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A Review on Design & Analysis of Double Pipe Heat Exchanger

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***Abstract*— Heat exchangers are used in industrial processes to recover heat between two process fluids. Although the necessary equations for heat transfer and the pressure drop in a double pipe heat exchanger are available, using these equations the optimization of the system cost is laborious. In this paper the optimal design of the exchanger has been formulated as a geometric programming with a single degree of difficulty. The solution of the problem yields the optimum values of inner pipe diameter, outer pipe diameter and utility flow rate to be used for a double pipe heat exchanger of a given length, when a specified flow rate of process stream is to be treated for a given inlet to outlet temperature.**

Keywords— : Design; Economy; Geometric programming; Heat exchanger; Optimization

I. INTRODUCTION

Heat transfer equipment is defined by the function it fulfills in a process. The objective of any such equipment is to maximize the heat transferred between the two fluids. However, the problem that occurs is that the parameters which increase the heat transfer also increase the pressure drop of the fluid flowing in a pipe which increases the cost of pumping the fluid. Therefore, adesign which increases the heat transferred, but simultaneously could keep the pressure drop of the fluid flowing in the pipes to permissible limits, is very necessary. A common problem in industries is to extract maximum heat from a utility stream coming out of a particular process, and to heat a process stream. A solution to extract the maximum heat could have been to increase the heat transfer area or to increase the coolant flow rate but both the solutions increase the cost of pumping so increasing these parameters without pressure drop considerations is not advisable. Traditional design method of heat exchangers involves the consideration of all the design variables with a laborious procedure of trial and error, taking all possible variations into consideration. Though this time consuming procedure can be reduced some what by making some reasonable assumptions as described by [6], but still no convenient method has been developed for optimal design of double pipe heat exchangers. In other optimum design methods, such as Lagrange multiplier method, the optimum results are again obtained in a long time by changing one variable at a time and using a trial-error or a graphical method. In the current literature (for example, [8]), focus is on

optimizing the area of the heat exchanger irrespective of the different flow rates of the utility that can be used. Using this pressure drop is not minimized to the fullest extent. This fact can be avoided through the design method discussed in the paper. We have considered the design of a double pipe heat exchanger in which its cost is optimized by considering three main parameters – the inner and outer diameter of the heat exchanger and the flow rate of the utility. The design of the exchanger has been formulated as a geometric programming with a single degree of difficulty. It is assumed that the flow rate, the inlet and the required outlet temperature of the process fluid and the inlet temperature of the utility are known for the specific design of the exchanger.

Heat exchangers, as the name implies, transfer heat from one substance to another. A heat exchanger is a heat transfer device that exchanges heat between two or more process fluids. Heat exchangers have widespread industrial and domestic applications and in the process industry for the recovery of the heat. They are an essential component in thermal power system, refrigeration system, and other cooling system. In all theses systems, heat is transfer from one fluid to other. The counter current heat exchanger is most favourite because it is gives maximum rate of heat transfer for a given surface area In many thermal equipments design are based on the steady state in calculation of the characteristic variable. Many applications require knowledge of the transient behaviour of the thermal devices. In fact, it is necessary to explore the unsteady state of thermal properties when the real time control, state computation, optimization, and rational use of energy are investigated. In additional, the unsteady state gives more details and information than steady state & also gives indication to validity of the steady state assumption.

Double pipe heat exchangers are the simplest recuperators in which heat is transferred from the hot fluid to the cold fluid through a separating cylindrical wall. It consists of concentric pipes separated by mechanical closures. Inexpensive, rugged and easily maintained, they are primarily adapted to high-temperature, high-pressure applications due to their relatively small diameters.

In order to construct an approximate model efficiently even though the problem has a large number of design variables, researchers in the iDOT (the center of innovative design optimization technology, in Hanyang University) [7,8] have proposed the progressive quadratic response surface model (PQRSM) and applied it to the MDO (multidisciplinary design optimization) problem. The PQRSM has the following two merits: Firstly, it requires only (2n + 1) points for determining the regression coefficients of linear and quadratic terms in each approximation. The two-factor interaction terms are also determined by using the normalized quasi-Newton formula. Moreover, it algorithmically converges from the global quadratic to the local approximations in the context of the trust region model management strategy. Secondly, the PQRSM does not require the additional CPU time to explicitly construct a quadratic approximate model because it uniquely determines all the regression coefficients and updates the remained regression coefficients for the two-factor interaction terms using the uniquely determined terms. In this study, the optimal values of the design variables of a plate-fin type heat sink are numerically obtained using the CFD associated with the PQRSM in order to minimize the pressure drop under the required temperature rise. The overall procedure including the analysis of flow/thermal fields and the optimization is carried out through the batch-job process. The efficiency of the PQRSM is also investigated by comparing the optimized solutions with those of the sequential quadratic programming (SQP) method which is a gradient- based local optimization technique.

