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DESIGN AND DEVELOPMENT OF MODEL BASED CONTROLLER FOR CONTINUOUS STIRRED TANK REACTOR – FERMENTATION PROCESS

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Abstract - A Model based Controller for the Continuous Stirred Tank Reactor (CSTR) is designed and developed using Proportional, Integral and Derivative (PID) Controller for the process of the biological system in the bioreactor. The model of the controller is based on the First principle method guided by experimental results. The mathematical model is a linearized representation of the state space at the point of operation and also the representation of the input output transfer function. The PID controller evaluation and simulation is simulated using process system MATLAB. The PID controller is the most versatile controller in the industry that provides the desired control action needed by adjusting those parameters to control a mechanism. To predict the plant restriction, the PID controller utilizes the control action and also the process model is explicated. The parameters of the reactor such as flow, tank level and temperature has to be controlled in the process of Continuous Stirred Tank Reactor (CSTR). In CSTR micro-organism inoculated under different conditions. The processed control algorithm enhances the conditions for the growth of micro-organisms in the bioreactor by effectively regulating the tank level and temperature of the process.

Key Words*: *CSTR, PID, First Principle, ISE, IAE, ITAE, MATLAB

1. INTRODUCTION

The Continuous Stirred Tank Reactor (CSTR) is an important subject of process control and also simulates the field of chemical and control engineering research. In order to predict CSTR's working theory, it is important to understand its dynamic characteristics which effectively involve the design of the control system. CSTR is a batch reactor equipped with an impeller for efficient mixing. A model based controller for CSTR is designed to control the parameters to get an efficient output in the process system. The CSTR is the bioreactor most commonly used for the development and inoculation of bioprocess micro – organisms. Due to its simplicity, better operation, proper mixing and control of parameters including temperature, pressure, flow, pH, mass balance, heat balance and oxygen supply. This process is conducted in continuous mode.

The ethanol is used as an alternative fuel source for petrol and other goods. Bioreactor is continuously run for the processing of ethanol. For the ethanol fermentation cycle, biomass and substrate are continuously fed into the CSTR. Fermentation is the biochemical mechanism in which the chemical degradation of substances by micro – organisms requires for the release of effervescence and heat by the action of enzyme. Inside the reactor micro – organisms perform the conversion of raw material into necessary products. The growth of micro – organism is dependent on the number of parameters such as the temperature, volume, flow, pH, etc. The growth of the micro – organisms is determined under the favourable conditions. The successful product is obtained, based on regulating the parameters. Depending on the range of temperature, micro-organisms are classified into three types namely

- Psychrophiles – T<20°C
- Mesophiles - 20°C<T<50°C
- Thermophiles – T>50°C

For example, Thermophiles are grown for the cultivation process; the growth rate will increase until it reaches the optimum temperature beyond it growth rate decrease. The parametric growth conditions are maintained and controlled by the design of the controller. Therefore the model of the CSTR is designed accordingly.

The model of Continuous Stirred Tank Heater (CSTH) is simulated using Proportional-Integral-Derivative (PID) controllers by the first principles that have heat and volumetric equations. These equations are derived from the experimental data for calibration of sensors and actuators. The CSTH model is simulated in the Simulink which provides a platform for data-driven identification and fault detection [1]. A process simulation plays a major role in education and academic research for many years to note the similarities between the performance and application of methods for control, identification and diagnosis. It is difficult to tune the three parameters such as proportional gain(K_p),, integral gain (K_I) and derivative gain (K_D) which has modeling errors, system fluctuations and so on. Hence, we move on to robust based PID controllers.

A robust PID controller is designed to control the amount of liquid in the Continuous Stirred Tank Reactor (CSTR) with safety interlocks [2]. PID tuning is performed using the open loop method by Ziegler – Nichols. To monitor single parameters such as liquid level is lower than DCS. The PID architecture is ideal for small scale enterprises and there are minimal costs to them. Under CSTR, the liquid level is regulated by changing the tank's output flow rate by keeping the inlet flow rate constant.

The PID controller used in process industries is the most effective controlling technique [4]. It is accepted today as a basic technique for the industrial process and control system. The effect of finite number of moves on the regulated variable is calculated using a process model. The CSTR process modeling is applied using first principle differential equation. The PID Control method is an easy method to tune and most efficient method for enhancing the time domain efficiency of the CSTR process. The simulation demonstrates the capability of the proposed identification strategy for the CSTR method to effectively identify the lightweight, accurate and clear model.

2. MODELLING OF CSTR

The Continuous Stirred Tank Reactor (CSTR) is a reactor with a significant focus on process control and also enhances the research area of chemical and the control engineering. It's a batch reactor with an impeller for efficient mixing. It is a vessel in which reagents and products are added and removed. The elements are continuously stirred and mixed perfectly using the impeller. The impeller is useful for the perfect blending of the elements. The CSTR is the bioreactor most commonly used to generate and inoculate micro – organisms. The bioreactor is therefore a vessel in which sterile cultivation and environmental control conditions are maintained.

The design of the CSTR is based on the following factors:

- Size of the reactor
- Reagents nature
- Temperature of the reactor
- Pressure of the reactor
- Rate of chemical reaction
- Catalyst
- Stability of reactor

CSTR's principal components are agitator, baffle, sparger and jacket. The agitator is a tool used for the stirring mechanism of the reagents to preserve the ideal homogenous conditions. This also offers the supply of oxygen and feed for getting the commodity you want. Baffles maximize the product's productivity by undeviating the fluid path through the CSTR.

