

# Analysis of Advanced Controllers for Temperature Control in a Heat Exchanger

Saranya.SN<sup>1</sup>, Dr.Prabhakaran.D<sup>2</sup>, Dr.Thirumarimurugan.M<sup>3</sup>

P.G. Student, Department of Chemical Engineering, Coimbatore Institute of Technology, Coimbatore,  
Tamil Nadu, India<sup>1</sup>

Associate Professor, Department of Chemical Engineering, Coimbatore Institute of Technology, Coimbatore,  
Tamil Nadu, India<sup>2</sup>

Associate Professor, Department of Chemical Engineering, Coimbatore Institute of Technology, Coimbatore,  
Tamil Nadu, India<sup>3</sup>

**ABSTRACT:** The main goal of the experimental shell and tube heat exchanger presented in this paper is to control the temperature of the outgoing fluid to a desired set point in spite of different disturbances. The entire heat exchanger system is modelled using the experimental data, and the output transfer function is developed for the system. A proportional-integral-derivative (PID) controller using Ziegler-Nichols method, and internal model controller are tuned, this paper investigates the fuzzy logic control system design method for a heat exchanger. To verify the effectiveness simulations are done using Matlab-Simulink.

**KEYWORDS:** Heat Exchanger, Transfer function, Fuzzy, Internal model Controller

## I. INTRODUCTION

The shell and tube of heat exchanger is where heat transfer process occurred. The performance of heat exchanger depends on the accuracy of both elements. Therefore, both components have to be controlled in order to get a considerable result in process. For this purpose, the actual dynamics of both shell and tube of the heat exchanger is crucial. It is the most general type of heat exchanger in oil refineries and other huge chemical processes, and is suitable for higher-pressure applications

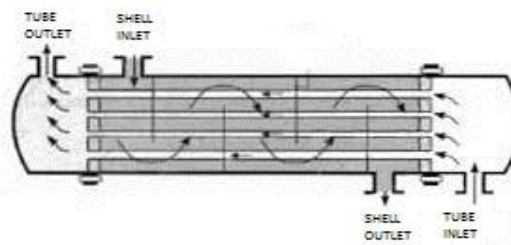


Fig.1: Shell and tube heat exchanger

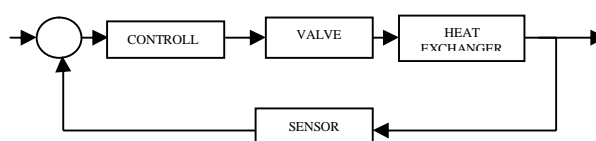


Fig.2: General block diagram of the process

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## II. MATHEMATICAL MODELING

In the heat exchanger system, actuator, valve, sensor are mathematically modeled using the Available experimental data. The data are summarized below. [13]

Time constant = 30 sec

Heat Exchanger response to variation of process fluid flow gain=1°C/ (kg/sec)

Heat Exchanger response to variation of process fluid temperature gain=1°C/°C

Steam Control valve capacity = 1.6 kg/sec

Control valve Time constant = 3 sec

The range of temperature sensor = 50°C to 150°C

Temperature sensor Time constant = 10 sec

From the data, transfer function and the gain are obtained as below.

