CONTROL AND OPTIMIZATION OF CONTINUOUS STIRRED TANK REACTOR USING INTELLIGENT TECHNIQUE

Mr. R. Dhanasekar[1], K. C. Keerthivashan[2], V. Guruprasath[3], S Baraneetharan[4]

[1]*Assistant Professor, Department of Electronics and Instrumentation Engineering, Bannari Amman Institute of Technology, Sathyamangalam, India.*

2,3,4Final Year Students, Department of Electronics and Instrumentation Engineering, Bannari Amman Institute of Technology, Sathyamangalam, India.

Abstract -

The so called Continuous Stirred Tank Reactors (or CSTR) are the ones used in any average industrial processing which contains homogeneous liquid-phase flow reactions. These reactors are used in the above-mentioned field because of the requirement of constant agitation.

Basically, chemical reactions that in a reactor are categorized into two types, they are exothermic and endothermic. These reactions cause disturbances in functioning of the reactor either in an excess energy form or energy draining form. So, energy either to be removed or added to a reactor when it occurs. The exothermic reactions are the ones needed to be sorted out at first hand, because of it creating potential safety problems and the possibility of exotic behavior such as multiple steady states. The exothermic reactions are sorted by the flow of coolant around the tank of the reactor in a jacket at a constant flow rate to maintain the set temperature of the reactor with the help of the pump at the both sides of the reactor. The existing methods such as Ziegler-Nicholas (ZN) method is poor in response for nonlinear processes and causes a big overshoot. By using the intelligent technique to control the flow of the coolant around the reactor from the feed tank is discussed further in this research material. The proposed model is virtually simulated by the use ofMATLAB.

Keywords: CSTR (continuous stirred tank reactor), nonlinear, MATLAB, PID, MPC.

1. INTRODUCTION

CSTR plays a major role in the petrochemical industry. And the emphasis of the control and optimization of the CSTR is due to the depletion of the fossil fuels in the earth, where the leftover amount to be handled properly with low wastage as much as possible. Most petroleum and petrochemical industries are vitally dependent on a reactor like CSTR. So, the actions causing any disturbance to it need to be eradicated in the first hand. The actions or the reactions which affect the workflow of it are exothermic and endothermic reactions which is mostly possible in any activities based on homogeneous liquids. The major disturbances are caused by the exothermic reactions which additionally increase the reactor temperature and cause a drastic disturbance in the workflow. There is a major obstacle in the eradication of the exothermic reaction, i.e., the nonlinearity in the CSTR function and it causes a flaw in the control of the reactor temperature. Therefore, the energy balance equation of the CSTR is needed to be linearized in mathematical modeling. The linearized equation is used to obtain the transfer function of the CSTR. Then the transfer function is implemented in the PID and MPC controller by using MATLAB. The output from the PID and MPC controller is obtained and based on the performance the comparison is made.

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2. CSTR (Continuous Stirred Tank Reactor)

Continuous stirred tank reactors are basically used for mixing and stirring of different components to obtain desired output. Mostly CSTR operation includes homogeneous liquids, where these operations attract chemical reactions like endothermic and exothermic. In which the exothermic reaction is needed to be taken care immediately otherwise it will result in the severe disturbance in the final output. Thus, to overcome these disturbances, the reactor is surrounded by a jacket filled with coolant medium. The fluid stream is flown through the jacket from a feed tank via the help of a pump. The temperature of the reactor is maintained by controlling the flow of the coolant around the reactor through the controller. An effective control measure is needed while controlling the coolant flow and maintaining the reactor temperature. This effective control flow is obtained with the help of the transfer function implemented in the controller we use. Type of controller also plays a major role in this process.

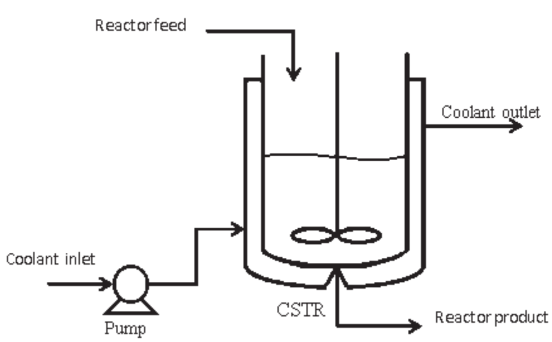


Figure 1 : CSTR

3. MATHEMATICAL MODELLING:

Mathematical modelling of the CSTR starts with acquiring of the material and energy balance equation. The following components are taken into account while framing the equation.