This also increases the exchanger's fluid velocity and effective heat transfer coefficient. Sparger is used for trapping the air inside the CSTR. It is a tool used by the micro-organism to have sample oxygen supply. The proper air circulation also improves the overall efficiency of the operation. The jacket is a structure that can be added to the portion of the entire device. It is involves exchanges the heat between the fluid which circulates in and around the walls of the vessel. This is designed for temperature control, using heating or cooling fluid circulation. Thus temperature plays an important role in micro - organism development.

Consider the isothermal process of ethanol production which is an alternative fuel for gasoline. Ethanol is produced from the chemical reaction of sugar by a micro-organism called yeast. The CSTR process is shown in the figure where the biomass and the substrate are stirred properly to obtain ethanol.

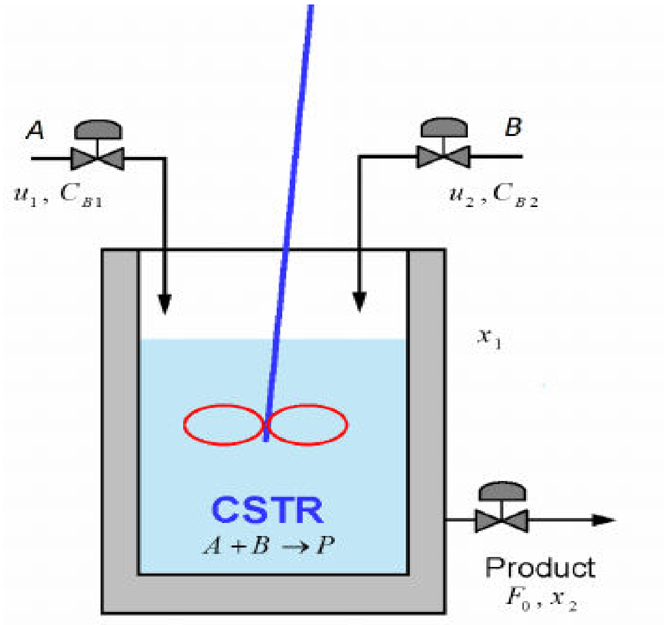

Fig. 1 Model of CSTR

The three elements of the process of the ethanol production are

- **Biomass (A):** Saccharomyces cerevisiae (yeast).
- **Substrate (B):** Glucose
- **Product (P) :** Ethanol

The overall chemical equation for the ethanol is

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

The flow and level of the plant are calculated by using range Differential Pressure Transmitter (DPT) which is in the range of 4 – 20 mA and orifice plates. The temperature is measured using the thermocouple of the type J metal. The energy passes into the jacket through the reactor walls by removing heat after reaction. The key goal is to regulate the temperature to get the optimal temperature product. Flow is the manipulated variable for the CSTR process where temperature and level are the control variable.

3. MATHEMATICAL MODELING OF CSTR

3.1 VOLUMETRIC AND HEAT BALANCE

The dynamic volumetric and heat balance equations are shown below

$$\frac{dV(x)}{dt} = f_1 + f_2 - f_{out}(x) \quad (1)$$

$$\frac{dH}{dt} = W_{st} + h_1\rho_1 f_1 + h_2\rho_2 f_2 \quad (2)$$

Where f_1 and f_2 are input feeds to the reactor and f_{out} represents the output product of the reactor and h_1, h_2 and h_{out} represents the enthalpy of feed1, feed2 and enthalpy of the end product. Then the ρ_1, ρ_2 and ρ_{out} represents the density of feed1, feed2 and the density of end product.

3.2 MASS BALANCE

The continuity equation is

$$\frac{d(\rho V)}{dt} = F\rho - F\rho = 0 \quad (3)$$

$\frac{dV}{dt} = 0$since volume is constant

3.3 CONTINUITY EQUATION OF BIOMASS

The mass balance equation for biomass is

$$\frac{d(Vx)}{dt} = Fx_i - Fx + Vr_1 \quad (4)$$

Where Fx_i - Biomass flow rate into the reactor

Fx - Biomass flow rate out of the rector

Vr_1- Biomass generation rate by reaction

$\frac{d(Vx)}{dt}$- Biomass accumulation rate within the reactor and r_1 - Cell generation rate

Dividing V on both sides,

Rate of Mass in – Rate of Mass Out +Rate of Generation = Accumulation

$$\frac{dx}{dt} = \left(\frac{F}{V}\right)x_i - \left(\frac{F}{V}\right)x + r_1 \quad (5)$$

In field of biochemical engineering, $\frac{F}{V}$ is Dilution rate (D_r)

Therefore, the simplified equation is

$$\frac{dx}{dt} = D_r x_i - D_r x + r_1 \quad (6)$$

$$\frac{dx}{dt} = D_r(x_i - x) + r_1 \quad (7)$$

3.4 CONTINUITY EQUATION OF SUBSTRATE

The mass balance equation for substrate is

$$\frac{d(VS)}{dt} = FS_i - FS - Vr_1 \quad (8)$$

whereFS_i -Substrate flow rate into the reactor

FS - Substrate flow rate out of the rector

Vr_1- Substrate generation rate by reaction

$\frac{d(VS)}{dt}$- Substrate accumulation rate within the reactor and r_1 - Cell generation rate

Dividing V on both sides,

Rate of Mass in – Rate of Mass Out +Rate of Generation = Accumulation

$$\frac{dS}{dt} = \left(\frac{F}{V}\right)S_i - \left(\frac{F}{V}\right)S + r_1 \quad (9)$$

