**%%** **\*\*\*\*\*\*\* Co-current PVDF flat sheet DCMD system tanks in series \*\*\*\*\*\*\***

clear; clc; close;

my\_file\_data=fopen('Temperature\_Membrane.dat','wt');

fprintf(my\_file\_data,'%18s %22s %22s %22s %22s %22s\n','Module\_Length (cm)','Feed\_Bulk Temp (C)','Permeate\_Bulk Temp (C)','Feed\_Boundary\_Temp (C)','Permeate\_Boundary\_Temp (C)','NaCl\_Concentration (g/kg)');

**%% ------------------------------------------ Laboratory-scale data --------------------------------------------------**

f\_l = 0.08; % Membrane length =8 cm to (m)

f\_w = 0.018; % Membrane width =1.8 cm to (m)

c\_d\_f = 0.005; % Feed channel height =5 mm to (m)

c\_d\_p = 0.005; % Permeate channel height =5 mm to (m)

m\_t = 0.00012; % Membrane thickness =0.12 mm to (m)

flux = 38.8; % Membrane water flux (kg/m2.h)

k\_m\_m = 0.19; % Membrane thermal conductivity(W/m.K)

m\_p = 0.75; % Membrane porosity

t\_fi = 71.3+273.15; % Feed inlet temperature (K)

n\_fi = 0.0167; % Feed inlet mass flow rate(kg/s)---0.01667

x\_fi = 0.03; % Feed inlet NaCl concentration =30 g/kg to(kg/kg)

t\_pi = 18.6+273.15; % Permeate inlet temperature (K)

n\_pi = 0.0166; % Permeate inlet mass flow rate(kg/s)---0.01663

**%% ----------------------------------------- Large-scale data --------------------------------------------------**

f\_l\_l = 1 ; % Membrane length = 100 cm to (m)

f\_w\_l = 0.5; % Membrane width = 50 cm to (m)

c\_d\_f\_l = 0.005; % Feed channel height = 5 mm to (m)

c\_d\_p\_l = 0.005; % Channel height = 5 mm to (m)

t\_fi\_l = 85+273.15; % Feed inlet temperature = 85°C to (K)

n\_fi\_l = 2.5; % Feed inlet mass flow rate = 2.5 (kg/s)

x\_fi\_l = 0.035; % Feed inlet NaCl concentration 35(g/kg) to (kg/kg)

t\_pi\_l = 20+273.15; % Permeate inlet temperature = 20°C to (K)

n\_pi\_l = 2.5; % Permeate inlet mass flow rate = 2.5 (kg/s)

**%% ========================= 1st step ==============================**

area = f\_l\*f\_w; % Membrane area (m2)

[x\_mi,k\_m,cp\_f,cp\_p,i\_s,hf,hp,re\_f, re\_p]=**MEMBRANE\_PROPERTY\_1**(x\_fi,c\_d\_f,f\_w,c\_d\_p,m\_p,...

k\_m\_m,t\_fi,t\_pi,n\_fi,n\_pi);

j\_m = area\*flux/3600; % Water vapor flux (kg/s)

**%%** **------------- Loop "i"**

**for** i = 1:1:10000 % Start of the ‘i’ loop

t\_fo\_guess(i) = t\_fi-i\*(t\_fi-t\_pi)/10000; % Guessed feed outlet temperature (K)

q\_f\_calc(i) = n\_fi\*cp\_f\*(t\_fi-t\_fo\_guess(i)); % Feed heat transfer rate (W)

t\_po\_calc(i) = q\_f\_calc(i)/(n\_pi\*cp\_p)+t\_pi; % Permeate outlet temperature (K)

t\_fb\_calc(i) = (t\_fi+t\_fo\_guess(i))/2; % Average bulk feed temperature (K)

t\_pb\_calc(i) = (t\_pi+t\_po\_calc(i))/2; % Average bulk permeate temperature (K)

t\_fmb\_calc(i) = t\_fb\_calc(i)-(q\_f\_calc(i))/(hf\*f\_l\*f\_w); % Bulk feed boundary layer temperature (K)

