Scilab Textbook Companion for Fundamental Of Engineering Thermodynamics by M. J. Moran, H. N. Shapiro, D. D. Boettner And M. B. Bailey[1]

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Book Description

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

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

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

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

Contents

List of Scilab Codes

Chapter 2

Energy and the first law of thermodynamics

Scilab code Exa 2.1 Example 1

```
//(2.1)  A gas in a piston cylinder assembly undergoes an expansion process for which the relationship between pressure and volume is given by p*(v^n) = constant.The initial pressure is 3 bar, the initial volume is 0.1 m3, and the final volume is 0.2 m3. Determine the work for the process,in kJ, if (a) n=1.5, (b) n=1.0,and (c) n=0.

//solution

// variable initialization
p1 = 3*(10^5) // initial pressure of gas in pascal
v1 = .1 //initial volumme of gas in meter^3
v2 = .2 //final volume of gas in meter^3

//part (a) i.e. n=1.5
funcprot(0);
function [constant] = f1(n)
```

```
    constant = p1*(v1^n);                           //p*(v^n) = constant
endfunction;

function [p] = f2(v,n)
    p = f1(n)/(v^n);                              //expressing pressure as function of volume
endfunction;

function [work1] = f3(n)
    work1 = intg(v1,v2,f2);                       //integrating pdv from initial to final volume
endfunction;

w1 = f3(1.5)/1000;                                //divided by 1000 to convert to KJ
disp(w1,"the work done for n=1.5 in KJ is");

//part(b) i.e. n = 1

w2 = f3(1)/1000;
disp(w2,"the work done for n=1 in KJ is");

//part(c) i.e. n=0

w3 = f3(0)/1000;
disp(w3,"the work done for n=0 in KJ is");
```

Scilab code Exa 2.2 Example 2

```
// (2.2) Four kilograms of a certain gas is contained within a piston cylinder assembly. The gas undergoes a process for which the pressure volume relationship is p*(v^1.5) = constant. The initial pressure is 3 bar, the
```

```
initial volume is 0.1 m3, and the final volume is 0.2 m3. The change in specific internal energy of the gas in the process is u2−u1 =− 4.6 kJ/kg. There are no significant changes in kinetic or potential energy. Determine the net heat transfer for the process, in kJ.

// solution

//variable initialization
p1 = 3*(10^5) // initial pressure in pascal
v1 = .1       // initial volume in m3
v2 = .2      // initial volume in m3
m = 4        //mass of the gas in kg
deltau = -4.6 // change in specific internal energy in KJ/Kg


funcprot(0);
function [constant] = f1(n)
    constant = p1*(v1^n);                          //p*(v^n) = constant
endfunction;

function [p] = f2(v,n)
    p = f1(n)/(v^n);                              //expressing pressure as function of volume
endfunction;

function [work] = f3(n)
    work = intg(v1,v2,f2);                        //integrating pdv from initial to final volume
endfunction;

w = f3(1.5)/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

disp(Q,"net heat transfer for the process in KJ")
```

Scilab code Exa 2.3 Example 3

```
//(2.3) Air is contained in a vertical piston cylinder assembly fitted with an electrical resistor. The atmosphere exerts a pressure of 1 bar on the top of the piston, which has a mass of 45 kg and a face area of .09 m2. Electric current passes through the resistor, and the volume of the air slowly increases by .045 m3 while its pressure remains constant. The mass of the air is .27 kg, and its specific internal energy increases by 42 kJ/kg. The air and piston are at rest initially and finally. The piston cylinder material is a ceramic composite and thus a good insulator. Friction between the piston and cylinder wall canbe ignored, and the local acceleration of gravity is g = 9.81 m/s2. Determine the heat transfer from the resistor to the air, in kJ, for a system consisting of (a) the air alone, (b) the air and the piston.

//solution

// variable initialization
patm = 10^5           // atmospheric pressure in pascal.
mp = 45                 // mass of piston in Kg
A = .09                 // face area of piston in m2
deltaV = .045           // increment of the volume of
```

```
air in m3
m = .27                  // mass of air in kg
deltau = 42              // specific internal energy increase of air in kJ/kg
g = 9.81                 // local acceleration of gravity


//part (a) i.e. air is system

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

printf('the answer given in book is incorrect.They have miscalculated deltaU.The correct heat transfer from resistor to air in KJ for air alone as system is:\n\n\tQ=%f',Q);

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

//part(b) i.e. (air+piston) is system

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

printf('\n\nthe answer given in book is incorrect.
```

```
They have miscalculated deltaU.The correct heat transfer from resistor to air in KJ for air + piston as system is:\n\n\tQt=%f',Qt);
```

Scilab code Exa 2.4 Example 4

```
//(2.4) During steady-state operation, a gearbox receives 60 kW through the input shaft and delivers power through the output shaft.For the gearbox as the system, the rate of energy transfer by convection is Qdot = -hA(tb-tf) where h = 0.171 kW/m2.k is the heat transfer coefficient, A= 1.0 m2 is the outer surface area of the gearbox, Tb = 300k is the temperature at the outer surface, and Tf 293k is the temperature of the surrounding air away from the immediate vicinity of the gearbox. For the gearbox, evaluate the heat transfer rate and the power delivered through the output shaft, each in kW.

//solution

// initializing variables
w1dot = -60                    // input work rate in KW
h = .171                       // heat transfer coefficient,unit in KW/m2 .K
A = 1                          // outer surface area of gearbox, unit in m2
Tb = 300                       // outer surface temperature in kelvin
Tf = 293                       // temperature of the sorrounding

Qdot = -h*A*(Tb-Tf);           // rate of energy
```

```
transfer by heat
wdot = Qdot;                 // steady state energy equation
w2dot = wdot-w1dot;

printf('the heat transfer rate in KW is:\n\tQdot = %f',Qdot);
printf('\n\nthe power delivered through output shaft in KW is:\n\tw2dot = %f',w2dot);
```

Scilab code Exa 2.5 Example 5

```
//(2.5) A silicon chip measuring 5 mm on a side and 1 mm in thickness is embedded in a ceramic substrate. At steady state, the chip has an electrical power input of 0.225 W. The top surface of the chip is exposed to a coolant whose temperature is 20 degree Celcius . The heat transfer coefficient for convection between the chip and the coolant is 150 W/m2 K. If heat transfer by conduction between the chip and the substrate is negligible, determine the surface temperature of the chip, in degree Celcius.

// solution

//variable initialization

s=5*(10^-3);                    //measurement on a side in meter
wdot = -.225                     //power input in watt
Tf = 293                        //coolant temprature in kelvin
h = 150                         //heat transfer
```

```
coefficient in w/m2 k

A = s^2;                                   //surface area
Tb = ((-wdot/(h*A)) + Tf - 273) ;          //surface temperature in degree

printf('the surface temperature of the chip in degree celcius is:\n\t Tb = %f',Tb);
```

Scilab code Exa 2.6 Example 6

```
//(2.6) The rate of heat transfer between a certain electric motor and its surroundings varies with time as Qdot = -.2[1-e^(-.05t)] where t is in seconds and Qdot in KW.The shaft of the motor rotates at a constant speed of omega = 100 rad/s and applies a constant torque of tau = 18 N.m to an external load. The motor draws a constant electric power input equal to 2.0 kW. For the motor, plot Qdot and Wdot,each in kW, and the change in energy deltaE in kJ, as functions of time from t =0 to t = 120s.

//solution

//initializing variables
omega = 100;                               // motor rotation speed in rad/s
tau = 18;                                  //torque applied by shaft in N.m
Welecdot = -2;                             // electric power
```

```
input in KW

funcprot(0);
Wshaftdot = (tau*omega)/1000;       //shaft work rate in KW
Wdot = Welecdot + Wshaftdot;        //net work rate in KW

function [Qdot]=f(t)
    Qdot = (-.2)* [1-%e^(-.05*t)];
endfunction

function [Edot]=f1(t)                //function for rate of change of energy
    Edot =(-.2)* [1-%e^(-.05*t)] - Wdot ;
endfunction;

function [deltaE] =f2(t)             //function for change in energy
    deltaE = intg(0,t,f1);
endfunction;

t = linspace(0,120,100);
for i = 1:100
    Qdt(1,i)= f((120/99)*(i-1));
    Wdt(1,i)= Wdot;
    dltaE(1,i)= f2((120/99)*(i-1));
end
plot2d(t,Qdt,rect=[0,-.25,120,0]);
plot2d(t,Wdt,style=5,rect=[0,-.25,120,0]);
xtitle("","time, s","Qdot, Wdot,KW");
legend("Qdot","Wdot");
xset('window',1);
plot2d(t,dltaE);
xtitle("deltaE versus time","Time, s","deltaE, KJ");
```

Chapter 3

Evaluating properties

Scilab code Exa 3.1 Example 1

```
// (3.1) A closed, rigid container of volume 0.5 m3 is placed on a hot plate. Initially, the container holds a two-phase mixture of saturated liquid water and saturated water vapor at p1 = 1 bar with a quality of 0.5. After heating, the pressure in the container is p2= 1.5 bar. Indicate the initial and final states on a T v diagram, and determine (a) the temperature, in degree Celcius, at each state.(b) the mass of vapor present at each state, in kg.(c) If heating continues, determine the pressure, in bar, when the container holds only saturated vapor.

// solution

//initializing variables
p1 = 10^5                    // initial pressure in pascal
x1 = .5                      // initial quality
p2 = 1.5*10^5                // pressure after heating in pascal
```

```
v = .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)

v1 = vf1 + x1*(vg1-vf1)         // specific volume in state 1 in m3/Kg
v2 = v1                         // specific volume in state 2 in m3/Kg
vf2 = 1.0582*10^(-3)            //  specific volume of fluid in state 2 in m3/Kg(from table A-3)
vg2 = 1.159                     //  specific volume of gas in state 2 in m3/Kg(from table A-3)

// part (a)
T1 = 99.63                      // temperature in degree celcius in state 1, from table A-3
T2 = 111.4                      // temperature in degree celcius in state 2, from table A-3
printf('the temperature in degree celcius in state 1 is:\n\t T1 = %f',T1);
printf('\nthe temperature in degree celcius in state 2 is:\n\t T2 = %f',T2);

// part (b)
m = v/v1                        // total mass in Kg
mg1 = x1*m                      // mass of vapour in state 1 in Kg
printf('\nthe mass of vapor in state 1 in Kg is:\n\t mg1 = %f',mg1 );
x2 = (v1-vf2)/(vg2-vf2)         // quality in state 2
mg2 = x2*m                      // mass of vapor in state 2 in Kg
printf('\nthe mass of vapor in state 2 in Kg is:\n\t mg2 = %f',mg2 );
```

```

//part(c)
p3 = 2.11                           // pressure in state 3 from table A-3
printf('\nthe pressure corresponding to state 3 in bar is:\n\t p3 = %f',p3 );
```

Scilab code Exa 3.2 Example 2

```
//(3.2) A vertical piston cylinder assembly containing 0.05 kg of ammonia, initially a saturated vapor, is placed on a hot plate. Due to the weight of the piston and the surrounding atmospheric pressure, the pressure of the ammonia is 1.5 bars. Heating occurs slowly, and the ammonia expands at constant pressure until the final temperature is 25C. Show the initial and final states on T v and p v diagrams, and determine(a) the volume occupied by the ammonia at each state, in m3.(b) the work for the process, in kJ.

// solution

// variable initialization

m = .05                             // mass of ammonia in kg
p1 = 1.5*10^5                               // initial pressure of ammonia in pascal
T2 = 25                             // final temperature in degree celcius

//part (a)
v1 = .7787                          // specific volume in
```

```
state 1 in m3/kg from table A-14
V1 = m*v1                           // volume occupied by ammonia in state 1 in m3
v2 = .9553                          // specific volume in state 2 in m3/kg from table A-15
V2 = m*v2                           // volume occupied by ammonia in state 2 in m3

printf('the volume occupied by ammonia in state 1 in m3 is:\n\t V1 = %f',V1);
printf('\nthe volume occupied by ammonia in state 2 in m3 is:\n\t V2 = %f',V2);

// part (b)
w = (p1*(V2-V1))/1000               // work in KJ
printf('\nthe work done for the process in KJ is:\n\t W = %f',w)
```

Scilab code Exa 3.3 Example 3

```
// (3.3)  A well-insulated rigid tank having a volume of .25 m3 contains saturated water vapor at 100C. The water is rapidly stirred until the pressure is 1.5 bars. Determine the temperature at the final state, in C, and the work during the process, in kJ.

//solution

//variable initialization
V = .25                             // volume of tank in m3
T1 = 100                            // initial temperature in degree celcius
p2 = 1.5                            // final pressure in
```

```
bars

v = 1.673                          // specific volume in m3/kg obtained using table A-2
u1 = 2506.5                        // specific internal energy in state 1 in KJ/Kg obtained from table A-2
T2 = 273                           // 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
m = V/v                            // mass of the system in kg
DeltaU = m*(u2-u1)                 // change in internal energy in KJ
W = - DeltaU                       // from energy balance
printf('the temperature at the final state in degree celcius is:\n T2 = %f',T2);
printf('\nthe work during the process in KJ is:\n\tW = %f',W);
```

Scilab code Exa 3.4 Example 4

```
// (3.4) Water contained in a piston cylinder assembly undergoes two processes in series from an initial state where the pressure is 10 bar and the temperature is 400C.Process 1  2 : The water is cooled as it is compressed at a constant pressure of 10 bar to the saturated vapor state. Process 2  3 : The water is cooled at constant volume to 150C.(a) Sketch both processes on T  v and p  v diagrams.(b) For the overall process determine the work, in kJ/kg. (c) For the overall process determine the heat transfer , in kJ/kg.
```

```

//solution

//variable initialization
P1 = 10*(10^5)                                          // initial pressure in pascal
T1 = 400                                         // initial temperature in degree celcius

v1 = .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
v2 = .1944                                       // specific volume in state 2 in m3/kg obtained from table A-3
w1to2 = (P1*(v2-v1))/1000             // work in KJ/Kg in process 1-2
w2to3 = 0                                         // work in process 2-3
W = w1to2 + w2to3                                  // net work in KJ/kg

v3 = v2
vf3 = 1.0905*10^(-3)                            // specific volume of fluid in state 3 from table A-2
vg3 = .3928                                     // specific volume of gas in state 3 from table A-2
x3 = (v3-vf3)/(vg3-vf3)
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
u3 = uf3+x3*(ug3-uf3)                           // specific internal energy in state 3 in Kj/Kg
```

```
q = (u3-u1) + W                          // heat
   transfer in Kj/Kg
printf(' the work done in the overall process in KJ/
   Kg is:\n\t W = %f',W);
printf(' \nthe heat transfer in the overall process
   in KJ/Kg is:\n\t Q = %f',q);
```

