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An Intelligent Control Strategies Implemented on Heat Exchanger System: A Case Study

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Abstract: Heat exchanger system is widely used in chemical process industries, including petroleum refining and petrochemical processing; in the food industry because it can sustain wide range of temperature and pressure. The main objective of the heat exchanger system is to control the temperature of outgoing fluid to a desired set point despite of different disturbances like deviation in input fluid flow and deviation in input fluid temperature. The main purpose of a heat exchanger system is to transfer heat energy from a hot fluid material to a cooler fluid material, so temperature control of outlet fluid is of prime importance. Due to inherent disadvantages of conventional control techniques so model based control technique is employed and an internal model based PID controller is developed to control the temperature of outlet fluid of the heat exchanger system. To control the temperature of outlet fluid of the heat exchanger system a conventional PID controller can be used. The entire heat exchanger system is modelled using experimental data and PID controller is used as the controlling unit. The designed controller regulates the temperature of the outgoing fluid to a desired set point in the shortest possible time irrespective of load and process disturbances, equipment saturation, stability and nonlinearity. The developed Fuzzy logic controller (FLC) has demonstrated improvement in the overshoot and improvement in settling time as compared to the classical controller. The PID controller is then replaced by a Fuzzy logic controller for a better control action, which had demonstrated better control accuracy and faster response.

Keywords: Feedback and Feed-forward controller, Fuzzy controller, PID controller, Shell and tube heat exchanger, Matlab.

I. INTRODUCTION

In practice, all chemical processes involve the production or absorption of energy in the form of heat. Heat exchanger is commonly used in industrial chemical processes to transfer heat from a hot liquid through a solid wall to a cooler fluid [1]. A heat exchanger is a device that is mostly used to transfer thermal energy between two or more fluids and it also transfer between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact [3]. There are different types of heat exchanger used in the industry but most of the industry use shell and tube type heat exchanger system. It consists of parallel tubes enclosed in a shell. HEs are key devices used in a wide variety of thermal applications in the chemical process industries, including petroleum refining and petrochemical processing; in the food industry, for example, for pasteurization of milk and canning of processed foods; in the generation of steam for production of power and electricity; nuclear reaction systems; aircraft and space vehicles; and in the field of cryogenics for the low-temperature separation of gases. There is a variety of application of heat exchanger system. Some of the applications HEs are the workhorses of the entire field of heating, ventilating, air-conditioning, and refrigeration electronic cooling, refrigeration and air conditioning, manufacturing, and power generation. In each of these cases, the purpose of the heat exchanger is to maintain a specific temperature condition, which is achieved by controlling the exit temperature of one of the fluids in response to variations of the operating conditions [5]. The concept of intelligent control lies with the fact that human intelligence is imbibed in to the controller architecture so that human behaviour can be emulated in the control decision. Human skilled knowledge is based upon heuristic information expanded in relation to the operation of the plant or process, and its intrinsic vagueness ("fuzziness") offers a powerful tool for the modelling of complex systems.

The fuzzy logic controller provides an algorithm, which converts the expert knowledge into an automatic control strategy. Fuzzy logic is capable of handling approximate information in a systematic way and therefore it is suited for controlling non linear systems and is used for modelling complex systems where an inexact model exists or systems where ambiguity or vagueness is common. The fuzzy control systems are rule-based systems in which a set of fuzzy rules represent a control decision mechanism to adjust the effects of certain system stimuli. With an effective rule base, the fuzzy control systems can replace a skilled human operator. The rule base of fuzzy logic reflects the human expert knowledge, expressed as linguistic variables, while the membership functions represent expert explanation of those variables. This research paper considers a shell and tube heat exchanger and builds a SISO model of the system with the help of experimental data available. This system also takes in to account different disturbance elements and transportation delay. First of all, a classical PID controller is implemented in a feedback control loop so as to obtain the control objectives. To further optimize the control performance, feed-forward controller is used in conjunction with the PID controller. In

