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```
clear; clc;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Solution for ChE 231 MATLAB Assignment 3 %
%           Spring 2017                    %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

## Given Parameters

---

Define given parameters

```
Y_XS=0.4; %g/g
alpha=2.5; %g/g
beta=0.15; %/hr
mu_m=0.8; %/hr
Pm=52; %g/L
Km=1.7; %g/L
Ki=20; %g/L
D=0.2; %/hr
Sf=10; %g/L
p=[Y_XS alpha beta mu_m Pm Km Ki D Sf];

% % Plot differential equations at various concentrations
% % in order to visually find range around each steady state
% X_vec=0:0.1:4; S_vec=0:0.1:2; P_vec=0:1:5;
%
% for k=1:length(P_vec)
%     for j=1:length(S_vec)
%         for i=1:length(X_vec)
%             X=X_vec(i);
%             S=S_vec(j);
%             P=P_vec(k);
%             F=bioreactor([X,S,P],p);
%             dX(i,j)=F(1);
%             dS(i,j)=F(2);
%             dP(i,j)=F(3);
%         end
%     end
%     figure(k)
%     mesh(X_vec,S_vec,dX','k')
%     hold on
%     mesh(X_vec,S_vec,dS')
```

```

% mesh(X_vec,S_vec,dP')
% legend('dX','dS','dP')
% xlabel('X'); ylabel('S'); zlabel('differential');
% clear dX dS dP
% end

```

## Question 1

```

display('-----')
display('Question 1:')

% solves washout steady state
x0=[0 100 0];
options=optimoptions('fsolve','display','off');
F_SS1=fsolve(@(x) bioreactor(x,p),x0,options);
display(F_SS1)

% solves washout steady state
x0=[1 1 1];
options=optimoptions('fsolve','display','off');
F_SS2=fsolve(@(x) bioreactor(x,p),x0,options);
display(F_SS2)
display('-----')

```

```

-----
Question 1:

F_SS1 =

    3.6669    0.8327   11.9175

F_SS2 =

    3.6669    0.8327   11.9175

-----

```

## Question 2

```

display('Question 2:')
display('Linearization dx/dt=Ax, where x=[X S P]':')
syms X S P
f=bioreactor([X S P],p);
A=jacobian(f,[X S P]);
X=F_SS2(1); S=F_SS2(2); P=F_SS2(3);
A=subs(A);
A=double(A);
display(A);
display('Eigen values of A:')
lambda=eig(A);
display(lambda)
display('-----')

```

Question 2:

Linearization  $dx/dt=Ax$ , where  $x=[X \ S \ P]^T$ :

A =

```
-0.0000    0.5713   -0.0183
-0.5000   -1.6283    0.0457
 0.6500    1.4283   -0.2457
```

Eigen values of A:

lambda =

```
-1.4719
-0.2022
-0.2000
```

-----

### Question 3

```
display('Question 3:')
display('(See MATLAB code for implementation of ode45 function)')
tspan=[0 10];
[t,sol]=ode45(@(t,x) bioreactor(x,p),tspan,F_SS2);

display('-----')
```

Question 3:

(See MATLAB code for implementation of ode45 function)

