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7.ANNEXURE

```
%evamodel.m
data;
b1_0=0;
b2_0=0;
b3_0=0;
b4_0=0;
c1_0=0;
c2_0=0;
c3_0=0;
c4_0=0;
t1_0=110;
t2_0=90;
t3_0=80;
t4_0=70;
t11_0=110;
t21_0=90;
t31_0=80;
t41_0=70;
dt = 5;
t = 0:dt:600000;
t=t';
N = length(t);
x = zeros(N,16);
x(1,:)=[b1_0,b2_0,b3_0,b4_0,c1_0,c2_0,c3_0,c4_0,t1_0,t2_0,t3_0,t4_0,
t11_0,t21_0,t31_0,t41_0];
    %initialise arrays
    A1=zeros(N-1,1);
    Z=zeros(N-1,1);


for i = 1:N-1
    % Fouling due to particulate settlement
    db1dt =(1/(2*r1*(1-
2*x(i,1))*pi*rho_sc1*h1*n1))*((kd*C1*kcon)/(krem+kcon)+kd*C1*exp(-
(krem+kcon)*(i-1)*dt)); %m
    db2dt =(1/(2*r2*(1-
2*x(i,2))*pi*rho_sc2*h2*n2))*((kd*C2*kcon)/(krem+kcon)+kd*C2*exp(-
(krem+kcon)*(i-1)*dt)); %m
```

```
    db3dt =(1/(2*r3*(1-2*x(i,3))*pi*rho_sc3*h3*n3))*((kd*C3*kcon)/(krem+kcon)+kd*C3*exp(-(krem+kcon)*(i-1)*dt)); %m

    db4dt =(1/(2*r4*(1-2*x(i,4))*pi*rho_sc4*h4*n4))*((kd*C4*kcon)/(krem+kcon)+kd*C4*exp(-(krem+kcon)*(i-1)*dt)); %m


    % Fouling due to chemical reaction calcium silicate and calcium phosphate

    dc1dt=(1/(2*r1*(1-2*x(i,5))*pi*rho_sc1*h1*n1))*(kd_s*(cb_s1-ce_s)^y1+kd_p*(cb_p1-ce_p)^y2); %m

    dc2dt=(1/(2*r2*(1-2*x(i,6))*pi*rho_sc2*h2*n2))*(kd_s*(cb_s2-ce_s)^y1+kd_p*(cb_p2-ce_p)^y2); %m

    dc3dt=(1/(2*r3*(1-2*x(i,7))*pi*rho_sc3*h3*n3))*(kd_s*(cb_s3-ce_s)^y1+kd_p*(cb_p3-ce_p)^y2); %m

    dc4dt=(1/(2*r4*(1-2*x(i,8))*pi*rho_sc4*h4*n4))*(kd_s*(cb_s4-ce_s)^y1+kd_p*(cb_p4-ce_p)^y2); %m


    %Total scale thickness by both particulate fouling and chemical precipitation

    a1=x(i,1)+x(i,5); %m

    a2=x(i,2)+x(i,6); %m

    a3=x(i,3)+x(i,7); %m

    a4=x(i,4)+x(i,8); %m


    %scale reduction after treating clear juice

    d1=a1-a;

    d2=a2-a;

    d3=a3-a;

    d4=a4-a;


    %Vapour flow rates

    v1=2*pi*(r1-a1)*h1*n1*35/3600; %kg

    v2=2*pi*(r2-a2)*h2*n3*30/3600; %kg

    v3=2*pi*(r3-a3)*h3*n3*25/3600; %kg

    v4=2*pi*(r4-a4)*h4*n4*20/3600; %kg


    %update A1 and Z1

    z=v1;

    A1(i)=a1;

    Z(i)=z;
```

```
%Vapour flow rates
v11=2*pi*(r1-d1)*h1*n1*35/3600; %kg
v21=2*pi*(r2-d2)*h2*n3*30/3600; %kg
v31=2*pi*(r3-d3)*h3*n3*25/3600; %kg
v41=2*pi*(r4-d4)*h4*n4*20/3600; %kg

% liquid outlet flowrates
l1=v1/0.4;
l2=v2/0.4;
l3=v3/0.4;
l4=v4/0.4;

% Heat capacity calculation
cp1=(4.187-x1*(0.0297-4.6*10^(-5)*p)+7.5*10^(-5)*x1*x(i,9)); %J/kgK
cp2=(4.187-x2*(0.0297-4.6*10^(-5)*p)+7.5*10^(-5)*x2*x(i,10)); %J/kgK
