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Temperature control of CSTR using PID Controller

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***Abstract*- Continuous stirred tank reactor system is a typical chemical reactor system with complex nonlinear dynamics characteristics. The purpose of this paper is to control the temperature of CSTR using PID controller and with the help of ZIEGLER NICHOLS method and we are done tuning of PID controller. The whole process of model design of and result, simulation are done in MATLAB SIMULINK software.**

Keywords- CSTR, PID, Coolant Temperature, Chemical Temperature

I. INTRODUCTION

The continuous stirred-tank reactor (CSTR), also known as vat- or backmix reactor is a common ideal reactor type in chemical engineering. A particular CSTR with a single steady-state as a function of jacket temperature may have multiple steady-state behaviour if the jacket inlet temperature is considered the manipulated. The PID algorithm is the most popular feedback controller used within the process industries. It has been successfully used for over 50 years. It is a robust easily understood algorithm that can provide excellent control performance despite the varied dynamic characteristics of process plant. Basically PID tries to correct the error between measured outputs and desired outputs of the process in order to improve the transient and steady state response as much as possible. The PID control scheme is named after its three correcting terms, whose sum constitutes the manipulated variable (MV). The proportional, integral, and derivative terms are summed to calculate the output of the PID controller. Defining u(t) as the controller output, the final form of the PID algorithm is:

$$U(t) = MV(t) = Kpe(t) + Ki\int e(t)dt + Kd\frac{de(t)}{dt}$$

In this paper 2DOF PID controller is also used because of its better control on non linear process. In order to achieve accurate and acceptable results fine tuning of the PID & 2 DOF PID is necessary and in this paper that is tried and presented.

II. MATHEMATICAL MODEL OF THE CSTR

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The mathematical model is developed from material balances. The CSTR reactor is shown in Fig 1.The mathematical model of the reactor comes from energy balance. An exothermic reaction A → B takes place in the reactor, which is in turn cooled by a coolant that flows through a jacket around the reactor. The jacket is assumed to be perfectly mixed. Heat transfer takes place through the reactor wall into jacket. The main is objective is to maintain the temperature of the reacting mixture at desired value. The manipulated variable is the coolant temperature.

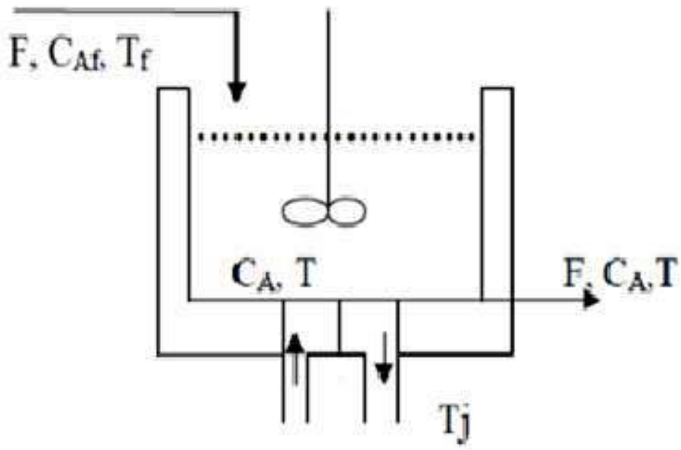

Fig .1: Continuous Stirred Tank Reactor with Cooling Jacket

The CSTR has three input signals: CAf-Concentration of feed stream, Tf -Inlet feed stream temperature, Tj- Jacket coolant temperature. The two output signals: CA Concentration of A in reactor tank, T-Reactor Temperature.

A. Overall material balance

Let us now identify the state variables for the CSTR .The CSTR process is modeled using energy conservation principle.
By applying energy balance equation,
Rate of energy accumulation = total energy input –total energy output.

$$\frac{dVp}{dt} = FinPin - FoutPout$$

Energy Balance assuming constant Cp-

$$\frac{d(Vpcp(T-Tref))}{dt} = FpCp(Tf - Tref) - FpCp(T - Tref) + (-\Delta H)Vr - UA(T - Tref)$$

B. Steady State Solution

The steady state solution is obtained when $\frac{dCA}{dt} = 0$

$and\ \frac{dT}{dt} = 0$, $that\ is$

$$F1(CA,T) = \frac{dCA}{dt} = 0 = \frac{F}{V}(CAf - CA)K0e^{-\frac{E}{RT}}CA$$

$$F2(CA,T) = \frac{dT}{dt} = 0 = \frac{F}{V}(Tf - T) + \left(-\frac{\Delta H}{pCp}\right)K0e^{\left(-\frac{E}{RT}\right)}CA - \frac{UA}{VpCp}(T - Tj)$$

To solve these two equations, all parameters and variables are specified in the Table I.