$$\text{Transfer function of process} = \frac{50}{30s+1}$$

$$\text{Transfer function of valve} = \frac{0.1333}{3s+1}$$

Gain of the Valve = 0.75

$$\text{Transfer function of sensor} = \frac{0.042}{3s+1}$$

$$\text{Transfer function of temp disturbance} = \frac{3}{30s+1}$$

$$\text{Transfer function of flow disturbance} = \frac{1}{30s+1}$$

## III. PID CONTROL OF HEAT EXCHANGER

PID controller is the most used controller because it is simple to operate and very robust. The latest implemented PID controller is based on a direct digital design. These digital PID has many algorithms to develop their performance, for example anti wind-up, auto-tuning, adaptive, fuzzy fine-tuning and Neural Networks with the necessary operations remaining the same. Here Zeigler-Nicholas tuning rule is used for the PID tuning since it provide easy tuning formulae to find out the P, PI, PID control parameters[14] For the PID Controller in the heat exchanger, the tuned parameters obtained are  $K_p = 8.533$ ,  $T_i = 0.3006$ ,  $T_d = 32.495$ . Usually, initial design values of PI controller obtained by all means to be adjusted repeatedly through computer simulation until the closed loop system performs effectively until the desired the result is obtained. The performance terms such as Rise time Overshoot, Settling time and error; By tuning value of parameters  $K_p$ ,  $K_i$  and  $K_d$  of the PID controller the steady state can be improved. The output of this is shown in the below graph at the end of the paper.

## IV. FUZZY

Fuzzy logic is a soft computing method in which linguistic variables, based upon fuzzy sets, are we are able to eliminate inexact or noisy data in order to find definitive solutions of a particular problem. Fuzzy logic are developed as a way to model the indecision of natural language [20, 21], it has been applied to many areas of science and technology [22-24]. The main benefit obtainable by fuzzy logic is that has ability to describe complex process in terms of linguistic variables, making inferences about their actions by means of expert-based if-then rules. This is determined by first defining the variables of a specific problem and then by associating them are called fuzzy sets (as opposed to crisp sets), which denote the fuzzy states of variables. The membership function distinct upon the set, either crisp of fuzzy is denoted by the linguistic-variable.

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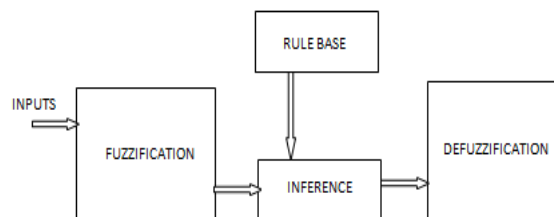


Fig.3:Fuzzy Rule Base

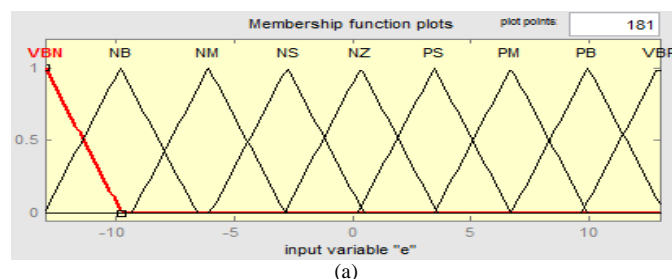
The model of simple fuzzy controller control signal depends on the measured inputs error and the change in error. The inputs are most usually tough or crisp measurements from equipment. A dynamic controller would have supplementary inputs, for example derivatives, integrals, or preceding values of measurements backwards in time. The block fuzzifications convert each input data to degrees of membership by a hunt for in one or numerous membership functions. The rules may use some variables, both in the condition and the termination of the rules. Basically, a linguistic controller has rules in the if-then format, but they can be available in different formats. The final result of fuzzy set must be converted to a number that can be sent to the process as a control signal. This operation is called defuzzification. Output scaling is also relevant. In this case the output is defined on a customary universe it must be scaled to engineering units.

The table that stated below are the fuzzy rules that have been used for tuning the process under control these rules have been framed in order to get a better control performance than other controllers which are under study.

Table1: Rules for fuzzy

e	d e	VBN	NB	NM	NS	NZ	PS	PM	PB	VBP
VBN	VBN	VBN	NB	NM	NS	NZ	PS	PM	PB	VBP
NB	NB	VBN	NB	NM	NS	NZ	PS	PM	PB	VBP
NM	NM	VBN	NB	NM	NS	NZ	PS	PM	PB	VBP
NS	NS	VBN	NB	NM	NS	NZ	PS	PM	PB	VBP
NZ	NZ	VBN	NB	NM	NS	NZ	PS	PM	PB	VBP
PS	PS	VBN	NB	NM	NS	NZ	PS	PM	PB	VBP
PM	PM	VBN	NB	NM	NS	NZ	PS	PM	PB	VBP
PB	PB	VBN	NB	NM	NS	NZ	PS	PM	PB	VBP
VBP	VBP	VBN	NB	NM	NS	NZ	PS	PM	PB	VBP

The figure that are represented below are the represented as the specification of the rules that are used for framing the fuzzy logic.



