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An Implementation and Comparative Analysis of PID Controller and their Auto tuning method Considering uncertainty for the Robust Control of Concentration in CSTR

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ABSTRACT

All the industrial process applications require solutions of a specific chemical strength of the chemicals or fluids considered for analysis. Such specific concentrations are achieved by mixing a full strength solution with water in the desired proportions. In this paper the control of concentration of one chemical with the help of other has been analyzed. This paper features the auto tuning technique of PID controller and is adopted for more reliable and robust control action considering uncertainty in the form of disturbance and load. In this paper, the comparison of the conventional PID and auto tuning is clarified.

Keywords: PID Control, Auto Tuner, Chemical Concentration, CSTR, Uncertainty rejection

1. INTRODUCTION

Chemical reactors often have significant heat effects, so it is important to be able to add or remove heat from them. In a CSTR (continuously stirred tank reactor) the heat is add or removed by virtue of the temperature difference between a jacked fluid and the reactor fluid. Often, the heat transfer fluid is pumped through agitation nozzle that circulates the fluid through the jacket at a high velocity. The reactant conversion in a chemical reactor is a function of a residence time or its inverse, the space velocity. For a CSTR, the product concentration can be controlled by manipulating the feed flow rate, which change the residence time for a constant chemical reactor.

A proportional controller could lead to offset between the desired set point and the actual output. This is because the process input which is controller output and the process output come to new equilibrium values before error goes down to zero. Now to make the controller output proportional to the integral of the error desired compensation is to be provided. This is known as the proportional integral control. As long as there continuous to be an error signal to the controller, the controller output will continue to change. Therefore, the integral of error forces the error signal to zero. Now add one more term that accounts for current rate of change i.e. derivative of the error. This is known as Proportional integral derivative control. Using knowledge of the error helps the controller to predict where in future the error is heading and compensate for it.

In this paper, CSTR has been used to mix ethylene oxide with water to make ethylene glycol. Here the purpose is to control the concentration of ethylene glycol with the help of concentration of ethylene oxide. But undershoot, overshoot and inverse response come in the considered system while performing in a conventional way. But after implementation of PID controller to the process, removing of those shoots can be seen but still the design requirement is not achieved. So finally auto tuning method of PID controller is implemented in order to achieve the design requirement.

This paper endeavors to design a system using two methods of auto tuning of PID parameters called Basic design mode and Extended design mode. Auto tuning is basically used to tune PID gains automatically in a Simulink model containing a PID controller block. The PID tuner allows achieving a good balance between performance and robustness. It automatically computes a linear model of the plant. The PID tuner considers the plant to be the combination of all blocks between the PID controller input and output. Thus, the plant includes all blocks in the control loop, other than the controller itself. The main objectives of PID tuner are closed-loop stability (in which system output remains bounded for bounded input), adequate performance (in which closed- loop system tracks reference changes and suppresses disturbance as rapidly as possible) and adequate robustness (the loop design has enough gain margin and phase margin to allow for modeling errors or variations in system dynamics.

Basic design mode of PID tuner refine the controller design by adjusting response time. It make the closed- loop response of the controlled system faster or slower. Extended design mode of PID tuner refine the controller design by separately adjust loop bandwidth and phase margin. The larger the loop bandwidth, the faster the controller responds to changes in the reference or disturbances in the loop. The larger the phase margin, the more robust the controller is against modeling errors or variations in plant dynamics. The objective of this paper is to show that by employing the proposed tuning of PID controllers, an optimization can be achieved. This can be seen by comparing the result of the PID tuner against the conventional PID controller.

