Fuzzy Controller for Propylene Oxide VRU Ex-Exchanger Cooler of Pars Petrochemical

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ABSTRACT:
Exchanger system is widely used in oil, gas and petrochemical plants because it can sustain wide range of temperature and pressure. The main purpose of a exchanger system is to transfer from a hot fluid to a cooler fluid or conversely, so temperature control of outlet fluid is of prime importance. To control the temperature of outlet fluid of the exchanger system a conventional PID controller can be used. Due to inherent disadvantages of conventional control techniques, Fuzzy logic controller is employed to control the temperature of outlet fluid of the exchanger system. 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 and nonlinearity.

KEYWORDS: PID Controller, FLC, Ex-Exchanger, Vapor Recovery Unit (VRU), Propylene Oxide

1. INTRODUCTION

1.1. Pars Petrochemical Company

Pars Petrochemical Company was established on March 23, 1998 and was registered in the name of Assaluyeh Petrochemical Company, and its effective activities began with the formation of a new board of directors on 07/10/1978. The name of this company was changed to Pars Petrochemical with the approval in the extraordinary meeting dated 02/17/79.

The company is located in the Pars Energy Special Economic Zone, which is located in the north of the Persian Gulf in the port of Assaluyeh. This area is 270 km southeast of Bushehr port and 570 km west of Bandar Abbas. Related executive activities began in 1999. The total foreign exchange investment was $ 720 million and the rial investment was 2,835 billion rials. Fifty percent of the shares of Ariasasol Polymer Company also belong to Pars Petrochemical Company. Pars Petrochemical Company consists of three production units and one external unit:

- Ethane Extraction Unit C2 + Recovery & Fractionation:

Finally, after the efforts of the employees of Pars Petrochemical Company, the ethane production unit of this company was inaugurated on July 28, 2006 and the memory of the martyrs of the Islamic Republic Party was inaugurated and put into operation by the then Speaker of the Islamic Consultative Assembly. The unit feed is 60 thousand tons of gas per day, which is supplied from the first and second refineries of South Pars Gas Complex. After extracting ethane and heavier hydrocarbons, 48 thousand tons per day of light gas called (Sales Gas) is returned to the refineries to Supply of feed from other complexes or injection into the national gas network to be used. The products of this unit are:

Ethane: The amount of production is 1 million and 600 thousand tons per year, of which 1 million and 267 thousand tons provides Ariasasol petrochemical feed and the remaining 333 thousand tons of Jam petrochemical feed.

Propane: The amount of production is 980 thousand tons per year, which is exported through wharves, companies, terminals and petrochemical tanks.

Butane: The amount of production is 570 thousand tons per year, which is exported through the company's docks, terminals and petrochemical tanks.

Gasoline: The production rate is 86 thousand tons per year, which is used as part of the feed of Jam and Nouri (Borzoyeh) petrochemicals and other domestic customers.

- Ethyl Benzene Unit:

It is another unit of Pars Petrochemical Company. Unit feed, 175 thousand tons of ethylene from the ninth olefin unit (Ariasol Petrochemical), 440 thousand tons of benzene from the fourth aromatic (Borzoyeh

Petrochemical) and if necessary up to 40 thousand tons of benzene from the third aromatic (Bu Ali Sina Petrochemical) The unit becomes ethyl benzene. The final product is 645,000 tons of ethyl benzene per year.

Styrene Monomer Unit:

Feed: 645 thousand tons of ethyl benzene and its final products 600 thousand tons of styrene monomer, 14 thousand tons of benzene and toluene mixture per year

Propylene Oxide Unit:

Propylene oxide is an organic compound with the molecular formula CH3CHCH2O. This colourless volatile liquid with an odour resembling to ether, is produced on a large scale industrially. Its major application is its use for the production of polyether polyols for use in making polyurethane plastics.

Propylene oxide (PO) can be produced by the conventional chlorohydrin or hydroperoxide process. ... In the hydroperoxide process, ethylbenzene or isobutane are oxidized to hydroperoxide, and then propylene and the hydroperoxide are reacted to produce PO with a large amount of styrene monomer or t-butanol co-products.