(a)

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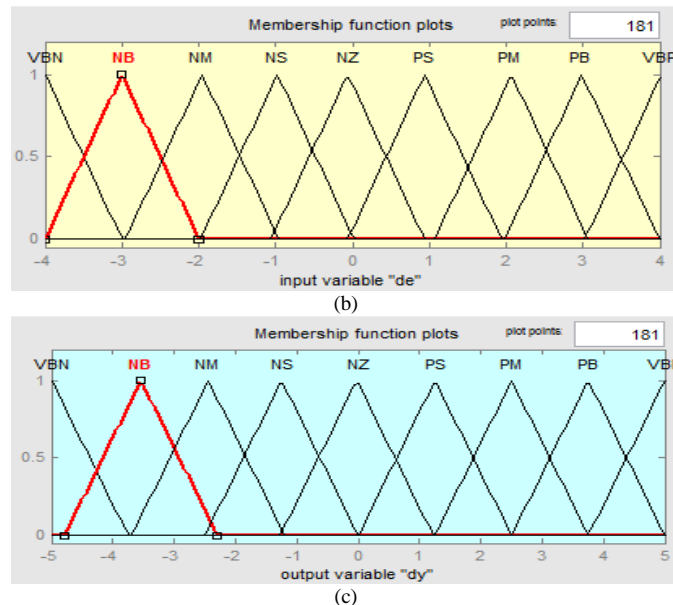


Fig4: (a), (b), (c) Representation of fuzzy in Max-Min

## V. INTERNAL MODEL CONTROL

The IMC principle states that the accurate control can be achieved only if the control system has either implicitly or explicitly some representation of the process to be controlled.

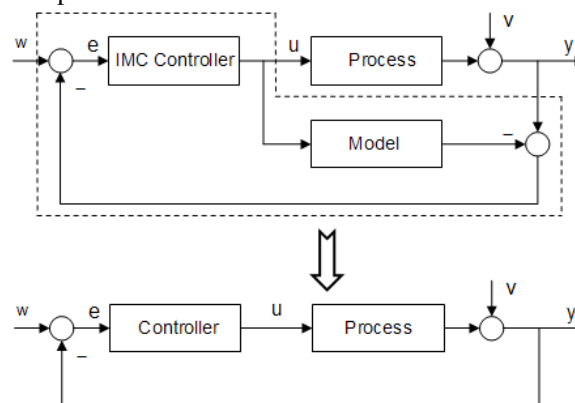


Fig5: General Block Diagram of Internal Model Controller

By using the following rules and considering the input one can design a IMC Controller:

Initially the process model is separated into two terms we determine a transfer function that has minimum phase characteristics .A system has non-minimum phase uniqueness if its transfer function contain zeros in the right half plane or transport lags, or both. Or a system has minimum phase uniqueness. For step change in disturbance is determined by

$$G_I = \frac{1}{G_{mm}} \quad (1)$$

The result of applying the above equation will obtain a transfer function that is stable and does not require prediction; On the other hand it will have terms that cannot be implemented because they require pure differentiation

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The IMC controller is obtained by multiplying it with the transfer function of the filter  $f(s)$  that can be represented as

$$f(s) = \frac{1}{(\lambda s + 1)^n} \quad (2)$$

Where  $\lambda$  is the filter parameter and  $n$  is an integer finally the equation of IMC can be obtained as

$$G_I = \frac{f}{G_{mm}} \quad (3)$$

The conventional transfer function  $G_c$ , use is formed with  $G_I$  and above equation is obtained and thereby process model,  $G_c$  turns out to be equal to a PID controller multiplied by a first-order transfer function thus

$$G_c = K_c \left( 1 + \tau_D s + \frac{1}{\tau_I s} \right) \left( \frac{1}{\tau_1 s + 1} \right) \quad (4)$$