II. DESIGN & DEVELOPMENT OF DOUBLE PIPE HEAT EXCHANGER

In order to study the heat transfer, heat transfer coefficient and pressure drop on large tube side for transient flow in a double pipe heat exchanger, a fully instrumented experimental setup is developed. The schematic of the experiment system is shown in Fig. 56. The experiment system has two cycles, hot water cycle and cold water cycle. For hot water cycle, the hot water is filled into the system through the reservoir tank and fulfills the pipes, electrical water heater and test pieces. Hot water is circulated in the small tube-side. The hot water is driven by a pump to conduct the heat exchange process by passing through the small tube side. After transfer heat in the double pipe heat exchanger hot water returns to the hot water collected tank. The water is heated up to 87°C thermostatically and maintained at that temperature in reservoir on small tube side. The mass flow rate of hot water can be adjusted by the flow control valve. For the cold water cycle, the cooling water is directly connected to the system from the over head water tank, and passes through the large tube side of the double pipe heat exchanger. Then it flows into the front head and then leaves to the atmosphere. The mass flow rate of water is also adjusted by the flow control valve located in the water loop.

To read the temperature at various point RTD thermometers are placed in double pipe heat exchanger at inlet and outlet of the double pipe heat exchanger. This temperature gradient shows us the amount of heat transfer taking place with the concentric tube in tube heat exchanger. Temperature scanner is used to measure temperature in digital form on double pipe heat exchanger at various points. The flow measurement of water in the double pipe heat exchanger setup orifice meter is designed & fitted in the setup. Pressure across the orifice is recoded through U-tube manometer. For calibration of orifice meter standard made rotameter is used in the systems.

Show the initial fabrication of experimental setup of double pipe heat exchanger in Fig. Two different diameter (small tube 1 in. & large tube 2 in.) pipe/tube used in double pipe heat exchangers. Both tube are fabricated by Gas welding process. Show the arrangement in Fig. S.S pipe is use in small diameter pipe (hot water side) & G.I pipe is use in larger diameter (cold water side). Fig Shows Final fabrication or Experimental setup of double pipe (tube in tube) heat exchangers.

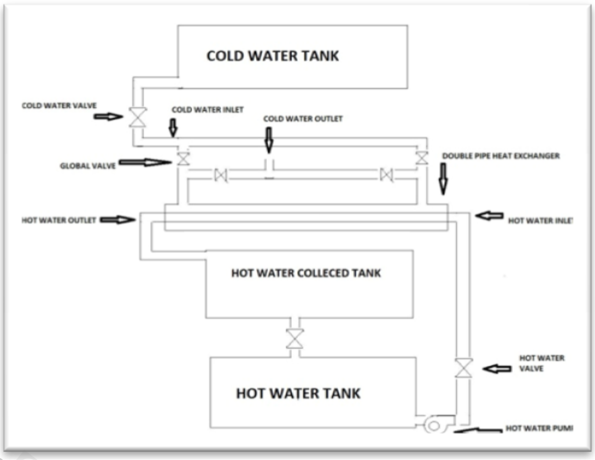

Fig: wire diagram of double pipe heat exchanger.
This is a wire diagram of double pipe heatexchanger.

III. EXPERIMENTAL PROCEDURE,RESULTS & ERRORS

A. *Experimental Procedure*

The overall characteristics of the exchanger unit are investigated experimentally. The steps taken are as follows:

1. Measuring the temperatures of water at the inlet and outlet sections and also at an intermediate point half way between the inle and outlet for each stream, using copperconstantan thermocouple wires.
2. Measuring the water flow rate for each stream using calibrated rotameters. Rotameters have been tested manually by measuring the amount of fluid collected in a vessel in a certainamount of time at room temperature.Rotameters have stainless steel floats.
3. Calculating the overall rate of heat transfer in the exchanger assuming heat losses from the outer tube stream to be negligible. Therefore the overall rate of heat transfer is equal to either the heat released from the hot stream or the heat absorbed by the cold stream, namely:

$$Q = (WC\Delta T)c = (WC\Delta T)h$$

4. Calculating the log-mean temperature difference between the two streams. The total heat transfer rate from the hot fluid to the cold fluid in the exchanger is expressed as:

$$Q = UA(LMTD)$$

5. Calculating the overall heat transfer coefficient at different operating conditions assuming to be constant throughout the exchanger, using Equation .
6. Calculating the film heat transfer coefficient for the inner tube side flow, using the Dittus- Boelter correlation:

Nu = 0.023Re0.8 Pr^n

The value of n is 0.3 if the inner tube side fluid is being cooled and 0.4 if the inner tube side fluid is being heated. The Dittus-Boelter correlation is valid for fully developed turbulent flow (Re>10000) in smooth tubes for fluids with Prandtl numbers ranging from about 0.6 to 100 and with moderate temperature differences between the wall and the fluid conditions. The other restriction for Equation 8 is that it is used when constant heat flux boundary condition is applied.