In field of biochemical engineering, $\frac{F}{V}$ is Dilution rate (D_r)

Therefore, the simplified equation is

$$\frac{dS}{dt} = D_r S_i - D_r S - r_1 \quad (10)$$

$$\frac{dS}{dt} = D_r(S_i - S) - r_1 \quad (11)$$

For chemical reaction,$A \rightarrow P$

$$-r_A = k \quad (12)$$

$$r_A = -k(C_A)^n \quad (13)$$

Where $-(C_A)^n r_A$=Rate of disappearance of A

r_A=Rate of formation of A

k= Constant of reaction rate

n=Order of reaction of A

For first order reaction, n=1

$$-r_A = kC_A \quad (14)$$

The cell mass growth net rate,

$$r_1 = \mu x \quad (15)$$

Where µ-Specific growth rate

Yield is defined as the ratio mass of products formed to the mass of the reactants consumed.

$$Y = \frac{Mass\ of\ cells\ formed\ (A)}{Mass\ of\ substrate\ consumed\ (P)}$$

$$Y = \frac{r_1}{r_2} \quad (16)$$

$$r_2 = \frac{r_1}{Y} \quad (17)$$

$$r_2 = \frac{\mu x}{Y} \quad (18)$$

Substituting the equation (15) and (18) in (7) and (11)

$$\frac{dx}{dt} = D_r(x_i - x) + \mu x \quad (19)$$

$$\frac{dS}{dt} = D_r(S_i - S) + \left(\frac{\mu x}{Y}\right) \quad (20)$$

3.5 RELATED EQUATIONS

3.5.1 Specific enthalpy

In the well mixed case:

$$h_{out} = \frac{H}{V\rho_{out}}$$

3.5.2 Level

The lower half of the CSTR includes heating wire, so that the reactor's volume and level is not linear. The tank volume and level are experimentally tested to get their relationship.

3.5.3 Outflow

The outflow valve's normal opening condition was set at 50 per cent. The empirical equation below was obtained during this condition by obtaining a square root between the water head in centimeters above the outflow valve and the measured flow in meter cube per second.

$$f_{out} = 10^{-4}\left(0.1013 * \sqrt{(55 + x)} + 0.024\right)$$

55+ x represents the head of the tank where the outflow valve is 55cm below the bottom level of the tank and x is the level of the tank.

3.5.4 Thermodynamic properties

Using the values obtained from steam table, the conversion of h to T. T to h and T to ρ was performed and they are arranged in linear lookup tables. The relation to unique enthalpies is 0 degree Celsius.

3.5.5 Heat transfer from steam system

The heat balance when CSTR is in steady state running with cold water inflow only is

$$W_{st} = h_{out}\rho_{out}f_{out} - h_1\rho_1 f_1$$

$$f_1 = f_{out} \text{ in steady state}$$

3.6 SENSORS AND CALIBRATION

The CSTR inputs are electrical signals, which should be in the range of 4 to 20 mA range. The outputs are calculated from the instruments of temperature, level and flow should be in the range of 4 to 20 mA. Calibration was calculated by measurements with many points in the range and is represented in the model as a linear look-up table on the piece – wise.

4. EXISTING SYSTEM

4.1 BLOCK DIAGRAM

The CSTR plays an important role in micro – organism development. The primary method of sterilization is where the solvent is sterilized to destroy the micro – organisms that influence the fermentation cycle.

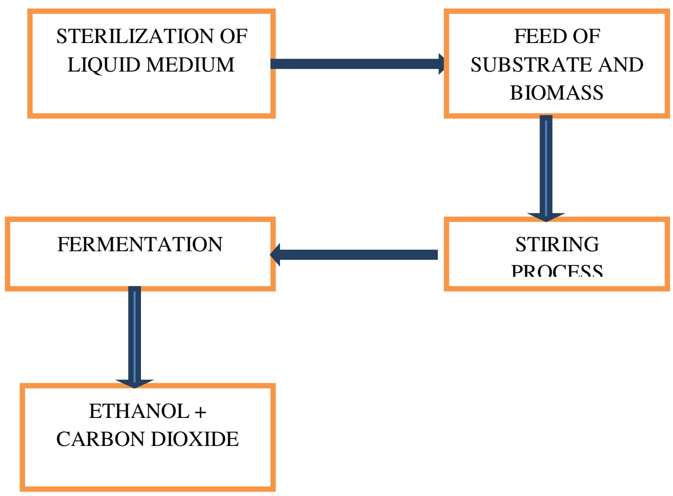

Fig 2 Block diagram of CSTR

Fermentation process carried out after sterilization. The following block diagram illustrates all of the CSTR method. The figure 2 explains the block diagram of CSTR.

4.1.1 Sterilization of liquid medium

The most commonly sterilized medium is the liquid medium which is sterilized in the batch vessel. For sterilization process, the liquid is heated by steaming the coils or jacket of the vessel. In large fermenters, the temperature increase of the medium is considered to be a sufficient time based on the rate of heat transfer. The temperature shall be kept constant for a period of time, once the temperature of the holding or sterilization has been reached. This time period is called holding time. Cooling water in the coils of fermenters is then used to reduce the medium temperature to the desired value. For batch sterilization systems, we must be able to estimate the holding time needed to achieve the desired value of cell destruction. Nutrient in the medium often killed during the killing of contaminant micro – organisms due to the effect of heat sterilization. To minimize the losses, keeping time should be kept as short as possible at the maximum sterilization temperature. Cell death happens at all stages, during the batch sterilization including the cycles of heating and cooling. The holding time is to be reduced, depending on the time of cell destructions.

