Experimental Studies and Controller Design of Shell and Tube Heat Exchanger Using With and Without Insert

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ABSTRACT

An experimental study of heat transfer characteristics with and without insert was found using water –water system on 1-2 pass shell and tube heat exchanger. Experimental results such as exchanger effectiveness, overall heat transfer coefficient were calculated using with and without insert. There is improvement in overall heat coefficient, efficiency in using twisted tape. In all the process industries the process variables like flow, pressure, level and temperature are the main parameters that need to be controlled in both set point and load changes. The transfer of heat is one of the main important operation in the heat exchanger .The transfer of heat may be fluid to fluid, gas to gas i.e. in the same phase or the phase change can occur on either side of the heat exchanger. . The control of heat exchanger is complex due to its nonlinear dynamics. For this nonlinear process of a heat exchanger the model is identified to be First Order plus Dead Time (FOPDT). The conventional controller is designed in both with and without insert and compared with IMC based-PI controller based on settling time ,rise time and it found to be IMC suitable for heat exchanger than the conventional PI tuning.

Key words: Heat Exchanger, Heat transfer Co-efficient, Insert, PI controller, IMC

I. INTRODUCTION

A heat exchanger is a heat-transfer device that is used for transfer of internal thermal energy between two or more fluids available at different temperatures. In most heat exchangers, the fluids are separated by a heat-transfer surface, and ideally they do not mix. Heat exchangers are used in the process, power, petroleum, transportation, air conditioning, refrigeration, cryogenic, heat recovery, alternate fuels, and other industries. Common examples of heat exchangers familiar to us in day-to-day use are automobile radiators, condensers, evaporators, air pre heaters, and oil coolers. Heat exchangers could be classified in many different ways. In process industries, shell and tube exchangers are used in great numbers, far more than any other type of exchanger. More than 90% of heat exchangers used in industry are of the shell and tube type. The shell and tube heat exchangers are the "work horses" of industrial process heat transfer**.** They are the first choice because of well established procedures for design and manufacture from a wide variety of materials, many years of satisfactory service, and availability of codes and standards for design and fabrication. They are produced in the widest variety of sizes and styles. There is virtually no limit on the operating temperature and pressure. Verlag(1) reported the thermal performance and pressure drop of the helical-coil heat exchanger with and without helical crimped fins. The heat exchanger consists of a shell and helically coiled tube unit with two different coil diameters. Each coil is fabricated by bending a 9.50 mm diameter straight copper tube into a helical-coil tube of thirteen turns. Cold and hot water are used as working fluids in shell side and tube side, respectively. The experiments are done at the cold and hot water mass flow rates ranging between 0.10 and 0.22 kg/s, and between 0.02 and.12 kg/s, respectively. The inlet temperatures of cold and hot water are between 15 and 25 °C, and between 35 and 45 °C, respectively. The cold water entering the heat exchanger at the outer channel flows across the helical tube and flows out at the inner channel. The hot water enters the heat exchanger at the inner helical-coil tube and flows along the helical tube. The effects of the inlet conditions of both working fluids flowing through the test section on the heat transfer characteristics are discussed. Vimal Kumar, Pooja Gupta, and K. D. P. Nigam (7) reported that helically coiled tubes find applications in various industrial processes like solar collectors, combustion systems, heat exchangers and distillation processes because of their simple and effective means of enhancement in heat and mass transfer. Though extensive work is available in the literature on curved tubes, no study is available considering the variation in thermo-physical properties of fluids (density, viscosity, thermal conductivity, and specific heat) with temperature. In the present work, the effect of temperature dependence of fluid properties is examined on both hydrodynamic and thermal performance of the curved tube having finite curvature and pitch, under cooling and heating conditions. The range of Reynolds number studied in the present work is varied from 100 to 400 using water and diethylene glycol as two different fluids. The secondary flow induced due to centrifugal force distorts the velocity and temperature profiles when the effect of temperature-dependent properties is taken into account. The friction factor obtained with variable property assumption under cooling is higher as compared to the constant property results. This is due to the increase in the value of viscosity near the wall of the curved tube that reduces the effect of the secondary flow. The Nusslet number also shows a marked dependence on the properties variation in the coil tube cross section. A new model is also developed in the present study based on the property-ratio technique for both friction factor and heat transfer. The study provides understanding of the fundamentals of energy transportation in curved ducts and will be very helpful in designing coiled tube heat exchangers with temperature-dependent properties. Present paper deals with performance improvement and controller design of 1-2 pass shell and tube heat exchanger using without insert.

