# Scilab Code for Unit Operations of Chemical Engineering by Warren L. McCabe, Julian C. Smith, Peter Harriott[1]

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# Chapter 1

# Definitions and Principles

## 1.1 Scilab Code

**Example 1.1** Example 1.1.sce

```
clear all;
clc;

//Example 1.1

//Solution
//(a)
//Using Eq.(1.6,), (1.26), and (1.27)
//Let N = 1N
N = 0.3048/(9.80665*0.45359237*0.3048); //[lbf]

//(b)
//Using (1.38), (1.16), (1.26), and (1.31)
//Let B = 1 Btu
B = 0.45359237*1000/1.8; //[cal]

//(c)
//Using Eq.(1.6), (1.14), (1.15), (1.26), (1.27),
    and (1.36)
//Let P = 1 atm
```

```
P = 1.01325*10^5*0.3048/(32.174*0.45359237*12^2); //
    [lbf/in.^2]

//(d)
// Using Eq.(1.8), (1.33), (1.37), (1.26), and
    (1.27)
//Let hp = 1hp
hp = 550*32.174*0.45359237*0.3048^2/1000; //[kW]
```

# Chapter 2

# Fluid Statics and its Application

## 2.1 Scilab Code

**Example 2.1** Example 2.1.sce

```
clear all;
clc;

//Example 2.1
rho_A = 13590;
rho_B = 1260;
Pa = 14000;
gc = 1;//[ft-lb/lbf-s^2]

//Using Eq.(2.5); Zb = 250 mmHg
Pb = -(250/1000)*(9.80665/1)*13590;

//Using Eq.(2.10)
Rm = (14000+33318)/(9.80665*(13590-1260))
disp('mm',Rm,'The reading in the mamometer is (Rm) =
   ')
```

---

**Example 2.2** Example 2.2.sce

```
clear all;
clc;

//Example 2.2

//(a)
//Using Eq.(2.15)
t = (100*1.1)/(1153-865)
rate_each_stream  = (1500*42)/(24*60)
total_liquid_holdup = 2*43.8*23
vol = total_liquid_holdup/0.95
disp('gal',vol,'vessel size =')

//(b) tank diameter
Zt = 0.90*4
ZA1 = 1.8 //[ft];
ZA2 = 1.8 + (3.6-1.8)*(54/72)
disp('ft',ZA2,'tank diameter =')
```

# Chapter 4

# Basic Equations of Fluid Flow

## 4.1 Scilab Code

**Example 4.1** Example 4.1.sce

```
clear all;
clc;

//Example 4.1

// (a)
// density of the fluid
rho = 0.887*62.37;// [lb/ft^3]
// total volumetric flow rate
q = 30*60/7.48; //[ft^3/hr]
// mass flow rate in pipe A and pipe B is same
mdot  = rho*q //[lb/hr]
// mass flow rate in each pipe of C is half of the
   total flow
mdot_C = mdot/2 //[lb/hr]
disp('lb/hr',mdot,'mass flow rate pipe A = ')
disp('lb/hr',mdot,'mass flow rate pipe B = ')
disp('lb/hr',mdot_C,'mass flow rate pipe C = ')

// (b)
```

```
// Using Eq.(4.4),
// velocity through pipe A
V_Abar = 240.7/(3600*0.0233) //[ft/s]

// velocity through pipe B
V_Bbar = 240.7/(3600*0.0513) //[ft/s]

// velocity through each pipe of C
V_Cbar = 240.7/(2*3600*0.01414) //[ft/s]

disp('ft/s',V_Abar,'velocity through pipe A = ')
disp('ft/s',V_Bbar,'velocity through pipe B = ')
disp('ft/s',V_Cbar,'velocity through pipe C = ')

// (c)
// Using Eq.(4.8),
// mass velocity through pipe A
GA = mdot/0.0233 // [kg/m^2-s]

// mass velocity through pipe B
GB = mdot/0.0513 //[kg/m^2-s]

// mass velocity through each pipe of C
GC = mdot/(2*0.01414) //[kg/m^2-s]

disp('kg/m^2-s',GA,'mass velocity through pipe A = ')
disp('kg/m^2-s',GB,'mass velocity through pipe B = ')
disp('kg/m^2-s',GC,'mass velocity through pipe C = ')
```

**Example 4.2** Example 4.2.sce

```
clear all;
clc;

//Example 4.2
```

```
//Applying Eq.(4.25)
//Pa = Pb, Ua = 0
// Zb = 0, Za = 5m

//The velocity at streamline discharge
Ub = sqrt(5*2*9.80665)//[m/s]
disp('m/s',Ub,'streamline discharge velocity (Ub) =')
```

**Example 4.3** Example 4.3.sce

```
clear all;
clc;

//Example 4.3
rho  = 998; // [kg/m^3]
Da = 50; //[mm]
Db = 20; //[mm]
pa  = 100; //[N/m^2]

//(a)
Va_bar = 1.0; //[m/s]
Vb_bar = Va_bar*(Da/Db)^2 //[m/s]
//Using Eq.(4.29)
//Za = Zb, hf = 0
pb  = pa-rho*(Vb_bar^2-Va_bar^2)/(2*1000) //[kN/m^2]
disp('kN/m^2',pb,'pb =')

//(b)
// Combining Eqs.(4.14) & (4.15)
//For x direction ,
//since Fg = 0, we get Eq.(4.30)
theta = %pi/4;
Va_xbar = Va_bar;
Sa = (%pi/4)*(Da/1000)^2; //[m^2]
Sax = Sa;
//From FIg 4.5
Vb_xbar = Vb_bar*cos(theta);//[m/s]
```

```
Sb = %pi/4*(Db/1000)^2; //[m^2]
Sbx = Sb*sin(theta);// [m^2]
//Using Eq.(4.6)
mdot = Va_bar*rho*Sa; //[kg/s]
//Substituting in Eq.(4.30)
//Solving for Fw,x
beta_a = 1; beta_b = 1;
Fw_x  = mdot*(beta_b*Vb_xbar-beta_a*Va_xbar)-Sax*pa
   *1000+Sbx*pb*1000 //[N]

//For y direction ,
//Va_ybar = 0, Say = 0
Vb_ybar = Vb_bar*sin(theta); //[m/s]
Sby = Sb*cos(theta); //[m^2]
Va_ybar = 0; //[m/s]
Say = 0;// [m/s]

Fw_y  = mdot*(beta_b*Vb_ybar-beta_a*Va_ybar)-Say*pa
   *1000+Sby*pb*1000 //[N]
```

**Example 4.4** Example 4.4.sce

```
clear all;
clc;

//Example 4.4
gc = 32.17; //[ft-lb/lbf-s^2]
rho_w = 62.37;//[lb/ft^3], density of water
sp_gravity = 1.84;
neta = 0.60;
hf  = 10; //[ft-lbf/lb], friction losses
Va_bar = 3; //[ft/s]
Da = 3; //[in.]
Db = 2; //[in.]
//From Appendix corss secional area respective to 3
   in. and 2in. diameter
Sa = 0.0513; //[ft^2]
Sb = 0.0233; //[ft^2]
```

```
Za = 0 ;//[ft]
Zb = 50 ;//[ft]
Vb_bar = Va_bar*(Sa/Sb); //[ft/s]
g =gc
//Using Eq.(4.32)
Wp = ((Zb*g/gc)+Vb_bar^2/(2*gc)+hf)/neta;//[ft-lbf/
    lb]

//Using Eq.(4.32) on pump itself
//station a is the suction connection and station b
    is the discharge
//Za = Zb
//Eq.(4.32) becomes
//the pressure developed by pume is deltaP = pb-pa
deltaP = sp_gravity*rho_w*(((Va_bar^2-Vb_bar^2)/(2*
    gc))+neta*Wp) //[lbf/ft^3]

mdot = Sa*Va_bar*sp_gravity*rho_w;

//the Power
P  = mdot*Wp/550  //[hp]
```

# Chapter 5

# Flow of Incompressible Fluids in Conduits and Thin Layers

## 5.1 Scilab Code

**Example 5.1** Example 5.1.sce

```
clear all;
clc;

//Example 5.1
// Given
mu = 0.004; //[kg/m-s]
D = 0.0779;// [m]
rho = 0.93*998; //[kg/m^3]
L = 45; //[m]

//For fittings, form Table 5.1
sum_Kf = 0.9 + 2*0.2;
//From Eq.(4.29), assuming alpha_a = 1,
// since pa = pb, and Va_bar = 0
//A = Vb_bar^2/2 + hf = g*(Za-Zb)
A = 9.80665*(6+9); //[m^2/s^2]
//Using Fig 5.9
f = 0.0055;
```

```
//Using Eq.(5.68), There is no exapnsion loss and Ke = 0.
//From Eq.(5.66), since Sa is very lage, Kc = 0.4. Hence
Vb_bar = sqrt(294.2/(2.7+2311*f));//[m/s]
//From Appendix 5, cross sectional area of the pipe
S = 0.00477; //[m^2]
flow_rate  = S*Vb_bar*3600 //[m^3/hr]
```

# Chapter 6

# Flow of Compressible Fluids

## 6.1 Scilab Code

**Example 6.1** Example 6.1.sce

```
clear all;
clc;

//Example 6.1
//Given
gama = 1.4;
M = 29;
R = 82.0568*10^-3; //[atm-m^3/Kg mol-K]
Nma = 0.8;
gc = 1; //[ft-lb/lbf-s^2]
//At Entrance
p0 = 20; //[atm]
T0 = 555.6; //[K]

//(a)
// Using Eq.(6.28)
//Pressure at throat
pt  = (1/(1+((gama-1)/2)*Nma^2)^(1/(1-1/gama)))*p0 //[atm]
//From Eq.(6.10)
```

```
rho0 = (p0*M)/(R*T0); //[kg/m^3]
// Using Eq.(6.10) and Eq.(6.26), the velocity in the throat
ut = sqrt((2*gama*gc*R*T0)/(M*(gama-1))*(1-(pt/p0)^(1-1/gama))); // [m^3-am/kg]^0.5
//In terms of [m/s], Using Appendix 2, 1 atm = 1.01325*10^ [N/m^2]
ut = ut*sqrt(1.01325*10^5) //[m/s]
//Using Eq.(6.23), density at throat
rho_t  = rho0*(pt/p0)^(1/gama) //[kg/m^3]
//The mass velocity at the throat,
Gt = ut*rho_t //[kg/m^2-s]
//Using Eq.(6.24), The temperature at throat
Tt = T0*(pt/p0)^(1-1/gama) // [K]

//(b)
// From Eq.(6.29)
pstar = ((2/(gama+1))^(1/(1-1/gama)))*p0 //[atm]
//From Eq.(6.24) and (6.29)
Tstar = T0*(pstar/p0)^(1-1/gama) //[K]
//From Eq.(6.23)
rho_star = rho0*(pstar/p0)^(1/gama) //[Kg/m^3]
//From Eq.(6.30)
G_star = sqrt(2*gama*gc*rho0*p0*101.325*10^3/(gama-1))*(pstar/p0)^(1/gama)*sqrt(1-(pstar/p0)^(1-1/gama)) //[Kg-m^2/s]
u_star = G_star/rho_star //[m/s]

//(c)
// By continuity, G inversely proportional to S, the mass velocity at dischage is
G_r  = G_star/2 // [Kg/m^3-s]
//Using Eq.(6.30)
// Let x = pr/p0
err = 1;
eps = 10^-3;
x = rand(1,1);

```

```
while(err>eps)
  xnew  = ((0.1294)/sqrt(1-x^(1-1/1.4)))^1.4;
  err = x-xnew;
  x=xnew;
end

//Using Eq.(6.27)
//The Mach Number at dischage is
Nmr = sqrt((2/(gama-1))*(1/x^(1-1/gama)-1))
```

**Example 6.2** Example 6.2.sce

```
clear all;
clc;

//Example 6.2
//Given
Tr = 1000; //[R]
pr = 20; //[atm]
Ma_a = 0.05;
gama = 1.4;
gc = 32.174; //[ft-lb/lbf-s^2]
M = 29;
R = 1545;
//(a)
//Using Eq.(6.45)
A = 2*(1+((gama-1)/2)*Ma_a^2)/((gama+1)*Ma_a^2);
fLmax_rh = (1/Ma_a^2-1-(gama+1)*log(A)/2)/gama

//(b)
//Using Eq.(6.28), the pressure at the end of the isentropic nozzle pa
A = (1+(gama-1)*(Ma_a^2)/2);
pa = pr/(A^(gama/(gama-1)))  // [atm]
//From Example 6.1, the density of air at 20atm and 1000R is 0.795 lb/ft^3
//Using Eq.(6.17), the acoustic velocity
Aa  = sqrt(gc*gama*Tr*R/M) //[m/s]
```

```
//The velocity at the entrance of the pipe
ua  = Ma_a*Aa //[m/s]
//When L_b = L_max, the gas leaves the pipe at the
   asterisk conditions, where
Ma_b = 1;
// Using Eq.(6.43)
A = (gama-1)/2;
Tstar = Tr *(1+A*Ma_a^2)/(1+A*Ma_b^2) // [K]
// Using Eq.(6.44)
rho_star = 0.795*Ma_a/sqrt(2*(1+(gama-1)*Ma_a^2/2)
   /(2.4)) //[lb/ft^3]
//Using Eq.(6.39)
pstar = p0*Ma_a/sqrt(1.2) // [atm]
//Mass velocity through the entire pipe
G = 0.795*ua //[lb/ft^2-s]
ustar = G/rho_star //[ft/s]

//(c)
//Using Eq.(6.45) with f_Lmax_rh = 400

err = 1;
eps = 10^-3;
Ma_ac = rand(1,1);
i =1;
while((err>eps))
  A = 2*(1+((gama-1)/2)*Ma_ac^2)/((gama+1)*Ma_ac^2);
  B = gama*400+1+(gama+1)*log(A)/2;
  Ma_anew  = sqrt(1/B);
  err = Ma_ac-Ma_anew;
  Ma_ac = Ma_anew;
end
Ma_ac;
uac  = Ma_ac*ua/Ma_a //[ft/s]
Gc = uac*0.795 //[lb/ft^2-s]
```

**Example 6.3** Example 6.3.sce

```
clear all;
```

```
clc;

//Example 6.3
//Given
pa = 2.7; //[atm]
T = 288; //[K]
D = 0.075; //[m]
L = 70; //[m]
Vbar  = 60; //[m/s]
M = 29;
rh = D/4; //[m]
mu = 1.74*10^-5 //[kg/m-s] Appendix 8
rho_a = (29/22.4)*(2.7/1)*(273/288) // [kg/m^3]
R = 82.056*10^-3;
G = Vbar*rho_a //[kg/m^2-s]
Nre = D*G/mu;
kbyd = 0.00015*(0.3048/0.075);
f = 0.0044; //[from Fig. 5.9]

//Using Eq.(6.52)
//pbar = 1.982; //[atm]
//pb = 1.264; //[atm]
err = 1;
eps = 10^-3;
pb = 1.5;

while(err>eps)
pbar = (pa+pb)/2;
A = ((f*L/(2*rh))+log(pa/pb));
pb_new = pa-(R*T*G^2/(pbar*29*101325))*A;
err = pb-pb_new;
pb = pb_new;
end
pb; //[atm]
pbar = (pa+pb)/2 // [atm]
```

# Chapter 7

# Flow Past Immersed Bodies

## 7.1 Scilab Code

**Example 7.1** Example 7.1.sce

```
clear all;
clc;

//Example 7.1
// Given
rho_p = 2800; // [kg/m^3]
g = 9.80665; //[m/s^2]
ac = 50*g; // [m/s^2]
//(a)
//From appendix 20
Dp_100 = 0.147; //[mm]
Dp_80  = 0.175; //[mm]
Dp  = (Dp_100+Dp_80)/2;//[mm]

//From Appendix 14
mu = 0.801; //[cP]
rho = 995.7; //[kg/m^2]
// Using Eq.(7.45)
K = Dp*10^-3*(g*rho*(rho_p-rho)/(mu*10^-3)^2)^(1/3);
//This is slightly above the Stoke's-law range
```

```
//Assuming
N_rep = 4.4;
//From Fig. 7.6
Cd = 7.9;
//From Eq.(7.37)
mu_ta = sqrt(4*g*(rho_p-rho)*Dp*10^-3/(3*Cd*rho)) // [m/s]

// (b)
//Using 'ac' in place of 'g' in Eq.(7.45)
K = K*50^(1/3);  // Since only acceleration changes
//Etimating
N_rep = 80; //From Fig. (7.6)
Cd = 1.2;
mu_tb1 = sqrt(4*ac*(rho_p-rho)*Dp*10^-3/(3*Cd*rho)) // [m/s]
// For irregular particles Cd is about 20 percent greater
//than that for spheres
Cd = 1.2*1.2;
mu_tb2 = sqrt(4*ac*(rho_p-rho)*Dp*10^-3/(3*Cd*rho)) // [m/s]
```

---

**Example 7.2** Example 7.2.sce

```
clear all;
clc;

//Example 7.2
//Given
g = 32.174; //[ft-lb/lbf-s^2]
eps = 0.8;
speg_s = 4.0;
speg_c = 1.594;
Ds  = 0.004; //[in.]
rho_w = 62.37; //[lbf/ft^3]
delta_speg = speg_s-speg_c;
delta_rho = rho_w*delta_speg; //[lbf/ft^3]
```

```
rho_c = rho_w*speg_c; //[lbf/ft^3]
//From Appendix 9
mu = 1.03; //[cP]
//Using Eq.(7.45)
K = Ds/12*(g*rho_c*(delta_rho)/(mu*6.72*10^-4)^2)
    ^(1/3);
//Using Eq.(7.40)
ut = g*(Ds/12)^2*delta_rho/(18*mu*6.72*10^-4) //[ft/
    s]

//The terminal velocity in hindered settling
//Calculating Reynolds Number
Nre = ut*rho_c*Ds/(12*mu*6.72*10^-4);
//From Fig.(7.7)
n = 4.1;
//Using Eq.(7.46)
us  = ut*eps^n //[ft/s]
```

**Example 7.3** Example 7.3.sce

```
clear all;
clc;

//Example 7.3
//The quantities needed are
mu = 0.01; //[P]
delta_rho = 0.24; //[g/cm^3]
//Using Eq.(7.51),solving the quadratic equation for
     Vom_bar
a = 1.75*1/(0.11*0.4^3);
b = 150*0.01*0.6/(0.11^2*0.4^3);
c = - 980*0.24;
Vom_bar = (-b+sqrt(b^2-4*a*c))/(2*a); //[cm/s]
//Corresponding Reynolds number
Nre = 0.11*0.194*0.124/0.01;
//From Fig 7.13
m = 3.9;
//For 25 percent exapnsion
```

```
LbyLm = 1.25;
eps = 0.52;
//From Eq.(7.59)
Vo_bar = 1.94*(0.52/0.40)^3.9 //[mm/s]
```

# Chapter 8

# Transportation and Metering of Fluids

## 8.1 Scilab Code

**Example 8.1** Example 8.1.sce

```
clear all;
clc;

//Example 8.1
//Given
vdot = 40; //[gal/min]
pb = 50; //[lbf/in.^2]
Za = 4; //[ft]
Zb = 10; //[ft]
hfs = 0.5; //[lbf/in.^2]
hfd = 5.5; //[lbf/in.^2]
neta = 0.6;
rho = 54; //[lb/ft^3]
pv = 3.8; //[lbf/in.^2]
g = 9.8; //[m/s^2]
gc = 32.17 //[ft-lb/lbf-s^2]
hf = hfs+hfd; // [lbf/in.^2]
//(a)
```

```
//Using data from Appendix 5
Vb_bar = vdot/6.34; //[ft/s]
//Using Eq.(4.32)

Wp_neta = ((14.7+pb)*144/rho)+(g/gc*10)+(Vb_bar
    ^2/(2*gc))+(hf*144/54)-(14.7*144/54); // [ft-lbf/
    lb]
delta_H = Wp_neta;

//(b)
mdot = vdot*rho/(7.48*60); // [lb/s]
//Using Eq.(8.7), the input power is
Pb = mdot*delta_H/(550*neta) // [hp]

//(c)
padash = 14.7*144/rho;
//The vapor pressure corresponding to a head
hv = pv*144/rho; // [ft-lbf/lb]
//friction in the suction line
hfs = 0.5*144/rho ; // [ft-lbf/lb]
//Using Eq.(8.7), value of available
NPSH = padash-hv-hfs-Za // [ft]
```

**Example 8.2** Example 8.2.sce

```
clear all;
clc;

// Example 8_2
// Given
pa = 29; //[in.Hg]
pb = 30.1; //[in.Hg]
va = 0; //[ft/s]
vb = 150; //[ft/s]
Ta = 200; //[F]
vdot = 10000; //[ft^3/min]
neta = 0.65;
M = 31.3;
```

```
R = 29.92;
gc = 32.17;//[ft-lb/lbf-s^2]
//actual suction density
rho_a = M*pa*(460+60)/(378.7*30*(460+Ta)); //[lb/ft^3]
//acual discharge density
rho_b = rho_a*pb/pa; //[lb/ft^3]
// average density of the flowing gas
rho = (rho_a+rho_b)/2; //[lb/ft^3]
//mass flow rate
mdot  = vdot*M/(378.7*60) //[lb/s]
//developed pressure
dev_p = (pb-pa)*144*14.7/(R*rho); //[ft-lbf/lb]
//velocity head
vel_head = vb^2/(2*gc); //[ft-lbf/lb]
//Using Eq.(8.1), alpha_a = alpha_b = 1,va = 0, Za = Zb,
Wp = (dev_p+vel_head)/neta  // [ft-lbf/lb]
//Using Eq.(8.4)
Pb  = mdot*Wp/550 //[hp]
```

**Example 8.3** Example 8.3.sce

```
clear all;
clc;

//Example 8.3
//Given
vdot = 180; //[ft^3/min]
pa = 14; //[lbf/in.^2]
pb = 900; //[lbf/in.^2]
Ta = 80+460; //[K]
q0 = 0.063; //[m^3/s]
Cp = 9.3; //[Btu/lbmol-F]
gama = 1.31;
delta_Tw = 20; // [F]
//(a)
neta = 0.80;
```

```
//For a multistage compressor the total power is a
   minimum if each stage doed the same amount of
   work
//Hence using same copression ration for each stage
//Using Eq.(8.25)
//For one stage
comp_ratio = (900/14)^(1/3);
//Using Eq.(8.29), the power required by each stage
Pb = (Ta*q0*gama*vdot)*(comp_ratio^(1-1/gama)-1)
   /(520*(gama-1)*neta); // [hp]
//Total Power
Pt = 3*Pb // [hp]

//(b)
//Using Eq.(8.22), the temperature at the exit of
   each stage
Tb = Ta*comp_ratio^(1-1/gama)  // [R]

//(c) Since 1 lb mol = 378.7 std ft^3, the flow rate
    is
vdot = vdot*60/378.7; //[lb mol/h]
// Heat load in each cooler is
Hl = vdot*Cp*(Tb-Ta) // [Btu/h]
//Total heat loss
Htotal = 3*Hl; //[Btu/h]
//Cooling water requirement
cwr = Htotal/delta_Tw // [lb/h]
```

**Example 8.4** Example 8.4.sce

```
clear all;
clc;

//Example 8.4
//Given
q = 75/3600 ; // [m^3/s]
rho = 62.37*16.018; //[kg/m^3] From Appendix 4
Cv = 0.98;
```

```
g = 9.80665; //[m/s^2]
Sw = 1;
Sm = 13.6;
h = 1.25; //[m]
//(a)
//Using Eq.(2.10)
delta_p = g*h*(Sm-Sw)*rho ; //[N/m^2]
//Using Eq.(8.36), neglecting the effect of beta
Sb = q/(Cv*sqrt(2*delta_p/rho));
Db = sqrt(4*Sb/%pi)*100  //  [mm]

//(b)
press_loss = 0.1*delta_p; //[N/m^2]
// Power required at full flow
P = q*press_loss/1000 //  [kW]
```

---

**Example 8.5** Example 8.5.sce

```
clear all;
clc;

//Example 8.5
//Given
T = 100; //[F]
mu_O = 5.45; //[cP]
spg_O =  0.8927;
spg_m = 13.6;
spg_gl = 1.11;
q = 12000; //[bbl/d]
rho_ratio = 0.984;
rho_w = 62.37; //[lb/ft^3]
h = 30; //[in.]
gc = 32.174; //[ft-lb/lbf-s^2]
//(a)
//Using Eq.(8.42)
rhoB_60 = spg_O*rho_w; //[lb/ft^3]
rho_100 = spg_O*rho_w*rho_ratio; //[lb/ft^3]
mdot = q*42*rhoB_60/(24*3600*7.48); // [lb/s]
```

```
Da = 4.026/12; //[ft]
delta_p = h/12*(spg_m-spg_gl)*rho_w*(1); //[lbf/ft
    ^2]
//Using Eq.(8.42)
beeta = sqrt(4*mdot/(0.61*%pi*Da^2*sqrt(2*gc*delta_p
    *rho_100)));
Do = Da*beeta; //[ft]
// the orifice diameter
D = 12*Do //[in.]

//(b)
//Using Fig. 8.20, the fraction of differential
    pressure loss is
fra_prss_loss  = 0.68;
//Maximum power consumption
P = mdot*delta_p*fra_prss_loss/(rho_ratio*rho_w*
    spg_0*550) //[hp]
```