The mean effective temperature of batch sterilization is considered to be 121 ° C. During this time the medium exposure is kept limited.

The batch sterilization process is designed on the following features:

- During the heating and cooling periods of the sterilization cycle, there occurs increase and decrease in the temperature of the fermentation medium
- Presence of number of micro-organisms in the medium
- 'Design' organism's thermal death characteristics.

Del Factor Calculation

Del Factor Calculation during Heating and Cooling

The relationship between Del factor, temperature and time

$$\nabla = A.t.e^{-\left(\frac{E}{RT}\right)}$$

Del factor is calculated from the heating and cooling periods of time.

Del Factor Calculation during constant temperature

Del factor is calculated during the holding time

$$\nabla_{holding} = \nabla_{overall} - \nabla_{heating} - \nabla_{cooling}$$

After the sterilization and calculation process, the contamination probability should be 1 in 1000.

4.1.2 Feed of substrate and biomass

- **Biomass:** In a bioreactor, the total mass of all organisms is known as biomass. The micro-organism used for the fermentation process is Saccharomyces cerevisiae (yeast).
- **Substrate:** Inside the bioreactor, the total volume of glucose solution consumed by micro-organisms which results in the conversion of raw material to final product.
- **Product:** It is accompanied by the reaction of micro-organisms to yield ethanol as a product.

4.1.3 Stirring process

To obtain the final product, the substrate and biomass are stirred continuously. The biomass used here is yeast and the substrate used here is glucose and both are stirred continuously to obtain the end product as ethanol.

Parameters such as temperature and level should be constantly monitored if there are any changes in these parameters which will result in the growth of micro – organisms. So, the stirring mechanism plays a major role in the fermentation process.

4.1.4 Fermentation

Since, the fermentation process has large time delay and slow dynamics inorganic salts are added with the yeast. The co-enzymes are formed by the help of inorganic salt which affect the oxygen concentration and temperature of the reactor. The overall chemical equation for the ethanol production is

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

Steps involved in the yeast fermentation

1. Sucrose is converted into ethanol where the enzyme invertase breaks the glycosidic linkage between the molecules of glucose and fructose.
$$C_{12}H_{22}O_{11} + H_2O \rightarrow 2C_6H_{12}O_6$$
2. Glucose molecule is cleaved into two pyruvate molecules. This process is called as glycolysis
$$C_6H_{12}O_6 + 2ADP + 2P_i + 2NAD^+ \rightarrow 2CH_3COCOO^- + 2ATP + 2NADH + 2H_2O + 2H^+$$
3. Pyruvate is converted into ethanol and carbon di-oxide by the following two steps
$$CH_3COCOO^- + H^+ \rightarrow CH_3CHO + CO_2$$
$$CH_3CHO + NADH + H^+ \rightarrow C_2H_5OH + NAD^+$$

4.2 WORKING PROCESS OF CSTR

CSTR is the bio reactor used mostly to cultivate micro – organisms. Sterilization is the first step in the reactor where the unwanted bacteria are destroyed and the water temperature is preserved up to 121 ° C. The liquid water is to be sterilized due to micro – organism's contamination in the bioreactor.

During the process of heat sterilization not only the infected micro – organisms have died but also the nutrients present in the medium have been lost. To minimize the losses, keeping time should be kept as short as possible at the maximum sterilization temperature. The substrate and biomass is constantly fed into the reactor. The substrate is the glucose solution used in the fermentation process at the bioreactor. The production of ethanol is affected by the presence of yeast as biomass.

The glucose and yeast are constantly mixed to produce the final product ethanol. The parameters like temperature, level and flow should be properly controlled. If those parameters change, the growth of micro – organism can be affected. Medium temperature should be kept about 30 ° C and 40 ° C. If medium temperature exceeds above optimum micro-organism growth temperature is affected. In order to solve these problems we developed a controller based on PID to obtain an efficient product. Therefore the temperature in the bioreactor plays a significant role in the development of micro- organisms.

5. LINERIZATION

5.1 STANDARD OPERATING CONDITIONS

Many examples of simulations from the literature are presented in the form of transfer function State – space model. Here too, these forms are presented to make the stirred tank reactor model suitable for linear design and analysis of control. There are two points of operation and they are linearized. One operating point is used for CSTR reaction with biomass feed and other operating point is used for both biomass and substrate feed. Time delays present in the input and output are calculated and they are reduced using different controllers. For CSTR reaction with biomass feed, one operating point is used and other operating point is used for both bio - mass and substrate feed. Time delays are calculated in the input and output. They are reduced using different controllers.