t\_pmb\_calc(i)= t\_pb\_calc(i)+(q\_f\_calc(i))/(hp\*f\_l\*f\_w); % Bulk permeate boundary layer temperature (K)

q\_v\_calc(i) = 1000\*(1.7535\*t\_fmb\_calc(i)+2024.3)\*j\_m; % Latent heat transfer rate (W)

q\_c\_calc(i) = f\_l\*f\_w\*k\_m\*(t\_fmb\_calc(i)-t\_pmb\_calc(i))/m\_t; % Conductive heat transfer rate (W)

q\_m\_calc(i) = q\_v\_calc(i)+q\_c\_calc(i); % Membrane heat transfer rate (W)

t\_fo\_calc(i) = t\_fi - q\_m\_calc(i)/(cp\_f\*n\_fi); % Feed outlet temperature (K)

**if** t\_fo\_guess(i) < t\_fo\_calc(i)

**break**

**end**

**end** % End of the i loop

%----------------------------------------------------------------------------------------------------------------------------------------------

x\_fo\_calc = x\_fi\*n\_fi/(n\_fi-j\_m); % Feed outlet NaCl concentration (kg/kg)

x\_mo\_calc = (x\_fo\_calc/58.44)/(x\_fo\_calc/58.44+...

(1-x\_fo\_calc)/18.02); % Convert NaCl concentration from kg/kg to mole fraction

x\_mb\_calc = (x\_mi+x\_mo\_calc)/2; % Bulk feed NaCl mole fraction

w\_a = 1-0.5\*x\_mb\_calc-10\*x\_mb\_calc^2 ; % Water activity

p\_sat\_fm = (1-x\_mb\_calc)\*(1-0.5\*x\_mb\_calc-10\*x\_mb\_calc^2)\*133.3224\*10^...

(8.07131-1730.630/(t\_fmb\_calc(i)-39.724));

p\_sat\_pm = 133.3224\*10^(8.07131-1730.630/(t\_pmb\_calc(i)-39.724));

cm\_dis = (flux\*area/3600)/(area\*( p\_sat\_fm- p\_sat\_pm)); % Membrane water vapor permeation

coefficient (kg/m2.Pa.s)

**%% ========================== 2nd step ============================**

area\_l = f\_l\_l\*f\_w\_l; % Membrane area (m2)

[x\_mi\_l,k\_m,cp\_f\_l,cp\_p\_l,i\_s\_l,hf\_l,hp\_l]=**MEMBRANE\_PROPERTY\_1**(x\_fi\_l,c\_d\_f\_l,f\_w\_l,c\_d\_p\_l,m\_p,k\_m\_m,t\_fi\_l,t\_pi\_l,n\_fi\_l,n\_pi\_l);

**%% ------------- Loop "m"**

**for** m = 1:1:10000 % Start of the m loop

t\_fo\_guess\_l(m) = t\_fi\_l-m\*(t\_fi\_l-t\_pi\_l)/10000; % Guessed feed outlet temperature (K)

q\_f\_calc\_l(m) = n\_fi\_l\*cp\_f\_l\*(t\_fi\_l-t\_fo\_guess\_l(m)); % Feed heat transfer rate (W)

t\_po\_calc\_l(m) = q\_f\_calc\_l(m)/(n\_pi\_l\*cp\_p\_l)+t\_pi\_l; % Permeate outlet temperature (K)

t\_fb\_calc\_l(m) = (t\_fi\_l+t\_fo\_guess\_l(m))/2; % Average bulk feed temperature (K)

t\_pb\_calc\_l(m) = (t\_pi\_l+t\_po\_calc\_l(m))/2; % Average bulk permeate temperature (K)

t\_fmb\_calc\_l(m) = t\_fb\_calc\_l(m)-q\_f\_calc\_l(m)/(hf\_l\*f\_l\_l\*f\_w\_l); % Bulk feed boundary layer temperature (K)

t\_pmb\_calc\_l(m) = t\_pb\_calc\_l(m)+q\_f\_calc\_l(m)/(hp\_l\*f\_l\_l\*f\_w\_l); % Bulk permeate boundary layer temperature(k)

j\_m\_calc\_l(m) = f\_w\_l\*f\_l\_l\*cm\_dis\*((1-x\_mi\_l)\*(1-0.5\*x\_mi\_l-10\*x\_mi\_l^2)...

