Scilab Textbook Companion for Fundamental of Thermodynamics by Moran and Shapiro[1]

Created by
Jatin Pavagadhi
MCA
Computer Engineering
Changa Institute, Gujarat
College Teacher
None
Cross-Checked by
Harpreeth Singh

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Book Description

Title: Fundamental of Thermodynamics

Author: Moran and Shapiro

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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 2

Energy and the First Law of Thermodynamics

Scilab code Exa 2.1 Example 1

```
// Given:-
p1 = 3*(10**5)                                  //initial pressure of gas in pascal
v1 = 0.1                                        //initial volumme of gas in meter^3
v2 = 0.2                                        //final volume of gas in meter^3

// calculations
// Part (a) i.e. n=1.5
//constant = p1*(v1**n)                            // p*(v^n) = constant
constant1 = p1*(v1**1.5)
constant2 = p1*(v1**1)
constant3 = p1*(v1**0)
// function p
function v = p1(v)
    v = constant1/(v^1.5)
endfunction
```

```

function v = p2(v)
    v = constant2/(v^1)
endfunction

function v = p3(v)
    v = constant3/(v^0)
endfunction

work1 = intg(v1,v2,p1)                    // integrating pdv from initial to final volume
w1 = work1(1)/1000                              // divided by 1000 to convert to KJ
printf( 'The work done for n=1.5 in KJ is %.2f',w1)

//part(b) i.e. n = 1
work2 = intg(v1,v2,p2)
w2 = work2(1)/1000
printf( 'The work done for n=1 in KJ is %.2f',w2)

//part(c) i.e. n=0
work3 = intg(v1,v2,p3)
w3 = work3(1)/1000
printf( 'The work done for n=0 in KJ is %.2f',w3)
```

Scilab code Exa 2.2 Example

```
// Given:-
p1 = 3*(10**5)                                  // initial pressure in pascal
v1 = 0.1                                        // initial volume in m3
v2 = 0.2                                        // final volume
m = 4.0                                         //
```

```
mass of the gas in kg
deltau = -4.6                                          // change in specific internal energy in KJ/Kg

// Calculations

constant = p1*(v1**1.5)                                  // p*(v^n) = constant

function v = p(v)
    v = constant/(v**1.5)                              // expressing pressure as function of volume
endfunction

work = intg(v1,v2,p)                              // integrating pdv from initial to final volume
w=work(1)/1000                                  // divided by 1000 to convert to KJ

deltaU = m*deltau                               // change in internal energy in KJ
Q = deltaU + w                                    // neglecting kinetic and potential energy changes

// Result
printf('net heat transfer for the process in KJ %.2f',Q)
```

Scilab code Exa 2.3 Example

```
// Given:-
clc;
patm = 10**5                                  // atmospheric pressure in pascal.
```

```
mp = 45.0                                    // mass of piston in Kg
A = 0.09                                     // face area of piston in m2
deltaV = 0.045                               // increment of the volume of air in m3
m = 0.27                                     // mass of air in kg
deltau = 42.0                                // specific internal energy increase of air in kJ/kg
g = 9.81                                     // local acceleration of gravity


// Part (a) i.e. air is system
// Calculations
p = (mp*g)/A + patm                           // constant pressure of air obtained from equilibrium of piston
w = (p*deltaV)/1000                           // work done in KJ
deltaU = m*deltau                             // internal energy change of air in KJ
Q = w + deltaU                                // applying first with air as system
// Result
printf('\nheat transfer from resistor to air in KJ for air alone as system is: %.2f',Q)

// The answer given in book is incorrect. deltaU is incorrect in book.

// Part(b) i.e. (air+piston) is system
// Calculations
wd = (patm*deltaV)/1000                        // work done in KJ
deltaz = (deltaV)/A                            // change in elevation of piston
```

```
deltaPE = (mp*g*deltaz)/1000                        // change in potential energy of piston in KJ
Qt = wd + deltaPE + deltaU                          // applying first law with air plus piston as system
// Result
printf('\nheat transfer from resistor to air in KJ for air + piston as system is: %.2f',Qt)

// note : The answer given in book is incorrect.They have miscalculated deltaU.
```

Scilab code Exa 2.4 Example

```
// Given:-
w1dot = -60.0                        // input work rate in KW
h = 0.171                            // heat transfer coefficient, unit in KW/m2 .K
A = 1.0                              // outer surface area of gearbox, unit in m2
Tb = 300.0                           // outer surface temperature in kelvin
Tf = 293.0                           // temperature of the sorrounding

// Calculations
Qdot = -h*A*(Tb-Tf);                 // rate of energy transfer by heat
wdot = Qdot;                         // steady state energy equation
w2dot = wdot-w1dot;

// Results
printf('The heat transfer rate in KW is:\n\tQdot = %f',Qdot)
```

```
printf( 'The power delivered through output shaft in KW is: = %f',w2dot);
```

Scilab code Exa 2.5 Example

```
// Given:-
s=5*(10**-3)                                // measurement on a side in meter
wdot = -0.225                                 // power input in watt
Tf = 293.0                                    // coolant temprature in kelvin
h = 150.0                                     // heat transfer coefficient in w/m2 k
A = s**2                                     // surface area

// Calculation
Tb = ((-wdot/(h*A)) + Tf - 273)      // surface temperature in degree

// Result
printf( 'The surface temperature of the chip in degree celcius is: %f ',Tb);
```

Scilab code Exa 2.6 Example

```
// Given:-
omega = 100.0                               //motor rotation speed in rad/s
tau = 18.0                                  //torque applied by shaft in N.m
Welecdot = -2.0                             //electric power input in KW
```

```

Wshaftdot = (tau*omega)/1000       //shaft work rate in KW
Wdot = Welecdot + Wshaftdot        //net work rate in KW

//function [Qdot]=f(t)
//Qdot = (−0.2)∗ [1−2∗∗(−0.05∗t)]


//function [Edot]=f1(t)                     //function for rate of change of energy
//Edot = (−0.2)∗[1−2∗∗(−0.05∗t)] − Wdot

//function [deltaE] =f2(t)                  //function for change in energy

t = linspace(0,120,100);
for i = 1:100
    Qd(i) = i
    Wd(i) = i
    dltaE(i) = i
    Qd(i) =  (-0.2*(1-%e^(-0.05*t(i))))
    Wd(i) = Wdot
    dltaE(i) = 4*(1 - %e^(-0.05*t(i)))
end

subplot(2,2,1)
plot(t,Qd)
xlabel(”Time (s)”)
ylabel(”Qdot (KW)”)

subplot(2,2,2)
plot(t,Wd)
xlabel(”Time (s)”)
ylabel(”Wdot (KW)”)

subplot(2,2,3)
```

```
plot(t,dltaE)
xlabel(”Time (s)”)
ylabel(”deltaE (KJ)”)
```

Chapter 3

Evaluating Properties

Scilab code Exa 3.1 Example

```
// Given:-
// Those with 1 are of state 1 and 2 are with state
   2

// State 1
p1 = 10**5                        // initial pressure
   in pascal
x1 = 0.5                          // initial quality

T1 = 99.63                        // temperature in
   degree celcius , from table A-3
v = 0.5                           // volume of
   container in m3
vf1 = 1.0432*(10**(-3))           // specific volume of
    fluid in state 1 in m3/Kg(from table A-3)
vg1 = 1.694                       // specific volume of
    gas in state 1 in m3/kg(from table A-3)

// State 2
p2 = 1.5*(10**5)                  // pressure after
   heating in pascal
```

```

T2 = 111.4                          // temperature in degree celcius in state 2, from A-3
vf2 = 1.0582*(10**(-3))             // specific volume of fluid in state 2 in m3/Kg, from A-3
vg2 = 1.159                         // specific volume of gas in state 2 in m3/Kg,from A-3

// Calculations

v1 = vf1 + x1*(vg1-vf1)             // specific volume in state 1 in m3/Kg
v2 = v1                             // specific volume in state 2 in m3/Kg
m = v/v1                            // total mass in Kg
mg1 = x1*m                          // mass of vapour in state 1 in Kg

x2 = (v1-vf2)/(vg2-vf2)             // quality in state 2
mg2 = x2*m                          // mass of vapor in state 2 in Kg

// State 3
p3 = 2.11                           // pressure in state 3 from table A-3

// Results
printf('The temperature in state 1 is %f degree celcius.',T1)
printf('The temperature in state 2 is %f degree celcius.',T2)
printf('The mass of vapour in state 1 is %.2f kg.',mg1)
printf('The mass of vapour in state 2 is %.2f kg.',mg2)
printf('The pressure corresponding to state 3 is %.2f bar',p3)
```

Scilab code Exa 3.2 Example

```
// Given:-
m = 0.05                            // mass of ammonia in kg
p1 = 1.5*(10**5)                    // initial pressure of ammonia in pascal
v1 = 0.7787                         // specific volume in state 1 in m3/kg from table A-14
v2 = 0.9553                         // specific volume in state 2 in m3/kg from table A-15
T2 = 25.0                           // final temperature in degree celcius

// Calculations

V1 = m*v1                           // volume occupied by ammonia in state 1 in m3
V2 = m*v2                           // volume occupied by ammonia in state 2 in m3
w = (p1*(V2-V1))/1000               // work in KJ

// Results
printf(' The volume occupied by ammonia in state 1 is %.2f m^3.',V1)
printf(' The volume occupied by ammonia in state 2 is %.2f m^3',V2)
printf(' The work done for the process is %.2f KJ',w)
```

Scilab code Exa 3.3 Example

```
// Given:-
V = 0.25              // volume of tank in m3
v = 1.673             // specific volume in m3/kg obtained using table A-2

// State 1
T1 = 100.0              // initial temperature in degree celcius
u1 = 2506.5             // specific internal energy in state 1 in KJ/Kg obtained from table A-2

// State 2
p2 = 1.5                // final pressure in bars
T2 = 273.0              // temperature in state 2 in degree celcius obtained from table A-4
u2 = 2767.8             // specific internal energy in state 2 in KJ/Kg obtained from table A-4

// Calculations
m = V/v                 // mass of the system in kg
DeltaU = m*(u2-u1)      // change in internal energy in KJ
W = - DeltaU            // from energy balance

// Results
printf( ' The temperature at the final state in is %.2f degree celcius.',T2)
printf( ' The work during the process is %f KJ.',W);
```

Scilab code Exa 3.4 Example

```
// Given:-
// State
P1 = 10*(10**5)                                  // initial pressure in pascal
```

```
T1 = 400.0                                      // initial temperature in degree celcius
v1 = 0.3066                                     // specific volume in state 1 in m3/kg obtained from table A-4
u1 = 2957.3                                     // specific internal energy in state 1 in KJ/Kg obtained from table A-4

// State 2

v2 = 0.1944                                     // specific volume in state 2 in m3/kg obtained from table A-3
w2to3 = 0                                       // work in process 2-3


// State 3
v3 = v2
vf3 = 1.0905*(10**(-3))                         // specific volume of fluid in state 3 from table A-2
vg3 = 0.3928                                    // specific volume of gas in state 3 from table A-2
uf3 = 631.68                                    // specific internal energy for fluid in state 3 from table A-2
ug3 = 2559.5                                    // specific internal energy for gas in state 3 from table A-2

// Calculations
w1to2 = (P1*(v2-v1))/1000                       // work in KJ/Kg in process 1-2
W = w1to2 + w2to3                               // net work in KJ/kg
x3 = (v3-vf3)/(vg3-vf3)
u3 = uf3+x3*(ug3-uf3)                           // specific internal energy in state 3 in Kj/Kg
```

```
q = (u3-u1) + W                              // heat transfer in Kj/Kg

// Results
printf(' The work done in the overall process is %f KJ/kg.',W);
printf(' The heat transfer in the overall process is %f KJ/kg.',q);
```

Scilab code Exa 3.6 Example

```
// Given:-
// State 1
p1 = 20.0                              // initial pressure in MPa
T1 = 520.0                             // initial temperature in degree celcius
Z1 = 0.83                              // compressibility factor
R = 8.314                              // universal gas constant in SI unit
n = 1000.0/18.02                       // number of moles in a kg of water

// State 2
T2 = 400.0                             // final temperature in degree celcius

// From table A-1
Tc = 647.3                             // critical temperature in kelvin
pc = 22.09                             // critical pressure in MPa

// Calculations
```

```
Tr = (T1+273)/Tc                  // reduced temperature
Pr = p1/pc                        // reduced pressure
v1 = (Z1*n*R*(T1+273))/(p1*(10**6))
vr = v1*(pc*(10**6))/(n*R*Tc)
Tr2 = (T2+273)/Tc
PR = 0.69                          // at above vr and Tr2
P2 = pc*PR

// Results
printf(' The specific volume in state1 is %f m3/kg and the corresponding value obtained from table A-4 is .01551 m^3/Kg',v1)
printf(' The pressure in MPa in the final state is %f MPa and the corresponding value from the table is 15.16Mpa',P2);
```

Scilab code Exa 3.7 Example

```
// Given:-
T1 = 300.00                                    // temperature in state 1 in kelvin
P1 = 1.00                                      // pressure in state 1 in bar
P2 = 2.00                                      // pressure in state 2 in bar
R = 287.00                                     //gas constant of air in SI units

// Calculations
v1 = (R*T1)/(P1*10**5)                        //specific volume in state 1
P = linspace(1,2,50)
for i = 1:50
```

```
    v(i) = v1
end


T2 = (P2*10**5*v1)/R
v3 = (R*T2)/(P1*10**5)
vv = linspace(v1,v3,50)
for i = 1:50
    Pa(i) = P1
end

//function[out]= f(inp)
//out = (R*T2)/(inp

VV = linspace(v1,v3,50)
for j = 1:50
    pp(j) = (R*T2)/VV(j)/(10**5)
end
vcommon = cat(1,v,VV')
pcommon = [P  pp']
size(vcommon)
size(pcommon)
//subplot(211)
plot(vcommon,pcommon)
xlabel('v')
ylabel('p(bar)')

//subplot(212)
plot(vv,Pa)
xlabel('v')
ylabel('p(bar)')

//The two steps are shown in one graph and the other
    on is shown in the other graph"""

printf( 'The temperature in kelvin in state 2 is T2
   = %f',T2)
printf( 'The specific volume in state 3 in m^3/kg is
```

```
    v = %f',v3)
```

Scilab code Exa 3.8 Example

```
// Given:-
// State 1
m = 0.9                              // mass of air in kg
T1 = 300.0                           // initial temperature in kelvin
P1 = 1.0                             // initial pressure in bar

// State 2
T2 = 470.0                           // final temperature in kelvin
P2 = 6.0                             // final pressure in bar
Q = -20.0                            // heat transfer in kj

// From table A-22
u1 = 214.07                          // in KJ/kg
u2 = 337.32                          // in KJ/Kg

// Calculations
deltaU = m*(u2-u1)                   // change in internal energy in kj
W = Q - deltaU                       // in KJ/kg

// Results

printf( ' The work during the process is %f KJ.',W);
```

Scilab code Exa 3.9 Example

```
// Given:-
// State 1
m1 = 2.0                                // initial mass of gas in tank 1 in kg
T1 = 350.0                              // initial temperature in kelvin in tank1
p1 = 0.7                                // initial pressure in bar in tank 1

// State 2
m2 = 8.0                                // initial mass of gas in tank 2 in kg
T2 = 300.0                              // initial temperature in kelvin in tank 2
p2 = 1.2                                // initial pressure in bar in tank 2
Tf = 315.0                              // final equilibrium temperature in kelvin

// From table A-20
Cv = 0.745                              // in KJ/Kg.k

// Calculations
pf = ((m1+m2)*Tf)/((m1*T1/p1)+(m2*T2/p2))
Ui = (m1*Cv*T1)+(m2*Cv*T2)
Uf = (m1+m2)*Cv*Tf
deltaU = Uf-Ui
Q = deltaU

// Results
printf(' The final equilibrium pressure is %f bar.',pf);
```

```
printf('The heat transfer for the process is %f KJ.',Q);
```

Scilab code Exa 3.11 Example

```
// Given:-
p1 = 1.0                                    // initial pressure in bar
T1 = 295.0                                  // initial temperature in kelvin
p2 = 5.0                                    // final pressure in bar
n = 1.3                                     // polytropic constant
R = 8314/28.97                              // gas constant for air in SI units

// From table A-22
u2 = 306.53
u1 = 210.49

// Calculations
T2 = T1*(p2/p1)**((n-1)/n)
w = R*(T2-T1)/(1-n)
Q = u2-u1+w/1000

// Results
printf('The work done per unit mass is %f KJ/kg.',w/1000)
printf('The heat transfer per unit mass is %f KJ/kg.',Q);
```

Chapter 4

Control Volume Analysis Using Energy

Scilab code Exa 4.1 Example

```
// Given:-
// At inlet 1:-
p1= 7.0                                              // pressure in bar
T2= 200.0                                            // temperature in degree celcius
m1dot= 40.0                                          // mass flow rate in kg/s

// At inlet 2:-
p2= 7.0                                              // pressure in bar
T2= 40.0                                             // temperature in degree celcius
A2= 25.0                                             // area in cm^2

// At exit:-
p3= 7.0                                              //
```

```
pressure in bar
AV3= 0.06                                          // Volumetric flow rate through wxir in m^3/s

// From table A-3
v3 = (1.108)*(10**(-3))                            // specific volume at the exit in m^3/kg

// from table A-2
v2= (1.0078)*(10**(-3))                            // specific volume in state 2 in m^3/kg

// Calculation:-
m3dot= AV3/v3                                      // mass flow rate at exit
m2dot = m3dot-m1dot                                // mass flow rate at inlet 2
V2= (m2dot*v2)/(A2*(10**(-4)))

// Results:-
printf(' The mass flow rate at the inlet 2 is %.2f kg/s.',m2dot)
printf(' The mass flow rate at the exit is %.2f kg/s.',m3dot)
printf(' The velocity at the inlet is %.2f m/s.',V2)
```

Scilab code Exa 4.3 Example

```
// Given:-
p1= 40.0                                       // pressure in bar
T1= 400.0                                      // temperature in degree celcius
V1= 10.0                                       //
```

```
velocity m/s

// At exit:-
p2= 10.0                                             // pressure in bar
V2= 665.0                                            // velocity in m/s
mdot= 2.0                                            // mass flow rate in kg/s

// From table A-4
h1= 3213.6                                           // snpecific enthalpy in kJ/kg
v2 = 0.1627                                          // specific volume at the exit in m^3/kg

// Calculation:-
h2 = h1 + ((V1**2-V2**2)/2)/1000                     // snpecific enthalpy in kJ/kg
A2=(mdot*v2)/V2                                      // Exit area

// Results:-
printf( ' The exit Area of the nozzle is %.4f m^2', A2)
```

Scilab code Exa 4.4 Example

```
// Given:-
m1dot = 4600.0                                           // mass flow rate in kg/h
Wcvdot= 1000.0                                           // turbine power output in kv
p1= 60.0                                                 // pressure in bar
```

```
T1=400.0                                                    // temperature in degree celc
V1= 10.0                                                    // velocity in m/s

// At exit:-
p2= 0.10                                                    // pressure in bar
q2= 0.90                                                    // quality
V2= 50.0                                                    // velocity in m/s

// From table A-2 and A-3:-
h1= 3177.2                                                  // specific enthalpy at inlet in kJ/kg
hf2= 191.83
hg2= 2584.63

// Calculation:-
h2 = hf2+q2*(hg2-hf2)                                       // specific enthalpy at exit in kJ/kg
Qcvdot = Wcvdot + m1dot*((h2-h1)+(V2**2- V1**2)/(2*1000))/3600

// Results:-
printf( ' The rate of heat transfer between the turbine and surroundings is %.2f kW',Qcvdot)
```

Scilab code Exa 4.5 Example

```
// Given:-
p1=1.00                                                     // pressure in bar
t1= 290.00                                                  //
```

```
temperature in kelvin
A1= 0.1                                        // area in m^2
V1= 6.00                                       // velocity in m/s

// At exit:-

p2=7.00                                        // pressure in bar
t2= 450.00                                     // temperature in kelvin
V2= 2.00                                       // velocity in m/s
Qcvdot= -180.0                                 // heat transfer rate in kJ/min
R= 8.314                                       // universal gas constant in SI units

// from table A-22

h1= 290.16                                     // specific enthalpy in kJ/kg
h2= 451.8                                      // specific enthalpy in kJ/kg

// Calculations:-

v1 =  (R*1000*t1)/(28.97*p1*10**5)             // specific volume
mdot=(A1*V1)/v1                                // mass flow rate
Wcvdot = Qcvdot/60 + mdot*((h1-h2)+(V1**2-V2**2)
   /(2*1000))

// Results:-

printf( ' The power input to the compressor is %.2f
```

```
kw',Wcvdot)
```

Scilab code Exa 4.6 Example

```
// Given:-
// At Entry:=
t1=20.0                    // Temperatue in deg celcius
p1=1.0                     // pressure in atm
AV1= 0.1                   // volumetric flow rate in litre/s
D1=2.5                     // Diameter of th hose in cm

// At Exit:=
t2=23.0                    // temperatuer in deg celcius
p2=1.0                     // pressure in atm
V2=50.0                    // Velocity in m/s
Z2=5.0                     // elevation in m
g= 9.8                     // acceleration due to gravity in m/s^2

// from table A-2 and A-19:-

v= (1.0018)*((10.0)**(-3)) // specific volume in m^3/kg
c= 4.18

// Calculation:-
mdot = (AV1/1000)/v        //
```

```
mass flow rate in kg/s
V1= (AV1/1000)/(3.14*(D1/(2*100))**2)              // Entry velocity in m/s
deltah = c*(t2-t1)+v*(p2-p1)
Wcvdot= ((mdot*10)/9)*(-deltah+(V1**2-V2**2)/(2*1000)+g*(0-Z2)/1000)

// Results:-
printf(' The power input to the motor is %.2f kw',Wcvdot)
```

Scilab code Exa 4.7 Example

```
// Given:-
// Entering:-
p1=0.1                                    // pressure in bar
x1= 0.95                                  // Quality
p2= 0.1                                   // pressure in bar
t2= 45.0                                    // temperature in deg celcius
t3=20.0                                     // temperature of cooling entry in deg cel
t4=35.0                                     // temperature of cooling exit

// From table A-3
hf= 191.53                                // Enthalpy in KJ/kg
hg= 2584.7                                // Enthalpy in KJ/kg
h2=188.45                                 // Assumption at states 2,3 and 4, h is approx equal
```

```
    to hf(T), in kJ/kg
deltah4_3= 62.7                              // Assumption 4, in kJ/kg


// Calculations:-
h1= hf + x1*(hg-hf)
ratio= (h1-h2)/(deltah4_3)
QRate= (h2-h1)                               // Part B

// Results:-
printf('The rate of the mass flow rate of the cooling water to the mass flow rate of  the condenstaing stream is (m3dot/m1dot) %.2f ',ratio)
printf('The rate of energy transfer from the condensing steam to the cooling water of the steam passing  through the condenser is %.2f kJ/kg.',QRate)
```

Scilab code Exa 4.8 Example

```
// Given:-
T1 = 293.0                                                  // In kelvin
P1= 1.01325 * (10**5)                              // In pascal
V1max= 1.3                                                  // maximum velocity of entering air in m/s
T2max= 305.0                                              // maximum temperature at the exit in kelvin
```

```
pec= -80.0                              //power received by electronic components in watt
Pf= -18.0                               //Power received by fan in watt
R= 8.314                                //Universal gas constant
M= 28.97*(10**(-3))                     // Molar mass of air in kg
Qcvdot=0                                //Heat transfer from the outer surface of the electronics enclosure to the surroundings is negligible.
Cp= 1.005*(10**3)                       // in j/kg*k


// Calculations:-

Wcvdot = pec +Pf                        // total electric power provided to electronic components and fan in watt
mdotmin=  (-Wcvdot)/(Cp*(T2max-T1))     // minimum mass flow rate
v1= ((R/M)*T1)/P1                       // specific volume
A1min = (mdotmin*v1)/V1max
D1min = (4*A1min/(%pi))**(0.5)

// Results:-
printf(' The smallest fan inlet diameter is %.2f cm',D1min*100)
```

Scilab code Exa 4.9 Example

```
// Given:-
P1 = 20.0                                  // pressure in supply line in bars
P2 = 1.0                                   // exhaust pressure in bar
T2 = 120.0                                 // exhaust temperature in degree celcius

// from table A-3 at 20 bars
hf1 = 908.79                             // Enthalpy in kj/kg
hg1 = 2799.5                             // Enthalpy in kj/kg

// from table A-4, at 1 bar and 120 degree celcius
h2 = 2766.6                              // in kj/kg
h1 = h2                                  // from throttling process assumption


// Calculations:-
x1 = (h1-hf1)/(hg1-hf1)

// Results:-
printf(' The quality of the steam in the supply line is %.2f',x1)


// Note : rounding off error. please check manually.
```

Scilab code Exa 4.10 Example

```
// Given:-
P1 = 1.0                        // pressure of industrial discharge in bar
T1 = 478.0                      // temperature of industrial discharge in kelvin
m1dot = 69.78                   // mass flow rate of industrial discharge in kg/s
T2 = 400.0                      // temperature of exit products from steam generator in kelvin
P2 = 1.0                        // pressure of exit products from steam generator in bar
P3 = 0.275                      // pressure of water stream entering the generator in Mpa
T3 = 38.9                       // temperature of water stream entering the generator in degree celcius
m3dot = 2.079                   // mass flow rate of water stream entering in kg/s
P5 = 0.07                       // exit pressure of the turbine in bars
x5 = 0.93                       // quality of turbine exit

// Part (a)
m2dot = m1dot                   // since gas and water streams do not mix
m5dot = m3dot                   // --DO

// from table A-22, A-2 and A-3:-
h1 = 480.3                      // in kj/kg
h2 = 400.98                     // in Kj/kg
h3 = 162.9                      // assumption: h3 = hf(T3), units in Kj/kg
hf5 = 161.0                     // in kj/kg
hg5 = 2571.72                   // in kj/kg

```

```
// Part (b)
P4 = P3                          // from the assumption that there is no pressure drop for water flowing through the steam generator
T4 = 180                         // in degree celcius

// Calculations:-
h5 = hf5 + x5*(hg5-hf5)
Wcvdot = m1dot*h1 + m3dot*h3 - m2dot*h2 - m5dot*h5
h4 = h3 + (m1dot/m3dot)*(h1 -h2)      // from steady state energy rate balance
                                      // interpolating in table A-4, with these P4 and h4
// Results:-
printf(' The power developed by the turbine is %.2f kJ/s.',Wcvdot)
printf(' Turbine inlet temperature is %.2f degree celcius.',T4)
```

Scilab code Exa 4.11 Example

```
// Given:-
V = 0.85                                  // volume of tank in m^3
T1 = 260.0                                // initial temperature of the tank in degree celcius
X1 = 0.7                                  // initial quality

// from table A-2
uf1 = 1128.4                              // in kg/kg
ug1 = 2599.0                              // in kg/kg
```

```

vf1 = 1.2755e-3                           // in m^3/kg
vg1 = 0.04221                             // in m^3/kg



// for final state, from table A-2,
u2 = 2599.0                               // units in KJ/kg
v2 = 42.21e-3                             // units in m^3/Kg
he = 2796.6                               // units in KJ/kg

// Calculations:-
u1 = uf1 + X1*(ug1-uf1)                   // in kj/kg
v1 = vf1 + X1*(vg1-vf1)                   // in m^3/kg
m1 = V/v1                                 // initial mass in kg
m2 =  V/v2                                // final mass in kg
U2 = m2*u2                                // final internal energy in KJ
U1 = m1*u1                                // initial internal energy in KJ
Qcv = (U2-U1) - he*(m2-m1)

// Results:-
printf(' The amount of heat transfer is %.2f KJ.',Qcv)
```

Scilab code Exa 4.12 Example

```
// Given:-
Pv = 15.0
```

```
                                                    // pressure in the vessel in bar
Tv = 320.0                                          // temperature in the vessel in degree celcius
Vt = 0.6                                            // volume of a tank in m^3
Tt = 400.0                                          // temperature in the tank in degree celcius when the tank is full

// Since the tank is initially empty:-
m1 = 0
u1 = 0

// From table A-4, at 15bar and 400 degree celcius:-
v2 = 0.203                                          // Volume in m^3/kg
m2 = Vt/v2                                          // mass within the tank at the end of the process in kg
hi = 3081.9                                         // in kj/kg
u2 = 2951.3                                         // in kj/kg

// Calculations:-
deltaUcv = m2*u2-m1*u1
Wcv = hi*(m2-m1)-deltaUcv

// Results:-
printf(' The amount of work developed by the turbine is %.2f kJ.',Wcv)
```

Chapter 5

The Second Law of Thermodynamics

Scilab code Exa 5.1 Example

```
// Given :-
W = 410.00                                    // net work
   output in kj claimed
Q = 1000.00                                   // energy
   input by heat transfer in kj
Tc = 300.00                                   //
   temperature of cold reservoir in kelvin
TH = 500.00                                   //
   temperature of hot reservoir in kelvin

// Calculations
eta = W/Q                                     // thermal
   efficiency
etamax = 1-(Tc/TH)

// Results
printf( ' Eta = %.4f',eta)
printf( ' Etamax  = %.4f',etamax)
printf( ' Since eta is more than etamax, the claim
```

```
is not authentic')
```

Scilab code Exa 5.2 Example

```
// Given :-
Qcdot = 8000.00                                   // in kj/h
Wcycledot = 3200.00                               // in kj/h
Tc = 268.00                                       // temperature of compartment in kelvin
TH = 295.00                                       // temperature of the surrounding air in kelvin

// Calculations
beta = Qcdot/Wcycledot                            // coefficient of performance
betamax = Tc/(TH-Tc)                              // reversible coefficient of performance

// Results
printf(' Coefficient of performance is %.3f',beta)
printf(' Coefficient of performance of a reversible cycle is %.3f',betamax)
```

Scilab code Exa 5.3 Example

```
// Given :-
Tc = 283.0                        // in kelvin
TH = 295.0                        // in kelvin
QH = 5*(10**5)                    // in kj per day

// Calculations
```

```
Wcyclemin = (1-(Tc/TH))*QH

// Results
printf(' Minimum theoretical work input for one day of operation in kJ is: %.2f',Wcyclemin)
```

Chapter 6

Using Entropy

Scilab code Exa 6.1 Example

```
// Given:-
T = 373.15                                  // temperature in kelvin

// From table A-2

p = 1.014*(10**5)                           // pressure in pascal
vg = 1.673
vf = 1.0435e-3
sg = 7.3549
sf = 1.3069

// Calculations
w = p*(vg-vf)*(10**(-3))
Q = T*(sg-sf)

// Results
printf(' The work per unit mass is %.3f KJ/Kg',w)
printf(' The heat transfer per unit mass is %.2f kj/kg',Q)
```

Scilab code Exa 6.2 Example

```
// Given:-
// Assumptions:

// From table A-2 at 100 degree celcius
ug = 2506.5                                        // in
   kj/kg
uf = 418.94                                        // in
   kj/kg
sg = 7.3549
sf = 1.3069


// Calculations:-
// From energy balance
W = -(ug-uf)
// From entropy balance
sigmabym = (sg-sf)

// Results
printf( ' The net work per unit mass is %.2f KJ/kg.
   ',W)
printf( ' The amount of entropy produced per unit
   mass is %.2f KJ/kg.',sigmabym)
```

Scilab code Exa 6.3 Example

```
// Given:-
T1 = 273.0                                     // initial
    temperature of saturated vapor in kelvin
```

```
P2 = 0.7*(10**6)                          // final pressure in pascal

// From table A-10,
u1 = 227.06                               // in kj/kg

// minimum theoretical work corresponds to state of isentropic compression
// From table A-12,
u2s = 244.32                              // in kj/kg

// Calculations
Wmin = u2s-u1

// Results
printf(' The minimum theoretical work input required per unit mass of refrigerant is: %.2f kJ/kg',Wmin)
```

Scilab code Exa 6.4 Example

```
// Given :-
Qdot = -1.2                          // in kilo watt
Tb = 300.0                           // in kelvin
Tf = 293.0                           // in kelvin
// Calculations

// Part (a)
// From entropy balance
sigmadot = -Qdot/Tb

// Part(b)
// From entropy balance
```

```
sigmadt = -Qdot/Tf

// Results
printf(' The rate of entropy production with gearbox as system is %f kw/k',sigmadot)
printf(' The rate of entropy production with gearbox + sorrounding as system is %f kw/k',sigmadt)
```

Scilab code Exa 6.5 Example

```
// GIven:-
Tmi = 1200.0                                            // initial temperature of metal in kelvin
cm = 0.42                                               // specific heat of metal in KJ/kg.k
mm = 0.3                                                // mass of metal in kg
Twi = 300.0                                             // initial temperature of water in kelvin
cw = 4.2                                                // specific heat of water in KJ/Kg.k
mw = 9.0                                                // mass of water in kg

// Calculations
// Part(a)
// Solving energy balance equation yields
Tf = (mw*(cw/cm)*Twi+mm*Tmi)/(mw*(cw/cm)+mm)

// Part (b)
// Solving entropy balance equation yields
sigma = mw*cw*log(Tf/Twi)+mm*cm*log(Tf/Tmi)

// Results
```

```
printf(' The final equilibrium temperature of the metal bar and the water is %.2f kelvin.',Tf)
printf(' The amount of entropy produced is: %.2f kJ/k.',sigma)
```

Scilab code Exa 6.6 Example

```
// Given:-
P1 = 30.0                                       // pressure of steam entering the turbine in bar
T1 = 400.0                                      // temperature of steam entering the turbine in degree celcius
V1 = 160.0                                      // velocity of steam entering the turbine in m/s
T2 = 100.0                                      // temperature of steam exiting in degree celcius
V2 = 100.0                                      // velocity of steam exiting in m/s
Wcvdot = 540.0                                  // work produced by turbine in kJ/kg of steam
Tb = 350.0                                      // temperature of the boundary in kelvin

// From table A-4 and table A-2
h1 = 3230.9                                     // specific enthalpy at entry in Kj/kg
```

```
h2 = 2676.1                                                    // specific enthalpy at exit in kj/kg

// Calculations

// Reduction in mass and energy balance equations results in
Qcvdot = Wcvdot + (h2 - h1)+ (V2**2-V1**2)/(2*(10**3))  // heat transfer rate

// From table A-2
s2 = 7.3549                                                       // in kj/kg.k
// From table A-4
s1 = 6.9212                                                       // in kj/kg.k

// From entropy and mass balance equations
sigmadot = -(Qcvdot/Tb) + (s2-s1)

// Results
printf( 'The rate at which entropy is produced within the turbine per kg of steam  flowing is %.2f kJ/kg.k',sigmadot)
```

Scilab code Exa 6.7 Example

```
// Given:-
T1 = 294.0                                      // entry temperature of air in kelvin
P1 = 5.1                                        // entry pressure of air in bars
```

```
T2 = 352.0                                      // exit temperature of hot stream in kelvin
P2 = 1.0                                        // exit pressure of hot stream in bars
T3 = 255.0                                      // exit temperature of cold stream in kelvin
P3 = 1.0                                        // exit pressure of cold stream in bars
cp = 1.0                                        // in kj/kg.k

// Calculations
R = 8.314/28.97
se = 0.4*(cp*log((T2)/(T1))-R*log(P2/P1)) + 0.6*(cp*log((T3)/(T1))-R*log(P3/P1))
                                                // specific entropy in kj/kg.k


// Results
printf(' Specific entropy in kj/kg.k = %.3f KJ/kg.',se)
printf(' Since se > 0, the claim of the writer is true');
```

Scilab code Exa 6.8 Example

```
// Given:-
P1 = 3.5                                        // pressure of refrigerant entering the compressor in bars
T1 = 268.0                                      // temperature of refrigerant entering the compressor in kelvin
P2 = 14.0                                       //
```

```
pressure of refrigerant entering the condenser in bars
T2 = 348.0                                    //temperature of refrigerant entering the condenser in kelvin
P3 = 14.0                                     //pressure of refrigerant exiting the condenser in bars
T3 = 301.0                                    //temperature of refrigerant exiting the condenser in kelvin
P4 = 3.5                                      //pressure of refrigerant after passing through expansion valve in bars
P5 = 1.0                                      //pressure of indoor return air entering the condenser in bars
T5 = 293.0                                    //temperature of indoor return air entering the condenser in kelvin
AV5 = 0.42                                    //volumetric flow rate of indoor return air entering the condenser in m^3/s
P6 =  1.0                                     //pressure of return air exiting the condenser in bar
T6 = 323.0                                    //temperature of return air exiting the condenser in kelvin

// Part(a)

// From table A-9
s1 = 0.9572                                   //in kj/kg.k
// Interpolating in table A-9
s2 = 0.98225                                  //in kj/kg.k
```

```
h2 = 294.17                                    // in kj/kg
// From table A-7
s3 = 0.2936                                    // in kj/kg.k
h3 = 79.05                                     // in kj/kg

h4 = h3                                        // since expansion through valve is throttling process

// From table A-8
hf4 = 33.09                                    // in kj/kg
hg4 = 246.00                                   // in kj/kg
sf4 = 0.1328                                   // in kj/kg.k
sg4 = 0.9431                                   // in kj/kg.k
cp = 1.005                                     // in kj/kg.k

// Calculations

x4 = (h4-hf4)/(hg4-hf4)                        // quality at state 4
s4 = sf4 + x4*(sg4-sf4)                        // specific entropy at state 4

// CONDENSER!!
v5 = ((8314/28.97)*T5)/(P5*(10**5))            // specific volume at state 5
mairdot = AV5/v5
h6 = cp*T6
h5 = cp*T5
mrefdot = mairdot*(h6-h5)/(h2-h3)
```

```
deltaS65 = cp*log(T6/T5)-(8.314/28.97)*log(P6/P5) // change in specific entropy
sigmacond = (mrefdot*(s3-s2)) + (mairdot*(deltaS65))

// COMPRESSOR!!
sigmacomp = mrefdot*(s2-s1)

// VALVE!!
sigmavalve = mrefdot *(s4-s3)

// Results
printf(' The rates of entropy production for control volume enclosing the condenser  is %f kw/k',sigmacond);
printf(' The rates of entropy production for control volume enclosing the compressor  is %f kW/K.',sigmacomp);
printf(' The rates of entropy production for control volume enclosing the expansion valve  is %f kW/K ',sigmavalve)
```

Scilab code Exa 6.9 Example

```
// Given:-
P1 = 1.00                                          // initial pressure in bar
T1 = 300.00                                        // initial temperature in kelvin
T2 = 650.00                                        // final temperature in kelvin

// Part(a)
// From table A-22
pr2 = 21.86
pr1 = 1.3860
```

```
k = 1.39                                    // From table A-20

// Calculations
p2 = P1*(pr2/pr1)
p2a = P1*((T2/T1)**(k/(k-1)))

// Results
printf(' P2  =  %f bar.',p2)
printf(' Part(b) IT software problem');
printf(' P2a  = %f bar',p2a);
```

Scilab code Exa 6.10 Example

```
// Given:-
m1 = 5.00                // initial mass in kg
P1 = 5.00                // initial pressure in bar
T1 = 500.00              // initial temperature in kelvin
P2 = 1.00                // final pressure in bar

// From table A-22
pr1 = 8.411



// Using this value of pr2 and interpolation in table A-22
T2 = 317.00              // in kelvin

// Calculations
```

```
pr2 = (P2/P1)*pr1
m2 = (P2/P1)*(T1/T2)*m1

// Results
printf('The amount of mass remaining in the tank  is %f kg',m2)
printf('and its temperature is %f kelvin.',T2);
```

Scilab code Exa 6.11 Example

```
// Given:-
P1 = 1.00                                    // inlet pressure in bar
T1 = 593.00                                  // inlet temperature in kelvin
P2 = 1.00                                    // exit pressure in bar
eta =0.75                                    // turbine efficiency

// From table A-4
h1 = 3105.6                                  // in Kj/kg
s1 = 7.5308                                  // in kj/kg.k
// From table A-4 at 1 bar
h2s = 2743.00                                // in kj/kg
```

```

// Calculations
w = eta*(h1 - h2s)

// Result
printf(' The work developed per unit mass of steam flowing through is %f kJ/kg.',w);
```

Scilab code Exa 6.12 Example

```
// Given:-
P1 = 3.00                                   // pressure of air entering in bar
T1 = 390.00                                 // temperature of air entering in kelvin
P2 = 1.00                                   // pressure of exit air
Wcvdot = 74.00                              // work developed in kj/kg

// From table A-22,at 390k
h1 = 390.88                                 // in kj/kg
pr1 = 3.481

// From interpolation table A-22
h2s = 285.27                                // in kj/kg

// calculations
pr2 = (P2/P1)*pr1
Wcvdots = h1 - h2s
eta = Wcvdot/Wcvdots

// Result
```

```
printf(' The turbine efficiency is %.4f ',eta)
```

Scilab code Exa 6.13 Example

```
// Given:-
P1 = 1.00                                                   //
   pressure of entering steam in Mpa
T1 = 593.00                                                 //
   temperature of entering steam in kelvin
V1 = 30.00                                                  //
   velocity of entering steam in m/s
P2 = 0.3                                                    //
   pressure of exit steam in Mpa
T2 = 453.00                                                 //
   temperature of exit steam in kelvin

// From table A-4, at T1 = 593 kelvin and P1 = 1 Mpa
   ;
// and at T2 = 453 kelvin and P2 = .3 Mpa
h1 = 3093.9                                                 //
   in kj/kg
s1 = 7.1962                                                 //
   in kj/kg.k
h2 = 2823.9                                                 //
   in kj/kg


// Interpolating in table A-4
h2s = 2813.3                                                //
   in kj/kg

// Calculations
V2squareby2 = h1 - h2 + (V1**2)/2000
V2squareby2s = h1 - h2s + (V1**2)/2000
eta = V2squareby2/V2squareby2s
```

```

// Results
printf('The nozzle efficiency is %.4f',eta)
```

Scilab code Exa 6.14 Example

```
// Given:-
// From table A-9
h1 = 249.75                                         // in kj/kg
h2 = 294.17                                         // in kj/kg
mdot = 0.07                                         // in kg/s

// From table A-9
s1 = 0.9572                                         // in Kj/Kg.k
h2s = 285.58                                        // in kj/kg

// Calculations
wcvdot = -(mdot*(h2-h1))
eta = (h2s-h1)/(h2-h1)

// Results
printf('The power in  is %f kw',wcvdot);
printf('The isentropic efficiency is %.3f',eta)
```

Scilab code Exa 6.15 Example

```
// Given:-
P1 = 1.00                                // pressure of entering air in bar
T1 = 293.00                              // temperature of entering air in kelvin
P2 = 5.00                                // pressure of exit air in bar
n = 1.3
R = 8.314/28.97

// From table A-22
h1 = 293.17                              // in kj/kg
h2 = 426.35                              //  in kj/kg

// Calculations
T2 = T1*((P2/P1)**((n-1)/n))              // in kelvin
wcvdot=((n*R)/(n-1))*(T1-T2)             // in kj/kg
Qcvdot= wcvdot + (h2-h1)                 // in kj/kg

// Results
printf( ' The work per unit mass passing through the device is %.2f kJ/kg',wcvdot)
printf( ' The heat transfer per unit mass is %.2f kJ/kg. ',Qcvdot)
```

Chapter 7

Exergy Analysis

Scilab code Exa 7.1 Example

```
// Given:-
v = 2450.00                                             // volume of gaseous products in cm^3
P = 7.00                                                // pressure of gaseous product in bar
T = 867.00                                              // temperature of gaseous product in degree celcius
T0 = 300.00                                             // in kelvin
P0 = 1.013                                              // in bar

// From table A-22
u = 880.35                                              // in kj/kg
u0 = 214.07                                             // in kj/kg
s0T = 3.11883                                           // in kj/kg.k
s0T0 = 1.70203                                          // in kj/kg.k
```

```

// Calculations

e = (u-u0) + (P0*(8.314/28.97)*(((T+273)/P)-(T0/P0))
    ) - T0*(s0T-s0T0-(8.314/28.97)*log(P/P0))  // kj/
    kg

// Results
printf(' The specific exergy of the gas is %.3f kJ/
    kg.',e)
```

Scilab code Exa 7.2 Example

```
// Given:-
mR = 1.11                                        // mass of
    the refrigerant in kg
T1 = -28.00                                      // initial
    temperature of the saturated vapor in degree
    celcius
P2 = 1.4                                         // final
    pressure of the refrigerant in bar
T0 = 293.00                                      // in kelvin
P0 = 1.00                                        // in bar

// Part (a)
// From table A-10
u1 = 211.29                                      // in kj/kg
v1 = 0.2052                                      // in m^3/kg
s1 = 0.9411                                      // in kj/kg.
    k
// From table A-12
u0 = 246.67                                      // in kj/kg
v0 = 0.23349                                     // in m^3/kg
s0 = 1.0829                                      // in kj/kg.
    k
```

```

// From table A-12
u2 = 300.16                                    // in kj/kg
s2 = 1.2369                                    // in kj/kg.k
v2 = v1

// Calculations
E1 = mR*((u1-u0) + P0*(10**5)*(v1-v0)*(10**(-3))-T0*(s1-s0))
E2 = mR*((u2-u0) + P0*(10**5)*(v2-v0)*(10**(-3))-T0*(s2-s0))

// Results for Part A
printf(' Part(a) The initial exergy is %.2f kJ.',E1)
printf(' The final exergy is %.2f kJ.',E2)
printf(' The change in exergy of the refrigerant is %.2f kj',E2-E1)


// Part (b)
// Calculations
deltaU = mR*(u2-u1)
// From energy balance
deltaPE = -deltaU
// With the assumption::The only significant changes of state are experienced by the refrigerant and the suspended mass. For the refrigerant,
// there is no change in kinetic or potential energy. For the suspended mass, there is no change in kinetic or internal energy. Elevation is
// the only intensive property of the suspended mass that changes
deltaE = deltaPE

// Results for part b
printf(' Part(b)The change in exergy of the
```

```
suspended mass is %.3f kJ',deltaE)


// Part(c)
// Calculations
deltaEiso = (E2-E1) + deltaE

// Results
printf(' Part(c)The change in exergy of an isolated system of the vessel and pulley mass assembly is  %.2f kJ',deltaEiso)
```

Scilab code Exa 7.3 Example

```
// Given :-
T = 373.15                                  // initial temperature of saturated liquid in kelvin
T0 = 293.15                                 // in kelvin
P0 = 1.014                                  // in bar

// Part(a)
// From table A-2
ug = 2506.5                                 // in kj/kg
uf = 418.94                                 // in kj/kg
vg = 1.673                                  //
```

```
in m^3/kg
vf = 1.0435*(10**(-3))                    // in m^3/kg
sg = 7.3549                               // in kj/kg.k
sf = 1.3069                               // in kj/kg.k


// Calculations
// Energy transfer accompanying work
etaw = 0                                  // since p = p0
// Exergy transfer accompanying heat
Q = 2257                                  // in kj/kg,obtained from example 6.1
etah = (1-(T0/T))*Q

// Exergy destruction
ed = 0                                    // since the process is accomplished without any irreversibilities
deltae = ug-uf + P0*(10**5)*(vg-vf)/(10**3)-T0*(sg-sf)

// Results
printf(' Part(a)the change in exergy is %.2f kJ/kg.',deltae)
printf(' The exergy transfer accompanying work is %.2f kJ/kg.',etaw)
printf(' The exergy transfer accompanying heat is %.2f kJ/kg',etah)
printf(' The exergy destruction is %.2f kJ/kg.',ed)
```

```


// Part(b)
Deltae = deltae                                                   // since the end states are same
Etah = 0                  // since process is adiabatic
// Exergy transfer along work
W = -2087.56                                                      // in kj/kg from example 6.2
Etaw = W- P0*(10**5)*(vg-vf)/(10**3)
// Exergy destruction
Ed = -(Deltae+Etaw)

// Results
printf( ' Part(b)the change in exergy is %.2f kJ/kg.',Deltae)
printf( ' The exergy transfer accompanying work is %.2f kJ/kg.',Etaw)
printf( ' The exergy transfer accompanying heat is %.2f kJ/kg.',Etah)
printf( ' The exergy destruction is %.2f kJ/kg.',Ed)
```

Scilab code Exa 7.4 Example

```
// Given:-
T0 = 293.00               // in kelvin
Qdot = -1.2               // in KW, from example 6.4a
Tb = 300.00               // temperature at the outer surface of the
```

```
gearbox in kelvin from example 6.4a
sigmadot = 0.004 // rate of entropy production in KW/k from example 6.4a

// Calculations
R = -(1-T0/Tb)*Qdot // time rate of exergy transfer accompanying heat
Eddot = T0*sigmadot // rate of exergy destruction

// Results
printf(' Balance sheet');
printf('\n Rate of exergy in high speed shaft 60Kw')
printf('\n Disposition of the exergy: Rate of exergy out low-speed shaft %.1f Kw',58.8 )
printf('\n Heat transfer is %.3f kw.',R)
printf('\n Rate of exergy destruction is %.3f kw',Eddot)
```

Scilab code Exa 7.5 Example

```
// Given:-
p1 = 3.0 // entry pressure in Mpa
p2 = 0.5 // exit pressure in Mpa
T1 = 320.0 // entry temperature in degree celcius
T0 = 25.0
```

```
                                              // in degree celcius
p0 = 1.0                                      // in atm

// From table A-4
h1 = 3043.4                                   // in kj/kg
s1 = 6.6245                                   // in kj/kg.k
h2 = h1                                       // from reduction of the steady-state mass and energy rate balances
s2 = 7.4223                                   // Interpolating at a pressure of 0.5 MPa with h2 = h1, units in kj/kg.k

// From table A-2
h0 = 104.89                                   // in kj/kg
s0 = 0.3674                                   // in kj/kg.k

// Calculations
ef1 = h1-h0-(T0+273)*(s1-s0)                  // flow exergy at the inlet
ef2 = h2-h0-(T0+273)*(s2-s0)                  // flow exergy at the exit
// From the steady-state form of the exergy rate
```

```
balance
Ed = ef1-ef2                                          // the exergy destruction per unit of mass flowing is

// Results
printf('The specific flow exergy at the inlet is %.2f kJ/kg.',ef1)
printf('The specific flow exergy at the exit is %.2f kJ/kg.',ef2)
printf('The exergy destruction per unit of mass flowing is %.2f kJ/kg.',Ed)
```

Scilab code Exa 7.6 Example

```
// Given:-
T1 = 610.0                                            // temperature of the air entering heat exchanger in kelvin
p1 = 10.0                                             // pressure of the air entering heat exchanger in bar
T2 = 860.0                                            // temperature of the air exiting the heat exchanger in kelvin
p2 = 9.70                                             // pressure of the air exiting the heat exchanger in bar
T3 = 1020.0                                           // temperature of entering hot combustion gas in
```

```
kelvin
p3 = 1.10                // pressure of entering hot  combustion gas in bar
p4 = 1.0                 // pressure of exiting hot combustion gas in bar
mdot = 90.0                                                  // mass flow rate in kg/s
T0 = 300.0                                                    // in kelvin
p0 = 1.0                 // in bar

// Part (a)
// From table A-22
h1 = 617.53                                                  // in kj/kg
h2 = 888.27                                                  // in kj/kg
h3 = 1068.89                                                // in kj/kg

// Calculations
h4 = h3+h1-h2

// Using interpolation in table A-22 gives
T4 = 778                 // in kelvin

```

```
// Results
printf(' The exit temperature of the combustion gas is %f kelvin.',T4);

// Part(b)
// From table A-22
s2 = 2.79783                                                    // in kj/kg.k
s1 = 2.42644                                                    // in kj/kg.k
s4 = 2.68769                                                    // in kj/kg.k
s3 = 2.99034                                                    // in kj/kg.k

// Calculations for part b

deltaR = (mdot*((h2-h1)-T0*(s2-s1-(8.314/28.97)*log(p2/p1))))/1000
deltRc = mdot*((h4-h3)-T0*(s4-s3-(8.314/28.97)*log(p4/p3)))/1000

// Results for part b
printf(' The net change in the flow exergy rate from inlet to exit of compressed gas    is %.3f MW.',deltaR)
printf(' The net change in the flow exergy rate from inlet to exit of hot combustion gas    is %.3f MW.',deltRc)

// Part(c)
//From an exergy rate balance
Eddot = -deltaR-deltRc

```

```
// Results
printf(' The rate exergy  destroyed,  is %.3f MW.',Eddot)
```

Scilab code Exa 7.7 Example

```
// Given:-
p1 = 30.0                                                    // pressure of entering steam in bar
t1 = 400.0                                                   // temperature of entering steam in degree celcius
v1 = 160.0                                                   // velocity of entering steam in m/s
t2 = 100.0                                                   // temperature of exiting saturated vapor in degree celcius
v2 = 100.0                                                   // velocity of exiting saturated vapor in m/s
W = 540.0                                                    // rate of work developed in kj per kg of steam
Tb = 350.0                                                   // the temperature on the boundary where heat transfer occurs in kelvin
T0 = 25.0                                                    // in degree celcius
p0 = 1.0                                                     //
```

```
in atm

// From table A-4
h1 = 3230.9                                            // in kj/kg
s1 = 6.9212                                            // in kj/kg.k
// From table A-2
h2 = 2676.1                                            // in kj/kg
s2 = 7.3549                                            // in kj/kg.k
// From example 6.6
Q = -22.6                                               // in kj/kg

// Calculations
DELTAef = (h1-h2)-(T0+273)*(s1-s2)+(v1**2-v2**2)/(2*1000)
// The net exergy carried in per unit mass of steam flowing in kj/kg
Eq = (1-(T0+273)/Tb)*(Q)                               // exergy transfer accompanying heat in kj/kg
Ed = ((1-(T0+273)/Tb)*(Q))-W+(DELTAef)                 // The exergy destruction determined by rearranging the steady-state form of the exergy
                                                        // rate balance
```

```

// Results
printf(' Balance sheet')
printf(' Net rate of exergy %f kJ/kg,',DELTAef)
printf(' Disposition of the exergy:')
printf('* Rate of exergy out')
printf(' Work %f kJ/kg.',W)
printf(' Heat transfer %f',-Eq)
printf('    Rate of exergy destruction %f kJ/kg.',Ed)
```

Scilab code Exa 7.8 Example

```
// Given:-
clc;
m1dot = 69.78                                                    // in kg/s
p1 = 1.0                                                         // in bar
T1 = 478.0                                                       // in kelvin
T2 = 400.0                                                       // in kelvin
p2 = 1.0                                                         // in bar
p3 = 0.275                                                       // in Mpa
T3 = 38.9
```

```
// in degree celcius
m3dot = 2.08 // in kg/s
T4 = 180.0 // in degree celcius
p4 = 0.275 // in Mpa
p5 = 0.07 // in bar
x5 = 0.93
Wcvdot = 876.8 // in kW
T0 = 298.0 // in kelvin


// Part(a)
// From table A-22
h1 = 480.35 // in kj/kg
h2 = 400.97 // in kj/kg
s1 = 2.173 // in kj/kg
s2 = 1.992 // in kj/kg

```

```
// From table A-2E
h3 = 162.82                                                    // in kj/kg
s3 = 0.5598                                                    // in kj/kg.k
// Using saturation data at 0.07 bars from Table A-3
h5 = 2403.27                                                   // in kj/kg
s5 = 7.739                                                     // in kj/kg.k
//The net rate exergy carried out by the water stream

// From table A-4
h4 = 2825.0                                                    // in kj/kg
s4 = 7.2196                                                    // in kj/kg.k
// Calculations
netRE = m1dot*(h1-h2-T0*(s1-s2-(8.314/28.97)*log(p1/p2))) // the net rate exergy  carried into the control volume
netREout = m3dot*(h5-h3-T0*(s5-s3))
// From an exergy rate balance applied to a control volume enclosing the steam generator
Eddot = netRE + m3dot*(h3-h4-T0*(s3-s4))                 // the rate exergy is destroyed in the heat-recovery steam generator

// From an exergy rate balance applied to a control volume enclosing the turbine
EdDot = -Wcvdot + m3dot*(h4-h5-T0*(s4-s5))
```

```
                    // the rate exergy is destroyed in the tpurbine

// Results
printf('\n balance sheet')
printf('\n- Net rate of exergy in: %f kJ/kg.',netRE)
printf('\n Disposition of the exergy:')
printf('\ n    Rate of exergy out')
printf('\n power developed %f kJ/kg.',netRE-netREout-Eddot-EdDot)
printf('\n water stream  %f',netREout)
printf('\ n    Rate of exergy destruction')
printf('\n heat-recovery steam generator %f kJ/kg',Eddot)
printf('\n turbine %f',EdDot)

// note : answer is slightly different because of rounding off error.
```

Scilab code Exa 7.9 Example

```
// Given:-
T0 = 273.00                                                      // in kelvin
pricerate = 0.08                                                 // exergy value at $0.08 per kw.h

// From example 6.8
sigmadotComp = 17.5e-4                                           // in kw/k
sigmadotValve = 9.94e-4                                          // in kw/k
```

```
sigmadotcond = 7.95e-4                                        // in kw/k

// Calculations
// The rates of exergy destruction
EddotComp = T0*sigmadotComp                                   // in kw
EddotValve = T0*sigmadotValve                                 // in kw
Eddotcond = T0*sigmadotcond                                   // in kw

mCP = 3.11                                                    // From the solution to Example 6.14, the magnitude of the compressor power in kW

// Results
printf(' Daily cost in dollars of exergy destruction due to compressor irreversibilities = %.3f',EddotComp*pricerate*24)
printf(' Daily cost in dollars of exergy destruction due to irreversibilities in the throttling valve = %.3f',EddotValve*pricerate*24)
printf(' Daily cost in dollars of exergy destruction due to irreversibilities in the condenser = %.3f ',Eddotcond*pricerate*24)
printf(' Daily cost in dollars  of electricity to operate compressor = %.3f',mCP*pricerate*24)
```

Scilab code Exa 7.10 Example

```
// Given:-
EfFdot = 100.00                                               //
```

```
exergy rate of fuel entering the boiler in MW
cF = 1.44
// unit cost of fuel in cents per kw.h
Zbdot = 1080.00
// the cost of owning and operating boiler in dollars per hour
Ef1dot = 35.00
// exergy rate of exiting steam from the boiler in MW
p1 = 50.00
// pressure of exiting steam from the boiler in bar
T1 = 466.00
// temperature of exiting steam from the boiler in degree celcius
Ztdot = 92.00
// the cost of owning and operating turbine in dollars per hour
p2 = 5.00
// pressure of exiting steam from the turbine in bars
T2 = 205.00
// temperature of exiting steam from the turbine in degree celcius
m2dot = 26.15
// mass flow rate of exiting steam from the turbine in kg/s
T0 = 298.00
```

```
// in kelvin


// Part(a)
// From table A-4,
h1 = 3353.54                                                   // in kj/kg
h2 = 2865.96                                                   // in kj/kg
s1 = 6.8773                                                    // in kj/kg.k
s2 = 7.0806                                                    // in kj/kg.k

// Calculations
// From assumption,For each control volume,Qcvdot = 0 and kinetic and potential energy effects are negligible,the mass and energy rate
// balances for a control volume enclosing the turbine reduce at steady state to give
Wedot = m2dot *(h1-h2)/1000                              // power in MW
Ef2dot = Ef1dot+m2dot*(h2-h1-T0*(s2-s1))/1000           // the rate exergy exits with the steam in MW

// Results
printf(' For the turbine,the power is %.2f MW.',Wedot)
printf(' For the turbine,the rate exergy exits with the steam is %.2f MW.',Ef2dot)

// Part(b)
// Calculations
```

```
c1 = cF*(EfFdot/Ef1dot) + ((Zbdot/Ef1dot)/10**3)*100            // unit cost of exiting steam from boiler in cents/Kw.h
c2 = c1                                                         // Assigning the same unit cost to the steam entering and exiting the turbine
ce = c1*((Ef1dot-Ef2dot)/Wedot) + ((Ztdot/Wedot)/10**3)*100  // unit cost of power in cents/kw.h

// Results
printf('The unit costs of the steam exiting the boiler of exergy is: %.2f cents per kw.h.',c1)
printf('The unit costs of the steam exiting the turbine of exergy is: %.2f cents per kw.h.',c2)
printf('Unit cost of power is: %f cents per kw.h.',ce)

// Part(c)
C2dot = (c2*Ef2dot*10**3)/100                                        // cost rate for low-pressure steam in dollars per hour
Cedot = (ce*Wedot*10**3)/100                                          // cost rate for power in dollars per hour

// Results
printf(' The cost rate of the steam exiting the turbine is: %.2f dollars per hour.',C2dot)
printf(' The cost rate of the power is: %.2f dollars per hour.',Cedot)
```

Chapter 8

Vapor Power Systems

Scilab code Exa 8.1 Example

```
// Given:-
p1 = 8.0
    // pressure of saturated vapor entering the
    turbine in MPa
p3 = 0.008
    // pressure of saturated liquid exiting the
    condenser in MPa
Wcycledot = 100.00
    // the net power output of the cycle in MW

// Analysis
// From table A-3
h1 = 2758.0
    // in kj/kg
s1 = 5.7432
    // in kj/kg.k
s2 = s1
sf = 0.5926
    // in kj/kg.k
sg = 8.2287
    // in kj/kg.k
```

```
hf = 173.88                                  // in kj/kg
hfg = 2403.1                                 // in kj/kg
v3 = 1.0084e-3                               // in m^3/kg

// State 3 is saturated liquid at 0.008 MPa, so
h3 = 173.88                                  // in kj/kg

// Calculations
x2 = (s2-sf)/(sg-sf)                         // quality at state 2
h2 = hf + x2*hfg
p4 = p1
h4 = h3 + v3*(p4-p3)*10**6*10**-3            // in kj/kg

// Part(a)
//Mass and energy rate balances for control volumes around the turbine and pump give, respectively
wtdot = h1 - h2
wpdot = h4-h3

// The rate of heat transfer to the working fluid as it passes through the boiler is determined using mass and energy rate balances as
qindot = h1-h4

eta = (wtdot-wpdot)/qindot                          // thermal efficiency)

// Result for part a
printf(' The thermal efficiency for the cycle is %.2f',eta)

// Part(b)
```

```
bwr = wpdot/wtdot                                              // back work ratio

// Result
printf(' The back work ratio is %f',bwr)

// Part(c)
mdot = (Wcycledot*10**3*3600)/((h1-h2)-(h4-h3))          // mass flow rate in kg/h

// Result
printf(' The mass flow rate of the steam is %.2f kg/h .',mdot)

// Part(d)
Qindot = mdot*qindot/(3600*10**3)                          // in MW

// Results
printf('The rate of heat transfer,Qindot , into the working fluid as it passes through the boiler, is %.2f MW.',Qindot)

// Part(e)
Qoutdot = mdot*(h2-h3)/(3600*10**3)                        // in MW

// Results
printf(' The rate of heat transfer,Qoutdot from the condensing steam as it passes through the condenser, is %.2f MW.',Qoutdot)

// Part(f)
// From table A-2
hcwout= 146.68                                                  // in kj/kg
hcwin= 62.99
```

```
                                                        // in kj/kg
mcwdot= (Qoutdot*10**3*3600)/(hcwout-hcwin)            // in kg/h

// Results
printf( ' The mass flow rate of the condenser cooling water is %.2f kg/ h.',mcwdot)
```

Scilab code Exa 8.2 Example

```
// Given:-
etat= .85                                               // given that the turbine and the pump each have an isentropic efficiency of 85%
// Analysis
// State 1 is the same as in Example 8.1, so
h1 = 2758.0                                             // in kj/kg
s1 = 5.7432                                             // in kj/kg.k
// From example 8.1
h1 = 2758.0                                             // in kj/kg
h2s = 1794.8                                            // in kj/kg
// State 3 is the same as in Example 8.1, so
h3 = 173.88                                             // in kj/kg

// Calculations
h2 = h1 - etat*(h1-h2s)                                 // in kj/kg
wpdot = 8.06/etat                                       // where the value 8.06 is obtained from example 8.1
```

```

h4 = h3 + wpdot

// Part(a)
eta = ((h1-h2)-(h4-h3))/(h1-h4)              // thermal efficiency

// Result for part (a)
printf(' Thermal efficiency is:  %.3f',eta)

// Part(b)
Wcycledot = 100                               // given,a net power output of 100 MW
// Calculations
mdot = (Wcycledot*(10**3)*3600)/((h1-h2)-(h4-h3))
// Result for part (b)
printf(' The mass flow rate of steam, in kg/h, for a net power output of 100 MW is %.3f kg/h.  ',mdot)

// Part(c)
Qindot = mdot*(h1-h4)/(3600 * 10**3)
// Result
printf(' The rate of heat transfer Qindot into the working fluid as it passes through the boiler, is %.3f MW.',Qindot)

// Part(d)
Qoutdot = mdot*(h2-h3)/(3600*10**3)
// Result
printf(' The rate of heat transfer  Qoutdotfrom the condensing steam as it passes through the condenser, is   %.3f MW.',Qoutdot)

// Part(e)
// From table A-2
hcwout = 146.68                               // in kj/kg
```

```
hcwin = 62.99                                   // in kj/kg
mcwdot = (Qoutdot*10**3*3600)/(hcwout-hcwin)
// Result
printf('The mass flow rate of the condenser cooling water, is: %.3f kg/h.',mcwdot)
```

Scilab code Exa 8.3 Example

```
// Given:-
clc;
T1 = 480.0                           // temperature of steam entering the first stage turbine in degree celcius
p1 = 8.0                             // pressure of steam entering the first stage turbine in MPa
p2 = 0.7                             // pressure of steam exiting the first stage turbine in MPa
T3 = 440.0                           // temperature of steam before entering the second stage turbine
Pcond = 0.008                        // condenser pressure in MPa
Wcycledot = 100.0                    // the net power output in MW

// Analysis
// From table A-4
h1 = 3348.4                          // in kj/kg
s1 = 6.6586                          // in kj/kg.k
s2 = s1                              // isentropic expansion through the first-stage turbine
// From table A-3
sf = 1.9922                          // in kj/kg.k
sg = 6.708                           // in kj/kg.k
hf = 697.22                          // in kj/kg
```

```
hfg = 2066.3                          // in kj/kg

// Calculations
x2 = (s2-sf)/(sg-sf)
h2 = hf + x2*hfg
// State 3 is superheated vapor with p3 = 0.7 MPa and T3=  440C, so from Table A-4
h3 = 3353.3                           // in kj/kg
s3 = 7.7571                           // in kj/kg.k
s4 = s3                               // isentropic expansion through the second-stage turbine
// For determing quality at state 4,from table A-3
sf = 0.5926                           // in kj/kg.k
sg = 8.2287                           // in kj/kg.k
hf = 173.88                           // in kj/kg
hfg = 2403.1                          // in kj/kg

// Calculations
x4 = (s4-sf)/(sg-sf)
h4 = hf + x4*hfg

// State 5 is saturated liquid at 0.008 MPa, so
h5 = 173.88
// The state at the pump exit is the same as in Example 8.1, so
h6 = 181.94

// Part(a)
eta = ((h1-h2)+(h3-h4)-(h6-h5))/((h1-h6)+(h3-h2))
// Result
printf( '\n The thermal efficiency of the cycle is: %.2f',eta)

// Part(b)
mdot = (Wcycledot*3600*10**3)/((h1-h2)+(h3-h4)-(h6-h5))
printf( '\n The mass flow rate of steam, is: %.2f kg/h.',mdot)
```

```

// Part(c)
Qoutdot = (mdot*(h4-h5))/(3600*10**3)
printf('\nThe rate of heat transfer Qoutdot from the condensing steam as it passes through the condenser, is %.2f MW',Qoutdot)
```

Scilab code Exa 8.4 Example

```
// Given :-
// Part (a)
etat = 0.85                              // given efficiency
// From the solution to Example 8.3, the following specific enthalpy values are known, in kJ/kg
h1 = 3348.4
h2s = 2741.8
h3 = 3353.3
h4s = 2428.5
h5 = 173.88
h6 = 181.94


// Calculations
h2 = h1 - etat*(h1 - h2s)                // The specific enthalpy at the exit of the first-stage turbine in kj/kg
h4 = h3 - etat*(h3-h4s)                  // The specific enthalpy at the exit of the second-stage turbine in kj/kg
eta = ((h1-h2)+(h3-h4)-(h6-h5))/((h1-h6)+(h3-h2))

```

```
// Result
printf( ' The thermal efficiency is:  %f',eta)

// Part (b)
x = linspace(0.85,1,50)
for i =1:50
    h2(i) = h1 - x(i)*(h1 - h2s)
                                             // The
       specific enthalpy at the exit of the first-
       stage turbine in kj/kg
    h4(i) = h3 - x(i)*(h3-h4s)
                                               // The
        specific enthalpy at the exit of the second-
       stage turbine in kj/kg
    y(i)  = ((h1-h2(i))+(h3-h4(i))-(h6-h5))/((h1-h6)
       +(h3-h2(i)))
end

plot(x,y)
xlabel('isentropic turbine efficiency')
ylabel('cycle thermal efficiency')
```

Scilab code Exa 8.5 Example

```
// Given:-
T1 = 480.0

   // temperature of steam entering the turbine in
   degree celcius
p1 = 8.0

   // pressure of steam entering the turbine in MPa
Pcond = 0.008

   // condenser pressure in MPa
```

```
etat = 0.85                                       // turbine efficiency
Wcycledot = 100.0                                 // net power output of the cycle


// Analysis
// With the help of steam tables
h1 = 3348.4                                       // in kj/kg
h2 = 2832.8                                       // in kj/kg
s2 = 6.8606                                       // in kj/kg.k
h4 = 173.88                                       // in kj/kg
// With s3s = s2, the quality at state 3s is x3s= 0.8208; using this, we get
h3s = 2146.3                                      // in kj/kg

// Calculations
// The specific enthalpy at state 3 can be determined using the efficiency of the second-stage turbine
h3 = h2 - etat*(h2-h3s)

// State 6 is saturated liquid at 0.7 MPa. Thus,
h6 = 697.22                                       // in kj/kg
```

```
// For determining specific enthalpies at states 5
   and 7 ,we have
p5 = 0.7

   // in MPa
p4 = 0.008

   // in MPa
p7 = 8.0

   // in MPa
p6 = 0.7

   // in MPa
v4 = 1.0084e-3

   // units in m^3/kg,obtained from steam tables
v6 = 1.1080e-3

   // units in m^3/kg,obtained from steam tables

// Calculations
h5 = h4 + v4*(p5-p4)*10**6*10**-3

   // in kj/kg
h7 = h6 + v6*(p7-p6)*10**3

   // in kj/kg

// Applying mass and energy rate balances to a
   control volume enclosing the open heater, we find
    the fraction y of the flow extracted at state 2
   from
y = (h6-h5)/(h2-h5)

// Part(a)
wtdot = (h1-h2) + (1-y)*(h2-h3)
```

```
   // the total turbine work output, units in KJ/Kg
wpdot = (h7-h6) + (1-y)*(h5-h4)

   // The total pump work per unit of mass passing
   through the first-stage turbine,in KJ/kg
qindot = h1 - h7

   // in kj/kg
eta = (wtdot-wpdot)/qindot

// Results
printf(' The thermal efficiency is: %.2f',eta)

// Part(b)
m1dot = (Wcycledot*3600*10**3)/(wtdot-wpdot)

// Results
printf(' The mass flow rate of steam entering the
   first turbine stage, is: %.2f kg/h.',m1dot)
```

Scilab code Exa 8.6 Example

```

// Given:-
// Analysis
// State 1 is the same as in Example 8.3, so
h1 = 3348.4

   // in kj/kg
s1 = 6.6586

   // in kj/kg.k
// State 2 is fixed by p2  2.0 MPa and the specific
   entropy s2, which is the same as that of state 1.
    Interpolating in Table A-4, we get
```

```
h2 = 2963.5                    // in kj/kg
// The state at the exit of the first turbine is the same as at the exit of the first turbine of Example 8.3, so
h3 = 2741.8                    // in kj/kg
// State 4 is superheated vapor at 0.7 MPa, 440C. From Table A-4,
h4 = 3353.3                    // in kj/kg
s4 = 7.7571                    // in kj/kg.k
// Interpolating in table A-4 at p5 = .3MPa and s5 = s4, the enthalpy at state 5 is
h5 = 3101.5                    // in kj/kg
// Using s6 = s4, the quality at state 6 is found to be
x6 = 0.9382
// Using steam tables, for state 6
hf = 173.88                    // in kj/kg
hfg = 2403.1                   // in kj/kg

h6 = hf + x6*hfg

// At the condenser exit, we have
h7 = 173.88
```

```
// in kj/kg
v7 = 1.0084e-3 // in m^3/kg
p8 = 0.3 // in MPa
p7 = 0.008 // in MPa

h8 = h7 + v7*(p8-p7)*10**6*10**-3 // The specific enthalpy at the exit of the first pump in kj/kg
// The liquid leaving the open feedwater heater at state 9 is saturated liquid at 0.3 MPa. The specific enthalpy is
h9 = 561.47 // in kj/kg

// For the exit of the second pump,
v9 = 1.0732e-3 // in m^3/kg
p10 = 8.0 // in MPa
p9 = 0.3 // in MPa
h10 = h9 + v9*(p10-p9)*10**6*10**-3 // The specific enthalpy at the exit of the second pump in kj/kg
// The condensate leaving the closed heater is saturated at 2 MPa. From Table A-3,
```

```
h12 = 908.79 // in kj/kg
h13 = h12 // since The fluid passing through the trap undergoes a throttling process
// For the feedwater exiting the closed heater
hf = 875.1 // in kj/kg
vf = 1.1646e-3 // in m^3/kg
p11 = 8.0 // in MPa
psat = 1.73 // in MPa
h11 = hf + vf*(p11-psat)*10**6*10**-3 // in kj/kg

ydash = (h11-h10)/(h2-h12) // the fraction of the total flow diverted to the closed heater
ydashdash = ((1-ydash)*h8+ydash*h13-h9)/(h8-h5) // the fraction of the total flow diverted to the open heater

// Part(a)
wt1dot = (h1-h2) + (1-ydash)*(h2-h3) // The work developed by the first turbine per unit of mass entering in kj/kg
wt2dot = (1-ydash)*(h4-h5) + (1-ydash-ydashdash)*(h5
```

```
-h6)                              // The work developed by the second turbine per unit of mass in kj/kg
wp1dot = (1-ydash-ydashdash)*(h8-h7)                                              // The work for the first pump per unit of mass in kj/kg
wp2dot = h10-h9                                                    // The work for the second pump per unit of mass in kj/kg
qindot = (h1-h11) + (1-ydash)*(h4-h3)                                             // The total heat added expressed on the basis of a unit of mass entering the first

eta = (wt1dot+wt2dot-wp1dot-wp2dot)/qindot                                        // thermal efficiency

// Result
printf(' The thermal efficiency is: %.2f',eta)

// Part(b)
Wcycledot = 100.0                                                  // the net power output of the cycle in MW
m1dot = (Wcycledot*3600*10**3)/(wt1dot+wt2dot-wp1dot-wp2dot)

// Result
printf(' The mass flow rate of the steam entering the first turbine, in kg/h is: %.2f',m1dot)
```

Scilab code Exa 8.7 Example

```

// Given:-
// Analysis
// The solution to Example 8.2 gives
h1 = 2758
    // in kj/kg
h4 = 183.36
    // in kj/kg
// From table A-22
hi = 1491.44
    // in kj/kg
he = 843.98
    // in kj/kg
// Using the conservation of mass principle and
    energy rate balance, the ratio of mass flow rates
     of air and water is
madotbymdot = (h1-h4)/(hi-he)
// From example 8.2
mdot = 4.449e5
    // in kg/h
madot =  madotbymdot*mdot
    // in kg/h

// Part(a)
T0 = 295
```

```
    // in kelvin
// From table A-22
si = 3.34474

    // in kj/kg.k
se = 2.74504

    // in MW
// Calculation
Rin = madot*(hi-he-T0*(si-se))/(3600*10**3)
                                              // The net rate
    at which exergy is carried into the heat
    exchanger


// Result
printf('The net rate at which exergy is carried into
     the heat exchanger unit by the gas stream, is :
    %.2f MW ',Rin)

// Part(b)
// From table A-3
s1 = 5.7432

    // in kj/kg.k
// From interpolation in table A-5 gives
s4 = 0.5957
```

```
    // in kj/kg.k
// Calculation
Rout = mdot*(h1-h4-T0*(s1-s4))/(3600*10**3)                                    // in MW
// Result
printf('The net rate at which exergy is carried from the heat exchanger by the water stream, is : %.2f MW.',Rout)

// Part(c)
Eddot = Rin-Rout                                                               // in MW
// Result
printf('The rate of exergy destruction, in MW is : %.2f',Eddot)

// Part(d)
epsilon = Rout/Rin
// Result
printf('The exergetic efficiency is: %.2f',epsilon)
```

Scilab code Exa 8.8 Example

```

// Given:-
T0 = 295.00                                                                    // in kelvin
P0 = 1.00                                                                      // in atm

// Analysis
```

```
// From table A-3
s1 = 5.7432        // in kj/kg.k
s3 =0.5926        // in kj/kg.k

// Using h2 = 1939.3 kJ/kg from the solution to Example 8.2, the value of s2 can be determined from Table A-3 as
s2 = 6.2021        // in kj/kg.k
s4 = 0.5957        // in kj/kg.k
mdot = 4.449e5        // in kg/h

// Calculations
Eddot = mdot*T0*(s2-s1)/(3600*10**3)        // the rate of exergy destruction for the turbine in MW
EddotP = mdot*T0*(s4-s3)/(3600*10**3)        // the exergy destruction rate for the pump

// Results
printf(' The rate of exergy destruction for the turbine is: %.2f MW.',Eddot)
// From the solution to Example 8.7, the net rate at which exergy is supplied by the cooling combustion gases is 231.28 MW
printf(' The turbine rate of exergy destruction expressed as a percentage is:  %.f',(Eddot/231.28)*100)
```

```
// However, since only 69% of the entering fuel exergy remains after the stack loss and combustion exergy destruction are accounted for,
// it can be concluded that
printf(' Percentage of the exergy entering the plant with the fuel destroyed within the turbine is : %.2f',0.69*(Eddot/231.28)*100)
printf(' The exergy destruction rate for the pump in MW is : %.2f ',EddotP)
printf('and expressing this as a percentage of the exergy entering the plant as calculated above, we have %.2f',(EddotP/231.28)*69)
printf(' The net power output of the vapor power plant of Example 8.2 is 100 MW. Expressing this as a percentage of the rate at which exergy is ')
printf('carried into the plant with the fuel, %.2f',(100/231.28)*69)
```

Scilab code Exa 8.9 Example

```

// Given:-
T0 = 295                                        // in kelvin
// Analysis
// From solution to Example 8.2.
mcwdot = 9.39e6                                 // mass flow rate of the cooling water in kg/h

// Part(a)
// With saturated liquid values for specific enthalpy and entropy from Table A-2
he = 146.68
```

```
   // in kj/kg
hi = 62.99

   // in kj/kg
se = 0.5053

   // in kj/kg.k
si = 0.2245

   // in kj/kg.k
// Calculations
Rout = mcwdot*(he-hi-T0*(se-si))/(3600*10**3)
                              // The net rate at
   which exergy is carried out of the condenser in
   MW
// Results
printf( ' The net rate at which exergy is carried
   from the condenser by the cooling water, is: %.2f
   MW. ',Rout)
printf( ' Expressing this as a percentage of the
   exergy entering the plant with the fuel, we get %
   .2f percent',(Rout/231.28)*69)

// Part(b)
// From table
s3 = 0.5926

   // in kj/kg.k
s2 = 6.2021

   // in kg/kg.k
mdot = 4.449e5

   // in kg/h
// Calculations
Eddot = T0*(mdot*(s3-s2)+mcwdot*(se-si))
   /(3600*10**3)                    // the rate of
```

```
   exergy destruction for the condenser in MW
// Results
printf('The rate of exergy destruction for the
   condenser is: %.2f MW.',Eddot)
printf('Expressing this as a percentage of the
   exergy entering the plant with the fuel, we get,
   %.2f percent',(Eddot/231.28)*69)
```

Chapter 9

Gas Power Systems

Scilab code Exa 9.1 Example

```
// Given:-
T1 = 300.00

   // The temperature at the beginning of the
   compression process in kelvin
p1 = 1.00

   // the pressure at the beginning of the
   compression process in bar
r = 8.00

   // compression ratio
V1 = 560.00

   // the volume at the beginning of the compression
    process in cm^3
T3 = 2000.00

   // maximum temperature during the cycle in kelvin

// Part(a)
```

```
// At T1 = 300k,table A-22 gives
u1 = 214.07          // in kj/kg
vr1 = 621.2
// Interpolating with vr2 in Table A-22, we get
T2 = 673.00          // in kelvin
u2 = 491.2           // in kj/kg
// At T3 = 2000 K, Table A-22 gives
u3 = 1678.7          // in kj/kg
vr3 = 2.776
// Interpolating in Table A-22 with vr4 gives
T4 = 1043            // in kelvin
u4 = 795.8           // in kj/kg

// Calculations
// For the isentropic compression Process 1   2
vr2 = vr1/r
// With the ideal gas equation of state
p2 = p1*(T2/T1)*(r)          // in bars
// Since Process 2   3 occurs at constant volume, the ideal gas equation of state gives
p3 = p2*(T3/T2)              // in bars
// For the isentropic expansion process 3   4
```

```
vr4 = vr3*(r)
// The ideal gas equation of state applied at states 1 and 4 gives
p4 = p1*(T4/T1)                                    // in bars

// Results
printf('At state1, the pressure is: %f bar.',p1)
printf('At state1, the temperature is %f kelvin.',T1)
printf('At state2, the pressure is : %.3f bar.',p2)
printf('At state2, the temperature is %f kelvin.',T2)
printf('At state3, the pressure is : %.3f bar.',p3)
printf('At state3, the temperature is %f kelvin.',T3)
printf('At state4, the pressure is : %.4f bar.',p4)
printf('At state4, the temperature is %f kelvin.',T4)

// Part(b)
eta = 1-(u4-u1)/(u3-u2)                            // thermal efficiency
// Result
printf('The thermal efficiency is : %.2f ',eta)

// Part(c)
R = 8.314                                          // universal gas constant, in SI units
M = 28.97                                          // molar mass of air in grams
```

```
// Calculations
m = ((p1*V1)/((R/M)*T1))*10**-6*10**5*10**-3                                    // mass of the air in kg
Wcycle = m*((u3-u4)-(u2-u1))                                                     // the net work per cycle in KJ
mep = (Wcycle/(V1*(1-1/r)))*10**6*10**3*10**-5                                   // in bars

// Result
printf(' The mean effective pressure, is : %.4f atm.',mep)
```

Scilab code Exa 9.2 Example

```

// Given :-
clc;
r = 18.00                                    // compression ratio
T1 = 300.00                                  // temperature at the beginning of the compression process in kelvin
p1 = 0.1                                     // pressure at the beginning of the compression process in MPa
rc = 2.00                                    // cutoff ratio

// Part(a)
```

```
// With T1 = 300 K, Table A-22 gives
u1 = 214.07                                           // in kj/kg
vr1 = 621.2
// Interpolating in Table A-22, we get
T2 = 898.3                                            // in kelvin
h2 = 930.98                                           // in kj/kg
// From Table A-22,
h3 = 1999.1                                           // in kj/kg
vr3 = 3.97

// Interpolating in Table A-22 with vr4, we get
u4 = 664.3                                            // in kj/kg
T4 = 887.7                                            // in kelvin

// Calculations
// Since Process 2  3 occurs at constant pressure, the ideal gas equation of state gives
T3 = rc*T2                                            // in kelvin
// With the ideal gas equation of state
p2 = p1*(T2/T1)*(r)                                   // in MPa
p3 = p2
// For the isentropic compression process 1  2
```

```
vr2 = vr1/r
// For the isentropic expansion process 3  4
vr4 = (r/rc)*vr3
// The ideal gas equation of state applied at states 1 and 4 gives
p4 = p1*(T4/T1)                                     // in MPa

// Results
printf( '\n At state1 , the pressure is : %.2f bar.', p1)
printf( '\n At state1 , the temperature is %.2f kelvin.' ,T1)
printf( '\n At state2 , the pressure in bar is : %.2f bar.',p2)
printf( '\n At state2 , the temperature is  %.2f kelvin.',T2)
printf( '\n At state3 , the pressure in bar is : %.2f bar.',p3)
printf( '\n At state3 , the temperature is %.2f kelvin.',T3)
printf( '\n At state4 , the pressure is: %.2f MPa.', p4)
printf( '\n At state4 , the temperature is %.2f kelvin.',T4)

// Part(b)
eta = 1- (u4-u1)/(h3-h2)
printf( '\n The thermal efficiency is : %.2f ',eta)

// Part(c)
R = 8.314                                           // universal gas constant , in SI units
M = 28.97                                           // molar mass of air in grams
```

```

// Calculations
wcycle = (h3-h2)-(u4-u1)
    // The net work of the cycle in kj/kg
v1 = ((R/M)*T1/p1)/10**3
    // The specific volume at state 1 in m^3/kg
mep = (wcycle/(v1*(1-1/r)))*10**3*10**-6
                                                     // in MPa

// Results
printf( '\n The mean effective pressure , is : %.2f
   MPa.',mep)
```

Scilab code Exa 9.3 Example

```
// Given :-
T1 = 300.00
    // beginning temperature in kelvin
p1 = 0.1
    // beginning pressure in MPa
r = 18.00
    // compression ratio
pr = 1.5
    // The pressure ratio for the constant volume
    part of the heating process
vr = 1.2
    // The volume ratio for the constant pressure
    part of the heating process
```

```

// Analysis
// States 1 and 2 are the same as in Example 9.2, so
u1 = 214.07

   // in kj/kg
T2 = 898.3

   // in kelvin
u2 = 673.2

   // in kj/kg

// Interpolating in Table A-22, we get
h3 = 1452.6

   // in kj/kg
u3 = 1065.8

   // in kj/kg

// From Table A-22,
h4 = 1778.3

   // in kj/kg
vr4 = 5.609

// Interpolating in Table A-22, we get
u5 = 475.96

   // in kj/kg

// Calculations
// Since Process 2  3 occurs at constant volume,
   the ideal gas equation of state reduces to give
T3 = pr*T2

   // in kelvin
```

```
// Since Process 3  4 occurs at constant pressure, the ideal gas equation of state reduces to give
T4 = vr*T3                                                  // in kelvin
// Process 4  5 is an isentropic expansion, so
vr5 = vr4*r/vr

// Part(a)
eta = 1-(u5-u1)/((u3-u2)+(h4-h3))
// Result
printf('The thermal efficiency is : %.2f',eta)

// Part(b)
// The specific volume at state 1 is evaluated in Example 9.2 as
v1 = 0.861                                                  // in m^3/kg
mep = (((u3-u2)+(h4-h3)-(u5-u1))/(v1*(1-1/r)))*10**3*10**-6                      // in MPa

// Result
printf('The mean effective pressure, is : %.2f MPa.',mep)
```

Scilab code Exa 9.4 Example

```
// Given:-
T1 = 300.00                                                 // in kelvin
AV = 5.00                                                   // volumetric flow rate in m^3/s
```

```
p1 = 100.00

   // in kpa
pr = 10.00

   // compressor pressure ratio
T3 = 1400.00

   // turbine inlet temperature in kelvin

// Analysis
// At state 1, the temperature is 300 K. From Table
   A-22,
h1 = 300.19

   // in kj/kg
pr1 = 1.386


// Interpolating in Table A-22,
h2 = 579.9

   // in kj/kg
// From Table A-22
h3 = 1515.4

   // in kj/kg
pr3 = 450.5

// Interpolating in Table A-22, we get
h4 = 808.5

   // in kj/kg

// calculations
pr2 = pr*pr1
pr4 = pr3*1/pr

```

```

// Part(a)
eta = ((h3-h4)-(h2-h1))/(h3-h2)            // thermal efficiency
// Result
printf(' The thermal efficiency is : %.4f ',eta)

// Part(b)
bwr = (h2-h1)/(h3-h4)            // back work ratio
// Result
printf(' The back work ratio is : %.4f',bwr)

// Part(c)
R = 8.314            // universal gas constant, in SI units
M = 28.97            // molar mass of air in grams
// Calculations
mdot = AV*p1/((R/M)*T1)            // mass flow rate in kg/s
Wcycledot = mdot*((h3-h4)-(h2-h1))            // The net power developed
// Result
printf(' The net power developed, is : %.2f kW.',Wcycledot)
```

Scilab code Exa 9.6 Example

```
// Given:-
T1 = 300.00

   // in kelvin
AV = 5.00

   // volumetric flow rate in m^3/s
p1 = 100.00

   // in kpa
pr = 10.00

   // compressor pressure ratio
T3 = 1400.00

   // turbine inlet temperature in kelvin
Wt_ms = 706.9

   // kJ/kg
Wc_m = 279.7
// Analysis
// At state 1, the temperature is 300 K. From Table
   A-22,
h1 = 300.19

   // in kj/kg
pr1 = 1.386


// Interpolating in Table A-22,
h2 = 579.9

   // in kj/kg
// From Table A-22
h3 = 1515.4

   // in kj/kg
pr3 = 450.5
```

```

// Interpolating in Table A-22, we get
h4 = 808.5          // in kj/kg

// calculations
Wtbym = 0.8*Wt_ms
Wcbym = Wc_m/0.8
h2 = 300.19 + Wcbym

//pr2 = pr*pr1
//pr4 = pr3*1/pr


// Part(a)
//eta = ((h3-h4)-(h2-h1))/(h3-h2)          // thermal efficiency
Qinbym = h3 - h2
n = (Wtbym-Wcbym)/Qinbym
// Result
printf( '\n The thermal efficiency is : %.3f ',n)

// Part(b)
//bwr = (h2-h1)/(h3-h4)          // back work ratio
bwr = Wcbym/Wtbym
// Result
printf( '\n The back work ratio is : %.3f',bwr)

// Part(c)
R = 8.314          // universal gas constant , in SI units
M = 28.97
```

```
    // molar mass of air in grams
// Calculations
//mdot = AV*p1/((R/M)*T1)

    // mass flow rate in kg/s
Wcycledot = 5.807*(Wcbym-Wtbym)
                                                            //
    The net power developed
// Result
printf( '\n The net power developed , is : %.f kW .'
    ,-Wcycledot)
```

Scilab code Exa 9.7 Example

```
// Given:-
// Part(a)
etareg = 0.8

    // regenerator effectiveness of 80%.
// From example 9.4
h1 = 300.19

    // in kj/kg
h2 = 579.9

    // in kj/kg
h3 = 1515.4

    // in kj/kg
h4 = 808.5

    // in kj/kg

// Calculations
hx = etareg*(h4-h2)+h2
```

```
    // in kj/kg
eta = ((h3-h4)- (h2-h1))/(h3-hx)

    // thermal efficiency
// Result
printf('The thermal efficiency is:  %.2f',eta)

// Part(b)

etareg = linspace(0,0.8,50)
for i = 1:50
    x(i) = (etareg(i)*(h4-h2))+h2
    eta(i) = ((h3-h4)- (h2-h1))/(h3-x(i))
end

plot(etareg,eta)
xlabel('Regenerator effectiveness')
ylabel('Thermal efficiency')
```

Scilab code Exa 9.8 Example

```
// Given:-
// Analysis
// States 1, 2, and 3 are the same as in Example
    9.4:
h1 = 300.19

    // in kj/kg
h2 = 579.9

    // in kj/kg
h3 =  1515.4

    // in kj/kg
```

```
// The temperature at state b is the same as at state 3, so
hb = h3

pa = 300.00                                              // in kpa
p3 = 1000.00                                             // in kpa
// From table A-22
pr3 = 450.5

// Interpolating in Table A-22, we get
ha = 1095.9                                              // in kj/kg
p4 = 100.00                                              // in kpa
pb = 300.00                                              // in kpa
// Interpolating in Table A-22, we obtain
h4 = 1127.6                                              // in kj/kg

// Calculions
pra = pr3*(pa/p3)
prb = pra
pr4 = prb*(p4/pb)
// Since the regenerator effectiveness is 100%,
hx = h4
eta = ((h3-ha)+(hb-h4)-(h2-h1))/((h3-hx)+(hb-ha))                                  // thermal efficiency

```

```
// Result
printf(' The thermal efficiency is : %.2f ', eta)
```

Scilab code Exa 9.9 Example

```
// Given:-
T1 = 300.00

    // in kelvin
p1 = 100.00

    // in kpa
p2 = 1000.00

    // in kpa
p3 = p2
pc = 300.00

    // in kpa
pd = 300.00

    // in kpa
Td = 300.00

    // in kelvin


// Part(a)
// From table A-22
prd = 1.386
// Interpolating in Table A-22, we get
T2 = 422

    // in kelvin
h2 = 423.8
```

```
// in kj/kg
// Calculations
pr2 = prd*(p2/pd)
// Result
printf(' The temperature at the exit of the second compressor stage  is : %.2f kelvin.',T2)

// Part(b)
// From Table A-22 at T1 = 300
h1 = 300.19                                 // in kj/kg
// Since Td = T1,
hd = 300.19                                 // in kj/kg
// with pr data from Table A-22 together
pr1 = 1.386
// Interpolating in Table A-22, we obtain
hc = 411.3                                  // in kj/kg
// Calculations
prc = pr1*(pc/p1)
wcdot = (hc-h1)+(h2-hd)                     // The total compressor work per unit of mass in kj/kg
// Result
printf(' The total compressor work input per unit of mass flow is : %.2f kJ/kg',wcdot)

// Part(c)
// Interpolating in Table A-22, we get
T3 = 574                                    // in kelvin
```

```
h3 = 579.9

   // in kj/kg
// Calculations
pr3 = pr1*(p3/p1)
wcdot = h3-h1

   // The work input for a single stage of
   compression in kj/kg
// Results
printf(' For a single stage of compression, the
   temperature at the exit state is : %.2f kelvin',
   T3)
printf(' For a single stage of compression, the
   work input is : %.2f kJ.',wcdot)
```

Scilab code Exa 9.11 Example

```
// Given:-
T1 = 300.00

   // in kelvin
p1 = 100.00

   // in kpa
mdot = 5.807

   // in kg/s
p2 = 300.00

   // in kpa
p3 = p2
p4 = 1000.00

   // in kpa
```

```
p5 = p4
p6 = p4
T6 = 1400.00

   // in kelvin
T8 = T6
p7 = 300.00

   // in kpa
p8 = p7
etac = 0.8

   // isentropic efficiency of compressor
etat = 0.8

   // isentropic efficiency of turbine
etareg = 0.8

   // regenerator effectiveness
// Analysis
// From example 9.9
h1 = 300.19

   // in kj/kg
h3 = h1

   // in kj/kg
h2s = 411.3

   // in kj/kg
h4s = 423.8

   // in kj/kg
// From example 9.8
h6 = 1515.4

   // in kj/kg
h8 = h6
```

```
h7s = 1095.9
   // in kj/kg
h9s = 1127.6
   // in kj/kg

// Calculations
h4 = h3 + (h4s-h3)/etac
   // in kj/kg
h2 = h1 + (h2s-h1)/etac
   // in kj/kg
h9 = h8-etat*(h8-h9s)
   // in kj/kg
h7 = h6-etat*(h6-h7s)
   // in kj/kg
h5 = h4+etareg*(h9-h4)
   // in kj/kg

// Part(a)
// Calculations
wtdot = (h6-h7)+(h8-h9)
   // The total turbine work per unit of mass flow
   in kj/kg
wcdot = (h2-h1)+(h4-h3)
   // The total compressor work input per unit of
   mass flow in kj/kg
qindot = (h6-h5)+(h8-h7)
   // The total heat added per unit of mass flow in
   kj/kg
```

```
eta = (wtdot-wcdot)/qindot
   // thermal efficiency
// Result
printf('The thermal efficiency is:  %.2f',eta)

// Part(b)
bwr = wcdot/wtdot
   // back work ratio
// Result
printf('The back work ratio is: %.2f',bwr)

// Part(c)
Wcycledot = mdot*(wtdot-wcdot)
   // net power developed in kw
// Result
printf('The net power developed, is: %.2f kW.',
   Wcycledot)
```

Scilab code Exa 9.12 Example

```
// Given:-
Ta = 240.00
   // in kelvin
pa = 0.8
   // in bar
Va = 278.00
   // in m/s
PR = 8.00
```

```
    // pressure ratio across the compressor
T3 = 1200.00

    // in kelvin
p5 = 0.8

    // in bar

// From table A-22
ha = 240.02

    // in kj/kg
h1 = ha + ((Va**2)/2)*10**-3

    // in kj/kg
// Interpolating in Table A-22 gives
pr1 = 1.070
pra = .6355

// Interpolating in Table A-22, we get
h2 = 505.5

    // in kj/kg
// At state 3 the temperature is given as T3 = 1200
   K. From Table A-22
h3 = 1277.79

    // in kj/kg


// Interpolating in Table A-22 with h4, gives
pr4 = 116.8
// pr data from table A-22 gives
pr4 = 116.00
pr3 = 238.00
// From table A-22
h5 = 621.3
```

```
        // in kj/kg

// The expansion through the nozzle is isentropic to
p5 = .8

        // in bars

// Calculations
p1 = (pr1/pra)*pa

        // in bars
// With the help of assumption, 'The turbine work
        output equals the work required to drive the
        compressor.',
h4 = h3+h1-h2

        // in kj/kg
p2 = PR*p1

        // in bars
// Using assumption 'There is no pressure drop for
        flow through the combustor',
p3 = p2
p4 = p3*(pr4/pr3)

        // in bars
pr5 = pr4*(p5/p4)
V5 = ((2*(h4-h5)*10**3))**(0.5)

        // the velocity at the nozzle exit in m/s

// Results
printf(' The velocity at the nozzle exit in m/s is:
        %.2f', V5)
printf(' pa in bars = %.2f',pa)
printf(' p1 in bars = %.2f',p1)
printf(' p2 in bars = %.2f',p2)
printf(' p3 in bars = %.2f',p3)
```

```
printf( ' p4 in bars = %.2f',p4)
printf( ' p5 in bars = %.2f',p5)
```

Scilab code Exa 9.13 Example

```
// Given:-
Wnetdot = 45.00
    // in MW
T1 = 300.00
    // in kelvin
p1 = 100.00
    // in kpa
etac = 0.84
    // The isentropic efficiency of the compressor
T3 = 1400.00
    // in kelvin
p2 = 1200.00
    // in kpa
p3 = p2
etat = 0.88
    // isentropic efficiency of the turbine
T5 = 400.00
    // in kelvin
p4 = 100.00
    // in kpa
p5 = p4
```

```
T7 = 400.00

   // in degree celcius
p7 = 8.00

   // in MPa
etatw =0.9

   // isentropic efficiency of turbine of the vapor
   cycle
p8 = 8.00

   // in kpa
p9 = p8
etap = 0.8

   // isentropic efficiency of pump of the vapor
   cycle
T0 = 300.00

   // in kelvin
p0 = 100.00

   // -in kpa

// Analysis
// With procedure similar to that used in the
   examples of chapters 8 and 9,we can determine
   following property data
h1 = 300.19

   // in kj/kg
h2 = 669.79

   // in kj/kg
h3 = 1515.42

   // in kj/kg
```

```
h4 = 858.02
     // in kj/kg
h5 = 400.98
     // in kj/kg
h6 = 183.96
     // in kj/kg
h7 = 3138.30
     // in kj/kg
h8 = 2104.74
     // in kj/kg
h9 = 173.88
     // in kj/kg
s1 = 1.7020
     // in kj/kg.k
s2 = 2.5088
     // in kj/kg.k
s3 = 3.3620
     // in kj/kg.k
s4 = 2.7620
     // in kj/kg.k
s5 = 1.9919
     // in kj/kg.k
s6 = 0.5975
     // in kj/kg.k
s7 = 6.3634
```

```
                                        // in kj/kg.k
s8 = 6.7282                             // in kj/kg.k
s9 = 0.5926                             // in kj/kg.k

// Part(a)
// By applying mass and energy rate balances
// Calculations
mvdotbymgdot = (h4-h5)/(h7-h6)          // ratio of mass flow rates of vapor and air
mgdot = (Wnetdot*10**3)/(((h3-h4)-(h2-h1)) + mvdotbymgdot*((h7-h8)-(h6-h9)))        // mass flow rate of air in kg/s
mvdot = mvdotbymgdot*mgdot              // mass flow rate of vapor in kg/s
Wgasdot = mgdot*((h3-h4)-(h2-h1))*10**-3                                            // net power developed by gas turbine in MW
Wvapdot = mvdot*((h7-h8)-(h6-h9))*10**-3                                            // net power developed by vapor cycle in MW

// Results
printf(' Mass flow rate of air is: %.2f kg/s.',mgdot)
printf(' Mass flow rate of vapor is: %.2f kg/s.',mvdot)
printf(' Net power developed by gas turbine is: %.2f MW.',Wgasdot)
printf(' Net power developed by vapor cycle is: %.2f MW.',Wvapdot)


```

```
// Part(b)

// The net rate of exergy increase of the air passing through the combustor is
Edotf32 = mgdot*(h3-h2-T0*(s3-s2))*10**-3 // in MW
// The net rate exergy is carried out by the exhaust air stream at 5 is
Edotf51 = mgdot*(h5-h1-T0*(s5-s1))/10**3 // in MW
// The net rate exergy is carried out as the water passes through the condenser is
Edotf89 = mvdot*(h8-h9-T0*(s8-s9))*10**-3 // in MW
R = 8.314 // universal gas constant, in SI units
M = 28.97 // molar mass of air in grams
// The rate of exergy destruction for air turbine is
Eddott = mgdot*T0*(s4-s3-(R/M)*log(p4/p3))/10**3 // in MW
// The rate of exergy destruction for compressor is
Eddotc = mgdot*T0*(s2-s1-(R/M)*log(p2/p1))/10**3 // in MW
// The rate of exergy destruction for steam turbine is
Eddotst = mvdot*T0*(s8-s7)/10**3 // in MW
// The rate of exergy destruction for pump is
Eddotp = mvdot*T0*(s6-s9)/10**3 // in MW
// For heat exchanger
EddotHE = T0*(mgdot*(s5-s4)+mvdot*(s7-s6))/10**3
```

```
                                        // in MW

// Results
printf(' Balance sheet')
printf('Net exergy increase of the gas passing')
printf(' Through the combustor: %.2f MW',Edotf32)
printf('Disposition of the exergy:')
printf('    Net power developed')
printf('gas turbine cycle %.2f MW',Wgasdot)
printf('vapor cycle %.2f MW',Wvapdot)
printf('    Net exergy lost')
printf('with exhaust gas at state 5 %.2f MW',
   Edotf51)
printf('from water passing through condenser %.2f
   MW',Edotf89)
printf('    Exergy destruction')
printf('air turbine %.2f MW',Eddott)
printf('compressor %.2f MW',Eddotc)
printf('steam turbine %.2f MW',Eddotst)
printf('pump %.2f MW',Eddotp)
printf('heat exchanger %.2f MW',EddotHE)
```

Scilab code Exa 9.14 Example

```

// Given:-
Tnot = 360.00

    // in kelvin
pnot = 1.00

    // in MPa
A2 = 0.001

    // in m^2
```

```
k = 1.4

// Calculations
pstarbypnot = (1+(k-1)/2)**(k/(1-k))
pstar =  pstarbypnot*pnot

// Part(a)
// Since back pressure of 500 kpa is less than critical pressure pstar(528kpa in this case) found above, the nozzle is choked
// At the exit
M = 1.00
p2 = pstar                                    // in MPa
T2 = Tnot/(1+((k-1)/2)*(M**2))                // exit temperature in kelvin
R = 8.314                                     // universal gas constant, in SI units
Mwt = 28.97                                   // molar mass of air in grams
V2 = ((k*(R/Mwt)*T2*10**3)**0.5)              // exit velocity in m/s
mdot = (p2/((R/Mwt)*T2))*A2*V2*10**3                                    // mass flow rate in kg/s

// Results
printf(' The exit mach number for back pressure of 500kpa is: %.2f',M)
printf(' The mass flow rate in kg/s for back pressure of 500kpa is: %.2f',mdot)

// Part(b)
```

```
// Since the back pressure of 784kpa is greater than critical pressure of pstar determined above,the flow throughout the nozzle is subsonic and the exit pressure equals the back pressure,
p2 = 784.00                                 // exit pressure in kpa
// Calculations
M2 = (((2.00)/(k-1))*(((pnot*10**3)/p2)**((k-1)/k)-1))**0.5                              // exit mach number
T2 = Tnot/(1+((k-1)/2)*(M2**2))                              // exit temperature in kelvin
V2 = M2*((k*(R/Mwt)*10**3*T2)**0.5)                                                       // exit velocity in m/s
mdot2 = (p2/((R/Mwt)*T2))*A2*V2                              // mass flow rate in kg/s
// Results
printf(' The mass flow rate at the exit for back pressure of 784kpa is: %.2f kg/s.',mdot2)
printf(' The exit mach number for back pressure of 784 kpa is: %.2f',M2)
```

Scilab code Exa 9.15 Example

```
// Given:-
// Part(a)
Mt = 0.7                                     // mach mumber at the throat
At = 6.25
```

```
    // throat area in cm^2
Ae = 15.00
    // exit area in cm^2

// The flow throughout the nozzle, including the exit, is subsonic. Accordingly, with this value for A2byAstar, Table 9.1 gives
M2 = 0.24
// For M2 = 0.24,
T2byTnot = 0.988
p2bypnot = 0.959
k = 1.4
T0 = 280.00
    // in kelvin
pnot = 6.8
    // in bars
// Calculations
// With Mt = 0.7, Table 9.1 gives
AtbyAstar = 1.09437
A2byAstar = (Ae/At)*AtbyAstar
T2 = T2byTnot*T0
    // in kelvin
p2 = p2bypnot*pnot
    // in bars
V2 = M2*((k*(8.314/28.97)*T2*10**3)**0.5)                                        // velocity at the exit in m/s
mdot = (p2/((8.314/28.97)*T2))*Ae*V2*10**-2                                    // mass flow rate in kg/s
// Results
printf(' Part(a) the mass flow rate in kg/s is: %.2f',mdot)
```

```
printf(' The exit pressure in bars is:  %.2f',p2)
printf(' The exit mach number is:  %.2f',M2)

// Part(b)
Mt = 1.00

   // mach number at the throat
// From table 9.1
M2 = 0.26
T2byTnot = 0.986
p2bypnot = 0.953

T0 = 280.00

   // in kelvin
pnot = 6.8

   // in bars
// Calculations
T2 = T2byTnot*T0

   // in kelvin
p2 = p2bypnot*pnot

   // in bars
k = 1.4
V2 = M2*((k*(8314/28.97)*T2)**0.5)

   // exit velocity in m/s
mdot = (p2/((8.314/28.97)*T2))*Ae*V2*10**-2
                                          // mass flow
    rate in kg/s
// Results
printf(' Part(b)  the mass flow rate  is:  %.f kg/s
   .',mdot)
printf(' The exit pressure is: %f bars. ',p2)
printf(' The exit mach number is:  %f',M2)

```

```
// Part(c)
// From part (b), the exit Mach number in the present part of the example is
M2 = 2.4
// Using this, Table 9.1 gives
p2bypnot = 0.0684
pnot = 6.8                                    // in bars
// Calculation
p2 = p2bypnot*pnot                            // in bars
// Results
// Since the nozzle is choked, the mass flow rate is the same as found in part (b).
printf(' Part(c)  the mass flow rate is:  %f kg/s.',mdot)
printf(' The exit pressure is:  %f bars.',p2)
printf(' The exit mach number is:  %f',M2)

// Part(d)
// Since a normal shock stands at the exit and the flow upstream of the shock is isentropic, the Mach number Mx and the pressure px correspond to the values found in part (c),
Mx = 2.4
px = 0.465                                    // in bars
// Then, from Table 9.2
My = 0.52
//py is the exit pressure
pybypx = 6.5533
py = px*pybypx

// The pressure downstream of the shock is thus 3.047 bars. This is the exit pressure
```

```
// The mass flow is the same as found in part (b).
// Results
printf(' Part(d) the mass flow rate is: %f kg/s.',mdot)
printf(' The exit pressure is: %.3f bars.',py)
printf(' The exit mach number is: %f',My)

// Part(e)
// A shock stands in the diverging portion where the area is
Ax = 12.5                                                    // in cm^2
// Since a shock occurs, the flow is sonic at the throat, so
Axstar = 6.25                                                // in cm^2
At = Axstar
// The Mach number Mx can then be found from Table 9.1, by using AxbyAxstar as
Mx = 2.2

// Results
// With Mx = 2.2, the ratio of stagnation pressures is obtained from Table 9.2 as
pnotybypnotx = 0.62812

// Using this ratio and noting that the flow is subsonic after the shock, Table 9.1 gives
M2 = 0.43
// For M2 = 0.43,
p2bypnoty = 0.88
// Calculations
A2byAystar = (Ae/Axstar)*pnotybypnotx
p2 = p2bypnoty*pnotybypnotx*pnot                             // in bars
```

```

// Results
// Since the flow is choked, the mass flow rate is the same as that found in part (b).
printf(' part(e)  the mass flow rate is: %f kg/s.',mdot)
printf(' the exit pressure is:  %f bars',p2)
printf(' the exit mach number is:  %f',M2)
```

Chapter 10

Refrigeration and Heat Pump Systems

Scilab code Exa 10.1 Example

```
// Given:-
Tc = 273.00
    // temperature of cold region in kelvin
Th = 299.00
    // temperature of hot region in kelvin
mdot = 0.08
    // mass flow rate in kg/s

// Analysis
// At the inlet to the compressor, the refrigerant
    is a saturated vapor at 0C, so from Table A-10
h1 = 247.23
    // in kj/kg
s1 = 0.9190
```

```
// in kj/kg.k

// The pressure at state 2s is the saturation pressure corresponding to 26C, or
p2 = 6.853 // in bars
// The refrigerant at state 2s is a superheated vapor with
h2s = 264.7 // in kj/kg
// State 3 is saturated liquid at 26C, so
h3 = 85.75 // in kj/kg
h4 = h3 // since The expansion through the valve is a throttling process

// Part(a)
Wcdot = mdot*(h2s-h1) // The compressor work input in KW
printf(' The compressor power, in kW, is: %.2f',Wcdot)

// Part(b)
Qindot = mdot*(h1-h4)*60/211 // refrigeration capacity in ton
printf(' The refrigeration capacity in tons is: %.2f',Qindot)

// Part(c)
beta1 = (h1-h4)/(h2s-h1)
printf(' The coefficient of performance is: %.2f',
```

```
   beta1)

// Part(d)
betamax = Tc/(Th-Tc)
printf('The coefficient of performance of a Carnot
    refrigeration cycle operating between warm and
   cold regions at 26 and 0C, respectively is: %.2f
   ',betamax);
```

Scilab code Exa 10.2 Example

```
// Given:-
mdot = 0.08

   // mass flow rate in kg/s
// Analysis
// At the inlet to the compressor, the refrigerant
   is a saturated vapor at 10C, so from Table A-10,
h1 = 241.35

   // in kj/kg
s1 = .9253

   // in kj/kg.k
// Interpolating in Table A-12 gives
h2s = 272.39

   // in kj/kg.k
// State 3 is a saturated liquid at 9 bar, so
h3 = 99.56

   // in kj/kg
h4 = h3

   // since The expansion through the valve is a
```

```
throttling process

// Part(a)
Wcdot = mdot*(h2s-h1)   // The compressor power input in KW
// Result
printf( ' \nThe compressor power in kw is:  %.2f', Wcdot)

// Part(b)
Qindot = mdot*(h1-h4)*60/211   // refrigeration capacity in tons
// Result
printf( ' \nThe refrigeration capacity in tons is:  %.2f',Qindot)

// Part(c)
beta1 = (h1-h4)/(h2s-h1)
// Result
printf( ' \nThe coefficient of performance is:  %.2f',beta1)
```

Scilab code Exa 10.3 Example

```
// Given:-
Tnot = 299   //in kelvin
etac = .8   //compressor efficiency of 80 percent
mdot = .08
```

```
   //mass flow rate in kg/s
//analysis
//State 1 is the same as in Example 10.2, so
h1 = 241.35

   //in kj/kg
s1 = .9253

   //in kj/kg.k
//from example 10.2
h2s = 272.39

   //in kj/kg
h2 =(h2s-h1)/etac + h1
                                                 //in
   kj/kg
//Interpolating in Table A-12,
s2 = .9497

   //in kj/kg.k
h3 = 91.49

   //in kj/kg
s3 = .3396
h4 = h3

   //since The expansion through the valve is a
   throttling process
//from data table
hf4 = 36.97

   //in kj/kg
hg4 = 241.36

   //in kj/kg
sf4 = .1486

   //in kj/kg.k
```

```
sg4 = .9253                                  //in kj/kg.k
x4 = (h4-hf4)/(hg4-hf4)                      //quality at state 4
s4 = sf4 + x4*(sg4-sf4)                      //specific entropy at state 4 in kj/kg.k

//part(a)
Wcdot = mdot*(h2-h1)                         //compressor power in kw
printf('The compressor power in kw is: %.2f kW',Wcdot)

//part(b)
Qindot = mdot*(h1-h4)*60/211                 //refrigeration capacity in ton
printf('The refrigeration capacity in ton is: %.2f ton',Qindot)

//part(c)
beta = (h1-h4)/(h2-h1)                       //coefficient of performance
printf('The coefficient of performance is: %.2f',beta)

//part(d)
Eddotc = mdot*Tnot*(s2-s1)                   //in kw
Eddotv = mdot*Tnot*(s4-s3)                   //in kw
printf('The rate of exergy destruction within the compressor is: %.2f kW',Eddotc)
```

```
printf( 'The rate of exergy destruction within the
   valve is: %.2f kw',Eddotv)
```

Scilab code Exa 10.4 Example

```
// Given:-
p1 = 1.00

   // in bar
T1 = 270.00

   // in kelvin
AV = 1.4

   // in m^3/s
r = 3.00

   // compressor pressure ratio
T3 = 300.00

   // turbine inlet temperature in kelvin

// Analysis
// From Table A-22,
h1 = 270.11

   // in kj/kg
pr1 = 0.9590
// Interpolating in Table A-22,
h2s = 370.1

   // in kj/kg
// From Table A-22,
h3 = 300.19
```

```
   // in kj/kg
pr3 = 1.3860
// Interpolating in Table A-22, we obtain
h4s = 219.00
   // in kj/kg
// Calculations
pr2 = r*pr1
pr4 = pr3/r

// Part(a)
R = 8.314
   // universal gas constant, in SI units
M = 28.97
   // molar mass of air in grams

// Results
mdot = (AV*p1)/((R/M)*T1)*10**2
   // mass flow rate in kg/s
Wcycledot = mdot*((h2s-h1)-(h3-h4s))
printf( ' The net power input in kw is: %.2f',
   Wcycledot)

// Part(b)
Qindot = mdot*(h1-h4s)
   // refrigeration capacity in kw
printf( ' The refregeration capacity in kw is: %.2f
   ',Qindot)

// Part(c)
beta = Qindot/Wcycledot
   // coefficient of performance
printf( 'The coefficient of performance is: %.2f',
```

```
   beta)
```

Scilab code Exa 10.5 Example

```
// Given:-
// Part(a)
wcdots = 99.99

   // work per unit mass for the isentropic
   compression determined with data from the
   solution in Example 10.4 in kj/kg
mdot = 1.807

   // mass flow rate in kg/s from 10.4
etac = 0.8

   // isentropic efficiency of compressor
Wcdot = (mdot*wcdots)/etac

   // The power input to the compressor in kw

// Using data form the solution to Example 10.4
   gives
wtdots =81.19

   // in kj/kg
etat = 0.8

   // isentropic efficiency of turbine
// Calculations
Wtdot = mdot*etat*wtdots

   // actual turbine work in kw
Wdotcycle = Wcdot-Wtdot
```

```
   // The net power input to the cycle in kw
// Result
printf( ' The net power input in kw is:  %.2f',
   Wdotcycle)

// Part(b)
h3 = 300.19

   // in kj/kg
// From table A-22
h1 = 270.11

   // in kj/kg
// Calculations
h4 = h3 -Wtdot/mdot
Qindot = mdot*(h1-h4)

   // refrigeration capacity in kw
// Result
printf( ' The refrigeration capacity in kw is:  %.2f
   ',Qindot)

// Part(c)
beta = Qindot/Wdotcycle

   // coefficient of performance
// Result
printf( ' The coefficient of performance is:  %.2f',
   beta)
```

Chapter 11

Thermodynamic Relations

Scilab code Exa 11.1 Example

```
// Given:-
m = 4.00

    // mass of carbon monoxide in kg
T = 223.00

    // temperature of carbon monoxide in kelvin
D = 0.2

    // inner diameter of cylinder in meter
L = 1.00

    // length of the cylinder in meter
pi=3.14
// Analysis
M = 28.00

    // molar mass in kg/kmol

// Calculations
V = (pi*D**2.00/4.00)*L
```

```
   // volume occupied by the gas in m^3
vbar = M*(V/m)

   // The molar specific volume in m^3/kmol

// Part(a)
// From Table A-1 for CO
Tc = 133

   // in kelvin
Pc = 35

   // in bar
Tr = T/Tc

   // reduced temperature
Rbar = 8314

   // universal gas constant in N.m/kmol.K
Z = 0.9
// Calculations
vrdash = (vbar*Pc*10**5)/(Rbar*Tc)                              //
   pseudoreduced specific volume
p = (Z*Rbar*T/vbar)*10**-5

   // in bar
// Result
printf( '\n part(a)the pressure in bar is:  %.2f bar
   ',p)

// Part(b)
// The ideal gas equation of state gives
// Calculations
p = (Rbar*T/vbar)/10**5

   // in bar
```

```
// Result
printf( '\n Part(b)the pressure in bar is: %.2f bar',p)

// Part(c)
// For carbon monoxide, the van der Waals constants a and b can be read directly from Table A-24
a = 1.474                      // in (m^3/kmol)^2
b = 0.0395                     // in m^3/kmol
// Calculations
p = (Rbar*T/(vbar-b))/10**5 - a/vbar**2
// Result
printf( '\n Part(c)the pressure in bars is:  %.2f bar',p)

// Part(d)
// For carbon monoxide, the Redlich Kwong constants can be read directly from Table A-24
a = 17.22                      // in m^6*K^.5/kmol^2
b = 0.02737                    // in m^3/kmol
// Calculations
p = (Rbar*T/(vbar-b))/10**5 - a/(vbar*(vbar+b)*T**.5)
// Result
printf( '\n Part(d)the pressure in bar is:  %.2f bar', p)
```

Scilab code Exa 11.3 Example

```
// Given:-
// Part(a)
v = 0.4646

   // specific volume in in m^3/kg
M = 18.02

   // molar mass of water in kg/kmol
// At the specified state, the temperature is 513 K
   and the specific volume on a molar basis is
vbar = v*M

   // in m^3/kmol
// From Table A-24
a = 142.59

   // (m^3/kmol)^2 * K^.5
b = 0.0211

   // in m^3/kmol

Rbar = 8314.0

   // universal gas constant in N.m/kmol.K
T = 513.0

   // in kelvin
delpbydelT = (Rbar/(vbar-b) + a/(2*vbar*(vbar+b)*T
   **1.5)*10**5)/10**3              // in kj/(m^3*K)

// By The Maxwell relation
delsbydelv = delpbydelT
// Result
printf(' The value of delpbydelT in kj/(m^3*K) is:
     %.2f',delpbydelT);

```

```
// Part(b)
// A value for (dels/delv)T can be estimated using a graphical approach with steam table data, as follows: At 240C, Table A-4 provides the values for specific entropy s and specific volume v tabulated below
T = 240.0                                          // in degree celcius
// At p =1, 1.5, 3, 5, 7, 10 bar respectively
y = [7.994, 7.805, 7.477, 7.230, 7.064, 6.882]
x = [2.359, 1.570, 0.781, 0.4646, 0.3292, 0.2275]
plot(x,y)
xlabel("Specific volume")
ylabel("Specific entropy")

// The pressure at the desired state is 5 bar.The corresponding slope is
delsbydelv = 1                                     // in kj/m^3.K
printf(' From the data of the table,delsbydelv = %.2f',delsbydelv);
```

Scilab code Exa 11.4 Example

```
// Given:-
// Analysis
// For comparison, Table A-2 gives at 100C,
hgf =2257.00                                       // in kj/kg
ugf = 2087.6                                       // in kj/kg
```

```
sgf = 6.048         // in kj/kg.K
// Values
printf(' From table, hg-hf = %.2f',hgf);
printf(' From table, ug-uf = %.2f',ugf);
printf(' From table, sg-sf = %.2f',sgf);

// Part(a)
T = 373.15          // in kelvin
// If we plot a graph between temperature and saturation pressure using saturation pressure temperature data from the steam tables, the desired slope is:
delpbydelT = 3570.00          // in N/(m^2.K)
vg = 1.673          // in m^3/kg
vf = 1.0435e-3          // in m^3/kg
// Calculations
// From the Clapeyron equation
hgf = T*(vg-vf)*delpbydelT*10**-3          // in kj/kg
// Result
printf('\n Part(a)using Clapeyron equation, hg-hf = %.2f KJ/kg', hgf);

// Part(b)
psat = 1.014e5          // in N/m^2
```

```
hgf = 2256.00
   // can be obtained using IT software in kj/kg
// Calculations
ugf = hgf - psat*(vg-vf)/10**3
   // in kj/kg
// Result
printf( '\n Part(b)ug−uf = %.2f KJ/kg',ugf)
// Part(c)
// Calculation
sgf =hgf/T
   // in kj/kg.K
// Result
printf( '\n Part(c)sg−sf = %.2f  KJ/kg. k',sgf)
```

Scilab code Exa 11.6 Example

```
// Given:−
// Part(a)
v = 1.00/998.21
   // specific volume of water in m^3/kg
T = 293.00
   // given temperature in kelvin
beta = 206.6e-6
   // volume expansivity in /K
k = 45.90e-6
   // isothermal compressibility in /bar
// Interpolating in Table A−19
cp = 4.188
```

```
// in kj/kg.k
// Calculations
cpv = (v*T*beta**2.00/k)*10**2 // in kj/kg.k
cv = cp-cpv // in kj/kg.k
errorPercentage = 100*(cp-cv)/cv
// Result
printf( ' The percentage error is: %.2f', errorPercentage)

// Part(b)
// Calculations
K = cp/cv // specific heat ratio
c = ((K*v/k)*10**5)**0.5 // velocity of sound in m/s
// Result
printf( ' The velocity of sound is: %.2f m/s',c)
```

Scilab code Exa 11.8 Example

```
// Given:-
p1 = 100.00 // in bar
T1 = 300.00 // in kelvin
p2 = 40.00
```

```
   // in bar
T2 = 245.00

   // in kelvin


// From table A-23
h1starbar = 8723.00

   // in kj/kmol
h2starbar = 7121.00

   // in kj/kmol
// From Tables A-1
Tc = 126.00

   // critical temperature in kelvin
pc = 33.9

   // critical pressure in bar
M = 28.00

   // molar mass in kg/kmol
Rbar = 8.314

   // universal gas constant in kj/(kmol.K)
Term1 = 0.5
Term2 = 0.31

// Calculations
TR1 = T1/Tc

   // reduced temperature at the inlet
PR1 = p1/pc

   // reduced pressure at the inlet
TR2 = T2/Tc
```

```
   // reduced temperature at the exit
PR2 = p2/pc

   // reduced pressure at the exit
wcvdot = (1.00/M)*(h1starbar-h2starbar-Rbar*Tc*(
   Term1-Term2))                          // in kj/kg

// Result
printf( ' The work developed , in kJ per kg of
   nitrogen flowing is :  %.2f',wcvdot)
```

Scilab code Exa 11.9 Example

```

// Given:-
// Part(a)
// With values from Table A-23
sT2bar = 185.775

   // in kj/(kmol.K)
sT1bar = 191.682

   // in kj/(kmol.K)
Rbar = 8.314

   // universal gas constant
M = 28.00

   // molar mass in kg/kmol
p2 = 40.00

   // in bar
p1 = 100.00
```

```
                                    // in bar
Term1 = 0.21
Term2 = 0.14

// Calculations

S2StarBarMinusS1StarBar = sT2bar-sT1bar-Rbar*log(p2/p1)                    // The change in specific entropy in kj/(kmol.K)
sigmacvdot = (1.00/M)*(S2StarBarMinusS1StarBar-Rbar*(Term2-Term1))
// Result
printf(' the rate of entropy production in kj/kg.K is: %.2f', sigmacvdot)

// Part(b)
// From Table A-23,
h2starbar = 6654.00                                    // in kj/kmol
h1starbar = 8723.00                                    // in kj/kmol
Tc = 126.00                                    // critical temperature in kelvin
Term2 = 0.36
Term1 = 0.5
wcvdot = 50.1                                    // from example 11.8

// Calculations
wcvdots = (1.00/M)*(h1starbar-h2starbar-Rbar*Tc*(Term1-Term2))                         // isentropic work in kj/kg
etat = wcvdot/wcvdots
```

```
    // turbine efficiency

// Result
printf(' The isentropic turbine efficiency is: %.2f
    ', etat)
```

Scilab code Exa 11.10 Example

```

// Given:-
// Analysis
V = 0.241

    // volume of the mixture in m^3
T = 511.00

    // temperature of the mixture in kelvin
n1 = 0.18

    // number of moles of methane in kmol
n2 = 0.274

    // number of moles of butane in kmol
Rbar = 8314

    // universal gas constant in (N.m)/(kmol.K)

// Calculations
n = n1 + n2

    // The total number of moles of mixture
y1 = n1/n

    // mole fraction of methane
y2 = n2/n
```

```
    // mole fraction of butane
vbar = V/(n)

    // The specific volume of the mixture on a molar
    basis in m^3/kmol

// Part(a)
p = (Rbar*T/vbar)*10**-5

    // in bar
// Result
printf('The pressure in bar obtained using ideal
    gas equation is: %.2f',p)

// Part(b)
// From table A-1
Tc1 = 191.00

    // critical temperature for methane in kelvin
Pc1 = 46.4

    // critical pressure for methane in bar
Tc2 = 425.00

    // critical temperature for butane in kelvin
Pc2 = 38.00

    // critical pressure for butane in bar
Z = 0.88


// Calculations
Tc = y1*Tc1 + y2*Tc2

    // critical temperature in kelvin
Pc = y1*Pc1 + y2*Pc2
```

```
   // critical pressure in bar
TR = T/Tc

   // reduced temperature of the mixture
vRdash= vbar*Pc/(Rbar*Tc)
p = ((Z*Rbar*T)/vbar)*10**-5

   // mixture pressure in bar
// Result
printf( ' Pressure obtained using Kay s rule
   together with the generalized compressibility
   chart , is: %.2f ',p)

// Part(c)
// Table A-24 gives the following van der Waals
   constants values for methane
a1 = 2.293

   // in (m^3/kmol)^2
b1 = 0.0428

   // in m^3/kmol
// Table A-24 gives the following van der Waals
   constants values for butane
a2 = 13.86

   // in (m^3/kmol)^2
b2 = 0.1162

   // in m^3/kmol

a = (y1*a1**.5 + y2*a2**.5)**2

   // in bar*(m^3/kmol)^2
b = y1*b1+y2*b2

   // in m^3/kmol
// From van der Waals equation
```

```
p = ((Rbar*T)/(vbar-b))*10**-5 - a/(vbar**2)
printf(' The pressure in bar from van der Waals equation is:  %.2f',p)

// Part(d)
// For methane
TR1 = T/Tc1
vR1dash = (.241/.18)*10**5*Pc1/(Rbar*Tc1)
Z1 = 1.00
// For butane
TR2 = T/Tc2
vR2dash = (.88*10**5*Pc2)/(Rbar*Tc2)
Z2 = 0.8
Z = y1*Z1 + y2*Z2
// Accordingly, the same value for pressure as determined in part (b) using Kay s rule results:
p = 70.4

// Result
printf(' The pressure in bar obtained using the rule of additive pressures employing the generalized compressibility chart is: %.2f',p)
```

Chapter 12

Ideal Gas Mixtures and Psychrometrics Applications

Scilab code Exa 12.1 Example

```
// Given:-
n1 = 0.08
         // mole fraction of CO2
n2 = 0.11
         // mole fraction of H2O
n3 = 0.07
         // mole fraction of O2
n4 = 0.74
         // mole fraction of N2

// Part(a)
M1 = 44.0
         // molar mass of CO2 in kg/kmol
M2 = 18.0
```

```
   // molar mass of H2O in kg/kmol
M3 = 32.0

   // molar mass of O2 in kg/kmol
M4 = 28.0

   // molar mass of N2 in kg/kmol

// Calculations
M = M1*n1 + M2*n2 + M3*n3 + M4*n4
                                                  //
    in kg/kmol
// Result
printf( 'The apparent molecular weight of the
   mixture in kg/kmol is:  %f',M)

// Part(b)
mf1 = (M1*n1/M)*100.0

   // mass fraction of CO2 in percentage
mf2 = (M2*n2/M)*100.0

   // mass fraction of H2O in percentage
mf3 = (M3*n3/M)*100.0

   // mass fraction of O2 in percentage
mf4 = (M4*n4/M)*100.0

   // mass fraction of N2 in percentage

// Results
printf( 'The mass fraction of CO2 in percentage is:
    %f',mf1)
printf( 'The mass fraction of H2O in percentage is:
    %f',mf2)
printf( 'The mass fraction of O2 in percentage is:
   %f',mf3)
```

```
printf( 'The mass fraction of N2 in percentage is:
   %f',mf4)
```

Scilab code Exa 12.2 Example

```
// Given:-
mf1 = 0.1

   // mass fractiion of H2
mf2 = 0.6

   // mass fraction of N2
mf3 = 0.3

   // mass fraction of CO2

// Part(a)
M1 = 2.0

   // molar mass of H2 in kg/kmol
M2 = 28.0

   // molar mass of N2 in kg/kmol
M3 = 44.0

   // molar mass of CO2 in kg/kmol

// Calculations
n1 = (mf1/M1)/(mf1/M1 + mf2/M2 + mf3/M3)
                                                  // mole
   fraction of H2
n2 = (mf2/M2)/(mf1/M1 + mf2/M2 + mf3/M3)
                                                  // mole
   fraction of N2
n3 = (mf3/M3)/(mf1/M1 + mf2/M2 + mf3/M3)
```

```
                                                // mole fraction of CO2

// Results
printf( 'The mole fraction of H2 in percentage is: %f',n1*100)
printf( 'The mole fraction of N2 in percentage is: %f',n2*100)
printf( 'The mole fraction of CO2 in percentage is: %f',n3*100)

// Part(b)
// Calculation
M = n1*M1 + n2*M2 + n3*M3                          // in kg/kmol
// Result
printf( 'The apparent molecular weight of the mixture in kg/kmol is:  %f',M);
```

Scilab code Exa 12.3 Example

```
// Given:-
m1 = 0.3                                    // mass of CO2 in kg
m2 = 0.2                                    // mass of N2 in kg
p1 = 1.0                                    // in bar
T1 = 300.0                                  // in kelvin
```

```
p2 = 3.0                                              // in bar
n = 1.25

// Part(a)
// Calculation
T2 = T1*(p2/p1)**((n-1)/n)                            // in kelvin
// Result
printf( 'The final temperature in Kelvin is:  %f',T2 );

// Part(b)
Rbar = 8.314                                          // universal gas constant in SI units
// Calculations
M = (m1+m2)/(m1/44 + m2/28)                           // molar mass of mixture in kg/kmol
W = ((m1+m2)*(Rbar/M)*(T2-T1))/(1-n)                                          // in kj
// Result
printf( 'The work in kj is:  %f',W )

// Part(c)
// From table A-23
uCO2T1 = 6939.0                                       // internal energy of CO2 on molar mass basis at temperature T1
uCO2T2 = 9198.0                                       // internal energy of CO2 on molar mass basis at temperature T2
```

```
uN2T1 = 6229.0 // internal energy of N2 on molar mass basis at temperature T1
uN2T2 = 7770.0 // internal energy of N2 on molar mass basis at temperature T2
deltaU = (m1/44)*(uCO2T2-uCO2T1) + (m2/28)*(uN2T2-uN2T1) // internal energy change of the mixture in KJ

// With assumption, The changes in kinetic and potential energy between the initial and final states can be ignored
Q = deltaU + W
// Result
printf( 'The heat transfer in kj is: %f',Q);

// Part(d)
// From table A-23
sbarT2CO2 = 222.475
sbarT1CO2 = 213.915
sbarT2N2 = 198.105
sbarT1N2 = 191.682
Rbar = 8.314 // universal gas constant
// Calculation
deltaS = (m1/44)*(sbarT2CO2-sbarT1CO2-Rbar*log(p2/p1)) + (m2/28)*(sbarT2N2-sbarT1N2-Rbar*log(p2/p1))
// Result
printf( 'The change in entropy of the mixture in kj/k is: %f',deltaS)
```

Scilab code Exa 12.4 Example

```
// Given:-
y1 = 0.8

   // mole fraction of CO2
y2 = 0.2

   // mole fraction of O2
T1 = 700.0

   // in kelvin
p1 = 5.0

   // in bars
V1 = 3.0

   // in m/s
p2 = 1.0

   // in bars


// Part(a)
// From table A-23
sO2barT1 = 231.358
sCO2barT1 = 250.663
// Calculations

RHS = y2*sO2barT1 + y1*sCO2barT1 + 8.314*log(p2/p1)
// Using table A-23
LHSat510K = y2*221.206 + y1*235.7
LHSat520K = y2*221.812 + y1*236.575
// Using linear interpolation ,
T2 = 510 +((520-510)/(LHSat520K-LHSat510K))*(RHS-
   LHSat510K)
// Result
printf( 'The temperature at the nozzle exit in K is:
```

```
    %f',T2);

// Part(b)
// From table A-23
sbarO2T2 = 221.667
    // in kj/kmol.K
sbarO2T1 = 231.358
    // in kj/kmol.K
sbarCO2T2 = 236.365
    // in kj/kmol.K
sbarCO2T1 = 250.663
    // in kj/kmol.K
// Calculations
deltasbarO2 = sbarO2T2-sbarO2T1-8.314*log(p2/p1)
                              // in kj/kmol.K
deltasbarCO2 = sbarCO2T2-sbarCO2T1-8.314*log(p2/p1)
                           // in kj/kmol.K
// Results
printf( 'The entropy changes of the CO2 from inlet
   to exit , in KJ/Kmol.K is:  %f',deltasbarCO2)
printf( 'The entropy change of the O2 from inlet to
   the exit in kj/kmol.k is:  %f',deltasbarO2)

// Part(c)
// From table A-23, the molar specific enthalpies of
    O2 and CO2 are
h1barO2 = 21184.0
h2barO2 = 15320.0
h1barCO2 = 27125.0
h2barCO2 = 18468.0
// Calculations
M = y1*44.0 + y2*32.0
   // apparent molecular weight of the mixture in kg
```

```
   /kmol
deltah = (1.0/M)*(y2*(h1barO2-h2barO2) + y1*(
   h1barCO2-h2barCO2))
V2 = sqrt(V1**2+ 2*deltah*10**3)
// Result
printf( 'The exit velocity in m/s is:  %f',V2)
```

Scilab code Exa 12.5 Example

```
// Given:-
nN2 = 0.79

   // initial moles of nitrogen in kmol
pN2 = 2.0

   // initial pressure of nitrogen in bars
TN2 = 250.0

   // initial temperature of nitrogen in kelvin
nO2 = 0.21

   // initial moles of oxygen in kmol
pO2 = 1.0

   // initial pressure of oxygen in bars
TO2 = 300.0

   // initial temperature of oxygen in kelvin

// Part(a)
MN2 = 28.01

   // molar mass of nitrogen in kg/kmol
MO2 = 32.0
```

```
   // molar mass of oxygen in kg/kmol
// Calculations
// With the help of table A-20
cvbarN2 = MN2*0.743

   // in kj/kmol.K
cvbarO2 = MO2*0.656

   // in kj/kmol.K
T2 = (nN2*cvbarN2*TN2+nO2*cvbarO2*TO2)/(nN2*cvbarN2+
   nO2*cvbarO2)
// Result
printf('The final temperature of the mixture in
   kelvin is: %f',T2);

// Part(b)
// Calculation
p2 = ((nN2+nO2)*T2)/(nN2*TN2/pN2 + nO2*TO2/pO2)
// Result
printf('The final pressure of the mixture in bar is
   : %f',p2);

// Part(c)
Rbar = 8.314

   // universal gas constant
// Calculations
cpbarN2 = cvbarN2 + Rbar
cpbarO2 = cvbarO2 + Rbar
yN2 = nN2/(nN2+nO2)

   // mole fraction of N2
yO2 = nO2/(nN2+nO2)

   // mole fraction of O2
sigma = nN2*(cpbarN2*log(T2/TN2)-Rbar*log(yN2*p2/pN2
   )) + nO2*(cpbarO2*log(T2/TO2)-Rbar*log(yO2*p2/pO2
   ))
```

```
// Result
printf('The amount of entropy produced in the mixing process, in kJ/K is: %f',sigma);
```

Scilab code Exa 12.6 Example

```
// Given:-
T1 = 32.0                    // temperature of dry air in degree celcius
p1 = 1.0                     // pressure of dry air in bar
AV1 = 100.0                  // volume rate of dry air in m^3/min
T2 = 127.0                   // temperature of oxygen stream in degree celcius
p2 = 1.0                     // pressure of oxygen stream in bar
T3 = 47.0                    // temperature of mixed stream in degree celcius
p3 = 1.0                     // pressure of mixed stream in bar

// Part(a)
Rbar = 8314.0                // universal gas constant
Ma = 28.97
```

```
   // molar mass of air
Mo = 32.0

   // molar mass of oxygen
// From table A-22 and A-23
haT3 = 320.29

   // in kj/kg
haT1 = 305.22

   // in kj/kg
hnotT2 = 11711.0

   // in kj/kmol
hnotT1 = 9325.0

   // in kj/kmol

// Calculations
va1 = (Rbar/Ma)*(T1+273.0)/(p1*10**5)
                                                  //
   specific volume of air in m^3/kg
ma1dot = AV1/va1

   // mass flow rate of dry air in kg/min
modot = ma1dot*(haT3-haT1)/((1/Mo)*(hnotT2-hnotT1))
                                    // in kg/min
// Results
printf( 'The mass flow rate of dry air in kg/min is:
    %f',ma1dot);
printf( 'The mass flow rate of oxygen in kg/min is:
    %f',modot);

// Part(b)
nadot = ma1dot/Ma

   // molar flow rate of air in kmol/min
nodot = modot/Mo
```

```
    // molar flow rate of oxygen in kmol/min
ya = nadot/(nadot+nodot)

    // mole fraction of air
yo = nodot/(nadot+nodot)

    // mole fraction of oxygen
// Results
printf( 'The mole fraction of dry air in the exiting
     mixture is:  %f',ya)
printf( 'The mole fraction of dry oxygen in the
    exiting mixture is:  %f',yo)

// Part(c)
// With the help of tables A-22 and A-23
sanotT3 = 1.7669

    // in kj/kg.K
sanotT1 = 1.71865

    // in kj/kg.K
sbarT3 = 207.112

    // in kj/kmol.K
sbarT2 = 213.765

    // in kj/kmol.K
// Calculations
sigmadot = ma1dot*(sanotT3-sanotT1-(8.314/Ma)*log(ya
    ))+ (modot/Mo)*(sbarT3-sbarT2-8.314*log(yo))
// Result
printf( 'The time rate of entropy production, in kJ/
    K . min is:  %f',sigmadot)
```

Scilab code Exa 12.7 Example

```
// Given:-
m =1.0

   // mass of sample in kg
T1 = 21.0

   // initial temperature in degree celcius
psi1 = 0.7

   // initial relative humidity
T2 = 5.0

   // final temperature in degree celcius

// Part(a)
// From table A-2
pg = 0.02487

   // in bar
// Calculations
pv1 = psi1*pg

   // partial pressure of water vapor in bar
omega1 = 0.622*(0.2542)/(14.7-0.2542)
// Result
printf( 'the initial humidity ratio is:  %f',omega1)

// Part(b)
// The dew point temperature is the saturation
   temperature corresponding to the partial pressure
   , pv1. Interpolation in Table A-2 gives
T = 15.3

   // the dew point temperature in degree celcius
// Result
printf( 'The dew point temperature in degree celcius
```

```
    is:  %f',T)

// Part(c)
// The partial pressure of the water vapor remaining in the system at the final state is the saturation pressure corresponding to 5C:
// Calculations
mv1 = 1/((1/omega1)+1)                    // initial amount of water vapor in the sample in kg
ma = m-mv1                    // mass of dry air present in kg
pg = 0.00872                    // in bar
omega2 = 0.622*(pg)/(1.01325-pg)                    // humidity ratio after cooling
mv2 = omega2*ma                    // The mass of the water vapor present at the final state
mw = mv1-mv2

// Result
printf( 'The amount of water vapor that condenses, in kg. is:  %f',mw)
```

Scilab code Exa 12.8 Example

```

// Given:-
V = 35.0
```

```
   // volume of the vessel in m^3
p1 = 1.5

   // in bar
T1 = 120.0

   // in degree celcius
psi1 = 0.1
T2 = 22.0

   // in degree celcius

// Part(a)
// The dew point temperature at the initial state is
    the saturation temperature corresponding to the
   partial pressure pv1. With the given relative
   humidity and the saturation pressure at 120C from
    Table A-2
pg1 = 1.985
// Interpolating in Table A-2 gives the dew point
   temperature as
T = 60.0

   // in degree celcius
// Calculation
pv1 = psi1*pg1

   // partial pressure in bar
// Result
printf( 'The dew point temperature corresponding to
   the initial state, in degee celcius is: %f',T)

// Part(b)
Rbar = 8314.0

   // universal gas constant
Mv = 18.0
```

```
// molar mass of vapor in kj/kmol
// Interpolation in Table A-2
Tdash = 56.0    // in degrees
vv1 =((Rbar/Mv)*(T1+273))/(pv1*10**5)    // the specific volume of the vapor at state 1 in m^3/kg
// Result
printf( 'The temperature at which condensation actually begins in degree celcius is:  %f',Tdash)

// Part(c)
// From table
vf2 = 1.0022e-3
vg2 = 51.447
vv2 = vv1    // specific volume at final state
// Calculations
mv1 = V/vv1    // initial amount of water vapor present in kg
x2 = (vv2-vf2)/(vg2-vf2)    // quality
mv2 = x2*mv1    // the mass of the water vapor contained in the system at the final state
mw2 = mv1-mv2
// Result
printf( 'The amount of water condense in kg is:  %f',mw2)
```

Scilab code Exa 12.9 Example

```

// Given:-
V = 35.0
    // volume of vessel in m^3
p1 = 1.5
    // initial pressure in bar
T1 = 120.0
    // initial temperature in degree celcius
psi = 0.1
T2 = 22.0
    // in degree celcius
Rbar = 8314.0
    // universal gas constant
Ma = 28.97
    // molar mass of air
pv1 = 0.1985
    // in bar, from example 12.8
mv2 = 0.681
    // in kg, from examples 12.8
mv1 = 3.827
    // in kg, from example 12.8
mw2 = 3.146
```

```
    // in kg, from example 12.8
// evaluating internal energies of dry air and water
     from Tables A-22 and A-2, respectively
ua2 = 210.49

    // in kj/kg
ua1 = 281.1

    // in kj/kg
ug2 = 2405.7

    // in kj/kg
uf2 = 92.32

    // in kj/kg
ug1 = 2529.3

    // in kj/kg


// Calculations
ma =( ((p1-pv1)*10**5)*V)/((Rbar/Ma)*(T1+273))
                                                // mass of dry
    air in kg
Q = ma*(ua2-ua1) + mv2*ug2 + mw2*uf2 - mv1*ug1

// Result
printf( 'The heat transfer during the process, in kJ
     is: %f',Q)
```

Scilab code Exa 12.10 Example

```

// Given :-
AV1 = 150.0
```

```
   // entry volumetric flow rate in m^3/min
T1 = 10.0

   // entry temperature in degree celcius
psi1 = 0.8
T2 = 30.0

   // exit temperature in degree celcius
p = 1.0

   // in bar

// Part(a)
Rbar = 8314.0

   // universal gas constant
Ma = 28.97

   // molar mass of air
// The specific enthalpies of the dry air are
   obtained from Table A-22 at the inlet and exit
   temperatures T1 and T2, respectively:
ha1 = 283.1

   // in kj/kg
ha2 = 303.2

   // in kj/kg
// The specific enthalpies of the water vapor are
   found using hv  hg and data from Table A-2 at T1
   and T2, respectively:
hv1 = 2519.8

   // in kj/kg
hv2 = 2556.3

   // in kj/kg
// From table A-2
```

```
pg1 = 0.01228                                    // in bar
// Calculations
pv1 = psi1*pg1                                   // the partial pressure of the water vapor in bar
pa1 = p-pv1
va1 = (Rbar/Ma)*(T1+273)/(pa1*10**5)             // specific volume of the dry air in m^3/kg
madot = AV1/va1                                  // mass flow rate of the dry air in kg/min
omega = 0.622*(pv1/(p-pv1))                      // humidity ratio
Qcvdot = madot*((ha2-ha1)+omega*(hv2-hv1))       // in kj/min
// Result
printf('Rate of heat transfer, in kJ/min is: %.2f',Qcvdot);

// Part(b)
// From Table A-2 at 30C
pg2 = 0.04246                                    // in bar
// Calculations
pv2 = pv1
psi2 = pv2/pg2                                   // relative humidity at the exit
// Result
printf('The relative humidity at the exit is: %.2f',psi2);
```

Scilab code Exa 12.11 Example

```

// Given:-
T1 = 30.0

   // in degree celcius
AV1 = 280.0

   // in m^3/min
psi1 = 0.5

   // relative humidity at the inlet
T2 = 10.0

   // in degree celcius
p = 1.013

   // pressure in bar

// Part(a)
// From table A-2
pg1 = 0.04246

   // in bar
Rbar = 8314

   // universal gas constant
Ma = 28.97

   // molar mass of air
// Calculations
pv1 = psi1*pg1
```

```
    // in bar
pa1 = p-pv1

    // partial pressure of the dry air in bar
madot = AV1/((Rbar/Ma)*((T1+273)/(pa1*10**5)))
                                            // common mass
    flow rate of the dry air in kg/min
// Result
printf( '\n The mass flow rate of the dry air in kg/
    min is:  %.2f',madot);

// Part(b)
// From table A-2
pv2 = 0.01228

    // in bar
// Calculations
omega1 = 0.622*(pv1/(p-pv1))
omega2 = 0.622*(pv2/(p-pv2))
mwdotbymadot = omega1-omega2
// Result
printf( '\n The rate at which water is condensed, in
     kg per kg of dry air flowing through the control
     volume is:  %.4f',mwdotbymadot);

// Part(c)
// From table A-2 and A-22
ha2 = 283.1

    // in kg/kj
ha1 = 303.2

    // in kg/kj
hg1 = 2556.3

    // in kg/kj
hg2 = 2519.8
```

```
    // in kg/kj
hf2 = 42.01

    // in kg/kj
// Calculations
Qcvdot = madot*((ha2-ha1)-omega1*hg1+omega2*hg2+(
    omega1-omega2)*hf2)              // in kj/min
// Result
printf( '\n The required refrigerating capacity , in
    tons is: %.2f',Qcvdot/211);
```

Scilab code Exa 12.12 Example

```

// Given:-
T1 = 22.0

    // entry temperature of moist air in degree
    celcius
Twb = 9.0

    // wet-bulb temperature of entering moist air in
    degree celcius
madot = 90.0

    // mass flow rate of dry air in kg/min
Tst = 110.0

    // temperature of injected saturated water vapor
    in degree celcius
mstdot = 52.0

    // mass flow rate of injected saturated water
    vapor in kg/h
p = 1.0
```

```
                                                        // pressure in bar

// Part(a)
// By inspection of the psychrometric chart
omega1 = 0.002
// Calculation
omega2 = omega1 + mstdot/(madot*60)
// Result
printf('The humidity ratio at the exit is: %.2f',omega2);

// Part(b)
// The steady-state form of the energy rate balance can be rearranged as
// (ha + omega*hg)2 = (ha + omega*hg)1 + (omega2-omega1)*hg3
// On putting values in the above equation from tables and figures, temperature at the exit can then be read directly from the chart
T2 = 23.5                                               // in degree celcius
// Result
printf('The temperature at the exit in degree celcius is: %.2f',T2)
```

Scilab code Exa 12.13 Example

```

// Given:-
T1 = 38.0                                               // temperature of entering air in degree celcius
psi1 = 0.1
```

```
   // relative humidity of entering air
AV1 = 140.0

   // volumetric flow rate of entering air in m^3/
   min
Tw = 21.0

   // temperature of added water in degree celcius
T2 = 21.0

   // temperature of exiting moist air in degree
   celcius
p = 1.0

   // pressure in atm

// Part(a)
// From table A-2
pg1 = 0.066

   // in bar
// The specific volume of the dry air can be
   evaluated from the ideal gas equation of state.
   The result is
va1 = .887

   // in m^3/kg
cpa = 1.005
// From table A-2
hf = 88.14
hg1 = 2570.7
hg2 = 2539.94
// Calculations
pv1 = psi1*pg1

   // the partial pressure of the moist air entering
    the control volume in bar
```

```
omega1 = 0.622*(pv1/(p*1.01325-pv1))
omega2 = (cpa*(T1-T2)+omega1*(hg1-hf))/(hg2-hf)
madot = AV1/va1

   // mass flow rate of the dry air in kg/min
mwdot = madot*60*(omega2-omega1)

   // in kg/h
// Result
printf( '\n The mass flow rate of the water to the
   soaked pad in is:  %.2f kg(water)/h',mwdot);

// Part(b)
pv2 = (omega2*p*1.01325)/(omega2+0.622)
                                                 // in
   bars
// At 21C, the saturation pressure is
pg2 = 0.02487
psi2 = pv2/pg2
// Result
printf( '\n The relative humidity of the moist air
   at the exit to the evaporative cooler is:  %.2f',
   psi2)
```

Scilab code Exa 12.14 Example

```

// Given:-
AV1 = 142.0

   // in m^3/min
T1 = 5.0

   // in degree celcius
omega1 = 0.002
```

```
AV2 = 425.0

   // in m^3/min
T2 = 24.0

   // in degree celcius
psi2 = 0.5
p = 1.0

   // in bar


// Part(a)
// From the psychrometric chart , Fig. A-9.
va1 = 0.79

   // in m^3/kg
va2 = 0.855

   // in m^3/kg
omega2 = 0.0094
// Calculations
ma1dot = AV1/va1

   // in kg/min
ma2dot = AV2 /va2

   // in kg/min
omega3 = (omega1*ma1dot+omega2*ma2dot)/(ma1dot +
   ma2dot)
// Result
printf( '\n The humidity ratio is: %.4f',omega3);

// Part(b)
// Reduction of the energy rate balance gives
// (ha + omega*hv)3 = [ma1dot*(ha + omega*hv)1 +
   ma2dot*(ha + omega*hv)2]/(ma1dot+ma2dot)
// With (ha + omega*hv)1 = 10kj/kg and (ha + omega*
```

```
hv)2 = 47.8kj/kg from figure A-9
LHS = (ma1dot*10+ma2dot*47.8)/(ma1dot + ma2dot)

// This value for the enthalpy of the moist air at the exit, together with the previously determined value for omega3, fixes the state of the exiting moist air. From inspection of Fig. A-9,
T3 = 19.0                                          // in degree celcius
// Result
printf('\n The temperature of the exiting mixed stream in degree celcius T3 is : %.2f',T3)
```

Scilab code Exa 12.15 Example

```

// Given:-
T1 = 38.0                                          // in degree celcius
m1dot = 4.5e7                                      // in kg/h
T2 = 30.0                                          // in degree celcius
m2dot = 4.5e7                                      // in kg/h
T3 = 25.0                                          // in degree celcius
psi3 = 0.35
T4 = 35.0
```

```
    // in degree celcius
psi4 = 0.9
T5 = 20.0

    // in degree celcius

// Analysis
// The humidity ratios omega3 and omega4 can be determined using the partial pressure of the water vapor obtained with the respective relative humidity
omega3 =0.00688
omega4 = 0.0327
// From tables A-2 and A-22
hf1 = 159.21
hf2 = 125.79
ha4 = 308.2
ha3 = 298.2
hg4 = 2565.3
hg3 = 2547.2
hf5 = 83.96
// Calculations
madot = (m1dot*(hf1-hf2))/(ha4-ha3+omega4*hg4-omega3*hg3-(omega4-omega3)*hf5)   // in kg/h
m5dot = madot*(omega4-omega3)

    // in kg/h
// Results
printf( 'The mass flow rate of dry air in kg/h is: %.2f',madot)
printf( 'The mass flow rate of makeup water in kg/h is:  %.2f',m5dot)
```

Chapter 13

Reacting Mixtures and Combustion

Scilab code Exa 13.1 Example

```

// Given:-
// Part(a)
// The combustion equation can be written in the
   form of
// C8H18 + a(O2 + 3.76N2) - b CO2 + c H2O + d N2
// Using conservation of mass principle
b = 8.00
c = 18.00/2.00
a = (2.00*b+c)/2.00
d = 3.76*a

// The air fuel ratio on a molar basis is
AFbar = a*(1+3.76)/1.00
Ma = 28.97

   // molar mass of air
MC8H18 = 114.22
```

```
// molar mass of C8H18
// The air fuel ratio expressed on a mass basis is
AF = AFbar*(Ma/MC8H18)

// Result
printf(' The air fuel ratio on a molar basis is: %f', AFbar);
printf(' The air fuel ratio expressed on a mass basis is: %.2f',AF)

// Part(b)
// For 150% theoretical air, the chemical equation for complete combustion takes the form
// c8H18 + 1.5*12.5*(O2 + 3.76N2) -- b CO2 + c H2O + d N2 + e O2
// Using conservation of mass
// Calculations
b = 8.00
c =18.00/2.00
e = (1.5*12.5*2 - c -2*b)/2.00
d = 1.5*12.5*3.76
// The air fuel ratio on a molar basis is
AFbar = 1.5*12.5*(1+3.76)/1
// The air fuel ratio expressed on a mass basis is
AF = AFbar*(Ma/MC8H18)

// Results
printf(' The air fuel ratio on a molar basis is: %f', AFbar)
printf(' The air fuel ratio expressed on a mass basis is: %.2f',AF)
```

Scilab code Exa 13.2 Example

```
// Given:-
// Part(a)
// The chemical equation
// a CH4 + b*(O2 + 3.76N2) -- 9.7CO2 + .5CO + 2.95 O2 + 86.85N2 + cH2O
// Calculations
// Applying conservation of mass
a = 9.7 + 0.5
c = 2.0*a
b = ((9.7)*(2.0)+(0.5)+((2.0)*(2.95))+c)/2.00
Ma = 28.97                              // molar mass of air
MCH4 = 16.04                            // molar mass of methane
// On a molar basis, the air fuel ratio is
AFbar = (b*(1+3.76))/a
// On a mass basis
AF = AFbar*(Ma/MCH4)

// Results
printf( ' The air-fuel ratio on a molar basis is: %f',AFbar)
printf( ' The air-fuel ratio on a mass basis is: %.2f',AF)

// Part(b)
// The balanced chemical equation for the complete combustion of methane with the theoretical amount of air is
// CH4 + 2(O2 + 3.76N2) -- CO2 + 2H2O + 7.52N2
// The theoretical air fuel ratio on a molar basis is
// Calculations
AFbartheo = 2.00*(1+3.76)/1.0
// The percent theoretical air is
Ta = AFbar/AFbartheo
```

```
// Result
printf(' The percent theoretical air is: %.2f',Ta*100)

// Ppart(c)
// The mole fraction of the water vapor is
yv = 20.4/(100+20.4)
pv = yv*1
// Interpolating in Table A-2,
T = 57    // in degree celcius
// Result
printf(' The dew point temperature of the products, in C, if the mixture were cooled at 1 atm is: %f',T);
```

Scilab code Exa 13.3 Example

```

// Given:-
// Part(a)
// The chemical equation
// (.8062CH4 + .0541C2H6 + .0187C3H8 + .0160C4H10 + .1050N2) + a(O2 + 3.76N2) --- b(.078CO2 + .002CO + .07O2 + .85N2) + c H2O
// Calculations
// Using mass conservation
b = (0.8062 + 2*.0541 + 3*.0187 + 4*.0160)/(.078 + .002)
c = (4*.8062 + 6*.0541 + 8*.0187 + 10*.0160)/2
a = (b*(2*.078+.002+2*.07) + c)/2
// The air fuel ratio on a molar basis is
AFbar = a*(1+3.76)/1
// Result
```

```
printf(' The air-fuel ratio on a molar mass basis is:  %.2f',AFbar)

// Part(b)
p = 1.0                                     // in bar
V = 100.0                                   // in m^3
Rbar = 8314.0                               // in N.m/kmol.K
T = 300.0                                   // in kelvin
// Calculations
// The amount of fuel in kmol
nF = (p*10**5*V)/(Rbar*T)
// The amount of product mixture that would be formed from 100 m3 of fuel mixture is
n = nF*(b+c)
// Result
printf(' The amount of products in kmol that would be formed from 100 m3 of fuel mixture at 300 K and 1 bar is:  %.2f',n)

// Part(c)
// The balanced chemical equation for the complete combustion of the fuel mixture with the theoretical amount of air is
// (10.8062CH4 + 0.0541C2H6 + 0.0187C3H8 + 0.0160C4H10 + 0.1050N2) + 2(O2 + 3.76N2)   --- 1.0345CO2 + 1.93H2O + 7.625N2
// Calculations
// The theoretical air fuel ratio on a molar basis is
AFbartheo = 2*(1+3.76)/1
```

```
// The percent theoretical air is
Ta = AFbar/AFbartheo
// Result
printf(' The percent of theoretical air is: %.2f ', Ta*100)
```

Scilab code Exa 13.4 Example

```

// Given:-
// The balanced chemical equation for complete combustion with the theoretical amount of air is obtained from the solution to Example 13.1 as
// C8H18 +12.5O2 + 47N2 ---- 8CO2 + 9H2O + 47N2
// From tabel A-25
hRbar = -249910                                    // in kj/kmol
mfdot = 1.8e-3                                     // mass flow rate of liquid octane in kg/s
M = 114.22                                         // molar mass of octane
Wcvdot = 37                                        // power output of the engine in kw

// Calculations
// With enthalpy of formation values for CO2 and H2O(g) from Table A-25, and enthalpy values for N2, H2O, and CO2 from Table A-23
hpbar = 8*(-393520 + (36876 - 9364)) + 9*(-241820 + (31429 - 9904)) + 47*((26568 - 8669))
nFdot = mfdot/M
```

```
                                                                  // molar flow rate of the fuel in kmol/s
Qcvdot = Wcvdot + nFdot*(hpbar-hRbar)                                                    // in kw

// Result
printf(' The rate of heat transfer from the engine, in kW is: %.2f',Qcvdot)
```

Scilab code Exa 13.5 Example

```

// Given:-
// When expressed on a per mole of fuel basis, the balanced chemical equation obtained in the solution to Example 13.2  takes the form
// CH4 + 2.265O2 + 8.515N2 ------ .951CO2 + .049CO + .289O2 + 8.515N2 + 2H2O
cpbar = 38.00                                                                  // specific heat in KJ/kmol.K
// From table A-25
hfnotbar = -74850.00                                                           // enthalpy of formation for methane
// From table A-23
deltahbarO2 = 14770-8682
deltahbarN2 = 14581-8669

// Calculations
hRbar = hfnotbar + cpbar*(400-298) + 2.265*deltahbarO2 + 8.515*deltahbarN2      // in kj/kmol
// With enthalpy of formation values for CO2, CO,
```

```
and H2O(g) from Table A-25 and enthalpy values from Table A-23
hpbar = .951*(-393520 + (88806 - 9364)) + .049*(-110530 + (58191 - 8669)) + .289*(60371 - 8682) + 8.515*(57651 - 8669) + 2*(-241820 + (72513 - 9904))
Qcvdot = hpbar - hRbar                    // in kj/kmol

// Result
printf(' The rate of heat transfer from the combustion chamber in kJ per kmol of fuel is: %.2f',Qcvdot)
```