5.2 OPERATING POINT 1

5.2.1 Open loop state space model

The state space model is

$$\frac{dx}{dt} = A\underline{x} + B\underline{u}'$$

$$\underline{y}' = C\underline{x}$$

$$\begin{bmatrix} u_1'(t) \\ u_2'(t) \end{bmatrix} = \begin{bmatrix} u_1(t-1) \\ u_2(t) \end{bmatrix}$$

$$\begin{pmatrix} y_1(t) \\ y_2(t) \\ y_3(t) \end{pmatrix} = \begin{pmatrix} y_1'(t) \\ y_2'(t) \\ y_3'(t-8) \end{pmatrix}$$

Where u_1 is the biomass valve position in mA; u_2 is the steam valve position in mA; y_1 is the level measurement in mA; y_2 biomass flow measurement in mA; y_3 is the temperature measurement in mA; x_1 the tank volume, output of the integrator in the valve transfer function; x_2 the output of the integrator in the valve transfer function; x_3 the total enthalpy in the tank, output of the enthalpy in the integrator.

$$A=\begin{bmatrix} -0.3731 * 10^{-2} & 3.684 * 10^{-6} & 0 \\ 0 & -2.632 * 10^{-1} & 0 \\ 4.158 * 10^{3} & 3.696 * 10^{-1} & -2.732 * 10^{-2} \end{bmatrix}$$

$$B=\begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 1.413 \end{bmatrix}$$

$$C=\begin{bmatrix} 2690 & 0 & 0 \\ 0 & 2.842 * 10^{-1} & 0 \\ -1979.2 & 0 & 1.123 * 10^{-2} \end{bmatrix}$$

5.2.2 Open loop transfer function model

$Y(s)$, $U(s)$ are the Laplace transform of the vectors of the input and output variables. The transfer function model should be in the following form

$$Y(s) = G(s)U(s) = \begin{pmatrix} G_{11}(s) & 0 \\ G_{21}(s) & 0 \\ G_{31}(s) & G_{32}(s) \end{pmatrix} U(s)$$

$$G_{11}(s) = \frac{0.0099105 e^{-3}}{s^2 + 0.266931s + 0.0009819992}$$

$$G_{21}(s) = \frac{2.8421 * 10^{-1} e^{-s}}{s + 0.263}$$

$$G_{31}(s) = \frac{-0.003142 e^{-9s}}{s^2 + 0.291s + 0.007190624}$$

$$G_{32}(s) = \frac{0.015867 e^{-8s}}{s + 0.02732}$$

5.3 OPERATING POINT 2

5.3.1 Open loop state-space model

The state-space model is

$$\frac{dx}{dt} = A\underline{x} + B\underline{u}'$$

$$\underline{y}' = C\underline{x}$$

$$\begin{bmatrix} u_1'(t) \\ u_2'(t) \\ u_3'(t) \end{bmatrix} = \begin{bmatrix} u_1(t-1) \\ u_2(t) \\ u_3(t) \end{bmatrix}$$

$$\begin{pmatrix} y_1(t) \\ y_2(t) \\ y_3(t) \end{pmatrix} = \begin{pmatrix} y_1'(t) \\ y_2'(t) \\ y_3'(t-8) \end{pmatrix}$$

Where u_1 the biomass valve position in mA; u_2 is the steam valve position in mA;u_3 is the substrate valve position in mA.y_1 is the level measurement in mA;$u_3 y_2$ biomass flow measurement in mA; y_3 is the temperature measurement in mA; x_1 the tank volume, output of the integrator in the valve transfer function; x_2 the output of the integrator in the valve transfer function;x_3 the total enthalpy in the tank, output of the enthalpy in the integrator.

$$A = \begin{bmatrix} -0.37313 * 10^{-3} & 0.15789 * 10^{-5} & 0 \\ 0 & -0.26316 & 0 \\ 4158 & -0.15842 & 0.027316 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 & 0 & 0.429 * 10^{-4} \\ 1 & 0 & 0 \\ 0 & 0.64 & 8.8712 \end{bmatrix}$$

$$C = \begin{bmatrix} 2690 & 0 & 0 \\ 0 & 0.15132 & 0 \\ -1979.2 & 0 & 0.11226 * 10^{-1} \end{bmatrix}$$

5.3.2 Open loop transfer function model

$Y(s)$, $U(s)$ are the Laplace transform of the vectors of the input and output variables. The transfer function model should be in the following form

$$Y(s) = G(s)U(s) = \begin{bmatrix} G_{11}(s) & 0 & G_{13}(s) \\ G_{21}(s) & 0 & 0 \\ G_{31}(s) & G_{32}(s) & G_{33}(s) \end{bmatrix} U(s)$$

Where

$$G_{11}(s) = \frac{0.4274 * 10^{-2} e^{-s}}{s^2 + 0.266931s + 0.0009819992}$$

$$G_{21}(s) = \frac{0.15132 * e^{-s}}{s + 0.2632}$$

$$G_{31}(s) = \frac{-0.0031466 * e^{-9s}}{s^2 + 0.29052s + 0.007190624}$$

$$G_{32}(s) = \frac{-0.0071849 * e^{-8s}}{s + 0.02732}$$

$$G_{13}(s) = \frac{0.11540}{s + 0.003731}$$

$$G_{32}(s) = \frac{0.014683 * e^{-8s}}{s + 0.02732}$$

6. CONTROLLER DESIGN

6.1 PID CONTROLLER

CSTR is widely used in process industries which is dynamic in nature. The Proportional-Integral-Derivative (PID) controller is the most useful controller in the industries which provide the desired control action that is required to control a process by tuning certain parameters. A linear relation exists between error and controller output in proportional control (P).

$$p = K_p e(t)$$

Where, K_P= proportional gain, $e(t)$= error. Here, the change in controller output is proportional to the error. The equation for integral controller (I) is

$$p(t) = K_I \int_0^t e(t)\,dt$$

Where, K_I = Derivative gain, $e(t)$= errorr. The equation for derivative controller (D) is

$$p(t) = K_D \frac{de(t)}{dt}$$

Where, K_D = Derivative gain. The values of K_P, K_I and K_D are tuned in the PID controller by using the Zieger-Nichols open loop method [1].

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

The T_i and T_d represents the integration time and derivative time.