2. CASE STUDY

In this paper, CSTR has been considered in which concentration of two chemicals is controlled for better results, the chemical 'X' and 'Y' and the byproduct is 'Z'. Ethylene oxide (X) is reacted with water (Y) in a continuously stirred tank reactor (CSTR) to form ethylene glycol (Z) .Assume that the CSTR is manipulated at a constant temperature and that the water is in large excess. The stoichiometric equation is

X+Y= Z…………………………………… (1)

The reactant conversion in a chemical reactor is a function of residence time or its inverse, the space velocity. For an isothermal CSTR, the product concentration can be controlled by manipulated the feed flow rate, which change the residence time (for a constant volume reactor). It is convenient to work in molar units when writing components balances, particularly if chemical reaction is involved. Let C_X and C_Z represent the molar concentration of X and Z (mol/volume).

$$\frac{dVC_X}{dt} = F_i C_{Xi} - FC_X + Vr_X \quad \text{............ (2)}$$

$$\frac{dVC_Z}{dt} = -FC_z + Vr_Z \quad \text{… ………….... (3)}$$

Where r_X and r_Z represent rate of generation of species X and Z per unit volume, and C_{Xi} represents the inlet concentration of species X. If the concentration of the water change than the reaction rate is second order with respect to the concentration of Ethylene oxide

$$r_X = -k_1C_X - k_3C_X^2 \text{………………………….. (4)}$$

Where k_1, k_2 & k_3 are the reaction rate constants and the minus sign indicate that X is consumed in the reaction. Each mole X reacts with a mole of Y and produces one mole of Z, so the rate of generation of Z is

$$r_Z = k_1 C_X - k_2C_Z \quad \text{………………………….. (5)}$$

Expanding the left hand side of equation (1)

$$\frac{dVC_X}{dt} = V\frac{dC_X}{dt} + C_X\frac{dV}{dt} \quad \text{……… (6)}$$

Combining eq (1) & (5)

$$\frac{dC_X}{dt} = \frac{F_i}{V}(C_{Xi} - C_X) - k_1C_X - k_3C_X^2 \quad \text{... (7)}$$

Similarly,

$$\frac{dC_Z}{dt} = -\frac{F}{V}C_Z + k_1C_X - k_2C_Z \quad \text{…………....(8)}$$

3. PROBLEM FORMULATION

The linear space model or case study of CSTR is given by

$$\dot{x} = Ax + Bu \quad \text{………………………………….. (9)}$$

$$y = Cx + Du \quad \text{…………………………………..(10)}$$

Where the states, inputs and output are in deviation variable form.

The first input (dilution rate) is manipulated and the second (feed concentration of A) is a disturbance input. Linearization of the two modeling equations (from equation (6) & (7)) at steady state solution to find the following state space matrices is done:

$$A = \begin{bmatrix} -Fs/V-K1-2K3Cxs & 0 \\ K1 & -Fs/V-K2 \end{bmatrix}$$

$$B = \begin{bmatrix} Cxfs-Cxs & Fs/V \\ -Czs & 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 0 & 1 \end{bmatrix}$$

$$D = \begin{bmatrix} 0 & 0 \end{bmatrix}$$

For the particular reaction under consideration, the rate constants are k_1=5/6 /min k_2 =5/3 /min k_3=1/6 mol/litre.min Based on the steady state operating point of C_{Xs} = 3 gmol/liter, C_{Zs} = 1.117 gmol/liter and F_s/V = 0.5714 min^{-1}. The state model is

$$A = \begin{bmatrix} -2.4048 & 0 \\ 0.83333 & -2.2381 \end{bmatrix}$$

$$B = \begin{bmatrix} 7 & 0.5714 \\ -1.117 & 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 0 & 1 \end{bmatrix}$$

$$D = \begin{bmatrix} 0 & 0 \end{bmatrix}$$

The manipulated input output process transfer function G(s) = $C(s\boldsymbol{I} - \mathbf{A})^{-1}$ B is calculated with the help of Matlab.

$$G_p(s) = \frac{-1.117s + 3.1472}{s^2 + 4.6429s + 5.3821} \quad \text{.. (11)}$$

It is desired to produce 100 million pounds per day of ethylene glycol. The feed stream concentration is 1.0 lbmol/ft^3 and an 80% conversion of ethylene oxide has been to be determined reasonable. Since 80% of ethylene oxide is

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converted to ethylene glycol, the ethylene glycol concentration is 0.8 lbmol /ft^3. In this process, disturbance is considered in order to have a more robust control of concentration. It is seen that the output has inverse response with delay time as well as overshoot. To overcome this problem and to obtain the desired requirement, the implementation of PID and their auto tuning method is done.