Where,  $K_c, \tau_D, \tau_I, \tau_1$  are the function of the process in the  $G_I$  and  $G$

The experimental data are taken and are modeled accordingly as stated above and the following results have been obtained

$$G = G_{mm} G_{ma} \quad (5)$$

$$G_{mm} = \frac{4.9875}{(3s + 1)(30s + 1)(90s^2 + 33s + 1)} (-90s^2 - 33s + 1)$$

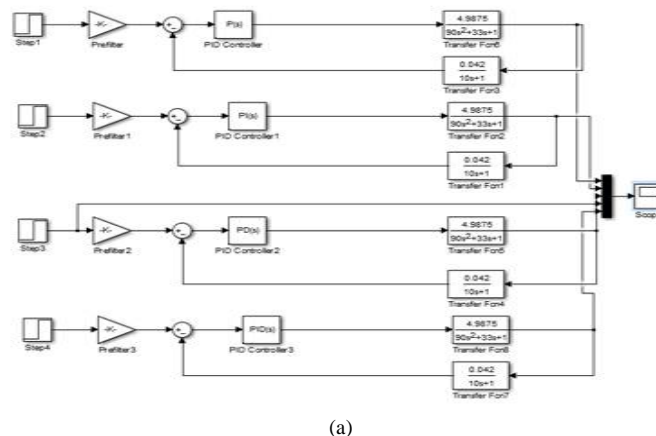
$$G_I = \frac{(3s + 1)(30s + 1)(90s^2 + 33s + 1)}{4.9875} \frac{1}{(\lambda s + 1)^2}$$

In Practice  $\lambda$  is taken more than the time constant value, Here, the value of  $\lambda$  is taken as 1. Substituting the value to the above equation we get a transfer function of Internal Model Controller denoted as  $G_c$

$$G_c = \frac{90s^2 + 33s + 1}{(1.2468s^2 + 4.9875s)} \quad (6)$$

## VI. SIMULATION AND RESULTS

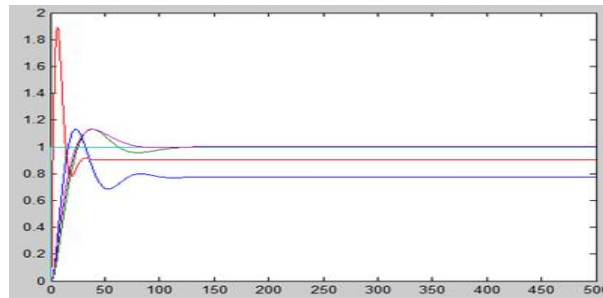
The following represents the Simulation Of P, PI, PD, PID Controllers they are done the find out the best control response from the conventional controllers



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(b)

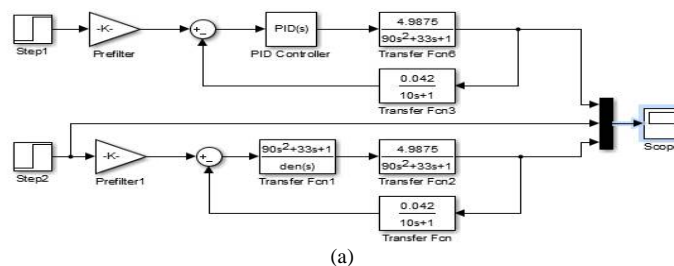
Fig6: (a) Block diagram representation of P, PI, PD, PID Controllers, (b) Simulation Graph of P, PI, PD, PID Controllers

From the above comparison it is seen that the PID has a good response when comparing with the controllers such as P, PI, PD the evaluation the above results are given below. These state that the PID has a better response than the other controller like P, PI and PD.