-----

### Question 4

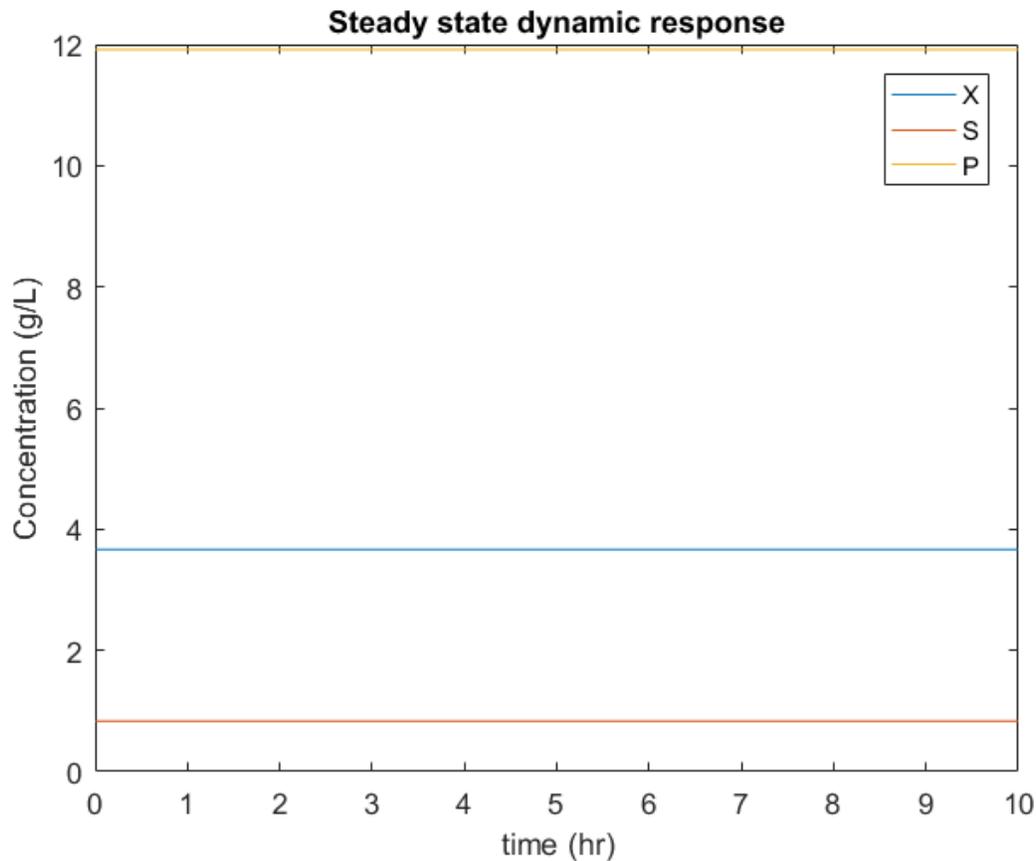
```
display('Question 4:')
display('(See figure 1)')
figure(1)
plot(t,sol)
legend('X','S','P'); xlabel('time (hr)'); ylabel('Concentration (g/L)');
title('Steady state dynamic response');
display('The dynamic responses are straight lines because the system')
display('is initially at steady state. Differentials equal zero.')
display('-----')
```

Question 4:

(See figure 1)

The dynamic responses are straight lines because the system is initially at steady state. Differentials equal zero.