B. Experimental Results

The experimental procedure for each run was to set a pre-defined temperature and flow rate for the hot water stream, set the cold water flow rate and then wait for the steady state conditions to be reached. Following steps 1 to 7 for each run provides a value for the heat transfer coefficient of the outer tube flow. Repeating the experiment for different operating conditions, results in a set of tabulated data. A range of 8 operating conditions measured as described in steps 1 and 2. The heat transfer characteristics calculated as described in steps 3 to 5. Calculating the film heat transfer coefficient for the tube side flows as mentioned in step 6, requires one to know viscosity, Reynolds number, Prandtl number, Nusselt number, and conductivity of water. The inner tube side heat transfer coefficients based on Equation and the outer tube side heat transfer coefficients based on Equation.

C. Experimental Errors

The accuracy for measured heat transfer coefficients is affected by the effectiveness of thermal insulation, the amount of heat lost to the ambient, the accuracy of the thermocouple system, and the accuracy of rotameters. Simple one-dimensional calculations clearly indicate that 99% of the heat transferred from the inner tube flow goes to the outer tube flow and only 1% is lost into the insulation material. It is estimated that the thermocouple system including the thermocouple wire variations, digital voltmeter characteristics and all associated measurements, communications and transformation procedure is able to give readings of • ± 0.1% about the true temperature. The rotameters used to measure the inner tubeand outer tube flow rates were quoted by the manufacturer as being able to measure to • ± 2%
of the readings. Thus for a typical run, where the stream temperature difference is about 18oC, an error of about ±1.5%.is expected for the evaluated heat transfer coefficients. The errors are much greater when the stream temperature differences are lower. For example, for the stream temperature difference of 3oC, the estimated error in the evaluated heat transfer coefficients is ±7%.

The mean heat transfer coefficient, the variance, the standard deviation and the coefficient of variation for both counter-flow and parallel-flow arrangements are listed. It can be seen that for counter-flow arrangement, 75% of the data are within one standard deviation from the mean and 100% of the data are within two standard deviations from the mean. For parallel-flow arrangement, 50% of the data are within one standard deviation from the mean and 100% of the data are within two standard deviations from the mean.

IV. Conclusion

It has been possible to formulate the optimal design of heat exchanger as a geometric programming problem having single degree of difficulty. Since the optimal design minimizes the weighted sum of the heat transfer cost, the pumping cost and the cost of the utility used, by changing the weights one can achieve higher heat transfer by appropriate changes.

A strategy is proposed to control the outlet internal fluid temperature of a parallel-flow heat exchanger. The main idea consists in inserting the manipulated inlet temperature of the external fluid in one of the two partial differential equations of the model of the heat exchanger by means of a Dirac function. Furthermore, the spatial weighted average temperature of the internal fluid has been introduced, as ameasured output, in order to ensure the existence of the characteristic index for system controllabity. Based on nonlinear geometric control, a state-feedback law that ensures a desired performance of the measured output is derived. The heat exchanger being a minimum phase system, the closedloop system is demonstrated to be exponentially stable. To achieve a desired performance of the outlet internal fluid temperature, a control strategy is proposed where a PI external controller is introduced
to provide the set point of the introduced measured output by taking as input the error between the outlet internal fluid temperature and its desired set point. The effectiveness of the proposed control design is emphasized through numerical experiments. The simulation results show that the control strategy ensures a satisfactory tracking and disturbance rejection. The practical implementation of the proposed control strategy needs the entire state of the heat exchanger which is actually of infinite dimension. To provide the whole state estimation from the available measurements of fluid temperatures at the outlets, the Kalman filter is designed based on the finite-approximation model of the heat exchanger obtained by spatial finite differences. It is also demonstrated that the closed-loop system remains exponentially stable in the presence of an observer. The simulation results show
the ability of the Kalman filter to provide a satisfactory estimation of the entire state from the available measurements, which allows the controller to track the actual temperature of the internal fluid at the outlet with acceptable performance.

A solution method of the shell and tube heat exchanger design optimisation problem was proposed based on the utilization of a genetic algorithm. Referring to the literature test cases, reduction of capital investment up to 7.4% and savings in operating costs up to 93% were obtained, with an overall decrease of total cost up to 52%, showing the improvement potential of the proposed
method. Furthermore, the genetic algorithm allows for rapid solution of the design problem and enables to examine a

number of alternative solutions of good quality, giving the designer more degrees of freedom in the final choice with respect to traditional methods. As a future work, it is intended to deal in detail with issues of mechanical design and the equipment manufacturing process to significantly improve the estimation capability of the capital investment and obtain a more realistic heat exchanger optimisation procedure.