1.2. Vapor Recovery Unit (VRU) of Pars Petrochemical Company

In the downstream segment of oil, gas and petrochemical operations, it is critical to eliminate harmful vapors with potentially toxic and explosive properties from gasoline and other fuel types before the products are sold. Vapor recovery is particularly crucial as hydrocarbon storage containers may be prone to leaks via the hatches and safety valves as the internal vapor pressure builds up over time.

Vapor recovery is the process of removing harmful vapor and fluid contaminants from crude products to improve the purity and prevent the release of toxic pollutants into the environment. Vapor removal is also done in chemical processing industries to recover unwanted vapors from storage units to keep the chemicals pure and safe for use and transport.

A Vapor Recovery Unit (VRU) is an engineered compression package, which aims to lower emissions levels coming from the vapors of gasoline or other fuels while recovering valuable hydrocarbons to be sold or reused as fuel onsite. A package for vapor recovery is designed to capture about 95% of Btu-rich vapors, generating many benefits, guaranteeing less air pollution, and recovering gasoline vapors to be used as fuel.

In practice, all chemical process involves production or absorption of energy in the form of heat. Exchanger is commonly used in a chemical process to transfer heat from the hot fluid through a solid wall to a cooler fluid or conversely. There are different types of exchanger used in the industry but most of the industry use shell and tube type exchanger system. Shell and tube ex-exchangers are probably the most common type of exchangers applicable for a wide range of operating temperatures and pressures. In shell and tube ex-exchanger one fluid flows through the tubes and a second fluid flows within the space between the tubes and the shell [1]. The outlet temperature of the shell and tube exchanger system has to be kept at a desired set point according to the process requirement. Firstly, a classical PID controller is implemented in a feedback control loop so as to achieve the control objectives. PID controller exhibits high overshoots which is undesirable. To minimize the overshoot Fuzzy logic controller is implemented. Fuzzy logic has become one of the most successful of today’s technologies for developing sophisticated control systems. The reason is very simple: Fuzzy logic addresses applications perfectly as it resembles human decision making with an ability to generate precise solutions from certain or approximate information.

The paper is organized as follows: section 2 gives a brief introduction of exchanger system. Assumptions made and sources of disturbances are also described along with mathematical modeling of system. Section 3 describes PID Controller and its tuning method. Section 4 describes Fuzzy logic controller, its membership function and rule base. Section 5 shows simulation model and its resultant graphs. Section 6 and 7 shows result, discussions and conclusion.

The breathing losses and boil-off vapor from the ship shall be compressed and returned back to Battery Limit. The vapor recovery unit (VRU) shall consist of gas compressor(s), scrubber, and control system to allow safe, efficient and smooth operation with varying flows. The vendor is requested to propose the most cost-effective solution. This duty specification is provided for ammonia that is applied for both berth 16 and 17 requirements.

1.3. Requirement

It is anticipated that multiple compressor(s) will be required to achieve the desired performance specification. If multiple compressor(s) are used the piping arrangement and the instrumentation and control system configuration must be designed for simultaneous operation of all to compressor(s) as required. All machines shall be electrical driven. The vendor shall supply and install all instruments associated with the package. A suitable control scheme for the gas return to pipe line shall be included. Functional design specification and control philosophy shall be included in the package specification to enable others to effectively design the proposed control system.

Utilities shall be supplied to the package boundary as required, at the conditions stated in section 10 of this document. Vendor shall specify the utility consumption requirements for peak flow.

Vendor shall provide all equipment including pressure relief valves and interconnecting instrument and piping between equipment within the package boundary. (To be confirmed by client).

2. EXCHANGER SYSTEM

A typical interacting chemical process for heating/cooling consists of a refrigerant package and a shell and tube exchanger system. The refrigeration gas comes from the refrigerant package through the tubes. Whereas, the process fluid (propylene oxide) flows through the shells of the shell and tube ex exchanger system. The process fluid which is the output of the ex-changer is pumped to fifth station. The ex-exchanger cools the fluid to a desired set point using refrigeration gas supplied from the refrigerant package.