The tuning method used for the tuning of PID controller is Ziegler – Nichols tuning method. This technique is also called as "Ultimate cycle method". It is a closed loop tuning method which is applicable to any system with or without any self-regulation. The procedure for tuning the PID controller is

1. The integral and derivative actions are reduced to the minimum effect when it reaches steady state at the normal level of operation.
2. When we provide periodic small disturbances as input to the system the value of the proportional gain K_p is gradually increased.
3. This process is repeated until it reaches the continuous and ascertained oscillations. This is called critical gain 'k'. Hence, the period of oscillation is called ultimate period 'T_c '.

From the critical gain and period, the settings for K_p , T_i , T_d are calculated as follows

$$K_p = 0.5K_c \,;\, T_i = \frac{T_c}{2} \,;\, T_d = \frac{T_c}{8}$$

7. OUTPUT AND DISCUSSION

7.1 OPERATING POINT 1

The level and the temperature are controlled in the CSTR. The flow is the manipulated variable in the process. The set-point of the level is 12 mA where the temperature set-point is 10.5 mA.

7.1.1 Simulink of PID

The level and temperature of the reactor should be monitored properly. The level of the plant is controlled by the outlet flow of the tank. The level and temperature are the two controlled variables and flow is the manipulated variables where level and flow are cascaded.

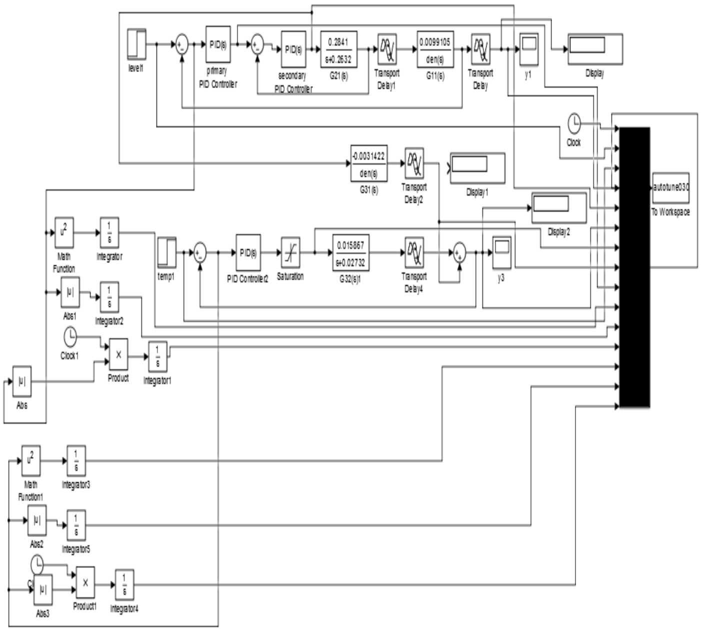

Fig 3 Simulink of PID for operating point 1

Fig 3 shows the simulation of PID for operating point 1. The error values such as ISE (Integral Square Error), ITAE (Integral Time Absolute Error), and IAE (Integral Absolute Error) are calculated and analyzed using MATLAB simulation.

From the below graph we can clearly identify that there is a peak overshoot and time delay. The settling time of this process occurs at 1328 and peak overshoot percentage is 15.8%. The offset error for the level of CSTR using PID controller is 0.51. The fig 4 shows the level response of CSTR for PID controller. The graph is drawn for the, Levelsp (mA), Levelpv (mA), and LevelPID (mA).

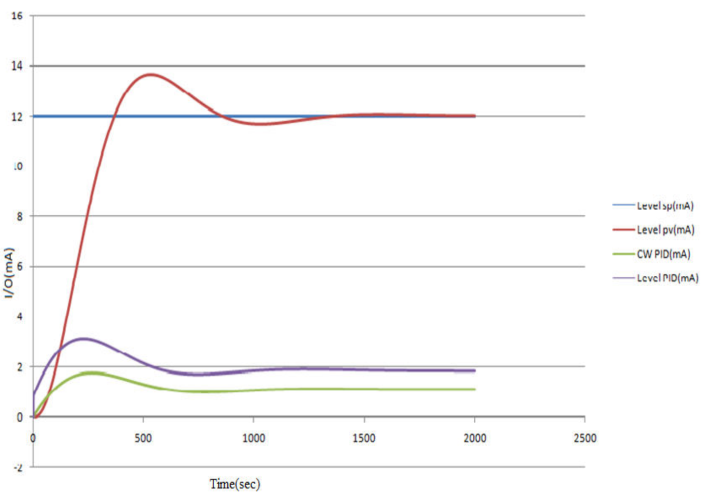

Fig 4 Level response

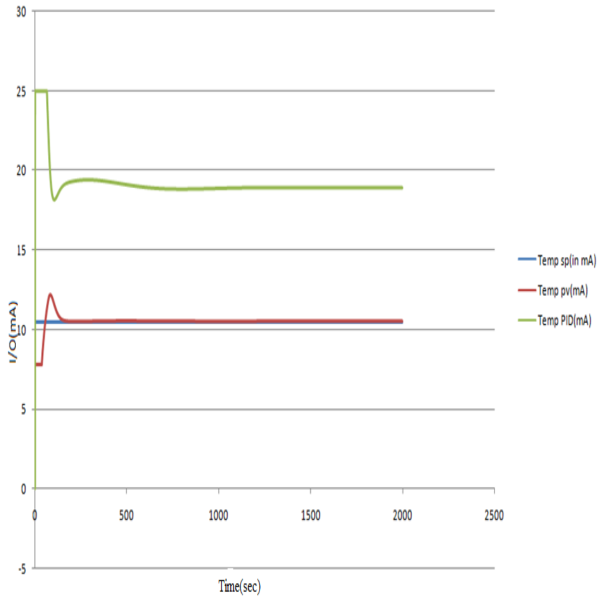

Fig 5 Temperature response

From this graph we can clearly identify that there is a peak overshoot and time delay. The settling time of this process occurs at 216.25 and peak overshoot percentage is 14.28%. The offset error for the level of CSTR using PID controller is 0.00129. The fig 5 shows the Temperature response of CSTR for PID controller. The graph is drawn for the, Tempsp (mA), Temppv (mA), and TempPID (mA).