This study demonstrates successful application of harmony search algorithm for the optimal design of shell and tube heat exchangers. The HSA is simple in concept, few in parameters and easy for implementation. Moreover, it does not require any derivative information. These features increase the applicability of the HSA, particularly in thermal systems design, where the problems are usually non-convex and have a large amount of discrete variables or discontinuity in the objective function. One of the features presented in this study is the use of global sensitivity analysis. The aim of the sensitivity analysis is to identify geometrical parameters that have the largest impact on total cost of STHXs. The GSA could successfully found the most important parameters. The algorithm ability was demonstrated using an illustrative example and the performance was compared with genetic algorithm. Results reveal that the proposed algorithm can converge to optimum solution with higher accuracy in comparison with genetic algorithm.

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 surface 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. The optimization algorithm applied to the formulated problem involves a tube count table search based on a controlled path along the decision variable space. The definition of variable bounds, feasibility tests and fathoming procedures allow a sensible reduction of computational costs. The algorithm can be associated to any desired rating code for the necessary thermal and hydraulic evaluations.

References

[1] M. Alamir, Nonlinear moving horizon observers: theory & real-time implementation, in: G. Besanc, on (Ed.), Nonlinear Observers & Applications, Lecture Notes in Control and Information Sciences, Springer-Verlag, 2007.
[2] M. Alamir, J.-P. Corriou, Nonlinear receding-horizon state estimation for dispersive adsorption columns with nonlinear isotherm, Journal of Process Control 13 (2003) 517–523.
[3] C. Antoniades, P.D. Christofides, Integrating nonlinear output feedback control and optimal actuator/sensor placement for transport-reaction processes, Chemical Engineering Science 56 (15) (2001) 4517–4535.
[4] W.M. Rosenhow, P.J. Hartnett, Handbook of Heat Transfer, McGraw-Hill, 1973.
[5] R.K. Shah, K.J. Bell, The CRC Handbook of Thermal Engineering, CRC Press, 2000.
[6] G.F. Hewitt (Ed.), Heat Exchanger Design Handbook, Begell House, New York, 1998.
[7] F.O. Jegede, G.T. Polley, Optimum heat exchanger design, Transactions of the Institution of Chemical Engineers 70 (Part A) (1992) 133– 141.
[8] M. Reppich, S. Zagermann, A new design method for segmentally baffled heat exchangers, Computers and Chemical Engineering 19 (Suppl.) (1995) S137–S142.
[9] T.K. Poddar, G.T. Polley, Heat exchanger design through parameter plotting, Transactions of the Institution of Chemical Engineers 74 (Part A) (1996) 849–852.
[10] R. Selbas_, O. Kızılkan, M. Reppich, A new design approach for shell-and-tube heat exchangers using genetic algorithms from economic point of view, Chem. Eng. Process. 45 (2006) 268–275.
[11] P.D. Chauduri, U.M. Diwekar, J.S. Logsdon, An automated approach for the optimal design of heat exchangers, Ind. Eng. Chem. Res. 36 (9) (1997) 3685– 3693.
[12] Y. Ozcelik, Exergetic optimization of shell and tube heat exchangers using a genetic based algorithm, Appl. Therm. Eng. 27 (2007) 1849–1856.
[13] Abdelmessih, A. N., and Bell, K. J., .Effect of Mixed Convection and U-Bends on the Design of Double Pipe Heat Exchangers., ***Heat Transfer Engineering***, Vol. 20, No. 3, (1999), 25-36.
[14] Abdelmessih, A. N., and Bell, K. J., .Laminar Flow Heat 406 . Vol. 15, No. 4, December 2002 IJE Transactions B: Applications Transfer Downstream from U-Bends., ***Proc. Second U. K. Natl. Conf. Heat Transfer***, Vol. II, (1988), 1087-1100.
[15] Abdelmessih, A. N., .Laminar Flow Heat Transfer Downstream from U-Bends., Ph. D. Thesis, Oklahoma State University, Stillwater, OK, (1987).
[16] R.J. Duffin, E.L. Peterson, C. Zener, Geometric Programming, John Wiley, New York, NY, 1967.
[17] W.H. Ray, J. Szekely, Process Optimization with Application in Metallurgy and Chemical Engineering, John Wiley & Sons Inc., New York, 1973.
[18] E.N. Sieder, G.E. Tate, Heat transfer and pressure drop of liquids in tubes, Ind. Eng. Chem. 28 (12) (1936) 1429–1435.