Question 1 b) Designing Simulink model & Steady-state

First order equations, f(x,u):

```
-(Fi/V+alpha*exp(-beta/x(2)))*x(1) + Fi/V*u(1)
Fi/V*Ti - Fi/V*x(2) - (delta_Hr)/(pho*Cp)*alpha*exp(-beta/x(2))*x(1)
```

Number of states = 2

Differential Equation Editor   (Fcn block syntax)

Name: Reactor

# of inputs: 1

First order equations, f(x,u):   x0

```
-(Fi/V+alpha*exp(-beta/x(2)))*x(1) + Fi/V*u(1)
Fi/V*Ti - Fi/V*x(2) - (delta_Hr)/(pho*Cp)*alpha*exp(-beta/x(2))*x(1)
```

dx/dt=

```
CAinit
Tinit
```

Number of states = 2   Total = 2

Output Equations, f(x,u):

```
x(1)
x(2)
```

y =

Model Workspace

Workspace data

Data source: MATLAB Code

MATLAB Code:

```matlab
1  Ti = 549.67;
2  Cp = 0.8;
3  pho = 52;
4  delta_Hr = -500*10^3;
5  V = 1200;
6  Fi = 20;
7  alpha = 2.4*10^15;
8  beta = 2*10^4;
9  Cp = 1.05506*10^3*0.8; % Converted to kJ/l
10 CAiss = 0.8;
11 Tinit = 559;
12 CAinit = 0.0193;
```

```
>> ss_point

 Operating point for the Model Q1_model.
 (Time-Varying Components Evaluated at time t=0)

States:
----------
(1.) Q1_model/Reactor Model/Integ1
        x: 0.0193
(2.) Q1_model/Reactor Model/Integ2
        x: 559

Inputs:
----------
(1.) Q1_model/FR
        u: 0.8
```

Steady State values obtained using **findop**:

$C_{A,ss}$ = 0.0193 lb/ft^3

T_{ss} = 558.564 Rankine = 98.894 Fahrenheit

Question 1 c) Transfer function form

From c_{Ai} to c_A

```
>> G(1)

ans =

   0.01667 s + 0.0001194
  -----------------------
  s^2 + 0.6996 s + 0.01138

Continuous-time transfer function.
```

From c_{Ai} to T_i

```
>> G(2)

ans =

          0.1283
  -----------------------
  s^2 + 0.6996 s + 0.01138

Continuous-time transfer function.
```

Verified using hand calculations in hand written part

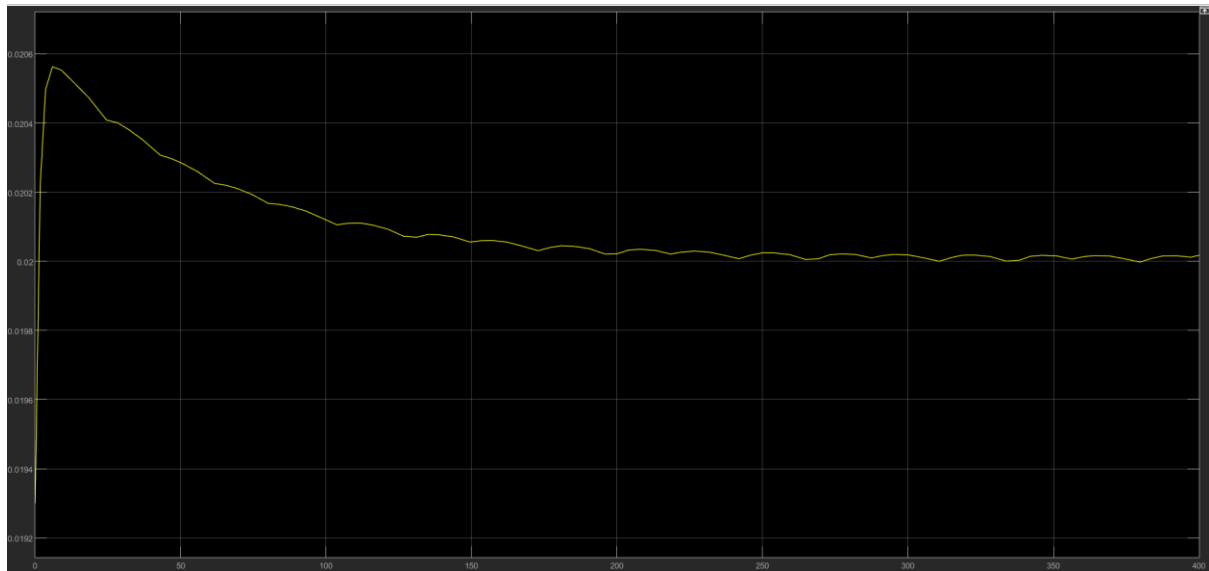## Question 1d): Step response for 10% step change in C_{Ai}

