Scilab Textbook Companion for Unit Operations Of Chemical Engineering by W. L. McCabe, J. C. Smith And P. Harriot[1]

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Book Description

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Scilab numbering policy used in this document and the relation to the above book.

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

AP Appendix to Example(Scilab Code that is an Appednix to a particular Example of the above book)

For example, Exa 3.51 means solved example 3.51 of this book. Sec 2.3 means a scilab code whose theory is explained in Section 2.3 of the book.

Contents

List of Scilab Codes

Chapter 1

Definitions and Principles

Scilab code Exa 1.1 Power calculation

Power calculation

```
//clear//
clear;
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

Scilab code Exa 2.1 reading in the mamometer

reading in the mamometer

```
//clear//
clear;
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) =
    ')
```

Scilab code Exa 2.2 tank diameter

tank diameter

```
//clear//
clear;
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

Scilab code Exa 4.1 mass velocity through pipe

mass velocity through pipe

```
//clear//
clear;
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 = ')
```

Scilab code Exa 4.2 streamline discharge velocity streamline discharge velocity

```
//clear//
clear;
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) ='
  )
```

Scilab code Exa 4.3 Force

Force

```
//clear//
clear;
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]
```

Scilab code Exa 4.4 Power

Power

```
//clear//
clear;
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

Scilab code Exa 5.1 flow$_{r}ate$

flow_rate

```
//clear//
clear;
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

Scilab code Exa 6.1 The Mach Number at dischage is

```
The Mach Number at dischage is
```

```
//clear//
clear;
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))
```

Scilab code Exa 6.2 Mass velocity

Mass velocity

```
//clear//
clear;
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 = pa*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]
```

Scilab code Exa 6.3 Pressure calculation

Pressure calculation

```
//clear//
clear;
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

Scilab code Exa 7.1 Velocity

Velocity

```
//clear//
clear;
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]
```

Scilab code Exa 7.2 Calculating Reynolds Number

`Calculating Reynolds Number`

```
//clear//
clear;
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]
```

Scilab code Exa 7.3 Velocity and pressure

Velocity and pressure

```
//clear//
clear;
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

Scilab code Exa 8.1 vapor pressure

vapor pressure

```
//clear//
clear;
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]
```

Scilab code Exa 8.2 velocity

velocity

```
//clear//
clear;
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]
```

Scilab code Exa 8.3 Cooling water requirement

`Cooling water requirement`

```
//clear//
clear;
```

```
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]
```

Scilab code Exa 8.4 press$_{loss}$

press_loss

```
//clear//
clear;
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]
```

Scilab code Exa 8.5 Maximum power consumption

```
Maximum power consumption
```

```
//clear//
clear;
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_O*550) //[hp]
```

Scilab code Exa 8.6 volumetric flow rate

volumetric flow rate

```
//clear//
clear;
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

Scilab code Exa 9.1 Power

Power

```
//clear//
clear;
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]
```

Scilab code Exa 9.2 Power calculation

Power calculation

```
//clear//
clear;
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]
```

Scilab code Exa 9.3 Power calculation

Power calculation

```
//clear//
clear;
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]
```

Scilab code Exa 9.4 Time

Time

```
//clear//
clear;
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]
```

Scilab code Exa 9.5 slurry density

slurry density

```
//clear//
clear;
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]
```

Scilab code Exa 9.6 find out mean bubble diameter

find out mean bubble diameter

```
//clear//
clear;
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]
```

Scilab code Exa 9.7 velocity

velocity

```
//clear//
clear;
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.
```

Scilab code Exa 9.8 volume

volume

```
//clear//
clear;
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

Scilab code Exa 10.1 temperature and thermal condutivity

temperature and thermal condutivity

```
//clear//
clear;
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]
```

Scilab code Exa 10.2 the heat loss from unit square area

```
the heat loss from unit square area
```

```
//clear//
clear;
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]
```

Scilab code Exa 10.3 mean for silica

mean for silica

```
//clear//
clear;
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]
```

Scilab code Exa 10.4 Temperature

`Temperature`

```
//clear//
clear;
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]
```

Scilab code Exa 10.5 penetration distance

`penetration distance`

```
//clear//
clear;
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

Scilab code Exa 11.1 Overall heat transfer coefficient

Overall heat transfer coefficient