-----



### Question 5

```

display('Question 4:')
D=0.15;      %/hr
p=[Y_XS alpha beta mu_m Pm Km Ki D Sf];
[t,sol]=ode45(@(t,x) bioreactor(x,p),tspan,F_SS2);
display('(See figure 2)')
figure(2)
plot(t,sol)
legend('X','S','P'); xlabel('time (hr)'); ylabel('Concentration (g/L)');
title('Dynamic response with D=0.15 hr^{-1}');

D=0.25;      %/hr
p=[Y_XS alpha beta mu_m Pm Km Ki D Sf];
[t,sol]=ode45(@(t,x) bioreactor(x,p),tspan,F_SS2);
display('(See figure 3)')
figure(3)
plot(t,sol)
legend('X','S','P'); xlabel('time (hr)'); ylabel('Concentration (g/L)');
title('Dynamic response with D=0.25 hr^{-1}');
set(gca,'FontSize',12); set(gca,'FontName','Times');
display('Biomass concentration increases with lower dilution rate,')
display('and decreases with higher dilution rate.')
display('-----')

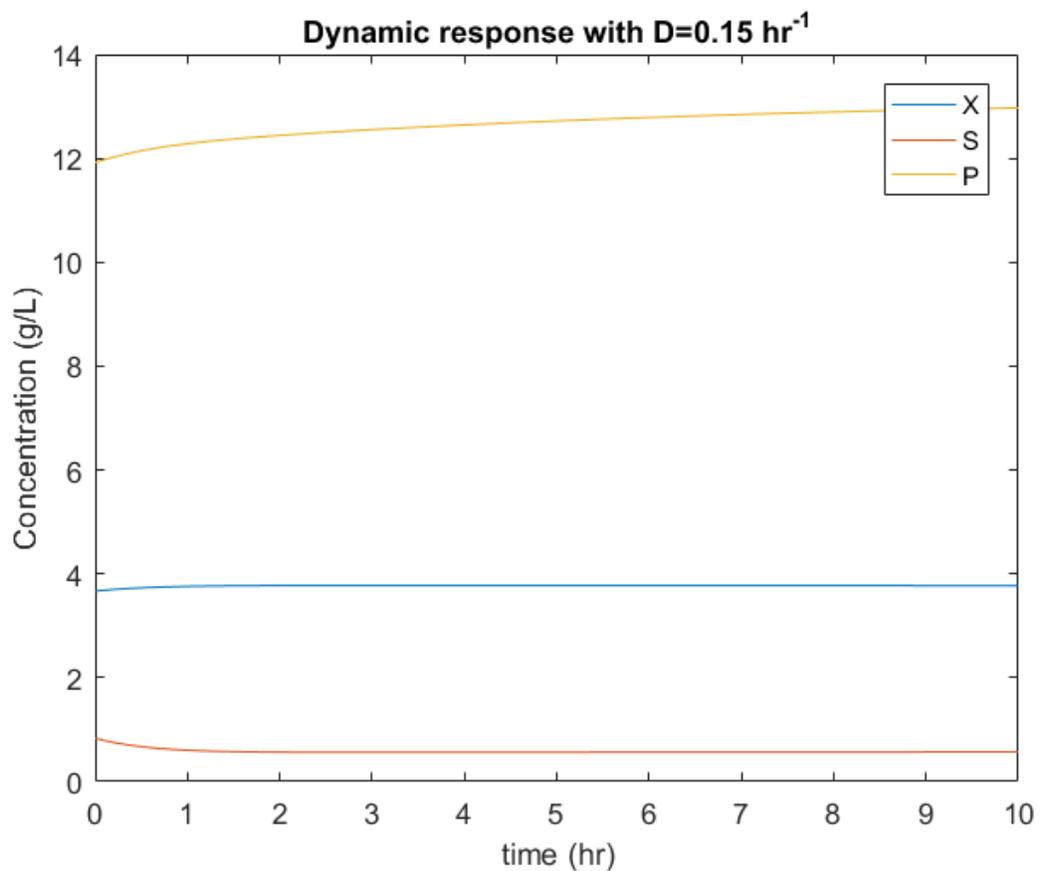
```