**Example 8.6** Example 8.6.sce

```
clear all;
clc;

//Example 8.4
//Given
Cpt = 0.98;
Ta = 200; //[F]
Da = 36; //[in.]
pa = 15.25; //[in.]
h = 0.54; //[in.]
P = 29.92; //[in.]
spg_m =13.6; //[specific gravity of mercury]
rho_w = 62.37; //[lb/ft^3]
gc = 32.174; //[ft-lb/lbf-s^2]
//Using Eq.(8.52)
Pabs = P+pa/spg_m; //[in.]
rho = 29*492*31.04/(359*(200+460)*29.92); //[lb/ft
    ^3]
```

```
//From manometer reading
delta_p = h/12*rho_w //[lbf/ft^3]

//Using Eq.(8.53, m*aximum velocity, assuming Nma is
    negligible
umax = Cpt*sqrt(2*gc*delta_p/rho) // [ft/s]
//The reynolds number based on maximum velocity
mu_air = 0.022 ; //[cP] form Appendix 8
Nre_max = (Da/12)*umax*rho/(mu_air*0.000672);
//Using Fig 5.7, to obtain average velocity
Vbar = 0.86*umax // [ft/s]
Nre = Nre_max*0.86;
//The volumetric flow rate
q = Vbar*(Da/12)^2*%pi/4*520/660*Pabs/P*60 //[ft^3/
   min]
```

# Chapter 9

# Agitation and Mixing of Liquids

## 9.1 Scilab Code

**Example 9.1** Example 9.1.sce

```
clear all;
clc;

//Exapmle 9.1
//Given
Dt = 6; //[ft]
h = 2; //[ft]
n = 90/60; //[rps]
mu = 12*6.72*10^-4; //[lb/ft-s]
g = 32.17; //[ft/s^2]
rho = 93.5; //[lb/ft^3]
Da = 2; // [ft]

Nre = Da^2*n*rho/mu;
//From curve A of Fig. 9.12
Np = 5.8
//Form Eq.(9.20)
P = Np*rho*n^3*Da^5/g  //[ft-lbf/s]
```

```
P = P/550 //[hp]
```

**Example 9.2** Example 9.2.sce

```
clear all;
clc;

//Example 9.2
//Given
Dt = 6; //[ft]
h = 2; //[ft]
n = 90/60; //[rps]
mu = 12*6.72*10^-4; //[lb/ft-s]
g = 32.17; //[ft/s^2]
rho = 93.5; //[lb/ft^3]
Da = 2; // [ft]

Nre = Da^2*n*rho/mu;
//Froude number
Nfr = n^2*Da/g;
//From Table 9.1
a = 1;
b = 40.0;
//Using Eq.(9.19)
m = (a-log(Nre)/2.303)/b;
//Using Fig. 9.12, curve D,
Np = 1.07;
//Corrected valus of Np
Np =  Np*Nfr^m;

//Form Eq.(9.20)
P = Np*rho*n^3*Da^5/g //[ft-lbf/s]
P = P/550 //[hp]
```

**Example 9.3** Example 9.3.sce

```
clear all;
clc;
```

```
//Example 9.3
//Given
Dt = 6; //[ft]
h = 2; //[ft]
n = 90/60; //[rps]
mu = 1200*6.72*10^-2; //[lb/ft-s]
g = 32.17; //[ft/s^2]
rho = 70 //[lb/ft^3]
Da = 2; // [ft]

Nre = Da^2*n*rho/mu;
//From Table 9.3
KL = 65;
//From Eq.(9.21)
Np = KL/Nre;
P = Np*rho*n^3*Da^5/g  //[ft-lbf/s]
P = P/550 //[hp]
```

**Example 9.4** Example 9.4.sce

```
clear all;
clc;

//Example 9.4
//Given
Dt = 6; //[ft]
Da = 2; //[ft]
n = 80/60; //[rps]
T = 70; //[F]
rho = 62.3; //[lb/ft^3], From Appendix 14
mu = 6.6*10^-4; // [lb/ft-s], From Appendix 14

Nre = Da^2*n*rho/mu;
//From Fig. 9.15
ntT = 36;
tT = ntT/1.333 //[s]
```

**Example 9.5** Example 9.5.sce

```
clear all;
clc;

//Example 9.5
//Given
Dt = 6; //[ft]
H = 8; //[ft]
T = 70; //[F]
sp_gr = 3.18;
w_fr = 0.25;
Da = 2; //[ft]
h = 1.5; //[ft]
gc = 32.17; //[ft-lb/lbf-s^2]
// (a)
//Using data of Buurman et al. in Fig.(9.19)
//change in nc
delta_nc = (104/200)^0.2*(2.18/1.59)
    ^0.45*(33.3/11.1)^0.13;
//change in P
dalta_P = delta_nc^3;

//Using Fig. 9.19
V = %pi/4*Dt^2*H*7.48 ; //[gal]
P = 3.3*V/1000 //[hp]

//(b)
//From Table 9.3, for a cour blade turbine,
KT = 1.27;
Np = KT;
//slurry density
rho_m = 1/((w_fr/sp_gr)+(1-w_fr))*62; // [lb/ft^3]

nc = (P*gc*550/(Np*rho_m*Da^5))^(1/3) // [r/s]
```

**Example 9.6** Example 9.6.sce

```
clear all;
clc;

//Example 9.6
//Given
Dt = 2; //[m]
Da = 0.667; //[m]
n = 180/60; //[rps]
T = 20; //[C]
qg = 100; //[m^3/h]
rho = 1000; //[kg/m^3]
mu = 10^-3; //[kg/m-s]
ut = 0.2; //[m/s]
//(a)
//The power input is calculated and followed by correction of gas effect
Nre = n*Da^2*rho/mu;
//For a flat blade turbine, from Table 9.3
KT = 5.75;
//Using Eq.(9.24)
Po = KT*n^3*Da^5*rho/1000; //[kW]
At = %pi/4*Dt^2; //[m^2]
//Superficial gas velocity
Vs_bar = At*qg/3600/10 //[m/s]
//From Fig. 9.20 Pg/Po = 0.60
Pg = Po*0.6; //[kW]
//From Fig.9.7, depth of liquid is equal to diameter of the tank
//Hence, liquid volume
V = %pi/4*Dt^2*Dt; //[m^3]
//The input power per unit volume
PgbyV = Pg/V ; //[kW/m^3]

//(b)
sigma = 72.75; //[g/s^2]
rho_L = 10^-3; //[g/mm]
PgbyV = PgbyV*10^3 ; //[g/mm-s^2]
//Using Eq.(9.46)
```

```
//Let x = shi^(0.5)
//solving the equation as quadratic equation
a = 1;
b = -(Vs_bar/ut)^0.5;
c = -0.216*((PgbyV)^0.4)*(rho_L^0.2)/(sigma^0.6)*(
    Vs_bar/ut)^(0.5);
x = (-b+sqrt(b^2-4*a*c))/(2*a);
shi = x^2;

//(c)
//To find out mean bubble diameter
//Using Eq.(9.44)
Ds_bar = 4.15*sigma^0.6/(PgbyV^0.4*rho_L^0.2)*shi
    ^0.5+0.9 // [mm]

//(d)
//From Eq.(9.40)
aprime = 6*shi/Ds_bar //[mm^-1]
```

**Example 9.7** Example 9.7.sce

```
clear all;
clc;

//Exapmle 9.7
//Given
Dt = 2; //[m]
Da = 0.667; //[m]
n = 180/60; //[rps]
T = 20; //[C]
qg = 100; //[m^3/h]
rho = 1000; //[kg/m^3]
mu = 10^-3; //[kg/m-s]
ut = 0.2; //[m/s]
At = %pi/4*Dt^2; //[m^2]
//Using values form Example 7.6
//Assuming Pg/Po decresaes to 0.25
PgbyV = 0.25*20490/6.28; //[W/m^3]
```

```
//Using Eq.(9.47)
Vs_barc = 0.114*(PgbyV)*(Dt/1.5)^0.17/1000 //[m/s]
qg = Vs_barc*At*3600 //[m^3/h]
//The calculated flooding velocity is beyond the range of the data on which Eq.(9.47)
//was based, so it may not be relaible. Based on Vs_barc, the highest measured value, qg
//would be 850 m^3/h.
```

**Example 9.8** Example 9.8.sce

```
clear all;
clc;

//Example 9.8
//Given
D1 = 1; //[ft]
D6 = 6
Nre_i = 10^4;
Da = 4; //[in.]
t1 = 15; //[s]
P = 2; //[hp/gal]

//(a)
//Using Fig. 9.15
//the mixing factor ntT is constant and time tT is asumed constant,
//speed n will be the same in both vessels.
//Using Eq.(9.24) with consant density
PbyD_ratio = (D6/D1)^2;
//The Power input required in the 6-ft vessel is then
Pin = 2*PbyD_ratio //[hp/1000gal]

//(b)
//Using Eq.(9.54) with same input power per unit volume in both vessels
n6byn1 = (D6/D1)^(2/3)
```

```
//blending in the 6-ft vessel would be
t6 = t1*n6byn1 // [s]
```

# Chapter 10

# Heat Transfer by Conduction

## 10.1 Scilab Code

**Example 10.1** Example 10.1.sce

```
clear all;
clc;

//Exmple 10.1
//Given
T1 = 32; //[F]
T2 = 200; //[F]
k1 = 0.021; //[Btu/ft-h-F]
k2 = 0.032; //[Btu/ft-h-F]
A = 25; //[ft^2]
B = 6/12; //[ft]
//average temperature and thermal condutivity of the
    wall
Tavg = (40+180)/2; //[F]
kbar = k1+(Tavg-T1)*(k2-k1)/(T2-T1); //[Btu/ft-h-F]
delta_T = 180-40; //[F]
//Using Eq.(10.5)
q = kbar*A*delta_T/B //[Btu/h]
```

**Example 10.2** Example 10.2.sce

```
clear all;
clc;

//Example 10.2
//Given
delta1 = 4.5/12 ;//[ft]
k1 = 0.08; //[Btu/ft-h-F]
delta2 = 9/12; //[ft]
k2 = 0.8; //[ft]
Tin = 1400 //[F]
Tout = 170 //[F]
Rc = 0.5; //[ft^2-h-F/Btu]
//(a)
//Considering unit cross sectional area
A = 1; //[ft^2]
RA = delta1/k1; //[ft^2-h-F/Btu]
RB = delta2/k2; //[ft^2-h-F/Btu]
R = RA+RB; //[ft^2-h-F/Btu]
delta_T = Tin-Tout; //[F] overall temperature drop
//Using Eq.(10.9)
q = A*delta_T/R //[Btu/h]

//(b)
//The temperature drop in one series of resistances is to the
//individual resistance as the overall temperature drop is to the
//overall resistance, or
delta_TA = RA*delta_T/R; //[F]
//Temperature at the inteface
Tf =  Tin-delta_TA  //[F]

//(c) The total resistance will now include contact resistance
R = R+Rc; //[ft^2-h-F/Btu]
//the heat loss from unit square area
q = delta_T/R //[Btu/h]
```

**Example 10.3** Example 10.3.sce

```
clear all;
clc;

//Example 10.3
//Given
r1 = 60/2; //[mm]
r2 = (50+r1); //[mm]
k2 = 0.055; //[W/m-C]
r3 = 40+r2; //[mm]
k3 = 0.05; //[W/m-C]
To = 30;  //[C]
Ti = 150; //[C]
//Logrithimic mean for silica layer and cork layer
rl_s = (r2-r1)/log(r2/r1) //[mm]
rl_c = (r3-r2)/log(r3/r2) //[mm]

//Using Eq.(10.15) and Eq.(10.14) simulataneously
//And Adding these two Equations
qbyL = (Ti-To)/4.13 //[W/m]
```

**Example 10.4** Example 10.4.sce

```
clear all;
clc;

//Example 10.4
//Given
k = 0.075; //[Btu/ft-h-F]
rho = 56.2; //[lb/ft^3]
Cp  = 0.40; //[Btu/lb-F]
s = 0.5/12; //[ft.]
Ts = 250; //[F]
Ta = 70; //[F]
Tb_bar = 210; //[F]

//(a)
```

```
Temp_diff_ratio = (Ts-Tb_bar)/(Ts-Ta);
alpha = k/(rho*Cp);
// From Fig.10.6
N_Fo =0.52;
tT = N_Fo*s^2/alpha //[h]

//(b)
//Substituting in Eq.(10.23)
QTbyA = s*rho*Cp*(Tb_bar-Ta) //[Btu/ft^2]
```

---

**Example 10.5** Example 10.5.sce

```
clear all;
clc;

//Example 10.5
//Given
Ts = -20; //[C]
Ta = 5; //[C]
T  = 0; //[C]
t = 12; //[h]
alpha = 0.0011; //[m^2/h]

//(a)
Temp_diff_ratio = (Ts-T)/(Ts-Ta);
//From Fig.(10.8),
Z = 0.91;
//therefore depth
x = Z*2*sqrt(alpha*t) //[m]

//(b)
//From Eq.(10.27), the penetration distance is
x_rho = 3.64*sqrt(alpha*t) //[m]
```

---

# Chapter 11

# Principles of Heat Flow in Fluids

## 11.1 Scilab Code

**Example 11.1** Example 11.1.sce

```
clear all;
clc;

//Example 11.1
//From Appendix 5
Di = 1.049/12; //[ft]
Do = 1.315/12; //[ft]
xw = 0.133/12; //[ft]
km = 26; //[Btu/ft-h-F]
//Using Eq.(10.15) for Logrithmic mean diameter
   DL_bar
DL_bar = (Do-Di)/log(Do/Di); //[ft]
//From Table 11.1
hi = 180; //[Btu/ft^2-h-F]
ho = 300; //[Btu/ft^2-h-F]
hdi = 1000; //[Btu/ft^2-h-F]
hdo = 500; //[Btu/ft^2-h-F]

```

```
//Overall heat transfer coefficient
Uo = 1/(Do/(Di*hdi)+Do/(Di*hi)+(xw*Do)/(km*DL_bar)
    +1/ho+1/hdo) //[Btu/ft^2-h-F]
```

# Chapter 12

# Heat Transfer to Fluids without Phase Change

## 12.1 Scilab Code

**Example 12.1** Example 12.1.sce

```
clear all;
clc;

//Example 12.1
To = 230; //[F]
Ti = 80; //[F]
//Using Table 12.1
hi = 400; //[Btu/ft^2-h-F]
ho = 500; //[Btu/ft^2-h-F]
//From Appendix 6
Di = 0.620; //[in.]
Do = 0.750; //[in.]
//Using Eq.(12.39)
detla_Tt = (1/hi)/(1/hi+(Di/(Do*ho)))*(To-Ti)
```

**Example 12.2** Example 12.2.sce

```
clear all;
clc;
```

```
//Example 12.2
//Given
Tb1 = 141; //[F]
Tb2 = 79; //[F]/
Tw1 = 65; //[F]
Tw2 = 75; //[F]
Vb_bar = 5; //[ft/s]
rho_b = 53.1; //[lb/ft^3]
mu_b = 1.16; //[lb/ft-h], Form Appendix 9
k_b = 0.089; //[Btu/ft-h-F], From Appendix 13
Cp_b = 0.435; //[Btu/lb-F], From Appendix 16
//Using Appndix 14
rho_w = 62.3; //[lb /ft^3]
mu_w = 2.34; //[lb/ft-h]
k_w = 0.346; //[Btu/ft-h-F]
Cp_w = 1; //[Btu/lb-F]


//Soultion
Tavg_b = (Tb1+Tb2)/2; //[F]
Tavg_w = (Tw1+Tw2)/2; //[F]
Dit = 0.745/12; //[ft]
Dot = 0.875/12; //[ft]
//Using Appendix 5
//The inside diameter of the jacket
Dij = 1.610/12; //[ft]
//From Appendix 6, the inside sectional area of the copper tube (for a 7/8 in. BWG 16 tube)
S = 0.00303; //[ft^2]
//Equivalent diameter of the annular jacket space
De = 4*(%pi/4*(Dij^2-Dot^2)/(%pi*(Dij+Dot))); //[ft]
mb_dot = Vb_bar*rho_b*S; //[lb/s]
//The rate of heat flow
q = mb_dot*Cp_b*(Tb1-Tb2); //[Btu/s]
//mass flow rate of water
mw_dot = q/(Cp_w*(Tw2-Tw1)); //[lb/s]
//Water velocity
```

```
Vw_bar = mw_dot/(%pi/4*(Dij^2-Dot^2)*rho_w); //[ft/s]
//Reynolds number for benzene and water
Nre_b = Dit*Vb_bar*rho_b*3600/mu_b;
Nre_w = De*Vw_bar*rho_w*3600/mu_w;
//Prandtl Number for benzene and water
Npr_b = Cp_b*mu_b/k_b;
Npr_w = Cp_w*mu_w/k_w;

//Preliminary estimates of the coefficients are obtained using Eq.(12.32), omitting the
//correction for viscosity ratio:
//Benzene
hi = 0.023*Vb_bar*3600*rho_b*Cp_b/(Nre_b^0.2*Npr_b^(2/3)); //[Btu/ft^2-h-F]
//Water
ho = 0.023*Vw_bar*3600*rho_w*Cp_w/(Nre_w^0.2*Npr_w^(2/3)); //[Btu/ft^2-h-F]
//Using Eq.(12.39)
//Temperature drop over the benzene resistance
delta_Ti = (1/hi)/(1/hi+Dit/(Dot*ho))*(Tavg_b-Tavg_w); //[F]
Tw = Tavg_b - delta_Ti; //[F]

//The viscosities of the liquids at Tw
muw_b = 1.45; //[lb/ft-h]
muw_w = 2.42*0.852; //[lb/ft-h]
//Using Eq.(12.24), viscosity-correction factors phi are
phi_b = (mu_b/muw_b)^0.14;
phi_w = (mu_w/muw_w)^0.14;
//The corrected coefficients are
hi = hi*phi_b; //[Btu/ft^2-h-F]
ho = ho*phi_w; //[Btu/ft^2-h-F]
//The temperature drop over the benzene resistance and the wall temperature
delta_Ti = (1/hi)/(1/hi+Dit/(Dot*ho))*(Tavg_b-Tavg_w); //[F]
```

```
Tw = Tavg_b - delta_Ti //[F]
//This is so close to previously calculated wall
    temperature that a second approximation
//is unnecessary
//Using Eq.(11.29), neglecting the resistance of the
    tube wall
Uo = 1/(Dot/(Dit*hi)+1/ho); //[Btu/ft^2-h-F]
disp('The overall coefficient is');
disp('Btu/ft^2-h-F',Uo);
```

**Example 12.3** Example 12.3.sce

```
clear all;
clc;

//Example 12.3
//Given
L = 15; //[ft]
k = 0.082; //[Btu/ft-h-F]
Cp = 0.48; //[Btu/lb-F]
T1 = 150; //[F]
T2 = 250; //[F]
Tw = 350; //[F]
//From Table 12.3
mu1 = 6; //[cP]
mu2 = 3.3; //[cP]
mu_w = 1.37; //[cP]
mu = (mu1+mu2)/2; //[cP]
//From Appendix 5
D = 0.364/12; //[ft]
//viscosity-correction factor phi is
phi = (mu/mu_w)^0.14;
//Assuming Laminar flow and Graetz number large
    enough to apply Eq.(12.25)
//Using Eq.(12.25)
//h = k/D*2*phi*(Cp*mdot/(k*L))^(1/3);
//To use Eq.(12.18)
```

```
Log_T = ((Tw-T1)-(Tw-T2))/log((Tw-T1)/(Tw-T2)); //[F]
//From Eq.(12.18)
//h = Cp*100*mdot/(%pi*D*L*Log_T)
//From Eq.(12.25) and Eq.(12.18)
mdot = (4.69/0.233)^(3/2); //[lb/h]
//and
h = 0.233*mdot; //[Btu/ft^2-h-F]
disp('lb/h',mdot,'oil flow rate')

disp('Btu/ft^2-h-F',h,'Expected Coefficient')
Ngz = mdot*Cp/(k*L);
//This is large enough so that Eq.(12.25) applies,
//Reynolds Number
Nre = D*mdot/((%pi/4*D^2)*mu*2.42);
//Nre is in Laminar Range
```

**Example 12.4** Example 12.4.sce

```
clear all;
clc;

//Example 12.4
//Given
P = 1; //[atm]
Vbar = 1.5; //[ft/s]
Ti = 68; //[F]
To = 188; //[F]
Tw = 220; //[F]
Tbar = (Ti+To)/2; //[F]
D = 2.067/12; //[ft], from Appendix 5
mu = 0.019; //[cP], at 128[F], from Appendix 8
rho = 29/359*(492/(68+460)); //[lb/ft^3], at 68[F]
G = Vbar*rho*3600; //[lb/ft^2-h]
Nre = D*G/(mu*2.42);
g = 32.14;
//Hence the flow is laminar
//Applying Eq.(12.25)
```

```
Cp = 0.25; //[Bu/lb-F], at 128[F], Appendix 15
k = 0.0163; //[Btu/ft-h-F], at 128[F], Appendix 12
//By linear interpolation
mu_w = 0.021; //[cP], Appendix 5
//internal cross sectional area of pipe is
S = 0.02330; //[ft^2], Appendix 5
//mass flow rate
mdot = G*S; //[lb/h]
//the heat load
q = mdot*Cp*(To-Ti); //[Btu/h]
//The logrithmic mean temperature difference is
delta_T1 = Tw-To; //[F]
delta_T2 = Tw-Ti; //[F]
Log_T = (delta_T1-delta_T2)/log(delta_T1/delta_T2); //[F]

//heat transfer coefficient h = q/A*Log_T
//A = 0.541*L
//Also from Eq.(12.25), the heat transfer coefficient is
//h = 2*k/D*(mdot*Cp/k*L)^(1/3)*(mu/mu_w)^(1/4)
//Equating the two realtionships for h
L = (6.820/0.9813)^(3/2); // [ft]
//This result is corrected for the effect of natural convection
//To use Eq.(12.80)
beeta = 1/(460+Tbar) ;//[R^-1], at 128[F]
delta_T = Tw-Tbar; //[F]
rho = 0.0676; //[lb/ft^3]
//Grashof number
Ngr = D^3*rho^2*g*beeta*delta_T/(mu*6.72*10^-4)^2;
//From Eq.(12.80)
phi_n = 2.25*(1+0.01*Ngr^(1/3))/log10(Nre);
//this is factor is used to correct the value of L
L = L/phi_n; //[ft]
disp('ft',L,'lenght of heated section is')
```

# Chapter 13

# Heat Transfer to Fluids with Phase Change

## 13.1 Scilab Code

**Example 13.1** Example 13.1.sce

```
clear all;
clc;

//Example 13.1
//Given
Pa = 1; //[atm]
lambda = 139.7; //[Btu/lb]
L = 5; //[ft]
Tw = 175; //[F]
hi = 400; //[Btu/ft^2-h-F]
g = 4.17*10^8; //[ft/h^2]
Th = 270; //[F]
rho_f = 65.4; //[lb/ft^3]
kf = 0.083; //[Btu/ft-h-F], from Appendix 13
muf = 0.726; //[lb/ft-h], from Appendix 9
Do = 0.75/12; //[ft]
Di = Do-(2*0.065)/12; //[f]
//(a)
```

```
Twall = 205; //[F]
err = 50;
h = 1.13;
while(err>10)
delta_To = Th-Twall;
//from Eq.(13.11)
Tf = Th-3*(Th-Twall)/4; //[F]
h = h*(kf^3*rho_f^2*g*lambda/(delta_To*L*muf))^(1/4)
    ; //[Btu/ft^2-h-F]
//Using Eq.(12.29)
delta_Ti = 1/hi/(1/hi+Di/(Do*h))*(Th-Tw); //[F]
Twall_new = Tw + delta_Ti; //[F]
err = Twall_new-Twall; //[F]
Twall = Twall_new; //[F]
end
//To ckeck whether the flow is actually laminar
Ao = 0.1963*L; //[ft^2], from Appendix 6
//the rate of heat transfer
q = h*Ao*(Th-Twall); //[Btu/h]
mdot = q/lambda; //[lb/ft-h]
disp('[Btu/ft^2-h-F]',h,'coefficient of
    chlorobenzene is')


//(b)
//For a horizontal condenser, Using Eq.(13.16)
N =6;
Twall = 215; //[F]
err = 50;
h = 0.725;
muf = 0.68; //[lb/ft-h], from Appendix 6
while(err>10)
delta_To = Th-Twall;
//from Eq.(13.11)
Tf = Th-3*(Th-Twall)/4; //[F]
h = h*(kf^3*rho_f^2*g*lambda/(6*delta_To*Do*muf))
    ^(1/4); //[Btu/ft^2-h-F]
//Using Eq.(12.29)
```

```
delta_Ti = 1/hi/(1/hi+Di/(Do*h))*(Th-Tw); //[F]
Twall_new = Tw + delta_Ti; //[F]
err = Twall_new-Twall; //[F]
Twall = Twall_new; //[F]
end
disp('[Btu/ft^2-h-F]',h,'coefficient of
    chlorobenzene is')
```

**Example 13.2** Example 13.2.sce

```
clear all;
clc;

//Example 13.2
//Given
P = 2; //[atm]

//(a)
//From Fig. 13.7
// Critical pressure of benzene
Pc = 47.7; //[atm]
PbyPc = P/Pc;
//From Fig. 13.7 the ordinate (q/A)max/Pc is about
    190, and
qbyA_max = 190*Pc*14.696; //[Btu/h-ft^2]
disp('Btu/h-ft^2',qbyA_max,'The maximum heat flux is
    ')
//Also from Fig. 13,7
delta_Tc = 62; //[F]
disp('F',delta_Tc,'The critical temperature
    difference is')
// film coefficient
h = qbyA_max/delta_Tc; //[Btu/h-ft^2-F]
disp('Btu/h-ft^2-F',h,'The film coefficient is')

//(b)
//Given
P = 0.2; //[atm]
```

```
PbyPc = P/Pc;
//Using Eq.(13.20)
//noting that lambda, sigma and rho_L are nearly
    constant and rho_L>rho_V
// qbyA_max~rho_V^(1/2)~P^(1/2)
qbyA_max = qbyA_max*(0.2/2)^(1/2); //[Btu/h-ft^2]
disp('Btu/h-ft^2',qbyA_max,'The maximum heat flux is
    ')
//The critical temperature difference would be
    greater than 100 [F] and
//the film coefficient would be less than 410 [Btu/h
    -ft^2-F]
```