7.2 OPERATING POINT 2

The parameter such as level and the temperature are controlled in the process of CSTR. The flow is the manipulated variable in the process. The set-point of the level is 12 mA where the temperature set-point is 10.5 mA.

7.2.1 Simulink of PID For Level

The level plays a major role in the CSTR plant. The level of the plant is controlled by the outlet flow of the tank. The output of the controller is given as feedback to the error calculator. Again, the error is given as an input to the controller.

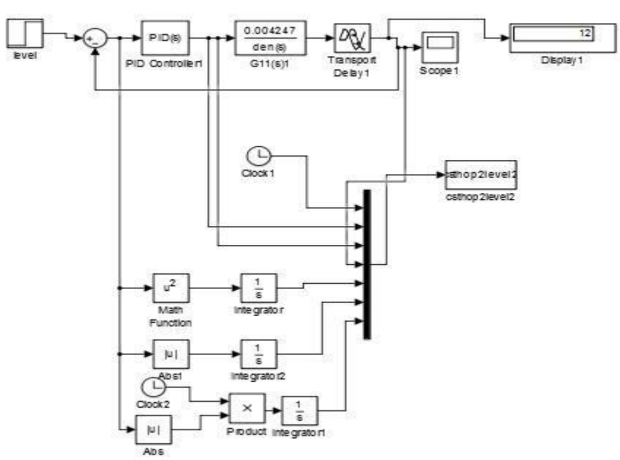

Fig 6 Simulink of PID for level

Fig 6 shows the simulation of PID controller for level of the operating point2. The error values such as LISE (Integral Square Error), LITAE (Integral Time Absolute Error) and LIAE (Integral Absolute Error) are calculated and analyzed using MATLAB simulation.

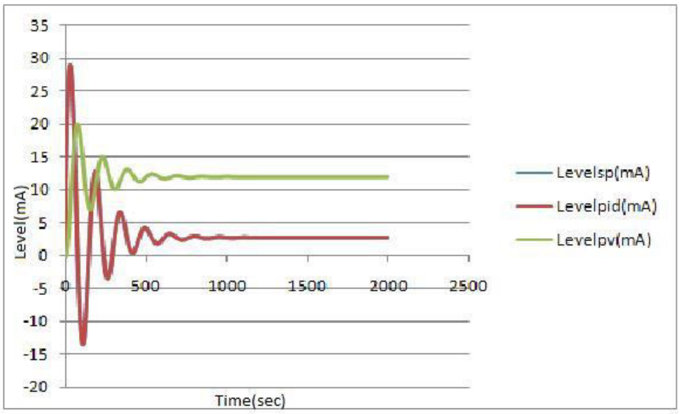

Fig. 7 Response of PID for level

From this graph we can clearly identify that there is a peak overshoot and time delay. The settling time of this process occurs at 750 and peak overshoot percentage is 15.8%. The offset error for the level of CSTR using PID controller is 0.51. The fig 7 shows the level response of CSTR for PID controller. The graph is drawn for the, Levelsp (mA), Levelpv (mA), and LevelPID (mA).

7.2.2 Simulink of PID for Temperature

The temperature is the most important factor in the CSTR plant for the growth of micro-organisms. The temperature's set point and the output of the controller is given as an input to the error detector. The output of the error detector is again given as an input to the math function and absolute error.

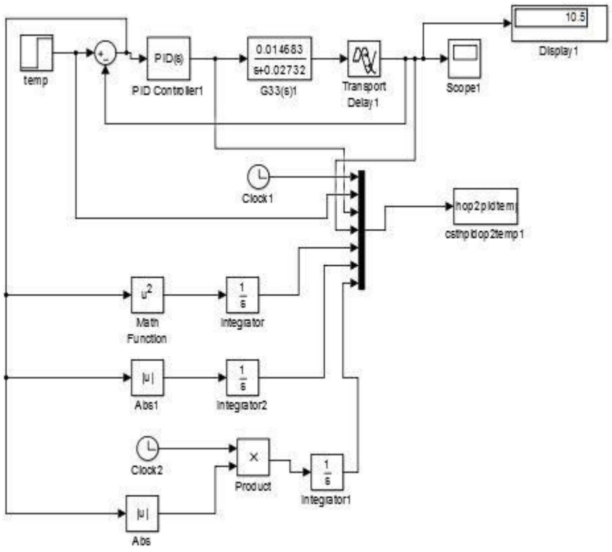

Fig 8 Simulink of PID for Temperature

Fig 8 shows the simulation of PID controller for Temperature of the operating point2. The error values such as TISE (Temperature Integral Square Error), TITAE (Temperature Integral Time Absolute Error) and TIAE (Temperature Integral Absolute Error) are calculated and analyzed using MATLAB simulation.