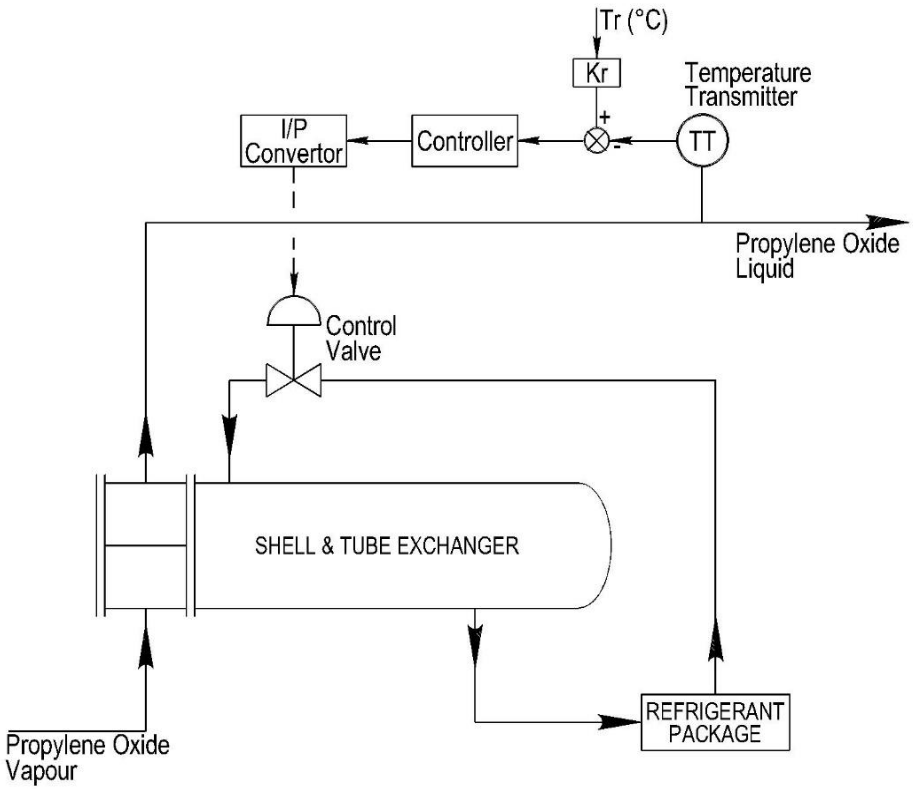

Fig. 1. Shell and tube exchanger system control scheme.

2.1. Assumptions

Different assumptions have been considered in this research paper. (i) Inflow and the outflow rate of fluid are same, so that the fluid level is maintained constant in the ex-exchanger. (ii) The temperature storage capacity of the insulating wall is negligible.

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 is sent to the transmitter unit, which eventually converts the thermocouple output to a standardized signal in the range of 4-20 mA. This output of the transmitter unit is given to the controller unit. The 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 valve. The actuator unit takes the controller output in the range of 4-20 mA and converts it in to a standardized pressure signal in the range of 3-15 psig. The valve actuates according to the controller decisions. Fig 1 shows the control scheme adopted in ex-exchanger system.

2.2. Sources of Disturbances

There can be two types of disturbances in this process. (i) the flow variation of input fluid (ii) the temperature variation of input fluid.

2.3. Mathematical Modeling of Ex- Exchanger System

In this section the ex- exchanger system, actuator,

valve, sensor is mathematically modeled using the available experimental data. The experimental process data are summarized below [2].
Exchanger response to the refrigerant gas flow gain = 50°C/kg/sec
Time constants = 30 sec
Exchanger response to variation of process fluid flow gain = 1°C/kg/sec
Exchanger response to variation of process temperature gain = 3°C/°C
Control valve capacity for steam = 1.6 kg/sec
Time constant of control valve = 3 sec
The range of temperature sensor = 50°C to 150°C
Time constant of temperature sensor = 10 sec
From the experimental data, transfer functions and the gains are obtained as below.

Transfer function of process = $\frac{50e^{-s}}{30s+1}$

Gain of valve = 0.13

Transfer function of valve = $\frac{0.13}{3s+1}$

Gain of current to pressure converter = 0.75
Transfer function of disturbance variables
(i) Flow= $\frac{1}{30s+1}$ (dominant). (ii) Temperature= $\frac{3}{30s+1}$

Transfer function of thermocouple = $\frac{0.16}{10s+1}$

3. PROPORTIONAL-INTEGRAL-DERIVATIVE (PID) CONTROLLER

The mnemonic PID refers to the first letters of the names of the individual terms that make up the standard three- term controller. These are P for the proportional term, I for the integral term and D for the derivative term in the controller. PID controllers are probably the most widely used industrial controller. Even complex industrial control systems may comprise a control network whose main control building block is a PID control module. In PID controller Proportional (P) control is not able to remove steady state error or offset error in step response. This offset can be eliminated by Integral (I) control action. Output of I controller at any instant is the area under actuating error signal curve up to that instant. I control removes offset, but may lead to oscillatory response of slowly decreasing amplitude or even increasing amplitude, both of which are undesirable. Derivative (D) control action has high sensitivity. It anticipates actuating error, initiates an early correction action and tends to increase stability of system [2].

