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# Analysis of Temperature Control of CSTR Using S Function

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*Abstract*— **Continuous stirred tank reactor system is a typical chemical reactor system with complex nonlinear dynamics characteristics. There has been considerable in his state estimation and real time control based on mathematical modelling. However the luck of understanding the dynamics of CSTR it is quite difficult to develop a mathematical model for the system. In this paper we are using S function block which is used for removing the drawback of transfer function approach. The transfer approach neglects the initial condition of the system. But S function approach accounts all the initial condition before the process.**

*Keywords*— **CSTR , PID controller, S function file, function file, state space block**

## 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 CSTR often refers to a model used to estimate the key unit operation variables when using a continuous agitated-tank reactor to reach a specified output. The mathematical model works for all fluids liquids, gases, and slurries. In a perfectly mixed reactor, the output composition is identical to composition of the material inside the reactor, which is a function of residence time and rate of reaction.

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.

$$U(t) = MV(t)=Kpe(t)+Ki\int e(t)dt+K_d\frac{de(t)}{dt} \quad ................ (1.1)$$

S-functions (system-functions) provide a powerful mechanism for extending the capabilities of the Simulink environment. An S-function is a computer language description of a Simulink block written in MATLAB, C, C++, or Fortran. S-functions are compiled as MEX files using the mex utility. As with other MEX files, S-functions are dynamically linked subroutines that the MATLAB interpreter can automatically load and execute. S-functions use a special calling syntax called the S-function API that enables you to interact with the Simulink engine. This interaction is very similar to the interaction that takes place between the engine and built-in Simulink blocks.

S-functions follow a general form and can accommodate continuous, discrete, and hybrid systems. By following a set of simple rules, you can implement an algorithm in an S-function and use the S-Function block to add it to a Simulink model.

Simulations on mathematical models has several advantages over the experiment on a real model or system. The mathematical model is developed from material balances. Simulation is very important and popular tool now a day, when computation speed of computers increases exponentially every day numerical mathematics is used for steady-state analysis and dynamic analysis. Simulation results are used for choosing of an optimal working point and an external linear model of this nonlinear plant. This paper deals with simulation experiments on one type of nonlinear systems, CSTR reactor

In this paper we are considering an exothermic reaction A → B + heat. Due to this reaction temperature of reactor increases. Our objective is to control the temperature of reactor T constant according to our requirement. The only manipulated variable is coolant temperature. The reaction is of first order.

## 2.MATHEMATICAL MODELLING

**We** can describe the dynamic behaviour of CSTR by mass balance and energy balance. Using mass balance and energy balance we can get two differential equation of concentration and temperature.

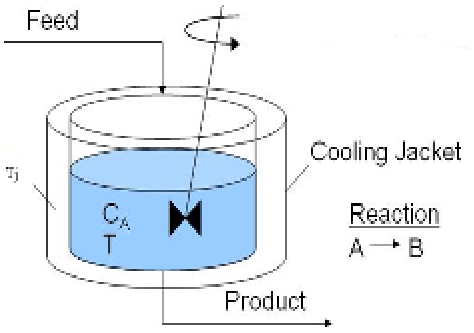

Figure1.CSTR with cooling jacket

### 2.1.Steady state solution

$$\frac{dC_A}{dt} = \frac{F}{V}(C_{Af} - C_A)\text{-}k_0 \exp\left(-\frac{E_a}{R(T+460)}\right)C_A........$$

(1.2)

$$\frac{dT}{dt} = \frac{F}{V}(T_f - T) + \frac{-\Delta H}{\rho C_p} k_0 \exp\left(-\frac{E_a}{R(T+460)}\right)C_A - \frac{UA}{V\rho c_p}(T - T_J) .........(1.3)$$

### 2.2 Creating reactor function file

With the complexity of medium-size to large-size nonlinear models, it may be more efficient to use a set of differential equations written in an m-file.

```
m- file for nonisothermal CSTR
function    dx = reactor(t,x,Tj)
Ca  = x(1)          ;  % lbmol/ft^3
T   = x(2)        ;  % oF
Ea  = 32400        ;  % BTU/lbmol
k0  = 15e12        ;  % hr^-1
dH  = -45000        ;  % BTU/lbmol
U   = 75          ;  % BTU/hr-ft^2-oF
rhocp = 53.25       ;  % BTU/ft^3
R   = 1.987         ;  % BTU/lbmol-oF
V   = 750           ;  % ft^3
F   = 3000          ;  % ft^3/hr
Caf = 0.132         ;  % lbmol/ft^3
Tf  = 60          ;  % oF
A = 1221            ;  % ft^2
ra  = k0*exp(-Ea/(R*(T+460)))*Ca;
dCa = (F/V)*(Caf-Ca)-ra;
dT  = (F/V)*(Tf-T)-(dH)/(rhocp)*ra-(U*A)/(rhocp*V)*(T-
Tj);
dx =[dCa;dT];
```

### 2.3 Writing S function file

Above m-files will be accessed by Simulink through the S-function block. Thus, this method mixes the advantages of an m-file which can be run directly by solvers such as ode45, with the graphical links to other Simulink blocks

```
6.function
[sys,x0,str,ts]=reactor_sfcn(t,x,u,flag,Cinit,Tinit)
switch flag
case 0  % initialize
str=[]                    ;
ts = [0 0]                ;
s = simsizes              ;
s.NumContStates = 2     ;
s.NumDiscStates = 0     ;
s.NumOutputs = 2        ;
s.NumInputs = 1         ;
s.DirFeedthrough = 0    ;
s.NumSampleTimes = 1    ;
sys = simsizes(s)         ;
x0 = [Cinit, Tinit]       ;
case 1
Tj  = u                  ;
sys = reactor(t,x,Tj)     ;
case 3  % output
sys = x                  ;
case {2 4 9}
sys =[]                  ;
otherwise
error(['unhandled flag =',num2str(flag)])   ;
end
```

### 2.4. Linearization of model using MATLAB command

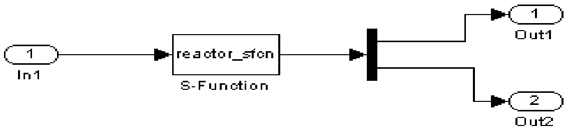

Figure2.

[A,B,C,D] = linmod('simulink1',.08,80)

To liberalize the system we have to use limmod command at operating point (.08,80) Then we get state space model of CSTR in matrix form.

$$A = \begin{bmatrix} -4.0060 & -0.0000 \\ 5.1074 & -6.2615 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 \\ 2.2930 \end{bmatrix}$$

$$C = \begin{bmatrix} 1.0000 & 0 \\ 0 & 1.0000 \end{bmatrix}$$

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

In the proposed CSTR, an irreversible exothermic reaction takes place. The heat of the reaction is removed by a coolant medium that flows through a jacket around the reactor. The fluid inside the reactor is perfectly mixed and sent out through the exit valve .The jacket surrounding the reactor also has feed and exit streams. The jacket is assumed to be perfectly mixed and at a lower temperature than the reactor.

The feed stream concentration is 0.132 lbmol/ft and an 40% conversion of A has been to be determined reasonable. Since 40% of A is converted to B, remaining concentration of A is 0.08 lbmol/ft$^3$. The initial condition of concentration and temperature before the process has been started is .1 lbmol/ft$^3$ and 40 $^0$F.

Our objective is to control the temperature of reactor T constant at 80$^0$F by manipulating the coolant temperature.

### 3.SIMULATION TESTING AND RESULT

Simulink design of Open loop system with initial condition and unit step input.