Figure 1: C_A response (non linear model)

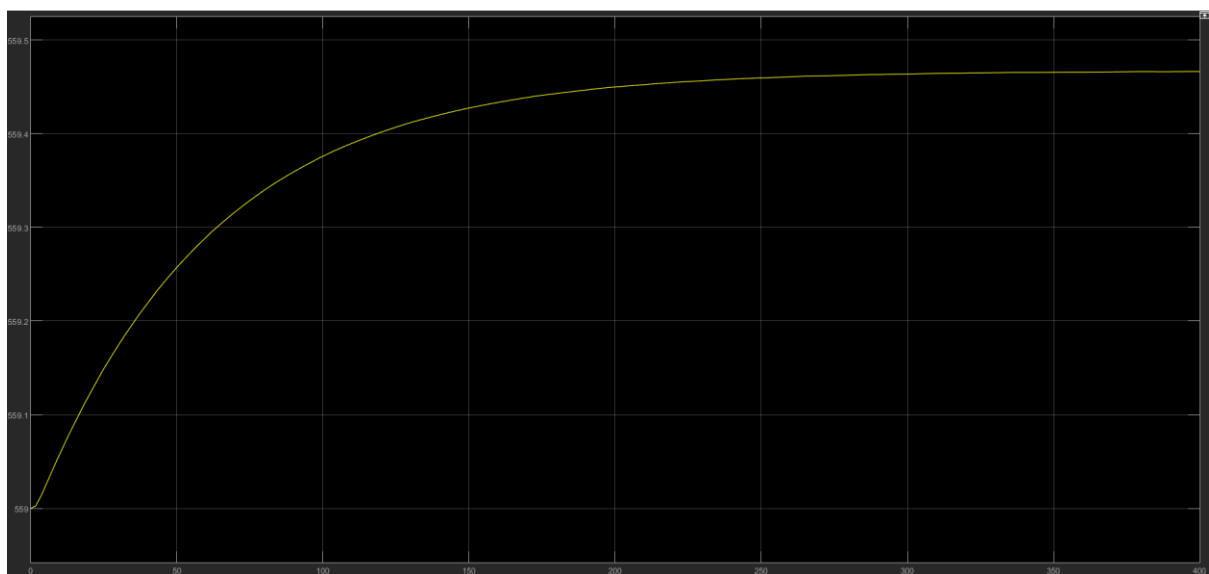$C_{A,ss}$ **= 0.0200** (obtained from out.yout)

Figure 2: T response (non-linear model)