Scilab code Exa 3.5 Example 5

```
//(3.5) For the system of Example 3.1, plot the heat
    transfer, in kJ, and the mass of saturated vapor
    present, in kg, each versus pressure at state 2
   ranging from 1 to 2 bar. Discuss the results.

 printf('The problem is solved by using the software
     referred to in the book. The data can be
    retrieved from that software');
```

Scilab code Exa 3.6 Example 6

```
// (3.6) A closed, rigid tank filled with water
   vapor, initially at 20 MPa, 520C, is cooled until
    its temperature reaches 400C. Using the
   compressibility chart, determine. (a) the
   specific volume of the water vapor in m3/kg at
   the initial state.(b) the pressure in MPa at the
   final state.Compare the results of parts (a) and
   (b) with the values obtained from the superheated
    vapor table, Table A-4.

//solution

//variable initialization
```

```
p1 = 20                                 //initial pressure in MPa
T1 = 520                                // initial temperature in degree celcius
T2 = 400                                // final temperature in degree celcius

//part(a)
//from table A-1
Tc = 647.3                              //critical temperature in kelvin
pc = 22.09                              //critical pressure in MPa

Tr = (T1+273)/Tc                        //reduced temperature
Pr = p1/pc                              //reduced pressure
Z1 = .83                                //compressibility factor
R = 8.314                               //universal gas constant in SI unit
n = 1000/18.02                          //number of moles in a kg of water
v1 = (Z1*n*R*(T1+273))/(p1*10^6)
printf('the specific volume in state1 in m3/Kg is:\n\t v1 = %f',v1)
printf('\n and the corresponding value obtained from table A-4 is .01551 m^3/Kg')

//part(b)
vr = v1*(pc*10^6)/(n*R*Tc)
Tr2 = (T2+273)/Tc
//at above vr and Tr2
PR = .69
P2 = pc*PR
printf('\n\n the pressure in MPa in the final state is: \n\t P2 = %f',P2)
printf('\n and the corresponding value from the table is 15.16Mpa')
```

Scilab code Exa 3.7 Example 7

```
//(3.7) One pound of air undergoes a thermodynamic cycle consisting of three processes.Process 1  2 : constant specific volume Process 2  3 : constant-temperature expansion Process 3  1 : constant-pressure compression. At state 1, the temperature is 300K, and the pressure is 1 bar. At state 2, the pressure is 2 bars. Employing the  ideal gas equation of state, (a) sketch the cycle on p  v coordinates. (b) determine the temperature at state 2, in K; (c) determine the specific volume at state 3, in m3/kg.

//solution

//variable initialization
T1 = 300                                         //temperature in state 1 in kelvin
P1 = 1                                           //pressure in state 1 in bar
P2 = 2                                           //pressure in state 2 in bar

R = 287                                          //gas constant of air in SI units
v1 = (R*T1)/(P1*10^5)                                  //specific volume in state 1
P = linspace(1,2,100)
for i = 1:100
    v(1,i) = v1
end
```

```

plot2d(v,P,rect=[0,0,5,2.5]);

T2 = (P2*10^5*v1)/R
v3 = (R*T2)/(P1*10^5)
vv = linspace(v1,v3,100)
plot(vv,P1)

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

VV = linspace(v1,v3,100)
for j = 1:100
    pp(1,j) = f(VV(1,j))/(10^5)
end
plot2d(VV,pp)
xtitle("","v","p(bar)")

printf('the temperature in kelvin in state 2 is:\n\t
    T2 = %f',T2)
printf('\n\nthe specific volume in state 3 in m^3/kg
    is \n\t v = %f',v3)
```

Scilab code Exa 3.8 Example 8

```
//(3.8) A piston cylinder assembly contains 0.9 kg
    of air at a temperature of 300K and a pressure
   of 1 bar. The air is compressed to a state where
   the temperature is 470K and the pressure is 6
   bars. During the compression, there is a heat
   transfer from the air to the surroundings equal
   to 20 kJ. Using the ideal gas model for air,
   determine the work during the process, in kJ.

```

```
//solutiion

//variable initialization
m = .9                                      // mass of air in kg
T1 = 300                                    // initial temperature in kelvin
P1 = 1                                      // initial pressure in bar
T2 = 470                                    // final temperature in kelvin
P2 = 6                                      // final pressure in bar
Q = -20                                     // heat transfer  in kj

//from table A-22
u1 = 214.07                                 // in KJ/kg
u2 = 337.32                                 // in KJ/Kg
deltaU = m*(u2-u1)                          // change in internal energy in kj
W = Q - deltaU                              // in KJ/kg
printf('the work during the process in KJ is \n\t W = %f',W)
```

Scilab code Exa 3.9 Example 9

```
// (3.9)  Two tanks are connected by a valve. One tank contains 2 kg of carbon monoxide gas at 77C and 0.7 bar. The other tank holds 8 kg of the same gas at 27C and 1.2 bar. The valve is opened and the gases are allowed to mix while receiving energy byheat transfer from the surroundings. The  final equilibrium temperature is 42C. Using the ideal gas model, determine (a) the final
```

```
equilibrium pressure, in bar (b) the heat transfer for the process, in kJ.

//solution

//variable initialization

m1 = 2                                //initial mass of gas in tank 1 in kg
T1 = 350                              //initial temperature in kelvin in tank1
p1 = .7                               //initial pressure in bar in tank 1
m2 = 8                                //initial mass of gas in tank 2 in kg
T2 = 300                              //initial temperature in kelvin in tank 2
p2 = 1.2                              //initial pressure in bar in tank 2
Tf = 315                              //final equilibrium temperature in kelvin

pf = ((m1+m2)*Tf)/((m1*T1/p1)+(m2*T2/p2))

printf('the final equilibrium pressure in bar is: \n \t pf = %f',pf)

//from table A-20
Cv = .745                           //in KJ/Kg.k
Ui = (m1*Cv*T1)+(m2*Cv*T2)
Uf = (m1+m2)*Cv*Tf
deltaU = Uf-Ui
Q = deltaU
printf('\n\nthe heat transfer for the process in KJ is :\n\t Q = %f',Q)
```

Scilab code Exa 3.10 Example 10

```
//(3.10)  One kmol of carbon dioxide gas (CO2) in a piston cylinder assembly undergoes a constant-pressure process at 1 bar from T1 = 300 K to T2. Plot the heat transfer to the gas, in kJ, versus T2 ranging from 300 to 1500 K. Assume the ideal gas model, and determine the specific internal energy change of the gas using. (a)Ubar data from IT.(b) a constant Cv bar evaluated at T1 from IT.

printf('This is solved by the referred software ')
```

Scilab code Exa 3.11 Example 11

```
//(3.11)  Air undergoes a polytropic compression in a piston cylinder assembly from p1 = 1 bar, T1 = 22C to p2 = 5 bars. Employing the ideal gas model, determine the work and heat transfer per unit mass, in kJ/kg, if n = 1.3.

//solution

//variable initialization
p1 = 1                                  //initial pressure in bar
T1 = 295                                //initial temperature in kelvin
p2 = 5                                  //final pressure in bar
```

```
n=1.3                                   //polytropic constant
R = 8314/28.97                                   // gas constant for air in SI units

T2 = T1*(p2/p1)^((n-1)/n)
w = R*(T2-T1)/(1-n)
printf('the work done per unit mass in KJ/Kg is :\n\tW = %f',w/1000)

//from table A-22
u2 = 306.53
u1 = 210.49
Q = u2-u1+w/1000

printf('\n\nthe heat transfer per unit mass in KJ/Kg is:\n\t Q = %f',Q)
```

Chapter 4

Control volume analysis using energy

Scilab code Exa 4.1 Example 1

```
//(4.1)    A feedwater heater operating at steady state has two inlets and one exit. At inlet 1, water vapor enters at p1 = 7 bar, T1=  200C with a mass flow rate of 40 kg/s. At inlet 2, liquid water at p2 = 7 bar, T2 = 40C enters through an area A2 = 25 cm2. Saturated liquid at 7 bar exits at 3 with a volumetric flow rate of 0.06 m3/s. Determine the mass flow rates at inlet 2 and at the exit, in kg/s, and the velocity at inlet 2, in m/s.

//solution

//variable initialization
P1 = 7                                  //pressure at inlet 1 in bar
T1 = 200                                //temperature at inlet 1 in degree celcius
m1dot = 40                              //mass flow
```

```
    rate in Kg/s at inlet 1
P2 = 7                                        //pressure
   in bar at inlet 2
T2 = 40                                       //
   temperature at inlet 2 in degree celcius
A2 = 25                                       //area of
   inlet 2 in cm^2
P3 = 7                                        //exit
   pressure in bar
AV3 = .06                                     //
   volumetric flow rate through exit in m^3/s

//from table A-3
v3 = 1.108*10^(-3)                            //specific
   volume at the exit in m^3/Kg
m3dot = AV3/v3                                //mass flow
    rate at the exit
m2dot = m3dot-m1dot                           //mass flow
    rate at inlet 2
//from table A-2
v2 = 1.0078*10^(-3)                           //specific
   volume in state 2 in m^3/kg
V2 =m2dot*v2/(A2*10^(-4))
printf('the mass flow rate at the inlet 2 in kg/s is
    \n\t m2dot = %f',m2dot)
printf('\n the mass flow rate at the exit in kg/s is
    \n\t m3dot =%f',m3dot)
printf('\n\nthe velocity at inlet 2 in m/s is \n\t
   V2 = %f',V2)
```

Scilab code Exa 4.2 Example 2

```
// (4.2)    Water flows into the top of an open
```

```
barrel at a constant mass flow rate of 7 kg/s. Water exits through a pipe near the base with a mass flow rate proportional to the height of liquid inside:medot = 1.4L, where L is the instantaneous liquid height, in m. The area of the base is 0.2 m2, and the density of water is 1000 kg/m3. If the barrel is initially empty, plot the variation of liquid height with time and comment on the result.

//solution

//variable initialization
midot = 7                                           //inlet mass flow rate in kg/s
A = .2                                              //area of base in m^2
d = 1000                                            //density of water in kg/m^3

function Ldot = f(t,L)
    Ldot = (midot/(d*A))-((1.4*L)/(d*A))
endfunction

t=0:.01:1000
L = ode(0,0,t,f)
plot2d(t,L)
xtitle("","time","height")
```

Scilab code Exa 4.3 Example 3

```
// (4.3)   Steam enters a converging diverging nozzle operating at steady state with p1 = 40 bar, T1= 400C, and a velocity of 10 m/s. The steam flows through the nozzle with negligible heat
```

```
transfer and no significant change in potential energy. At the exit, p2 = 15 bar, and the velocity is 665 m/s. The mass flow rate is 2 kg/s. Determine the exit area of the nozzle, in m2.

//solution

//variable initialization
p1 = 40                                   //entry pressure in bar
T1 = 400                                  //entry temperature in degree celcius
V1 = 10                                   //entry velocity in m/s
P2 = 15                                   //exit pressure in bar
V2 =665                                   //exit velocity in m/s
mdot = 2                                  //mass flow rate in kg/s

//from table A-4
h1 = 3213.6                              //specific enthalpy in in kj/kg

h2 = h1+((V1^2-V2^2)/2)/1000

//from table A-4
v2 = .1627                               //specific volume at the exit in m^3/kg
A2 = mdot*v2/V2
printf('the exit area of the nozzle in m^2 is \n\t A2 = %e',A2)
```

Scilab code Exa 4.4 Example 4

```
//(4.4)   Steam enters a turbine operating at steady state with a mass flow rate of 4600 kg/h. The turbine develops a power output of 1000 kW. At the inlet, the pressure is 60 bar, the temperature is 400C, and the velocity is 10 m/s. At the exit, the pressure is 0.1 bar, the quality is 0.9 (90%), and the velocity is 50 m/s. Calculate the rate of heat transfer between the turbine and surroundings, in kW.

//solution

//variable initialization
m1dot = 4600                                //mass flow rate in Kg/h
Wcvdot = 1000                               //turbine power output in kw
P1 = 60                                     //inlet pressure in bar
T1 = 400                                    //inlet temperature in degree celcius
V1 = 10                                     //inlet velocity in m/s
P2 = .1                                     //exit pressure in bar
x2 = .9                                     //the quality at the exit
V2 = 50                                     //exit velocity in m/s

//from table A-4
h1 = 3177.2                                 //specific enthalpy at the inlet in kj/kg
//from table A-3
hf2 = 191.83
hg2 = 2584.63

h2 = hf2+x2*(hg2-hf2)                       //specific
```

```
enthalpy at the exit in kj/kg
Qcvdot = Wcvdot + m1dot*((h2-h1)+(V2^2-V1^2)/(2*1000))/3600
printf('the rate of heat transfer between the turbine and surroundings in kw is:\n\t Qcvdot = %f',Qcvdot)
```

Scilab code Exa 4.5 Example 5

```
//(4.5)   Air enters a compressor operating at steady state at a pressure of 1 bar, a temperature of 290 K, and a velocity of 6 m/s through an inlet with an area of 0.1 m2. At the exit, the pressure is 7 bar, the temperature is 450 K, and the velocity is 2 m/s. Heat transfer from the compressor to its surroundings occurs at a rate of 180 kJ/min. Employing the ideal gas model, calculate the power input to the compressor, in kW.

//solution

//variable initialization
P1 = 1                                      //entry pressure in bar
T1 = 290                                    //entry temperature in kelvin
V1 = 6                                      //entry velocity in m/s
A1 = .1                                     //inlet area in m^2
P2 = 7                                      //exit pressure in bar
T2 = 450                                    //exit temperature in kelvin
```

```
V2 = 2                                  //exit velocity in m/s
Qcvdot = -180                           //heat transfer rate in KJ/min

R = 8.314                               //univsersal gas constant in SI units
v1 = (R*1000*T1)/(28.97*P1*10^5)        //specific volume
mdot = (A1*V1)/v1                       //mass flow rate

//from table A-22
h1 = 290.16                            //specific enthalpy in KJ/kg
h2 = 451.8                             //specific enthalpy in Kj/Kg
Wcvdot = Qcvdot/60 + mdot*((h1-h2)+(v1^2-V2^2)/(2*1000));
printf('the power input to the compressor in kw is :\n\tWcvdot = %f',Wcvdot)
```

Scilab code Exa 4.6 Example 6

```
// (4.6) A power washer is being used to clean the siding of a house. Water enters at 20C, 1 atm, with a volumetric flow rate of 0.1 liter/s through a 2.5-cm-diameter hose. A jet of water exits at 23C, 1 atm, with a velocity of 50 m/s at an elevation of 5 m. At steady state, the magnitude of the heat transfer rate from the power unit to the surroundings is 10% of the power input. The water can be considered incompressible, and g = 9.81 m/s2. Determine the power input to the motor, in kW.
```

```


//solution

//variable initialization
T1 = 20                              //entry
   temperature in degree celcius
P1 = 1                               //entry
   pressure in atm
AV1 = .1                             //entry
   volumetric flow rate in litre/s
D1 = 2.5                             //diameter of
   the hose in cm
T2 = 23                              //exit
   temperature in degree celcius
P2 = 1                               //exit
   pressure in atm
V2 =50                               //exit
   velocity in m/s
Z2 = 5                               //elevation in
    m
g = 9.81                             //acceleration
    due to gravity in m/s^2

//from table A-2
v = 1.0018*10^(-3)                   //specific
   volume in m^3/kg

mdot = (AV1/1000)/v                  //mass flow
   rate in kg/s
V1 = (AV1/1000)/(%pi*(D1/(2*100))^2)  //entry
   velocity in m/s
c = 4.18                             //from table A
   -19
deltah = c*(T2-T1)+v*(P2-P1)
Wcvdot = (mdot/.9)*[-deltah+(V1^2-V2^2)/(2*1000)+g
   *(0-Z2)/1000]
printf('the power input to the motor in KW is :\n\t
```

```
 = %f',Wcvdot)
```

Scilab code Exa 4.7 Example 7

```
// (4.7)   Steam enters the condenser of a vapor power plant at 0.1 bar with a quality of 0.95 and condensate exits at 0.1 bar and 45C. Cooling water enters the condenser in a separate stream as a liquid at 20C and exits as a liquid at 35C with no change in pressure. Heat transfer from the outside of the condenser and changes in the kinetic and potential energies of the flowing streams can be ignored. For steady-state operation, determine (a) the ratio of the mass flow rate of the cooling water to the mass flow rate of the condensing stream. (b) the rate of energy transfer from the condensing steam to the cooling water, in kJ per kg of steam passing through the condenser.

//solution

//variable initialization
P1 = .1                                         //pressure of steam entering in bar
x1 = .95                                        //quality of steam entering
P2 = .1                                         //pressure of exiting condensate in bar
T2 = 45                                         //temperature of exiting condensate in degree celcius
T3 = 20                                         //temperature of cooling entry water in degree celcius
```

```
T4 = 35                                     //temperature of cooling exit water in degree celcius

//part (a)
//from table A-3
hf = 191.83                                 //in KJ/kg
hg = 2584.7                                 //in Kj/kg
h1 = hf + x1*(hg-hf)                        //in kj/kg

h2 = 188.45                                 //by assumption At states 2, 3, and 4, h is approximately equal to hf(T), in kj/kg
deltah4_3= 62.7                             //by assumption 4,in kj/kg
ratio = (h1-h2)/(deltah4_3)
printf('the ratio of the mass flow rate of the cooling water to the mass flow rate of the condensing stream is :\n\t m3dot/m1dot = %f',ratio)

//part(b)
Qrate = (h2-h1)
printf('\n\nthe rate of energy transfer from the condensing steam to the cooling water, in kJ per kg of steam passing through the condenser is :\n\t Qrate =  %f',Qrate)
```

Scilab code Exa 4.8 Example 8

```
// (4.8)  The electronic components of a computer are cooled by air flowing through a fan mounted at the inlet of the electronics enclosure. At steady state, air enters at 20C, 1 atm. For noise control, the velocity of the entering air cannot
```

```
exceed 1.3 m/s. For temperature control, the temperature of the air at the exit cannot exceed 32C. The electronic components and fan receive, respectively, 80 W and 18 W of electric power. Determine the smallest fan inlet diameter, in cm, for which the limits on the entering air velocity and exit air temperature are met.

//solution

//variable initialization
T1 = 293                                   //temperature of entering air in kelvin
P1 = 1.01325*(10^5)                        //pressure of entering air in pascal
V1max = 1.3                                //maximum velocity of entering air in m/s
T2max = 305                                //maximum temperature at the exit in kelvin
Pec = -80                                  //power received by elecrtonic components in watt
Pf = -18                                   //power received by fan in watt

R = 8.314                                  //universal gas constant in SI units
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

Wcvdot = Pec + Pf                          //total electric power provided to the 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 = sqrt(4*A1min/(%pi))
printf('the smallest fan inlet diameter in cm is:\n\t D1min = %f',D1min*100)
```

Scilab code Exa 4.9 Example 9

```
// (4.9)  A supply line carries a two-phase liquid vapor mixture of steam at 20 bars. A small fraction of the flow in the line is diverted through a throttling calorimeter and exhausted to the atmosphere at 1 bar. The temperature of the exhaust steam is measured as 120C. Determine the quality of the steam in the supply line.

//solution

//variable initialization
P1 = 20                                //pressure in supply line in bars
P2 = 1                                 //exhaust pressure in bar
T2 = 120                               //exhaust temperature in degree celcius

//from table A-3 at 20 bars
hf1 = 908.79                        //in kj/kg
hg1 = 2799.5                        //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
x1 = (h1-hf1)/(hg1-hf1)
printf('the quality of the steam in the supply line is:\n\tx1 = %f',x1)
```

Scilab code Exa 4.10 Example 10

```
//(4.10)  An industrial process discharges gaseous combustion products at 478K, 1 bar with a mass flow rate of 69.78 kg/s. As shown in Fig. E 4.10, a proposed system for utilizing the combustion products combines a heat-recovery steam generator with a turbine. At steady state, combustion products exit the steam generator at 400K, 1 bar and a separate stream of water enters at .275 MPa, 38.9C with a mass flow rate of 2.079 kg/s. At the exit of the turbine, the pressure is 0.07 bars and the quality is 93%. Heat transfer from the outer surfaces of the steam generator and turbine can be ignored, as can the changes in kinetic and potential energies of the flowing streams. There is no significant pressure drop for the water flowing through the steam generator. The combustion products can be modeled as air as an ideal gas. (a) Determine the power developed by the turbine, in kJ/s. (b) Determine the turbine inlet temperature, in C.

//solution

//variable initialization
P1 = 1                          //pressure of industrial discharge in bar
```

```
T1 = 478                        //temperature of industrial discharge in kelvin
m1dot = 69.78                   //mass flow rate of industrial discharge in kg/s
T2 = 400                       //temperature of exit products from steam generator in kelvin
P2 = 1                         //pressure of exit products from steam generator in bar
P3 = .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 = .07                       //exit pressure of the turbine in bars
x5 = .93                       //quality of turbine exit

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

//from table A-22,
h1 = 480.3                    //in kj/kg
h2 = 400.98                    //in Kj/kg

//from table A-2,
h3 = 162.9                    //assumption: h3 = hf(T3), units in Kj/kg

//from table A-3
hf5 = 161                     //in kj/kg
hg5 = 2571.72                 //in kj/kg

h5 = hf5 + x5*(hg5-hf5)
Wcvdot = m1dot*h1 + m3dot*h3 - m2dot*h2 - m5dot*h5

```

```
printf('the power developed by the turbine in kj/s
   is: \n\t Wcvdot = %f',Wcvdot)

//part(b)
P4 = P3                  //from the assumption that
   there is no pressure drop for water flowing
   through the steam generator
h4 = h3 + (m1dot/m3dot)*(h1 -h2)     //from steady
   state energy rate balance
//interpolating in table A-4, with these P4 and h4
T4 = 180                 //in degree celcius
printf('\n\nturbine inlet temperature in degree
   celcius is :\n\t T4 = %f',T4)
```

Scilab code Exa 4.11 Example 11

```
//(4.11)  A tank having a volume of 0.85 m3
   initially contains water as a two-phase
   liquid vapor mixture at 260C and a quality of
   0.7. Saturated water vapor at 260C is slowly
   withdrawn through a pressure-regulating valve at
   the top of the tank as energy is transferred by
   heat to maintain the pressure constant in the
   tank. This continues until the tank is filled
   with saturated vapor at 260C. Determine the
   amount of heat transfer, in kJ. Neglect all
   kinetic and potential energy effects.


//solution

//variable initialization
V = .85                                  //volume of
   tank in m^3
T1 = 260                                 //initial
```

```
temperature of the tank in degree celcius
X1 = .7                                   //initial quality

//from table A-2
uf1 = 1128.4                              //in kg/kg
ug1 = 2599                                //in kg/kg

vf1 = 1.2755e-3                           //in m^3/kg
vg1 = .04221                              //in m^3/kg

u1 = uf1 + X1*(ug1-uf1)                   //in kj/kg
v1 = vf1 + X1*(vg1-vf1)                   //in m^3/kg

m1 = V/v1                                 //initial mass in kg

//for final state , from table A-2,
u2 = 2599                                 // units in KJ/kg
v2 = 42.21e-3                             //units in m^3/Kg
he = 2796.6                               //units in KJ/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)
printf('the amount of heat transfer in KJ is : \n\t Qcv = %f',Qcv)
```

Scilab code Exa 4.12 Example 12

```
// (4.12)  Steam at a pressure of 15 bar and a temperature of 320C is contained in a large vessel. Connected to the vessel through a valve is a turbine followed by a small initially evacuated tank with a volume of 0.6 m3. When emergency power is required, the valve is opened and the tank fills with steam until the pressure is 15 bar. The temperature in the tank is then 400C. The filling process takes place adiabatically and kinetic and potential energy effects are negligible. Determine the amount of work developed by the turbine, in kJ.


// solution

//variable initialization
Pv = 15                                   //pressure in the vessel in bar
Tv = 320                                  //temperature in the vessel in degree celcius
Vt = .6                                   //volume of a tank in m^3
Tt = 400                                  //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 = .203                                 // in m^3/kg
m2 = Vt/v2                                // mass within the tank at the end of the process in kg
//from table A-4,
```

```
hi = 3081.9                                   //in kj/kg
u2 = 2951.3                                   //in kj/kg
deltaUcv = m2*u2-m1*u1
Wcv = hi*(m2-m1)-deltaUcv
printf('the amount of work developed by the turbine in kj is:\n\t Wcv = %f ',Wcv)
```

Scilab code Exa 4.13 Example 13

```
//(4.13) An air compressor rapidly fills a .28m3 tank, initially containing air at 21C, 1 bar, with air drawn from the atmosphere at 21C, 1 bar. During filling, the relationship between the pressure and specific volume of the air in the tank is pv^1.4 = constant. The ideal gas model applies for the air, and kinetic and potential energy effects are negligible. Plot the pressure, in atm, and the temperature, in F, of the air within the tank, each versus the ratio m/m1, where m1 is the initial mass in the tank and m is the mass in the tank at time t > 0. Also, plot the compressor work input, in kJ, versus m/m1. Let m/m1 vary from 1 to 3.



//solution
printf('its an IT software problem')
```

Scilab code Exa 4.14 Example 14

```
// (4.14)   A tank containing 45 kg of liquid water initially at 45C has one inlet and one exit with equal mass flow rates. Liquid water enters at 45C and a mass flow rate of 270 kg/h. A cooling coil immersed in the water removes energy at a rate of 7.6 kW. The water is well mixed by a paddle wheel so that the water temperature is uniform throughout. The power input to the water from the paddle wheel is 0.6 kW. The pressures at the inlet and exit are equal and all kinetic and potential energy effects can be ignored. Plot the variation of water temperature with time.


//solution

//variable initialization

funcprot(0)
mcv = 45                                            //initial mass of water in kg
Ti = 318                                            //initial temperature of water in kelvin
mdot = 270/3600                                     //mass flow rate in kg/s
Qcvdot = -7.6*10^3                                  //rate of energy removal by coil in Watt
Wcvdot = -.6*10^3                                   //power input from the paddle in Watt

c = 4.2*10^3                                            //specific heat for liquid water in J/Kg.k

function Tdot= f(t,T)
    Tdot = (Qcvdot-Wcvdot+mdot*c*(Ti-T))/(mcv*c)
endfunction
```

```

t = 0:.1:3600
T = ode(Ti,0,t,f)
plot2d(t/3600,T)
xtitle(””,”time(h)”,”water temperature(kelvin)”)
```

Chapter 5

The second law of thermodynamics

Scilab code Exa 5.1 Example 1

```
// (5.1)  An inventor claims to have developed a power cycle capable of delivering a net work output of 410 kJ for an energy input by heat transfer of 1000 kJ. The system undergoing the cycle receives the heat transfer from hot gases at a temperature of 500 K and discharges energy by heat transfer to the atmosphere at 300 K. Evaluate this claim.

//solution

//variable initialization
W = 410                                                       //net work output in kj claimed
Q = 1000                                                      //energy input by heat transfer in kj
Tc = 300                                                      //temperature of cold reservoir in kelvin
TH = 500                                                      //
```

```
temperature of hot reservoir in kelvin

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


printf('eta = %f',eta)
printf('\n etamax  = %f',etamax)
printf('\n since eta is more than etamax, the claim is not authentic')
```

Scilab code Exa 5.2 Example 2

```
// (5.2)  By steadily circulating a refrigerant at low temperature through passages in the walls of the freezer compartment, a refrigerator maintains the freezer compartment at 5C when the air surrounding the refrigerator is at 22C. The rate of heat transfer from the freezer compartment to the refrigerant is 8000 kJ/h and the power input required to operate the refrigerator is 3200 kJ/h. Determine the coefficient of performance of the refrigerator and compare with the coefficient of performance of a reversible refrigeration cycle operating between reservoirs at the same two temperatures.


//solution

//variable initialization
funcprot(0)
Qcdot = 8000                                   //in kj/h
```

```
Wcycledot = 3200                              //in kj/h
Tc = 268                                      //temperature of compartment in kelvin
TH = 295                                     //temperature of the surrounding air in kelvin

beta = Qcdot/Wcycledot                       //coefficient of performance
betamax = Tc/(TH-Tc)                          //reversible coefficient of performance
printf('coefficient of performance is : \n\t beta = %f',beta)
printf('\n\n coefficient of performance of a reversible cycle is :\n\t betamax = %f',betamax)
```

Scilab code Exa 5.3 Example 3

```
//(5.3)   A dwelling requires 5 * 10^5 kJ per day to maintain its temperature at 22C when the outside temperature is 10C. (a) If an electric heat pump is used to supply this energy, determine the minimum theoretical work input for one day of operation, in kJ.


//solution

//variable initialization
Tc = 283                           //in kelvin
TH = 295                           //in kelvin
QH = 5*10^5                        //in kj per day

Wcyclemin = (1-Tc/TH)*QH
printf('minimum theoretical work input for one day
```

```
of operation in kj is:\n\tWmin = %e',Wcyclemin)
```

Chapter 6

Using entropy

Scilab code Exa 6.1 Example 1

```
// (6.1)  Water, initially a saturated liquid at 100C, is contained in a piston cylinder assembly. The water undergoes a process to the corresponding saturated vapor state, during which  the piston moves freely in the cylinder. If the change of state is brought about by heating the water as it undergoes an internally reversible process at constant pressure and temperature, determine the work and heat transfer per unit of mass, each in kJ/kg.

//solution


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

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

printf('the work per unit mass in kj/kg is\n\t w =
    %f',w)
printf('\nthe heat transfer per unit mass in kj/kg
    is \n\t Q = %f',Q)
```

Scilab code Exa 6.2 Example 2

```
//(6.2)   Water initially a saturated liquid at 100C
     is contained within a piston cylinder assembly
    . The water undergoes a process to the
    corresponding saturated vapor state, during which
     the piston moves freely in the cylinder. There
    is no heat transfer with the surroundings. If the
     change of state is brought about by the action
    of a paddle wheel, determine the net work per
    unit mass, in kJ/kg, and the amount of entropy
    produced per unit mass,in Kj/kg.k

//solution

//Assumptions:
//1. The water in the piston cylinder assembly is
    a closed system.
//2. There is no heat transfer with the surroundings
    .
//3. The system is at an equilibrium state initially
     and finally. There is no change in kinetic or
    potential energy between these
//two states.
```

```

//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

//from energy balance,
W = -(ug-uf)
printf('the net work per unit mass in kj/kg is:\n\t w = %f ',W)

//from entropy balance
sigmabym = (sg-sf)
printf('\n\nthe amount of entropy produced per unit mass in kj/kg.k is :\n\t sigmabym =%f',sigmabym)
```

Scilab code Exa 6.3 Example 3

```
//(6.3)   Refrigerant 134a is compressed adiabatically in a piston cylinder assembly from saturated vapor at 0C to a final pressure of 0.7 MPa. Determine the minimum theoretical work input required per unit mass of refrigerant, in kJ/kg.

//solution

//variable initialization
T1 = 273                           //initial temperature of saturated vapor in kelvin
P2 = .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
Wmin = u2s-u1
printf('the minimum theoretical work input required per unit mass of refrigerant in kj/kg is:\n\t Wmin = %f',Wmin)
```

Scilab code Exa 6.4 Example 4

```
//(6.4)   Referring to Example 2.4, evaluate the rate of entropy production sigmadot in kW/K, for (a) the gearbox as the system and (b) an enlarged system consisting of the gearbox and enough of its surroundings that heat transfer occurs at the temperature of the surroundings away from the immediate vicinity of the gearbox, Tf = 293 K (20 C).

//solution

//variable initialization
Qdot = -1.2                           //in kilo watt
Tb = 300                              //in kelvin
Tf = 293                              //in kelvin


```

```
//part (a)
//from entropy balance
sigmadot = -Qdot/Tb
printf('the rate of entropy production in kw/k with gearbox as system is:\n\t sigmadot = %e',sigmadot)

//part(b)
//from entropy balance
sigmadt = -Qdot/Tf
printf('\n\nthe rate of entropy production in kw/k with gearbox + sorrounding as system is:\n\t sigmadot = %e',sigmadt)
```

Scilab code Exa 6.5 Example 5

```
//(6.5)   A 0.3 kg metal bar initially at 1200K is removed from an oven and quenched by immersing it in a closed tank containing 9 kg of water initially at 300K. Each substance can be modeled as incompressible. An appropriate constant specific heat value for the water is cw = 4.2 kJ/kg. K, and an appropriate value for the metal is cm = 0.42 kJ/kg  K. Heat transfer from the tank contents can be neglected. Determine (a) the final equilibrium temperature of the metal bar and the water, in K, and (b) the amount of entropy produced, in kJ/k.


//solution

//variable initialization
Tmi = 1200                                          //initial temperature of metal in kelvin
```

```
cm = .42                                            //specific heat of metal in KJ/kg.k
mm = .3                                             //mass of metal in kg
Twi = 300                                           //initial temperature of water in kelvin
cw = 4.2                                            //specific heat of water in KJ/Kg.k
mw = 9                                              //mass of water in kg


//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)

printf('the final equilibrium temperature of the metal bar and the water in kelvin is :\n\t Tf = %f',Tf)
printf('\n\n the amount of entropy produced in kj/k is: \n\tsigma = %f ',sigma)
```

Scilab code Exa 6.6 Example 6

```
//(6.6)   Steam enters a turbine with a pressure of 30 bar, a temperature of 400C, and a velocity of 160 m/s. Saturated vapor at 100C exits with a velocity of 100 m /s. At steady state, the turbine develops work equal to 540 kJ per kg of steam flowing through the turbine. Heat transfer between the turbine and its surroundings occurs
```

```
at an average outer surface temperature of 350 K. Determine the rate at which entropy is produced within the turbine per kg of steam flowing, in kJ/kg.k. Neglect the change in potential energy between inlet and exit

//solution

//variable initialization
P1 = 30                                    //pressure of steam entering the turbine in bar
T1 = 400                                   //temperature of steam entering the turbine in degree celcius
V1 = 160                                   //velocity of steam entering the turbine in m/s
T2 = 100                                   //temperature of steam exiting in degree celcius
V2 = 100                                   //velocity of steam exiting in m/s
Wcvdot = 540                               //work produced by turbine in kJ/kg of steam
Tb = 350                                   //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

//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)

printf('the rate at which entropy is produced within the turbine per kg of steam flowing, in kJ/kg.k is:\n\t entropyrate = %f',sigmadot)
```

Scilab code Exa 6.7 Example 7

```
//(6.7)   An inventor claims to have developed a device requiring no energy transfer by work or heat transfer, yet able to produce hot and cold streams of air from a single stream of air at an intermediate temperature. The inventor provides steady-state test data indicating that when air enters at a temperature of 21C and a pressure of 5.1 bars, separate streams of air exit at temperatures of -18C and 79C, respectively, and each at a pressure of 1 bar. Sixty percent of the mass entering the device exits at the lower temperature. Evaluate the inventor s claim, employing the ideal gas model for air and ignoring changes in the kinetic and potential energies of the streams from inlet to exit.

//solution

//variable initialization
T1 = 294                                       //entry temperature of air in kelvin
```

```
P1 = 5.1                                        //entry pressure of air in bars
T2 = 352                                        //exit temperature of hot stream in kelvin
P2 = 1                                          //exit pressure of hot stream in bars
T3 = 255                                        //exit temperature of cold stream in kelvin
P3 = 1                                          //exit pressure of cold stream in bars

cp = 1                                          //in kj/kg.k
R = 8.314/28.97
se = .4*(cp*log((T2)/(T1))-R*log(P2/P1)) + .6*(cp*log((T3)/(T1))-R*log(P3/P1))             //specific entropy in kj/kg.k

printf('specific entropy in kj/kg.k = %f',se)
printf('\n\nsince se > 0, the claim of the writer is true')
```

Scilab code Exa 6.8 Example 8

```
//(6.8)      Components of a heat pump for supplying heated air to a dwelling are shown in the schematic below. At steady state, Refrigerant 22 enters the compressor at −5C, 3.5 bar and is compressed adiabatically to 75C, 14 bar. From the compressor, the refrigerant passes through the condenser, where it condenses to liquid at 28C, 14 bar. The refrigerant then expands through a throttling valve to 3.5 bar. The states of the refrigerant are shown on the accompanying T   s diagram. Return air from the dwelling enters the
```

```
condenser at 20C, 1 bar with a volumetric flow rate of 0.42 m3/s and exits at 50C with a negligible change in pressure. Using the ideal gas model for the air and neglecting kinetic and potential energy effects, (a) determine the rates of entropy production, in kW/K, for control volumes enclosing the condenser, compressor, and expansion valve, respectively. (b) Discuss the sources of irreversibility in the components considered in part (a).


//solution


//variable initialization
P1 = 3.5                                        //pressure of refrigerant entering the compressor in bars
T1 = 268                                        //temperature of refrigerant entering the compressor in kelvin
P2 = 14                                         //pressure of refrigerant entering the condenser in bars
T2 = 348                                        //temperature of refrigerant entering the condenser in kelvin
P3 = 14                                         //pressure of refrigerant exiting the condenser in bars
T3 = 301                                        //temperature of refrigerant exiting the condenser in kelvin
P4 = 3.5                                        //pressure of refrigerant after passing through expansion valve in bars
P5 = 1                                          //
```

```
pressure of indoor return air entering the condenser in bars
T5 = 293                                            //temperature of indoor return air entering the condenser in kelvin
AV5 = .42                                           //volumetric flow rate of indoor return air entering the condenser in m^3/s
P6 =  1                                             //pressure of return air exiting the condenser in bar
T6 = 323                                            //temperature of return air exiting the condenser in kelvin

//part(a)

//from table A-9
s1 = .9572                                          //in kj/kg.k
//interpolating in table A-9
s2 = .98225                                         //in kj/kg.k
h2 = 294.17                                         //in kj/kg
//from table A-7
s3 = .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                                          //in kj/kg
sf4 = .1328                                        //in kj/kg.k
sg4 = .9431                                        //in kj/kg.k

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
cp = 1.005                                        //in kj/kg.k
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)

printf('\nthe rates of entropy production, in kW/K, for control volume enclosing the condenser is \n\t R1 = %e ',sigmacond)
printf('\nthe rates of entropy production, in kW/K, for control volume enclosing the compressor is \n\t R2 = %e ',sigmacomp)
```

```
printf('\nthe rates of entropy production, in kW/K,
   for control volume enclosing the expansion valve
   is \n\t R3 = %e ',sigmavalve)
```

Scilab code Exa 6.9 Example 9

```
// (6.9)   Air undergoes an isentropic process from
   p1 = 1 bar, T1= 300K to a final state where the
   temperature is T2= 650K.,Employing the ideal gas
    model, determine the final pressure p2, in atm.
   Solve using (a) pr data from Table A-22 (b)
   Interactive Thermodynamics: IT, and (c) a
   constant specific heat ratio k evaluated at the
   mean temperature, 475K, from Table A-20.

//solution

//variable initialization
P1 = 1                                     //initial
   pressure in bar
T1 = 300                                   //initial
   temperature in kelvin
T2 = 650                                   //final
   temperature in kelvin

//part(a)
//from table A-22
pr2 = 21.86
pr1 = 1.3860
p2 = P1*(pr2/pr1)
printf('part(a) P2 in bar = %f ',p2)
//part(b)
printf('\n part(b) IT software problem')
//part(c)
k = 1.39                                  //from
```

```
table A-20
p2a = P1*((T2/T1)^(k/(k-1)))
printf('\n part(c) P2a in bar = %f',p2a)
```

Scilab code Exa 6.10 Example 10

```
//(6.10) A rigid, well-insulated tank is filled initially with 5 kg of air at a pressure of 5 bar and a temperature of 500 K. A leak develops, and air slowly escapes until the pressure of the air remaining in the tank is 1 bar. Employing the ideal gas model, determine the amount of mass remaining in the tank and its temperature.


//solution

//variable initialization
m1 = 5                                               //initial mass in kg
P1 = 5                                               //initial pressure in bar
T1 = 500                                             //initial temperature in kelvin
P2 = 1                                               //final pressure in bar

//from table A-22
pr1 = 8.411

pr2 = (P2/P1)*pr1

//using this value of pr2 and interpolation in table A-22
T2 = 317                                             //
```

```
    in kelvin

m2 = (P2/P1)*(T1/T2)*m1
printf('the amount of mass remaining in the tank in kg is :\n \t m2 = %f',m2)
printf('\n and its temperature in kelvin  is : \n\t T = %f',T2)
```

Scilab code Exa 6.11 Example 11

```
//(6.11)    A steam turbine operates at steady state with inlet conditions of p1 = 5 bar, T1=  320C. Steam leaves the turbine at a pressure of 1 bar. There is no significant heat transfer between the turbine and its surroundings, and kinetic and potential energy changes between inlet and exit are negligible. If the isentropic turbine efficiency is 75%, determine the work developed per unit mass of steam flowing through the turbine, in kJ/kg.


//solution

//variable initialization
P1 = 1                                           //inlet pressure in bar
T1 = 593                                         //inlet temperature in kelvin
P2 = 1                                           //exit pressure in bar
eta = .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
   //in kj/kg
w = eta*(h1 - h2s)
printf('the work developed per unit mass of steam
   flowing through in kj/kg is : \n\t w = %f',w)
```

Scilab code Exa 6.12 Example 12

```
//(6.12)    A turbine operating at steady state
   receives air at a pressure of p1 = 3.0 bar and a
   temperature of T1=  390 K. Air exits the turbine
   at a pressure of p2 = 1.0 bar. The work developed
    is measured as 74 kJ per kg of air flowing
   through the turbine. The turbine operates
   adiabatically, and changes in kinetic and
   potential energy between inlet and exit can be
   neglected. Using the ideal gas model for air,
   determine the turbine efficiency.

//solution

//variable initialization
P1 = 3                                          //
```

```
pressure of air entering in bar
T1 = 390                                    //temperature of air entering in kelvin
P2 = 1                                      //pressure of exit air
Wcvdot = 74                                 //work developed in kj/kg

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

pr2 = (P2/P1)*pr1

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

Wcvdots = h1 - h2s

eta = Wcvdot/Wcvdots

printf('the turbine efficiency is : \n\t eta = %f',eta)
```

Scilab code Exa 6.13 Example 13

```
//(6.13)    Steam enters a nozzle operating at steady state at p1 = 1.0 MPa and T1=  320C with a velocity of 30 m/s. The pressure and temperature at the exit are p2 = 0.3 MPa and T2 = 180C. There is no significant heat transfer between the nozzle and its surroundings, and changes in potential energy between inlet and exit can be
```

```
neglected. Determine the nozzle efficiency.


//solution

//variable initialization
P1 = 1      //pressure of entering steam in Mpa
T1 = 593    //temperature of entering steam in kelvin
V1 = 30     //velocity of entering steam in m/s
P2 = .3     //pressure of exit steam in Mpa
T2 = 453    //temperature of exit steam in kelvin

//from table A-4, at T1 = 593 kelvin and P1 = 1 Mpa; 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
V2squareby2 = h1 - h2 + (V1^2)/2000

//interpolating in table A-4
h2s = 2813.3                                     //in
```

```
   kj/kg
V2squareby2s = h1 - h2s + (V1^2)/2000
eta = V2squareby2/V2squareby2s
printf('the nozzle efficiency is :\n\t eta = %f',eta
   )
```

Scilab code Exa 6.14 Example 14

```
//(6.14)      For the compressor of the heat pump
   system in Example 6.8, determine the power, in kW
   , and the isentropic efficiency using (a) data
   from property tables, (b) Interactive
   Thermodynamics: IT.


//solution

//part(a)
//from table A-9
h1 = 249.75
                                                  //in
   kj/kg
h2 = 294.17
                                                  //in
   kj/kg

mdot = .07
                                                   //in
    kg/s

wcvdot = mdot*(h1-h2)
//from table A-9
s1 = .9572
                                                   //in
    Kj/Kg.k
```

```
h2s = 285.58                                        //in kj/kg

eta = (h2s-h1)/(h2-h1)

printf('the power in KW is: \n\t p = %f',wcvdot)
printf('\n the isentropic efficiency is : \n\t eta = %f',eta)
```

Scilab code Exa 6.15 Example 15

```
//(6.15)   An air compressor operates at steady state with air entering at p1 = 1 bar, T1=  20C, and exiting at =p2  5 bar. Determine the work and heat transfer per unit of mass passing through the device, in kJ/kg, if the air undergoes a polytropic process with n = 1.3. Neglect changes in kinetic and potential energy between the inlet and the exit. Use the ideal gas model for air.

//solution

//variable initialization
P1 = 1                  //pressure of entering air in bar
T1 = 293                //temperature of entering air in kelvin
P2 = 5                  //pressure of exit air in bar
n = 1.3

T2 = T1*((P2/P1)^((n-1)/n))            //in kelvin
R = 8.314/28.97
```

```
wcvdot=((n*R)/(n-1))*(T1-T2)                              // in kj/kg

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

Qcvdot= wcvdot + (h2-h1)                                  // in kj/kg
printf('the work per unit mass passing through the device in kj/kg is: w = %f',wcvdot)
printf('\nthe heat transfer per unit mass in Kj/kg is : q = %f ',Qcvdot)
```

Chapter 7

Exergy analysis

Scilab code Exa 7.1 Example 1

```
// (7.1) A cylinder of an internal combustion engine contains 2450 cm3 of gaseous combustion products at a pressure of 7 bar and a temperature of 867C just before the exhaust valve opens. Determine the specific exergy of the gas, in kJ/kg. Ignore the effects of motion and gravity, and model the combustion products as air as an ideal gas. Take T0 = 300 K (27C) and p0= 1.013 bar.


//solution


//variable initialization
v = 2450                    //volume of gaseous products in cm^3
P = 7                       //pressure of gaseous product in bar
T = 867
```

```
                    //temperature of gaseous product in degree celcius
T0 = 300                    //in kelvin
P0 = 1.013                  //in bar

//from table A-22
u = 880.35                  //in kj/kg
u0 = 214.07                 //in kj/kg
s0(T) = 3.11883                                                          //in kj/kg.k
s0(T0) = 1.70203                                                         //in kj/kg.k

e = (u-u0) + (P0*(8.314/28.97)*[((T+273)/P)-(T0/P0)]) - T0*[s0(T)-s0(T0)-(8.314/28.97)*log(P/P0)]          //in kj/kg
printf('the specific exergy of the gas, in kJ/kg is \n\t e = %f',e)
```

Scilab code Exa 7.2 Example 2

```
//(7.2)   Refrigerant 134a, initially a saturated vapor at −28C, is contained in a rigid, insulated vessel. The vessel is fitted with a paddle wheel
```

```
connected to a pulley from which a mass is suspended. As the mass descends a certain distance, the refrigerant is stirred until it attains a state where the pressure is 1.4 bar. The only significant changes of state are experienced by the suspended mass and the refrigerant. The mass of refrigerant is 1.11 kg. Determine (a) the initial exergy, final exergy, and change in exergy of the refrigerant, each in kJ. (b) the change in exergy of the suspended mass, in kJ. (c) the change in exergy of an isolated system of the vessel and pulley mass assembly, in kJ. Discuss the results obtained, and compare with the respective energy changes. Let T0 = 293 K (20C), p0 = 1 bar.

//solution

//variable initialization
mR = 1.11                                                    //mass of the refrigerant in kg
T1 = -28                                                     //initial temperature of the saturated vapor in degree celcius
P2 = 1.4                                                     //final pressure of the refrigerant in bar
T0 = 293                                                     //in kelvin
P0 = 1                                                       //in bar

//part (a)
//from table A-10
u1 = 211.29                                                 //in kj/kg
v1 = .2052                                                  //in m^3/kg
s1 = .9411                                                  //in
```

```
    kj/kg.k
//from table A-12
u0 = 246.67                                            //in
    kj/kg
v0 = .23349                                            //in
   m^3/kg
s0 = 1.0829                                            //in
    kj/kg.k

E1 = mR*[(u1-u0) + P0*10^5*(v1-v0)*10^(-3)-T0*(s1-s0
    )]

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

E2 = mR*[(u2-u0) + P0*10^5*(v2-v0)*10^(-3)-T0*(s2-s0
    )]

printf('part(a)the initial exergy in kj is :\n\t E1
   = %f',E1)
printf('\nthe final exergy in kj is :\n\t E2 = %f',
    E2)
printf('\nthe change in exergy of the refrigerant in
     kj is \n\tdeltaE = %f',E2-E1)


//part (b)
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
printf('\n\n\npart(b)the change in exergy of the
   suspended mass, in kJ is :\n\t deltaE = %f',
   deltaE)


//part(c)
deltaEiso = (E2-E1) + deltaE
printf('\n\n\npart(c)the change in exergy of an
   isolated system of the vessel and pulley mass
   assembly, in kJ is :\n\t deltaEiso = %f',
   deltaEiso)
```

Scilab code Exa 7.3 Example 3

```
//(7.3)    Water initially a saturated liquid at 100
   C is contained in a piston cylinder assembly.
   The water undergoes a process to the
   corresponding saturated vapor state, during which
    the piston moves freely in the cylinder. For
   each of the two processes described below,
   determine on a unit of mass basis the change in
   exergy, the exergy transfer accompanying work,
   the exergy transfer accompanying heat, and the
   exergy destruction, each in kJ/kg. Let T0 = 20C,
   p0 = 1.014 bar. (a) The change in state is
   brought about by heating the water as it
   undergoes an internally reversible process at
   constant temperature and pressure. (b) The change
    in state is brought about adiabatically by the
   stirring action of a paddle wheel.
```

```


//solution

//variable initialization
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

deltae = ug-uf + P0*10^5*(vg-vf)/(10^3)-T0*(sg-sf)
```

```

//exergy 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

printf('part(a)the change in exergy in kj/kg is:\n\t deltae = %f ',deltae)
printf('\nthe exergy transfer accompanying work in kj/kg is:\n\t etaw = %f',etaw)
printf('\nthe exergy transfer accompanying heat in kj/kg is:\n\t etah = %f',etah)
printf('\nthe exergy destruction in kj/kg is:\n\t ed = %f',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

printf('\n\n\npart(b)the change in exergy in kj/kg is:\n\t Deltae = %f ',Deltae)
printf('\nthe exergy transfer accompanying work in kj/kg is:\n\t Etaw = %f',Etaw)
printf('\nthe exergy transfer accompanying heat in kj/kg is:\n\t Etah = %f',Etah)
printf('\nthe exergy destruction in kj/kg is:\n\t Ed = %f',Ed)
```

Scilab code Exa 7.4 Example 4

```
//(7.4)    For the gearbox of Examples 2.4 and 6.4(a), develop a full exergy accounting of the power input. Let T0 = 293 K.


//solution

//Since the gearbox volume is constant, the rate of exergy transfer accompanying power reduces to the power itself. Accordingly, exergy is transferred into the gearbox via the high-speed shaft at a rate equal to the power input, 60 kW, and exergy is transferred out via the low-speed shaft at a rate equal to the power output, 58.8 kW. Additionally, exergy is transferred out accompanying heat transfer and destroyed by irreversibilities within the gearbox.

T0 = 293                                            //
```

```
in kelvin
Qdot = -1.2                                          //in KW, from example 6.4a
Tb = 300                                             //temperature at the outer surface of the gearbox in kelvin from example 6.4a
sigmadot = 4e-3                                      //rate of entropy production in KW/k from example 6.4a

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

printf('balance sheet')
printf('\nrate of exergy in:\n high speed shaft\t\t 60Kw')
printf('\nDisposition of the exergy:\n    Rate of exergy out\nlow-speed shaft\t\t 58.8Kw')
printf('\nheat transfer in kw\t\t%f',norm(R))
printf('\n    Rate of exergy destruction in kw\t\t%f',Eddot)
```

Scilab code Exa 7.5 Example 5

```
//Superheated water vapor enters a valve at 3.0 MPa, 320C and exits at a pressure of 0.5 MPa. The expansion is a throttling process. Determine the specific flow exergy at the inlet and exit and the exergy destruction per unit of mass flowing, each in kJ/kg. Let T0 = 25C, p0= 1 atm.

//solution

```

```
//variable initialization
p1 = 3
   //entry pressure in Mpa
p2 = .5
   //exit pressure in Mpa
T1 = 320
   //entry temperature in degree celcius
T0 = 25
   //in degree celcius
p0 = 1
   //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

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

printf(' the specific flow exergy at the inlet in kj/kg is :\n\t ef1 =%f',ef1)
printf('\nthe specific flow exergy at the exit in kj/kg is:\n\t ef2 = %f',    ef2)
printf('\nthe exergy destruction per unit of mass flowing in kj/kg is:\n\t = %f',Ed)
```

Scilab code Exa 7.6 Example 6

```
//Compressed air enters a counterflow heat exchanger operating at steady state at 610 K, 10 bar and exits at 860 K, 9.7 bar. Hot combustion gas enters as a separate stream at 1020 K, 1.1 bar and exits at 1 bar. Each stream has a mass flow rate of 90 kg/s. Heat transfer between the outer surface of the heat exchanger and the surroundings can be ignored. Kinetic and potential energy effects are negligible. Assuming the combustion gas stream has the properties of air, and using the ideal gas model for both streams, determine for the heat exchanger(a) the exit temperature of the combustion gas, in K. (b) the net change in the flow exergy rate from inlet to exit of each stream, in MW. (c) the rate exergy is destroyed, in MW. Let T0 = 300 K, p0 = 1 bar.

```

```

//solution

//variable initialization
T1 = 610                                                          //temperature of the air entering heat exchanger in kelvin
p1 = 10                                                           //pressure of the air entering heat exchanger in bar
T2 = 860                                                          //temperature of the air exiting the heat exchanger in kelvin
p2 = 9.7                                                          //pressure of the air exiting the heat exchanger in bar
T3 = 1020                                                         //temperature of entering hot combustion gas in kelvin
p3 = 1.1                                                          //pressure of entering hot  combustion gas in bar
p4 = 1                                                            //pressure of exiting hot combustion gas in bar
mdot = 90                                                         //mass flow rate in kg/s
T0 = 300                                                          //in kelvin
p0 = 1
```

```
//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

//from reduction of mass and energy rate balances for the control volume at steady state
h4 = h3+h1-h2

//using interpolation in table A-22 gives
T4 = 778                                                          //in kelvin
printf('the exit temperature of the combustion gas in kelvin is:\n\tT4 = %f',T4)


//part(b)
//from table A-22
s2 = 2.79783                                                      //in kj/kg.k
s1 = 2.42644                                                      //in kj/kg.k

deltaR = (mdot*((h2-h1)-T0*(s2-s1-(8.314/28.97)*log(p2/p1))))/1000

```

```
//from table A-22
s4 = 2.68769                                                    //in kj/kg.k
s3 = 2.99034                                                    //in kj/kg.k

deltRc = mdot*((h4-h3)-T0*(s4-s3-(8.314/28.97)*log(p4/p3)))/1000

printf('\nthe net change in the flow exergy rate from inlet to exit of compressed gas in MW is:\n\t deltaR = %f',deltaR)
printf('\nthe net change in the flow exergy rate from inlet to exit of hot combustion gas in MW is:\n\tdeltRc =%f ',deltRc)

//part(c)
//from an exergy rate balance
Eddot = -deltaR-deltRc

printf('\nthe rate exergy  destroyed, in MW is:Eddot = %f',Eddot)
```

Scilab code Exa 7.7 Example 7

```
//Steam enters a turbine with a pressure of 30 bar, a temperature of 400C, a velocity of 160 m/s. Steam exits as saturated vapor at 100C with a velocity of 100 m/s. At steady state, the turbine develops work at a rate of 540 kJ per kg of steam flowing through the turbine. Heat transfer between the turbine and its surroundings occurs at an average outer surface temperature of 350 K.
```

```
Develop a full accounting of the net exergy
   carried in by the steam, per unit mass of steam
   flowing. Neglect the change in potential energy
   between inlet and exit. Let T0 = 25C, p0=  1 atm.

//solution

//variable initialization
p1 = 30                                                      
   //pressure of entering steam in bar
t1 = 400                                                     //
   temperature of entering steam in degree celcius
v1 = 160                                                     //
   velocity of entering steam in m/s
t2 = 100                                                     //
   temperature of exiting saturated vapor in degree
   celcius
v2 = 100                                                     //
   velocity of exiting saturated vapor in m/s
W = 540                                                      
   //rate of work developed in kj per kg of steam
Tb = 350                                                     //
   the temperature on the boundary where heat
   transfer occurs in kelvin
T0 = 25                                                      
   //in degree celcius
p0 = 1                                                       
   //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

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

//from example 6.6
Q = -22.6                                          //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 balanceff

printf('balance sheet')
printf('\nNet rate of exergy in:\t%f',DELTAef)
printf('\nDisposition of the exergy:')
printf('\ n    Rate of exergy out')
printf('\nwork\t%f',W)
printf('\nheat transfer\t%f',-Eq)
```

```
printf('\n    Rate of exergy destruction\t%f',Ed)
```

Scilab code Exa 7.8 Example 8

```
//(7.8) Suppose the system of Example 4.10 is one option under consideration for utilizing the combustion products discharged from an industrial process. (a) Develop a full accounting of the net exergy carried in by the combustion products. (b) Discuss the design implications of the results.


//solution

//variable initialization
m1dot = 69.78                                    //in kg/s
p1 = 1                                           //in bar
T1 = 478                                         //in kelvin
T2 = 400                                         //in kelvin
p2 = 1                                           //in bar
p3 = .275                                        //in Mpa
T3 = 38.9
```

```
    //in degree celcius
m3dot = 2.08

    //in kg/s
T4 = 180

    //in degree celcius
p4 = .275

    //in Mpa
p5 = .07

    //in bar
x5 = .93
Wcvdot = 876.8

    //in kW
T0 = 298

    //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

```

```
netRE = m1dot*(h1-h2-T0*(s1-s2-(8.314/28.97)*log(p1/p2)))           //the net rate exergy  carried into the control volume


//from table A-2E
h3 = 162.82                                                  //in kj/kg
s3 = .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

netREout = m3dot*(h5-h3-T0*(s5-s3))                                 //the net rate exergy carried out by the water stream

//from table A-4
h4 = 2825                                                    //in kj/kg
s4 = 7.2196                                                  //in kj/kg.k

//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


printf('balance sheet')
printf('\nNet rate of exergy in:\t%f',netRE)
printf('\nDisposition of the exergy:')
printf('\ n    Rate of exergy out')
printf('\npower developed\t%f',1772.8-netREout-Eddot-EdDot)
printf('\nwater stream\t%f',netREout)
printf('\ n    Rate of exergy destruction')
printf('\nheat-recovery steam generator\t%f',Eddot)
printf('\nturbine\t%f',EdDot)
```

Scilab code Exa 7.9 Example 9

```
//(7.9)    For the heat pump of Examples 6.8 and 6.14, determine the exergy destruction rates, each in kW, for the compressor, condenser, and throttling valve. If exergy is valued at $0.08 per kw.h, determine the daily cost of electricity to operate the compressor and the daily cost of exergy destruction in each component. Let T0 = 273 K (0C), which corresponds to the temperature of the outside ai.


//solution

T0 = 273
```

```
//in kelvin
pricerate = .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

//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

printf('Daily cost in dollars of exergy destruction due to compressor irreversibilities =\t %f',EddotComp*pricerate*24)
printf('\naDaily cost in dollars of exergy destruction due to irreversibilities in the throttling valve =\t %f',EddotValve*pricerate*24)
printf('\naDaily cost in dollars of exergy destruction due to irreversibilities in the condenser =\t %f',Eddotcond*pricerate*24)
printf('\naDaily cost in dollars  of electricity to operate compressor =\t %f',mCP*pricerate*24)
```

Scilab code Exa 7.10 Example 10

```
//(7.10) A cogeneration system consists of a natural gas-fueled boiler and a steam turbine that develops power and provides steam for an industrial process. At steady state, fuel enters the boiler with an exergy rate of 100 MW. Steam exits the boiler at 50 bar, 466C with an exergy rate of 35 MW. Steam exits the turbine at 5 bar, 205C and a mass flow rate of 26.15 kg/s. The unit cost of the fuel is 1.44 cents per kw.h of exergy. The costs of owning and operating the boiler and turbine are, respectively, dollar 1080/h and dollar 92/h. The feedwater and combustion air enter with negligible exergy and cost. The combustion products are discharged directly to the surroundings with negligible cost. Heat transfer with the surroundings and kinetic and potential energy effects are negligible. Let T0 = 298 K. (a) For the turbine, determine the power and the rate exergy exits with the steam, each in MW. (b) Determine the unit costs of the steam exiting the boiler, the steam exiting the turbine, and the power, each in cents per kw.h of exergy. (c) Determine the cost rates of the steam exiting the turbine and the power, each in $/h.



//solution

//variable initialization
EfFdot = 100
```

```
//exergy rate of fuel entering the boiler in MW
cF = 1.44

//unit cost of fuel in cents per kw.h
Zbdot = 1080

//the cost of owning and operating boiler in dollars per hour
Ef1dot = 35

//exergy rate of exiting steam from the boiler in MW
p1 = 50

//pressure of exiting steam from the boiler in bar
T1 = 466

//temperature of exiting steam from the boiler in degree celcius
Ztdot = 92

//the cost of owning and operating turbine in dollars per hour
p2 = 5

//pressure of exiting steam from the turbine in bars
T2 = 205

//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
```

```
                                        //in kelvin


//part(a)
//from table A-4,
h1 = 3353.54                            //in kj/kg
h2 = 2865.96                            //in kj/kg
//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

//from table A-4
s1 = 6.8773                             //in kj/kg.k
s2 = 7.0806                             //in kj/kg.k

Ef2dot = Ef1dot+m2dot*(h2-h1-T0*(s2-s1))/1000                          //the rate exergy exits with the steam in MW
printf('for the turbine,the power in MW is:\t%f',Wedot)
printf('\nfor the turbine,the rate exergy exits with the steam in MW is:\t%f',Ef2dot)

//part(b)
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

printf('\n\nthe unit costs of the steam exiting the boiler in cents per kw.h of exergy is:\t%f',c1)
printf('\nthe unit costs of the steam exiting the turbine in cents per kw.h of exergy is:\t%f',c2)
printf('\nunit cost of power in cents per kw.h is:\t%f',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

printf('\n\nthe cost rate of the steam exiting the turbine in dollars per hour is:  %f',C2dot)
printf('\nthe cost rate of the power in dollars per hour is:  %f',Cedot)
```

Chapter 8

Vapor power systems

Scilab code Exa 8.1 Example 1

```
//(8.1)...Steam is the working fluid in an ideal
   Rankine cycle. Saturated vapor enters the turbine
    at 8.0 MPa and saturated liquid exits the
   condenser at a pressure of 0.008 MPa. The net
   power output of the cycle is 100 MW. Determine
   for the cycle (a) the thermal efficiency, (b) the
    back work ratio, (c) the mass flow rate of the
   steam, in kg/h, (d) the rate of heat transfer,
   Qindot , into the working fluid as it passes
   through the boiler, in MW, (e) the rate of heat
   transfer,Qoutdot from the condensing steam as it
   passes through the condenser, in MW, (f) the mass
    flow rate of the condenser cooling water, in kg/
    h, if cooling water enters the condenser at 15C
   and exits at 35C.


//solution

//variable initialization
p1 = 8
```

```
   //pressure of saturated vapor entering the
   turbine in MPa
p3 = .008

   //pressure of saturated liquid exiting the
   condenser in MPa
Wcycledot = 100

   //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 = .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

x2 = (s2-sf)/(sg-sf)
```

```
//quality at state 2
h2 = hf + x2*hfg
//State 3 is saturated liquid at 0.008 MPa, so
h3 = 173.88                                      //in kj/kg

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)
printf('the thermal efficiency for the cycle is: %f',eta)

//part(b)
bwr = wpdot/wtdot                                //back work ratio
printf('\n\nthe back work ratio is: %e',bwr)

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

```
printf('\n\nthe mass flow rate of the steam in kg/h is:  %e',mdot)

//part(d)
Qindot = mdot*qindot/(3600*10^3)                                        //in MW
printf('\n\nthe rate of heat transfer,Qindot , into the working fluid as it passes through the boiler , in MW is:  %f',Qindot)

//part(e)
Qoutdot = mdot*(h2-h3)/(3600*10^3)                                      //in MW
printf('\n\nthe rate of heat transfer,Qoutdot from the condensing steam as it passes through the condenser, in MW is:  %f',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
printf('\n\nthe mass flow rate of the condenser cooling water, in kg/ h is:  %e',mcwdot)
```

Scilab code Exa 8.2 Example 2

```
//(8.2)  Reconsider the vapor power cycle of Example 8.1, but include in the analysis that the turbine and the pump each have an isentropic
```

```
   efficiency of 85%. Determine for the modified
   cycle (a) the thermal efficiency, (b) the mass
   flow rate of steam, in kg/h, for a net power
   output of 100 MW, (c) the rate of heat transfer
   Qindot into the working fluid as it passes
   through the boiler, in MW, (d) the rate of heat
   transfer  Qoutdotfrom the condensing steam as it
   passes through the condenser, in MW, (e) the mass
    flow rate of the condenser cooling water, in kg/
   h, if cooling water enters the condenser at 15C
   and exits as 35C. Discuss the effects on the
   vapor cycle of irreversibilities within the
   turbine and pump.


//solution

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
   //in kj/kg
h2s = 1794.8
   //in kj/kg

```

```
h2 = h1 - etat*(h1-h2s)  //in kj/kg
//State 3 is the same as in Example 8.1, so
h3 = 173.88  //in kj/kg

//from solution to example 8.1
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
printf('thermal efficiency is: %f',eta)

//part(b)
Wcycledot = 100  //given,a net power output of 100 MW
mdot = (Wcycledot*10^3*3600)/((h1-h2)-(h4-h3))
printf('\n\nthe mass flow rate of steam, in kg/h, for a net power output of 100 MW is: %e',mdot)

//part(c)
Qindot = mdot*(h1-h4)/(3600 * 10^3)
printf('\n\nthe rate of heat transfer Qindot into the working fluid as it passes through the boiler, in MW is: %f',Qindot)

//part(d)
Qoutdot = mdot*(h2-h3)/(3600*10^3)
```

```
printf('\n\nthe rate of heat transfer  Qoutdotfrom
   the condensing steam as it passes through the
   condenser, in MW is:  %f',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)
printf('\n\nthe mass flow rate of the condenser
   cooling water, in kg/h is:  %e',mcwdot)
```

Scilab code Exa 8.3 Example 3

```
//(8.3)  Steam is the working fluid in an ideal
   Rankine cycle with superheat and reheat. Steam
   enters the first-stage turbine at 8.0 MPa, 480C,
   and expands to 0.7 MPa. It is then reheated to
   440C before entering the second-stage turbine,
   where it expands to the condenser pressure of
   0.008 MPa. The net power output is 100 MW.
   Determine (a) the thermal efficiency of the cycle
   , (b) the mass flow rate of steam, in kg/h, (c)
   the rate of heat transfer Qoutdot from the
   condensing steam as it passes through the
   condenser, in MW. Discuss the effects of reheat
   on the vapor power cycle.

//solution

//variable initialization
```

```
T1 = 480
    //temperature of steam entering the first stage
    turbine in degree celcius
p1 = 8
    //pressure of steam entering the first stage
    turbine in MPa
p2 = .7
    //pressure of steam exiting the first stage
    turbine in MPa
T3 = 440
    //temperature of steam before entering the second
     stage turbine
Pcond = .008
    //condenser pressure in MPa
Wcycledot = 100
    //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

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
```

```

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))
printf('the thermal efficiency of the cycle is:  %f',eta)

//part(b)
mdot = (Wcycledot*3600*10^3)/((h1-h2)+(h3-h4)-(h6-h5))
printf('\n\nthe mass flow rate of steam, in kg/h is:  %e',mdot)

//part(c)
Qoutdot = (mdot*(h4-h5))/(3600*10^3)
printf('\n\nthe rate of heat transfer Qoutdot from the condensing steam as it passes through the condenser, in MW is:  %f',Qoutdot)
```

Scilab code Exa 8.4 Example 4

```
//(8.4)  Reconsider the reheat cycle of Example 8.3, but include in the analysis that each turbine stage has the same isentropic efficiency. (a) If etat =  85%, determine the thermal efficiency. (
```

```
b) Plot the thermal efficiency versus turbine stage efficiency ranging from 85 to 100%.


//solution

//part (a)
etat = .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

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))
printf('the thermal efficiency is:  %f',eta)


//part (b)
x = linspace(.85,1,50);
for i = 1: 50
    h2(1,i) = h1 - x(1,i)*(h1 - h2s) //The specific enthalpy at the exit of the
```

```
first-stage turbine in kj/kg
h4(1,i) = h3 - x(1,i)*(h3-h4s)    //The specific enthalpy at the exit of the second-stage turbine in kj/kg
end

for i = 1:50
    y(1,i) = ((h1-h2(1,i))+(h3-h4(1,i))-(h6-h5))/((h1-h6)+(h3-h2(1,i)))
end
plot2d(x,y)
xtitle("","isentropic turbine efficiency","cycle thermal efficiency")
```

Scilab code Exa 8.5 Example 5

```
//Consider a regenerative vapor power cycle with one open feedwater heater. Steam enters the turbine at 8.0 MPa, 480C and expands to 0.7 MPa, where some of the steam is extracted and diverted to the open feedwater heater operating at 0.7 MPa. The remaining steam expands through the second-stage turbine to the condenser pressure of 0.008 MPa. Saturated liquid exits the open feedwater heater at 0.7 MPa. The isentropic efficiency of each turbine stage is 85% and each pump operates isentropically. If the net power output of the cycle is 100 MW, determine (a) the thermal efficiency and (b) the mass flow rate of steam entering the first turbine stage, in kg/h.

//solution

//variable initialization
```

```
T1 = 480

    //temperature of steam entering the turbine in
    degree celcius
p1 = 8

    //pressure of steam entering the turbine in MPa
Pcond = .008

    //condenser pressure in MPa
etat = .85

    //turbine efficiency
Wcycledot = 100

    //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
//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 = .7

    //in MPa
p4 = .008

    //in MPa
p7 = 8

    //in MPa
p6 = .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

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
printf('the thermal efficiency is:  %f',eta)

//part(b)
m1dot = (Wcycledot*3600*10^3)/(wtdot-wpdot)
printf('\nthe mass flow rate of steam entering the first turbine stage, in kg/h is:  %e',m1dot)
```

Scilab code Exa 8.6 Example 6

```
//(8.6)   Consider a reheat regenerative vapor power cycle with two feedwater heaters, a closed feedwater heater and an open feedwater heater. Steam enters the first turbine at 8.0 MPa, 480C and expands to 0.7 MPa. The steam is reheated to 440C before entering the second turbine, where it expands to the condenser pressure of 0.008 MPa. Steam is extracted from the first turbine at 2 MPa and fed to the closed feedwater heater. Feedwater leaves the closed heater at 205C and 8.0 MPa, and condensate exits as saturated liquid
```

```
 at 2 MPa. The condensate is trapped into the
open feedwater heater. Steam extracted from the
second turbine at 0.3 MPa is also fed into the
open feedwater heater, which operates at 0.3 MPa.
 The stream exiting the open feedwater heater is
saturated liquid at 0.3 MPa. The net power output
 of the cycle is 100 MW. There is no stray heat
transfer from any component to its surroundings.
If the working fluid experiences no
irreversibilities as it passes through the
turbines, pumps, steam generator, reheater, and
condenser, determine (a) the thermal efficiency,
(b) the mass flow rate of the steam entering the
first turbine, in kg/h.


//solution

//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 = .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 = .3 //in MPa
p7 = .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                                                //in MPa
p9 = .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                                                         //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 turbine

eta = (wt1dot+wt2dot-wp1dot-wp2dot)/qindot
                                              //thermal
   efficiency
printf('the thermal efficiency is:  %f',eta)

//part(b)
Wcycledot = 100

   //the net power output of the cycle in MW
m1dot = (Wcycledot*3600*10^3)/(wt1dot+wt2dot-wp1dot-
   wp2dot)
printf('\nthe mass flow rate of the steam entering
   the first turbine, in kg/h is:  %e',m1dot)
```

Scilab code Exa 8.7 Example 7

```
//(8.7)  The heat exchanger unit of the boiler of
   Example 8.2 has a stream of water entering as a
   liquid at 8.0 MPa and exiting as a saturated
   vapor at 8.0 MPa. In a separate stream, gaseous
   products of combustion cool at a constant
   pressure of 1 atm from 1107 to 547C. The gaseous
   stream can be modeled as air as an ideal gas. Let
    T0 = 22C, p0 = 1 atm. Determine (a) the net rate
    at which exergy is carried into the heat
   exchanger unit by the gas stream, in MW, (b) the
   net rate at which exergy is carried from the heat
    exchanger by the water stream, in MW, (c) the
   rate of exergy destruction, in MW, (d) the
   exergetic efficiency given by Eq. 7.45.
```

```


//solution

//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
Rin = madot*(hi-he-T0*(si-se))/(3600*10^3)

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

//part(b)
//from table A–3
s1 = 5.7432

   //in kj/kg.k
//from interpolation in table A–5 gives
s4 = .5957

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

//part(c)
Eddot = Rin-Rout

   //in MW
printf('\n\nthe rate of exergy destruction, in MW is
   : %f',Eddot)

//part(d)
epsilon = Rout/Rin
printf('\n\nthe exergetic efficiency is: %f',
   epsilon)
```

Scilab code Exa 8.8 Example 8

```
//(8.8)  Reconsider the turbine and pump of Example 8.2. Determine for each of these components the rate at which exergy is destroyed, in MW. Express each result as a percentage of the exergy entering the plant with the fuel. Let T0 = 22C, p0 = 1 atm

//solution

T0 = 295                                          //in kelvin
P0 = 1                                            //in atm

//analysis
//from table A-3
s1 = 5.7432                                       //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

mdot = 4.449e5                                    //in kg/h
Eddot = mdot*T0*(s2-s1)/(3600*10^3)
```

```
                                                    //the rate of exergy destruction for the turbine in MW
printf('the rate of exergy destruction for the turbine in MW is: %f',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('\nThe 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('\npercentage of the exergy entering the plant with the fuel destroyed within the turbine is: %f',.69*(Eddot/231.28)*100)

//from table A-3
s3 =.5926                                           //in kj/kg.k
//from solution of example 8.7
s4 = .5957                                          //in kj/kg.k
EddotP = mdot*T0*(s4-s3)/(3600*10^3)                //the exergy destruction rate for the pump
printf('\n\nthe exergy destruction rate for the pump in MW is: %f',EddotP)
printf(' and expressing this as a percentage of the exergy entering the plant as calculated above, we have %f',(EddotP/231.28)*69 )

printf('\n\nThe 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
```

```
carried into the plant with the fuel, %f',(100/231.28)*69)
```

Scilab code Exa 8.9 Example 9

```
//(8.9)  The condenser of Example 8.2 involves two separate water streams. In one stream a two-phase liquid vapor mixture enters at 0.008 MPa and exits as a saturated liquid at 0.008 MPa. In the other stream, cooling water enters at 15C and exits at 35C. (a) Determine the net rate at which exergy is carried from the condenser by the cooling water, in MW. Express this result as a percentage of the exergy entering the plant with the fuel. (b) Determine for the condenser the rate of exergy destruction, in MW. Express this result as a percentage of the exergy entering the plant with the fuel. Let T0 = 22C and p0 = 1 atm.


//solution
T0 = 295                    //in kelvin
//analysis
//from solution to Example 8.2.
mcwdot = 9.39e6             //mass flow rate of the cooling water in kg/h

//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 = .5053 //in kj/kg.k
si = .2245 //in kj/kg.k
Rout = mcwdot*(he-hi-T0*(se-si))/(3600*10^3) //The net rate at which exergy is carried out of the condenser in MW
printf(' the net rate at which exergy is carried from the condenser by the cooling water, in MW is:  %f',Rout)
printf('.  Expressing this as a percentage of the exergy entering the plant with the fuel, we get %f',(Rout/231.28)*69)
printf('percent')

//part(b)
//from table
s3 = .5926 //in kj/kg.k
s2 = 6.2021 //in kg/kg.k
mdot = 4.449e5 //in kg/h
Eddot = T0*(mdot*(s3-s2)+mcwdot*(se-si))/(3600*10^3) //the rate of exergy destruction for the condenser in MW
printf('\n\nthe rate of exergy destruction for the condenser in MW is:  %f',Eddot)
```

```
printf('. Expressing this as a percentage of the
   exergy entering the plant with the fuel, we get,
    %f',(Eddot/231.28)*69)
printf('percent')
```

Chapter 9

Gas power systems

Scilab code Exa 9.1 Example 1

```
//(9.1)  The temperature at the beginning of the compression process of an air-standard Otto cycle with a compression ratio of 8 is 300K, the pressure is 1 bar, a d the cylinder volume is 560 cm3. The maximum temperature during the cycle is 2000K. Determine (a) the temperature and pressure at the end of each process of the cycle, (b) the thermal efficiency, and (c) the mean effective pressure, in atm.

//solution

//variable initialization
T1 = 300                                //The temperature at the beginning of the compression process in kelvin
p1 = 1                                  //the pressure at the beginning of the compression process in bar
```

```
r = 8

    //compression ratio
V1 = 560

    //the volume at the beginning of the compression
    process in cm^3
T3 = 2000

    //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
//For the isentropic compression Process 1   2
vr2 = vr1/r
//Interpolating with vr2 in Table A-22, we get
T2 = 673

    //in kelvin
u2 = 491.2

    //in kj/kg
//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
//At T3 = 2000 K, Table A-22 gives
u3 = 1678.7
```

```
//in kj/kg
vr3 = 2.776
//For the isentropic expansion process 3  4
vr4 = vr3*(r)
//Interpolating in Table A-22 with vr4 gives
T4 = 1043 //in kelvin
u4 = 795.8 //in kj/kg
//the ideal gas equation of state applied at states 1 and 4 gives
p4 = p1*(T4/T1) //in bars
printf('at state1, the pressure in bar is:  %f',p1)
printf('\natstate1, the temperature in kelvin is  %f',T1)
printf('\n\nat state2, the pressure in bar is:  %f',p2)
printf('\natstate2, the temperature in kelvin is  %f',T2)
printf('\n\nat state3, the pressure in bar is:  %f',p3)
printf('\natstate3, the temperature in kelvin is  %f',T3)
printf('\n\nat state4, the pressure in bar is:  %f',p4)
printf('\natstate4, the temperature in kelvin is  %f',T4)

//part(b)
eta = 1-(u4-u1)/(u3-u2) //thermal efficiency
printf('\n\n\nthe thermal efficiency is:  %f',eta)

```

```
//part(c)
R = 8.314                    //universal gas constant , in SI units
M = 28.97                    //molar mass of air in grams
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
printf('\n\n\nthe mean effective pressure , in atm. is:   %f',mep/1.01325)
```

Scilab code Exa 9.2 Example 2

```
//(9.2)    At the beginning of the compression process of an air-standard Diesel cycle operating with a compression ratio of 18, the temperature is 300 K and the pressure is 0.1 MPa. The cutoff ratio for the cycle is 2. Determine (a) the temperature and pressure at the end of each process of the cycle , (b) the thermal efficiency , (c) the mean effective pressure , in MPa.

//solution

//variable initialization
r = 18
```

```
    //compression ratio
T1 = 300

    //temperature at the beginning of the compression
     process in kelvin
p1 = .1

    //pressure at the beginning of the compression
    process in MPa
rc = 2

    //cutoff ratio

//part(a)
//With T1 = 300 K, Table A−22 gives
u1 = 214.07

    //in kj/kg
vr1 = 621.2
//For the isentropic compression process 1   2
vr2 = vr1/r
//Interpolating in Table A−22, we get
T2 = 898.3

    //in kelvin
h2 = 930.98

    //in kj/kg
//With the ideal gas equation of state
p2 = p1*(T2/T1)*(r)

    //in MPa
//Since Process 2   3 occurs at constant pressure,
    the ideal gas equation of state gives
T3 = rc*T2

    //in kelvin
//From Table A−22,
```

```
h3 = 1999.1                //in kj/kg
vr3 = 3.97

p3 = p2
//For the isentropic expansion process 3  4
vr4 = (r/rc)*vr3
//Interpolating in Table A-22 with vr4, we get
u4 = 664.3                 //in kj/kg
T4 = 887.7                 //in kelvin
//the ideal gas equation of state applied at states 1 and 4 gives
p4 = p1*(T4/T1)            //in MPa
printf('at state1, the pressure in bar is: %f',p1)
printf('\natstate1, the temperature in kelvin is %f',T1)
printf('\n\nat state2, the pressure in bar is: %f',p2)
printf('\natstate2, the temperature in kelvin is %f',T2)
printf('\n\nat state3, the pressure in bar is: %f',p3)
printf('\natstate3, the temperature in kelvin is %f',T3)
printf('\n\nat state4, the pressure in bar is: %f',p4)
printf('\natstate4, the temperature in kelvin is %f',T4)

//part(b)
eta = 1- (u4-u1)/(h3-h2)
```

```
printf('\n\n\nthe thermal efficiency is:  %f',eta)

//part(c)
wcycle = (h3-h2)-(u4-u1)        //The net work of the cycle in kj/kg
R = 8.314        //universal gas constant, in SI units
M = 28.97        //molar mass of air in grams
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
printf('\n\n\nthe mean effective pressure, in MPa is:  %f',mep)
```

Scilab code Exa 9.3 Example 3

```
//(9.3)   At the beginning of the compression process of an air-standard dual cycle with a compression ratio of 18, the temperature is 300 K and the pressure is 0.1 MPa. The pressure ratio for the constant volume part of the heating process is 1.5:1. The volume ratio for the constant pressure part of the heating process is 1.2:1. Determine (a) the thermal efficiency and (b) the mean effective pressure, in MPa.


//solution
```

```

//variable initialization
T1 = 300
                                   //beginning temperature in kelvin
p1 = .1
                                   //beginning pressure in MPa
r = 18
                                   //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
//Since Process 2  3 occurs at constant volume, the
    ideal gas equation of state reduces to give
T3 = pr*T2
                                   //in kelvin
//Interpolating in Table A-22, we get
h3 = 1452.6
```

```
   //in kj/kg
u3 = 1065.8

   //in kj/kg
//Since Process 3  4 occurs at constant pressure,
   the ideal gas equation of state reduces to give
T4 = vr*T3

   //in kelvin
//From Table A-22,
h4 = 1778.3

   //in kj/kg
vr4 = 5.609
//Process 4  5 is an isentropic expansion, so
vr5 = vr4*r/vr
//Interpolating in Table A-22, we get
u5 = 475.96

   //in kj/kg

//part(a)
eta = 1-(u5-u1)/((u3-u2)+(h4-h3))
printf('the thermal efficiency is:  %f',eta)

//part(b)
//The specific volume at state 1 is evaluated in
   Example 9.2 as
v1 = .861

   //in m^3/kg
mep = (((u3-u2)+(h4-h3)-(u5-u1))/(v1*(1-1/r)))
   *10^3*10^-6                         //in MPa
printf('\nthe mean effective pressure, in MPa is:
   %f',mep)
```

Scilab code Exa 9.4 Example 4

```
//(9.4)   Air enters the compressor of an ideal air-standard Brayton cycle at 100 kPa, 300 K, with a volumetric flow rate of 5 m3/s. The compressor pressure ratio is 10. The turbine inlet temperature is 1400 K. Determine (a) the thermal efficiency of the cycle, (b) the back work ratio, (c) the net power developed, in kW.