\*133.3224\*10^(8.07131-1730.630/(t\_fmb\_calc\_l(m)-39.724))-133.3224\*...

10^(8.07131-(1730.630/(t\_pmb\_calc\_l(m)-39.724)))); % Water flux across the membrane (kg/s)

q\_v\_calc\_l(m) = 1000\*(1.7535\*t\_fmb\_calc\_l(m)+2024.3)\*j\_m\_calc\_l(m); % Latent heat transfer rate (W)

q\_c\_calc\_l(m) = f\_l\_l\*f\_w\_l\*k\_m\*(t\_fmb\_calc\_l(m)-t\_pmb\_calc\_l(m))/m\_t; % Conductive heat transfer rate (W)

q\_m\_calc\_l(m) = q\_v\_calc\_l(m)+q\_c\_calc\_l(m); % Membrane heat transfer rate (W)

t\_fo\_calc\_l(m) = t\_fi\_l - q\_m\_calc\_l(m)/(cp\_f\_l\*n\_fi\_l); % Feed outlet temperature (K)

**if** t\_fo\_guess\_l(m) < t\_fo\_calc\_l(m)

**break**

**end**

**end** % End of the m loop

%----------------------------------------------------------------------------------------------------------------------------------------------

t\_fo\_pre\_l = t\_fo\_calc\_l(m); % Preliminary feed outlet temperature (K)

t\_fb\_pre\_l = (t\_fi\_l+t\_fo\_pre\_l)/2; % Preliminary feed bulk temperature (K)

t\_po\_pre\_l = t\_po\_calc\_l (m); % Preliminary permeate outlet temperature (K)

t\_pb\_pre\_l = (t\_pi\_l+t\_po\_pre\_l)/2; % Preliminary permeate bulk temperature (K)

x\_fo\_pre\_l = x\_fi\_l\*n\_fi\_l/(n\_fi\_l-j\_m\_calc\_l(m)); % Preliminary feed outlet NaCl concentration (kg/kg)

x\_fb\_pre\_l = (x\_fi\_l+x\_fo\_pre\_l)/2; % Preliminary bulk feed NaCl concentration (kg/kg)

x\_mo\_pre\_l = (x\_fo\_pre\_l/58.44)/(x\_fo\_pre\_l/58.44+...

(1-x\_fo\_pre\_l)/18.02); % Convert NaCl concentration from kg/kg to mole fraction

x\_mb\_pre\_l = (x\_mi\_l+x\_mo\_pre\_l)/2; % Preliminary bulk feed NaCl mole fraction

%----------------------------------------------------------------------------------------------------------------------------------------------

[x\_mo\_pre\_l\_1,k\_m,cp\_f\_new\_l,cp\_p\_new\_l,i\_s\_new\_l,hf\_new\_l,hp\_new\_l,re\_f\_new\_l,re\_p\_new\_l]=**MEMBRANE\_PROPERTY\_1**(x\_fb\_pre\_l, c\_d\_f\_l,f\_w\_l, c\_d\_p\_l, m\_p, k\_m\_m, t\_fb\_pre\_l, t\_pb\_pre\_l, n\_fi\_l, n\_pi\_l);

**%% ============================ 3rd step =============================**

t\_n = f\_l\_l\*100; % Number of tanks in one module (each tank has a length of 1 cm)

**%% ------------- Loop "k"**

**for** k = 1:1:t\_n % Start of the k loop

**if** k == 1

n\_fi\_tis = n\_fi\_l;

t\_fi\_tis = t\_fi\_l;

x\_fi\_tis = x\_fi\_l;

n\_pi\_tis = n\_pi\_l;

t\_pi\_tis = t\_pi\_l;