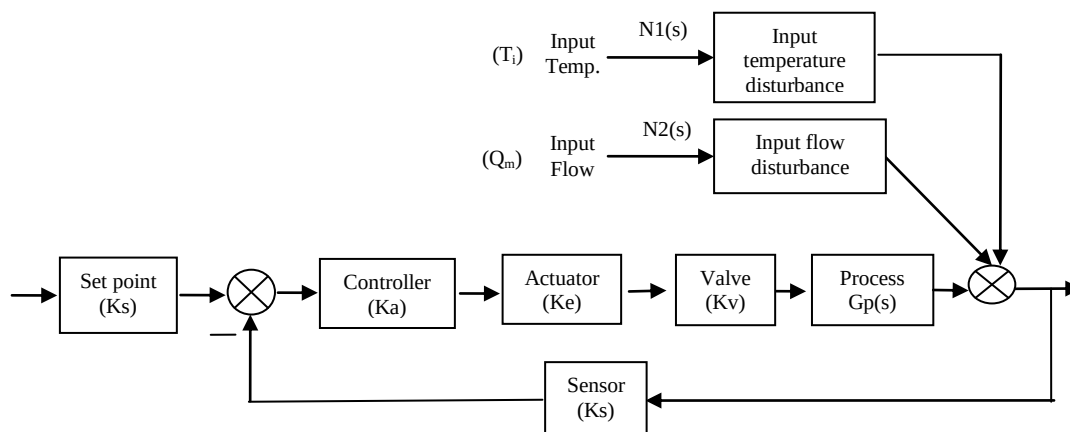
classical control methods different performance indices were calculated for feedback and feedback plus feed-forward control loops to achieve the desired robustness and system stability. Auto-tuning of PID controllers is also implemented and simulated in this paper. To achieve the desired control objective and implement human intelligence in controller architecture a fuzzy logic controller is designed and implemented. All the system level simulation and controller design in this paper are carried out in Simulink. A comparative study of all the control performance is evaluated in this paper.

II. CASE STUDY

A typical interacting chemical process for heating consists of a chemical reactor and a shell and tube heat exchanger system. The process fluid which is the output of the chemical reactor is stored in the storage tank. The process fluid considered in this case is $\text{Al}_2(\text{SO}_4)_3 + \text{H}_2\text{SO}_4 + \text{Alum}$. The storage tank supplies the fluid to the shell and tube heat exchanger system. The heat exchanger heats up the fluid to a desired set point using super heated steam at 180°C supplied from the boiler. The storage tank supplies the process fluid to the heat exchanger system using a pump and a non returning valve. The super heated steam comes from the boiler and flows through the tubes, whereas, the process fluid flows through the shells of the shell and tube heat exchanger system. After the steam heats up the process fluid, the condensed steam at 100°C goes out of the heat exchanger system. There is also a path for non-condensed steam to go out of the shell and tube heat exchanger in order to avoid blocking of the heat exchanger. Different assumptions have been considered. The first assumption is that the inflow and the outflow rate of fluid are same, so that the fluid level is maintained constant in the heat exchanger. The second assumption is the heat storage capacity of the insulating wall is negligible. In this feedback process control loop, the controller is reverse acting, the valve used is of air to open (fail-close) type. A thermocouple is used as the sensing element which is implemented in the feedback path of the control architecture. The temperature of the outgoing fluid is measured by the thermocouple and the output of the thermocouple (voltage) is sent to the transmitter which eventually converts the temperature output to a standardized signal in the range of 4-20 mA. This output of the transmitter unit is given to the controller unit. In this heat exchanger system a PID controller has been taken as the controlling unit.

The PID controller implements the control algorithm, compares the output with the set point and then gives necessary command to the final control element via the actuator unit. The actuator unit is a current to pressure converter and the final control unit is an air to open (fail close) valve. The actuator unit takes the controller output in the range of 4-20 mA and converts it in to a standardized pressure unit, i.e in the range of 3-15 psig. The valve actuates according to the controller decisions. There can be two types of disturbances in this process, one is the flow variation of input fluid and the second is the temperature variation of input fluid. But in practice the flow variation of input fluid is a more prominent disturbance than the temperature variation in input fluid. So, in feed forward control loop the input fluid flow is measured and the disturbance in the flow is controlled using a feed forward controller. The output of the feedback and the feed forward controller is added and the resultant output is given to the control valve. With the addition of feed forward controller the control performance is optimized. We have developed a block diagram of these control loops and modelled the heat exchanger system, actuator, valve, sensor using the experimental data available. The transfer function model of the individual systems are generated which in turn combined to acquire the transfer function of the whole system.