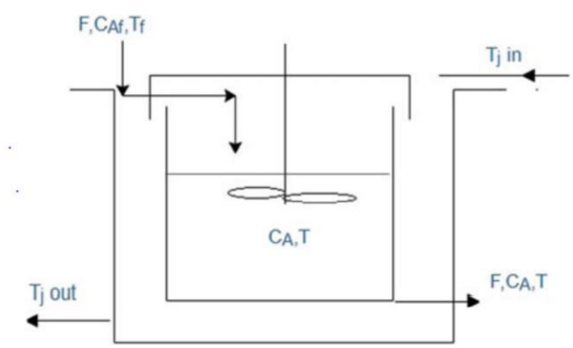
(1) The reactor temperature
(2) The coolant temperature
(3) Flow rate into the tank
(4) Volume of the tank
(5) Feed, output concentration

The components mixture inside the reactor should be maintained perfectly and the density of the incoming and outgoing stream are kept at equal in the completely insulated jacket. The reactor volume is always kept at constant.

The following equation is obtained with the help of energy balance and material equation.

□□□ / □□ = □/□ (□□□ − □□) − □0□□□(−□/□□)□□ (1)

□□ / □□ = □/□ (□□ − □) + (−□□)/□□□ □0□□□(−□/□□)□□ − □□/□□□□ (□ −□□) (2)



Following are the parameters and the values are taken from the leading journals.

E(Activation energy)	32000400 Btu/Ibmol
H (Heat of the reaction)	39000 Btu/Ibmol
K (Frequency factor)	16.96*10^12 h^{-1}
F (Volumetric flow rate)	2000 ft^3/h
V (Volume of the reactor)	5000 ft^3

State Space model of the system is obtained using the above values and the state variable C_A and T. The manipulated variable is jacket temperature (T_j) and disturbance is the feed temperature (T_f).

$$A = \begin{bmatrix} -7.990 & -0.0136 \\ 2922.9 & 5.143 \end{bmatrix}, B = \begin{bmatrix} 0 & 0 \\ 0.8713 & 4 \end{bmatrix},$$
$$C = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \quad (3)$$

Figure - 2

4. PID (Proportional Integral derivative) controller:

PID controller is a proportional integral derivative controller which works on control loop mechanism based on feedback. PID controllers are widely used in industrial areas for controlling various equipment because of its easier realization and feasibility. It is mostly used to regulate the temperature, flow, process and other variables. A PID controller can calculate error that is the difference between set point and the actual value continuously. The transfer function to be implemented in the PID controller in parallel by including the filter coefficient N is follows

$$G(s) = P + I(s) + D\frac{N_s}{s+N} \quad (7)$$

Here, G(s) is the transfer function obtained, whereas N is filter coefficient. P, I and Dare the gained parameters. Several tuning methods are seen used in the calculation of gain of the controller, here PID tuner module in MATLAB is used. This tuning provides reference tracking and effective disturbance rejection.

P = 1.317, I = 1.573, D = 0.249, N = 25.777

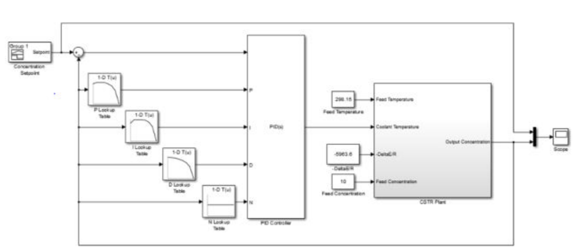


Figure - 3PID controller of CSTR.

5. MPC (Model Predictive Controller):

$$G_{cstr} = \frac{T}{T_j} = \frac{0.8714s + 6.963}{S^2 + 2.848s - 1.132} \quad (4)$$

$$G_{disturbance} = \frac{T}{T_j} = \frac{4s + 31.964}{S^2 + 2.848s - 1.132} \quad (5)$$

Eigen values of A = -3.2,0.35 (6)

MPC is generally used to predict the performance of the plant in which it is implemented. It is an advanced process control method that satisfies a set of constraints on input and output variables while controlling the process. More than one input and output processes can be easily controlled using MPC. It adjusts the manipulated variable according to the anticipation of changes in the control variable. MPCs are mostly used in the chemical industry and oil refineries. MPC will provide control action based on the future events like feed forward controller. Mainly predictions are done based on the step response model.