Ideal PID controller in continuous time is given as

$$y(t) = K_p\left(e(t) + \frac{1}{T_i \int_0^t e(t)dt} + T_d \frac{de(t)}{dt}\right)$$

(1)

Laplace domain representation of ideal PID controller is

$$Gc(s) = \frac{Y(s)}{E(s)} = K_p(1 + \frac{1}{T_i\ s} + T_d S) \qquad (2)$$

3.1. Tuning of PID Controller

Ziegler and Nichols proposed rules for determining values of Kp, Ti $and\ Td$ based on the transient response characteristics of a given plant. Closed loop oscillation based PID tuning method is a popular method of tuning PID controller. In this kind of tuning method, a critical gain Kc is induced in the forward path of the control system. The high value of the gain takes the system to the verge of instability. It creates oscillation and from the oscillations, the value of frequency and time are calculated. Table 1 gives experimental tuning rules based on closed loop oscillation method [3,4].

Table 1. Closed loop oscillation based tuning methods.

Type of Controller	K_p	T_i	T_d
P	0.5K_c	∞	**0**
PI	0.45 K_c	0.83 T	**0**
PID	**0.6K_c**	**.5T**	**0.125 T**

The characteristic equation 1 + $(s)(s)$ = 0 in this case is obtained as below

$$900s3 + 420s2 + 43s + 0.78Kc+1 = 0 \qquad (3)$$

Applying Routh stability criterion in above eq gives Kc = 24.44

Auxiliary equation is $420s2 + 0.78Kc + 1 = 0$ (4)

Substituting s = jω gives ω = 0.218 and T = 28.82
For the PID controller the values of parameters obtained using Ziegler Nichols closed loop oscillation based tuning methods are:

Kp = 14.66 Ti = 14.41 Td = 3.60

Usually, initial design values of PID controller obtained by all means needs to be adjusted repeatedly through computer simulations until the closed loop system performs or compromises as desired. These adjustments are done in MATLAB simulation.

4. FUZZY LOGIC CONTROLLER (FLC)

The design of fuzzy logic controller is attempted in exchanger. The fuzzy controllers are designed with two input variables, error and rate of error and one output variable (i.e.) the hot water flow rate to the shell side. The mamdani based fuzzy inference system uses linear membership function for both inputs and outputs. For the fuzzy logic controller, the input variables are error (e)and rate of error (Δe), and the output variable is controller output(Δy). Triangular membership functions are used for input variables and the output variable. The universe of discourse of error, rate of error and output are [-13, 13], [-4, 4] and [-5, 5] respectively. The rule base framed for shell and tube exchangers are tabulated in Table 3[5,7].

The structure of the rule base provides negative feedback control in order to maintain stability under any condition. For the evaluation of the rules, the fuzzy reasoning unit of the FLC has been developed using the Max-Min fuzzy inference method [8]. In the particular FLC, the centroid defuzzification method is used. Linguistic variables for error, rate of error and controller output are tabulated in table 2. [6].

Fig 2, 3 and 4 shows membership functions of different variables implemented in FIS editor in MATLAB toolbox and fig 5 shows surface view of all variables in 3 dimension [9].

Table 2. Linguistic variables.

VBN	**Very big negative**	**PS**	**Small positive**
NB	Big negative	PM	**Medim positive**
NM	Medium negative	PB	**Big positive**
NS	Small negative	VBP	**Very big positive**
Z	**Zero**		

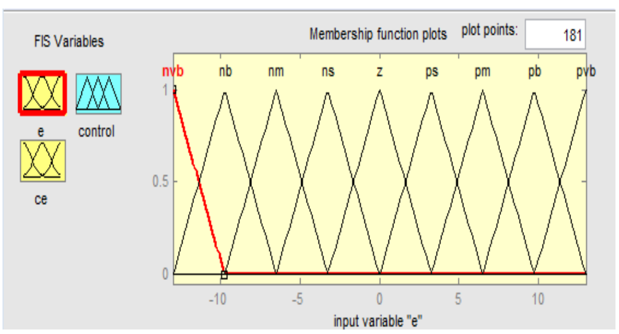

Fig. 2. Membership function for error.