Figure 1 Mathematical modeling of heat exchanger system



Experimental data has been used to find out the transfer function of each block and different controllers are used for controlling this system these are describing in below.

A. Experimental Data

Experimental data used for mathematical modelling of heat exchanger system

Exchanger response to the steam flow gain	= 50° C /(kg/sec)
Time constant	= 30 sec
Exchanger response to variation of process fluid flow gain	= 3° C/Kg/sec
Exchanger response to variation of process temperature gain	= 1° C /Kg/sec
Control valve has capacity	= 1.6 kg/sec of steam
Time constant of the control valve	= 3 sec
The range of sensor	= 50° C to 150° C
Time constant of sensor	= 10 sec

Transfer function of disturbance variables (flow and temperature disturbances respectively)

Transfer function of the Process	:	$\frac{50}{30s+1}$
Gain of the Valve	:	0.133
Transfer function of the Valve	:	$\frac{0.009975}{30s+1}$
Gain of I to P Converter	:	0.75
Disturbance Variables	:	$\frac{1}{30s+1}, \frac{3}{30s+1}$
Critical Gain	:	KC
Transfer function of the Sensor	:	$\frac{0.16}{10s+1}$

B. PID Controller

The Characteristic equation ($1 + G(s) * H(s) = 0$) in this case is obtained as below.

$$900s^3 + 420s^2 + 43s + 0.798Kc + 1 = 0$$

Applying Routh stability criterion in eq. (1) gives KC as 23.8.

$$\text{Auxiliary equation } 420s^2 + 0.798Kc + 1 = 0$$

$$\text{From eq. (2) } \omega = 0.218 \text{ and } T = 28.79$$

The equation of PID controller is

$$c(t) = c_0 + K_c \left(e(t) + \frac{1}{t_i} \int_0^t e(t) dt + t_d \frac{de(t)}{dt} \right)$$

According to Zeigler-Nichols tuning criteria; $K_p=0.6K_c$, $T_i=0.5T$ and $T_d=0.125T$.

For the PID controller in the heat exchanger, the values of tuning parameters are obtained as

$$K_p=14.28, T_i=14.395, T_d=3.59$$

$$P= K_c = 23.8 \text{ I}= K_c/T_i = 0.99 \text{ D}= K_c*T_d= 85.446$$

For the PID controller in the heat exchanger, the values of tuning parameters obtained are $K_p=14.28$, $\tau_i=14.395$, $\tau_d=3.59$ and $P= 23.8$, $I= 1.65$, $D=85.442$

C. Feedback and Feed-forward Controller

In feed forward controller we have tried to regulate the flow disturbance of the input fluid. $G_p(s)$ is the transfer function of the process where as $G_d(s)$ is the transfer function of flow disturbance.

$$G_c = \frac{5}{90s^2 + 33s + 1}$$

$$G_d = \frac{1}{30s + 1}$$

The transfer function of the feed-forward controller is

$$G_{cf} = \frac{-G_d(s)}{G_p(s)}$$

$$G_c = \frac{-18s^2 - 6.6s - 0.2}{(30s + 1)(\lambda s + 1)}$$

Here, ' λ ' is the filter parameter, whose range is from 0 to 1. It has been used to make the transfer function semi proper.

D. Fuzzy Logic Controller

Multi-valued logic is fuzzy logic. Fuzzy logic is derived from fuzzy set theory. It deals with reasoning, approximations rather than precise values.

Table 1 IF-THEN RULE BASE FOR FUZZY CONTROLLER

	$e(t)$							
		NB	NS	NM	Z	PS	PM	PB
$\Delta e(t)$	NB	NB	NB	NB	NB	NM	NS	Z
	NM	NB	NB	NB	NM	NS	PS	PS
	NS	NB	NB	NM	NS	NS	PS	PS
	Z	NB	NS	NS	Z	Z	PM	PM
	PS	NM	NS	Z	PS	PS	PB	PB
	PM	NS	Z	PS	PM	PM	PB	PB
	PB	Z	PS	PM	PB	PB	PB	PB

Where NB indicates Negative Big, NM indicates Negative Medium, NB indicates Negative Big, Z indicates Zero, PS indicates Positive Small, PM indicates Positive Medium, PB indicates Positive Big. Designing a good fuzzy rule base is the key to obtain satisfactory control performance for a particular operation. Classical analysis and control strategy are incorporated in the rule base. The rule base used in simulation and each rule has the form IF $e(t)$ is NB AND $\Delta e(t)$ is NB THEN $u(t)$ is NB. The control literature has worked towards reducing the size of the rule base and optimizing the rule base using different optimization techniques like GA, PSO for intelligent controller. At last defuzzified output is obtained from fuzzy inputs. In this research work centroid method of de-fuzzification is used.