4. SIMULATION, RESULTS AND COMPARISONS

Our Design requirement

Overshoot = 0
Undershoot = 0
Rise time (t_r) = 6 sec (appx)
Settling time (t_s) = 10 sec (appx)
Inverse response = 0

CASE 1

In this paper, uncertainty in the form of step disturbance of final value 0.5 is considered to the output of the conventional system in order to have a robust control of concentration in CSTR.

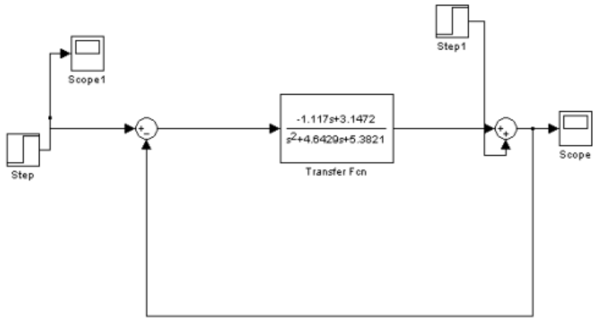

Fig. 1: Process model without controller

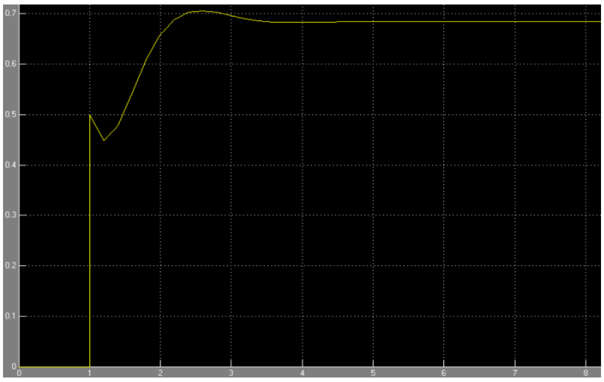

Fig. 2: System output without controller

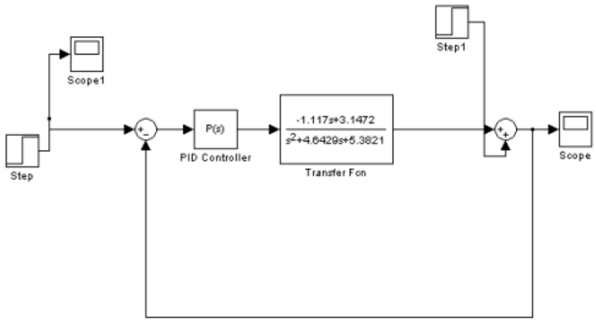