II. EXPERIMENTAL DESCRIPTION

First the 2 liquids are filled in the storage tanks and the cut off temperature of the heater of the hot fluid is set to a particular temperature called set point (60°C).The cold and hot fluid pumps are switched on once the set point is attained. The hot fluid flow rate is set at 15 lpm(Liter per Minitute) while the cold water flow rate is set at 5 lpm.The fluid is allowed to flow until a steady state is attained and then the hot outlet, hot inlet and cold outlet temperatures are noted. The above procedure is repeated for steps of 1 lpm of cold fluid till 15lpm while hot fluid flow rate is maintained constant. The fluid is allowed to flow until a steady state is attained and then the hot outlet, hot inlet and cold outlet temperatures are noted. The above procedure is repeated for steps of 1 lpm of cold fluid till 15lpm while hot fluid flow rate is maintained constant. The heat transfer characteristics such as Nussle number, Reynolds number, and effiency, heat transfer coefficient in two cases i.e. with and without insert found and compared and tabulated.

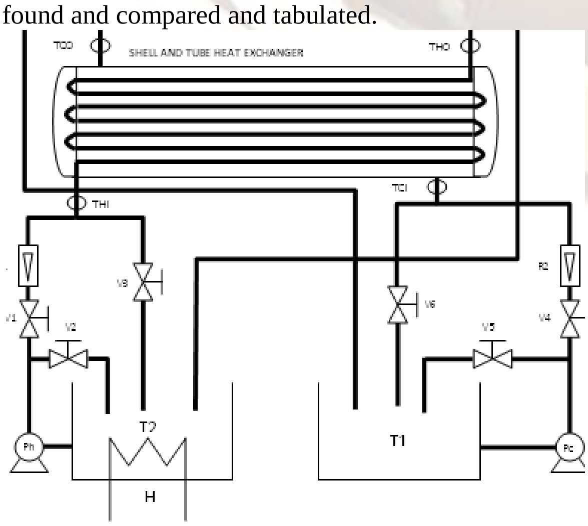

Fig.1 Experimental set up of shell and Tube Heat exchanger

Fig.2 Schematic Diagram of Tube Heat Exchanger

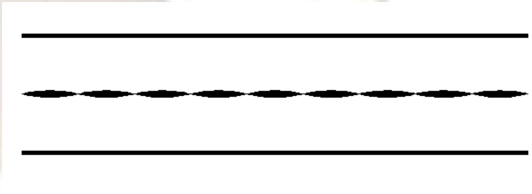

Fig 3 Specimen of inset

Specifications:
Lengthof insert=57.8cm
Width =0.9mm
Thicknes =1mm
Distance b/wtwo twists=6.42

III. SETUP SPECIFICATIONS

- Tube length = 0.55m
- Number of tubes = 24
- Inside diameter of tube = 0.157448m
- Outside diameter of tube = 0.017399m
- Tube Pitch = 0.0217486m
- Shell diameter = 0.2032m
- Clearance = 4.34975 * 10^{-3}m
- Baffle diameter = 0.2032m

IV. COMPARISON OF THE Two SYSTEMS

The experiments were carried out on 1-2 pass shell and tube heat exchanger and calculated the nusselt number, Reynolds number, prandtal number and in both with and without insert and corresponding graphs of comparison are drawn .the results are represented graphically as shown in following figures.