**elseif** k ~= 1

n\_fi\_tis = n\_fo\_tis\_calc\_vec(k-1);

t\_fi\_tis = t\_fo\_tis\_calc\_vec(k-1);

x\_fi\_tis = x\_fo\_tis\_calc\_vec(k-1);

n\_pi\_tis= n\_po\_tis\_calc\_vec(k-1);

t\_pi\_tis = t\_po\_tis\_calc\_vec(k-1);

**end**

**%% ------------- Loop "j"**

**for** j = 1:1:100000 % Start of the j loop

t\_fo\_tis\_guess(j) = t\_fi\_tis-j\*(t\_fi\_tis-t\_pi\_tis)/100000; % Guessed feed outlet temperature in tank k (K)

q\_f\_tis\_calc(j) = n\_fi\_tis\*cp\_f\_new\_l\*(t\_fi\_tis-t\_fo\_tis\_guess(j)); % Feed heat transfer rate in tank k (W)

t\_po\_tis\_calc(j) = q\_f\_tis\_calc(j)/(n\_pi\_tis\*cp\_p\_new\_l)+t\_pi\_tis; % Permeate outlet temperature in tank ‘k’ (K)

t\_fb\_tis\_calc(j) = (t\_fi\_tis+t\_fo\_tis\_guess(j))/2; % Average bulk tank k feed temperature (K)

t\_pb\_tis\_calc(j) = (t\_pi\_tis+t\_po\_tis\_calc(j))/2; % Average bulk tank k permeate temperature (K)

t\_fmb\_tis\_calc(j) = t\_fb\_tis\_calc(j)-q\_f\_tis\_calc(j)/(hf\_new\_l\*0.01\*f\_w\_l); % Bulk feed boundary layer

the temperature in tank ‘k’ (K)

t\_pmb\_tis\_calc(j) = t\_pb\_tis\_calc(j)+q\_f\_tis\_calc(j)/(hp\_new\_l\*0.01\*f\_w\_l); % Bulk permeate boundary

layer temperature in tank ‘k’(K)

j\_m\_tis\_calc(j) = f\_w\_l\*0.01\*cm\_dis\*((1-x\_mb\_pre\_l)\*(1-0.5\*x\_mb\_pre\_l-10\*...

x\_mb\_pre\_l^2)\*133.3224\*10^(8.07131-1730.630/(t\_fmb\_tis\_calc(j)-39.724))-...

133.3224\*10^(8.07131-1730.630/(t\_pmb\_tis\_calc(j)-39.724))); % Water flux across the membrane in tank ‘k’ (kg/s)

q\_v\_tis\_calc(j) = 1000\*(1.7535\*t\_fmb\_tis\_calc(j)+2024.3)\*j\_m\_tis\_calc(j); % Latent heat transfer rate (W)

q\_c\_tis\_calc(j) = 0.01\*f\_w\_l\*k\_m\*(t\_fmb\_tis\_calc(j)-t\_pmb\_tis\_calc(j))/m\_t; % Conductive heat transfer

the rate in tank k (W)

q\_m\_tis\_calc(j) = q\_v\_tis\_calc(j)+q\_c\_tis\_calc(j); % Membrane heat transfer rate in tank k (W)

t\_fo\_tis\_calc(j) = t\_fi\_tis - q\_m\_tis\_calc(j)/(cp\_f\_new\_l\*n\_fi\_tis); % Feed outlet temperature in tank k (K)

n\_fo\_tis\_calc(j) = n\_fi\_tis-j\_m\_tis\_calc(j); % Feed mass outlet flow rate in tank k (kg/s)

n\_po\_tis\_calc(j) = n\_pi\_tis+j\_m\_tis\_calc(j); % Permeate mass outlet flow rate in tank ‘k’ (kg/s)

x\_fo\_tis\_calc(j) = x\_fi\_tis\*n\_fi\_tis/n\_fo\_tis\_calc(j); % Tank k feed outlet NaCl concentration

(kg/kg)