cp3=(4.187-x3*(0.0297-4.6*10^(-5)*p)+7.5*10^(-5)*x3*x(i,11)); %J/kgK
cp4=(4.187-x4*(0.0297-4.6*10^(-5)*p)+7.5*10^(-5)*x4*x(i,12)); %J/kgK

% Enthalpy calculation
hc1=(x(i,9)*(4.187-x1*(0.0297-4.6*10^(-5)*p)+3.75*10^(-
5)*x1*x(i,9))); %J/kg
hc2=(x(i,10)*(4.187-x2*(0.0297-4.6*10^(-5)*p)+3.75*10^(-
5)*x2*x(i,10))); %J/kg
hc3=(x(i,11)*(4.187-x3*(0.0297-4.6*10^(-5)*p)+3.75*10^(-
5)*x3*x(i,11))); %J/kg
hc4=(x(i,12)*(4.187-x4*(0.0297-4.6*10^(-5)*p)+3.75*10^(-
5)*x4*x(i,12))); %J/kg

% Temperature variation
dt1dt=(1/(pi*(r1-
a1)^2*n1*(1100)*h1*cp1*10^3))*((f/3600)*cp1*10^3*(t_f-x(i,9))-
v1*(lda1*10^3-hc1*10^3)+2*pi*(t0-x(i,9))*h1*n1/(1/(hs1*10^3*(r1-
a1))+r1*(log((r1+aw)/r1))/(2*pi*kst*10^3)+(r1-a1)*(log(abs(r1)/(r1-
a1)))/(2*pi*ksc*10^3)+1/(hj*10^3*(r1+aw))));
dt2dt=(1/(pi*(r2-
a2)^2*n2*(1150)*h2*cp2*10^3))*((l1/3600)*cp2*10^3*(x(i,9)-x(i,10))-
v2*(lda2*10^3-hc2*10^3)+2*pi*(x(i,9)-
x(i,10))*h2*n2/(1/(hs1*10^3*(r2-
a2))+r2*(log((r2+aw)/r2))/(2*pi*kst*10^3)+(r2-a2)*(log(abs(r2)/(r2-
a2)))/(2*pi*ksc*10^3)+1/(hj*10^3*(r2+aw))));
```

```
    dt3dt=(1/(pi*(r3-
a3)^2*n3*(1200)*h3*cp3*10^3))*((l2/3600)*cp3*10^3*(x(i,10)-x(i,11))-
v3*(lda3*10^3-hc3*10^3)+2*pi*(x(i,10)-
x(i,11))*h3*n3/(1/(hs1*10^3*(r3-
a3))+r3*(log((r3+aw)/r3))/(2*pi*kst*10^3)+(r3-a3)*(log(abs(r3)/(r3-
a3)))/(2*pi*ksc*10^3)+1/(hj*10^3*(r3+aw))));

    dt4dt=(1/(pi*(r4-
a4)^2*n4*(1250)*h4*cp4*10^3))*((l3/3600)*cp4*10^3*(x(i,11)-x(i,12))-
v4*(lda4*10^3-hc4*10^3)+2*pi*(x(i,11)-
x(i,12))*h4*n4/(1/(hs1*10^3*(r4-
a4))+r4*(log((r4+aw)/r4))/(2*pi*kst*10^3)+(r4-a4)*(log(abs(r4)/(r4-
a4)))/(2*pi*ksc*10^3)+1/(hj*10^3*(r4+aw))));


    % Temperature variation after juice treatment

    dt11dt=(1/(pi*(r1-
d1)^2*n1*(1100)*h1*cp1*10^3))*((f/3600)*cp1*10^3*(t_f-x(i,13))-
v11*(lda1*10^3-hc1*10^3)+2*pi*(t0-x(i,13))*h1*n1/(1/(hs1*10^3*(r1-
d1)+r1*log((r1+aw)/r1))/(2*pi*kst*10^3)+(r1-d1)*(log(abs(r1)/(r1-
d1)))/(2*pi*ksc*10^3)+1/(hj*10^3*(r1+aw))));

    dt21dt=(1/(pi*(r2-
d2)^2*n2*(1150)*h2*cp2*10^3))*((f/3600)*cp2*10^3*(x(i,13)-x(i,14))-
v21*(lda2*10^3-hc2*10^3)+2*pi*(x(i,13)-
x(i,14))*h2*n2/(1/(hs1*10^3*(r2-
d2)+r2*log((r2+aw)/r2))/(2*pi*kst*10^3)+(r2-d2)*(log(abs(r2)/(r2-
d2)))/(2*pi*ksc*10^3)+1/(hj*10^3*(r2+aw))));

    dt31dt=(1/(pi*(r3-
d3)^2*n3*(1200)*h3*cp3*10^3))*((f/3600)*cp3*10^3*(x(i,14)-x(i,15))-
v31*(lda3*10^3-hc3*10^3)+2*pi*(x(i,14)-
x(i,15))*h3*n3/(1/(hs1*10^3*(r3-
d3)+r3*log((r3+aw)/r3))/(2*pi*kst*10^3)+(r3-d3)*(log(abs(r3)/(r3-