# Chapter 14

# Radiation Heat Transfer

## 14.1 Scilab Code

**Example 14.1** Example 14.1.sce

```
clear all;
clc;

//Example 14.1
//Given
d = 150; //[mm]
T1 = 300+272; //[K]
T3 = 25+273; //[K]
eps1 = 0.56;
eps2 = 1.0;
eps3 = eps1;
sigma = 5.672

//(a)
//Using Eq.(14.38)
//q12 = sigma*A1*F12*(T1^4-T2^4)
//q23 = sigma*A2*F23*(T2^4-T3^4)
//At equilibrium , q12=q23
//From Eq.(14.39)
F12 = 1/(1/eps1+1/eps2-1)
```

```
F23 = F12;
//A1 = A2
T2 = (100*((T1/100)^4+(T3/100)^4)^(1/4))/2^(1/4); //
    [K]
disp('F',T2,'the temperature of lacquered sheet is')

//(b)
//From Eq.(14.38), heat flux
q12byA = sigma*F12*((T1/100)^4-(T2/100)^4); //[W/m
    ^2]
disp('W/m^2',q12byA,'the heat flux is')
```

# Chapter 15

# Heat-Exchange Equipment

## 15.1 Scilab Code

**Example 15.1** Example 15.1.sce

```
clear all;
clc;

//Example 15.1
//Given
Ds = 35/12; //[ft]
Do = 0.75/12; //[ft]
p = 1/12; //[ft]
P = 1; //[ft]
mdot = 10^5; //[lb/h]
mu_60 = 0.70; //[cP], at 60 [F], from Appendix 9
mu_140 = 0.38; //[cP], at 140 [F], from Appendix 9
Cp = 0.41; //[Btu/lb-F], from Appendix 16
k = 0.092; //[Btu/ft-h-F], from Appendix 13

//Shell side coefficient is found using Donohue Eq.(15.4)
//From Eq.(15.2), the area for crossflow is
Sc = 2.9167*P*(P-Do/p); //[ft^2]
//The number of tubes in the baffle window is
```

```
    approximately equal to the fractional
//area of the window f times the total nmber of
    tubes. For a 25 percent baffle
f = 0.1955
Nb = f*828;
//Nb~161
Nb = 161;
//Using Eq.(15.1), area of the baffle window
Sb = (f*%pi*Ds^2/4)-(Nb*%pi*Do^2/4); //[ft^2]
//Using Eq.(15.3), the mass velocities are
Gc = mdot/Sc; //[lb/ft^2-h]
Gb = mdot/Sb; //[lb/ft^2-h]
Ge = sqrt(Gc*Gb); //[lb/ft^2-h]
//Using Eq.(15.4)
ho = k/Do*(0.2*(Do*Ge/(mu_60*2.42))^0.6*(Cp*mu_60
    *2.42/k)^0.33*(mu_60/mu_140)^0.14);//[Btu/ft^2-h-
    F]
disp('Btu/ft^2-h-F',ho,'The individual heat transfer
     coefficent of benzene is')
```

---

**Example 15.2** Example 15.2.sce

```
clear all;
clc;

//Example 15.2
//Given
Tca = 70; //[C]
Tcb = 130; //[C]
Tha = 240; //[C]
Thb = 120; //[C]
//Solution
//Using Eq.(15.7) and (15.8)
neta_h = (Tcb-Tca)/(Tha-Tca);
Z = (Tha-Thb)/(Tcb-Tca);
//From Fig 15.7a, the correction factor is found
Fg = 0.735;
//the temperature drops are
```

```
//At shell inlet:
deltaT_i = Tha-Tcb; //[C]
//At shell outlet:
deltaT_o = Thb-Tca; //[C]
Log_T = (deltaT_i-deltaT_o)/log(deltaT_i/deltaT_o);
// the correct value of Log_T is
Log_T = Fg*Log_T; //[C]
disp('C',Log_T,'The correct mean emperature drop is')
//Because of low value of Fg, a 1-2 heat exchanger is not suitable for this duty
```

**Example 15.3** Example 15.3.sce

```
clear all;
clc;

//Exapmle 15.3
//Given
Tca = 70; //[C]
Tcb = 130; //[C]
Tha = 240; //[C]
Thb = 120; //[C]
//Solution
//Using Eq.(15.7) and (15.8)
neta_h = (Tcb-Tca)/(Tha-Tca);
Z = (Tha-Thb)/(Tcb-Tca);
//Using Fig 15.7b, the correction factor is
Fg = 0.945;
//the temperature drops are
//At shell inlet:
deltaT_i = Tha-Tcb; //[C]
//At shell outlet:
deltaT_o = Thb-Tca; //[C]
Log_T = (deltaT_i-deltaT_o)/log(deltaT_i/deltaT_o);
// the correct value of Log_T is
Log_T = Fg*Log_T; //[C]
```

```
disp('C',Log_T,'The correct mean emperature drop is'
   )
```

**Example 15.4** Example 15.4.sce

```
clear all;
clc;

//Example 15.4
//Given
N = 28;
xF = 0.5/12; //  [ft]
yF = 0.035/12; //[ft]
km = 26; //  [Btu/ft-h-F]
AT = 2.830; //[ft^2/ft]
Ab = 0.416; //[ft^2/ft]
hi = 1500; //[Btu/ft^2-h-F]
G = 5000; //[lb/h-ft^2]
Tavg = 130; //[F]
Tw = 250; //[F]
mu = 0.046; //[lb/ft-h], from Appendix 8
Cp = 0.25; //[Btu/lb-F], from Appendix 15
k = 0.0162; //[Btu/ft-h-F], from Appendix 12
ID_shell = 3.068/12; //[ft], from Appendix 5
OD_pipe = 1.9/12; //[ft], from Appendix 5
//cross sectional area of shell space
Ac = %pi/4*(ID_shell^2-OD_pipe^2)-N*xF*yF //[ft^2]
//The perimeter of air space
Ap = %pi*ID_shell+AT; //[ft]
//hydraulic radius
rh = Ac/Ap; //[ft]
//equivalent diameter
De = 4*rh; //[ft]
//Reynolds Number
Nre = De*h/mu
//In computing mu_w the resistance of the wall and
   the steam film
//are considered negligible, so
```

```
mu_w = 0.0528; //[lb/ft-h]
Npr = mu*Cp/k
//Using Fig. 15.17, the heat transfer factor is
jh = 0.0031;
ho = jh*Cp*G*(mu/mu_w)^0.14/Npr^(2/3); //[Btu/ft^2-h-F]

//For rectangular fins, disreagrding the contribution of the ends of the fins to
//the perimeter, Lp = 2L and S = Lyf, where yf is the fin thickness and L is the
//length of the fin. Then, from Eq.(15.11)
aFxF = xF*sqrt(2*ho/(km*yF));
//From Fig. 15.16
netaF = 0.93;
Dt = 1.610/12; //[ft], from Appendix 5
DLbar = (OD_pipe-Dt)/log(OD_pipe/Dt); //[ft]
Ai = %pi*Dt*1.0; //[ft^2]
AF = AT-Ab; //[ft^2/ft]
xw = (OD_pipe-Dt)/2; //[ft]

//Using Eq.(15.10), the overall coefficient
Ut =  1/(Ai/(ho*(netaF*AF+Ab))+(xw*Dt/(km*DLbar))+1/hi);//[Btu/ft^2-h-F]
disp('Btu/ft^2-h-F',Ut,'The overall heat transfer coefficent is')
```

# Chapter 16

# Evaporation

## 16.1 Scilab Code

**Example 16.1** Example 16.1.sce

```
clear all;
clc;

//Example 16.1
//Given
mdot = 20000; //[lb/h]
xin = 0.20;
xout = 0.50;
Pg = 20; //[lbf/in.^2]
Pabs = 1.93; //[lbf/in.^2]
U = 250; //[Btu/ft^2-h-F]
Tf = 100; //[F]

//Solution
//the amount of water in feed and thick liquor, from material balance
w_feed = 80/20; //[lb/per pound of solid]
w_liquor = 50/50; //[lb/per pound of solid]
//water evaporated
w_eva = w_feed-w_liquor; //[lb/per pound of solid]
```

```
//or
w_eva = w_eva*mdot*xin; //[lb/h]
//Flow raye of thick liquor is
ml_dot = mdot-w_eva //[lb/h]

//Steam consumed
//Since with strong solutions of NaOH the heat of dilution is not negligible,
//the rate of heat transfer is found from Eq.(16.4) and Fig. 16.8.
//The vaporiztion temperature of the 50 percent solution at a pressure of 100 mmHg
//is found as follows
Tb_w = 124; //[F], at 100 mmHg, from Appendix 7
Tb_s = 197; //[F], from Fig. 16.8
BPE = Tb_s-Tb_w; //[F]
//From Fig. 16.8, the enthalpies of the feed and thick liquor are found
Hf = 55;  //[Btu/lb], 20% solids, 100 [F]
H   = 221; //[Btu/lb], 50% solids, 197 [F]
//Enthalpy of the leaving water vapor is found from the steam table
Hv = 1149; //[Btu/lb], At 197 [F] and 1.93 [lbf/in.^2]
//Enthalpy of the vapor leaving the evaporator
lambda_s = 939;//[Btu/lb], At 20 [lbf/in.^2], from Appendix 7
//Using Eq.(16.4), the rate of heat transfer and steam consumption
q = (mdot-ml_dot)*Hv + ml_dot*H - mdot*Hf; //[Btu/h]
ms_dot = q/lambda_s; //[lb/h]
disp('lb/h',ms_dot,'steam consumed is')
//Economy
Economy = ml_dot/ms_dot
disp(Economy,'Economy')
//Heating Surface
//The condensation temperature of the steam is 259 [F], the heating area required is
```

```

A = q/(U*(259-197)) //[ft^2]
disp('ft^2',A,'heating area required is')
```

**Example 16.2** Example 16.2.sce

```
clear all;
clc;

//Example 16.2
//Given
Ti = 108; //[C]
Tl = 52; //[C]
U1 = 2500; //[W/m^2]
U2 = 2000; //[W/m^2]
U3 = 1000; //[W/m^2]

//Solution
//Total temperature drop
delta_T = Ti-Tl; //[C]
//From Eq.(16.13), the temperature drops in several
    effects will be
//approximaely inversely proportional to the
    coeficients. Thus
delta_T1 = 1/U1/(1/U1+1/U2+1/U3)*delta_T; //[C]
delta_T2 = 1/U2/(1/U1+1/U2+1/U3)*delta_T; //[C]
delta_T3 = 1/U3/(1/U1+1/U2+1/U3)*delta_T; //[C]
//Consequently the boiling points will be
Tb1 = Ti-delta_T1; //[C]
Tb2 = Tb1-delta_T2; //[C]
disp('C',Tb1,'The boiling point in the first effect
    is')
disp('C',Tb2,'The boiling point in the second effect
     is')
```

**Example 16.3** Example 16.3.sce

```
clear all;
```

```
clc;

//Example 16.3
//Given
mdot_ft = 60000; //[lb/h]
xin = 0.10;
Tin = 180; //[F]
xout = 0.50
Ps = 50; //[lbf/in.^2]
Tc = 100; //[F]

//Solution
//From Table 16.2
U1 = 700;  //[Btu/ft^2-h-F]
U2 = 1000; //[Btu/ft^2-h-F]
U3 = 800;  //[Btu/ft^2-h-F]
//The total rate of evaporation is calculated from
   an overall material balance
//assuming the solds go through the evaporator
   without loss
//Table 16.3
mdot_fs = 6000;  //[lb/h]
mdot_fw = 54000; //[lb/h]
mdot_lt = 12000; //[lb/h]
mdot_ls = 6000;  //[lb/h]
mdot_lw = 6000;  //[lb/h]
w_evap = mdot_ft-mdot_fs; //[lb/h]
```

# Chapter 17

# Equilibrium-Stage Operations

## 17.1 Scilab Code

**Example 17.1** Example 17.1.sce

```
clear all;
clc;

//Example 17.1
//Given
yb = 0.30;

//Let
Vb = 100; //[mol]
Ace_in = yb*Vb; //[mol]
Air_in = Vb-Ace_in; //[mol]
//97 percent acetone aborbed, Acetone leaving is
Ace_out = 0.03*Ace_in; //[mol]
ya = Ace_out/(Air_in+Ace_out);
//Acetone absorbed
Ace_abs = Ace_in-Ace_out; //[mol]
//10 percent acetone in the leaving solution and no
    acetone in the entering oil
Lb = Ace_abs/0.1; //[mol]
La = Lb-Ace_abs; //[mol]
```

```
//To find out as intermediate point on the operating
    line , making an acetone balance
//around the top part of the tower , assuming a
    particular value of yV the moles of
//acetone left in the gas.
for i=1:30
  y(i) = i/(i+Air_in);
//The moles of acetone lost by the gas in the secion
    , must equal to the moles gained by //the liquid
Ace_lost = i-Ace_out; //[mol]
//Hence
x(i) = Ace_lost/(La+Ace_lost);
end
xe = linspace(0.001,0.15,100);
ye = 1.9*xe;

plot(x,y)
plot(xe,ye,'r')
xlabel('x')
ylabel('y')
legend('Operating line','Equilibrium line')
title('Diagram Example 17.1')
//The number of ideal stages determined from Fig is
    4
```

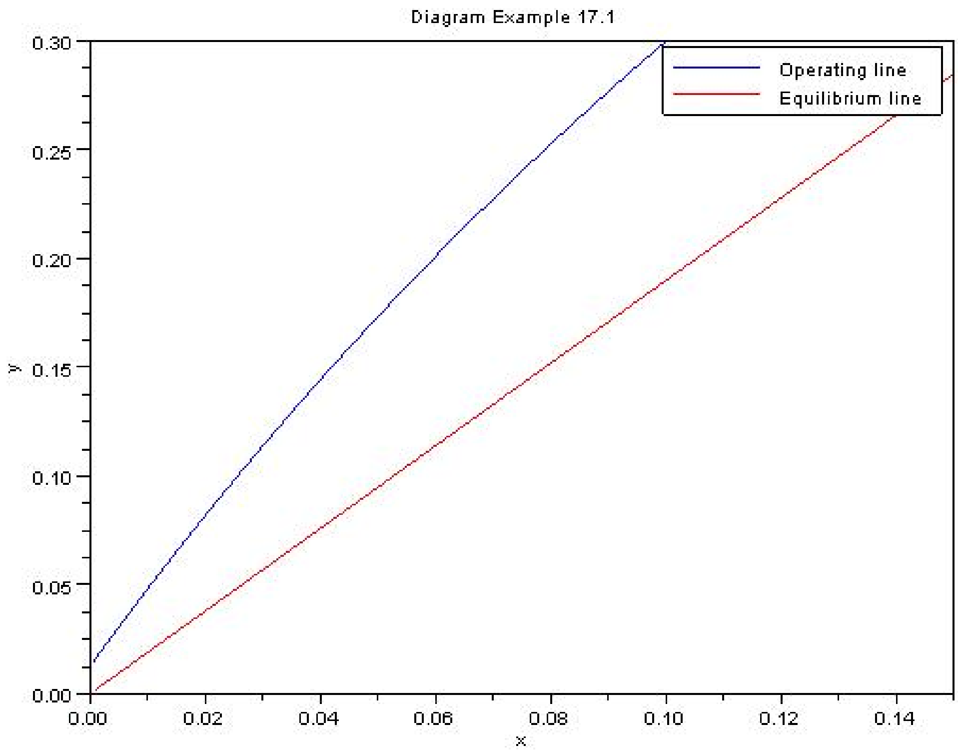


Figure 17.1: Diagram for Example 17.1

---

**Example 17.2** Example 17.2.sce

```
clear all;
clc;

//Example 17.2
//Given
Nreal = 7;
VbyL = 1.5;
m = 0.8;
yb = 0;
```

```
xb_star = 0;
//xb=0.1*xa;

//(a)
//Stripping Factor
S = m*VbyL;
//From an ammonia balance,
//ya =0.9*xa/VbyL;
//Also
//xa_star = ya/m
//Using Eq.(17.28)
//N = ln((xa-0.75*xa)/(0.1*xa-0))/ln(S)
N = log(0.25/0.1)/log(S);
disp(N,'Number of ideal trays required are')
stage_eff = N/Nreal*100;
disp('%',stage_eff,'Stage Efficiency is')

//(b)
VbyL = 2;
S = m*VbyL;
//Then,
//Let A = (xa-xa_star)/xb
A = exp(5.02);
//Let 'f' be the fraction of NH3 removed. Then xb = (1-f)*xa.
//By a material balance
//y = L/V*(xa-xb) = 1/2*(xa-(1-f)*xa)= 1/2*f*xa
//xa_star = ya/m = 0.5*f*xa/0.8 = 0.625*f*xa
//Thus,
//xa-xa_star = (1-0.625*f)*xa
//Also,
//xa-xa_star = 10.59*xb = 10.59*(1-f)*xa
//from these
f = 0.962
disp('%',f,'percentage removal obtained in this case is')
```

# Chapter 18

# Distillation

## 18.1 Scilab Code

**Example 18.1** Example 18.1.sce

```
clear all;
clc;

//Example 18.1
//Given
xF = 0.50;
P = 1; //[atm]
f =0.0001:0.2:1.2;
A = -(1./f-1);
x = [0.01:0.01:1];
for i =1:length(f)
  y(i,:) =-A(i)*x+xF/f(i)
end
//From Fig. 18.2
xB = [0.50,0.455,0.41,0.365,0.325,0.29];
yD = [0.71,0.67,0.63,0.585,0.54,0.5];
//From Fig 18.3
T = [92.2,93.7,95.0,96.5,97.7,99];
plot(f,T./100,f,xB,f,yD)
xlabel('f-moles vaporized per mole of feed')
```

```
ylabel('Concentration, mole fraction Benzene')
legend('Temperature(C)*100','Con. of Bnzene in
    liquid','Con. of Bnzene in vapor')
```

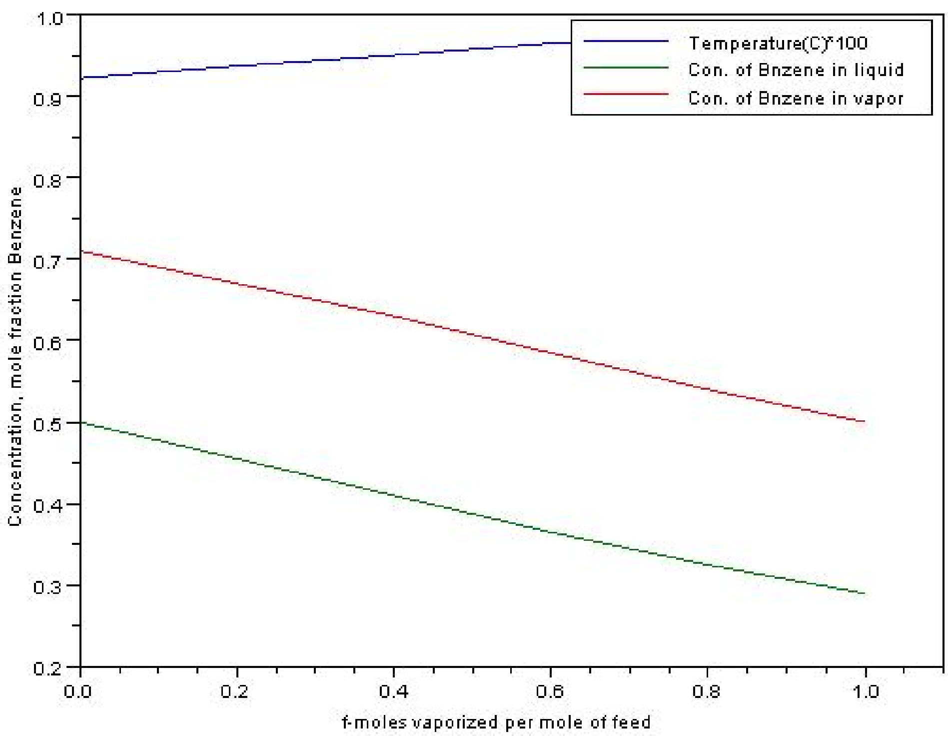


Figure 18.1: Results of Example 18.1

---

**Example 18.2** Example 18.2.sce

```
clear all;
clc;

//Example 18.2
```

```
//Given
mdot = 30000; //[kg/h]
wF_b = 40;
wD = 97;
wB = 2;
R = 3.5;
lambda_b = 7360; //[cal/g mol]
lambda_t = 7960; //[cal/g mol]
alpha = 2.5;
TB = 95; //[C]
TF = 20; //[C]
P = 1; //[atm]
Mb = 78;
Mt = 92;
Cp = 0.44; //[cal/g-C]
//(a)
//The concentrations of feed, overhead and bottoms in mole fraction of benzene are
xF = (wF_b/Mb)/(wF_b/Mb+((100-wF_b)/Mt));
xD = (wD/Mb)/(wD/Mb+((100-wD)/Mt));
xB = (wB/Mb)/(wB/Mb+((100-wB)/Mt));
//The average molecular weight of the feed is
Mavg = 100/(wF_b/Mb+(100-wF_b)/Mt);
//the average heat of vaporization
lambda_avg = xF*lambda_b+(1-xF)*lambda_t; //[cal/g mol]
//Feed rate
F = mdot/Mavg; //[kg mol/h]
//Using Eq.(18.5), by overall benzene balance
D = F*(xF-xB)/(xD-xB); //[kg mol/h]
B = F-D; //[kg mol/h]
disp('respectively','kg mol/h',B,'kg mol/h',F,'the mole of overhead and bottom products are')


//(b)Detemination of number of ideal plates and position of feed plate
//(i)
```

```
//Using Fig.18.16
//Drawing the feed line with f = 0 on equilibrium diagram,
//Plotting the operating lines with intercept from Eq.(18.19) is 0.216
//By counting the rectangular steps it is found that, besides the reboiler,
//11 ideal plates are neded and feed should be introduced on the 7th plate from
//the top.

//(ii)
//The latent heat of vaporization of the feed
lambda = lambda_avg/Mavg; //[cal/g]
//Using Eq.(18.24)
q = 1+Cp*(TB-TF)/lambda;
//From Eq.(18.31)
slope = -q/(1-q);
//From Fig. 18.17
//It is found that a reboiler and 10 ideal plates are needed and feed is to be introduced
//on the fifth plate

//(iii)
q = 1/3;
slope = -q/(1-q);
//From Fig. 18.18
//It calls for a reboiler and 12 plates, with the feed entering on the 7th plate

//(c)
//vapor flow in the rectifying section is
V = 4.5*D; //[kg mol/h]
lambda_s = 522; //[cal/g], From Appendix 7
q = [1, 1.37, 0.333]
//Using Eq.(18.27)
Vbar = V-F*(1-q)
//Using Eq.(18.32), steam required
```

```
ms_dot = lambda_t/lambda_s*Vbar; //[kg/h]
disp('respectively','kg/h',ms_dot(3),'kg/h',ms_dot(2),'kg/h',ms_dot(1),'the steam consumption in the above three cases is')


//(d)
Tw1 = 25; //[C]
Tw2 = 40; //[C]
//The cooling water needed is same in all cases, Using Eq.(18.33)
mw_dot = V*lambda_t/(Tw2-Tw1); //[kg/h]
rho_25 = 62.24*16.018; //[kg/m^3]
vw_dot = mw_dot/rho_25; //[m^3/h]
disp('m^3/h',vw_dot,'cooling water needed is')
```

**Example 18.3** Example 18.3.sce

```
clear all;
clc;

//Example 18.3
//Given
mdot = 30000; //[kg/h]
wF_b = 40;
wD = 97;
wB = 2;
R = 3.5;
lambda_b = 7360; //[cal/g mol]
lambda_t = 7960; //[cal/g mol]
alpha = 2.5;
TB = 95; //[C]
TF = 20; //[C]
P = 1; //[atm]
Mb = 78;
Mt = 92;
Cp = 0.44; //[cal/g-C]
//Solution
```

```
xF = (wF_b/Mb)/(wF_b/Mb+((100-wF_b)/Mt));
xD = (wD/Mb)/(wD/Mb+((100-wD)/Mt));
xB = (wB/Mb)/(wB/Mb+((100-wB)/Mt));
//The average molecular weight of the feed is
Mavg = 100/(wF_b/Mb+(100-wF_b)/Mt);
//the average heat of vaporization
lambda_avg = xF*lambda_b+(1-xF)*lambda_t; //[cal/g mol]
//Feed rate
F = mdot/Mavg; //[kg mol/h]
//Using Eq.(18.5), by overall benzene balance
D = F*(xF-xB)/(xD-xB); //[kg mol/h]
B = F-D; //[kg mol/h]
//Using Table 18.3, in all three cases respectively
xprime = [0.44,0.521,0.3];
yprime = [0.658,0.730,0.513];

//(a)
//Using Eq.(18.43)
RDm = (xD-yprime)./(yprime-xprime)
disp('respectively',RDm(3),RDm(2),RDm(1),'Minimum Reflux Ratio for three cases is')

//(b)
//For minimum umber of plates the, the reflux ratio is infinite, the operating lines
//coincides with the diagonal, and there are no differences between the three cases.
//The plot is given by Fig 18.22. A reboiler and eight plates are needed.
```