Fig. 3: Process model with P controller

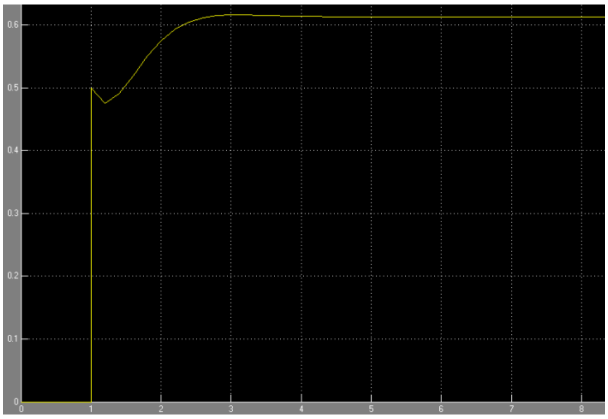

Fig. 4: System output with P controller

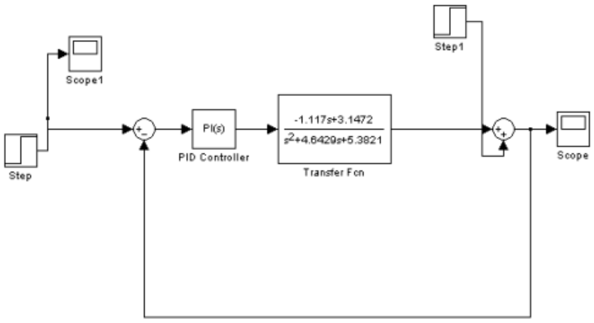

Fig. 5: Process model with PI controller

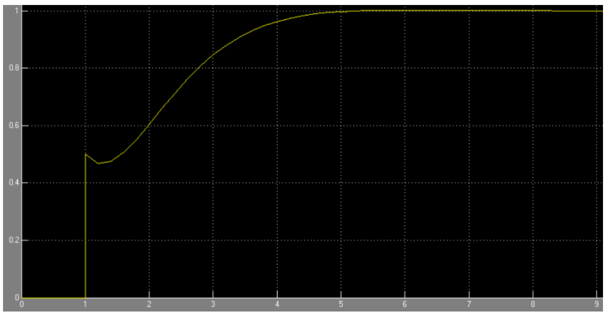

Fig. 6: System output with PI controller

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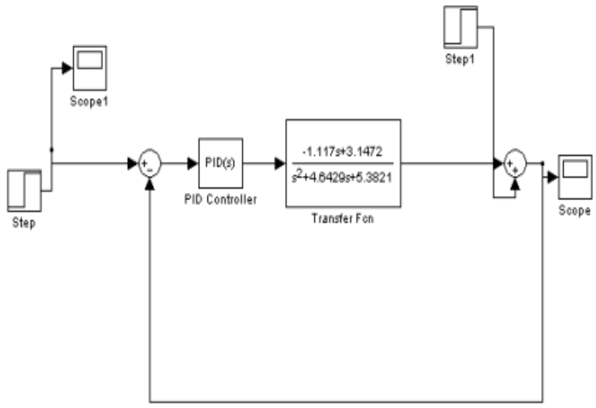

Fig.7: Process model with PID controller

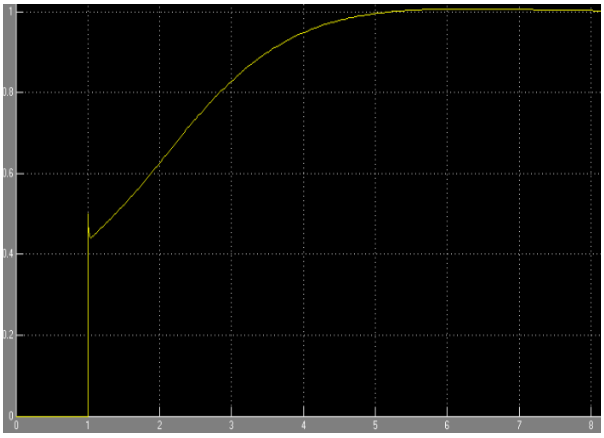

Fig. 8: System output with PID controller

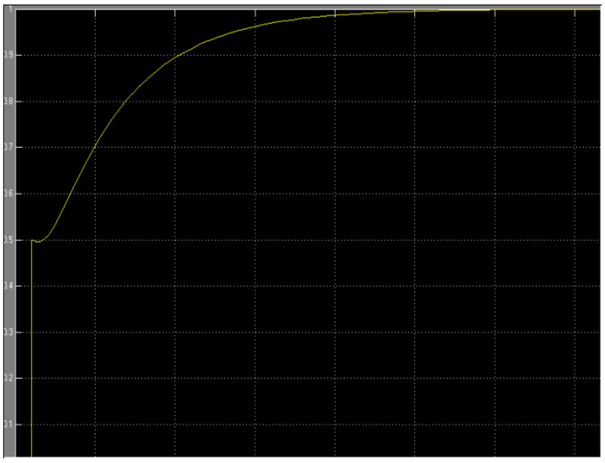

Fig. 9: System output with PID controller (Basic Design mode)