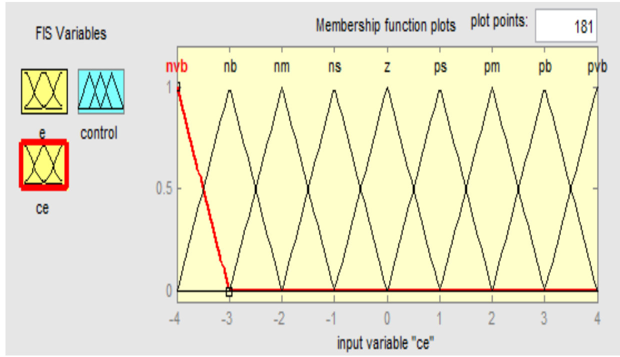

Fig. 3. Membership function for rate of error.

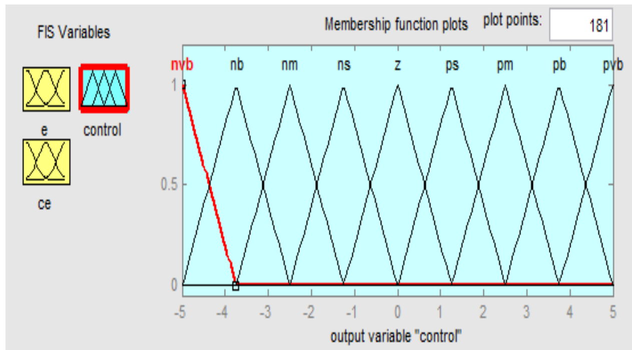

Fig. 4. Membership function for control output.

Table 3. Rule base for fuzzy logic controller.

e → Δe ↓	VBN	NB	NM	NS	Z	PS	PM	PB	VBP
VBN	VBN	VBN	VBN	VBN	VBN	NB	NM	NS	Z
NB	VBN	VBN	VBN	VBN	NB	NM	NS	Z	PS
NM	VBN	VBN	VBN	NB	NM	NS	Z	PS	PM
NS	VBN	VBN	NB	NM	NS	Z	PS	PM	PB
Z	VBN	NB	NM	NS	Z	PS	PM	PB	VBP
PS	NB	NM	NS	Z	PS	PM	PB	VBP	VBP
PM	NM	NS	Z	PS	PM	PB	VBP	VBP	VBP
PB	NS	Z	PS	PM	PB	VBP	VBP	VBP	VBP
VBP	Z	PS	PM	PB	VBP	VBP	VBP	VBP	VBP

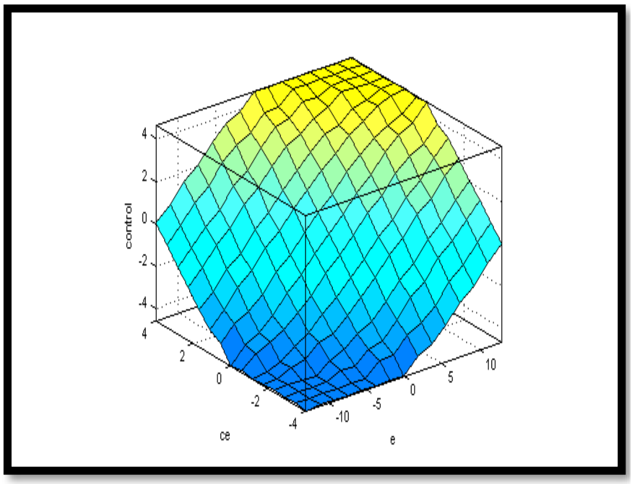

Fig. 5. 3D Surface view.

5. SIMULATION

The simulation for different control mechanism discussed above were carried out in Simulink in MATLAB and simulation results have been obtained. Fig 6 and 7 shows the PID controller and FLC system block diagram which is simulated in MATLAB.

Fig 8 and 9 shows step response of PID and FLC system where x axis denote time and y axis denote set point value.