**if** t\_fo\_tis\_guess(j) < t\_fo\_tis\_calc(j)

**break**

**end**

**end** % End of the j loop

%----------------------------------------------------------------------------------------------------------------------------------------------

n\_fi\_tis\_vec(k) = n\_fi\_tis(end); n\_fo\_tis\_calc\_vec(k) = n\_fo\_tis\_calc(end);

n\_pi\_tis\_vec(k) = n\_pi\_tis(end); n\_po\_tis\_calc\_vec(k) = n\_po\_tis\_calc(end);

t\_fi\_tis\_vec (k) = t\_fi\_tis(end); t\_fo\_tis\_guess\_vec(k) = t\_fo\_tis\_guess(end);

t\_fo\_tis\_calc\_vec (k) = t\_fo\_tis\_calc(end); t\_fb\_tis\_calc\_vec(k) = t\_fb\_tis\_calc(end);

t\_pi\_tis\_vec (k) = t\_pi\_tis(end); t\_po\_tis\_calc\_vec (k ) = t\_po\_tis\_calc(end);

t\_pb\_tis\_calc\_vec(k) = t\_pb\_tis\_calc(end); t\_fmb\_tis\_calc\_vec(k) = t\_fmb\_tis\_calc(end);

t\_pmb\_tis\_calc\_vec(k) = t\_pmb\_tis\_calc(end); x\_fi\_tis\_vec (k) = x\_fi\_tis(end);

x\_fo\_tis\_calc\_vec(k) = x\_fo\_tis\_calc(end); q\_f\_tis\_calc\_vec(k) = q\_f\_tis\_calc(end);

q\_v\_tis\_calc\_vec(k) = q\_v\_tis\_calc(end); q\_c\_tis\_calc\_vec(k) = q\_c\_tis\_calc(end);

q\_m\_tis\_calc\_vec(k) = q\_m\_tis\_calc(end); j\_m\_tis\_calc\_vec(k) = j\_m\_tis\_calc(end);

%----------------------------------------------------------------------------------------------------------------------------------------------

fprintf(my\_file\_data,'%12f %20.4f %21.4f %21.4f %22.4f %28.4f \n',[k;t\_fo\_tis\_calc\_vec(k)-273.15;...

t\_po\_tis\_calc\_vec(k)-273.15;t\_fmb\_tis\_calc\_vec(k)-273.15;t\_pmb\_tis\_calc\_vec(k)-273.15;...

x\_fo\_tis\_calc\_vec(k)\*1000]);

**end** % End of the k loop

%----------------------------------------------------------------------------------------------------------------------------------------------

fclose (my\_file\_data);

fclose('all');

%----------------------------------------------------------------------------------------------------------------------------------------------

t\_fo\_tis\_dis = t\_fo\_tis\_calc\_vec(k)-273.15; % Feed outlet temperature of the last tank (°C)

t\_po\_tis\_dis = t\_po\_tis\_calc\_vec(k)-273.15; % Permeate outlet temperature of the last tank (°C)

n\_fo\_tis\_dis = n\_fo\_tis\_calc\_vec(k); % Feed outlet mass flow rate of the last tank (kg/s)

n\_po\_tis\_dis = n\_po\_tis\_calc\_vec(k); % Permeate outlet mass flow rate of the last tank (kg/s)

x\_fo\_tis\_dis = x\_fo\_tis\_calc\_vec(k)\*1000; % Feed outlet NaCl concentration of the last tank (g/kg)

%----------------------------------------------------------------------------------------------------------------------------------------------

j\_m\_total\_dis = sum(j\_m\_tis\_calc\_vec)/area\_l\*3600 ; % Total cross-membrane water flux (kg/m2.h)

q\_f\_total\_dis = sum(q\_f\_tis\_calc\_vec); % Total feed heat loss (W)

q\_v\_total\_dis = sum(q\_v\_tis\_calc\_vec); % Total evaporation latent heat loss (W)

q\_m\_total\_dis = sum(q\_m\_tis\_calc\_vec); % Total heat loss inside the membrane (W)

%-------------------------------------------------------------------------------------------------------------------------------------

t\_e\_dis = sum(q\_v\_tis\_calc\_vec)/sum(q\_f\_tis\_calc\_vec); % Thermal efficiency