**Example 18.4** Example 18.4.sce

```
clear all;
clc;

//Example 18.4
//Given
```

```
xa = 0.02;
Vbar = 0.2; //[mol/mol of Feed]
xb = 0.0001;
yb = 0;
xe = 0:0.01:1;
m = 9
ye = m*xe;
//Let
F = 1; //[mol]
Lbar = F; //[mol]

//Solution
ya_star = m*xa;
yb_star = m*xb;
//By overall ethonal balance
ya = Lbar/Vbar*(xa-xb)+ yb
//Using Eq.(17.27), As both operting lines and equilibrium lines are straight
N = log((ya-ya_star)/(yb-yb_star))/log((yb_star-ya_star)/(yb-ya));

disp(N,'Ideal plates needed are' )
```

**Example 18.6** Example 18.6.sce

```
clear all;
clc;

//Example 18.6
//Given
xF = 0.40;
P = 1; //[atm]
D = 5800; //[kg/h]
R = 3.5;
LbyV = R/(1+R);
//Solution
//Physical properties of methanol
M = 32;
```

```
Tnb = 65; //[C]
rho_v = M*273/(22.4*338); //[kg/^3]
rho_l_0 = 810; //[kg/m^3], At 0C, from Perry, Chemical Engineers' Handbook
rho_l_20 = 792; //[kg/m^3], At 20C, from Perry, Chemical Engineers' Handbook
rho_l = 750; //[kg/m^3], At 65C
sigma = 19; //[dyn/cm], from Lange's Handbook of Chemistry
//(a)
//Vapor velocity and column diameter
//Using Fig. 18.28, the abscissa is
abscissa = LbyV*(rho_v/rho_l)^(1/2);
//for 18-in. plate spacing
Kv = 0.29;
//Allowable vapor velocity
uc = Kv*((rho_l-rho_v)/rho_v)^(1/2)*(sigma/20)^(0.2); //[ft/s]
//Vapor flow rate
V = D*(R+1)/(3600*rho_v); //[m^3/s]
//Cross setional area of the column
Bubbling_area = V/2.23; //[m^2]
//If the bubble area is 0.7 of the total column area
Column_area = Bubbling_area/0.7; //[m^2]
//Column diameter
Dc = sqrt(4*Column_area/%pi); //[m]
disp('respectively','m',Dc,'and','ft/s',uc,'the allowable velocity and colmn diameter are')

//(b)
//Pressure drop:
//Area of one unit of three holes on a trangular 3/4-in. pitch is
//1/2*3/4*(3/4*sqrt(3/2)) in.^2. The hole area in this section (half a hole)is
//1/2*%pi/4*(1/4)^2 in.^2. Thus the hole area is %pi/128*64/9*sqrt(3), or 10.08 percent
//of the bubbling area.
```

```
//Vapor velocity through holes:
uo = 2.23/0.1008; //[m/s]
//Using Eq.(18.58),
//From Fig. 18.27
Co = 0.73;
hd = 51.0*uo^2*rho_v/(Co^2*rho_l); //[mm methanol]
//Head of liquid on plate:
//Weir height
hw = 2*25.4; //[mm]
//Height of the liquid above weir:
//Assuming the downcomer area is 15 percent of the
    column
//area on each side of th column. From Perry, the
    chord
//length for sucha segmental downcomer is 1.62 times
     the radius
//of the colmn, so
Lw = 1.62*2.23/2; //[m]
//Liqiud Flow rate:
qL = D*(R+1)/(rho_l*60); //[m^3/min]
//From Eq.(18.60)
how = 43.4*(qL/Lw)^(2/3) //[mm]
//From Eq.(18.59), with
beeta = 0.6;
hI = beeta*(hw+how); //[mm]
//Total height of liquid, from Eq.(18.62)
hT = hd+hI; //[mm]
disp('mm methanol',hT,'pressure drop per plate is')

//(c)
//Froth height in th downcomer :
//Using Eq.(18.62).,Estimating
hf_L = 10; //[mm methanol]
//Then,
Zc = (2*hI)+hd+hf_L; //[mm]
//from Eq.(18.63)
Z = Zc/0.5; //[mm]
disp('mm methanol',Z,'Froth height in the downcomer
```

is ')

---

**Example 18.7** Example 18.7.sce

```
clear all;
clc;

//Example 18.7
//Given
xF = 0.40;
P = 1; //[atm]
D = 5800; //[kg/h]
R = 3.5;
LbyV = R/(1+R);
//Solution
//Physical properties of methanol
M = 32;
Tnb = 65; //[C]
rho_v = M*273/(22.4*338); //[kg/^3]
rho_l_0 = 810; //[kg/m^3], At 0C, from Perry,
    Chemical Engineers' Handbook
rho_l_20 = 792; //[kg/m^3], At 20C, from Perry,
    Chemical Engineers' Handbook
rho_l = 750; //[kg/m^3], At 65C
sigma = 19; //[dyn/cm], from Lange's Handbook of
    Chemistry
//(a)
//Vapor velocity and column diameter
//Using Fig. 18.28, the abscissa is
abscissa = LbyV*(rho_v/rho_l)^(1/2);
//for 18-in. plate spacing
Kv = 0.29;
//Allowable vapor velocity
uc = Kv*((rho_l-rho_v)/rho_v)^(1/2)*(sigma/20)^(0.2)
    /(3.2825112); //[ft/s]
//From Eq.(18.71), the F factor is
F = uc*sqrt(rho_v);
disp(F,'the value of F factor is')
```

**Example 18.8** Example 18.8.sce

```
clear all;
clc;

//Example 18.8
//Given
x0A = 0.15;
xAi = 0.015;

P = 1; //[atm]

//Solution

Pv = 3.4; //[atm]
alpha_o = 3.4; //at 36 C
Tbi = 27; //[C]
alpha_i = 3.6
alpha = (alpha_o+alpha_i)/2;
//Basis 1 mol Feed
n0A = 0.15; //[mol]
nA = 0.015; //[mol]
n0B = 0.85; //[mol]
//Using Eq.(18.79)
nB = n0B*(nA/n0A)^(1/alpha); //[mol]
n = nA+nB; //[mol]
xA = nA/n;
disp('mol',nB,'pentane removed is')
disp((1-xA),'xB',xA,'xA','composition of the
    remaining liquid is')
```

# Chapter 19

# Introduction to Multicomponent Distillation

## 19.1 Scilab Code

**Example 19.2** Example 19.2.sce

```
clear all;
clc;

//Example 19.2
//Given
P = 1.2; //[atm]
Tb = 97; //[C]
Td = 105; //[C]
f = 0.6;

xF(1) = 0.33;
xF(2) = 0.37;
xF(3) = 0.30;

//Solution
//(a)

//From Fig. 19.1
```

```
K(1) = 2.68/P;
K(2) = 1.21/P;
K(3) = 0.554/P;
//In Eq.(19.12), the right hand side of the equation
    becomes
RHS = (xF./(f*(K-1)+1));
RHS2 = sum(RHS)
disp('C',Td,'flash temperature is');
disp('percent',RHS(3),'n-octaneexane','percent',RHS
   (2),'n-heptane','percent',RHS(1),'n-hexane','
   Composition of the liquid product is');
y = RHS.*K;
disp('percent',y(3),'n-octane','percent',y(2),'n-
   heptane','percent',y(1),'n-hexane','Composition
   of the vapor product is');

//(b)
//To determine the temperature of the feed before
   flashing,
//an enthalpy balance is made using 105 C as the
   reference temperature.
//The heats of vaporization at 105 C and the average
    heat capacities of the
//liquid from 105 to 200 C are obtained from the
   literature.
Cp = [62,70,78]'; //[cal/mol-C], Cp(1) = n-hexane,
   Cp(2) = n-heptane, and Cp(3) = n-octane
delta_Hv = [6370,7510,8560]'; //[cal/mol], delta_hv
   (1) = n-hexane, delta_hv(2) = n-heptane, and
   delta_hv(3) = n-octane
//Based on liquid at 105 C, the enthalpies of the
   product are
H_vapor = f*sum((y.*delta_Hv)) //[cal]
H_liquid = 0;
//For the feed
Cp_bar = sum(xF.*Cp) //[cal/mol-C]
T0 = H_vapor/Cp_bar+Td;
disp('C',T0,'preheat temperature is')
```

**Example 19.3** Example 19.3.sce

```
clear all;
clc;

//Example 19.3
//Given
xF = [0.33,0.37,0.30]'; //[mole fraction] xF(1) = n-
    hexane, xF(2) = n-heptane, and xF(3) = n-octane
P = 1.2; //[atm]
f = 0.60;
xD_hex = 0.99; //[mole fraction]
xB_hex = [0.01]; //[mole fraction]
K(1) = 2.68/P;
K(2) = 1.21/P;
K(3) = 0.554/P;
//Solution
//The n-hexane is the light key(LK), the n-hepane is
    the heavy key(HK), and the
//n-octane is a heavy nonkey(HNK)
//Aplying mass balance and assuming no n-octane and
    0.99 mole fraction n-hexane in the
//distillate.
//Basis:
F = 100; //[mol/h]
//B+D = 100;
//For hexane,
//F*xF = D*xD+B*xB
//from the above two equaiton
A_BD = [1,1;xD_hex xB_hex];
B_BD = [F;F*xF(1)];
//A_BD*x_BD = B_BD
x_BD = inv(A_BD)*B_BD;
D = x_BD(1);
B = x_BD(2);
xD = [0.99,0.01,0.0]';
```

```
xB = [0.01,0.544,0.446]';
comp_D = xD.*D;
comp_B = xB.*B;

disp('mol/h',comp_D(3),'n-octane','mol/h',comp_D(2),
    'n-heptane','mol/h',comp_D(1),'n-hexane','The
    composition of the overhead  product is');
disp('mol/h',comp_B(3),'n-octane','mol/h',comp_B(2),
    'n-heptane','mol/h',comp_B(1),'n-hexane','The
    composition of the bottom product is');

//To find out minimum number of plates, using Eq
    .(19.13)[Fenske Equation]
//using relative volativity of the light key to the
    heavy key, which is the
//ratio of the K factors. The K values at the flash
    temperatue are taken from Example 19.2
alpha_LK_HK = K(1)/K(2);
Nmin = log((xD(1)/xD(2))/(xB(1)/xB(2)))/log(
    alpha_LK_HK)-1;
disp('plus a reboiler',Nmin,'The minimum number of
    ideal stages is');
```

**Example 19.4** Example 19.4.sce

```
clear all;
clc;

//Example 19.4
//Given
//x(1) = n-pentane, x(2) = n-hexane, x(3) = n-
    heptane and x(4) = n-octane
//xF = feed, xD = distillate and xB = bottom
xF = [4 40 50 6]'./100 //[mole fraction]
P = 1; //[atm]
xD1(2) = 0.98;
xD1(3) = 0.01;

```

```
//Solution
//The keys are n-hexane and n-heptane, and the other components are
//sufficiently different in volatility to be distributed.
//Basis:
F = 100; //[mol]
xD1(1) = 1;
xD1(4) = 0;
D = sum(F*xF.*xD1); //[mol]
xD = (F*xF.*xD1)./(D)
B = F-D; //[mol]
xB = (F*xF-D*xD)/B;
K_80 = [3.62,1.39,0.56,0.23]';
K_81 = [3.72,1.43,0.58]';
K_81_2 = [3.74,1.44,0.584]';
KxF = [0.145,0.556,0.280,0.014]';

//(a)
//The bubble point is 80 C, and at this temperature
alphaLK_HK = K_80./K_80(3);
//For an approximate solution,using Eq.(19.15)
RDm = (F/D)*(((D*xD(2)/(F*xF(2)))-alphaLK_HK(2)*(D*xD(3)/(F*xF(3)))))/(alphaLK_HK(2)-1))

//To use Underwood method, the K values at 80 C are converted to relative
//volatilities and the root of Eq.(19.29) between 1 and 2.48 is found by trial.
//Since q = 1.0, the terms must sum to zero.
phi = 1.5
f = 0;
err = 1;
while(err>0.1)
  fnew = sum(((alphaLK_HK.*xD)./(alphaLK_HK-phi)));
  err = abs(f-fnew);
  if (f>fnew)
    phi=phi+0.01;
```

```
  else
    phi=phi-0.01;
  end
    f = fnew;
end
RDm = f-1;

//(b)
//To get the conditions in the upper invariant zone, using Eq.(19.24) with
VbyD = RDm+1;
DbyV = inv(VbyD);
VbyF = VbyD*D/F;
LbyV = RDm/(RDm+1);
y_80 = DbyV*xD(1:3)./(1-LbyV./K_80(1:3))
y_81_1 = [0.046,0.637,0.317]';
x_81_1 = y_81_1./K_81 ;
//The vapor composition for lower inavariant zone is
//using Eq.(19.28), for q = 1.0
BbyVb = 0.552;
LbbyVb = 1.55;
K_83 = [1.52,0.618,0.258]';
y_83 = BbyVb*xB(2:4)./(LbbyVb./K_83-1);
y_83_3 = [0.662,0.326,0.012]';
x_83_3 = y_83_3./K_83 ;

disp('respectively','C',81.1,'C',83.3,'The tempeature in Lower zone and Upper zone is')
disp('respectively',y_83_3(1),'y =',x_83_3(1),'x = ','The LK composition in Lower zone is')
disp('respectively',y_83_3(2),'y =',x_83_3(2),'x =','The HK composition in Lower zone is')
disp('respectively',y_81_1(2),'y =',x_81_1(2),'x =','The LK composition in Upper zone is')
disp('respectively',y_81_1(3),'y =',x_81_1(3),'x =','The HK composition in Upper zone is')
```

**Example 19.5** Example 19.5.sce

```
clear all;
clc;

//Example 19.5
//Given
Nmin = 9.4+1;
//From Example 19.3
xF = [0.33,0.37,0.30]';
xD = [0.99,0.01,0]';
K = [2.23,1.01,0.462]';
alpha = [2.21,1.0,0.457]';

//For a liquid feed
q = 1;
phi = 1.45;
f = 0;
err = 1;
while(err>0.1)
  fnew = sum(((alpha.*xD)./(alpha-phi)));
  err = abs(f-fnew);
  if (f>fnew)
    phi=phi+0.01;
  else
    phi=phi-0.01;
  end
    f = fnew;
  end
  RDm = f-1;
  RD = RDm*1.5;

//A = (RD-RDm)/RD+1
//from Fig. 19.5
N = (Nmin+0.41)/(1-0.41);

disp(N,'The number of ideal plate required are')
```

# Chapter 20

# Leaching and Extraction

## 20.1 Scilab Code

**Example 20.1** Example 20.1.sce

```
clear all;
clc;

//Example 20_1
//Given
Fin = 2*10^3; //[kg/day]
//w(1) = paraffin wax, w(2) = paper pulp
wi = [0.25,0.75]'; //[wieght percent]

//Solution
//Using convenient units in Eq.(17.24)
//As the ratio of kerosene to pulp is constant, flow
    rates should be
//expressed in pounds of kerosene. Then, all the
    concentrations must
//be in pound of wax-free kerosene. The unextracted
    paper had no kerosene
//so the first cell must be treated separately.
//Refering to the Fig.20.3
//Basis:
```

```
F = 100; //[lb wax + kerosene-free pulp ]
//By making a mass balance over wax
//wax_in = F*(wi(1)/wi(2))+ 0.0005*s (s is the wax input with solvent)
//wax_out = F*(0.002)+(s-200)*0.05
//by wax_in = wax_out
s_in = (33.33+9.8)/(0.05-0.0005); //[lb]
//The concentration of this stream is, therefore
s_out = 200; //[lb]
s_stsol = s_in-s_out; //[lb]
wax_sol = s_stsol*0.05; //[lb]
//The concentration in the underflow to the second unit equals that
//of the overflow from the first stage, or 0.05 lb of wax per pound
//of kerosene. The wax in the underflow to unit 2 is
wax_uflow_2 = s_out*0.05; //[lb]
wax_oflow_21 = wax_uflow_2+wax_sol-F*(wi(1)/wi(2)) //[lb]

//The concentrations of this stream is, therefore,
ya = wax_oflow_21/871;
yastar = 0.05;
xa = yastar;
ybstar = 0.2/s_out;
xb = ybstar;
yb = 0.0005;

//Since 1 stage has already ben taken into account,
//Eq.(17.24), will give N-1 stages, Hence
N = log((yb-ybstar)/(ya-yastar))/log((yb-ya)/(ybstar-yastar));
disp(N+1,'The total number of ideal stages is');
```

**Example 20.2** Example 20.2.sce

```
clear all;
clc;
```

```
//Example 20.2
//Given
F = 1000; //[kg]
solv_O = 10; //[kg]
solv_B = 655; //[kg]
w_out = 60; //[kg]
//Solution
//Let solution retained is SR, from Table 20.1
SR =
    [0.5,0.505,0.515,0.530,0.550,0.571,0.595,0.620]';
xb = 0:0.1:0.7;
//Let x and y be the mass fraction of oil in the
    underflow and
//overflow solutions.

//At the solvent inlet,
Vb = solv_O + solv_B; //[kg solution/h]
yb = solv_O/Vb;
err = 1;
i = 1;
sr = SR(2);
xb1 = 0.0;
while(err>0.001)
  Lb = sr*F;
  xbnew = w_out/Lb;
  err = abs(xb1-xbnew);
  xb1 = xbnew;
  sr = SR(i)+(xb1-xb(i))/(xb(i+1)-xb(i))*(SR(i+1)-SR
     (i));
  i =i+1;
end
Lb = sr*F;
//Benzene in the underflow at Lb is
Underlow_B = Lb-w_out; //[kg solutions/h]

// At the solid inle
La = 400+25; //[kg solutions/h]
```

```
xa = 400/La;
w_in =  10+400; //[kg/h]
Extract_O = w_in - w_out; //[kg/h]
Extract_B = 655+25-447; //[kg/h]
Va = Extract_O+Extract_B; //[kg/h]
ya = Extract_O/Va;

//The answers to parts (a) to (d) are
//(a)
disp(ya,'The concentration of strong solution is');
//(b)
disp(xb1,'The concentration of the soultion adhering
    to the extracted solids is');
//(c)
disp('kg/h',Lb,'The mass of solution leaving with
   the extracted meal is');
//(d)
disp('kg/h',Va,'The mass of extract is');

//(e)
//To determine an intermediate point on the
   operating line, choosing,
xn = 0.5;
//Soulion retained
Ln = 0.571*F; //[kg/h]
//By overall balance, Eq.(20.1)
V_n_1 = Va+Ln-La; //[kg/h]
//By oil balance
y_n_1 = (Ln*xn+Va*ya-La*xa)/V_n_1;
y =0:0.1:1;
x = y;
plot(x,y,[xb1,xn,xa],[yb,y_n_1,ya])
xgrid()
xlabel('x')
ylabel('y')
title('Figure 20.4')
legend('y=x','operating line')
//Using Figure 20.4, number of ideal stages required
```

```
are
N = 4;
disp(N,'Number of stages required are')
```

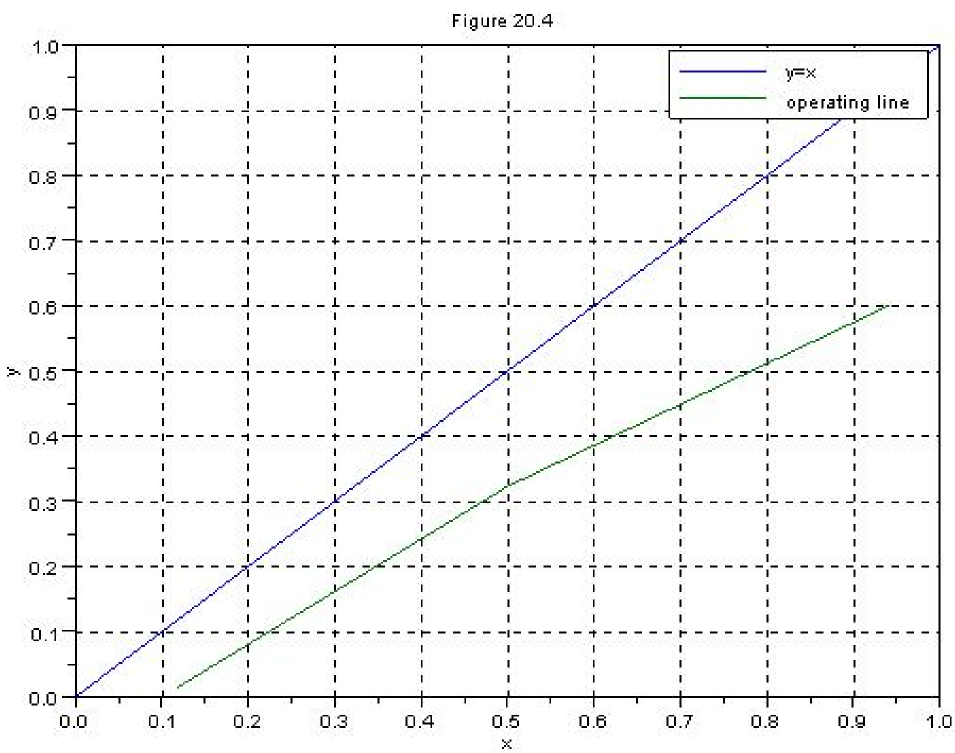


Figure 20.1: Diagram for Example 20.2

---

**Example 20.3** Example 20.3.sce

```
clear all;
clc;

//Example 20.3
```

```
//Given
T = 25; //[C]
//x(1) = Acetone, x(2)= water and x(3)= MIK
//F = feed
xF = [0.40, 0.60,0.0]';
xMIK_i = [0.0,0.0,1.0]';

//Solution
//Using data from Fig. 20.10, to plot equilibrium curve
//Fig. 20.13.
//Basis:
F = 100; //[mass units/h]
//Let n = mass flow rate of H2O in extarct
//m = mass flow rate of MIK in raffinate
//For 99 percent recovery of A, the extarct has
E_A = 0.99*xF(1)*F;
//And the Raffinate has
R_A =  xF(1)*F-E_A;
//The total flows are
//At the top,
//La = F = 40*A+60*H2O
//Va = 39.6*A+n*H20+(100-m)*MIK = 139.6 + n-m
//At the bottom,
Vb = 100; // MIK
//Lb = 0.4*A+(60-n)*H2O+m*MIK = 60.4 +m-n
//Since n and m are small and tend to cancel in the summatios for Va and La,
//the total extract flow Va is about 140, which would make
yA_a = 39.6/140;
xA = 0.4/60;
//From Fig 20.10, for
yA = 0.283, yH2O = 0.049
xA = 0.007, xMIK = 0.02
nm = [6;2];
err = 1;
while(err>0.1)
```

```
  nmold = nm;
  nm(1) = yH2O/(1-yH2O)*(39.6+100-nm(2));
  nm(2) = xMIK/(1-xMIK)*(0.4+60-nm(1));
  err = norm(nm-nmold);
end
n = nm(1);
m = nm(2);
Va = 139.6+n-m;
yA_a = 39.6/Va;
Lb = 60.4+m-n;
xA_b = 0.4/Lb;

//For an intermediate point on the operating line, picking
yA = 0.12;
//From Fig. 20.10,
yH2O = 0.03;
yMIK = 0.85;
//Since the raffinate phase has only 2 to 3 pecent MIK, assuming
//that the amount of MIK in the extract is 100, the same as the solvent
//fed:
V = 100/yMIK;
//By an overall balance from the solvent inlet (bottom) to the intermediate
//point,
xb = xA_b;
L = Lb+V-Vb;
yb = 0;
//A balance on A over the same section gives xA;
xA = (0.4+117.6*0.12-0)/L;
//For xA and xMIK = 0.03, A balance on MIK from the solvent
//inlet to the intermediate point gives
V_revised = 101.1/0.85;
L_revised = 54.4+118.9-100;
xA_revised = (0.4+118.9*0.12)/73.3;
```

```
y =0:0.1:1;
x = y;
plot(x,y,[0.00074,0.2,0.4,],[0,0.12,0.272,])
xgrid()
xlabel('x')
ylabel('y')
title('Figure 20.13')
legend('y=x','operating line')

//From Fig. 20.13
disp(3.4,'Number of stages')
```