```
//clear//
clear;
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

Scilab code Exa 12.1 Delta t

Delta t

```
//clear//
clear;
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)
```

Scilab code Exa 12.2 overall coefficient

```
overall coefficient
```

```
//clear//
clear;
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);
```

Scilab code Exa 12.3 Laminar Range

`Laminar Range`

```
//clear//
clear;
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
```

Scilab code Exa 12.4 lenght of heated section

`lenght of heated section`

```
//clear//
clear;
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

Scilab code Exa 13.1 coefficient of chlorobenzene

`coefficient of chlorobenzene`

```
//clear//
clear;
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')
```

Scilab code Exa 13.2 film coefficient

film coefficient

```
//clear//
clear;
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

Scilab code Exa 14.1 heat flux

heat flux

```
//clear//
clear;
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

Scilab code Exa 15.1 heat transfer coefficent

heat transfer coefficent

```
//clear//
clear;
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')
```

Scilab code Exa 15.2 heat exchanger

heat exchanger

```
//clear//
clear;
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
```

Scilab code Exa 15.3 correct mean temperature drop

`correct mean temperature drop`

```
//clear//
clear;
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'
    )
```

Scilab code Exa 15.4 heat transfer coefficent

heat transfer coefficent

```
//clear//
clear;
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*G/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, disregarding 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
    coefficient is')
```

Chapter 16

Evaporation

Scilab code Exa 16.1 heating area required

heating area required

```
//clear//
clear;
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')
```

Scilab code Exa 16.2 boiling point

```
boiling point
```

```
//clear//
clear;
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')
```

Scilab code Exa 16.3 total rate of evaporation

`total rate of evaporation`

```
//clear//
clear;
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

Scilab code Exa 17.1 number of ideal stages determined

`number of ideal stages determined`

```
//clear//
clear;
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
```

Scilab code Exa 17.2 percentage removal obtained

percentage removal obtained

```
//clear//
clear;
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

Scilab code Exa 18.1 mole fraction

mole fraction

```
//clear//
clear;
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')
```

Scilab code Exa 18.2 water needed

water needed

```
//clear//
clear;
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')
```

Scilab code Exa 18.3 Temperature

Temperature

```
//clear//
clear;
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.
```

Scilab code Exa 18.4 Ideal plates needed

Ideal plates needed

```
//clear//
clear;
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' )
```

Scilab code Exa 18.6 Froth height

Froth height

```
//clear//
clear;
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')
```

Scilab code Exa 18.7 F factor

F factor

```
//clear//
clear;
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')
```

Scilab code Exa 18.8 composition of the remaining liquid

`composition of the remaining liquid`

```
//clear//
clear;
clc;

//Example 18.8
//Given
xOA = 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
nOA = 0.15; //[mol]
nA = 0.015; //[mol]
nOB = 0.85; //[mol]
//Using Eq.(18.79)
nB = nOB*(nA/nOA)^(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

Scilab code Exa 19.2 preheat temperature

`preheat temperature`

```
//clear//
clear;
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')
```

Scilab code Exa 19.3 ideal stages

`ideal stages`

```
//clear//
clear;
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 volatility 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');
```

Scilab code Exa 19.4 tempeature in Lower zone and Upper zone

tempeature in Lower zone and Upper zone

```
//clear//
```

```
clear;
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')
```

Scilab code Exa 19.5 ideal plate required

`ideal plate required`

```
//clear//
clear;
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

Scilab code Exa 20.1 ideal stages

ideal stages

```
//clear//
clear;
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');
```

Scilab code Exa 20.2 Number of stages required

Number of stages required

```
//clear//
clear;
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')
```

Scilab code Exa 20.3 Number of stages

`Number of stages`

```
//clear//
clear;
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')
```

Chapter 21

Principles of Diffusion and Mass Transer between Phases

Scilab code Exa 21.1 diffusion

`diffusion`

```
//clear//
clear;
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');
```

Scilab code Exa 21.2 Volumetric Diffusivity

Volumetric Diffusivity

```
//clear//
clear;
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) = ')
```

Scilab code Exa 21.3 Diffusivity

Diffusivity

```
//clear//
clear;
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');
```

Scilab code Exa 21.4 Effective thickness

Effective thickness

```
//clear//
clear;
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')
```

Scilab code Exa 21.5 efficieny

efficieny