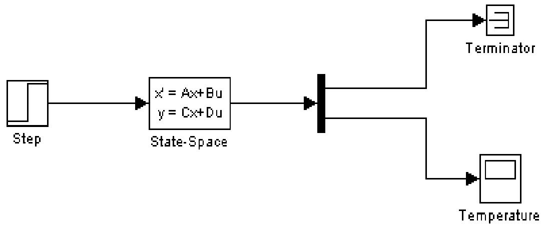

Figure3.

Open loop response of system

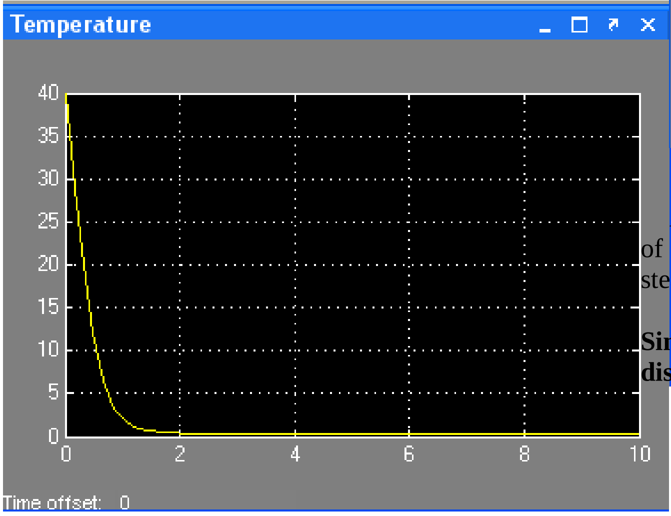

Figure4.

**Uncontrolled closed loop Simulink design of system**

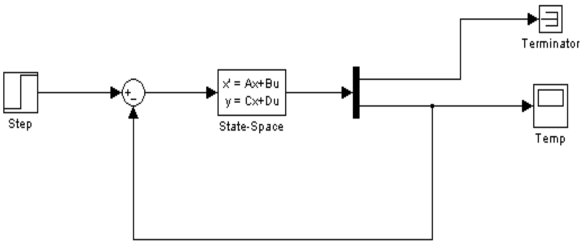

Figure5. Uncontrolled process

In this case we are giving set point value ($80^0$F) and feedback. No controlling element are used for controlling the process.

Uncontrolled closed loop response

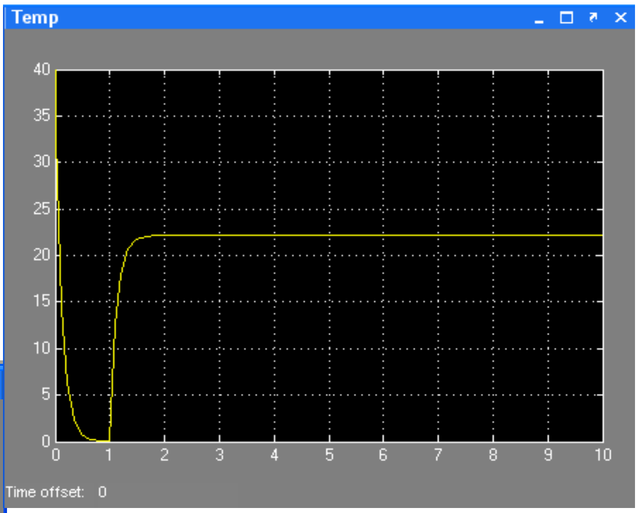

Figure6.

As observe from the figure6. The temperature response of system generates huge amount steady state error. This steady state error can be removed by using PID controller.