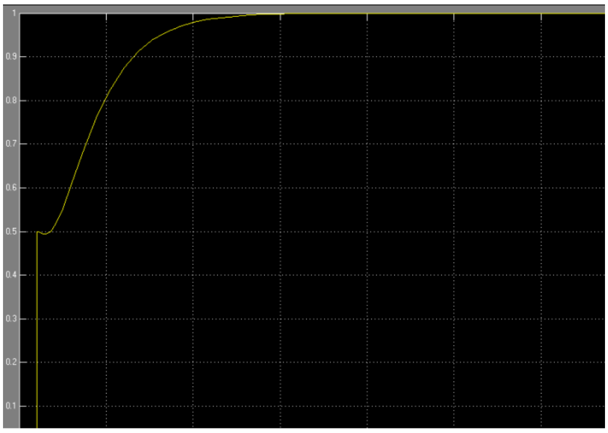

Fig. 10: System output with PID controller (Extended Design mode)

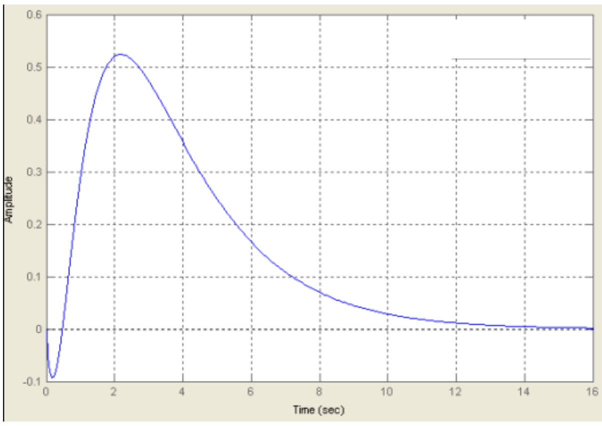

Fig. 11: Disturbance rejection plot with PID controller auto tuning (Extended Design mode)

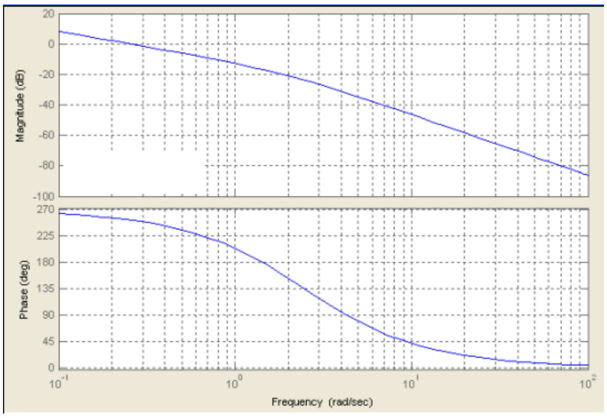

Fig. 12: Open- loop Bode plot with PID controller auto tuning (Extended design mode)

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So, based on the above results a comparison table is drawn of different methods of PID controller which is shown in table 1. In this table it can be seen that our design requirement is achieved in the Extended design mode of the PID controller.

Controller Types	**K_P**	**K_I**	**K_D**	**Rise time (t_r in sec)**	**Settling time (t_s in sec)**	**Overshoot(%)**	**Undershoot(%)**	**Peak**	**Inverse response**
Without controller	-	-	-	2.5	5.4	-	32	0.69	present
P	0.5	-	-	0.788	2.23	2.6	39	0.61	present
PI	0.5	1	-	2.04	3.62	0.497	0	1	present
PID	0.5	1	0.1	2.38	3.77	1.35	0	1.01	negligible
PID (Basic Design mode)	0	0.27383	0	10.8	20.3	0	0	0.999	negligible
PID (Extended Design mode)	**0**	**0.43604**	**0**	**5.63**	**10.6**	**0**	**0**	**1**	**negligible**

Table 1: Comparative analysis of different tuning methods of PID controller considering disturbance

CASE 2

In this paper, uncertainty in the form of load is also considered to the output of the conventional system for smooth control.