Table (1) Reactor Parameter's value

Reactor Parameter	Value
E,Btu/lbmol	32400
Ko,hr-1	$16.96 * 10^{12}$
U,Btu/hr-1	75
pCp,Btu/ft^{3of}	53.25
R,Btu/lbmolof	1.987
F,ft^3/hr	340
V, ft^3	85
Caf, lbmol/ ft^3	.132
Tf,	60
A	1221
$(-\Delta H)$,Btu/lbmol	40000
Tj	60

C. Linearization of dynamic eqeution

The stability of the non-linear equation can be found by using the following state space equation

X=AX+BU

Y=CX+DU

The non linear dynamic equations are

$$F1(CA,T) = \frac{dCA}{dt} = 0 = \frac{F}{V}(CAf - CA)K0e^{(-\frac{E}{RT})}CA$$

$$F2(CA,T) = \frac{dT}{dt} = 0 \quad = \frac{F}{V}(Tf - T) + \left(-\frac{\Delta H}{pCp}\right)K0e^{\left(-\frac{E}{RT}\right)}CA \quad - \frac{UA}{VpCp}(T - Tj)$$

Let us determine the state & Input variables in the form of a deviation variables:/RT

A=

$$\begin{bmatrix} -\frac{F}{V} - K0e^{-\frac{E}{RT}} & -K0e^{(-\frac{E}{RT})}\left(\frac{E}{RT^2}\right)CA \\ -\left(\frac{\Delta H}{pCP}\right)K0e^{-\frac{E}{RT}} & -\frac{F}{V} - \frac{UA}{VPCP} + \left(-\frac{\Delta H}{pCP}\right)K0e^{\frac{-E}{RT}}\left(\frac{E}{RT^2}\right)CA \end{bmatrix}$$

B= $\begin{matrix} 0 \\ \frac{UA}{VPCP} \end{matrix}$

C = 0 0

D = $\begin{matrix} 0 \\ 0 \end{matrix}$

Using all reactor parameter's value we can find the following

State space model system-

$$A = \begin{bmatrix} -7.3929 & -0.014674 \\ 2622.9 & 4.7534 \end{bmatrix}$$

B = $\begin{matrix} 0 \\ 1.4582 \end{matrix}$

C = 0 0

D = $\begin{matrix} 0 \\ 0 \end{matrix}$

By using MATLAB command we can find out reactor process transfer function (Gp)

$$Gp = \frac{1.4582s + 11.65}{S^2 + 3.434s + 3.557}$$

Plant output for step change

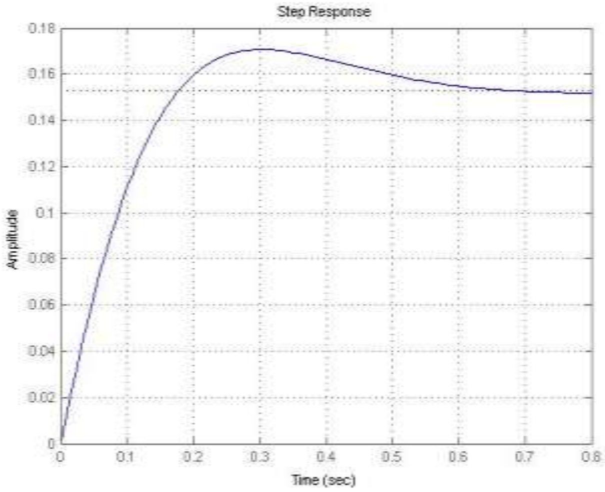

Fig: 2: Step response

The feed stream concentration is 0.132 lbmol/ft and an 50% conversion of propylene oxide has been to be determined reasonable. Since 50% of propylene oxide is converted to propylene glycol, the propylene glycol concentration is 0.066 lbmol/ft3. In this process. it is seen that the process has inverse response with delay time as well as overshoot. To overcome this problem and to obtain the desired response, we are using of PID controller and PID (two degree of freedom). For that, the controller parameters are calculated. The desired parameters for the PID controller are the proportional gain (KP) integral gain (KI) and the differential gain (KD) can be calculated by the Automatic PID tuning method in MATLAB software or Ziegler Nichols tuning method.

III. Stability Analysis

The stability of particular operating point is determined by finding the A-matrix for that particular operating point and finding the Eigen values of the A-matrix.

$$A=\begin{bmatrix} -7.3929 & -0.014674 \\ 2622.9 & 4.7534 \end{bmatrix}$$

A=[-7.9909 -0.013674;2922.9 4.5564]

Y =eig (A);

Y=-6.2737,-6.2737

Both Eigen value are (-ve) the point is stable.