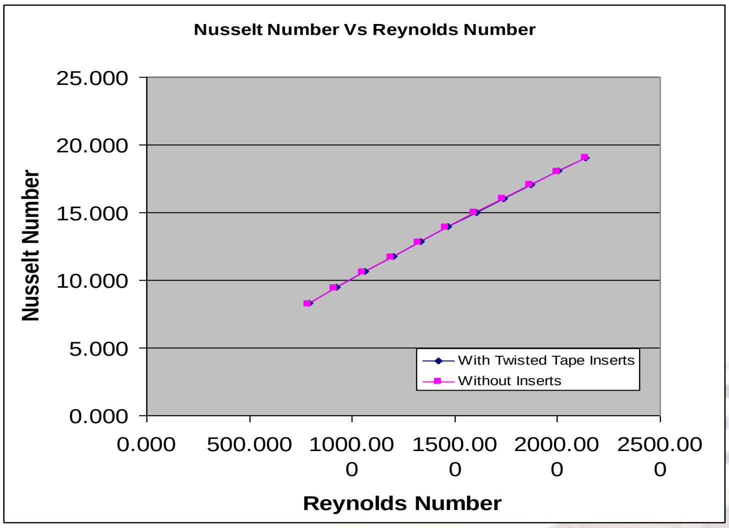

Fig3. Nusslelt Number vs. Reynolds Number.

Fig3 Compares Nussle number with Reynolds number for the water-water system with and without inserts. It is seen that as Reynolds number increases, the Nusselt number increases for tube side But it is observed that, the Nussle number for system without inserts is marginally higher than that system having inserts, for the same Reynolds number.

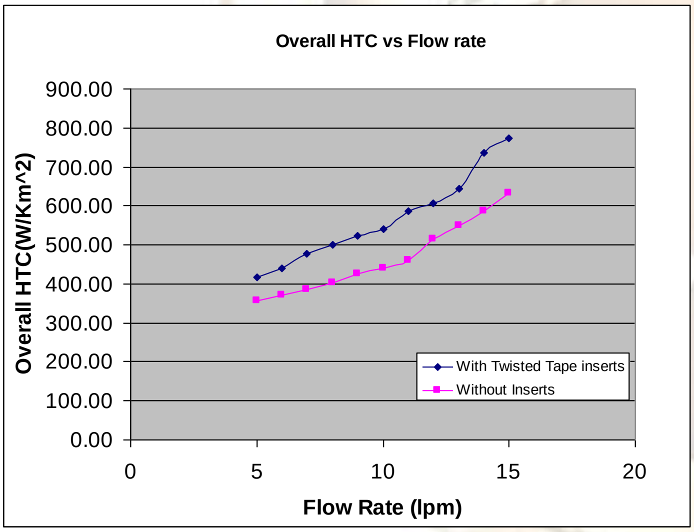

Fig4 Flow rate vs. Overall HTC

Fig 4compares flow-rate of cold fluid with overall heat transfer coefficient for the water-water system with and without insert. It is seen that as cold fluid flow rate increases, the overall heat transfer coefficient increases But it is observed that, the overall heat transfer coefficient for system without insert is lower than that system having inserts, for the same flow rate. This means that heat transfer is improved by the presence of insert in the tube side of the heat exchanger.

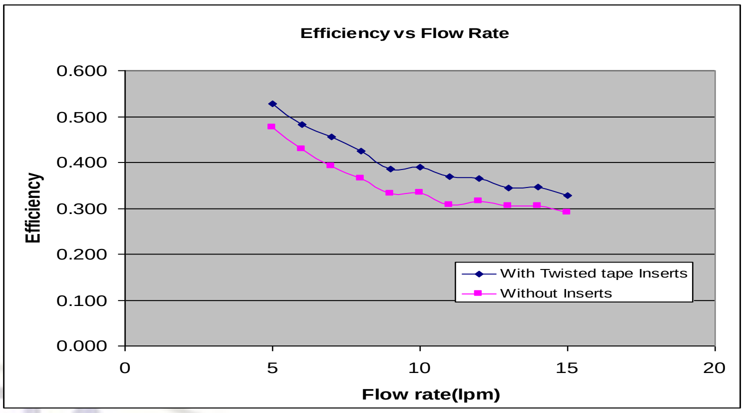

Fig.5 Flow rate vs. Efficiency.