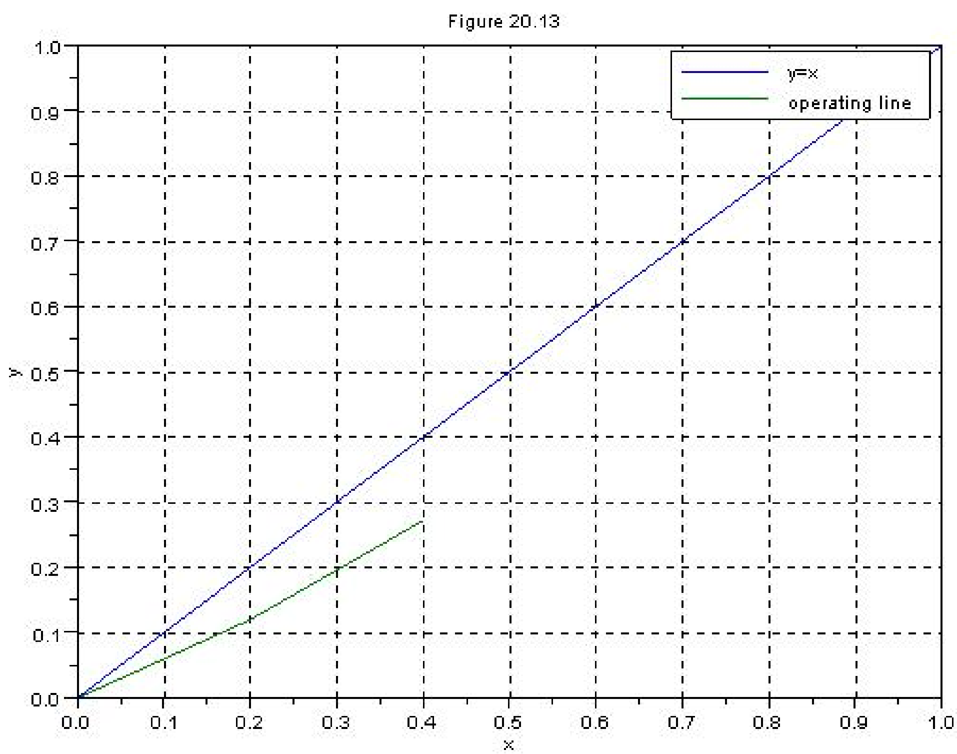


Figure 20.2: Diagram for Example 20.3

# Chapter 21

# Principles of Diffusion and Mass Transer between Phases

## 21.1 Scilab Code

**Example 21.1** Example 21.1.sce

```
clear all;
clc;

//Exapmle 21.1
//Given
yA = 0.20;
yAi = 0.10;

//Solution
//(a)
//Let A = Dv*rho_M/BT
A = 1; //assumed

//Using Eq.(21.19), for euilmolal diffusion,
JA = A*(yA-yAi);
//Form Eq.(21.24), for one way diffusion,
NA = A*log((1-yAi)/(1-yA));
NAbyJA = NA/JA;
```

```
disp('In this case the transfer rate with one-way diffusion is',NAbyJA-1,'percent greater than that with equimolal diffusion');

//(b)
//Whwn, b = BT/2
A = A*2;
yA = 1-exp(NA/2)*(1-yA)
disp(yA,'The value of yA halfway through the layer for one-way diffusion is');
```

**Example 21.2** Example 21.2.sce

```
clear all;
clc;

//Example 21.2
//Given
K = 273.16
T = 100+K ; //[K]
P = 10; //[atm]
//From Table 21.1
TcA = 198+K; //[K]
TcB = -147+K; //[K]
rho_cA = 0.552; //[g/cm^3]
rho_cB = 0.311; //[g/cm^3]
MA = 137.5;
MB = 28;

//Solution
VcA = MA/rho_cA //[cm^3/g mol]
VcB = MB/rho_cB //[cm^3/g mol]
//Substituing in Eq.(21.25)
Dv = (0.01498*T^1.81*(1/MA+1/MB)^0.5)/(P*(TcA*TcB)^0.1405*(VcA^0.4+VcB^0.4)^2); //[cm^2/s]
disp('cm^2/s',Dv,'Volumetric Diffusivity (Dv) = ')
```

**Example 21.3** Example 21.3.sce

```
clear all;
clc;

//Example 21.3
//Given
//1 = benzene and 2 = toluene
M1 = 78.11;
M2 = 92.13;
T1_bp = 80.1+273; //[K]
T2_bp = 110.6+273; //[K]
VA1 = 96.5; //[cm^3/mol]
VA2 = 118.3; //[cm^3/mol]
mu1 = 0.24; //[cP]
mu2 = 0.26; //[cP]
T  = 110+273; //[K]
//Solution
//From Eq.(21.26)
//For benzene in toulene,
Dv1 = 7.4*10^-8*(M2)^0.5*T/(mu2*VA1^0.6); //[cm^2/s]

//For toluene in benzene,
Dv2 = 7.4*10^-8*(M1)^0.5*T/(mu1*VA2^0.6); //[cm^2/s]

disp('cm^2/s',Dv1,'Diffusivity of benzene in toluene
    is');
disp('cm^2/s',Dv2,'Diffusivity of toluene in benzene
    is');
```

**Example 21.4** Example 21.4.sce

```
clear all;
clc;

//Example 21.4
//Given
Nre = 20000;
T = 40; //[C]
D = 2; //[in.]
```

```
Dv1 = 0.288; //[cm^2/s], for water-air
Dv2 = 0.145; //[cm^2/s], for ethanol-air
//Solution
//For air at 40 C
rho = 29/22410*273.16/313.16; //[g/cm^3]
mu = 0.0186; //[cP], from Appendix 8
mubyrho = mu*10^-2/rho; //[cm^2/s]

//(a)
// For the air-water system,
Nsc = mubyrho/Dv1;
//Form Eq.(21.54)
Nsh = 0.023*(Nre/2)^0.81*Nsc^0.44;
//In the film theory kc = D/BT and since Nsh = kc*D/
    Dv
BT1 = D/Nsh; //[in.]
disp('in.',BT1,'Effective thickness of the gas film
    is')

//(b)
//For the system air-ethanol,
Nsc = mubyrho/Dv2;
Nsh = 0.023*(Nre/2)^0.81*Nsc^0.44;
BT2 = D/Nsh; //[in.]
disp('in.',BT2,'Effective thickness of the gas film
    is')
```

**Example 21.5** Example 21.5.sce

```
clear all;
clc;

//Example 21.5
//Given

T = 110; //[C]
P = 1; //[atm]
mu = 0.26; //[cP]
```

```
Dvx = 6.74*10^-5; //[cm^2/s]
rho_mx = 8.47; //[mol/L]
Dvy = 0.0494; //[cm^2/s]
rho_my = 0.0318; //[mol/L]

//(a)
//Using Eq.(21.78)
kybykx = (Dvy/Dvx)^0.5*(rho_my/rho_mx);
//The gas-film coefficient predicted is only 10 percent
//and if m=1, 90 percent of the overall resistance to mass
//transfer would be in the gas film.
disp(kybykx*100,'fraction of the overall resistance in the gas phase is');

//(b)
//Assuming the column is operated at the same factor F
//Gas film:
rho_myprime = 0.00894; //[mol/L]
Dvyprime = (341/383)^1.81*(Dvy/0.25);
deltakyprime = sqrt(Dvyprime/Dvy)*rho_myprime/rho_my;
//Liquid film:
rho_mxprime = 8.93; //[mol/L]
muprime = 0.35; //[cP]
Dvxprime  =(341/383)*0.26*Dvx/muprime;
deltakxprime = sqrt(Dvxprime/Dvx)*(rho_mxprime/rho_mx);
//kyprime = deltakyprime*ky;
//kxprime = deltakxprime/0.102*ky;
//At 1 atm and ky = 0.102kx and Ky = 0.907/ky
//Kyprime = 0.476*ky
//For overall transfer units
NOy = 2*0.476/0.53;
neta = 1-exp(-NOy);
disp(neta,'The efficieny will be')
```

**Example 21.6** Example 21.6.sce

```
clear all;
clc;

//Example 21.6
//Given
Dvprime = 10^-7; //[cm^2/s]
rp = 0.04/2; //[cm]
t = 30*60; //[s]
//Then,
beeta = Dvprime*t/rp^2;
//form Fig. 10.6
phi = 0.26;
// Murphree efficiency
neta_M = 1-phi;
//Here the average efficieny is nearly equal to the
    Murphree efficiency.
disp(4/neta_M,'The actual number of stages is')
```

# Chapter 22

# Gas Absorption

## 22.1 Scilab Code

**Example 22.1** Example 22.1.sce

```
clear all;
clc;

//Example 22.1
//Given
Dp = 1; //[in.]
vdot = 25000; //[ft^3/h]
T = 68; //[F]
P = 1; //[atm]
ya = 0.02;
Mair = 29;
Mg = 17;
//Solution
//The average molecular weiht of the entering gas
M = (1-ya)*Mair+ya*Mg;
rho_y = M*492/(359*(460+68)); //[lb/ft^3]

//(a)
//Using Fig. 22.5, when Gy =Gx;
Gy = 0.472; //[lb/ft^2-s]
```

```
Gx = Gy; //[lb/ft^2-h]
des_value = Gy/2; //[lb/ft^2-h]
mdot = vdot*rho_y/3600; //[lb/s]
//Cross-sectional area of the tower
S = mdot/des_value //[ft^2]
//the diameter of the tower is
Dtower = sqrt(4*S/%pi); //[ft]
disp('ft',Dtower,'The tower diameter is');

//(b)
h = 20; //[ft]
//Using Fig 22.4, the pressure drop for
Gy = 850; //[lb/f^2-h]
Gx = Gy;
delta_P = 0.35; //[in.] (H2O/ft)
//The total pressure drop
Pt = delta_P*h; //[in.] H2O
disp('in. H2O' ,Pt,'The pressure drop would be');
```

**Example 22.2** Example 22.2.sce

```
clear all;
clc;

//Example 22.2
//Given
Dp = 1; //[in.]
vdot = 25000; //[ft^3/h]
T = 68; //[F]
P = 1; //[atm]
ya = 0.02;
Mair = 29;
Mg = 17;
//Solution
//The average molecular weiht of the entering gas
M = (1-ya)*Mair+ya*Mg;
rho_y = M*492/(359*(460+68)); //[lb/ft^3]
rho_x = 62.3; //[lb/ft^3]
```

```
//(a)
//Using Fig.(22.8), from Example 22.1 A = Gx/Gy = 1
    and
//Let
A = 1;
B = A*sqrt(rho_y/rho_x);
//Form Fig 22.8, the superficial vapor velocity at
    flooding
//is uof*sqrt(rho_y/(rho_x-rho_y))=0.11, therefore
uof = 0.11/sqrt(rho_y/(rho_x-rho_y)); //[m/s]
//The allowable vapor velocity
uo = uof*0.5; //[m/s]
uo = uo*3.28; //[ft/s]
//the corresponding mass velocity
Gy = uo*rho_y; //[lb/ft^2-s]
//The allowable mass velocity in the example was
    0.236 lb/ft^2-s.
//The increase by using structured packing is
increase = (Gy/0.236)-1;
disp(increase*100,'The percent increase in mass
    velocity is');

//(b)
//The pressure drop
delta_P = 20*1.22*(0.5/0.9)^1.8; //[in. H2O]
//This is 1.2 times the pressure drop of 7 in.H2O in
     the Intolax saddles.
disp('The pressure drop will be greater than Intolax
     Saddles')
```

---

**Example 22.3** Example 22.3.sce

```
clear all;
clc;

//Example 22.3
//Given
vdot = 4500; //[SCFM]
```

```
yin = 0.06;
yout = 0.0002;
P = 1; //[atm]
Tiy = 20; //[C]
Tix = 25; //[C]

//Solution
//From Perry
x = [0.0308,0.0406,0.0503,0.0735]';
y20 = [0.0239,0.0328,0.0417,0.0658]';
y30 = [0.0389,0.0528,0.0671,0.1049]';
y40 = [0.0592,0.080,0.1007,0.1579]';
deltaH = -8.31*10^3; //[cal/g mol], fro NH3=NH3(aq)
//Basis:
gas_in = 100; //[g mol dry]
air_in = (1-yin)*gas_in; //[mol]
NH3_in = yin*gas_in; //[mol]
H2O_in = 2.4; //[mol]
air_out = air_in; //[mol]
//The moles of NH3 in the outlet gas,
NH3_out = air_out*(yout/(1-yout)); //[mol NH3]
//The amount of NH3 absorbed
NH3_abs = NH3_in-NH3_out; //[mol]
//Heat Effects:
//The heat of absorption
Qa = -NH3_abs*deltaH; //[cal]
//Sensible heat changes in the gas are
Qair = air_in*7*5; //[cal]
QH2O =H2O_in*8*5; //[cal]
Qsy = 3290+96; //[cal]
//The amount of vaporization of water from the
    liquid
pH2O_20 = 17.5; //[mm Hg], at 20C
pH2O_25 = 23.7; //[mm Hg], at 25C
H2O_inlet = gas_in*(pH2O_20/742.5); //[mol]
H2O_outlet = 94.02*(pH2O_25/736.3); //[mol]
//The amount of water vaporized
H2O_vaporized = H2O_outlet-H2O_inlet; //[mol]
```

```
deltaHv = 583; //[cal/g]
Qv = deltaHv*H2O_vaporized*18.02; //[cal]
//From Eq.(22.31)
Qsx = Qa-(Qv+Qsy); //[cal]

Cp = 18; //[cal/g-mol-C]
xmax = 0.031;
Tb = 40; //[C]
Ta = 25; //[C]
err =1;
while(err>0.01)
  Lb = NH3_abs/xmax;
  Tbnew = Qsx/(Lb*Cp)+Ta;
  err = Tb-Tbnew;
  Tb=Tbnew;
  xmax = xmax+0.002;
end
Lmin = Lb-NH3_in; //[mol H2O]
La = 1.25*Lmin; //[mol]
Lb = La+NH3_in; //[mol]
//The temperature rise of the liquuid is
Tb = Qsx/(Lb*Cp)+Ta; //[C]
xb = NH3_in/La; //[C]
ystar = 0.044;
//Assuming temperature to be linear function of x, so
T = 30;
//x = 0.0137;
//Using the data given for 30C and interpolating to get the
//initial slope for 25 and the final value ystar for 35, the
//euilibrium line is drawn
y = [0.06, 0.03,0.01,0.0002]';
ystar = [0.048,0.017,0.0055,0]';
delta_y = y-ystar;
delta_yL = [0.0125, 0.0080,0.00138]';
delta_NOy = [2.4,2.5,7.1]';
```

```
NOy = sum(delta_NOy);
disp(NOy,'The value of NOy is');



plot(x,y20,x,y30,x,y40);
xgrid();
xlabel('x');
ylabel('y');
legend('20C','30C','40C');
title('x vs y of NH3 at different temperatures');
```

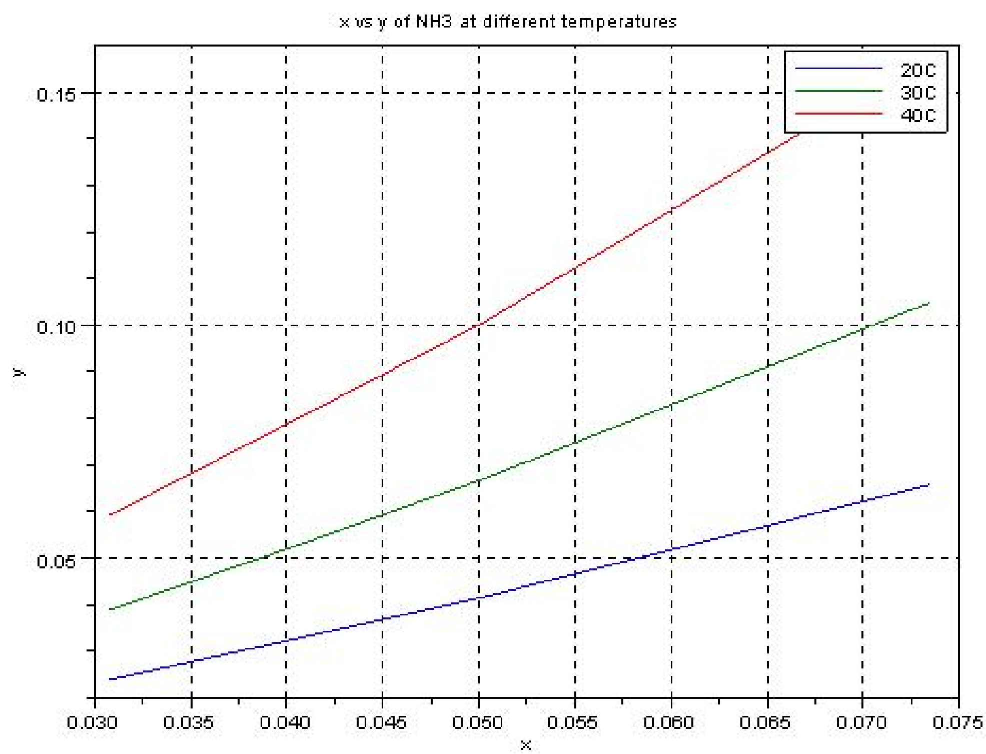


Figure 22.1: Diagram for Example 22.3

**Example 22.4** Example 22.4.sce

```
clear all;
clc;

//Example 22.4
//Given
ieee();
H = 0.0075; //[TCE]
T = 20; //[C]
P = 1; //[atm]
wa = 6*10^-6; //[g]
Ca = 6; //[ppm]
wb = 4.5*10^-9 //[g]
M = 18;

//Solution
m = H/P*10^6/M;
//With this large value of m, the desorption is
    liquid-phase controlled.
//At the minimum air rate, the exit gas will be in
    equilibrium with the
//incoming solution.
MTCE = 131.4;
j = 1.5;
for i = 1:7
xa = wa/MTCE*M;
ya = m*xa;
//Per cubic meter of solution fed, the TCE removed
    is
VTCE = 10^6*(wa-wb)/MTCE; //[mol]
//The total amount of gas leaving is
V = VTCE/ya; //[mol]
Fmin = V*0.0224; //[std m^3], as 1 gmol = 0.0224 std
    m^3
Vmin = Fmin*j;
```

```
//Density at the standard conditions,
rho = 1.259; //[kg/m^3],
//so the minimum rate on a mass basis is,
//Let A = (Gy/Gx)min
A = Vmin*rho/1000; //[kg air/kg water]
//If the air rate is 1.5 times the minimum value, then
ya = ya/j;
xastar = ya/m;
Castar = xastar*MTCE/M *10^6; //[ppm]
delta_Ca = Ca-Castar;

//At bottom
Cb = 0.0045; //[ppm]
Cbstar = 0; //[ppm]
delta_Cb = Cb-Cbstar; //[ppm]
delta_CL = (delta_Ca-delta_Cb)/log(delta_Ca/delta_Cb); //[ppm]
Nox(i) = (Ca-Cb)/delta_CL;
j = j+0.5;
end

Hox = 3; //[ft]
Z = Hox*Nox; //[ft]
//Going from 1.5 to 2Vmin or from 2 to 3Vmin decreases the tower height
//considerably, and the reduction in pumping work for water is more than
//the additional energy needed to force air through the column. Further
//increase in V does not change Z very much, and the optimum air rate is
//probably in the range 3 to 5Vmin./

disp(Nox,'Number of Transfer units with minimum air rates')
```

**Example 22.5** Example 22.5.sce

```
clear all;
clc;

//Example 22.5
//Solution
//Equlibrium data are shown in Fig.22.22
//By a heat balance similar to that of Eample 22.3
//The temperature rise of the liqui was estimated
//to be
delta_T = 12.5; //[C]
//Basis:
dry_gas_in = 100; //[mol]
sol_in = 140; //[mol]
N2_in = 87; //[mol]
CO2_in = 10; //[mol]
EO_in = 3; //[mol]
N2_out = 87; //[mol]
CO2_out = 10; //[mol]
EO_out = 3*0.02; //[mol]
IN = N2_in+CO2_in+EO_in; //[mol]
OUT = N2_out+CO2_out+EO_out; //[mol]
//Assuming negligible CO2 absorption and neglect effect of H2O on
//gas composition.
//At top:
xt = 0.004;
yt = EO_out/OUT;
//Moles of EO absorbed
EO_abs = 3*0.98; //[mol]
//Moles of EO absorbed in water
EO_H2O = 140*0.0004; //[mol]
//At bottom:
xb = (EO_abs+EO_H2O)/(140+EO_abs);
yb = 0.03;
//From Fig 22.22
y = [0.03,0.015,0.005,0.0006]';
delta_y1 = [0.008,0.0006,0.0024,0.0003]';

```

```
for i = 1:length(y)-1
  delta_y = y(i)-y(i+1);
  delta_yL = (delta_y1(i)-delta_y1(i+1))/log(delta_y1(i)/delta_y1(i+1));
  Noy1(i) = delta_y/delta_yL;
end
Noy = sum(Noy1);

//Column diameter:
//Using generalize pressure-drop correlation, Fig.22.6
//Based on the inlet gas,
Mbar = 0.87*28+0.1*44+0.03*44;
//At 40C,
rho_y = 30.1/359*20*273/313 //[lb/ft^3]
rho_x = 62.2; //[lb/ft^3]
//Let A = Gx/Gy*sqrt(rho_y/(rho_x-rho_y))
A = 1.4*18/(1*30.1)*sqrt(rho_y/(rho_x-rho_y));
//From Fig. 22.6, for
delta_P = 0.5; //[in.H2O/ft]
//Let B = Gy^2*Fp*mux^0.1/(rho_y*(rho_x-rho_y)*gc)
B = 0.045;
//From Table 22.1,
Fp = 40;
mu = 0.656; //[cP]
//so
Gy = sqrt(B*(rho_y)*(rho_x-rho_y)*32.2/(Fp*mu^0.1)); //[lb/ft^2-h]
//or
Gy = Gy*3600; //[lb/ft^2-s]
Gx = 1.4*18/(1*Mbar)*Gy; //[lb/f^2-s]
//For a feed rate
F = 10000*Mbar; //[lb/h]
S = F/Gx; //[ft^2]
D = sqrt(S*4/%pi); //[ft]
//Column heigth:
//From Fig. 22.20 at Gy = 500 and Gx = 1500
Hy_NH3 = 1.4; //[ft]
```

```
mu_40 =0.0181*10^-2; //[P], Appendix 8
Dv = 7.01*10^-3; //[cm^2/s], from Eq.(21.25)
rho = 2.34*10^-2; //[lb/ft^3]
Nsc = mu_40/(rho*Dv);
//Form Table 22.1,
fp = 1.36;
Hy_EO = 1.4*(1.1/0.66)^0.5*1/1.36*(Gy/500)^0.3*(1500/Gx)^0.4; //[ft]
//Form Fig. 22.19,
Hx_O2 = 0.9; //[ft]
Gx1 = 1500;
mu1 = 0.00656; //[P]
rho1 = 1; //[lb/ft^3]
//Using Eq.(21.28)
Dv1 = 2.15*10^-5; //[cm^2/s]
Nsc1 = mu1/(rho1*Dv1);
//Using Eq.(22.35), with the correction factor fp and Nsc = 381,
//for O2 in water at 25 C
Hx_EO = Hx_O2*(Gx/(mu1*100)/(Gx1/0.894))^0.3*(Nsc1/381)^0.5/1.36; //[ft]
//From Fig 22.22, the average value of m
m = 1.0;
//From Eq.(22.30)
HOy = 1.71+(1*0.96)/1.4; //[ft]

disp(NOy,'number of transfer units required')
disp('ft',D,'diameter of the column')
disp('ft',HOy,'packing height')
```

**Example 22.6** Example 22.6.sce

```
clear all;
clc;

//Example 22.6
//Solution
rho_m = 62.2/18; //[mol/ft^3]
```

```
//kya = 0.025*Gy^0.7*Gx^0.25
H2ObySO2 = 2*0.98964/0.01036;
//and
xb = 1/(H2ObySO2+1);
//The molal mass velocity of the feed gas Gm is
Gm_in = 200/29*(1/0.8); //[mol/ft^2-h]
SO2_in = Gm_in*0.2; //[mol/ft^2-h]
Air_in = Gm_in*0.8; //[mol/ft^2-h]
Air_out = Air_in; //[mol/ft^2-h]
SO2_out = Air_out*(0.005/(1-0.005)); //[mol/ft^2-h]
SO2_abs = SO2_in-SO2_out; //[mol/ft^2-h]
H2O_in = H2ObySO2*SO2_abs; //[mol/ft^2-h]
//Operating line
x = 0:6;
x = x/10^3;
A = x./(1-x);
B = H2O_in/Air_in*A+(0.005/0.995);
y = B./(B+1);
plot(x,y)
xgrid();
xlabel('x');
ylabel('y');
//legend('20C','30C','40C');
title('x vs y');
Gxbar = H2O_in*18.02+SO2_abs*64.1/2; //[lb/ft^2-h]
kxa = 0.131*Gxbar^0.82; //[mol/ft^3-h]
//The gas film coefficients are calculated for the bottom
//and the top of the tower:
//At bottom:
Gy_B = (Air_in*29)+(SO2_in*64.1); //[lb/ft^2-h]
kya_B = 0.025*Gy_B^0.7*Gx^0.25; //[mol/ft^3-h]
//At top:
Gy_T = (Air_out*29)+(SO2_out*64.1); //[lb/ft^2-h]
kya_T = 0.025*Gy_T^0.7*Gx^0.25; //[mol/ft^3-h]
//Assuming
yLbar = 0.82
C = kxa*yLbar/kya_B;
```

```
//a line from (yb,xb) with a slope of -C, gives
yi = 0.164;
yLbar = 0.818;
m = 20.1
Kya_prime = 1/(yLbar/kya_B+m/kxa); //[mol/ft^3-h]
//The fraction of the total resistance that is in
   the liquid is
Rf = m/kxa/(1/Kya_prime);
//For different values of y1
y1 =[0.2,0.15,0.1,0.05,0.02,0.005]';
delta_y1 = [0.103,0.084,0.062,0.034,0.015,0.005]';
y1i = [0.164,0.118,0.074,0.034,0.012,0.002]';
delta_yi = y1-y1i;
```