%-------------------------------------------------------------------------------------------------------------------------------------

t\_fmb\_tis\_in = t\_fmb\_tis\_calc\_vec(1); % Bulk feed boundary layer temperature of the first tank (K)

t\_fmb\_tis\_out = t\_fmb\_tis\_calc\_vec(k); % Bulk feed boundary layer temperature of the last tank (K)

t\_fmb\_tis\_bulk= (t\_fmb\_tis\_in+t\_fmb\_tis\_out)/2; % Bulk feed boundary temperature (K)

t\_pmb\_tis\_in = t\_pmb\_tis\_calc\_vec(1); % Bulk permeate boundary layer temperature of the first tank (K)

t\_pmb\_tis\_out = t\_pmb\_tis\_calc\_vec(k); % Bulk permeate boundary layer temperature of the last tank (K)

t\_pmb\_tis\_bulk= (t\_pmb\_tis\_in+t\_pmb\_tis\_out)/2; % Bulk permeate boundary temperature (K)

t\_f\_bulk = (t\_fi\_l+t\_fo\_tis\_calc\_vec(k))/2; % Bulk feed temperature (K)

t\_p\_bulk = (t\_pi\_l+t\_po\_tis\_calc\_vec(k))/2; % Bulk permeate temperature (K)

%----------------------------------------------------------------------------------------------------------------------------------------

tpc = (t\_fmb\_tis\_bulk-t\_pmb\_tis\_bulk)/(t\_f\_bulk-t\_p\_bulk); % Temperature polarization coefficient

%----------------------------------------------------------------------------------------------------------------------------------------

**%% =========================== Graphesthesia ==========================**

**%% Figure (1)**

subplot(3, 2, 1)

plot(1:t\_n,t\_fo\_tis\_calc\_vec-273.15,'LineWidth',1);

xlabel('Module Length (cm)','FontSize',8);

ylabel('Feed Bulk Temp (C)','FontSize',8);

xlim([1 t\_n]);set(gca,'fontsize',7);

grid on

**%% Figure (2)**

subplot(3, 2, 2)

plot(1:t\_n,t\_po\_tis\_calc\_vec-273.15,'LineWidth',1);

xlabel('Module Length (cm)','FontSize',8);

ylabel('Permeate Bulk Temp (C)','FontSize',8);

xlim([1 t\_n]);set(gca,'fontsize',7);

grid on

**%% Figure (3)**

subplot(3, 2, 3)

plot(1:t\_n,smooth(t\_fmb\_tis\_calc\_vec-273.15),'LineWidth',1);

xlabel('Module Length (cm)','FontSize',8);

ylabel('Feed Boundary Temp (C)','FontSize',8);

xlim([1 t\_n]);set(gca,'fontsize',7);

grid on

**%% Figure (4)**

subplot(3, 2, 4)

plot(1:t\_n,smooth(t\_pmb\_tis\_calc\_vec-273.15),'LineWidth',1);

xlabel('Module Length (cm)','FontSize',8);

ylabel('Permeate Boundary Temp (C)','FontSize',8);

xlim([1 t\_n]);set(gca,'fontsize',7);

grid on

**%% Figure (5)**

subplot(3, 2, [5 6])

plot(1:t\_n,x\_fo\_tis\_calc\_vec\*1000,'LineWidth',1);

xlabel('Module Length (cm)','FontSize',8);

ylabel('NaCl Concentration (g/kg)','FontSize',8);

xlim([1 t\_n]);set(gca,'fontsize',7);

grid on

**%% ------------------------------------ LABORATORY SCALE VALIDATION -------------------------------------**

t\_po\_lab = t\_po\_calc(end)-273.15; t\_fo\_lab = t\_fo\_calc(end)-273.15;

**%% ----------------------------------------------------------------------------------------------------------------------------**

t\_fo\_tis\_dis; t\_po\_tis\_dis; x\_fo\_tis\_dis; n\_fo\_tis\_dis;

n\_po\_tis\_dis; j\_m\_total\_dis; p\_sat\_fm; p\_sat\_pm;

cm\_dis; tpc; re\_f\_new\_l; re\_f;

re\_p; hf; hp; area\_l;

**%% \*\*\*\*\*\*\*\*\* THE END \*\*\*\*\*\*\*\*\***