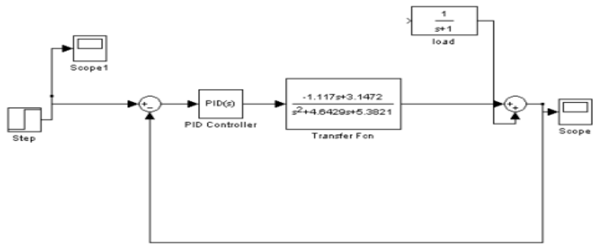

Fig. 13: Process model with load

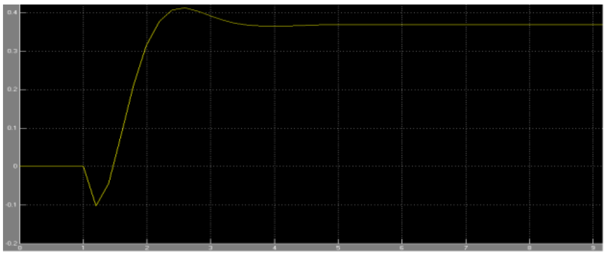

Fig. 14: System output without controller

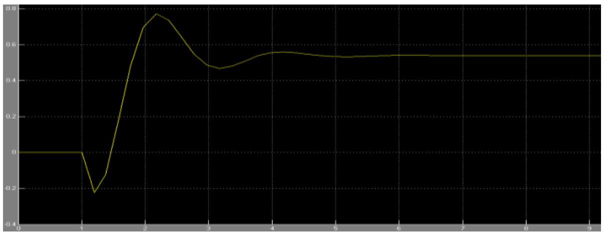

Fig. 15: System output with P controller

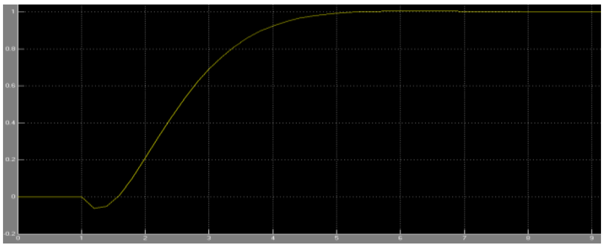

Fig. 16: System output with PI controller

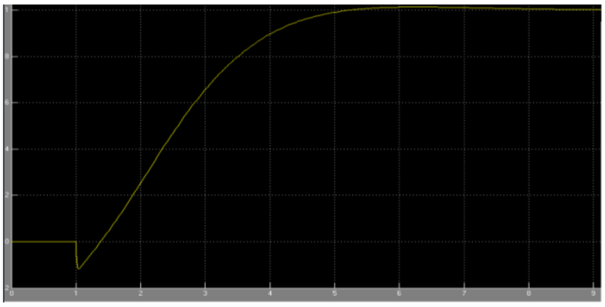

Fig. 17: System output with PID controller

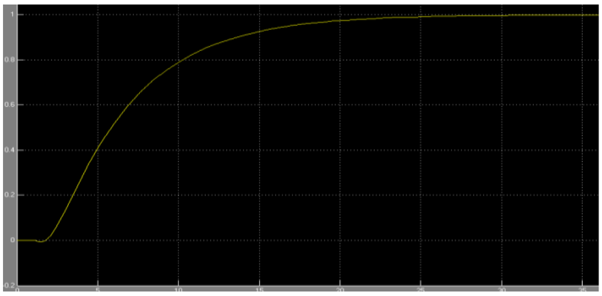

Fig. 18: System output with PID auto tuning controller (Basic Design mode)