IV. SIMULATION TESTING AND RESULT

The operation of the CSTR is disturbed by external factors such as changes in the feed flow rate and temperature .we need to form of control action to alleviate the impact of the changing disturbances and to keep T at desired set point (SP). In this system the manipulated temperature Tj is responsible to maintain the temperature Tat the desired SP. The CSTR with PID controller is shown in below. The reaction is exothermic and the heat generated is removed by the coolant, which flows in the jacket around the tank.

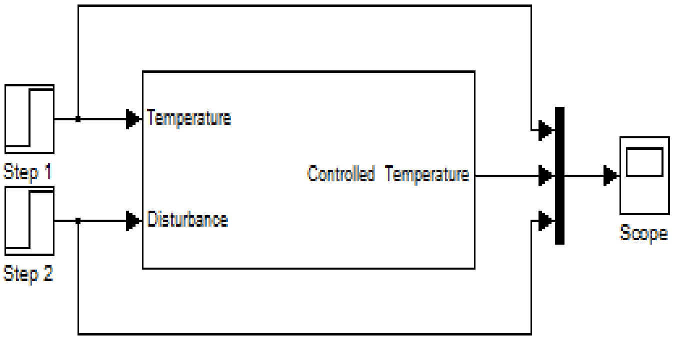

Fig.3: CSTR with One Degree of Freedom PID Controller

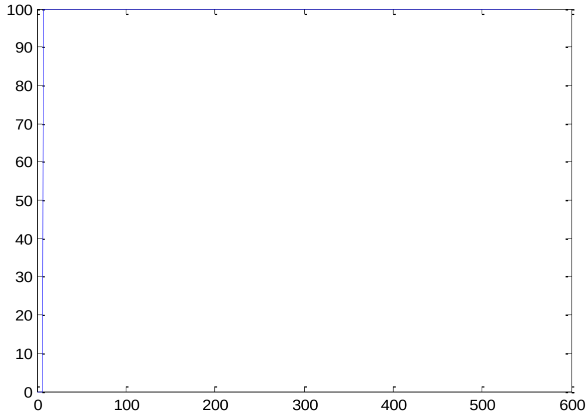

Fig. 4: Temperature response

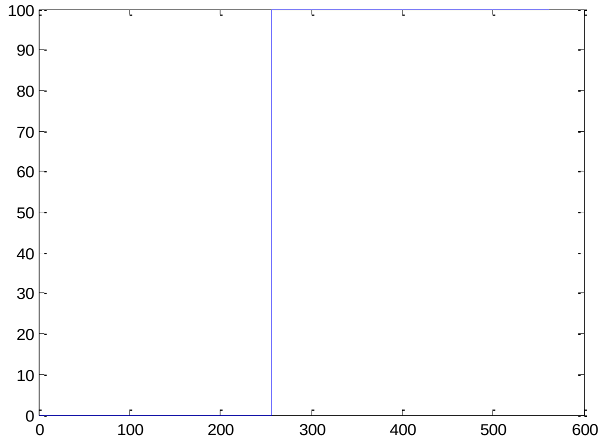

Fig.5: Disturbance Response

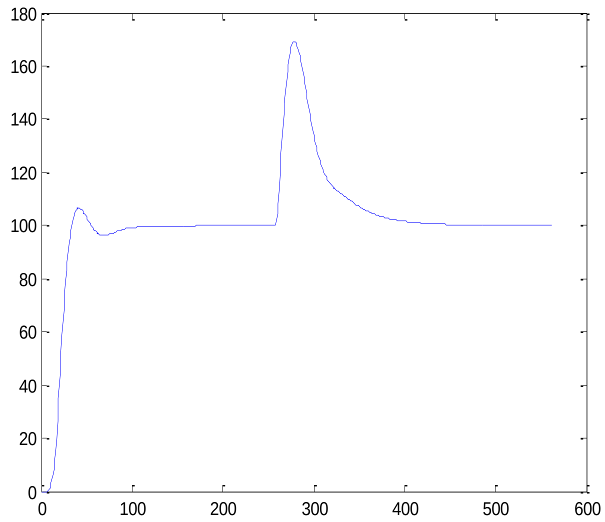

Fig.6: Controlled Temperature Response

V. CONCLUSION

When there is PID control with the system it generates a high value of overshoots with reference tracking response. The temperature control is found better with addition of two degree of freedom PID controller than PID controller**.** In this case, the overshoot been reduced to 0 % and a very small settling time has been achieved.

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