From the below graph we can clearly identify that there is a peak overshoot and time delay. The settling time of this process occurs at 250 and peak overshoot percentage is 12.38%. The offset error for the temperature of CSTR using PID controller is 0.51. The fig 9 shows the level response of CSTR for PID controller. The graph is drawn for the, Temperaturesp (mA), Temperaturepv (mA), and TemperaturePID (mA).

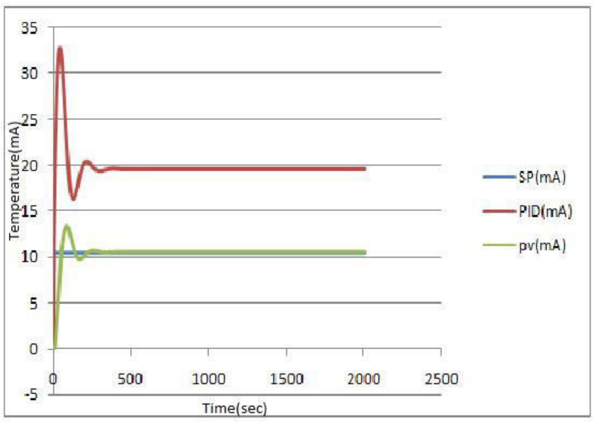

Fig 9 Temperature response

8. CONCLUSION

From the simulation results, PID provides better set point tracking capabilities under various inputs for different time. The PID based parameters tuning provides optimum values which yields efficient control action on Continuous Stirred Tank

Reactor (CSTR). Thus the manual operation is minimized by the use of PID controller in CSTR which tunes the controlled parameters effectively.

REFERENCES

[1] Nina F. Thornhill, Sachin C. Patwardhan, et.al, " A Continuous Stirred Tank Heater Simulation Model with Applications" , Journal of process control, July 2007.

[2] Munna Kumar, et.al, "Temperature control of fermentation bio-reactor for ethanol production using IMC and PID controller", Biotechnology reports, Feb 2019.

[3] K. Cahyari, et.al, "Performance of Continuous Stirred Tank Reactor (CSTR) on fermentative bio-hydrogen production from melon waste", Second international conference on chemical engineering, Jan 2013.

[4] R. Chen, K. Dave, et.al, "A non-linear dynamic model of a vinyl acetate process", Industrial and chemical industry research, 2003.

[5] Chong M L, et.al, "Bio hydrogen production from bio mass and industrial waste by dark Fermentation", International journal of hydrogen energy, 2009.

[6] Argun H, et.al, "Bio hydrogen production from waste peach pulp by dark fermentation", International journal of hydrogen energy, 2016.

[7] Reungsang, et.al, "Non-Sterile bio hydrogen fermentation from food waste in Continuous Stirred Tank Reactor (CSTR)", International journal of hydrogen energy, 2013.

[8] A. Rani, V. Singh, et.al, "Bio-reactor temperature control using modified Fractional order IMC-PID controller for ethanol production", chemical engineering research, 2017.

[9] Z K. Nagy, "Model based control of yeast fermentation bioreactor using optimally designed Artificial Neural Network", Journal of chemical engineering, 2007.

[10] M. Lawrynaczuk, "Modeling non-linear predictive control of yeast fermentation biochemical reactors using neural network", Journal of chemical engineering, 2008.

[11] Reyes-Reyes, et.al, " Temperature control of alcoholic fermentation process through T-S modeling technique", Journal of chemical research, 2018.

[12] V. Singh, A. Rani, et.al, "Two Degree of Freedom PID Based Inferential Control of Continuous Bioreactor for Ethanol Production", ISA Trans, 2017.

[13] A. Rani, V. Singh, N. Pachauri, "Two Degree of Freedom PID Based Inferential Control of Continuous Bioreactor for Ethanol Production", ISA Trans, 2017.

[14] M. Shyamalagowri, R. Rajeswari, "Model Predictive Control (MPC) design for non-linear process control reactor case study: CSTR (Continuous Stirred Tank Reactor)", IOSR Journal of Electrical and Electronics Engineering (JEEE), Aug 2013.

[15] S. Deepa, N. Anipriya, R. Subbulakshmy, "Design of Controllers for CSTR", International Journal of Power Electronics and Dynamics, Feb 2014.

[16] Vivek Agarwal, Manish Gupta, Umesh Gupta, Rahul Saraswat, "A Model Predictive Control using Multiple Linear Models for Continuous Stirred Tank Reactor (CSTR) and its Implementation Issues", Fourth International Conference on Communication Systems and Network Technologies, 2014.

[17] M. Arivalagan Masilamani, R. C Panda, K. Raj Kumar, S. Appun Raj, "Mathematical Modeling and Simulation Analysis of Continuous Stirred Tank Reactor (CSTR)", International Journal of Applied Engineer Research, 2015.

[18] Adel Abdulrahman, "Control of Yeast Fermentation Bio-reactor using Model Predictive Control based on Radial Basis Function Network Modeling", Journal of Science and Technology, 2014.

[19] Youen Zhao, Shoujun Zhou, Li Li, "Dynamic Characteristics Modelling of Continuous Stirred Tank Reactor (CSTR) Using Neural Network", First International Conference on Intelligent Networks and Intelligent Systems, 2008.

[20] Q Wu, Yj Wang, QM Zhu, K Warwick, "Neurofuzzy Model Based Predictive Control of Non – linear Continuous Stirred Tank Reactor (CSTR) system", Proceeding of the IEEE international, 2002.