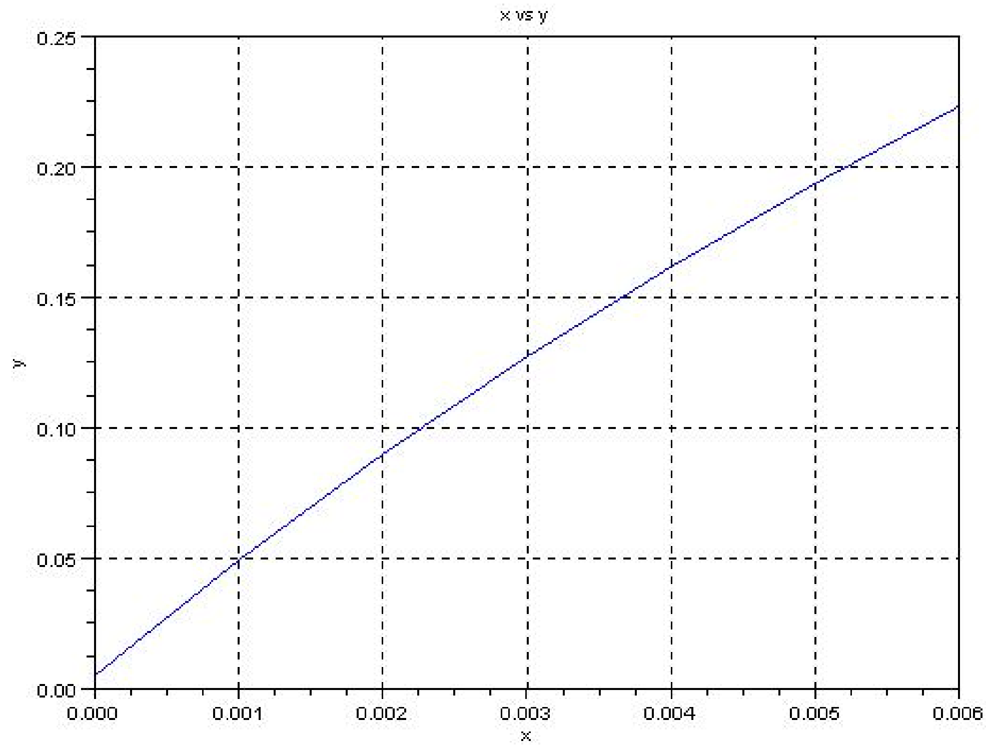


Figure 22.2: Diagram for Example 22.6

# Chapter 23

# Humidification Operations

## 23.1 Scilab Code

**Example 23.1** Example 23.1.sce

```
clear all;
clc;

//Example 23.1
//Given
T = 320; //[F]
P = 1 ; //[atm]
//(1)=CO2, (2)=H2O, (3)=O2, (4)=N2
y_in = [0.14,0.07,0.03,0.76]';
Tw = 80; //[F]
//Solution
//(a)
//Basis
F = 100; //[mol], of gas
Ts = 120; //[F]
Cps = [9.72,8.11,7.14,6.98]';
n_in = F*y_in; //[mol]
nCp = n_in.*Cps; //
sum_nCp = sum(nCp);
sum_n_in = sum(n_in); //[mol]
```

```
Tavg = (Ts+T)/2; //[F]
lambda_s = 1025.8*18; //[Btu/lb mol], at Ts, from Appendix 7
//Making a heat balance for z moles of water evaporated
z = sum_nCp*(T-Ts)/(lambda_s+18*(Ts-Tw));
//Total moles of water in exit gas
n_out(2) = z+n_in(2); //[mole]
//Partial pressure of the water in the exit gas
PH2O = n_out(2)/107.76*760; //[mm Hg]
//But at 120 F, PH2Oprime = 87.5 mm Hg (Appendix 7). Saturation
//temperature Ts must be greater than 120 F. Trying
Ts = 126; // [F]
Tavg = (Ts+T)/2; //[F]
lambda_s = 1022.3*18; //[Btu/lb mol], at Ts, from Appendix 7
//Making a heat balance for z moles of water evaporated
z = sum_nCp*(T-Ts)/(lambda_s+18*(Ts-Tw));
//Total moles of water in exit gas
n_out(2) = z+n_in(2); //[mole]
//Partial pressure of the water in the exit gas
PH2O = n_out(2)/107.76*760; //[mm Hg]
//This is close enough to the value of PH2Oprime
disp('F',Ts,'Adiabatic saturation temperature');

//(b)
//for Tin = Ts, by heat balance
z = sum_nCp*(T-Ts)/(lambda_s);
n_out(2) = z + n_in(2); //[mole]
//Partial pressure of the water in the exit gas
PH2O = n_out(2)/107.85*760; //[mm Hg]
//This is higher than the vapor pressure of water at 126 F,
//103.2 mm Hg, and Ts>126 F. Trying
Ts = 127; //[F]
Tavg = (Ts+T)/2; //[F]
```

```
lambda_s = 1021.7*18; //[Btu/lb mol], at Ts, from
    Appendix 7
//Making a heat balance for z moles of water
    evaporated
z = sum_nCp*(T-Ts)/(lambda_s);
//Total moles of water in exit gas
n_out(2) = z+n_in(2); //[mole]
//Partial pressure of the water in the exit gas
PH2O = n_out(2)/107.76*760; //[mm Hg]
//Thus 127 is too high and 126 is too low. Hence,
Ts = (126+127)/2; //[F]
disp('F',Ts,'Adiabatic saturation temperature');
```

**Example 23.3** Example 23.3.sce

```
clear all;
clc;

//Example 23.3
//Given
Hair_in = 0.022;
Tair_inpre = 70; //[F]
mdot = 15000; //[lb/h]
//Solution
//Using Fig. 23.10
Tair_inreh = 85; //[F]
Tair_outreh = 130; //[F]
Hin = 0.0030;
hya = 85;
Ts = 81; //[F]
Tair_outpre = 168; //[F]
humid_heat1 = 0.241; //[Btu/lb-F]
//Heat required to preheat the air is
Qpre = humid_heat1*mdot*(Tair_outpre-Tair_inpre); //
    [Btu/h]
humid_heat2 = 0.250; //[Btu/lb-F]
//Heat required in the reheater is
```

```
Qreh = humid_heat2*mdot*(Tair_outreh-Tair_inreh); //[Btu/h]
//Total heat required
Qt = Qpre+Qreh; //[Btu/h]
//To caluculate the volume of the sprqy chamber, Eq.(23.41) may
//be used. The average humid heat is
csbar = (humid_heat1+humid_heat2)/2; //[Btu/lb dry air-F]
//Substituing in Eq.(23.41) gives
VT = log((Tair_outpre-Ts)/(Tair_inreh-Ts))*mdot*csbar/hya; //[ft^3]
disp('ft^3',VT,'The volume of the spray chamber is')
```

# Chapter 24

# Drying of Solids

## 24.1 Scilab Code

**Example 24.1** Example 24.1.sce

```
clear all;
clc;

//Example 24.1
//Given
Twb = 80; //[F]
Tdb = 120; //[F]
v = 3.5; //[ft/s]
rho = 120; //[lb/ft^3]
Xe = 0;
Xc = 0.09;
lambda = 1049; //[Btu/lb]
M = 29;
B = 24; //[in.]
D = 2; //[in.]
Dc = 2; //[ft]
//Solution
//(a)
//mass velocity
G = v*M*492*3600/(359*(460+120)); //[lb/ft^2-h]
```

```
//the coefficent, by Eq.(24.13), in fps units, is
h = 0.01*G^0.2/2^0.2; //[Btu/ft^2-h-F]
//Substituting in Eq.(21.15) gives
Rc = 1.94*(Tdb-Twb)/(lambda); //[lb/ft^2-h]
disp('lb/ft^2-h',Rc,'Drying rate during the constant
    period is')

//(b)
//Since drying is from both faces, area
A = Dc*(B/12)^2; //[ft^2]
//The rate of drying
mvdot = Rc*A; //[lb/h]
//Volume of the cake
Vc = (B/12)^2*D/12; //[ft^3]
//mass of the bone-dry solid is
mdot_bd = rho*Vc; //[lb]
//The quantity of moisture to be vaporized is
X2 = 0.20;
X1 = 0.10;
Q = mdot_bd*(X2-X1); //[lb]
//Drying time
tT = Q/mvdot; //[h]
disp('h',tT,'drying time')
```

**Example 24.2** Example 24.2.sce

```
clear all;
clc;

//Example 24.2
//Given
X1 = 0.25;
X = 0.05;
Dvprime = 8.3*10^-6; //[cm^2/s]
D = 25.4; //[mm]

//Solution
s = D/(2*10); //[cm]
```

```
tT = 4*s^2/(%pi^2*Dvprime)*log(8*X1/(%pi^2*X))/3600;
    //[h]
disp('h',tT,'drying time is')
```

**Example 24.3** Example 24.3.sce

```
clear all;
clc;

//Example 24.3
//Given
Tw = 80; //[F]
Tdb = 120; //[F]
v = 3.5; //[ft/s]
rho = 120; //[lb/ft^3]
Xe = 0;
Xc = 0.09;
lambda = 1049; //[Btu/lb]
M = 29;
B = 24; //[in.]
D = 2; //[in.]
Dc = 2; //[ft]
X2 = 0.20;
X1 = 0.10;
Dcyl = 1/4; //[in.]
L = 4; //[in.]
Vbar = 3.5; //[ft/s]
Thb = 120;

//Solution
//Since the Xc is less than 10 percent, all drying
    takes place
//in the constant-rate period and the vaporrization
    temperature,
//as before, is 80 F.
//From Exapmle 24.1, mass of water to be evaporated
mdot = 8*(X2-X1); //[lb]
//The quantity of heat to be transferred
```

```
QT = mdot*lambda; //[Btu]
//mass of the dry soild in one cylinder is
mp = %pi/4*(Dcyl/12)^2*(L/12)*rho; //[lb]
//surface area of one cylinder is
Ap = %pi*(Dcyl/12)*(L/12); //[ft^2]
//Total area exposed by 8 lb solids
A = 8/mp*Ap; //[ft^2]
//The heat transfer coefficient is found from the
//equivalent form of Eq.(21.62)
//hDbyk = 1.17*Nre^0.585*Npr^(1/3)
//For air at 1 atm and 120F, the properties are
rho_a = M/359*492/580; //[lb/ft^3]
mu_a = 0.019; //[cP], from Appendix 8
k_a = 0.0162; //[Btu/ft-h-F], from Appendix 12
Cp_a = 0.25; //[Btu/lb-F], from Appendix 15
Nre = 1/48*Vbar*rho_a/(mu_a*6.72*10^-4);
Npr = mu_a*2.42*Cp_a/k_a;
//Form Eq.(21.62)
h = (k_a*1.17*Nre^0.585*Npr^(1/3))/(1/48); //[Btu/ft^2-h-F]
mdot_g = v*3600*rho_a; //[lb]
//From Fig. 23.2
cs = 0.25;
delta_Thb = Thb-Tw; //[F]
delta_Tha = 8.24; //[F]
//The heat transferred form the gas to a thin section of the bed
delta_TL = (delta_Thb-delta_Tha)/log(delta_Thb/delta_Tha); //[F]
//rate of heat transfer
qT = h*A*delta_TL; //[Btu/h]
//drying time
tT = QT/qT; //[h]
disp('h',tT,'Required drying time is')
```

**Example 24.4** Example 24.4.sce

```
clear all;
```

```
clc;

//Example 24.4
//Given
msdot = 2800; //[lb/h]
Xa = 0.15;
Xb = 0.005;
Ti = 80; //[F]
To = 125; //[F]
Thb = 260; //[F]
Hb = 0.01; //[lb water/lb dry air]
G = 700; //[lb/ft^2-h]
Cps = 0.52; //[Btu/lb-F]

//Solution
//Counter current operation will be used.
//Assuming
Nt = 1.5; //NTU
//From Fig. 23.2
Twb = 102; //[F]
//From Eq. (2.48)
Tha = (Thb-Twb)/exp(Nt)+Twb; //[F]
Tsb = To; //[F]
lambda = 1036; //[Btu/lb], at 102 F, from Appendix 7
Cpv = 0.45; //[Btu/lb-F], from Appendix 15
Cpl = 1.0; //[Btu/lb-F]
//From Eq.(24.9)
mvdot = msdot*(Xa-Xb); //[lb/h]
//The heat duty is found form substitution in Eq
    .(24.1)
qTdot = Cps*(To-Ti)+Xa*Cpl*(Twb-Ti)+(Xa-Xb)*lambda+
    Xb*Cpl*(To-Twb)+(Xa-Xb)*Cpv*(Tha-Twb); //[Btu/lb]
qT = qTdot*msdot; //[Btu/h]
//The flow rate of the entering air is found from a
    heat balance and the humid heat csb.
//From Fig. 23.2
csb = 0.245; //[Btu/lb-F],
mgdot = qT/(csb*(Thb-Tha)*(1+Hb)); //[lb/h of dry
```

```
    air]
//From Eq.(24.10), The outlet humidity
Ha = Hb+mvdot/mgdot; //[lb/lb]

//For a given flow rate, the cross-sectional area of
     the dryer must be
Ac = qT/(csb*(Thb-Tha))/G; //[ft^2]
//The dryer diameter is
D = (4*Ac/%pi)^0.5; //[ft]
delta_TL = ((Thb-Twb)-(Tha-Twb))/log((Thb-Twb)/(Tha-
    Twb)); //[F]
//Using Eq.(24.29), the dryer length
L = qT/(0.125*%pi*D*G^0.67*delta_TL); //[ft]
disp('respectively','ft',L,'ft',D,'Required diameter
     and length of the dryer is')
```

# Chapter 25

# Adsorption

## 25.1 Scilab Code

**Example 25.1** Example 25.1.sce

```
clear all;
clc;

//Example 25.1
//Given
ya = 0.002;
T = 20+273; //[K]

//Solution
//(a)
M = 86.17;
//from Perry's Chemical Engineers' Handbook, 6th ed.
Pprime = 120; //[mm Hg]
fs = Pprime; //[mm Hg]
rho_L = 0.615; //[g/cm^3], at normal boiling point (68.7 C)
P = 760; //[mm Hg]
p = ya*P; //[mm Hg]
f = p; //[mm Hg]
V = M/rho_L; //[cm^3/g mol]
```

```
//Let
A = T/V*log10(fs/f);
//From Fig. 25.4, volume adsorbed
V_ads = 31/100; //[cm^3 liquid/g carbon]
W = V_ads*rho_L; //[g/g carbon]
disp('g/g carbon',W,'The equilibrium capacity for
    the bed is')

//(b)
T = 40+273; //[K]
Pprime = 276; //[mm Hg]
fs = Pprime; //[mm Hg]
A = T/V*log10(fs/f);
//From Fig. 25.4, volume adsorbed
V_ads = 27/100; //[cm^3 liquid/g carbon]
W = V_ads*rho_L; //[g/g carbon]
disp('g/g carbon',W,'The equilibrium capacity for
    the bed is')
```

**Example 25.2** Example 25.2.sce

```
clear all;
clc;

//Example 25.2
//Solution
cbyc0 =0.05;
u0 = 58; //[cm/s]
Dv = 0.37; //[m^2/g]
c0 = 365; //[ppm]
S = 1194; //[m^2/g]
T = 25; //[C]
rho_b = 0.461; //[g/cm^3]
P = 737; //[mm Hg]
M = 74.12; //[g/mol]
eps = 0.457;
t = 1:0.5:8.5;
t(4) = 2.4; t(5) = 2.8; t(6) = 3.3;
```

```
cbyc0 =[0.005,0.01,0.027,0.05,0.1,0.2,0.29,0.56,0.0019,0.003,0.0079,0.0
t1 = t(1:8);
t2 = t(9:16);
cbyc01 = cbyc0(1:8);
cbyc02 = cbyc0(9:16);
plot(t1,cbyc01,t2,cbyc02);
xgrid();
xlabel('t, Hours');
ylabel('c/c0');
title('Brakthrough curves for Example 25.2');
legend('L = 8cm','L = 16cm');

//(a)
FA = u0*c0*10^-6/22400*273/298*737/760*M*3600; //[g/cm^2-h]
// The total solute adsorbed is the area above the graph multiplied
//by FA. For the 8-cm bed, the area is
Area_bed = 4.79; //[h]
//This area corresponds to the ideal time that would be required to adsorb
//the same amount if the breakthrough curve were a vertical line. The mass
//of carbon per unit cross-sectional area of the bed is
Ac = 8*rho_b; //[g/cm^2]
//Thus,
Wsol = FA*Area_bed/Ac; //[g solute/g carbon]
//At the break point, where
cbyc0_break = 0.05;
//and
t_break =2.4; //[h]
Area_bed_break = 2.37; //[h]
//The amount adsorbed up to the break point is then
Wb = FA*t_break/Ac; //[g solute/ g carbon]
ratio_W = Wb/Wsol;
```

```
//Thus 50 percent of the bed capacity is unused,
    which can be representd
//by a length 4 cm.
//For the 16-cm bed the breakthrough curve has the
    same initial slope as the cuve
//for 8-cm bed, and although data were not taken
    beyond cbyc0 = 0.25,
//the curves are assumed to be parallel
//For the entire bed,
tT = 9.59; //[h]
Wsat = FA*tT/(16*rho_b); //[g solute/ g carbon]
//At
cbyc0_break = 0.05;
t_break  =7.1; //[h]
Area_break = 7.07; //[h]
Wb = FA*Area_break/(16*rho_b); //[g solute/g carbon]
ratio_W = Wb/Wsat;
//At the break point, 74 percent of the bed capacity
     is used,
//which corresponds to an unused section of length
    0.26*16 cm.
//Within experimental error, the lengths of unused
    bed agree,
//and 4.1 cm is expected value for a still longer
    bed.
disp('cm',4.2,'length of the bed used','percent',
    ratio_W,'saturation capacity of the carbon')

//(b)
L = 32; //[cm]
L_exp = L-4.1; //[cm]
//Fraction of the bed used
fra_bed = L_exp/L;
//The break-point time is,
tb = L_exp*rho_b*Wsat/FA; //[h]
disp('h',tb,'break point-time ')
```

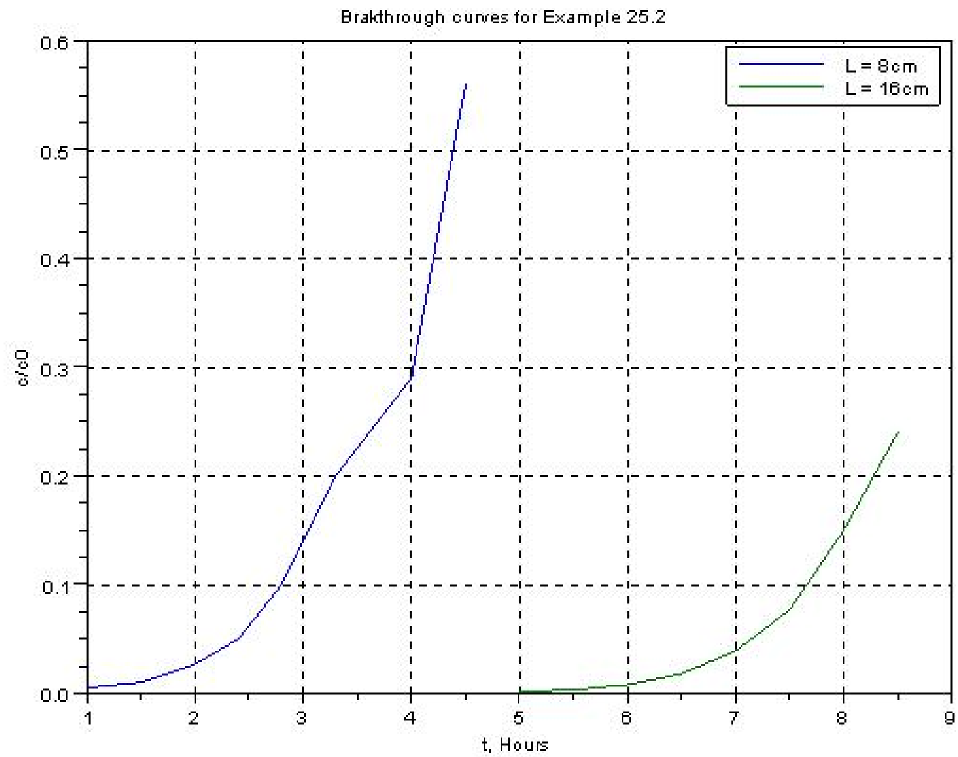


Figure 25.1: Breakthrough curves for Example 25.2

---

**Example 25.3** Example 25.3.sce

```
clear all;
clc;

//Example 25.3
//Solution
cbyc0 =0.05;
u0 = 58; //[cm/s]
Dv = 0.37; //[m^2/g]
c0 = 365; //[ppm]
```

```
S = 1194; //[m^2/g]
T = 25; //[C]
rho_b = 0.461; //[g/cm^3]
P = 737; //[mm Hg]
M = 74.12; //[g/mol]
eps = 0.457;
L = 8; //[cm]

//(a)
//From Example 25.2
ratio_W = 0.495;
tou = 0.495;
//From Fig. 25.10
N = -1.6/(tou-1); //at c/c0 = 0.05
Kca = N*u0/L; //[s^-1]
disp('s^-1',Kca,'Kca = ',N,'N = ')
//plot(t1,cbyc01,t2,cbyc02)

//(b)
Dp = 0.37; //[cm]
mubyrho = 0.152; //[cm^2/s], at 25C, 1atm
Dv = 0.0861; //[cm^2/s]
Nre = Dp*u0/mubyrho;
Nsc = mubyrho/Dv;
//From Eq.(21.62),
Nsh = 1.17*Nre^0.585*Nsc^(1/3);
kc = Nsh*Dv/Dp; //[cm/s]
a = 6*(1-eps)/Dp; //[cm^2/cm^3]
kca = kc*a; //[s^-1]
//Since Kca is slightly less than half the predicted value of kca,
//the external resistance is close to half the total resistance, and
//the calculated value of N need not be revised. The internal
//coefficient can be obtained from
Kc = Kca/a; //[cm/s]
kc_int1 = 1/(1/Kc-1/kc); //[cm/s]
```

```
//If the diffusion into the particle occured only in
    the gas phase, the
//maximum possible value of De would be about Dv/4,
   which leads to
kc_int2 = 10*Dv/(4*Dp); //[cm/s]
disp('Kca is slightly less than half the predicted
   value of kca');
```

**Example 25.4** Example 25.4.sce

```
clear all;
clc;

//Example 25.4
y = 0.0012;
vdot = 16000; //[ft^3/min]
P = 760; //[mm Hg]
rho_b = 30; //[lb/ft^3]
Lun = 0.5; //[ft]

//Solution
//(a)
//Form the hand book
Pprime = 151; //[mm Hg]
fs = Pprime; //[mm Hg]
rho_L = 0.805; //[g/cm^3], at 20C
Tnb = 79.6; //[C]
rho_e = 0.75; //[g/cm^3]
M = 72.1;
V = M/rho_e;
p = y*P; //[mm Hg]
f = p; //[mm Hg]
//At 35C
T = 35+273; //[K]
A = T/V*log10(fs/f);
//Form Fig. 25.4,
//the volume adsorbed
V_ads = 24; //[cm^3/100 g carbon]
```

```
Wsat = V_ads*rho_e; //[g/100 g carbon]
W0 = 1/3*Wsat; //[g/100 g carbon]
Working_capacity = Wsat-W0; //[g/100 g carbon]
//or
Working_capacity = Working_capacity/100; //[lb/lb carbon]
disp(Working_capacity,'Working capacity of the bed is')

//(b)
u0 = 1; //[ft/s]
A = vdot/u0; //[ft^2]
D = sqrt(4*A/%pi); //[ft]
Abed = 10*27; //[ft^2]
L1 = 4; //[ft]
c0 = y/359*273/298*72.1; //[lb/ft^3]
//Form Eq.(25.3)
tstar = L1*rho_b*(Working_capacity)/(u0*c0*3600); //[h]
Lu1 = L-Lun; //[ft]
tb1 = Lu1/L*tstar; //[h]

//if
L2 = 3; //[ft]
Lu2 = L2-Lun;
tb2 = Lu2/L*tstar; //[h]
//checking for delta_P
//Using Eq.(7.22)
phi_s = 0.7; //from Table 28.1
eps = 0.35; //from Table 7.1
mu = 1.21*10^-5; //[lb/ft-s]
rho = 0.074; //[lb/ft^3]
//For a 4*10-mesh carbon
Dp = 1.108*10^-2; //[ft]
deltaPbyL = 150*1*mu*(1-eps)^2/(32.2*phi_s^2*Dp^2*eps^3)+(1.75*rho*1^2*(1-eps)/(32.2*0.7*Dp*eps^3)); //[lbf/ft^2-ft]
deltaPbyL = deltaPbyL*12/62.4; //[in. H2O/ft]
```

```
//for
L = 3;
deltaP = 3*deltaPbyL; //[in. H2O]
//which satisfactory.
mc = 2*(10*27*3)*30; //[lb]

disp('ft',L2,'Allowing for uncertainties in the
    calculations, satisfactory bed length will be')
disp('ft/s',u0,'gas velocity needed')
disp('lb',mc,'carbon needed')
```