d3)))/(2*pi*ksc*10^3)+1/(hj*10^3*(r3+aw))));

    dt41dt=(1/(pi*(r4-
d4)^2*n4*(1250)*h4*cp4*10^3))*((f/3600)*cp4*10^3*(x(i,15)-x(i,16))-
v41*(lda4*10^3-hc4*10^3)+2*pi*(x(i,15)-
x(i,16))*h4*n4/(1/(hs1*10^3*(r4-
d4)+r4*log((r4+aw)/r4))/(2*pi*kst*10^3)+(r4-d4)*(log(abs(r4)/(r4-
d4)))/(2*pi*ksc*10^3)+1/(hj*10^3*(r4+aw))));


    x(i+1,1) = x(i,1)+ db1dt*dt;

    x(i+1,2) = x(i,2)+ db2dt*dt;

    x(i+1,3) = x(i,3)+ db3dt*dt;

    x(i+1,4) = x(i,4)+ db4dt*dt;

    x(i+1,5) = x(i,5)+ dc1dt*dt;

    x(i+1,6) = x(i,6)+ dc2dt*dt;

    x(i+1,7) = x(i,7)+ dc3dt*dt;

    x(i+1,8) = x(i,8)+ dc4dt*dt;

    x(i+1,9) = x(i,9)+ dt1dt*dt;

    x(i+1,10) = x(i,10)+ dt2dt*dt;
```

```
    x(i+1,11) = x(i,11)+ dt3dt*dt;
    x(i+1,12) = x(i,12)+ dt4dt*dt;
    x(i+1,13) = x(i,13)+ dt11dt*dt;
    x(i+1,14) = x(i,14)+ dt21dt*dt;
    x(i+1,15) = x(i,15)+ dt31dt*dt;
    x(i+1,16) = x(i,16)+ dt41dt*dt;

end



figure(1);
subplot (411),plot(t,x(:,1))
title('Scale thickness-particulate fouling- 1st')
xlabel('Time,[s]')
ylabel('Thickness,m')

subplot (412),plot(t,x(:,2))
title('Scale thickness-particulate fouling- 2nd')
xlabel('Time,[s]')
ylabel('Thickness,m')

subplot (413),plot(t,x(:,3))
title('Scale thickness-particulate fouling- 3rd')
xlabel('Time,[s]')
ylabel('Thickness,m')

subplot (414),plot(t,x(:,4))
title('Scale thickness-particulate fouling- 4th')
xlabel('Time,[s]')
ylabel('Thickness,m')

figure(2);
subplot (411),plot(t,x(:,5))
title('Scale thickness-chemical precipitation-1st')
xlabel('Time,[s]')
ylabel('Thickness,m')
```

```
subplot (412),plot(t,x(:,6))
title('Scale thickness-chemical precipitation-2nd')
xlabel('Time,[s]')
ylabel('Thickness,m')

subplot (413),plot(t,x(:,7))
title('Scale thickness-chemical precipitation-3rd')
xlabel('Time,[s]')
ylabel('Thickness,m')

subplot (414),plot(t,x(:,8))
title('Scale thickness-chemical precipitation-4th')
xlabel('Time,[s]')
ylabel('Thickness,m')

figure(3);
subplot (411),plot(t,x(:,9))
title('Temperature of 1st evaporator')
xlabel('Time,[s]')
ylabel('Temp(C)')
```



```
subplot (412),plot(t,x(:,10))
title('Temperature of 2nd evaporator')
xlabel('Time,[s]')
ylabel('Temp(C)')

subplot (413),plot(t,x(:,11))
title('Temperature of 3rd evaporator')
xlabel('Time,[s]')
ylabel('Temp(C)')

subplot (414),plot(t,x(:,12))
title('Temperature of 4th evaporator')
xlabel('Time,[s]')
ylabel('Temp(C)')

figure(4);
```

```
subplot (411),plot(t,x(:,13))