```
//clear//
clear;
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')
```

Scilab code Exa 21.6 number of stages

number of stages

```
//clear//
clear;
```

```
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

Scilab code Exa 22.1 pressure drop

pressure drop

```
//clear//
clear;
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');
```

Scilab code Exa 22.2 pressure drop

pressure drop

```
//clear//
clear;
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')
```

Scilab code Exa 22.3 temperatures

temperatures

```
//clear//
clear;
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');
```

Scilab code Exa 22.4 Transfer units

Transfer units

```
//clear//
clear;
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')
```

Scilab code Exa 22.5 packing height

packing height

```
//clear//
```

```
clear;
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_E0 = 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_02 = 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_E0 = Hx_02*(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')
```

Scilab code Exa 22.6 resistance

`resistance`

```
//clear//
```

```
clear;
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*Gxbar^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*Gxbar^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;
```

Chapter 23

Humidification Operations

Scilab code Exa 23.1 Adiabatic saturation temperature

Adiabatic saturation temperature

```
//clear//
clear;
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');
```

Scilab code Exa 23.3 volume of the spray chamber

volume of the spray chamber

```
//clear//
clear;
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]
//Substituting 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

Scilab code Exa 24.1 drying time

`drying time`

```
//clear//
clear;
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')
```

Scilab code Exa 24.2 drying time

`drying time`

```
//clear//
clear;
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')
```

Scilab code Exa 24.3 Required drying time

Required drying time

```
//clear//
clear;
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')
```

Scilab code Exa 24.4 diameter and length of the dryer

diameter and length of the dryer

```
//clear//
clear;
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

Scilab code Exa 25.1 equilibrium capacity

equilibrium capacity

```
//clear//
clear;
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')
```

Scilab code Exa 25.2 break point-time

break point-time

```
//clear//
clear;
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 ')
```

Scilab code Exa 25.3 value of kca

value of kca

```
//clear//
clear;
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');
```

Scilab code Exa 25.4 carbon needed

`carbon needed`

```
//clear//
clear;
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]
L = 3;

//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
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

Scilab code Exa 26.1 membrane area

membrane area

```
//clear//
clear;
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')
```

Scilab code Exa 26.4 concentration differnce

```
concentration differnce
```

```
//clear//
clear;
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');
```

Scilab code Exa 26.5 pressure drop

pressure drop

```
//clear//
```

```
clear;
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

Scilab code Exa 27.1 kilograms of crystals

`kilograms of crystals`

```
//clear//
clear;
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 = ')
```

Scilab code Exa 27.2 heat evolved

heat evolved

```
//clear//
clear;
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')
```

Scilab code Exa 27.3 plotting

plotting

```
//clear//
clear;
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')
```

Scilab code Exa 27.4 size of nuclues

size of nuclues

```
//clear//
clear;
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) = ');
```

Scilab code Exa 27.5 Total evaporation rate

Total evaporation rate

```
//clear//
clear;
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');
```

Scilab code Exa 27.6 differential mass distribution

differential mass distribution

```
//clear//
clear;
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');
```

Chapter 28

Properties Handling and Mixing of Particulate Soilds

Scilab code Exa 28.1 Fraction of the particle

Fraction of the particle

```
//clear//
clear;
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 =
    [4.699,3.327,2.362,1.651,1.168,0.833,0.589,0.417,0.295,0.208,0.147
```

```
//[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 = ');
```

Scilab code Exa 28.2 sum

sum

```
//clear//
clear;
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

Scilab code Exa 29.1 Power required

Power required

```
//clear//
clear;
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) = ');
```

Scilab code Exa 29.2 length

length

```
//clear//
clear;
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
```

Chapter 30

Mechanical Separations

Scilab code Exa 30.1 Overall Effectiveness

```
Overall Effectiveness
```

```
//clear//
clear;
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) =');
```

Scilab code Exa 30.2 Emperical Equation

Emperical Equation

```
//clear//
clear;
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');
```

Scilab code Exa 30.3 Filter Area

Filter Area

```
//clear//
clear;
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) =');
```

Scilab code Exa 30.4 Plotting

Plotting

```
//clear//
clear;
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 = l+1)
legend('Cf=10,','Cf=20','Cf=40','Cf = 40(Qm = 250/5)' );
```

Scilab code Exa 30.5 Diffusion

Diffusion

```
//clear//
clear;
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) ');
```