III. SIMULATION AND TESTING

The simulations for the different control mechanism discussed are carried out in Simulink and the simulation results have been obtained.

Figure 2 Simulink model of process with feedback PID controller with disturbance.

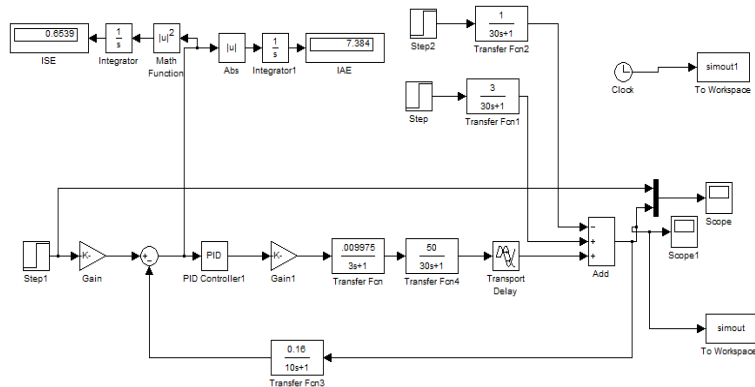


Figure 3 Step response of feedback PID controller with disturbance.

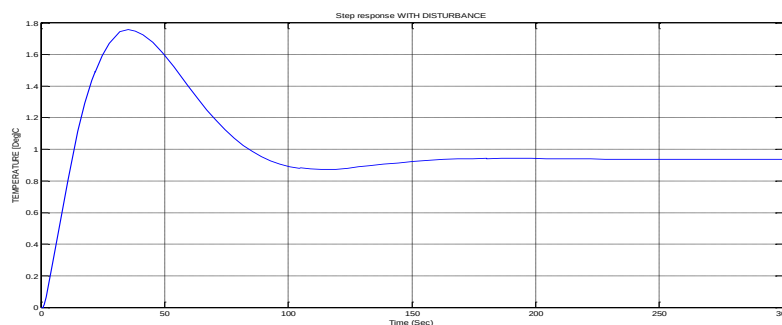


Figure 4 Simulink model of process with feedback and Feedforward PID controller with disturbance

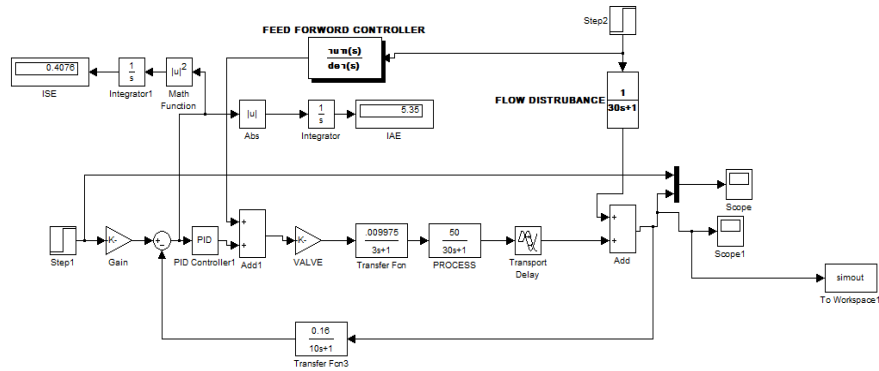


Figure 5 Step response of process with feedback and feed-forward controller.