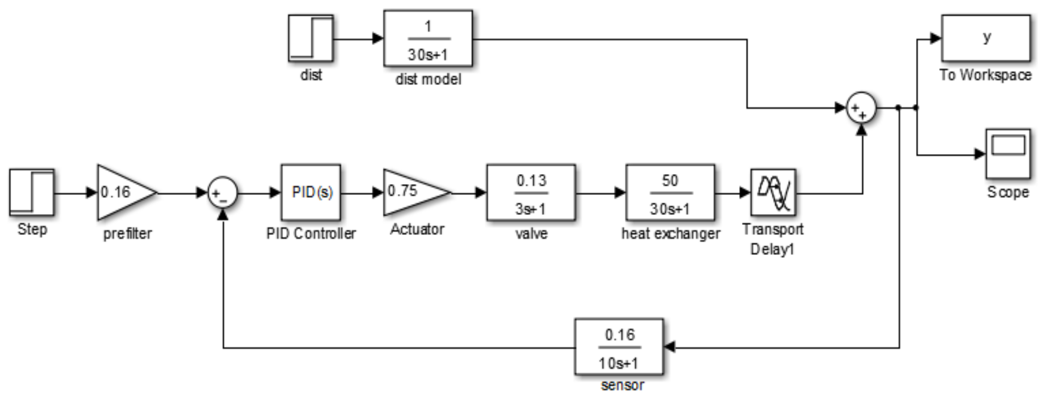

Fig. 6. PID Controller.

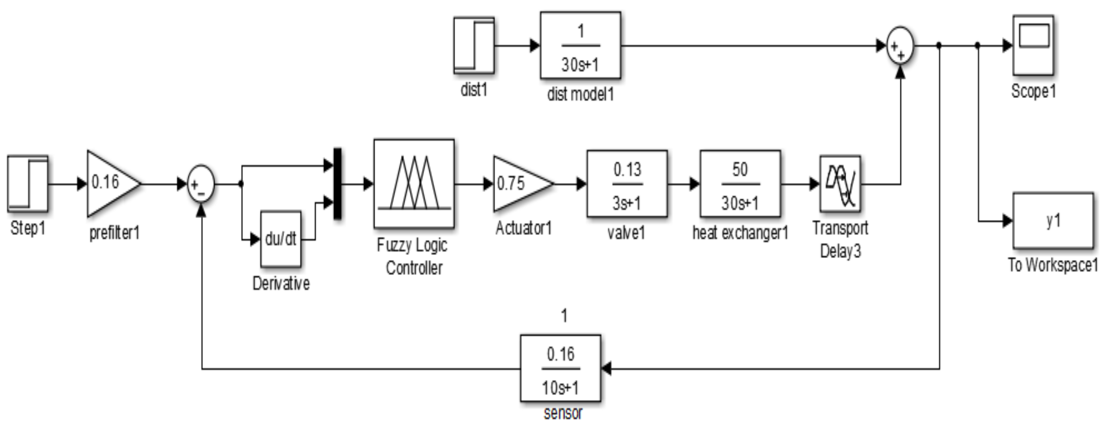

Fig .7. Fuzzy logic controller.