# Chapter 26

# Membrane Separation Processes

## 26.1 Scilab Code

**Example 26.1** Example 26.1.sce

```
clear all;
clc;

//Example 26.1
//Given
alpha = 5;
per = 0.2; //[scf/ft^2-h-atm]
Pf = 150; //[lbf/in.^2]
Pp = 15; //[lbf/in.^2]

//Solution
//(a)
R = Pp/Pf;
//At the feed inlet
xin = 0.209;
//Using Eq.(26.17)
A = alpha-1;
B = 1-alpha-1/R-xin*(alpha-1)/R;
```

```
C = alpha*xin/R;
yi_in = (-B-sqrt(B^2-4*A*C))/(2*A);
//At the discharge end
xd = 0.05;
//Using Eq.(26.17)
A = alpha-1;
B = 1-alpha-1/R-xd*(alpha-1)/R;
C = alpha*xd/R;
yi_d = (-B-sqrt(B^2-4*A*C))/(2*A);

//For an approximate solution , these terminal compositions are
//averaged to give
ybar = (yi_in+yi_d)/2;
//From an overall material balance
//Basis
Lin = 100; //[scfh]
V = (Lin*xin-Lin*xd)/(ybar-xd);
//disp(ybar,'and permeate composition is','percent',V/Lin*100,'The permeate in the feed is');


//For more accurate calculation
j = 2;
yi_in(1) = 0.5148;
x(1) = 0.209;
y(1)= 0.5148;
L = Lin;
deltaV = [];
deltaVybar = [];
ybar = [];
for i = 0.2:-0.01:xd
x(j) = i;
A = alpha-1;
B = 1-alpha-1/R-x(j)*(alpha-1)/R;
C = alpha*x(j)/R;
yi_in(j) = (-B-sqrt(B^2-4*A*C))/(2*A);
ybar(j-1) = (yi_in(j-1)+yi_in(j))/2;
```

```
deltaV(j) = L*(x(j-1)-x(j))/(ybar(j-1)-x(j));
V = sum(deltaV);
L = Lin - V;
deltaVybar(j) = deltaV(j-1)*ybar(j-1);
deltaVybarsum = sum(deltaVybar);
y(j-1) = deltaVybarsum/V;
j = j+1;
end
disp(y($),'and permeate composition is','percent',V/Lin*100,'The permeate recovered');;


//(b)
//The membrane area obtained from the flux of A using
//Eq.(26.29) and (26.13)
//for the first increment x = 0.209 to x = 0.2
deltaybar1 = 1.4856; //[scfh], for Lin = 100 scfh
//At x = 0.209
A1 = 0.209-0.1*0.5148;
//At x = 0.2
A2 = 0.2-0.1*(0.50);
Aavg = (A1+A2)/2
QAP1 = 0.2*10; //scfh/ft^3
//for specified flow of 300  scfh
deltaA = 1/2*1.486/Aavg*180; //[ft^2]
//The calculation continued with increments of 0.01
A = 211/2.0*180; //[ft^2]
disp('ft^2',A,'The membrane area needed is')
```

**Example 26.4** Example 26.4.sce

```
clear all;
clc;

//Example 26.4
//Given
F = 10; //[gal/day-ft^3]
```

```
Do = 300*10^-6; //[m]
Di = 200*10^-6; //[m]
vi = 0.5; //[cm/s]
rho = 1; //[g/cm^3]
mu = 0.01; //[g/cm-s], assumed
f = 0.97;

//Solution
//For 10 gal/day-ft^2
Jw = F*231*16.3871/(24*3600*929); //[cm/s]
Nre = Do*100*vi*rho/mu;
Ds = 1.6*10^-5; //[cm^2/s]
Nsc = mu/(rho*Ds);

//Using Eq.(12.69), Analogously to mass transfer
Nsh = (0.35+0.56*Nre^0.52)/Nsc^-0.3;
kc = Nsh*Ds/(Do*100); //[cm/s]
//From Eq.(26.49)
gama = Jw*f/kc;
disp('A concentration differnce of 12 percent will
    not be significant till good flow distribution is
    maintained');
```

**Example 26.5** Example 26.5.sce

```
clear all;
clc;

//Example 26.5
//Given (from Example 26.4)
F = 10; //[gal/day-ft^2], based on external area
Do = 300*10^-6; //[m]
Di = 200*10^-6; //[m]
vi = 0.5; //[cm/s]
rho = 1; //[g/cm^3]
mu = 10^-3; //[Pa-s], assumed
f = 0.97;
L = 3; //[m]
```

```

//Solution
//(a)
//Jw based on area
Jw = 4.72*10^-4*Do/Di*10^-2; //[m/s]
dt = 200*10^-6; //[m]
D = dt; //[m]
//From Eq.(26.53)
Vbar = 4*(Jw)*L/Di; //[m/s]
//From Eq.(26.56)
delta_ps = (Vbar*32*mu*L)/(D)^2*(1/2)/10^5; //[atm]
disp('atm',delta_ps,'pressure drop = ','m/s',Vbar,'
    exit velocity = ');

//(b)
//If the fibres are open at both ends, the effective
     length is 1.5m and
//the exit velocity is half as great. The pressure
    drop is one-fourth as
//large as it was:
deltaP = delta_ps/4; //[atm]
disp('atm',deltaP,'pressure drop (if both ends are
    open) = ')
```

# Chapter 27

# Crystallization

## 27.1 Scilab Code

**Example 27.1** Example 27.1.sce

```
clear all;
clc;

//Example 27.1
//Given
T = 60; //[F]
wA = 0.30; //[MgSO4]
wB = 0.70; //[H2O]

//Solution
//From Fig. 27.3 it is noted that the crystals are MgSO4.7H2O
//and that the concentration of the mother liquid is
xA = 0.245; //[anhydrous MgSO4]
xB = 0.755; //[H2O]
//Bases:
F_in = 1000; //[kg]
H2O_in = F_in*wB; //[kg]
H2O_evp = 0.05*H2O_in; //[kg]
M1 = 120.4; //[MgSO4 molecular weight]
```

```
M2 = 246.5; //[MgSO4.7H2O molecular weight]
M2_in = wA*F_in*M2/M1; //[kg]
H2O_free = F_in-H2O_evp-M2_in; //[kg]
ML = 100; //[kg]
M2_in100 = ML*xA*M2/M1; //[kg]
H2O_free100 = ML - M2_in100; //[kg]
M2_ML = M2_in100/H2O_free100*H2O_free; //[kg]
FC = M2_in - M2_ML; //[kg]
disp(FC,'kilograms of crystals obtained per kilogram
    of original mixture = ')
```

**Example 27.2** Example 27.2.sce

```
clear all;
clc;

//Example 27.2
//Given
//A = MgSO4, B = MgSO4.7H2O and C = H2O
T = 120; //[F]
wA = 0.325;

//Solution
//From Fig 27.4
//Enthalpy coordinate of the point wA
H1 = -33; //[Btu/lb]
//Enthalpy coordinate of the final magma at
    concentration wA
H2 = -78.4; //[Btu/lb]
//Per hundred pouds of original solution the change
    in enthalpy
F = 100; //[lb]
delta_H = F*(H1-H2); //[Btu]
//Applying "center-of gravity principle" to 70 F
    isotherm in Fig. 27.3
C_ML = 0.259;
C_CRY = 0.488;
//Crystals are
```

```
Cry = F*(wA-C_ML)/(C_CRY-C_ML); //[lb/100lb slurry]
//The heat evolved per ton of crystals is
H = delta_H/Cry*2000; //[Btu/ton]
disp('Btu/ton',H,'The heat evolved per ton of
   crystals is')
```

**Example 27.3** Example 27.3.sce

```
clear all;
clc;

//Example 27.3
//Given
sigma = 2.5; //[erg/cm^3]
T = 300; //[K]
N = 6.0222*10^23;
R = 8.3134*10^7; //[erg/g mol-K]
//Solution
M = 74.56; //[Molecular weight]
rho = 1.988; //[g/cm^3]
nu = 2;
VM = M/rho //[cm^3/g mol]
//Using Eq.(27.11)
//Exponential term, excluding 's'
A = 16*%pi*VM^2*N*sigma^3*10/(3*(T*R)^3*nu^2)
B0 = 1;
s(1) = sqrt(-A/log(B0/10^25));
//For B0;
s = s(1):0.0001:0.029;
B0 = exp(57.565)*exp(-A./s.^2);
plot(s,B0)
title('B0 vs s')
xlabel('s')
ylabel('B0')
```

**Example 27.4** Example 27.4.sce

```
clear all;
```

```
clc;

//Example 27.4
//Given
alpha = 1+0.029;
//From Example 27.3
sigma = 2.5; //[erg/cm^3]
T = 300; //[K]
N = 6.0222*10^23;
R = 8.3134*10^7; //[erg/g mol-K]
M = 74.56; //[Molecular weight]
rho = 1.988; //[g/cm^3]
nu = 2;
VM = M/rho; //[cm^3/g mol]

//Using Eq.(27.9)
L = 4*VM*sigma/(2*R*T*log(alpha))*10^7; //[nm]
disp('nm',L,'size of nuclues (L) = ');
```

**Example 27.5** Example 27.5.sce

```
clear all;
clc;

//Example 27.5
//Let: A = MgSO4; B = MgSO4.7H2O; C = H2O
//Given
xA = 0.31;
T = 86; //[F]
Tb = 2; //[F]
vbys = 0.15;
//PB =
rho_cr = 105; //[lb/ft^3]
rho_ml = 82.5; //[lb/ft^3]

//Solution
//Basis:
F = 10000; //[lb/h]
```

```
//From Fig 27.13 and Fig 27.4
crbyml = vbys*rho_cr/((1-vbys)*rho_ml);
ml_prod = F/crbyml; //[lb/h]
magma_prod = F+ml_prod //[lb/h]
xA_avg = (crbyml*0.488+0.285)/1.224;
//The enthalpy of the magam
Hmag = (crbyml*(-149)+(-43))/1.224; //[Btu/lb]
//These are the concenrations of the point e. The point for the feed must
//lie on the straight line ae.
//The enthalpy of the feed
Hf = -21; //[Btu/lb]
//Temperature of the feed
Tf = 130; //[F]
//By COG principle, the evaporation rate
evap_rate = magma_prod*(Hf-Hmag)/(1098-Hf); //[lb/h]
Total_feed = magma_prod+evap_rate; //[lb/h]
disp('F',Tf,'Temperature of the feed is');
disp('lb/h',Total_feed,'Total feed rate');
disp('lb/h',evap_rate,'Total evaporation rate');
```

**Example 27.6** Example 27.6.sce

```
clear all;
clc;

//Example 27.6
//Given
G = 0.0018; //[ft/h]
//Solution
//Screen opening of 20−mesh standard screen is,
L = 0.00273; //[ft], Appendix 20
a = 1; //[Eq.27.16]
//From Example 27.5
//The volume flow rate of mother liquor in the product magma
Q = 44520/82.5; //[ft^3/h]
//Since, when z=3,
```

```
Lpr = L; //[ft]
//Using Eq.(27.28)
//drawdown time
tou = Lpr/(3*G); //[h]
//volume of the liquid in the crystallizer
Vc = tou*Q; //[ft^3]
//Total magma volume
Vmagma = Vc/0.85*7.47; //[gal]
disp('gal',Vmagma,'The magma volume in the crystallizer be');
//Using Eq.(27.44)
//The nucleation rate is
C = 10000; //[lb/h]
rho_c = 105;
B0 = 9*C/(2*rho_c*Vc*Lpr^3); //[nuclei/ft^3-h]
disp('nuclei/ft^3-h',B0,'The nucleation rate necessary is');
//Using Eq.(27.40), the zero-size particle density is
n0 = B0/0.0018; //[nuclei/ft^4]
L1 = (0:8)*10^-3;
//Using Eq.(27.27)
//Let A = log10(n), B = log10(n0)
B = log10(n0);
A = B - 1.1*10^3*L1/(2.3026);
figure(1);
plot(L1*10^3,A);
xgrid();
xlabel('L x 10^3 ft');
ylabel('log n');
title('Population density vs length');

//From Fig. 27.15c for values of z corresponding to mesh openings.
L1 = [11,14,16,19,23,27,33,38,46,54,65,78]'*10^-2;
z = L1/(tou*G*100); //[mm]
t = 0;
function f = fun(z,xm)
```

```
  f = z^3*exp(-z)/6;
endfunction
[xm]=ode(0,0,z,fun);
for i=1:length(xm)
   Diff(i) = z(i)^3*exp(-z(i))/6;
end
figure(2);
subplot(2,1,1);
plot(z,xm);
xgrid();
xlabel('z');
ylabel('xm');
title('cumulative mass distribution');
subplot(2,1,2);
plot(z,Diff)
xgrid();
xlabel('z');
ylabel('dxm/dz');
title('differential mass distribution');
```

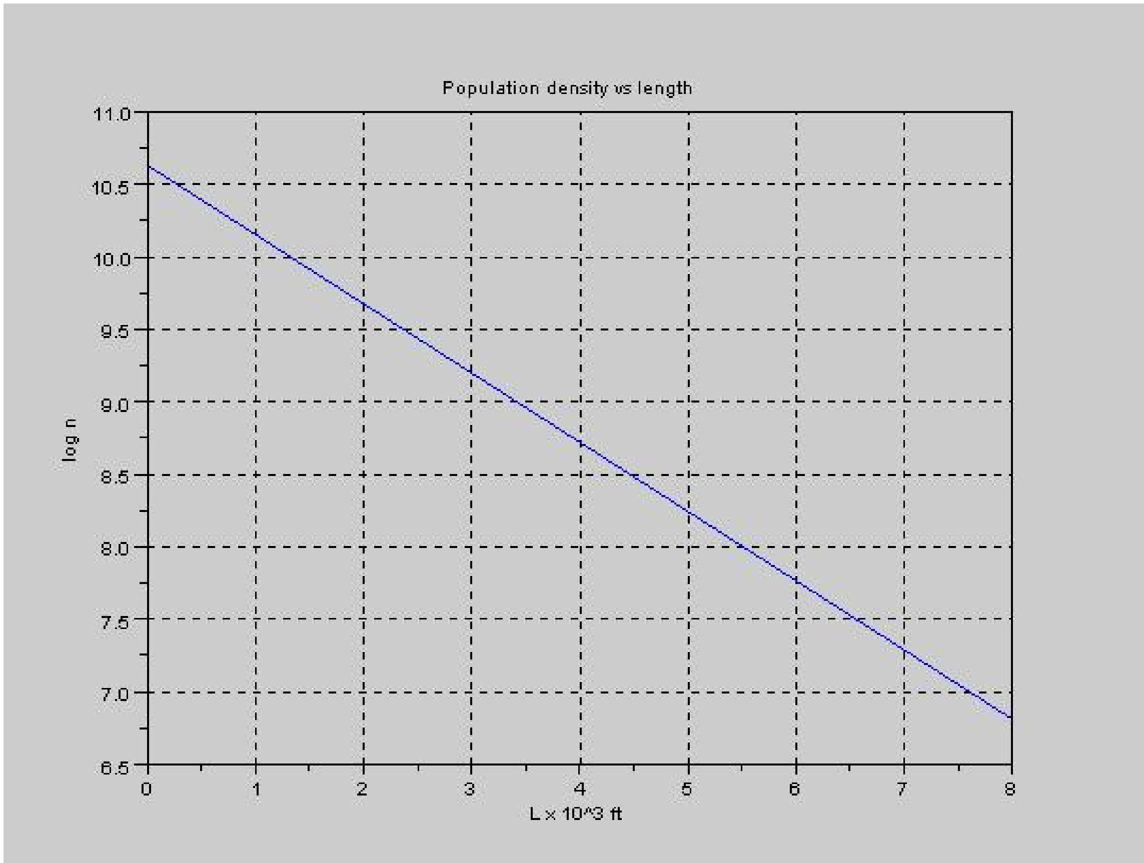


Figure 27.1: Population density vs. length Example 27.6

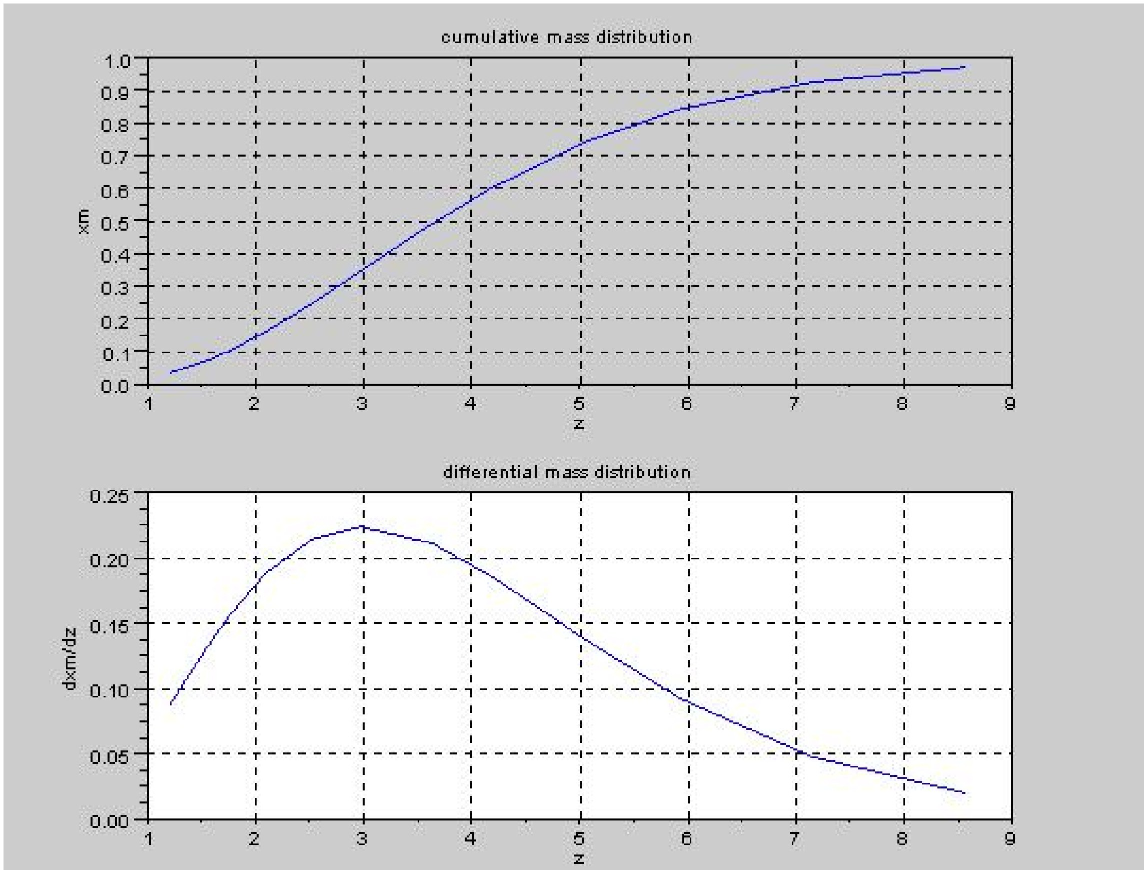


Figure 27.2: Size-distribution relations for Example 27.6

# Chapter 28

# Properties, Handling and Mixing of Particulate Soilds

## 28.1 Scilab Code

**Example 28.1** Example 28.1.sce

```
clear all;
clc;

//Example 28.1
//Given
rho_p = 0.002650; //[g/mm^3]
a = 2;
phi_s = 0.571;
//Solution
//(a)
//For the 4/6-mesh increment, from Table 28.2
x =
  [0,2.51,12.5,32.07,25.7,15.9,5.38,2.10,1.02,0.77,0.58,0.41,0.31,0
   //[mass fraction]
Dp =
  [4.699,3.327,2.362,1.651,1.168,0.833,0.589,0.417,0.295,0.208,0.14
   //[mm]
Dpbar(1) = 10^-5;
```

```
for i =2:length(Dp)
  Dpbar(i) = (Dp(i-1)+Dp(i))/2;
end

//(a)
//Using Eq.(28.4)
Aw = 6/(phi_s*rho_p)*sum(x(1:$-1)./Dpbar(1:$-1))/(1-x($)); //[mm^2/g]
Nw = 1/(a*rho_p)*sum(x(1:$-1)./Dpbar(1:$-1)^3)/(1-x($)); //[particles/g]
disp('particles/g',Nw,'Nw = ','mm^2/g',Aw,'Aw = ');

//(b)
//Using Eq.(28.9)
Dvbar = (1/sum(x(1:$-1)./Dpbar(1:$-1)^3)/(1-x($)))^(1/3); //[mm];
disp('mm',Dvbar,'Dvbar = ');

//(c)
//Using Eq.(28.6)
Dsbar = 1/sum(x(1:$-1)./Dpbar(1:$-1))/(1-x($)); //[mm]
disp('mm',Dsbar,'Dsbar = ');

//(d)
//Using Eq.(28.8) and Table 28.3
Dwbar = sum(x.*Dpbar); //[mm]
disp('mm',Dwbar,'Dwbar = ');

//(e)
//Using Eq.(28.11)
N2 = x($-1)/(a*rho_p*Dpbar($-1)^3); //[particles/g]
disp('particles/g',N2,'Nt = ');
fra = N2/Nw;
disp(fra,'Fraction of the particles in te top 12 increments = ');
```

**Example 28.2** Example 28.2.sce

```
clear all;
clc;

//Example 28.2
//Given
x = 0.14;
xavg = 0.10;
t = 3; //[min]
x
   =[10.24,9.3,7.94,10.24,11.08,10.03,11.91,9.72,9.20,10.76,10.97,10

//Solution
mu = xavg;
N =12;
xbar = mean(x);
//Substituing in Eq.(28.20)
Ip = sqrt((N-1)*mu*(1-mu)/(sum(x^2)-xbar*sum(x)));
//Using Eq.(28.18)
s = stdev(x);
disp(s,'s =',Ip,'Ip =')
```

# Chapter 29

# Size Reduction

## 29.1 Scilab Code

**Example 29.1** Example 29.1.sce

```
clear all;
clc;

//Example 29.1
//Given
mdot = 100; //[ton/h]
w1 = 0.80;
w2 = 0.80;
//Solution
Wi = 12.74; //From Table 29.1
Dpa = 2*25.4; //[mm]
Dpb = 0.125*25.4; //[mm]
//Using Eq.(29.10)
P = mdot*0.3162*Wi*(1/Dpb^0.5-1/Dpa^0.5); //[kW]
disp('kW',P,'Power required (P) = ');
```

**Example 29.2** Example 29.2.sce

```
clear all;
clc;

```

```
//Example 29.2
//Given
n = 1:7;
beeta = 1.3;
//From Table 29.2
Dpn = [3.327,2.362,1.651,1.168,0.833,0.589,0.417]'; //[mm]
Dpu = Dpn; //[mm]
xn0 = [0.0251,0.125,0.3207,0.2570,0.1590,0.0538,0.0210]';

Su(1) = 10*10^-4; //[s^-1]
//B(1) = 1;
//Solution

//(a)
//For the 4/6-mesh materials there is no input from coarser
//material and applying Eq.(29.11). At the end of time tT
x1 = xn0(1)*0.9;
tT = 1/Su(1)*log(xn0(1)/x1); //[s]
disp('s',tT,'Required time is');

//(b)

//Assuming Su varies with Dp^3
for i = 1:length(Dpn)-1
  Su(i+1) = Su(i)*(Dpn(i+1)/Dpn(i))^3; //[s^-1]
end
for i = 1:length(Dpn)
  for j = 1:length(Dpu)
//Using Eq.(29.13)
    if (j<i)
      B(i,j)=0;
    else
      B(i,j) = (Dpn(j)/Dpn(i))^beeta;
    end
```

```
end
end

for i = 1:length(Dpn)-1
  for j = 1:length(Dpu)-1
    if (j<i)
      delta_B(i,j)=0;
      else
      delta_B(i,j) = B(i,j)-B(i,j+1);
    end
  end
end
disp(delta_B,'individual breakage functions');

//(c)
deltaT = 30; //[s]
//Using Eq.(29.15)
x=[];
x(:,1) = xn0;
for n = 1:length(xn0)
    for t = 1:720
    if (n==1)
      x(n,t+1) = x(n,t)*(1-Su(n)*deltaT);
    else
      x(n,t+1) = x(n,t)*(1-Su(n)*deltaT)+ deltaT*Su(n-1)*delta_B(n-1,n-1)*x(n-1,t);
    end
  end
end
time = linspace(0,6,721);
for i =1:length(xn0)
  plot2d(time,x(i,:),style = i);
  xgrid();
  xlabel('time (h)');
  ylabel('mass fraction (xa)');
  title('Mass fractions');
  legend('x1','x2','x3','x4','x5','x6','x7');
end
```

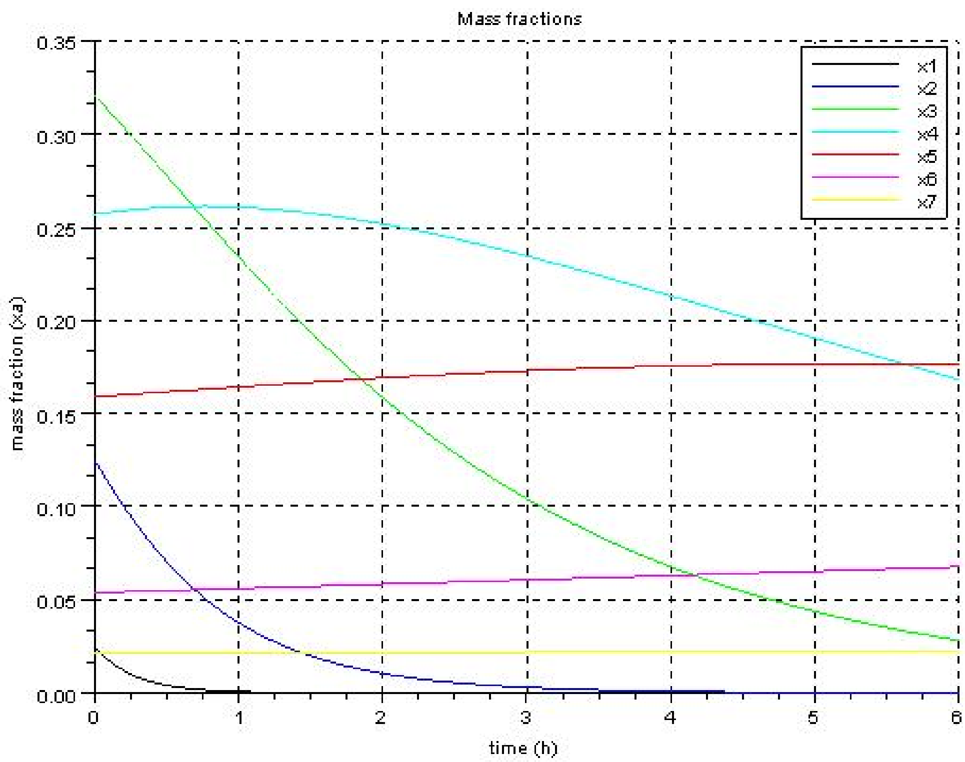


Figure 29.1: Mass-fractions of Example 29.2

# Chapter 30

# Mechanical Separations

## 30.1 Scilab Code

**Example 30.1** Example 30.1.sce

```
clear all;
clc;

//Example 30.1
//Given
//From Table 30.1
Dp = [4.699,3.327,2.362,1.651,1.168,0.833,0.589,0.417,0.208,0.0000001] //[mm]
F = [0,0.025,0.15,0.47,0.73,0.885,0.94,0.96,0.98,1.0]';
O = [0,0.071,0.43,0.85,0.97,0.99,1.00]'; //[1 to 7]
U = [0.0,0.195,0.58,0.83,0.91,0.94,0.975,1.00]'; //[3 to 10]

//Solution
plot(Dp,F)
plot(Dp(1:7),O,'r')
plot(Dp(3:$),U,'g')
```

```
xgrid();
xlabel('Dp mm');
ylabel('Cumulative mass fraction larger than Dp');
title('Analysis for Example 30.1');
legend('Feed','Oversize','Undersize');

//Cut-point diameter from the Table 30.1
Dcp = 1.651; //[mm]
xF = 0.47;
xD = 0.85;
xB = 0.195;
//From Eq.(30.3)
DbyF = (xF-xB)/(xD-xB);
BbyF = 1-DbyF;
//Using Eq.(30.7), overall effectiveness
E = (xF-xB)*(xD-xF)*(1-xB)*(xD)/((xD-xB)^2*((1-xF)*
    xF));
disp('respectively',BbyF,DbyF,'mass ratio of
    overflow and underflow is');
disp(E,'Overall Effectiveness (E) =');
```