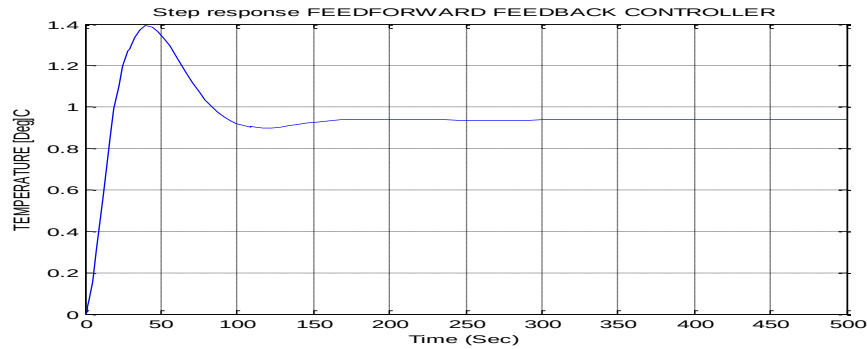


Figure 6 Simulink model of fuzzy controller

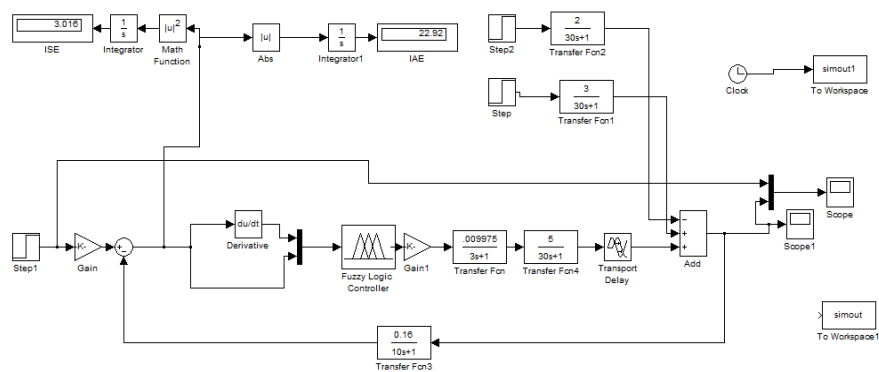
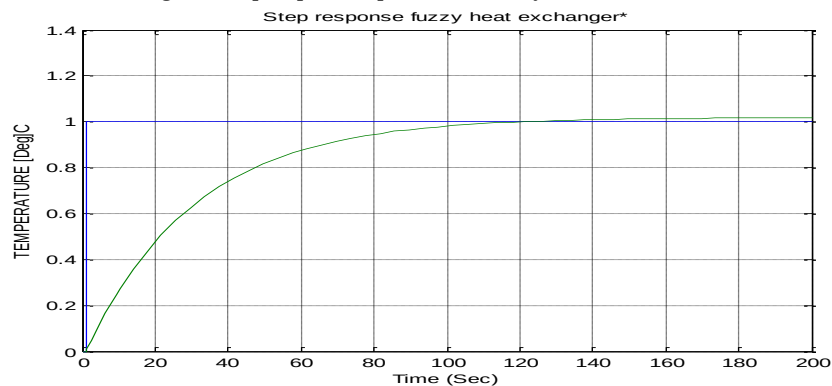


Figure 7 Step response of process with fuzzy controlle



IV. RESULTS AND OBSERVATION

The simulation results clearly shows that the fuzzy controller gives a much better control of temperature rather than classical PID controller and PID controller in conjunction with feed forward controller. To evaluate the performance of the different controllers we have considered two parameters of the step response of the system. The first parameter is the maximum overshoot and the 2nd parameter is the peak time and 3rd is the settling time. In all the three controllers these two parameters are evaluated and a comparative study of their performance has been shown in the table below.

TABLE II COMPARISON OF DIFFERENT PARAMETERS IN CONTROLLERS

S. No.	Parameters	Feedback PID With disturbances	Feedback plus feed forward controller	Fuzzy controller with disturbances
1.	% Overshoot	75.85	39.47	1.7360
2.	Peak time	35.18	40.46	120
3.	Settling time	200	145	130

From the above observations it is clear that in conventional PID controller in feedback loop the heat exchanger produces an overshoot is 75.85%. To compensate this kind of high overshoot we implemented a feed-forward controller in conjunction with the conventional PID. By implementing this method the system overshoot was reduced to 39.47%. Though the overshoot has somewhat decreased we can further reduce the overshoot by implementing fuzzy logic controller. By implementing fuzzy controller in the feedback loop the overshoot reduces. In feedback controller the settling time was 200 sec where as in feedback plus feed forward controller the settling time decreases to 145 sec, and in fuzzy controller the settling time decreases to 130 sec.