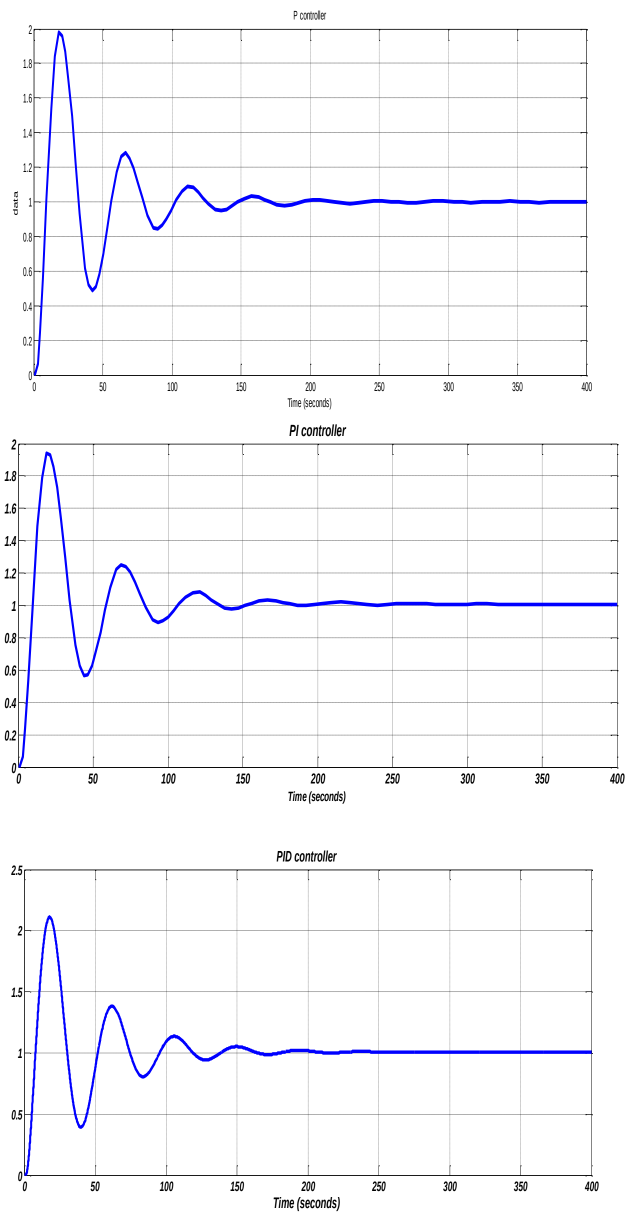

Fig. 8. PID Step response.

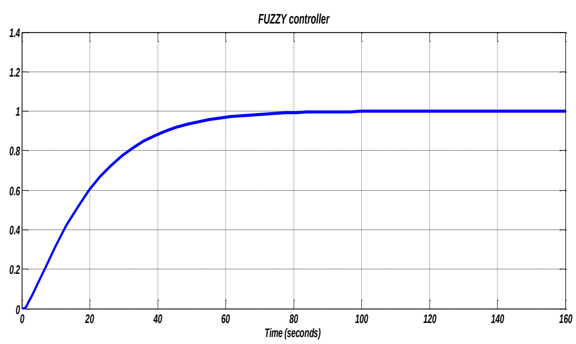

Fig. 9. FLC Step response.

6. SIMULATION RESULT AND DISCUSSION

To evaluate the performance of the different controllers this paper has considered two vital parameters of the step response of the system. The first parameter is the maximum overshoot and the second parameter is the settling time.

Peak Overshoot: It indicates maximum positive deviation of output with respect to its desired value.

It is defined as[8] $\%M_p = \dfrac{c(t_p) - c(\infty)}{c(\infty)} \times 100\%$

Settling Time: It is the time required for the response to reach and stay within a specified tolerance band of its final value. The tolerance band is taken randomly as 2%.

In this paper control of temperature of exchanger is done by 2 different controllers. In PID controller we set the parameters by using Ziegler Nichols closed loop method. After this we simulated the model in MATLAB and tuned the parameters until the response is satisfactory. In step response, we found overshoot and large settling time both of which are undesirable. Moreover, there are three tuning parameters which simultaneously be adjusted to get desired result.

Then a Fuzzy logic controller is developed with 9 membership functions for each variable. There were total 81 rules generated. The response is smooth as well as fastest as compared to PID controllers. So FLC is recommended because it is easy to implement, low cost and no need to know exact plant parameters. Different parameters are tabulated in table 4.

7. CONCLUSION

In this paper, a comparative study of performance of conventional (PID) and intelligent (FLC) controllers is studied. The aim of the proposed controller is to regulate the temperature of the outgoing fluid of a shell and tube exchanger system to a desired temperature in the shortest possible time and minimum or no overshoot After comparing results for different controllers, we obtain that fuzzy logic controller is the one which gives quick response without any oscillations. It is easy to implement fuzzy logic as it is computer oriented. PID controller, though good for industrial process but due to oscillatory response and large settling time is now going to be replaced by new technology like Fuzzy logic and Neural network.

Table 4. Comparison of different parameters.

Control System	Maximum Overshoot(%)	Settling Time (sec)
Feedback PID Controller	47.2	**88**
FLC	**0**	**65**

NOMENCLATURE

K_p	Proportional gain
T_i	Integral time
T_d	Derivative time
K_c	Critical gain
T	Time period of oscillation
m	Angular frequency of oscillation
(s)	Controller transfer function
e	Error between desired output and actual output

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