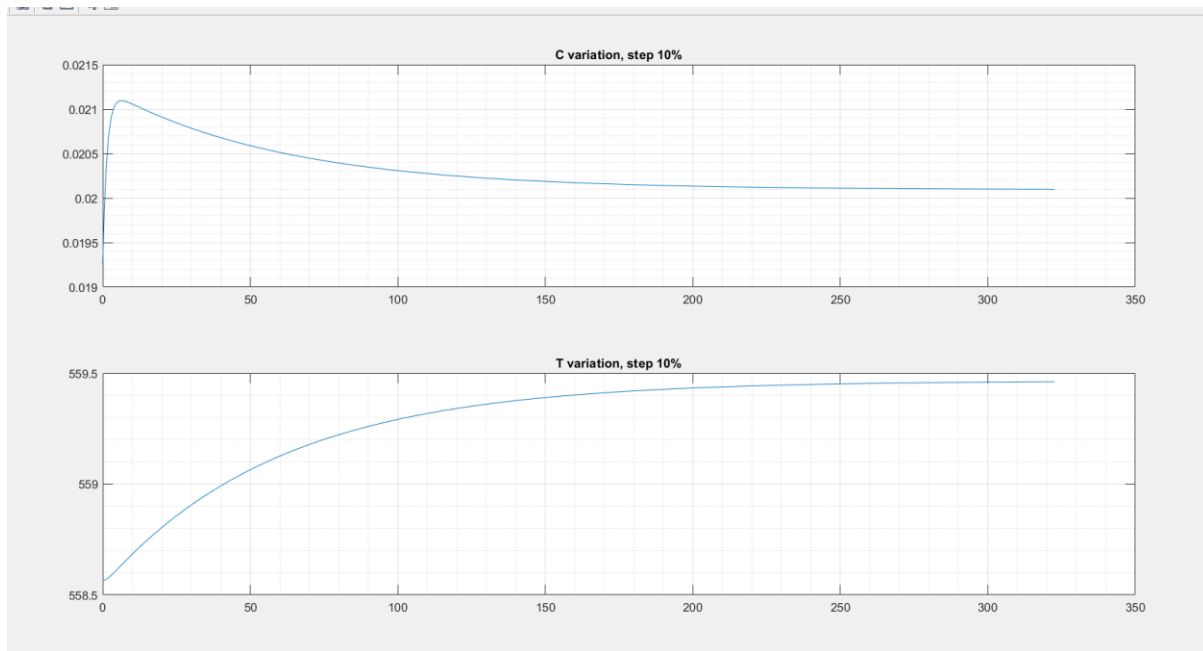T_{ss} **= 559.4663 Rankine = 99.7963 Fahrenheit**

Figure 3: Response from linear models

$C_{A,ss}$ = 0.0201 and **T_{ss} = 559.462 Rankine = 99.792 Fahrenheit**

% error in **$C_{A,ss}$**: 0.5 % and % error in **T_{ss}**: 0.004%. We see that the errors are not huge. So for computational simplicity we can adopt a linear model (provided input conditions aren't altered much)

Question 1 e)

Gain_C = (0.2-0.0193)/0.08 = 2.2588

Gain_T = (559.4663-558.564)/0.08 = 11.278

From the gains we can see that for a unit change in input variable, **Temperature** of reactor is affected more than the **concentration of A** in the reactor.

MATLAB Code

```
clear; close all;
%% Part b) Find steady-state and linearise
open_system('Q1_model')
% Read the operating conditions into an object
opc = operspec('Q1_model');
% Operating conditions
opc.Inputs.u = 0.8;
opc.Inputs.Known = 1;
% Constraints
%opc.States(1).Min = 0;opc.States(2).Min = 0;
%opc.States(1).Max = 0.8;
% Find the steady state point
ss_point = findop('Q1_model',opc);
% Linearize
linsys = linearize('Q1_model',ss_point); %Using lin mod: linmod('Q3_model',x_ss,[80 100])
[NUM, DEN] = ss2tf(linsys.A,linsys.B,linsys.C,linsys.D);
```

```matlab
NUM = {NUM(1,:) NUM(2,:)};
G = tf(NUM,DEN);
%% Hand calculations
Css=ss_point.States(1).x;
Tss=ss_point.States(2).x;
Ti = 549.67;
Cp = 0.8;
pho = 52;
delta_Hr = -500*10^3;
V = 1200;
Fi = 20;
alpha = 2.4*10^15;
beta = 2*10^4;
Cp = 1.05506*10^3*0.8; % Converted to kJ/lb
CAiss = 0.8;
Tinit = 559;
CAinit = 0.0193;
A =  zeros(2);
A(1,:) = [-(Fi/V + alpha*exp(-beta/Tss))  -alpha*exp(-beta/Tss)*beta/Tss^2*Css];
A(2,:) = [-delta_Hr/(pho*Cp)*alpha*exp(-beta/Tss) -delta_Hr/(pho*Cp)*alpha*exp(-beta/Tss)*beta/Tss^2*Css-Fi/V];
B = [Fi/V;0];
C = eye(2);
%% Part d): Computing response
% Since linear system, changes in input and output are proportional
[Y,T,X]=step(linsys);
figure();
subplot(2,1,1);plot(T,Y(:,1)*0.1*0.8+Css); title('C variation, step 10%');
grid on; grid minor;
subplot(2,1,2);plot(T,Y(:,2)*0.1*0.8+Tss); title('T variation, step 10%');
grid on; grid minor;
%% Part e): Comparing gains
Gain_T = 0.4663/0.08;
Gain_C = (0.2-0.0193)/0.08;
```

Simulink model: