Scilab Textbook Companion for Chemical Engineering Thermodynamics by T. E. Daubert[1]

Created by
Ravi Teja Peruru
B.E
Mechanical Engineering
RVR & JC College of engineering
College Teacher
NA
Cross-Checked by
Lavitha Pereira

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Book Description

Title: Chemical Engineering Thermodynamics

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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

Purpose Usefulness and Definitions of Thermodynamics

Scilab code Exa 1.1 Example 1

```
clc
clear
//Initialization of variables
P=2050 //kPa
T=700 //K
E=10 //J
//calculations
Pe=P*10^3 *0.3048^2 /4.4482 /144
Te=T*1.8-460
Ee=E*10^8 /(1055.1)
//results
printf("Temperature = %d F",Te)
printf("\n Pressure = %d lbf/in^2 ",Pe)
printf("\n Energy = %.3e Btu",Ee)
```

Chapter 2

PVT Properties of Fluids Equations of State

Scilab code Exa 2.1 Example 1

```
clc
clear
//Initialization of variables
basis = 1 //kmol n butane
P=1.013*10^5 //N/m^2
R=8.3143*10^3 //J/kmol K
T=272.6 //K
//calculations
V=basis*R*T/P
Ts=373.1 //K
Vs=basis*R*Ts/P
//results
printf("Volume in case 1 = %.2f m^3",V)
printf("\n Volume in case 2 = %.2f m^3",Vs)
```

Scilab code Exa 2.2 Example 2

```
clc
clear
//Initialization of variables
Vb=30 //m^3/kmol
P=1.013*10^5 //Pa
R=8.3143*10^3 //J/kmol K
T=373.1 //K
//calculations
Z=P*Vb/(R*T)
//results
printf("Compressibility factor = %.3f",Z)
```

Scilab code Exa 2.3 Example 3

```
clc
clear
//Initialization of variables
Pc=22.12*10^6 //Pa
Tc=647.3 //K
Vc=0.05697 //m^3/Kmol
R=8.3143*10^3
Tr=0.7
//calculations
Zc=Pc*Vc/(R*Tc)
T=Tr*Tc
Ps=10^6 //Pa
w=-log10(Ps/Pc) -1
//results
printf("critical compressibility factor  = %.3f",Zc)
printf("\n Accentric factor = %.4f",w)
```

Scilab code Exa 2.4.b Example 4b

```
clc
clear
//Initialization of variables
basis= 1 //kmol ammonia
P=10^6 //pa
a=4.19
b=0.0373
R=8314.3
Tc=405.5
Pc=11.28*10^6
//calculations
disp("part b")
an=27*R^2*Tc^2 /(64*Pc)
bn=R*Tc/(8*Pc)
V=3
//results
printf("Since an and bn are same as a and b, V is
    the same = %d m^3/kmol",V)
```

Scilab code Exa 2.4.c Example 4c

```
clc
clear
//Initialization of variables
disp("part c")
disp("USing SRK equation, P= RT/(V-b) -alph*a/(V*(V+
    b))")
disp("By trail and error method,")
//calculations
v2=2.98
//results
printf("volume = %.2f m^3/kmol",v2)
```

Scilab code Exa 2.4 Example 4

```
clc
clear
//Initialization of variables
basis= 1 //kmol ammonia
P=10^6 //pa
a=4.19
b=0.0373
R=8314.3
Tc=405.5
Pc=11.28*10^6
//calculations
disp("case a")
disp("Using vandwerwaals equation, ")
disp("(P+a/v^2)*(V-b) = R*T, on solving by trail and
    error method,")
V=3
printf("Volume = %d m^3/kmol",V)
```

Scilab code Exa 2.5 Example 5

```
clc
clear
//Initialization of variables
Pc=22.12*10^6 //Pa
Tc=647.3 //K
Zc=0.234
T=973.1 //K
P=25*10^6 //Pa
//calculations
Tr=T/Tc
Pr=P/Pc
Z=0.916
Zn=Z+0.05*(Zc-0.27)
```

```
//results
printf("Compresson factor = %.3f ",Zn)
```

Scilab code Exa 2.6 Example 6

```
clc
clear
//Initialization of variables
w=0.3448
Z0=0.898
Z1=0.08
//calculations
Z=Z0 + Z1*w
//results
printf("Compression factor = %.3f ",Z)
```

Chapter 3

Conservation of Energy First law of Thermodynamics

Scilab code Exa 3.1 Example 1

```
clc
//Initialization of variables
clear
mass=4000 //kg/m^2
Patm=1.013*10^5 //pa
g=9.807
M=28
R=8.3143*10^3
T=303 //K
P1=800*10^3 //pa
//calculations
Ps=Patm+mass*g
n=1/M
V1=n*R*T/P1
W=Ps*(2*V1)
//results
printf("Work done on the surroundings = %d J",W)
```

Scilab code Exa 3.2.b Example 2b

```
clc
clear
//Initialization of variables
t1=1000 //K
p1=20 //Mpa
p2=10 //Mpa
ti=600 //K
t2=700 //K
v1=0.02188
vi=0.02008
v2=0.02825
Ei=2617.5
E2=2893.1
E1=3441.8
x=0.22
m=1 //kg
cp=4.186
t3=639 //K
H3=2409.5
H1=3879.3
//calculations
Tf= ti+ (v1-vi)/(v2-vi) *(t2-ti)
Hf=H3 - m*cp*(t3-Tf)
Q2=Hf-H1
//results
disp("part b")
printf("Heat transfer = %.1f kJ/kg",Q2)
```

Scilab code Exa 3.2 Example 2

```
clc
clear
//Initialization of variables
t1=1000 //K
p1=20 //Mpa
p2=10 //Mpa
ti=600 //K
t2=700 //K
v1=0.02188
vi=0.02008
v2=0.02825
Ei=2617.5
E2=2893.1
E1=3441.8
x=0.22
m=1 //kg
cp=4.186
t3=639 //K
H3=2409.5
H1=3879.3
//calculations
Tf= ti+ (v1-vi)/(v2-vi) *(t2-ti)
Ef= Ei+ x*(E2-Ei)
Q1=Ef-E1
//results
disp("part a")
printf("Heat transfer = %.1f kJ/kg",Q1)
```

Scilab code Exa 3.3 Example 3

```
clc
clear
//Initialization of variables
p1=2.181
p2=2.637
```

```
p3=3.163
vg1=0.09150
vg2=0.07585
vg3=0.06323
vl1=0.00118
vl2=0.00120
vl3=0.00122
M=18
t1=490 //K
t2=500 //K
t3=510 //K
R=8.3143
//calculations
lam1= (p2-p1)*10^3 *M*(vg2-vl2) *2.154/ log(t3/t1)
lam2 = log(p3/p1) *R/(1/t1 -1/t3)
err=(lam2-lam1)/lam1
//results
printf("latent heat using calyperon equation = %d kJ
    /kmol",lam1)
printf("\n latent heat using the clasius calyperon
    equation = %d kJ/kmol",lam2)
printf("\n Error = %d percent",err*100)
```

Scilab code Exa 3.4 Example 4

```
clc
clear
//Initialization of variables
h1=147360
h2=29790
//calculations
Hr=h1-h2
//results
printf("heat of reaction = %d kJ/kmol",Hr)
```

Scilab code Exa 3.5 Example 5

```
clc
clear
//Initialization of variables
R=8314.3
T=700 //K
T2=437.5 //K
T3=350 //K
T4=T3
p2=0.552 //Mpa
p1=2.758 //Mpa
cp=29.3
R0=8.3
k=1.4
//calculations
cv=cp-R0
Q1=-R*T*log(p2/p1)
Q2=cv*(T2-T)
dH2= cp*(T2-T)
p3=p2*T3/T2
p3=0.345
Q3=cp*(T3-T2)
dE3=cv*(T3-T2)
W3=Q3-dE3
T5=T4*(p1/p3)^((k-1)/k)
dH4= cp*(T5-T4)
W4=-cv*(T5-T4)
Q5= cp*(T-T5)
dE5=cv*(T-T5)
W5=Q5-dE5
//results
disp("part a isothermal")
printf("dH = 0, dE=0, Q= W = %d kJ/kmol",Q1/10^3)
```

```
disp("part 2 isometric")
printf("dH = %d kJ/kmol, W=0,  Q= dE = %d kJ/kmol",
   dH2,Q2)
disp("part 3 isobaric")
printf("dE = %d kJ/kmol, W= %d kJ/kmol,  Q= dH = %d
   kJ/kmol",dE3,W3,Q3)
disp("part 4 adiabatic")
printf("dH = %d kJ/kmol, W= -dE = %d kJ/kmol,  Q= 0
   kJ/kmol",dH4,W4)
disp("part 5 isobaric")
printf("dE = %d kJ/kmol, W= %d kJ/kmol,  Q= dH = %d
   kJ/kmol",dE5,W5,Q5)
disp("The graph cannot be plotted since volume axis
   values are not known. In the textbook it is
   randomly drawn to be of that shape.")
```

Scilab code Exa 3.6 Example 6

```
clc
clear
//Initialization of variables
p=[2.75 0.5 0.31 0.31 2.75]
v=[116.17 654.8 654.8 597 110.65]
t=[440 440 170 140 410]
h=[3325 3356 2802.6 2738.5 3257.7]
e=[3005.6 3028.6 2602.6 2553.6 2953.4]
//calculations
dh1=h(2) - h(1)
de1=e(2) - e(1)
q2=e(3) - e(2)
dh2=h(3) - h(2)
dh3=h(4) - h(3)
de3=e(4) - e(3)
W3= p(3) *(v(4) - v(3))
Q3= de3+W3
```

```
dh4=h(5)  -h(4)
de4=e(5) -e(4)
dh5=h(1) - h(5)
de5= e(1) - e(5)
W5= p(5) *(v(1) - v(5))
q5 = de5+W5
//results
printf("In case 1 , dH = %.1f kJ/kg dE = %.1f kJ/kg
   W= pDv kJ/kg Q= %.1f + W kJ/kg",dh1,de1,de1)
printf("\n In case 2, W =0 kJ/kg Q = dE = %d kJ/kg
   dH = %.1f kJ/kg",q2,dh2)
printf("\n In case 3, dH= %.1f kJ/kg dE = %.1f kJ/kg
   W= %.1f kJ/kg Q = %.1f kJ/kg",dh3,de3,W3,Q3)
printf("\n In case 4, Q= 0 kJ/kg dH = %.1f kJ/kg dE
   = -W = %.1f kJ/kg",dh4,de4)
printf("\n In case 5, dH = %.1f kJ/kg dE = %.1f kJ/
   kg W = %.1f kJ/kg Q = %.1f kJ/kg",dh5,de5,W5,q5)
xlabel("Volume (m^3/kg)")
ylabel("Pressure (Mpa)")
plot(v,p)
```

Scilab code Exa 3.7 Example 7

```
clc
clear
//Initialization of variables
P=0.1*10^6 //Pa
P2=0.55*10^6 //Pa
M=28.84
R=8314.4
T1=303.1 //K
T2=316.1 //K
d1=0.154 //m
d2=0.028 //m
mass=0.25 //m^3/s
```

```
Q=2.764*10^8 //J/h
cp=29.3*10^3
//calculations
rho1= P*M/(T1*R)
u1=mass/(%pi/4 *d1^2)
rho2= P2*M/(R*T2)
u2=u1*d1^2 *rho1/(d2^2 *rho2)
Wsd= (u2^2 - u1^2 )/2 + cp/M *(T2-T1) + Q/(mass*rho1
    *3600)
mdot= u1*%pi/4 *d1^2 *rho1
Ws=Wsd*mdot/745.7
//results
printf("Power input to the compressor = %d hp",Ws)
```

Scilab code Exa 3.8 Example 8

```
clc
clear
//Initialization of variables
u1=1.1 //m/s
rho1=1.21*10^3 //kg/m^3
d1=0.078
z1=4
h2=18 //m
g=9.806
//calculations
mdot= u1*rho1*%pi/4 *d1^2
Wsd= z1+h2
Ws=Wsd*mdot*g
dP= Ws*rho1/mdot
//results
printf("Power input = %d W",Ws)
printf("Pressure drop = %.3f Mpa",dP/10^6)
```

Scilab code Exa 3.9 Example 9

```
clc
clear
//Initialization of variables
eff=0.75
Hf=[-110600 -241980 -393770 0]
Hc=[30.35 36 45.64 29.30]
T2=540 //C
T1=25 //C
mass=500 //kmol H2 produced
//calculations
dHr= Hf(3) + Hf(4) - Hf(1) -Hf(2)
dHpr= (eff*(Hc(3) +Hc(4)) + (1-eff)*(Hc(2)+Hc(1)))*(
    T2-T1)
q= dHr*eff +dHpr
heat = q*mass/eff
//results
printf("Heat produced = %.3e kJ",heat)
```

Scilab code Exa 3.10 Example 10

```
clc
clear
//Initialization of variables
eff=0.75
Hf=[-110600 -241980 -393770 0]
Hc=[30.35 36 45.64 29.30]
T2=540 //C
T1=25 //C
mass=500 //kmol H2 produced
work=10^6 //kJ
```

```
//calculations
dHr= Hf(3) + Hf(4) - Hf(1) -Hf(2)
dHpr= (eff*(Hc(3) +Hc(4)) + (1-eff)*(Hc(2)+Hc(1)))*(
    T2-T1)
q= dHr*eff +dHpr
heat = q*mass/eff
qe=heat-work
//results
printf("Heat produced = %.3e kJ",qe)
```

Scilab code Exa 3.11 Example 11

```
clc
clear
//Initialization of variables
so3=6
h2=-296840 //kJ/kmol
h3=-395720 //kJ/kmol
t2=400 //C
t1=25 //C
//calculations
Hr=so3*(h3-h2)
cp=[1.059 0.967 0.714]
n=[82.76 11 8]
M=[28 32 64]
Ht= sum(cp.*n.*M)
Hre=Ht*(t2-t1)
Hpr=Hre-Hr
Tf=t1 + Hpr/3261.6
//results
printf("temperature of exit gases = %d C",Tf)
```

Scilab code Exa 3.12 Example 12

```
clc
clear
//Initialization of variables
x=0.25
Hr=1.4278*10^6 //kJ/kmol
ti=25 //C
cp=[1.24 2.39 1.11]
M=[44 18 32]
z=[12 3 0.5]
r=4.186
//calculations
v=cp.*M.*z
v2=sum(v)
T=ti+ Hr/(v2)
//results
printf("Theoretical temperature = %d C",T)
```

Chapter 4

The Second Law of Thermodynamics and its Applications

Scilab code Exa 4.1 Example 1

```
clc
clear
//Initialization of variables
T=500 //K
Qr=5*10^6 //kJ
T2=600 //K
//calculations
dSS=Qr/T
dSS2=-Qr/T2
Ds=dSS+dSS2
//results
printf("Entropy change of the system = %d kJ/K",dSS)
printf("\n Entropy change of the surroundings = %d
   kJ/K",dSS2)
printf("\n Entropy change if the universe = %d kJ/K"
   ,Ds)
```

Scilab code Exa 4.2 Example 2

```
clc
clear
//Initialization of variables
p1=2.758 //Mpa
p2=0.552 //Mpa
T1=700 //K
T2=700 //K
n=1
R=8.3143
Cv=21
Cp=29.3
//calculations
dsa=n*R*log(p1/p2)
T3=437.5 //K
dsb=Cv*log(T3/T2)
T4=350 //K
dsc=Cp*log(T4/T3)
T5=634 //K
dsd=0
T6=700 //K
dse=Cp*log(T6/T5)
dstotal=dsa+dsb+dsc+dsd+dse
//results
printf("Entropy change in case a = %.3f kJ/kmol K",
   dsa)
printf("\n Entropy change in case b = %.3f kJ/kmol K
   ",dsb)
printf("\n Entropy change in case c = %.3f kJ/kmol K
   ",dsc)
printf("\n Entropy change in case d = %.3f kJ/kmol K
   ",dsd)
printf("\n Entropy change in case e = %.3f kJ/kmol K
```

```
    ",dse)
printf("\n Entropy change in total process = %.3f kJ
    /kmol K",dstotal)
```

Scilab code Exa 4.3 Example 3

```

clc
clear
//Initialization of variables
ratio=1/2
R=8.314
p1=0.5 //kPa
p2=0.1 //kPa
//calculations
ya=ratio/(1+ratio)
ds=-ya*R*log(ya) - (1-ya)*R*log(1-ya)
dss=R*log(p1/p2)
//results
printf("Entropy of mixing = %.3f kJ/kmol K",ds)
printf("\n Total entropy change of the universe = %
    .2f kJ/kmol K",dss)
```

Scilab code Exa 4.4 Example 4

```
clc
clear
//Initialization of variables
s1=7.096 //kJ/kg K
s2=7.915  //kJ/kg K
s3=7.16  //kJ/kg K
s4=7.014  //kJ/kg K
s5=6.999  //kJ/kg K
```

```
//calculations
dsa=s2-s1
dsb=s3-s2
dsc=s4-s3
dsd=s5-s4
dse=s1-s5
dstotal=dsa+dsb+dsc+dsd+dse
//results
printf("Change in entropy in process a =%.3f  kJ/kg
   K",dsa)
printf("\n Change in entropy in process b =%.3f  kJ/
   kg K",dsb)
printf("\n Change in entropy in process c =%.3f  kJ/
   kg K",dsc)
printf("\n Change in entropy in process d =%.3f  kJ/
   kg K",dsd)
printf("\n Change in entropy in process e =%.3f  kJ/
   kg K",dse)
printf("\n Change in entropy in total process  =%.3f
     kJ/kg K",dstotal)
```

Scilab code Exa 4.5 Example 5

```
clc
clear
//Initialization of variables
m1=5000 //kg/h
cp1=3.2 //kJ/kg K
cp2=4.186 //kJ/kg K
t1=220 //C
t2=30 //C
T1=210 //C
T2=20 //C
//calculations
m2=m1*cp1*(t1-t2)/(cp2*(T1-T2))
```

```
ds=m1*cp1*log((t2+273.1)/(t1+273.1)) + m2*cp2*log((
   T1+273.1)/(T2+273.1))
//results
printf("Change in entropy = %d kJ/h K",ds)
```

Scilab code Exa 4.6 Example 6

```

clc
clear
//Initialization of variables
s1=218.8 //kJ/kmol K
s2=188.85 //kJ/kmol K
s3=237.8 //kJ/kmol K
s4=205.2 //kJ/kmol K
//calculations
ds=s1+s2-s3-0.5*s4
//results
printf("Entropy change  = %.2f kJ/kmol K",ds)
```

Scilab code Exa 4.7 Example 7

```
clc
clear
//Initialization of variables
Q=6 //kJ/kg
p1=1.5 //Mpa
p2=0.1 //Mpa
t1=500 //C
t2=140.8 //C
h1=3473.1 //kJ
h2=2758.1 //kJ
s1=7.5698 //kJ/K
```

```
s2=7.5698 //kJ/K
eff=0.85
Ts=293.1 //K
//calculations
Wideal=h2-h1
Ws=eff*Wideal
dH=-Q-Ws
H2=h1+dH
S2=7.8005
ds=S2-s1
Wlost=Ts*ds+Q
//results
printf("lost work = %.1f kJ",Wlost)
```

Scilab code Exa 4.8 Example 8

```
clc
clear
//Initialization of variables
m=5000 ///kg/h
cp=3.2 //kJ/kg K
Ts=30+273.1 //K
t1=220 //C
t2=40 //C
Q=2.88*10^6 //kJ
//calculations
Q=m*cp*(t2-t1)
dss=m*cp*log((t2+273.1)/(t1+273.1))
Wlost=Ts*dss-Q
eff=Ts*dss/Q
//results
printf("Lost work = %d kJ",Wlost)
printf("\n Efficiency = %.3f",eff)
```

Scilab code Exa 4.9 Example 9

```
clc
clear
//Initialization of variables
R=8.314
cp=35.58
n=100/16
T1=300 //K
T2=500 //K
k=1.305
P2=3 //Mpa
P1=0.5 //Mpa
Ts=290 //K
//calculations
cv=cp-R
Wi=n*R*T1/(k-1) *((P2/P1)^((k-1)/k) -1)
Hi=Wi
Ha=n*cp*(T2-T1)
eta=abs(Hi/Ha)
dss1=cp*log(T2/T1) - R*log(P2/P1)
Wl1=Ts*dss1
dss2=n*cp*log(T2/T1)
dss3=abs(Ha/Ts)
dsst=dss2+dss3
Wl2=-Ts*dss2 +Ha
Wlost=Wl1+Wl2
//results
printf("Thermodynamic efficiency = %.3f",eta)
printf("\n Net work lost = %d kJ",Wlost)
```

Scilab code Exa 4.10 Example 10

```
clc
clear
//Initialization of variables
T1=673 //K
T2=293 //K
//calculations
eta=(T1-T2)/T1
//results
if eta>=0.5 then
    printf("Max efficiency  = %.3f and an efficiency
        of 0.5 is possible",eta)
else
    printf("Max efficiency  = %.3f and an efficiency
        of 0.5 is not possible",eta)
end
```

Scilab code Exa 4.11 Example 11

```
clc
clear
//Initialization of variables
T1=280 //K
T2=300 //K
//calculations
cop=T1/(T2-T1)
//results
printf("coefficient of performance = %.1f",cop)
```

Scilab code Exa 4.12 Example 12

```
clc
clear
//Initialization of variables
```

```
P=2 //Mpa
T1=212.4+273.1 //K
T2=25+273.1 //K
h1=2799.5
h2=104.89
s1=6.3409
s2=0.3674
//calculations
dh=h1-h2
ds=s1-s2
exergy=dh-T2*ds
//results
printf("exergy = %.1f kJ/kg",exergy)
```

Scilab code Exa 4.13 Example 13

```
clc
clear
//Initialization of variables
R=8314.3
T=700 //K
T2=437.5 //K
T3=350 //K
T4=T3
p2=0.552 //Mpa
p1=2.758 //Mpa
p3=0.345 //Mpa
cp=29.3
R0=8.3143
k=1.4
n=1
P0=0.103 //Mpa
//calculations
cv=cp-R0
p3=p2*T3/T2
```

```
p3=0.345
T5=T4*(p1/p3)^((k-1)/k)
G1=n*R*T*log(p2/p1)
V700=R*10^3 *T/(p2*10^9)
Sa= 209
Sb=199.2
Sc=204.7
S2=(T2-T)/6 *(Sa+4*Sc+Sb     )
G2=V700*(p3-p2)*10^3 -S2
saa=199.2
sbb=192.6
savg=(saa+sbb)*0.5
G3=-savg*(T3-T2)
pmid=(p3+p2)/2
vmid=2.88
sav=192.7
v4=8.435 //m^3
v5=1.911 //m^3
integ=(p1-p3)*10^3 /6 *(v4+4*vmid+v5)
G4=integ - sav*(T5-T3)
Sav=194.25
G5= -Sav*(T-T5)
Gt=G1/10^3 +G2+G3+G4+G5
//results
printf("in case 1, Change in gibbs free energy = %d
   kJ",G1/10^3)
printf("\n in case 2, Change in gibbs free energy =
   %d kJ",G2)
printf("\n in case 3, Change in gibbs free energy =
   %d kJ",G3)
printf("\n in case 4, Change in gibbs free energy =
   %d kJ",G4)
printf("\n in case 5, Change in gibbs free energy =
   %d kJ",G5)
printf("\n Net change in gibbs energy = %d kJ",Gt)
```

Scilab code Exa 4.14 Example 14

```
clc
clear
//Initialization of variables
v=1/430
pi=4.08 //Mpa
pf=10 //Mpa
pf2=1 //Mpa
pii=0.1 //Mpa
R=8314.3
n=1/28
T=273.1
//calculations
logpr=v*(pf-pii)*10^6 /(R*T*n)
pr=exp(logpr)
p=pr*pi
logpr=v*(pf2-pii)*10^6 /(R*T*n)
pr=exp(logpr)
p2=pr*pi
//results
printf("Final pressure = %.2f Mpa",p)
printf("\n Final pressure in case 2 = %.2f Mpa",p2)
```

Scilab code Exa 4.15 Example 15

```
clc
clear
//Initialization of variables
Hvap=338.14 //kJ/kg
T=409.3 //K
```

```
//calculations
dss=Hvap/T
dg=0
//results
printf("change in entropy and gibbs energy of system are %.3f kJ/kg K and %d kJ/kg respectivey",dss,dg)
printf("\n change in entropy and gibbs energy of universe are %.3f kJ/kg K and %d kJ/kg respectivey",-dss,-dg)
```

Scilab code Exa 4.16 Example 16

```
clc
clear
//Initialization of variables
T=373.1 //K
R=8314.3
Pd=0.1013*10^6 //Pa
P=10 //Mpa
p3=5*10^6 //Pa
vf=0.0373
a=424.447
//calculations
Vd=R*T/Pd
V=0.5
dss=-R*(log(p3/Pd) + log((V-vf)/(Vd-vf)))
dhh=R*T/10^3 - p3/10^3 *V+ a/V^2
//results
printf("Change in entropy = %.4f kJ/kmol K",dss/10^3)
printf("\n change in enthalpy= %d kJ/kmol",dhh)
```

Scilab code Exa 4.18 Example 18

```
clc
clear
//Initialization of variables
Tc=647.3 //K
dh=1.1
Db=-2
v2=0.234
v1=0.27
//calculations
dh2=dh+Db*(v2-v1)
dhh=dh2*Tc
dhbar=dhh*4.18/18
disp("From steam tables,")
h1=3777.5 //kJ/kg
h2=3928.2 //kJ/kg
dhs=h2-h1
err=abs(dhs-dhbar)/dhs
//results
printf("Enthalpy departure = %d kJ/kg",dhbar)
printf("\n Percentage error = %.1f ",err*100)
```

Scilab code Exa 4.19 Example 19

```
clc
clear
//Initialization of variables
w=0.3448
R=8.3143
Tc=647.3
//calculations
disp("From charts of entropy")
h0=0.57
h1=0.05
```

```
h2=h0+w*h1
h3=h2*R*Tc
dh=-h3
//results
printf("Enthalpy departure = %d kJ/kmol",dh)
disp("The answer is a bit different due to rounding
   off error in the textbook")
```

Scilab code Exa 4.20 Example 20

```
clc
clear
//Initialization of variables
ta=310 //K
pa=80 //kPa
r=10
k=1.4
R=8.3143
n=5/29
cv=20.93
//calculations
Qab=0
tb=ta*r^(k-1)
va=R*ta/pa
vb=va/r
pb=R*tb/vb
Wab= -n*R*ta/(k-1) *((pb/pa)^((k-1)/k) -1)
vc=vb
Qbc=500 //kJ
Wbc=0
tc=tb+ Qbc/(n*cv)
pc=R*tc/vc
Qcd=0
td=tc/r^(k-1)
vd=va
```

```
pd=td/tc*(vc/vd)*pc
Wcd=-n*R*tc/(k-1) *((pd/pc)^((k-1)/k)-1)
Wda=0
Qda=n*cv*(ta-td)
eta0=1-1/r^(k-1)
//results
printf("Efficiency of cycle = %.3f",eta0)
p=[pa pb pc pd]
t=[ta tb tc td]
Q=[Qab Qbc Qcd Qda]
W=[Wab Wbc Wcd Wda]
disp('Pressure (kPa) = ')
format('v',6);p
disp(p)
disp("Temperature (K)= ")
format('v',6);t
disp(t)
disp("Heat (kJ)= ")
format('v',6);Q
disp(Q)
disp("Work done (kJ) = ")
format('v',6);W
disp(W)
```

Scilab code Exa 4.21 Example 21

```
clc
clear
//Initialization of variables
ta=310 //K
tc=917.3 //K
td=365.2 //K
n=0.602
k=1.4
//calculations
```

```
lntb= 1/(1-n)/k
tb=tc- lntb*(td-ta)
rc=(tb/ta)^(1/(k-1))
//results
printf("Temperature at B = %.1f K",tb)
printf("\n Compression ratio = %d ",rc)
disp("The answer given in textbook for rc is wrong.
   please check using a calculator")
```

Scilab code Exa 4.22 Example 22

```
clc
clear
//Initialization of variables
pr=4
k=1.4
ta=298 //K
pa=0.1 //Mpa
pdr=0.01
tc=900 //K
pri=0.005 //Mpa
//calculations
pb=pr*pa
nji=1- (pr)^((1-k)/k)
tb=ta*(pb/pa)^((k-1)/k)
pc=pb-pdr
pd=pa+pri
td=tc*(pd/pc)^((k-1)/k)
//results
p=[pa pb pc pd]
t=[ta tb tc td]
printf("ideal thermal efficiency = %.3f ",nji)
disp("pressure (Mpa) = ")
format('v',6);p
disp(p)
```

```
disp("temperature (K) = ")
format('v',6);t
disp(t)
```

Scilab code Exa 4.23.a Example 23a

```
clc
clear
//Initialization of variables
sd=4.9269//kJ/kg/K
sf=1.1453//kJ/kg/K
sg=7.5320//kJ/kg/K
hf=359.86//kJ/kg
hg=2653.5//kJ/kg
hd=2409.7//kJ/kg
//calculations
x=(sd-sg)/(sf-sg)
he=x*hf+(1-x)*hg
etar=(hd-he)/(hd-hf)
//results
printf("Thermal efficiency = %.4f",etar)
```

Scilab code Exa 4.23.b Example 23b

```
clc
clear
//Initialization of variables
sd=6.7039//kJ/kg/K
sf=1.1453//kJ/kg/K
sg=7.5320//kJ/kg/K
hf=359.86//kJ/kg
hg=2653.5//kJ/kg
hd=3717.9//kJ/kg
```

```
//calculations
x=(sd-sg)/(sf-sg)
he=x*hf+(1-x)*hg
etar=(hd-he)/(hd-hf)
//results
printf("Thermal efficiency = %.4f",etar)
```

Scilab code Exa 4.24 Example 24

```
clc
clear
//Initialization of variables
ha=2510.6 //kJ/kg
hd=125.78 //kJ/kg
//calculations
kg=(10^6)/(ha-hd)
//results
printf("circulation rate = %d kg steam/h",kg)
```

Scilab code Exa 4.25 Example 25

```
clc
clear
//Initialization of variables
tin=298 //K
tout=273 //K
tout2=308 //K
tin2=294 //K
//calculations
eta1=(tin-tout)/tin
eta2=abs((tin2-tout2)/tin2)
//results
printf("Efficiency in case 1 = %.3f",eta1)
```

```
printf("\n efficiency in case 2 = %.3f",eta2)
```

Scilab code Exa 4.26 Example 26

```
clc
clear
//Initialization of variables
ma=500 //kg/h
cp1=3.2 //kJ/kg K
ta=20 //C
mb=200
mc=300 //kg/h
cp2=2.8 //kJ/kg K
tc=80 //C
tb=80 //C
me=50 //kg/h
te=120 //C
td=120 //C
hg=503.7
he=2706.3
//calcualtions
Ws=(mb+me)*hg + mc*cp2*(tc) - me*he -ma*cp1*(ta)
//results
printf("Net work done = %d kJ/h",Ws)
```

Scilab code Exa 4.27 Example 27

```
clc
clear
//Initialization of variables
hc=150 //Btu/lb
he=-115 //Btu/lb
hg=168 //Btu/lb
```

```
//calculations
frac=(hg-hc)/(hg-he)
//results
printf("Fraction of solid = %.3f",frac)
```

Scilab code Exa 4.28 Example 28

```
clc
clear
//Initialization of variables
H=2696.5 //kJ/kg
hg=2706.7 //kJ/kg
hf=504.7 //kJ/kg
//calculations
x= (H-hf)/(hg-hf)
x2=1
//results
printf("In case 1, fraction of vapor = %.3f",x)
printf("\n In case 2, fraction of vapor = %.3f",x2)
```

Chapter 5

Relationships among Thermodynamic Properties Graphical Representation of properties and processes

Scilab code Exa 5.5 Example 5

```

clc
clear
//Initialization of variables
R=8314.3
b=0.0306 //m^3/kmol
a=0.548*10^6 //pa m^6/kmol^6
T=973.1
P=25*10^6 //Pa
//calculations
Vi= R*T/P
x=poly(0,'x')
vec=roots(P*x^2 *(x-b) +a*(x-b) - R*T*(x^2))
volume= vec(1)
dH=8.0906*10^6 -P*volume +0.548*10^6 /volume
```

```
//results
printf("Change in enthalpy  = %.2e J/kmol",dH)
```

Chapter 7

Solution Properties and Physical Equilibria

Scilab code Exa 7.2 Example 2

```
clc
clear
//Initialization of variables
T=154.5 //C
P=8620*10^3 //Pa
Tc=135 //C
T0=273.1 //C
Pc=3648*10^3 //Pa
w=0.1756
V=0.154
R=8.3143*10^3
//calculations
Tr=(T+T0)/(T0+Tc)
Pr= P/Pc
Z=P*V/(R*(T+T0))
a= 0.42747*R^2 *(Tc+T0)^2 /Pc *(1+ (0.48508 +
   1.55171*w - 0.15613*w^2)*(1-sqrt(Tr)))^2
b=0.08664*R*(Tc+T0)/Pc
A= a*P/(R^2 *(T+T0)^2)
```

```
B=b*P/(R*(T+T0))
lnphi= (Z-1) - log(Z-B) - A/B *log((Z+B)/Z)
phi=exp(lnphi)
f=phi*P
//results
printf("fugacity = %d kPa",f/10^3)
//The answer is a bit different due to rounding off
   error in textbook
```

Scilab code Exa 7.3 Example 3

```
clc
clear
//Initialization of variables
T=154.5 //C
P=8620*10^3 //Pa
Tc=135 //C
T0=273.1 //C
Pc=3648*10^3 //Pa
w=0.1756
V=0.154
R=8.3143*10^3
D=0.35
Vc=0.263 //m^3/kmol
//calculations
Tr=(T+T0)/(T0+Tc)
Pr= P/Pc
Zc=Pc*Vc/(R*(Tc+T0))
phi1=0.44
phi2=phi1*10^(D*(Zc-0.27))
f=phi2*P
//results
printf("fugacity = %d kPa",f/10^3)
```

Scilab code Exa 7.4 Example 4

```
clc
clear
//Initialization of variables
f0=0.7

V=5.1e-2
P1=0.77 //Mpa
P2=10 //Mpa
R=8.3143*10^3
T=298 //K
//calculations
lnr= V/(R*T) *(P2-P1)*10^6
f=exp(lnr) *f0
//results
printf("Fugacity = %.3f Mpa",f)
```

Scilab code Exa 7.5 Example 5

```
clc
clear
//Initialization of variables
Pt=0.1013
ya=0.605
P1=0.1373
P2=0.06
xa=0.4
//calculations
if ya*Pt == xa*Pt & (1-ya)*Pt == (1-xa)*Pt then
    printf("The system is ideal")
else
```

```
    printf("The system is not ideal")
end
```

Scilab code Exa 7.6 Example 6

```
clc
clear
//Initialization of variables
Y=0.06
X=0.0012
P=2.53 //Mpa
//calculations
y=Y/(1+Y)
x=X/(1+X)
H=y*P/x
//results
printf("Henrys law constant = %.2f Mpa",H)
```

Scilab code Exa 7.7 Example 7

```
clc
clear
//Initialization of variables
Hi=55
Pi=11.8
xi=0.514
H2=18.1
H3=26.9
Pi2=17.4
//calculations
ai=Pi/Hi
gam=ai/xi
a2=Pi/H2
```

```
gam2=a2/xi
a3=Pi2/H3
gam3=a3/(1-xi)
//results
disp("part a")
printf("Activity of acetic acid = %.4f ",ai)
printf("\n Activity coefficient  = %.4f ",gam)

disp("part b")
printf("Activity of acetic acid = %.4f ",a2)
printf("\n Activity coefficient  = %.4f ",gam2)

disp("part c")
printf("Activity of toluene = %.4f ",a3)
printf("\n Activity coefficient  = %.4f ",gam3)
```

Chapter 8

Physical Equilibria among Phases

Scilab code Exa 8.1 Example 1

```
clc
clear
//Initialization of variables
function V = func(C,phi)
    V=C+2-phi
endfunction
//calculations and results
disp("part a")
printf("degrees of freedom = %d ",func(2,2))
disp("part b")
printf("degrees of freedom = %d ",func(3,2))
disp("part c")
printf("degrees of freedom = %d ",func(3,3))
```

Scilab code Exa 8.2 Example 2

```
clc
clear
//Initialization of variables
T=95 //C
P=1013 //kPa
Tc=135 //C
Pc=3648 //kPa
T0=273.1 //C
D=0.3
P0=1800 //kPa
D2=0.42
//calculations
Zc=0.283
Tr=(T+T0)/(Tc+T0)
Pr=P/Pc
phic=0.88
phi2=phic*10^(D*0.013)
Prd= P0/Pc
phi3=0.78
phi4= phi3*10^(D2*0.013)
gl= phi2*P/(phi3*P0)
//results
printf("equation is gl = %.3f *(y/x)",gl)
```

Scilab code Exa 8.3 Example 3

```
clc
clear
//Initialization of variables
ye=0.434
Pt=40.25 //kPa
xe=0.616
Pe1=22.9 //kPa
Pe2=29.6 //kPa
//calculations
```

```
ge= ye*Pt/(xe*Pe1)
gb=(1-ye)*Pt/((1-xe)*Pe2)
E= log10(ge) *(1+ (1-xe)*log(gb) /(xe*log(ge)))^2
B= log10(gb) *(1+ xe/(1-xe) *log(ge) /log(gb))^2
xe2=0.4
xb2=0.6
lnge2=E/(1+ E*xe2/(B*xb2))^2
lngb2=B/(1+ B*xb2/(E*xe2))^2
ge2=10^(lnge2)
gb2=10^(lngb2)
Pt1=ge2*Pe1
Pt2=gb2*Pe2
//results
printf("Total pressure in case 1  = %.2f kPa and in
   case 2 = %.2f kPa",Pt1, Pt2 )
```

Scilab code Exa 8.4 Example 4

```
clc
clear
//Initialization of variables
k4=1.8
k5=0.8
//calculations
A=[k4 k5;1 1]
b=[1; 1]
C=A\b
x4=C(1)
x5=C(2)
y4=k4*x4
y5=k5*x5
//results
printf("Vapor and liquid mole fractions of component
    1 = %.2f and %.2f respectively",y4,x4)
printf("\n Vapor and liquid mole fractions of
```

```
component 2 = %.2f and %.2f respectively",y5,x5)
```

Scilab code Exa 8.5 Example 5

```
clc
clear
//Initialization of variables
v1=81 //cm^3/gmol
v2=97 //cm^3/gmol
d1=9.2 //(cal/cm^3)^0.5
d2=8.6 //(cal/cm^3)^0.5
R=1.987
T=373.1 //K
//calculations
d=0.5*(d1+d2)
lng1=v1*(d1-d)^2 /(R*T)
lng2=v2*(d2-d)^2 /(R*T)
g1=exp(lng1)
g2=exp(lng2)
//results
printf("Activity coeffecients of components are %.3f
    and %.3f respectively",g1,g2)
```

Scilab code Exa 8.6 Example 6

```
clc
clear
//Initialization of variables
xe=0.3
xe2=0.9
Pe0=810
Pa0=470
ge=1.85
```

```
ge2=1.05
ga=1.15
ga2=3
Pt=820 //mm
Pt2=900 //mm
//calculations
ye=ge*xe*Pe0/Pt
ya=ga*(1-xe)*Pa0/Pt
yt=ye+ya
ye2=ye/yt
ya2=ya/yt
ye3=ge2*xe2*Pe0/Pt2
ya3=ga2*(1-xe2)*Pa0/Pt2
yt2=ye+ya
ye4=ye3/yt2
ya4=ya3/yt2
//results
printf("In case 1, ye = %.3f and ya = %.3f",ye2,ya2)
printf("\n In case 1, ye = %.3f and ya = %.3f",ye4,ya4)
disp('The calculations of ya in case 1 in textbook is wrong. please use a calculator')
```

Scilab code Exa 8.7 Example 7

```
clc
clear
//Initialization of variables
m1=121
m2=18
p1=0.0042
p2=0.0858
//calculations
massfrac= (p1*m1)/(p1*m1+p2*m2)
//results
```

```
printf("mass fractions of DMA and water are %.3f and %.3f respectively",massfrac,1-massfrac)
```

Scilab code Exa 8.9 Example 9

```
clc
clear
//Initialization of variables
FR=25
FE=19
bf=130 //kg
af=85 //kg
//calculations
law=FR/FE
x1=45/150
x2=65/150
ER=18.5/6
e=[0.5 0.1 0.9]
r=[0.28 0.96 0.04]
et=sum(e)
rt=sum(r)
ett=e/et
rtt=r/rt
//results
disp("the compositions of raffinate are ")
disp(rtt)
disp("the compositions of extract are")
disp(ett)
```

Scilab code Exa 8.10.a Example 10a

```
clc
clear
```

```
//Initialization of variables
v1=0.1316
v2=0.2941
x1=0.5
x2=0.2
x3=0.8
d1=14.87
d2=16.34
//calculations and results
vm=x1*(v1+v2)
phi1=x1*v1/vm
phi2=(1-x1)*v2/vm
Hl1=vm*phi1*phi2*(d1-d2)^2 *10^3
disp("case 1")
printf("enthalpy = %.1f kJ/mol",Hl1)
```

Scilab code Exa 8.10.b Example 10b

```
clc
clear
//Initialization of variables
v1=0.1316
v2=0.2941
x1=0.5
x2=0.2
x3=0.8
d1=14.87
d2=16.34
//calculations and results
vm=(1-x2)*v1+x2*v2
phi1=(1-x2)*v1/vm
phi2=(x2)*v2/vm
Hl2=vm*phi1*phi2*(d1-d2)^2 *10^3
disp("case 2")
printf("enthalpy = %.1f kJ/mol",Hl2)
```

Scilab code Exa 8.10.c Example 10c

```
clc
clear
//Initialization of variables
v1=0.1316
v2=0.2941
x1=0.5
x2=0.2
x3=0.8
d1=14.87
d2=16.34
//calculations and results
vm=(1-x3)*v1+x3*v2
phi1=(1-x3)*v1/vm
phi2=(x3)*v2/vm
H13=vm*phi1*phi2*(d1-d2)^2 *10^3
disp("case 3")
printf("enthalpy = %.1f kJ/mol",H13)
```

Chapter 9

Chemical Equilibria

Scilab code Exa 9.1.a Example 1a

```
clc
clear
//Initialization of variables
g11=178900 //kJ/kmol
g12=207037 //kJ/kmol
g21=211852 //kJ/kmol
g22=228097 //kJ/kmol
//calculations
dG=g21-g11
//results
printf("Standard free energy change = %d kJ/kmol",dG
    )
```

Scilab code Exa 9.1.b Example 1b

```
clc
clear
//Initialization of variables
```

```
m1=54.1
m2=56.1
m3=2
cp1=2.122 //kJ/kmol K
cp2=2.213 //kJ/kmol K
cp3=14.499 //kJ/kmol K
hf1=110200 //kJ/kmol
hf2=-126 //kJ/kmol
T=700 //K
Ts=298 //K
//calculations
hf=hf1-hf2
cpn=cp1*m1-cp2*m2+cp3*m3
h700=hf+ cpn*(T-Ts)
s298=103.7
s700 = s298 + cpn*log(T/Ts)
G700=h700-T*s700
//results
printf("Change in gibbs energy = %d kJ/kmol",G700)
disp("The answer is a bit different due to rounding
    off error in textbook")
```

Scilab code Exa 9.2 Example 2

```
clc
clear
//Initialization of variables
g1=150670 //kJ/kmol
g2=71500 //kJ/kmol
R=8.314
Ts=298 //K
T=700 //K
//calculationd
G=g1-g2
G2=33875 //kJ/kmol
```

```
K1=exp(-G/R/Ts)
K2=exp(-G2/R/T)
//results
printf("In case 1, equilibrium constant = %.2e",K1)
printf("\n In case 2, equilibrium constant = %.5f",
   K2)
```

Scilab code Exa 9.3 Example 3

```
clc
clear
//Initialization of variables
R=8.3143
T1=1273 //K
T2=2273 //K
k2=0.0018
A=123.94
B=7.554
C=8.552*10^-3
D=-13.25e-6
E=7.002e-9
F=13.494e-13
//calculations
function y= cp(T)
    y=A/T^2 +B/T +C +D*T +E*T^2 -F*T^3
endfunction
lnk=1/R *intg(T1,T2,cp)
k1=k2/ exp(lnk)
//results
printf("Equilibrium constant = %.5f ",k1)
```

Scilab code Exa 9.4.a Example 4a

```
clc
clear
//Initialization of variables
G=-30050 //kJ/kmol
R=8.314
T=573 //K
//calculations
lnk=G/(R*T)
k=exp(lnk)
x=poly(0,"x")
vec=roots(4*x^2 - k*(1-x)^2)
x2=vec(2)
//results
printf("Mole fraction of HCN = %.4f",x2)
```

Scilab code Exa 9.4.b Example 4b

```
clc
clear
//Initialization of variables
G=-30050 //kJ/kmol
R=8.314
T=573 //K
phi1=0.980
phi2=0.915
phi3=0.555
//calculations
lnk=G/(R*T)
k=exp(lnk)
kexp= k*phi1*phi2/phi3^2 /4
x=poly(0,"x")
vec=roots(x^2 - kexp*(1-x)^2)
x2=vec(2)
//results
printf("Mole fraction of HCN = %.4f",x2)
```

Scilab code Exa 9.5 Example 5

```
clc
clear
//Initialization of variables
kp=74
//calculations
f=poly(0,"f")
vec=roots(f^2 *(100-6*f) - kp^2 *(1-f)^2 *(9-6*f))
fn=vec(3)
//results
printf("Fractional conversion = %.3f",fn)
```

Scilab code Exa 9.6.a Example 6a

```
clc
clear
//Initialization of variables
C=3
phi=3
R=1
Sc=0
function V=fun(C,phi,R,Sc)
    V=2+C-phi-R-Sc
endfunction
//calculations
V=fun(C,phi,R,Sc)
//results
printf("Degrees of freedom = %d ",V)
```

Scilab code Exa 9.6.b Example 6b

```
clc
clear
//Initialization of variables
C=3
phi=1
R=1
Sc=1
function V=fun(C,phi,R,Sc)
    V=2+C-phi-R-Sc
endfunction
//calculations
V=fun(C,phi,R,Sc)
//results
printf("Degrees of freedom = %d ",V)
```

Scilab code Exa 9.6.c Example 6c

```
clc
clear
//Initialization of variables
C=6
phi=1
R=3
Sc=0
function V=fun(C,phi,R,Sc)
    V=2+C-phi-R-Sc
endfunction
//calculations
V=fun(C,phi,R,Sc)
//results
printf("Degrees of freedom = %d ",V)
```

Scilab code Exa 9.7 Example 7

```
clc
clear
//Initialization of variables
a1=0.956
y=0.014
x=0.956
M=18
z=0.475
P=8.37 //Mpa
//calculations
m=y/(x*M) *10^3
w=0.0856
phi1=-0.04
phi2=0.06
phi=10^(phi1+ w*phi2)
f=z*phi*P
K=m/(f*a1)
//results
printf("Equilibrium constant = %.3f",K)
```

Scilab code Exa 9.9 Example 9

```
clc
clear
//Initialization of variables
y=0.18
z=0.6
//calculations
mole=[1-y-z 5-y-2*z y 3*y+4*z z]
s=sum( mole)
```

```
molef=mole/s
//results
disp("Product composition moles = ")
format('v',6);mole
disp(mole)
disp("Mole fraction = ")
format('v',6);molef
disp(molef)
```

Scilab code Exa 9.10.a Example 10a

```
clc
clear
//Initialization of variables
kp=1.09
feed=[ 1 5 0 0 0 ]
//calculations
x=poly(0,"x")
vec=roots(kp/4^4 /4 *(1-x)*(5-2*x)^2 *(6+2*x)^2 -x
    ^5)
x=vec(5)
pro=[1-x 5-2*x x 4*x 0]
//results
disp("Equlibrium composition (moles)= ")
format('v',6);pro
disp(pro)
```

Scilab code Exa 9.10.b Example 10b

```
clc
clear
//Initialization of variables
kp=1.09
```

```
kp2=0.154
feed=[ 1 5 0 0 0 ]
//calculations
x=poly(0,"x")
vec=roots(kp/4^4 /4 *(1-x)*(5-2*x)^2 *(6+2*x)^2 -x^5)
x=vec(5)
pro=feed- [x 2*x -x -4*x 0]
y=poly(0,"y")
vec2=roots(kp2*(0.273-y)*(0.727-y)*(7.454+2*y)^2 -4*y^2 *(2.908+2*y)^2 *4)
y=vec2(4)
pro2=pro-[ y 0 y -2*y -2*y]
z=poly(0,"z")
vec3= roots(kp*(0.189-z)*(3.546-2*z)^2 *(7.622+2*z)^2 -(0.643+z)*(3.076+4*z)^4 *4)
z=vec3(5)
pro3=pro2 - [z 2*z -z -4*z 0]
w=poly(0,"w")
vec4=roots(kp2*(0.229-w)*(0.603-w)*(7.542+2*w) -(2.916+2*w)^2 *(0.168+2*w)^2 *4)
w=vec4(4)
w=0.01
pro4=pro3-[w 0 w -2*w -2*w]
//results
disp("feed = ")
format('v',6);feed
disp(feed)
disp("After reactor 1,")
format('v',6);pro
disp(pro)
disp("After reactor 2,")
format('v',6);pro2
disp(pro2)
disp("After reactor 3,")
format('v',6);pro3
disp(pro3)
disp("After reactor 4")
```

```
format('v',6);pro4
disp(pro4)
disp("The answers are a bit different due to
   rounding off error in textbook")
```