Fig. 5 compares flow-rate of cold fluid with efficiency for the water-water system with and without insert It is seen that as cold fluid flow rate increases, the efficiency decreases. But it is observed that, the efficiency for system with inserts is higher than that system without inserts, for the same flow rate. This means that heat transfer efficiency is improved by the presence of insert in the tube side of the heat exchanger. In other words, the heat exchanger with insert is a much more efficient system.

A correlation has developed for the experimental data for shell side and tube side for with insert and without insert for nusselt number. A graph is drawn between experimental and correlated values of Nusslelt number which shows the linear relationship of correlated and experimental results, which shows in fig. 6

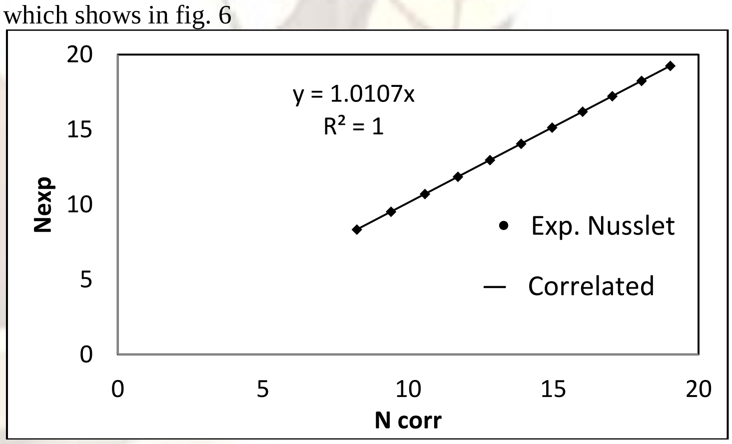

Fig. 6 graph is drawn between experimental and correlated values of Nusselt number

V. CONTROL OF HEAT – EXCHANGER

Nonlinear control is particularly important in the process industries because chemical processes are generally nonlinear. Most current nonlinear controller design methods are based on state feedback. However, they cannot be applied to many process control problems where the complete information is not available A heat exchanger is a device that is used to change the temperature distribution of two fluids, particularly in process industries, and many heat exchangers being manufactured are basically open loop systems, so the performance of the heat exchanger is determined by its fixed structural and mechanical design. In practice, if the temperature distribution, i.e. the performance of a heat exchanger, deviates beyond the accepted tolerance of the practical requirement, the solution is to replace the worn heat exchanger by a new one because of the lack of a suitable model for feedback control design, since modeling a heat exchanger for dynamic analysis and control design is not an easy task.

The control of heat exchanger is a complex process due to its nonlinear dynamics, steady state gain and time constant with process fluid Dug dale and Wen discussed about the controller optimization of tube type heat exchanger. Katayama et al. proposed a method of optimal tracking control of heat exchanger with change in load condition.

The selection of good control algorithm depends upon the performance comparison of different possible control techniques and selecting the best for the desired condition. To achieve the above for the dynamically changing process the controller parameter should perfectly match with the parameter. A control system designed for a particular process should provide fast and accurate changes for both set point changes as well for a load changes. Model based controllers are now popular because its ability to handle a process with dead time. One type of model based control is Internal Model Control (IMC) which is having both for open loop and closed loop system. IMC tuning is referred to a set of tuning procedures based on the internal model principle. The underlying idea behind internal model methodologies is to compute a controller and/or to set its values relative to a prescribed response formulated as a prescribed (internal) model. In this way, IMC designs belong to the class of model based control settings, whose origin can be traced back to the Proportional-Integral-Derivative (PID) tuning method proposed by Dahl in. In this paper, the design of IMC control structure for the shell and tube heat exchanger is implemented using with and without insert i.e. open loop response is obtained with and without insert in tube side for identification of process and . The mass flows of the two streams, inlet temperature of the two streams and outlet temperature of the two streams are the process variables associated with the function of each exchanger. Four of these variables are independent, and the values of the other two follow from these four. While theoretically any four of the variables can be independent, in most practical cases the flow rates and the inlet temperatures are determined by external circumstances. Therefore, the outlet temperatures become the output variables. One of these two outlet temperatures is the controlled variable, and the flow rate of the other stream is the manipulated variable. Hence here the hot fluid temperature is taken as controlled variable and cold fluid flow rate is taken as manipulated variable. In this work the process dynamics are modeled from a step response analysis by changing the cold fluid flow rate at different hot fluid inlet temperature. For the developed model an IMC control structure is designed and its performance measure is based on rise time, settling time and various performance indices are compared with conventional PI controller in both cases i.e. with and without insert.