**Simulink design of system with PID controller with no disturbance**

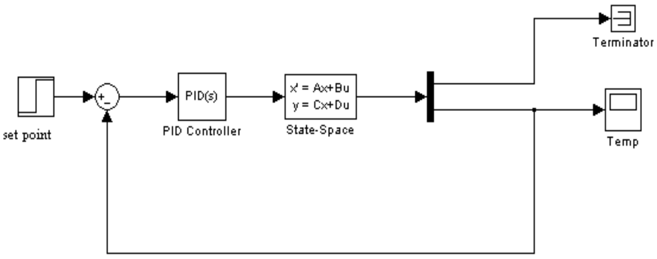

Figure6. CSTR with PID controller

Temperature output response with PID controller

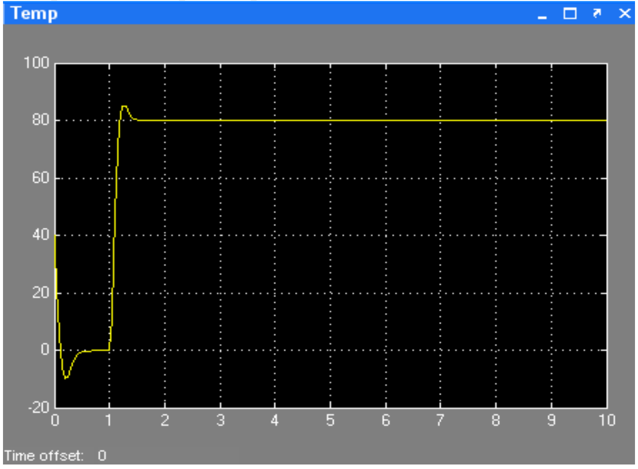

Figure7.

As observe from the figure7.

Settling time = 1.5 (sec) overshoot = 6%

Steady state error = 0

**Simulink design of system with PID controller with disturbance**

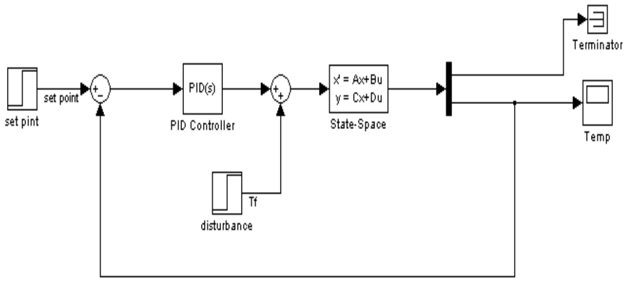

Figure8. CSTR with PID controller and disturbance

The tuning of controller parameters is done by automatic PID tuning method. Here the value of all PID controller parameter as follows

$K_P$ = .48 , $K_I$ =.3 , $K_D$ = -.10

Temperature output response with PID controller and disturbance

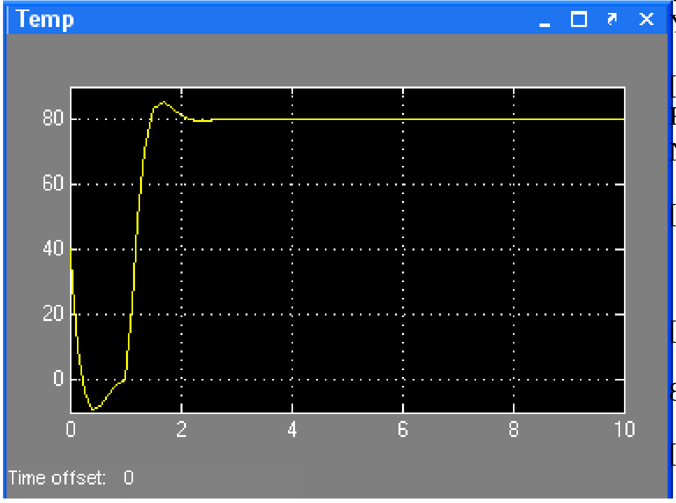

Figure9.

As observe from the figure9.
Settling time = 2.8(sec) overshoot = 9%
Steady state error = 0

## 4.CONCLUSION

In case of uncontrolled process response produce huge amount of steady state error. But when PID controller is used with no disturbance, the response settling time is 1.5 second and overshoot 6%.
But when PID controller is used with disturbance, the response settling time is 2.8 second and overshoot 9%.

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