title('Temperature of 1st evaporator-after juice treatment')
xlabel('Time,[s]')
ylabel('Temp(C)')

subplot (412),plot(t,x(:,14))
title('Temperature of 2nd evaporator-after juice treatment')
xlabel('Time,[s]')
ylabel('Temp(C)')

subplot (413),plot(t,x(:,15))
title('Temperature of 3rd evaporator-after juice treatment')
xlabel('Time,[s]')
ylabel('Temp(C)')

subplot (414),plot(t,x(:,16))
title('Temperature of 4th evaporator-after juice treatment')
xlabel('Time,[s]')
ylabel('Temp(C)')

figure(5);
plot(A1,Z)
title('Variation of vapour flow rate with Scale Thickness ')
xlabel('Scale Thickness (m)')
ylabel('Vapor Flow Rate (kg/s)')

% data.m

% Brix % of feed juice
xf=0.12;

% Brix of evaporators
x1=0.25;
x2=0.35;
x3=0.45;
x4=0.65;
```

```
%parameters for chemical precipitation
ce_s=6.2*10^(-4); %kg/m3 as SiO2
cb_p1=0.350; %kg/m3
cb_p2=0.450; %kg/m3
cb_p3=0.650; %kg/m3
cb_p4=0.700; %kg/m3
ce_p=1.42*10^(-9); %kg/m3 as P2O5
cb_s1=0.350; %kg/m3
cb_s2=0.450; %kg/m3
cb_s3=0.650; %kg/m3
cb_s4=0.700; %kg/m3

%Overall reaction constant
kd_s=0.01;
kd_p=0.0015;

% order of reactions
y1=1; %assumption
y2=1; %assumption

% Constants for partiulate settling
kd=0.198; %m/s
krem=0.1038; %s-1
kcon=0.024696; %s-1
C1= 0.1;  %kg/m3
C2= 0.2;  %kg/m3
C3= 0.3;  %kg/m3
C4= 0.4;  %kg/m3

%feed flow rate
f=56250; %kg /hr

%temeperature of steam C
t0=130; %C

%temperature of feed
t_f=100; %C
```

```
%Heat transfer data
hs1=35;       %kW/m2C
kst=0.045;    %kW/mC
ksc=0.00003758; %kW/mC
hj=3; %kW/m2

%thickness of the steel wall
aw=1.2*10^(-3); %m

% Height of evporator tubes
h1=2.14; %m
h2=2.14; %m
h3=1.84; %m
h4=1.84; %m

% Inner radius of evaporator tubes
r1=2.54*10^-2; %m
r2=2.54*10^-2; %m
r3=2.54*10^-2; %m
r4=2.54*10^-2; %m

% Number of tubes in each evaporator
n1=2756;
n2=2208;
n3=1360;
n4=1360;

%Purity of juice/syrup
p=0.95;

%latent heat of steam
lda1=2506; %kJ/kg
lda2=2450; %kJ/kg
lda3=2350; %kJ/kg
lda4=2300; %kJ/kg
```

```
% Density of scale
rho_sc= 1650; %kg/m3

%Electromagnetic treatment
q=1.95; % C
omega=2*pi*20;%s-1
I=15; %A
mi=1.256*10^-1;
n=500;
r=0.2; %m
alpha=9.8; %ms-2

%Effect of electromagnetic apparatus
E=omega*I*mi*n*r/2;
z=q*E/alpha;

%solving the quadratic eqaution to find the minimized scale
thickness
a = fzero(@(a) (r1-a)*a-z/(2*pi*h1*rho_sc*4*n1), 0.0004);

% density of scale varies from 1.2 to 2 % Assume linear variation
rho_sc1=1400; %kg/m3
rho_sc2=1600; %kg/m3
rho_sc3=1800; %kg/m3
rho_sc4=2000; %kg/m3
```