Scilab code Exa 13.6 Example

```

// Given:-
nCH4 = 1.00                    // moles of methane in kmol
nO2 = 2.00                     // moles of oxygen in kmol
T1 = 25.00                     // in degree celcius
p1 = 1.00                      // in atm
T2 = 900.00                    // in kelvin
Rbar = 8.314
```

```
    // universal gas constant
// The chemical reaction equation for the complete combustion of methane with oxygen is
// CH4 + 2O2  ---  CO2 + 2H2O

// Part(a)
// with enthalpy of formation values from table A-25
hfbarCO2 = -393520
hfbarH2O = -241820
hfbarCH4 = -74850
// Calculations
// with enthalpy values from table A-23
deltahbarCO2 = 37405-9364
deltahbarH2O = 31828-9904
Q = ((hfbarCO2 + deltahbarCO2)+2*(hfbarH2O + deltahbarH2O) - hfbarCH4) + 3*Rbar*(T1+273-T2)
// Result
printf(' The amount of heat transfer in kJ is: %.2f', Q)

// Part(b)
p2 = p1*(T2/(T1+273))                    // in atm
// Result
printf(' The final pressure in atm is: %.2f',p2)
```

Scilab code Exa 13.7 Example

```

// Given:-
// The combustion equation is
// CH4 + 2O2 + 7.52N2  ---  CO2 + 2H2O + 7.52N2

```

```
// Part(a)
// With enthalpy of formation values from Table A-25
hfbarCO2 = -393520                          // in kj/kmol
hfbarH2O = -285830                          // in kj/kmol
hfbarCH4 = -74850                           // in kj/kmol
M = 16.04                                   // molar mass of CH4 in kg/kmol
// Calculations
hRPbar = hfbarCO2 + 2*hfbarH2O - hfbarCH4                          // in kj/kmol
hRP = hRPbar/M                              // in kj/kg
// Result
printf(' Part(a)the enthalpy of combustion of gaseous methane,  fuel is: %f kJ/kg.',hRP)

// Part(b)
hfbarCO2 = -393520                          // in kj/kmol
hfbarH2O = -241820                          // in kj/kmol
hfbarCH4 = -74850                           // in kj/kmol
// Calculations
hRPbar = hfbarCO2 + 2*hfbarH2O - hfbarCH4                          // in kj/
```

```
kmol
hRP = hRPbar/M                    // in kj/kg
// Result
printf(' Part(b)the enthalpy of combustion of gaseous methane, fuel is:  %f kJ/kg',hRP);

// Part(c)
// From table A-23
deltahbarO2 = 31389-8682          // in kj/kmol
deltahbarH2O = 35882-9904         // in kj/kmol
deltahbarCO2 = 42769-9364         // in kj/kmol

// Using table A-21
// Calculations
// function cpbar = f(T)
T=298                             // in kelvin

function T = cpbar(T)
    T = (3.826 - (3.979e-3)*T + 24.558e-6*T**2 - 22.733e-9*T**3 + 6.963e-12*T**4)*8.314
endfunction

deltahbarCH4 = intg(298,1000,cpbar)
var = deltahbarCH4(1)

hRPbar = hRPbar + (deltahbarCO2 + 2*deltahbarH2O - var -2*deltahbarO2)
hRP = hRPbar/M
```

```
   // in kj/kg
// Result
printf(' Part(c)the enthalpy of combustion of
   gaseous methane, per kg of fuel is %.f kJ/kg',hRP
   );
```

Scilab code Exa 13.8 Example

```

// Given:-
// Part(a)
// For combustion of liquid octane with the
   theoretical amount of air, the chemical equation
   is
// C8H18(l) + 12.5 O2 + 47N2   ------- 8 CO2 + 9 H2O(
   g) + 47N2
// with enthalpy of formation data from Table A-25
hfbarC8H18 = -249910.0

   // in kj/kmol
hfbarCO2 = -393520.0
hfbarH2O = -241820.0

// Calculations
RHS = hfbarC8H18 -(8*hfbarCO2 + 9*hfbarH2O)
                                       // in kj/kmol
// at temperature 2400k
LHS1 = 5089337.0

   // in kj/kmol
// at temperature 2350 k
LHS2 = 4955163.0

   // in kj/kmol
```

```
// Interpolation between these temperatures gives
Tp = 2400.00 + ((2400.0-2350.0)/(LHS1-LHS2))*(RHS-LHS1)
// Result
printf(' The temperature in kelvin with theoretical amount of air is:  %.2f', Tp)

// Part(b)
// For complete combustion of liquid octane with 400% theoretical air, the chemical equation is
// C8H18(l) + 50O2 + 188N2 ------- 8CO2 + 9H2O + 37.5O2 + 188N2

// Proceeding iteratively as part(a)
Tp = 962                                      // in kelvin

// Result
printf(' The temperature in kelvin using 400 percent theoretical air is: %.2f ',Tp)
```

Scilab code Exa 13.9 Example

```

// Given:-

// Part(a)
Tp = 2395                                     // in kelvin, from example 13.8
// For combustion of liquid octane with the theoretical amount of air, the chemical equation is
// C8H18(l) + 12.5O2 + 47N2 --- 8CO2 + 9H2O(g) +
```

```
47N2

// From table A-25
sFbar = 360.79                    // absolute entropy of liquid octane in kj/kmol.K

// From table A-23
// For reactant side
sbarO2atTref = 205.03             // in kj/kmol.K
sbarN2atTref = 191.5              // in kj/kmol.K
Rbar = 8.314                      // universal gas constant in SI units
yO2 = 0.21
yN2 = 0.79
// For product side
yCO2 = 8.0/64.0
yH2O = 9.0/64.0
yN2p = 47.0/64.0

// Calculations
sbarO2 = sbarO2atTref - Rbar*log(yO2)                    // in kj/kmol.K
sbarN2 = sbarN2atTref - Rbar*log(yN2)                    // in kj/kmol.K
// With the help from table A-23
sbarCO2 = 320.173 - Rbar*log(yCO2)
sbarH2O = 273.986 - Rbar*log(yH2O)
sbarN2p = 258.503 - Rbar*log(yN2p)
sigmadot = (8*sbarCO2 + 9*sbarH2O + 47*sbarN2p) - sFbar - (12.5*sbarO2 + 47*sbarN2)
```

```

// Result
printf('The rate of entropy production, in kJ/K per kmol of fuel with theoretical amount of air is: %.2f',sigmadot)

// Part(b)
// The complete combustion of liquid octane with 400 % theoretical air is described by the following chemical equation:
// C8H18(l) + 50 O2 + 188N2 ---- 8 CO2 + 9H2O(g) + 37.5O2 + 188N2

// For product side
yCO2 = 8.0/242.5
yH2O = 9.0/242.5
yO2 = 37.5/242.5
yN2p = 188.0/242.5
// Calculations
// With help from table A-23
sbarCO2 = 267.12 - Rbar*log(yCO2)
sbarH2O = 231.01 - Rbar*log(yH2O)
sbarO2p = 242.12 - Rbar*log(yO2)
sbarN2p = 226.795 - Rbar*log(yN2p)
sigmadot = (8.0*sbarCO2 + 9.0*sbarH2O + 37.5*sbarO2p +188.0*sbarN2p) -sFbar - (50.0*sbarO2 + 188.0*sbarN2)

// Result
printf('The rate of entropy production, in kJ/K per kmol of fuel with 400 percent theoretical air is: %.2f ', sigmadot)
```

Scilab code Exa 13.10 Example

```

// Given:-
Rbar = 8.314
                                    
   // universal gas constant in SI units
// The chemical equation for the complete combustion
    of methane with oxygen is
// CH4 + 2O2 ---  CO2 + 2H2O
yCH4 = 1.0/3.0
yO2 = 2.0/3.0
yCO2 = 1.0/3.0
yH2O = 2.0/3.0
// From table A-25
sbarCH4atTref = 186.16
                                    
   // in kj/kmol.K
sbarO2atTref = 205.03
                                    
   // in kj/kmol.K
p2 = 3.02
                                    
   // in atm
pref = 1.0
                                    
   // in atm

// Calculations
sbarCH4 = sbarCH4atTref - Rbar*log(yCH4)
sbarO2 = sbarO2atTref - Rbar*log(yO2)
// With help from table A-23
sbarCO2 = 263.559 - Rbar*log(yCO2*p2/pref)
                                   // in kj/kmol.K
sbarH2O = 228.321 - Rbar*log(yH2O*p2/pref)
                                   // in kj/kmol.K
deltaS = sbarCO2 + 2*sbarH2O - sbarCH4 -2*sbarO2
                                  // in kj/K

// Result
```

```
printf( ' The change in entropy of the system  is: %.2f kJ/K ',deltaS)
```

Scilab code Exa 13.11 Example

```

// Given:-
// Methane is formed from carbon and hydrogen according to
// C + 2H2 ------ CH4

// In the present case, all substances are at the same temperature and pressure, 25C and 1 atm, which correspond to the standard reference state values
hCbar = 0
hH2bar = 0
gRbar = 0
// With enthalpy of formation and absolute entropy data from Table A-25
hfbarCH4 = -74850
sbarCH4 = 186.16
sbarC = 5.74
sbarH2 = 130.57
Tref = 298.15                    // in kelvin

// Calculation
gfbarCH4 = hfbarCH4 -Tref*(sbarCH4-sbarC-2*sbarH2)                    // in kj/kmol

// Result
printf( ' The gibbs function of formation of methane at the standard state is:  %f kJ/mol',gfbarCH4)
```

Scilab code Exa 13.12 Example

```

// Given:-
// Complete combustion of liquid octane with O2 is described by
// C8H18(l) + 12.5O2   -----   8CO2 + 9H2O

// Part(a)
Rbar = 8.314                               // universal gas constant in SI units
Tnot = 298.15                              // in kelvin
// From table A-25
gbarC8H18 = 6610.0
gbarO2 = 0
gbarCO2 = -394380
gbarH2O = -228590
yO2 = 0.2035
yCO2 = 0.0003
yH2O = 0.0312
M = 114.22                                 // molecular weight of liquid octane

// Calculations
ech = ((gbarC8H18 + 12.5*gbarO2 -8*gbarCO2 -9*gbarH2O) + Rbar*Tnot*log(yO2**12.5/(yCO2**8*yH2O**9    )))/M
// Result
printf(' Part(a) the chemical exergy obtained on a unit mass basis is: %.2f kJ/K',ech)
```

```

// Part(b)
// With data from Table A-25 and Model II of Table A-26
gbarH2O = -237180.0
ebarCO2 = 19870.0
ebarH2O = 900.0
ebarO2 = 3970.0

// Calculation
ech = ((gbarC8H18 + 12.5*gbarO2 -8*gbarCO2 - 9*gbarH2O) + 8*ebarCO2 + 9*ebarH2O - 12.5*ebarO2)/M
// Result
printf(' Part(b) chemical exergy on a unit mass basis is: %.3f kJ/K',ech)
```

Scilab code Exa 13.13 Example

```

// Given:-
Rbar = 8.314                                        // universal gas constant in SI units
Tnot = 298.0                                        // in kelvin
// With data from the steam tables
h = 2939.9                                          // in kj/kg
hnot = 104.9                                        // in kj/kg
s = 7.2307
```

```
// in kj/kg
snot = 0.3674                                           // in kj/kg
// With data from Table A-25
gbarH2Oliq = -237180.0
gbarH2Ogas = -228590.0
yeH2O = 0.0303
M =18.0                                                 // molar mass of steam

// Calculations
ech = (1.0/M)*(gbarH2Oliq-gbarH2Ogas + Rbar*Tnot*log(1/yeH2O))          // in kj/kg
ef = h-hnot-Tnot*(s-snot) + ech                                                  // in kj/kg

// Result
printf( ' The flow exergy of the steam, in is: %.2f kJ/kg ',ef)
```

Scilab code Exa 13.14 Example

```

// Given:-
// For 140% theoretical air, the reaction equation for complete combustion of methane is
// CH4 + 2.8(O2 + 3.76N2) ------ CO2 + 2H2O + 10.53N2 + .8O2

// For product side
yCO2p = 1.0/(1.0+2.0+10.53+.8)
yH2Op = 2.0/(1.0+2.0+10.53+.8)
```

```
yN2p = 10.53/(1.0+2.0+10.53+.8)
yO2p = 0.8/(1.0+2.0+10.53+.8)

Rbar = 8.314
    // universal gas constant in SI units
Tnot = 298.15
    // in kelvin

yeN2 = 0.7567
yeO2 = 0.2035
yeH2O = 0.0303
yeCO2 = 0.0003

// Calculations

ebarch = Rbar*Tnot*(log(yCO2p/yeCO2) + 2*log(yH2Op/
    yeH2O) + 10.53*log(yN2p/yeN2) + .8*log(yO2p/yeO2)
    )

// with data from tables A-23 at 480 and 1560 kelvin
    ,the thermomechanical contribution to the flow
    exergy, per mole of fuel, is
contri480 = 17712.0
    // kJ per kmol of fuel
contri1560 = 390853.0
    // kJ per kmol of fuel
efbar480 = contri480 + ebarch
    // kJ per kmol of fuel
efbar1560 = contri1560 + ebarch
    // kJ per kmol of fuel

// Results
```

```
printf(' At T= 480k, the flow exergy of the
    combustion products, in kJ per kmol of fuel is:
   %.2f',efbar480)
printf(' At T = 1560K, the flow exergy of the
    combustion products, in kJ per kmol of fuel is:
   %.2f',efbar1560)
```

Scilab code Exa 13.15 Example

```

// Given:-
mFdot = 1.8e-3

    // fuel mass flow rate in kg/s
ech = 47346.0

    // in kj/kg, from example 13.12(a)
Wcvdot = 37.0

    // power developed by the engine in kw

// Calculations
Efdot = mFdot*ech

    // rate at which exergy enters with the fuel in
   kw
epsilon = Wcvdot/Efdot

    // exergetic efficiency

// Result
printf(' The exergetic efficiency is: %.3f',
    epsilon)
```

Scilab code Exa 13.16 Example

```

// Given:-
Tnot = 298

   // in kelvin

// For the case of complete combustion with the
   theoretical amount of air
sigmadot = 5404.0

   // rate of entropy production from example 13.9,
   in kj/kmol.K
Efdot = 5407843.0

   // rate at which exergy enters with the fuel from
    example 13.12, in kj/kmol
// Calculations:-
Eddot = Tnot*sigmadot

   // in kj/kmol
epsilon = 1-Eddot/Efdot
// Result
printf(' The exergetic efficiency with theoretical
   amount of air is: %.3f',epsilon)

// For the case of combustion with 400% theoretical
   air
sigmadot = 9754.0

   // rate of entropy production from example 13.9,
   in kj/kmol.K
// Calculations
```

```
Eddot = Tnot*sigmadot  // in kj/kmol
epsilon = 1-Eddot/Efdot
// Result
printf( 'The exergetic efficiency with 400 percent theoretical amount of air is: %.3f ',epsilon)
```

Chapter 14

Chemical and Phase Equilibrium

Scilab code Exa 14.1 Example

```

// Given:-
// The reaction is CO + .5O2 ---   CO2
// Part(a)
T = 298.0

    // in kelvin
Rbar = 8.314

    // universal gas constant in SI units
// From table A-25

hfbarCO2 = -393520.0

    // in kj/kmol
hfbarCO = -110530.0

    // in kj/kmol
hfbarO2 = 0
```

```
   // in kj/kmol
deltahbarCO2 = 0

   // in kj/kmol
deltahbarCO = 0

   // in kj/kmol
deltahbarO2 = 0

   // in kj/kmol
sbarCO2 = 213.69

   // in kj/kmol.K
sbarCO = 197.54

   // in kj/kmol.K
sbarO2 = 205.03

   // in kj/kmol.K
// From table A–27
logKtable = 45.066
// Calculations
deltaG = (hfbarCO2-hfbarCO-.5*hfbarO2) + (
   deltahbarCO2-deltahbarCO-.5*deltahbarO2) - T*(
   sbarCO2-sbarCO-.5*sbarO2)
lnK = -deltaG/(Rbar*T)
logK = (1/log(10))*lnK
// Results
printf(' Part(a) the value of equilibrium constant
   expressed as log10K is:  %f',logK);
printf(' The value of equilibrium constant
   expressed as log10K from table A–27 is: %f ',
   logKtable);

// Part(b)
T = 2000.0
```

```
   // in kelvin
// From table A-23
hfbarCO2 = -393520.0

   // in kj/kmol
hfbarCO = -110530.0

   // in kj/kmol
hfbarO2 = 0

   // in kj/kmol
deltahbarCO2 = 100804-9364

   // in kj/kmol
deltahbarCO = 65408 - 8669

   // in kj/kmol
deltahbarO2 = 67881 - 8682

   // in kj/kmol
sbarCO2 = 309.210

   // in kj/kmol.K
sbarCO = 258.6

   // in kj/kmol.K
sbarO2 = 268.655

   // in kj/kmol.K
// Calculations
deltaG = (hfbarCO2-hfbarCO-.5*hfbarO2) + (
   deltahbarCO2-deltahbarCO-.5*deltahbarO2) - T*(
   sbarCO2-sbarCO-.5*sbarO2)
lnK = -deltaG/(Rbar*T)
logK = (1/log(10))*lnK
// From table A-27
logKtable = 2.884
// Results
```

```
printf(' Part(b) the value of equilibrium constant expressed as log10K is: %f ',logK);
printf(' The value of equilibrium constant expressed as log10K from table A-27 is: %f ',logKtable);
```

Scilab code Exa 14.2 Example

```

// Given:-
// Applying conservation of mass, the overall balanced chemical reaction equation is
// CO + .5O2      ------     zCO + (z/2)O2 + (1-z)CO2

// At 2500 K, Table A-27 gives
log10K = -1.44
// Part(a)
p = 1.0                                             // in atm
// Calculations
K = (10.0)**(log10K)                                // equilibrium constant
// Solving equation K = (z/(1-z))*(2/(2 + z))^.5 *(p/1)^.5 gives
z = 0.129
yCO = 2.0*z/(2.0 + z)
yO2 = z/(2.0 + z)
yCO2 = 2.0*(1.0 - z)/(2.0 + z)

// Results
printf(' Part(a) mole fraction of CO is: %.3f ',yCO)
printf(' Mole fraction of O2 is:  %.3f',yO2)
```

```
printf(' Mole fraction of CO2 is: %.3f',yCO2)

// Part(b)
p = 10.0 // in atm
// Solving equation K = (z/(1-z))*(2/(2 + z))^.5 *(p/1)^.5 gives
z = 0.062
yCO = 2.0*z/(2.0 + z)
yO2 = z/(2.0 + z)
yCO2 = 2.0*(1.0 - z)/(2.0 + z)

// Results
printf(' Part(b) mole fraction of CO is: %.3f',yCO)
printf(' Mole fraction of O2 is: %.3f',yO2)
printf(' Mole fraction of CO2 is: %.3f ',yCO2)
```

Scilab code Exa 14.3 Example

```

// Given:-
yCO = 0.298
p = 1 // in atm
pref = 1 // in atm
// With this value of K, table A-27 gives
T = 2881

// Calculations
// Solving yCO = 2z/(2 + z)
```

```
z = 2*yCO/(2 - yCO)
K = (z/(1-z))*(z/(2 + z))**.5*(p/pref)**.5

// Result
printf( ' The temperature T of the mixture in kelvin is:  %f',T);
```

Scilab code Exa 14.4 Example

```

// Given:-
// For a complete reaction of CO with the theoretical amount of air
// CO + .5 O2 + 1.88N2  ----  CO2 + 1.88N2
// Accordingly, the reaction of CO with the theoretical amount of air to form CO2, CO, O2, and N2 is
// CO + .5O2 + 1.88N2 --  zCO + z/2 O2 + (1-z)CO2 + 1.88N2

K = 0.0363
    // equilibrium constant the solution to Example 14.2
p =1.0
    // in atm
pref = 1.0
    // in atm

// Calculations
// Solving K = (z*z^.5/(1-z))*((p/pref)*2/(5.76+z))^.5 gives
z = 0.175
```

```
yCO = 2.0*z/(5.76 + z)
yO2 = z/(5.76 + z)
yCO2 = 2.0*(1.0-z)/(5.76 + z)
yN2 = 3.76/(5.76 + z)

// Results
printf(' The mole fraction of CO is: %.3f ',yCO)
printf(' The mole fraction of O2 is: %.3f ',yO2)
printf(' The mole fraction of CO2 is:  %.3f',yCO2)
printf(' The mole fraction of N2 is:  %.3f',yN2)
```

Scilab code Exa 14.5 Example

```

// Given:-
// Applying the conservation of mass principle, the
   overall dissociation reaction is described by
// CO2 --- zCO2 + (1-z)CO + ((1-z)/2)O2

p = 1.0

   // in atm
pref = 1.0

   // in atm
// At 3200 K, Table A-27 gives
log10k = -.189
// Solving k = ((1-z)/2)*((1-z)/(3-z))^.5 gives
z = 0.422

// Calculations
k = 10**log10k
// From tables A-25 and A-23
hfbarCO2 = -393520.0
```

```
    // in kj/kmol
deltahbarCO2 = 174695-9364
    // in kj/kmol
hfbarCO = -110530.0
    // in kj/kmol
deltahbarCO = 109667-8669
    // in kj/kmol
hfbarO2 = 0
    // in kj/kmol
deltahbarO2 = 114809-8682
    // in kj/kmol
hfbarCO2r =  -393520.0
    // in kj/kmol
deltahbarCO2r = 0
    // in kj/kmol

Qcvdot = 0.422*(hfbarCO2 + deltahbarCO2) + 0.578*(
    hfbarCO + deltahbarCO) + 0.289*(hfbarO2 +
    deltahbarO2)- (hfbarCO2r + deltahbarCO2r)

// Result
printf( ' The heat transfer to the reactor , in kJ
    per kmol of CO2 entering is:  %f', Qcvdot);
```

Scilab code Exa 14.8 Example

```

// Given:-
```

```
// The ionization of cesium to form a mixture of Cs,
    Cs+, and e- is described by
// Cs  ---  (1-z)Cs + zCs+ + Ze-

K = 15.63
z = 0.95
pref =1

   // in atm
// Calculation
p = pref*K*((1-z**2)/z**2)

// Results
printf( ' The pressure if the ionization of CS is 95
    percent complete is: %f atm',p);

x = linspace(0,10,100)
for i = 1:100
    y(i)= 100*((1/(1+x(i)/K))**0.5)
end

plot(x,y)
xlabel("Pressure (atm)")
ylabel("Ionization")
```

Scilab code Exa 14.10 Example

```

// Given:-
// With data from Table A-2 at 20C,
vf = 1.0018e-3

   // in m^3/kg
psat = 0.0239
```

```
    // in bar
p = 1.0

    // in bar
T = 293.15

    // in kelvin
Rbar = 8.314

    // universal gas constant in SI units
M = 18.02

    // molat mass of water in kg/kmol
e=2.715

// Calculations
pvbypsat = e**(vf*(p-psat)*10**5/((1000*Rbar/M)*T))
percent = (pvbypsat-1)*100

// Result
printf('The departure, in percent, of the partial
    pressure of the water vapor from the saturation
    pressure of water at 20 is: %.3f',percent)
```