program is developed to fit the set of data with linear fit, logarithmic fit and exponential fit in sequence. Though the program can be used to fit the data for different types of linear fits, it was not pursued because the accuracy of the linear fit was sufficient for design purposes. Firstly, a typical liquid-liquid heat exchanger, say, benzene-toluene system was considered for performing the thermal design using the program developed (in BASIC language). The program is used for a different system by changing a few lines which are a set of least squares' fit for different plots mentioned above.

Brief mote about the program

As mentioned in the abstract, the design of a heat exchanger is executed by dividing the heat exchanger in to numerous temperature sections. Thus each sectional division can be conceptualized to be a heat exchanger. The area of each sectional exchanger can be determined. The total area of the whole exchanger is computed by adding the area of each sectional exchanger.

Basically two programs were developed:
(a) Lease squares' fit program
(b) Thermal design of a typical shell and tube heat exchanger program.

Concise Algorithm for the thermal design of a liquid-liquid heat exchanger:

Step 1: Input the number of independent heat exchanger to be designed = NH.

Step 2: Input the number of data variables. ND and the number of output variables. NR for each exchanger.

Step 3: Input the data for flow rates of hot and clod fluids, temperatures of hot and cold fluids, physical properties such as C_ρ, μ, κ and (as polynomial equation in terms of temperatures (in the relevant range of temperature).

Step 4: Input the equipment data such as pitch, length, OD and ID of tubes, number of passes on tube side, number of passes on shell side, baffle spacing, clearance and ID of shell.

Step 5: Input the allowable pressure drop on tube side and shell side.

Step 6: Compute heat load, LMTD.

Step 7: Perform the tube side calculations by computing flow area, mass velocity, Reynolds number. J-H factor (from a least squares' fit), heat transfer coefficient of tube side fluid.

Step 8: **Perform the shell** side calculations by computing flow area, mass velocity, Reynolds number. J-H factor (from a list squares' fit), heat transfer coefficient of shell side fluid.

Step 9: Compute the clean overall heat transfer coefficient, the design overall heat transfer coefficient and report the dirt factor.

Step 10: Check the design alternatively.

(a) Assume a dirt factor from the tables.
(b) The reciprocal of clean overall coefficient is computed and the dirt factor assumed is added to it.
(c) The reciprocal of the sum calculated in step (b) is computed. This value is the overall design coefficient.
(d) The area of each of the sectional heat exchangers is computed by using the formula:

$$a_d = q/(U_d.LMTD)$$

(e) Finally, the total area is computed by summing up each of the sectional area.

The output design variables computed are taken in pairs- for example, shell side heat transfer coefficient and temperature. If a least squares' fit is executed, an equation is obtained with design area in terms of temperature of the mixture. Similarly, other output variables like shell side heat transfer coefficient, head load, etc. are considered in pairs with different combinations and linear or non-linear equations are generated by executing the least squares' fit program.

Hence, a number of short-cut equations are developed. However' three important equations are given in Table 1. It should be carefully noted that these short-cut equations are quite accurate for plant practice and can be used for a specific heat exchanger or a group of similar (both in mechanical constructions and thermal fluids use) heat exchangers.

This method of design is novel in that extensive data can be generated using Chemical Engineering design principles. From the data bank generated, the short-cut equations developed are compact and can be used for a similar problem without going through the detailed Chemical Engineering design procedure. Thus, reliable and compact equations relating important output variables were obtained. These equations are simple to use besides being apt for the problems on hand.

Table 1. Short-cut equations of some important output design variables

1.	$\Sigma q = 277812.56 + 15336.63 \Sigma A$
2.	$h_s = 819.66 - 1.68 \Sigma A$
3.	$h_1 = 515.50 + 1.84 \Sigma A$
4.	$q = 644614.004 - 572.44 (LMTD)$

Note: (i) Other combinations and forms of equations are possible and are probably more accurate. However, the accuracy of these equations suffice for plant practice.
(ii) Many other design variables were correlated similarly but are not shown here and only important variables which directly or indirectly affect the cost of the exchanger to a significant extent are shown in the above table.

Conclusions

The design of a heat exchanger by dividing it into a number of sections is quite accurate and the more the number of sectional heat exchanger considered, the more will be accuracy.

The short-cut equations shown for a few variables are useful and can be used where a similar situation is found to arise.

Nomenclature

A	=	Area of sectional heat exchange, m^2
Σ A	=	Cumulative area of the heat exchanger. m^2
h_s	=	Shell side heat transfer coefficient, Kcal/(h.m^2 °C)
h_1	=	Tube side heat transfer coefficient, Kcal/(h.m^2 °C)
LMTD	=	Logarithmic Mean Temperature Difference, °C
q	=	Heat load of sectional heat exchanger, Kcal/(h.m^2 °C)
Σ q	=	Cumulative heat load of the heat exchanger,kcal/h

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