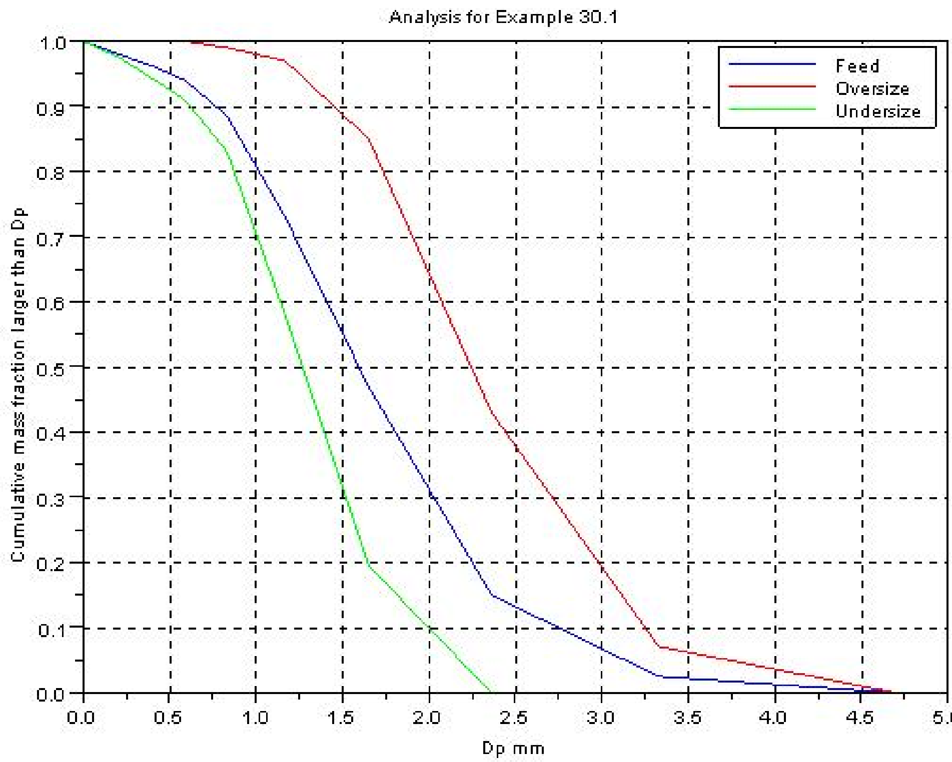


Figure 30.1: Analysis for Example 30.1

---

**Example 30.2** Example 30.2.sce

```
clear all;
clc;

//Example 30.2
//Given
//From Table 30.2
V = linspace(0.5,6,12)'; //[L]
t1 = [17.3,41.3,72,108.3,152.1,201.7]'; //[s]
t2 = [6.8,19,34.6,53.4,76,102,131.2,163]'; //[s]
```

```
t3 = [6.3,14,24.2,37,51.7,69,88.8,110,134,160]'; //[s]
t4 = [5,11.5,19.8,30.1,42.5,56.8,73,91.2,111,133,156.8,182.5]'; //[s]
t5 = [4.4,9.5,16.3,24.6,34.7,46.1,59,73.6,89.4,107.3]'; //[s]
figure(1);
plot(V(1:length(t1)),t1./V(1:length(t1)));
plot(V(1:length(t2)),t2./V(1:length(t2)),'r');
plot(V(1:length(t3)),t3./V(1:length(t3)),'g');
plot(V(1:length(t4)),t4./V(1:length(t4)),'k');
plot(V(1:length(t5)),t5./V(1:length(t5)),'y');
xgrid();
xlabel('V (L)');
ylabel('t/V (s/L)');
legend('deptaP = 6.7','deptaP = 16.2','deptaP = 28.2','deptaP = 36.3','deptaP = 49.1');
title('t/V vs V');

deltaP = [965,2330,4060,5230,7070]'; //[lbf/ft^2]
//From Fig. 30.15
//Slope(Kc/2)
slope = [10440,5800,3620,3060,2400]'; //[s/ft^6]
Kc = slope*2; //[s/ft^6]
//Intercept(1/q0)
Inter = [800,343,267,212,180]'; //[s/ft^3]
//Viscosity of water
muw = 5.95*10^-4; //[lb/ft-s], from Appendix 14
//Filter area
A = 440/30.48^2; //[ft^2]
//concentration
c = 23.5*28.31/454; //[lb/ft^3]
gc = 32.14;
//Using Eq.(30.22)
Rm = A*gc/muw*deltaP.*(Inter)/10^10;  //[ft^-1*10^10]
```

```
//Using Eq.(30.24)
alpha = A^2*gc/(c*muw)*deltaP.*(Kc)/10^11; //[ft/lb*10^-11]
figure(2);
plot2d(deltaP,Rm);
xgrid();
xlabel('deltaP (lbf/ft^2)');
ylabel('Rm (ft^-1*10^-10)');
title('Rm vs deltaP');
figure(3);
plot2d(log(deltaP),log(alpha));
xgrid();
xlabel('deltaP (lbf/ft^2)');
ylabel('alpha (lb/ft*10^-11)');
title('alpha vs deltaP');
//Form 30.17
disp(Rm,'Rm (ft^-1*10^-10) =');
disp(alpha,'alpha (lb/ft*10^-11) =');
alpha0 = 1.75*10^11/1000^0.26;
disp('alpha = 2.9*10^10*deltaP^2.6','Emperical Equation for the cake');
```

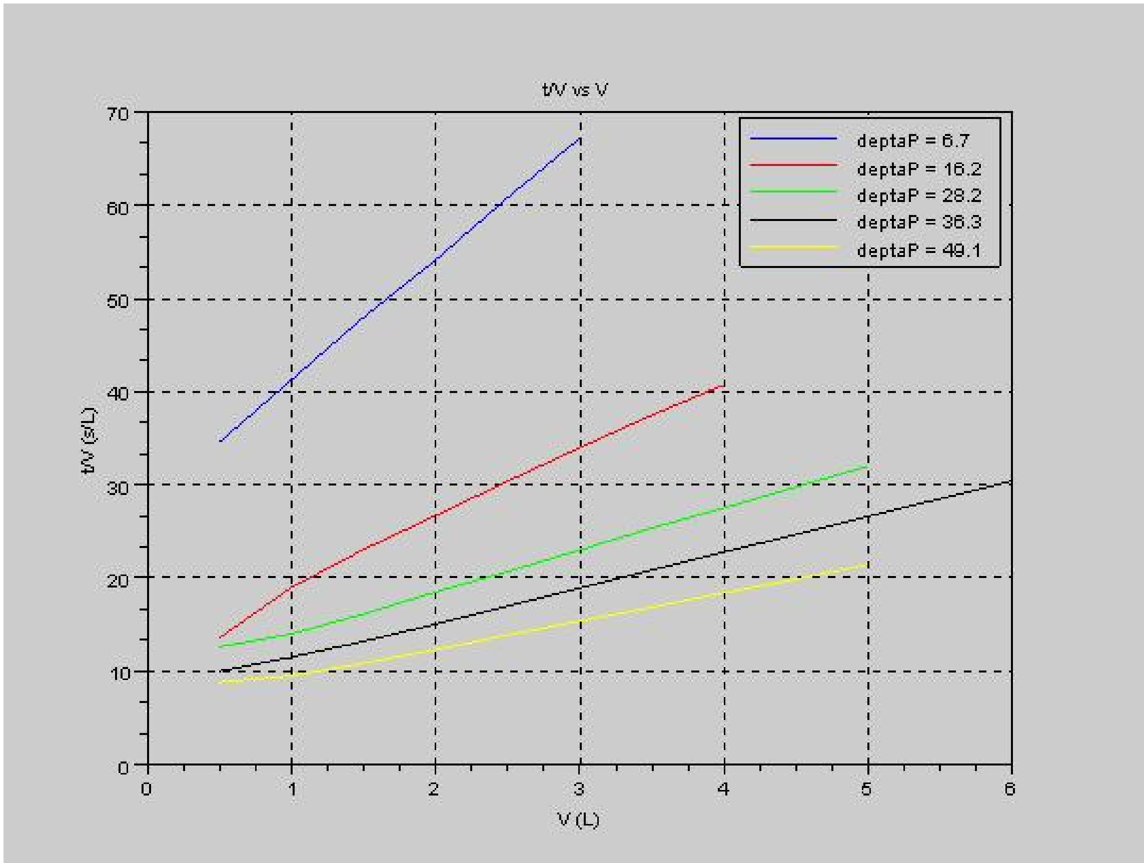


Figure 30.2: t/V vs. V for Example 30.2

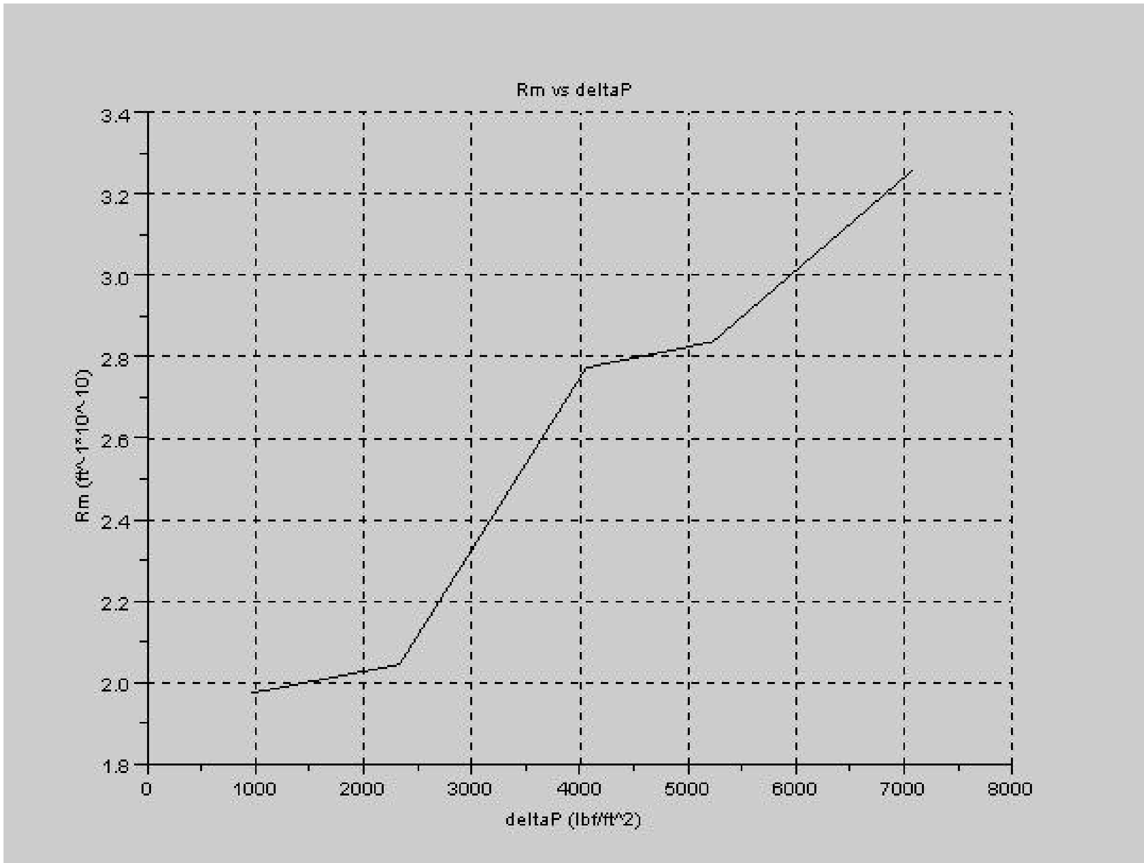


Figure 30.3: Rm vs. deltaP for Example 30.2

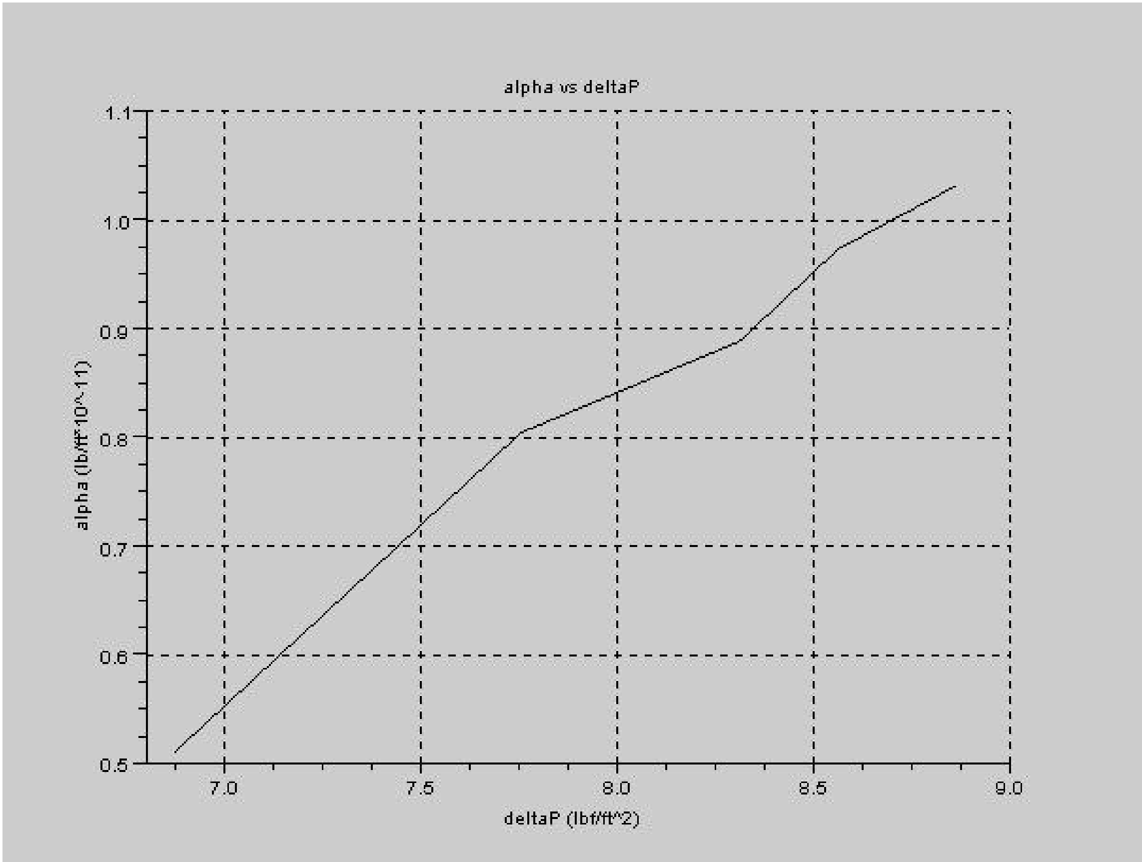


Figure 30.4: alpha vs. deltaP for Example 30.2

---

**Example 30.3** Example 30.3.sce

```
clear all;
clc;

//Example 30.3
//Given
f = 0.30;
tc = 5*60; //[s]
n = 1/tc; //[s^-1]
cF = 14.7; //[lb/ft^3]
```

```
deltaP = 1414;
mFbymC = 2
//Solution
alpha0 = 2.9*10^10; //[ft/lb], From Example 30.2
s = 0.26;
mu = 6.72*10^-4; //[lb/ft-s]
rho = 62.3; //[lb/ft^3]
gc =32.17;
//Using Eq.(30.19)
c = cF/(1-(mFbymC-1)*(cF/rho)); //[lb/ft^3]
mcdot = 10/(60*7.48)*(1/(cF/168.8+1))*cF; //[lb/s]
//Solving Eq.(30.34)
AT = mcdot*(alpha0*mu/(2*c*1414^(1-s)*gc*f*n))^(0.5)
    ;
disp('ft^2',AT,'Filter Area(AT) =');
```

**Example 30.4** Example 30.4.sce

```
clear all;
clc;

//Example 30.4
//Given
D = 2; //[cm]
Vbar = 150; //[cm/s]
rho = 1; //[g/cm^3]
mu = 0.01; //[g/cm-s]
Dv = 4*10^-7; //[cm^2/s]

//Solution
//(a)
Nre = Vbar*D*rho/mu;
Nsc = mu/(rho*Dv);
//Using Eq.(21.55)
Nsh = 0.0096*Nre^0.913*Nsc^0.346;
kc = Nsh*Dv/D; //[cm/s]
pi = poly([0,4.4*10^-3,-1.7*10^-6,7.9*10^-8],'c',"
    coeff");
```

```
//For
c1 = 10; //[g/L]
v = 10^-3; //[cm/s]
//Using Eq.(30.53)
cs = c1*exp(v/kc); //[g/L]
deltaPi = horner(pi,cs);
Qm = 250/36000; //[cm/s-atm]
//Using Eq.(30.50)
deltaP = v/Qm+deltaPi; //[atm]
//Using Eq.(30.53)
cs = 400;
vmax = kc*log(cs/c1); //[cm/s]
deltaP = vmax/Qm+horner(pi,cs); //[tm]
c = [10,20,40];
V=[];
deltaP=[];
for j = 1:length(c)
c1 = c(j);
i = 1;
vmax = kc*log(cs/c1)*10^4;
h = (vmax-1)/1000;
  for v = 1:h:vmax
     cs = c1*exp(v*10^-4/kc); //[g/L]
     deltaPi = horner(pi,cs); //[atm]
     deltaP(j,i) = v*10^-4/Qm+deltaPi; //[atm]
     V(j,i) = v*10^-4;
     i = i+1;
   end
end
V = V*36000;
for l=1:length(c)
  figure(1)
  plot2d(deltaP(l,:),V(l,:),style=l);
  xgrid();
  xlabel('deltaP (atm)');
  ylabel('Permeate flux (L/m^2-h)');
  title('Effective pressure drop and concentration
     on flux')
```

```
  legend('Cf=10,','Cf=20','Cf=40');
end

//(b)
Qmb =  Qm/5; //[cm/s-atm]
vb = 10^-3; //[cm/s]
c = 40; //[g/L]
c1 = 40;
csb = c1*exp(vb/kc);
deltaPi = horner(pi,csb);
deltaPb = vb/Qmb+deltaPi;
disp('The largest effect of the lower membrane permeability is a 30 percent reduction in low pressure drop');
i = 1;
vmax = kc*log(400/c1)*10^4;
h = (vmax-1)/1000;
for vb = 1:h:vmax
     csb = c1*exp(vb*10^-4/kc); //[g/L]
     deltaPi = horner(pi,csb); //[atm]
     deltaPb(i) = vb*10^-4/Qmb+deltaPi; //[atm]
     Vb(i) = vb*10^-4;
     i = i+1;
end
Vb = Vb*36000;
plot2d(deltaPb,Vb, style = 1+1)
legend('Cf=10,','Cf=20','Cf=40','Cf = 40(Qm = 250/5)');
```

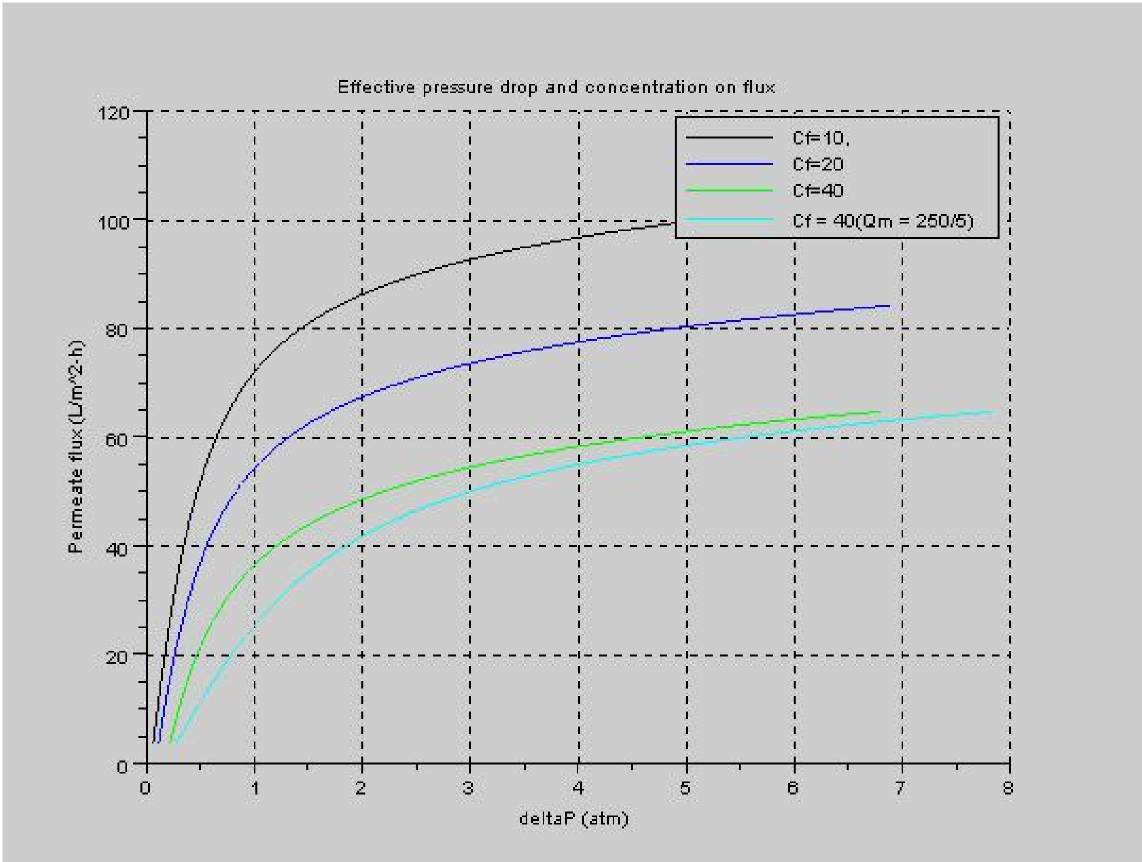


Figure 30.5: Effect of pressure drop and concentration on flux for Example 30.4

---

**Example 30.5** Example 30.5.sce

```
clear all;
clc;

//Example 30.5
//Given
D = 1.5; //[cm]
Nre = 25000;
Qm = 40; //[L/m62-h]
```

```
Mw = 30000;
Dv = 5*10^-7; //[cm^2/s]
R = 0.75;

//Solution
//(a)
//Base case:
v = Qm*2.78*10^-5; //[cm/s]
Nsc = 0.01/Dv;
//Using Eq.(21.55)
Nsh = 0.0096*Nre^0.913*Nsc^0.346;
kc = Nsh*Dv/D; //[cm/s]
//Let A = K/(1-K)
A = (1-R)/R*exp(-v/kc);
K = A/(1+A);
//If the flux is reduced to 0.556*10^-3 cm/s
//Let B = (1-R)/R
B = K/(1-K)*exp(0.556*10^-3/kc);
R = 1/(1+B);
//As flux approaches zero R appraoches 1-K:
Rmax = 1-K;
disp(R,'fraction rejected (R) =');
disp(Rmax,'maximum rejection (Rmax) =');

//(b)
//Using Fig. (30.24)
kc1 = kc;
M2 = 10000;
R2 = 0.35;
K1 = K;
lambda1 = 1-K1^0.5;
lambda2 = lambda1*(10000/Mw)^(1/3);
K2 = (1-lambda2)^2;
kc2 = kc1*3^0.22; //[cm/s]
//Let B2 = (1-R2)/R2
B2 = K2/(1-K2)*exp(v/kc2);
R2 = 1/(1+B2);
disp(R2,'fraction rejected (R2) =');
```

```
//(c)
Dpore = 10^-7; //[cm^2/s]
eps = 0.5;
tou = 2;
De = 2.5*10^-8; //[cm^2/s]
L = 2*10^-5; //[cm]
v = 5.56*10^-4; //[cm/s]
vLbyDe = v*L/De;
//Using Eq.(30.63)
K = 0.101;
c2bycs = K*exp(vLbyDe)/(K-1+exp(vLbyDe));
disp('Diffusion in the membrane makes the premeate
    concentrations about twice as high as it would be
     if c2=Kcs=0.101cs, indicating that the partition
     coefficient is lower than that estimated in part
    (a) ');
```