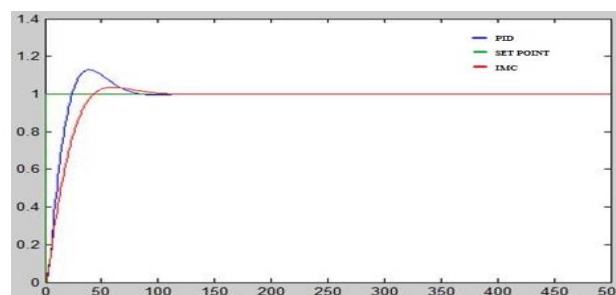
Table2: Comparison for the Above Result

S.No	Controller	Rise Time (sec)	Overshoot (%)	Settling Time (sec)
1	P	13.346	1.131	Error-0.22
2	PI	2.354	1.893	Error-0.09
3	PD	20.72	1.132	235
4	PID	18.94	1.129	196

The following are the representation of the Simulation of PID and IMC Controllers to are done in order to compare the performance of the both the controller to find the best one



(a)



(b)

Fig7: (a) Block Diagram representation of IMC and PID Controllers, (b) Simulation graph of IMC and PID Controllers

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The above figure represents the performance analysis of both the IMC and PID controller form which it is inferred that the overshoot and setting time is less when compared with that of the conventional PID controller. The table below gives the overall idea of the controller response that are made in the above diagram.

Table3: Comparison for the Above Result

S.No	Controller	Rise Time (sec)	Overshoot (%)	Settling Time (sec)
1	PID	18.94	1.129	196
2	IMC	30.9	1.103	150

The following are the representation of the Simulation Of PID, IMC And Fuzzy Controllers which are done to compare the Fuzzy with the Both of Convectional PID and Advanced IMC controller.

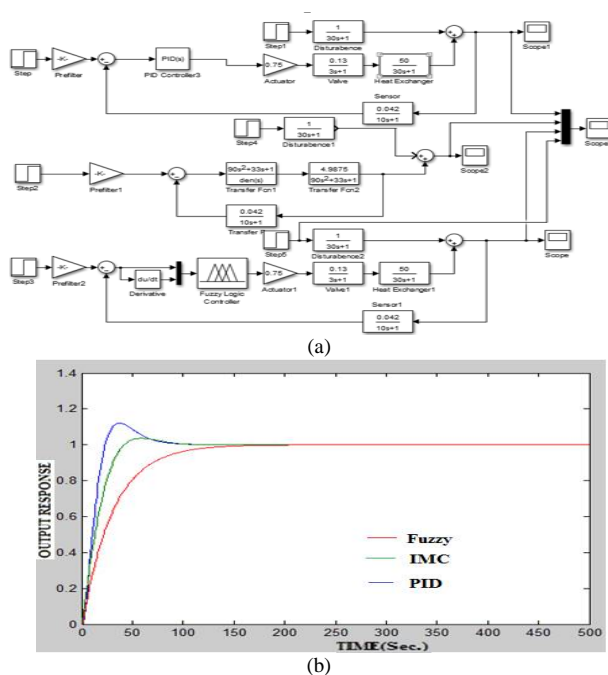


Fig8: (a) Block diagram of IMC, PID and Fuzzy Controllers, (b) Simulation graph of PID, IMC and Fuzzy

The above figures are the representation of advanced controllers such as IMC, Fuzzy and the conventional controller PID and their response to the process implemented.

The table represents the response of the system that are tuned which clearly indicates that the fuzzy has more advantage than the other controllers that are under study

Table 4: Comparison for the Above Result

S.No	Controller	Rise Time (sec)	Overshoot (%)	Settling Time (sec)
1	PID	18.94	1.129	196
2	IMC	30.9	1.103	150
3	Fuzzy	70	0	220

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## VII. RESULTS AND DISCUSSION

From the above discussions that were made it is concluded that the both the fuzzy and the IMC has good control in the heat exchanger temperature control. In fuzzy it is seen that there is no overshoot when that compared either that of IMC and PID controllers while the IMC has a fast settling time when compared to PID and Fuzzy controller.

## VIII. FUTURE SCOPE

The future work can be done by implementing more intelligent controllers such as combining fuzzy and neural network (i.e) Neuro-Fuzzy, or by combining internal model control and Fuzzy (i.e) Fuzzy Internal Model Control.

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