V. CONCLUSION AND FUTUR SCOPE

In this paper, a comparative study of performance of different conventional and fuzzy based controllers is studied and applied. The purpose of the proposed controller is to regulate the temperature of the outgoing fluid of a shell and tube heat exchanger system to a desired temperature in the shortest possible time and minimum or no overshoot irrespective of step change in load and process disturbances, equipment saturation, stability and non-linearity of different control equipments. After time response based analysis carried out on different controllers it is observed that fuzzy controller provides a satisfactory performance in both steady state and transient state and overcomes the drawbacks of conventional PID controller, feedback plus feed-forward controller. The fuzzy logic controller gives the best performance, but the control engineer faces different kind of challenges to design such a controller the key design challenge is to generate an optimized fuzzy rule base with minimum number of rules.

In future scope of this paper an existing rule base of N number of rules can be optimized using different optimization techniques like genetic algorithm, PSO, ant colony optimization. This dissertation proposes a genetic algorithm and Fuzzy-genetic based optimization of existing fuzzy rule base of N number of rules. The second challenge is to reduce the size of the number of rule base and optimal number of membership function has to be chosen and the optimal width of membership function has to be calculated. To achieve this objective system identification and estimation approach is used, properly control and The IMC based Fuzzy controller technique can be used to identify and estimate the new Neural -fuzzy membership function and optimize the existing one.

VI. References

- [1] K.Rajalakshmi, Ms.V.Mangaiyarkarasi, "Control of Heat Exchanger Using Internal Model Controller", IOSR Journal of Engineering (IOSRJEN) e-ISSN: 2250-3021, p-ISSN: 2278-8719 Vol. 3, Issue 7 (July. 2013), ||V1 || PP 09-15
- [2] E.Saranya and S.Arulselvi, "Design and Simulation of Conventional and Intelligent Controllers for Temperature Control Of Shell and Tube Heat Exchanger System", International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-2, Issue-3, July 2013.
- [3] Yuvraj Bhushan Khare Yaduvir Singh, "PID Control of Heat Exchanger System" International Journal of Computer Applications (0975 – 8887) Volume 8– No.6, October 2010.
- [4] Maidi, A., Diaf, M., and Corriou, J. P., "Optimal Linear PI Fuzzy Controller Design of a Heat Exchanger", Chemical Engineering and Processing, Vol.47, PP.938-945, 2008.
- [5] Berto, M. I., and JR, V. S., "Configuration of PID / Feed Back and PID / Feed Back / Feed Forward Controllers in Temperature Control of a HTST Heat Exchanger", 2thMercosur Congress on Chemical Engineering and 4thMercosur Congress on Process Systems Engineering, Sao Paulo, Brazil, 2004.
- [6] Diaz, G., Sen, M., Yang, K. T., and McClain, R. L., "Dynamic Prediction and Control of Heat Exchangers Using Artificial Neural Networks", International Journal of Heat and Mass Transfer, Vol.44, PP.1671-1679, 2001.
- [7] AL-Zobai, K. M. M., "Computer Control on Plate Heat Exchanger", PhD Thesis, Chemical Engineering, University of Baghdad, 2004. R. Nicole, "Title of paper with only first word capitalized," J. Name Stand. Abbrev., in press.
- [8] Xie, G. N., Wang, Q. W., Zeng, M., and Lou, L. Q., "Heat Transfer Analysis for Shell-and-Tube Heat Exchangers with Experimental Data by Artificial Neural Networks Approach", Applied Thermal Engineering, Vol.27, PP.1096-1104, 2007.
- [9] S Haugwitz, P Hagander and T Noren, "Modeling and control of novel heat exchanger reactor, the open plate reactor," Control Engineering Practice, 15, 2007, pp. 779-792.
- [10] Orlando Duran, Nibaldo Rodriguez and Luiz Airton Consalter, "Neural networks for cost estimation of shell and tube heat exchangers," in Proceedings of the International Multi Conference of Engineers and Computer Scientists, vol. II, 2008, pp. 1584-1589
- [11] S A Mandavgane and S L Pandharipande, "Application of optimum ANN architecture for heat exchanger modeling," Indian Journal of Chemical Technology, vol. 13, Nov 2006, pp. 634-639.