VI. PROCESS IDENTIFICATION

For designing of the controllers for heat exchanger process a open loop test is carried out on the heat exchanger .it is found that that heat exchanger exhibits (FOPTD) model. The FOPDT model parameters are found from the experimental data. The objective here is to maintain the hot fluid temperature which is taken as controlled variable. The cold flow rate is given as step change variation that is considered as manipulated variable. The two transfer functions in both cases are transfer function obtained. The two transfer functions both

with and without inserts. $G_1(s)=\dfrac{3.6e^{-5s}}{45s+1}$,

$$G_2(s)=\frac{3.6e^{-10s}}{48s+1}$$

VII. DESIGNING OF PI CONTROLLER

Ziegler – Nicholas tuning technique is closed loop procedure using a proportional control only and with the feedback loop closed, a set point change I introduced and the proportional gain is varied till the system exhibits sustained oscillation. The period of sustained oscillation is measured and standard formulas are used to find the tuning parameters.

$$K_c = 0.45 * K_u$$

$$\tau_i = P_u / 1.2$$

Where

K_u = ultimate gain

K_c = proportional gain

P_u = ultimate period of oscillation

K_c = proportional gain

τ_i = integral time.

For the two transfer functions above with and with and without inserts are PI controllers designed.

VIII. Internal Model Control

Internal model control is model based controller. Fig.7 shows the IMC structure which makes use of a process model to infer the effect of immeasurable disturbance on the process output and then counteracts that effect. The controller consists of an inverse of the process model.

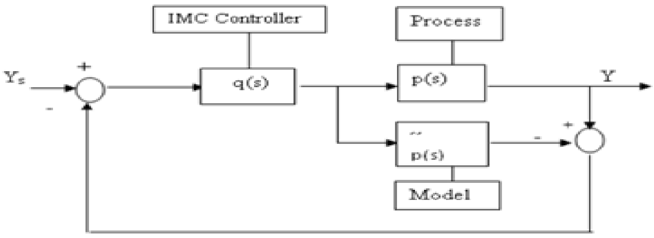

Fig.7. IMC Structure

$$p(s) = \frac{k e^{-\tau_D s}}{\tau s + 1}$$

$$q(s) = q(s)^{-} f$$

$$q(s)^{-} = \frac{\tau s + 1}{K}$$

$$f = \frac{1}{\lambda s + 1}$$

From the above equation, the only tuning parameter is λ and hence IMC controller is simple. In this paper IMC controller is designed using pi controller setting by the method proposed by skogested.

Responces of PI controller:

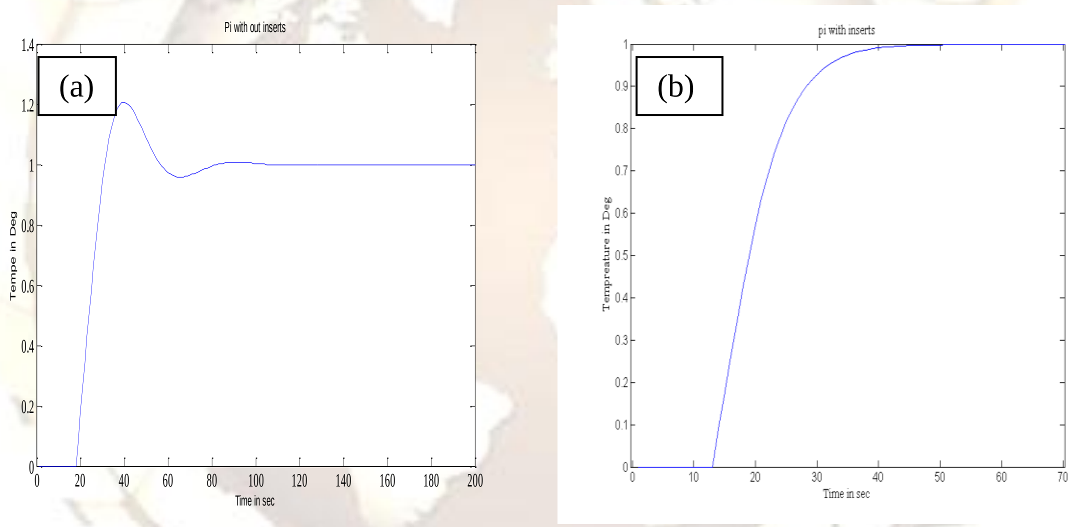

Fig.8. PI controllers (a) without insert and (b) with insert PI controllers.

Responces of IMC controllers

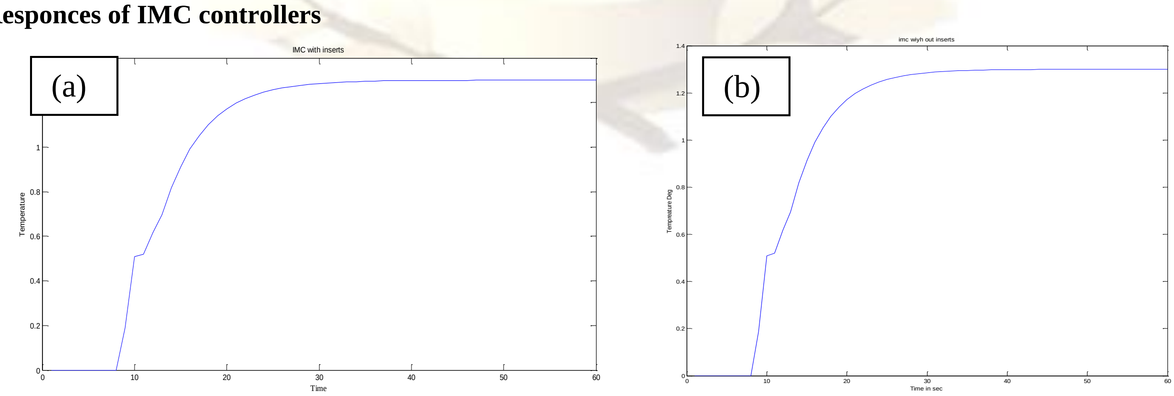

Fig 9. response of IMC (a) with inserts and (b) without insert

Comparison of PI and IMC:

PARAMETER	PI	IMC
Rise Time tr (s)	35	10
Settling Time ts (s)	100	40
ISE	54	26
IAE	39	24
ITAE	45	17

IX. CONCLUSIONS

1. The heat transfer characteristics, Reynolds number, Praandtal number, Nusslelt number, overall heat transfer coefficient and efficiency were calculated and compared using with and without insert.
2. Efficiency for system with insert is higher than that system without inserts for the same flow rate. This means that heat transfer efficiency is improved by the presence of insert the tube side of the heat exchanger graph is drawn between experimental and correlated vales of Nussle number which shows a linear relation.
3. For the non linear system the process identified to be (FOPTD) process by conducting loop test both with and without insert .PI control is designed in both cases and it was observed that pi control with inserts giving good response in terms of rise time and settling time. For the same process IMC is designed in both cases and compared with conventional controller. It is found that IMC is giving best response for non linear heat exchanger.

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