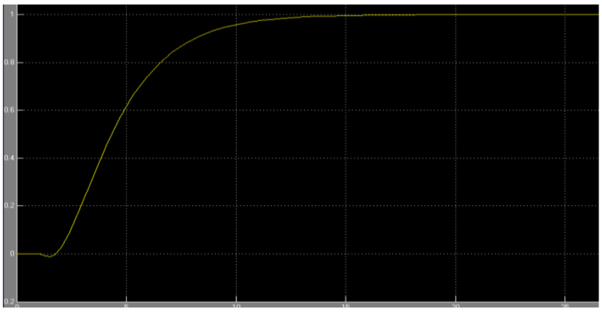

Fig. 19: System output with PID auto tuning controller (Extended Design mode)

Controller Types	K_P	K_I	K_D	Rise time (t_r in sec)	Settling time (t_s in sec)	Overshoot(%)	Undershoot(%)	Peak	Inverse response
Without controller	-	-	-	2.5	5.1	-	62	-	present
P	2	-	-	0.274	3.42	-	47	-	present
PI	0.5	1	-	2.04	3.62	0.497	0	1	present
PID	0.5	1	0.1	2.38	3.77	1.35	0	1.01	present
PID (Basic Design mode)	0	0.27383	0	10.8	20.3	0	0	0.999	negligible
PID (Extended Design mode)	**0**	**0.43604**	**0**	**5.63**	**10.6**	**0**	**0**	**1**	**negligible**

Table 2: Comparative Analysis of different tuning methods of PID controllers considering load

5. CONCLUSION

When implementation of the conventional PID controller is done to the process, it generates a very large overshoot together with undershoot. This is not the desired requirement. So after implementing auto tuner of PID controller, it can be seen that both overshoots and undershoots are reduced to a greater extent as compared to the conventional PID control. Finally the optimization is achieved in the Extended design mode of the PID controller. The CSTR concentration control is such a process which is perhaps more often used in all industrial processes including electrical, petroleum industry, power sectors, development sites, paper industry, beverages industry, etc. so the controlled stable operation of this drive attracts the researchers always, still keeping more and more future scope in it.

6. REFERENCES

[1] Yun Li,Kiam Heong Ang and Gregory C.Y.Chong, "*PID Control System Analysis and Design – Problems, Remedies, and Future Directions*". IEEE control system magazine, February 2006 pp. 32-41,2006

[2] Fried land B., "Advanced Control System Design", Prentice Hall, New Jersey, 1996.

[3] Yung C. Shin, Chengying Xu "Intelligent Systems: Modeling, Optimization, and Control" CRC Press 2009.

[4] Madlová, A., Anto¹ová, M., Baráthová, M., Polakoviè, M., ©tefuca, V., and Bále¹, V., Chem. Pap. 53, 366(1999).

[5] K.J. Astrom, & T. Hagglund, "*The future of PID control Control Engineering Practice",* pp.1163 -1175. 2001.

[6] Rajani K. Mudi, Chanchal Dey, & Tsu – Tian Lee, *"An improved auto – tuning scheme for PI controllers*", Journal of science Direct ISA Transactions, 47: 45 – 52, 2008.

[7] Luis E. Zarate, Peterson Resende, & M. Benjamin*," A Fuzzy Logic and Variable Structure Base Controller for CSTR Control*". Annual conference of IEEE, 2001.

[8] Xiao-Feng Li, Jian Sun, Hui-Yan Wu, Wei-Dong Zong, *"Application of the fuzzy PID to the Power Plant*", IEEE 2007.

[9] Schmidt, Lanny D. (1998). *The Engineering of Chemical Reactions*. New York: Oxford University Press. ISBN 0-19-510588-5

[10] Steven T.Karris, 'Introduction to Simulink with Engineering Applications', Orchard Publications,www.orchardpublications.com