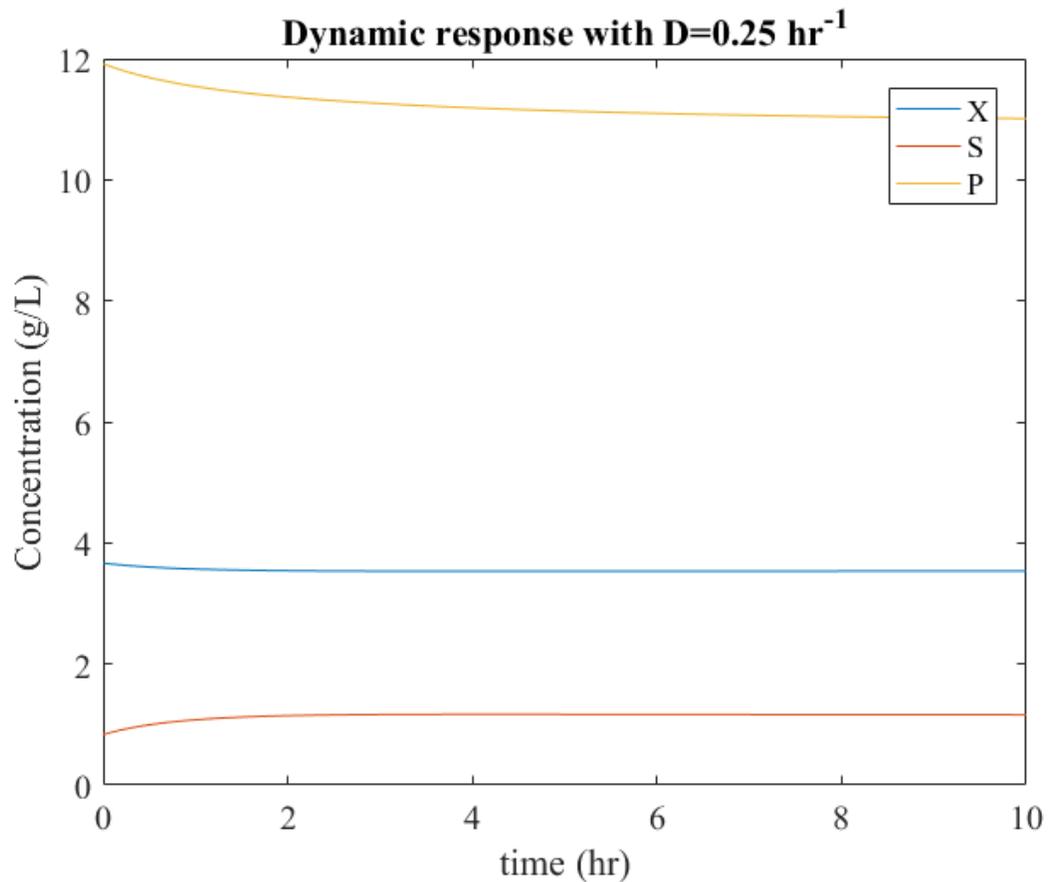
(See figure 2)

(See figure 3)

Biomass concentration increases with lower dilution rate,  
and decreases with higher dilution rate.

-----





## Question 6

```

display('Question 4:')
% First find the new jacobian matrix using new diltion rate
D=0.15;      %/hr
p=[Y_XS alpha beta mu_m Pm Km Ki D Sf];
syms X S P
f=bioreactor([X S P],p);
A=jacobian(f,[X S P]);
X=F_SS2(1); S=F_SS2(2); P=F_SS2(3);
A=subs(A);
A=double(A);
% Solve system linearized using jacobian matrix
[t,sol]=ode45(@(t,x) bioreactor_linear(x,A),tspan,F_SS2);
display('(See figure 4)')
figure(4)
plot(t,sol)
legend('X','S','P'); xlabel('time (hr)'); ylabel('Concentration (g/L)');
title('Linearized dynamic response with D=0.15 hr^{-1}');

% First find the new jacobian matrix using new diltion rate
D=0.25;      %/hr
p=[Y_XS alpha beta mu_m Pm Km Ki D Sf];
syms X S P
f=bioreactor([X S P],p);
A=jacobian(f,[X S P]);
X=F_SS2(1); S=F_SS2(2); P=F_SS2(3);
A=subs(A);
A=double(A);

```

```

% Solve system linearized using jacobian matrix
[t,sol]=ode45(@(t,x) bioreactor_linear(x,A),tspan,F_SS2);
display('(See figure 5)')
figure(5)
plot(t,sol);
legend('X','S','P'); xlabel('time (hr)'); ylabel('Concentration (g/L)');
title('Linear dynamic response with D=0.25 hr^{-1}');
display('Similar response in short time, however, non-realistic')
display('results with substrate concentration going negative.')
display('-----')

```

Question 4:

(See figure 4)

(See figure 5)

Similar response in short time, however, non-realistic  
 results with substrate concentration going negative.

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