The objectivefunction (J) is minimized by the optimizer with the best set of control units. And the predicted output comes as close to the reference.

$$J = \sum_{i=1}^{p} e(k+i)^T \alpha e(k+i) + \sum_{i=0}^{q-1} \Delta u(k+i)^T \beta \Delta u(k+i)$$
(8)

A powerful fast processor with the capability of large memory is required because of the optimization procedure.

Sample time = 1 sec
Prediction horizon = 20
Control horizon = 5
Rate of weight of manipulated variable = 0.2, Weight of output variable = [0,4]

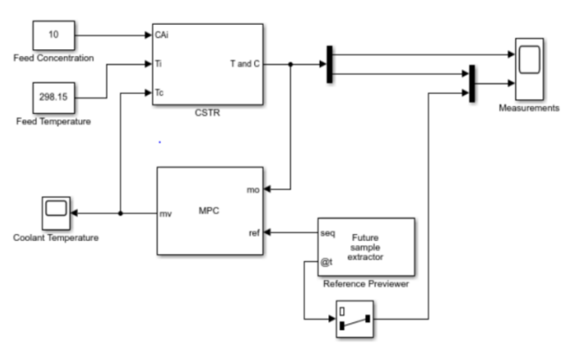


Figure - 4:MPC controller of CSTR

6. RESULTS:

The step response of the PID and MPC control systems are shown in the figure - 5. In figure - 6 with disturbance PID controller is seen showing overshoot behavior that constantly increases. This overshoot behavior seems to be last for only 10 - 15 seconds in the simulation, but when comparing with original time response it may catch up to several hours which seriously affects the output and may cause other side reactions

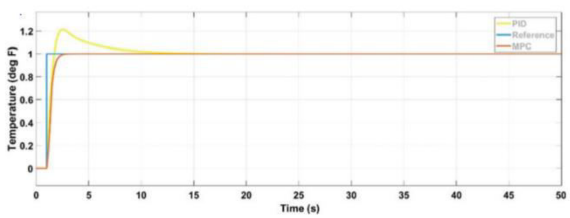


Figure - 5 : step response of PID and MPC controller.

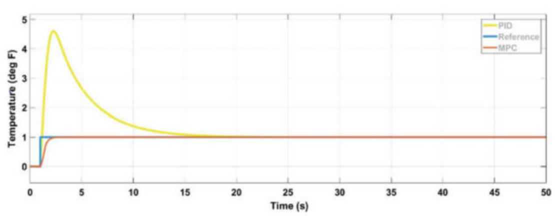


Figure -6: Step response with disturbance

Since the overshoot caused by PID controller

It is required to use an MPC controller to give the output temperature of the reactor as predicted with no overshoot.

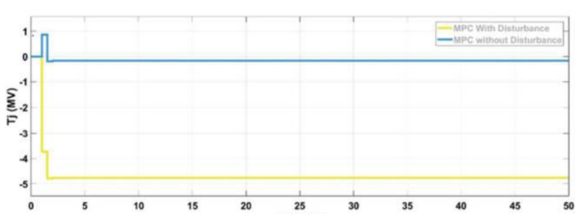


Figure - 7: Plant inputs with and without disturbance for MPC.

The manipulated variable (T_j) is constantly varied for achieving the desired output. Whereas that is not possible in PID.

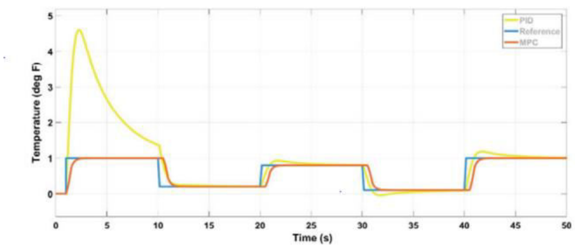


Figure - 8 : Set point tracking of the controller.

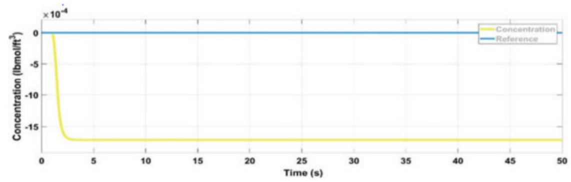


Figure - 9: Concentration (C_A) of CSTR

Controller	ISE	IAE	ITAE
PID	32.137	15.469	76.0007
MPC	0.271	0.427	0.564

7. CONCLUSION:

From the above observation and the result, it shows that MPC is the reliable temperature control of the reactor for rejecting disturbance and tracking set point. It is also more versatile and efficient. MPC gives the output concentration and the manipulated variable where the PID doesn't.

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