//solution

//variable initialization
T1 = 300                                   //in kelvin
AV = 5                                     //volumetric flow rate in m^3/s
p1 = 100                                   //in kpa
pr = 10                                    //compressor pressure ratio
T3 = 1400                                  //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

pr2 = pr*pr1
//interpolating in Table A-22,
h2 = 579.9 //in kj/kg
//from Table A-22
h3 = 1515.4 //in kj/kg
pr3 = 450.5

pr4 = pr3*1/pr
//Interpolating in Table A-22, we get
h4 = 808.5 //in kj/kg

//part(a)
eta = ((h3-h4)-(h2-h1))/(h3-h2) //thermal efficiency
printf('the thermal efficiency is:  %f',eta)

//part(b)
bwr = (h2-h1)/(h3-h4) //back work ratio
printf('\nthe back work ratio is:  %f',bwr)

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

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

    //mass flow rate in kg/s

Wcycledot = mdot*((h3-h4)-(h2-h1))
                                                        //
    The net power developed
printf('\n the net power developed, in kW is:  %f',
    Wcycledot)
```

Scilab code Exa 9.5 Example 5

```
printf('theoretical problem')
```

Scilab code Exa 9.6 Example 6

```
//(9.6) Reconsider Example 9.4, but include in the
    analysis that the turbine and compressor each
    have an isentropic efficiency of 80%. Determine
    for the modified cycle (a) the thermal efficiency
     of the cycle, (b) the back work ratio, (c) the
    net power developed, in kW.

//solution


etat = .8

    //turbine efficiency
etac = .8

    //compressor efficiency
```

```
//part(a)
wtdots = 706.9

    //The value of wtdots is determined in the
    solution to Example 9.4 as 706.9 kJ/kg
//The turbine work per unit of mass is
wtdot = etat*wtdots

    //in kj/kg

wcdots = 279.7

    //The value of wcdots is determined in the
    solution to Example 9.4 as 279.7 kJ/kg
//For the compressor, the work per unit of mass is
wcdot = wcdots/etac

    //in kj/kg

h1 = 300.19

    //h1 is from the solution to Example 9.4, in kj/
    kg
h2 = h1 + wcdot

    //in kj/kg

h3 = 1515.4

    //h3 is from the solution to Example 9.4, in kj/
    kg
qindot = h3-h2

    //The heat transfer to the working fluid per unit
     of mass flow in kj/kg
eta = (wtdot-wcdot)/qindot

    //thermal efficiency
```

```
printf('the thermal efficiency is:  %f',eta)

//part(b)
bwr = wcdot/wtdot                                   //back work ratio
printf('\nthe back work ratio is:  %f',bwr)

//part(c)
mdot = 5.807                                        //in kg/s, from example 9.4
Wcycledot = mdot*(wtdot-wcdot)                      //The net power developed by the cycle in kw
printf('\nthe net power developed, in kW. is:  %f',Wcycledot)
```

Scilab code Exa 9.7 Example 7

```
//(9.7)  A regenerator is incorporated in the cycle of Example 9.4. (a) Determine the thermal efficiency for a regenerator effectiveness of 80%. (b) Plot the thermal efficiency versus regenerator effectiveness ranging from 0 to 80%.

//solution


//part(a)
etareg = .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

hx = etareg*(h4-h2)+h2         //in kj/kg
eta = ((h3-h4)- (h2-h1))/(h3-hx)                          //thermal efficiency
printf('the thermal efficiency is:  %f',eta)

//part(b)
etareg = linspace(0,.8,50)
for i= 1:50
 hx(1,i) = etareg(1,i)*(h4-h2)+h2
end
for i = 1:50
    eta(1,i) = ((h3-h4)- (h2-h1))/(h3-hx(1,i))
end
plot(etareg,eta)
xtitle("","Regenerator effectiveness","Thermal efficiency")
```

Scilab code Exa 9.8 Example 8

```
//(9.8)  Consider a modification of the cycle of Example 9.4 involving reheat and regeneration. Air enters the compressor at 100 kPa, 300 K and is compressed to 1000 kPa. The temperature at the inlet to the first turbine stage is 1400 K. The expansion takes place isentropically in two stages, with reheat to 1400 K between the stages at a constant pressure of 300 kPa. A regenerator having an effectiveness of 100% is also incorporated in the cycle. Determine the thermal efficiency.


//solution

//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 //in kpa
p3 = 1000 //in kpa
//from table A-22
pr3 = 450.5
```

```
pra = pr3*(pa/p3)
//Interpolating in Table A-22, we get
ha = 1095.9                    //in kj/kg

p4 = 100                       //in kpa
pb = 300                       //in kpa
prb = pra
pr4 = prb*(p4/pb)
//Interpolating in Table A-22, we obtain
h4 = 1127.6                    //in kj/kg
//Since the regenerator effectiveness is 100%,
hx = h4

eta = ((h3-ha)+(hb-h4)-(h2-h1))/((h3-hx)+(hb-ha))                    //thermal efficiency
printf('the thermal efficiency is:  %f',eta)
```

Scilab code Exa 9.9 Example 9

```
//(9.9)  Air is compressed from 100 kPa, 300 K to 1000 kPa in a two-stage compressor with intercooling between stages. The intercooler pressure is 300 kPa. The air is cooled back to 300 K in the intercooler before entering the second compressor stage. Each compressor stage is isentropic. For steady-state operation and
```

```
   negligible changes in kinetic and potential
   energy from inlet to exit, determine (a) the
   temperature at the exit of the second compressor
   stage and (b) the total compressor work input per
    unit of mass flow. (c) Repeat for a single stage
    of compression from the given inlet state to the
    final pressure


//solution

//variable initialization
T1 = 300

   //in kelvin
p1 = 100

   //in kpa
p2 = 1000

   //in kpa
p3 = p2
pc = 300

   //in kpa
pd = 300

   //in kpa
Td = 300

   //in kelvin


//part(a)
//from table A-22
prd = 1.386
pr2 = prd*(p2/pd)
//Interpolating in Table A-22, we get
```

```
T2 = 422 //in kelvin
h2 = 423.8 //in kj/kg
printf('the temperature at the exit of the second compressor stage  is:  %f',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
prc = pr1*(pc/p1)
//Interpolating in Table A-22, we obtain
hc = 411.3 //in kj/kg

wcdot = (hc-h1)+(h2-hd) //the total compressor work per unit of mass in kj/kg
printf('\n\nthe total compressor work input per unit of mass flow is:  %f',wcdot)

//part(c)
pr3 = pr1*(p3/p1)
//Interpolating in Table A-22, we get
T3 = 574
```

```
//in kelvin
h3 = 579.9 //in kj/kg

wcdot = h3-h1 //The work input for a single stage of compression in kj/kg
printf('\n\nfor a single stage of compression, the temperature at the exit state is:  %f ',T3)
printf('\nfor a single stage of compression, the work input is:  %f',wcdot)
```

Scilab code Exa 9.10 Example 10

```
printf('theoretical problem')
```

Scilab code Exa 9.11 Example 11

```
//(9.11)  A regenerative gas turbine with intercooling and reheat operates at steady state. Air enters the compressor at 100 kPa, 300 K with a mass flow rate of 5.807 kg/s. The pressure ratio across the two-stage compressor is 10. The pressure ratio across the two-stage turbine is also 10. The intercooler and reheater each operate at 300 kPa. At the inlets to the turbine stages, the temperature is 1400 K. The temperature at the inlet to the second compressor stage is 300 K. The isentropic efficiency of each compressor and turbine stage is 80%. The regenerator effectiveness is 80%. Determine (a)
```

```
    the thermal efficiency, (b) the back work ratio,
    (c) the net power developed, in kW.


//solution

//variable initialization
T1 = 300

    //in kelvin
p1 = 100

    //in kpa
mdot = 5.807

    //in kg/s
p2 = 300

    //in kpa
p3 = p2
p4 = 1000

    //in kpa
p5 = p4
p6 = p4
T6 = 1400

    //in kelvin
T8 = T6
p7 = 300

    //in kpa
p8 = p7
etac = .8

    //isentropic efficiency of compressor
etat = .8
```

```
    //isentropic efficiency of turbine
etareg = .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

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)
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
printf('the thermal efficiency is:  %f',eta)

//part(b)
bwr = wcdot/wtdot

     //back work ratio
printf('\nthe back work ratio is:  %f',bwr)

//part(c)
Wcycledot = mdot*(wtdot-wcdot)
```

```
    //net power developed in kw
printf('\nthe net power developed, in kW is: %f',
    Wcycledot)
```

Scilab code Exa 9.12 Example 12

```
//(9.12) Air enters a turbojet engine at 0.8 bar,
    240K, and an inlet velocity of 1000 km/h (278 m/s
    ). The pressure ratio across the compressor is 8.
     The turbine inlet temperature is 1200K and the
    pressure at the nozzle exit is 0.8 bar. The work
    developed by the turbine equals the compressor
    work input. The diffuser, compressor, turbine,
    and nozzle processes are isentropic, and there is
     no pressure drop for flow through the combustor.
     For operation at steady state, determine the
    velocity at the nozzle exit and the pressure at
    each principal state. Neglect kinetic energy at
    the exit of all components except the nozzle and
    neglect potential energy throughout.

//solution

//variable initialization
Ta = 240

    //in kelvin
pa = .8

    //in bar
Va = 278

    //in m/s
PR = 8
```

```
   //pressure ratio across the compressor
T3 = 1200

   //in kelvin
p5 = .8

   //in bars

//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
p1 = (pr1/pra)*pa

   //in bars

p2 = PR*p1

   //in bars
//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
//using assumption 'There is no pressure drop for
   flow through the combustor',
p3 = p2
//with the help of assumption, 'The turbine work
```

```
   output equals the work required to drive the
   compressor.',
h4 = h3+h1-h2

   //in kj/kg
//Interpolating in Table A-22 with h4, gives
pr4 = 116.8
//pr data from table A-22 gives
pr4 = 116
pr3 = 238

p4 = p3*(pr4/pr3)

   //in bars

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

   //in bars
pr5 = pr4*(p5/p4)
//from table A-22
h5 = 621.3

   //in kj/kg

V5 = sqrt(2*(h4-h5)*10^3)

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

printf('the velocity at the nozzle exit in m/s is:
   %f',V5)
printf('\npa in bars = %f',pa)
printf('\np1 in bars = %f',p1)
printf('\np2 in bars = %f',p2)
printf('\np3 in bars = %f',p3)
printf('\np4 in bars = %f',p4)
printf('\np5 in bars = %f',p5)
```

Scilab code Exa 9.13 Example 13

```
//(9.13)  A combined gas turbine vapor power plant has a net power output of 45 MW. Air enters the compressor of the gas turbine at 100 kPa, 300 K, and is compressed to 1200 kPa. The isentropic efficiency of the compressor is 84%. The condition at the inlet to the turbine is 1200 kPa, 1400 K. Air expands through the turbine, which has an isentropic efficiency of 88%, to a pressure of 100 kPa. The air then passes through the interconnecting heat exchanger and is finally discharged at 400 K. Steam enters the turbine of the vapor power cycle at 8 MPa, 400C, and expands to the condenser pressure of 8 kPa. Water enters the pump as saturated liquid at 8 kPa. The turbine and pump of the vapor cycle have isentropic efficiencies of 90 and 80%, respectively. (a) Determine the mass flow rates of the air and the steam, each in kg/s, and the net power developed by the gas turbine and vapor power cycle, each in MW. (b) Develop a full accounting of the net rate of exergy increase as the air passes through the gas turbine combustor. Discuss. Let T0 = 300 K, p0 = 100 kPa.

//solution
Wnetdot = 45                                      //in MW
T1 = 300                                          //in kelvin
p1 = 100
```

```
    //in kpa
etac = .84

    //The isentropic efficiency of the compressor
T3 = 1400

    //in kelvin
p2 = 1200

    //in kpa
p3 = p2
etat = .88

    //isentropic efficiency of the turbine
T5 = 400

    //in kelvin
p4 = 100

    //in kpa
p5 = p4
T7 = 400

    //in degree celcius
p7 = 8

    //in MPa
etatw =.9

    //isentropic efficiency of turbine of the vapor cycle
p8 = 8

    //in kpa
p9 = p8
etap = .8
```

```
    //isentropic efficiency of pump of the vapor
    cycle
T0 = 300

    //in kelvin
p0 = 100

    //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
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

printf('mass flow rate of air in kg/s is:  %f',mgdot)
printf('\nmass flow rate of vapor in kg/s is:  %f',mvdot)
printf('\nnet power developed by gas turbine in MW is:  %f',Wgasdot)
printf('\nnet power developed by vapor cycle in MW is:  %f',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

printf('\n\nbalance sheet')
printf('\nNet exergy increase of the gas passing')
printf('\nthrough the combustor:\t%f',Edotf32)
printf('\nDisposition of the exergy:')
printf('\ n    Net power developed')
printf('\ngas turbine cycle\t%f',Wgasdot)
printf('\nvapor cycle\t%f',Wvapdot)
printf('\ n    Net exergy lost')
printf('\nwith exhaust gas at state 5\t%f',Edotf51)
printf('\nfrom water passing through condenser\t%f',
   Edotf89)
printf('\ n    Exergy destruction')
printf('\nair turbine\t%f',Eddott)
printf('\ncompressor\t%f',Eddotc)
printf('\nsteam turbine\t%f',Eddotst)
```

```
printf('\npump\t%f',Eddotp)
printf('\nheat exchanger\t%f',EddotHE)
```

Scilab code Exa 9.14 Example 14

```
//(9.14)  A converging nozzle has an exit area of 0.001 m2. Air enters the nozzle with negligible velocity at a pressure of 1.0 MPa and a temperature of 360 K. For isentropic flow of an ideal gas with k = 1.4, determine the mass flow rate, in kg/s, and the exit Mach number for back pressures of (a) 500 kPa and (b) 784 kPa.

//solution

//variable initialization
Tnot = 360                                                    //in kelvin
pnot = 1                                                      //in MPa
A2 = .001                                                     //in m^2
k = 1.4

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
```

```
p2 = pstar                    //in MPa
printf('the exit mach number for back pressure of 500kpa is:  %f',M)
T2 = Tnot/(1+((k-1)/2)*(M^2))                    //exit temperature in kelvin
R = 8.314                    //universal gas constant , in SI units
M = 28.97                    //molar mass of air in grams
V2 = sqrt(k*(R/M)*T2*10^3)                    //exit velocity in m/s
mdot = (p2/((R/M)*T2))*A2*V2*10^3                    //mass flow rate in kg/s
printf('\nthe mass flow rate in kg/s for back pressure of 500kpa is:  %f',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                    //exit pressure in kpa
M2 = {(2/(k-1))*[(pnot*10^3/p2)^((k-1)/k)-1]}^.5                    //exit mach number
T2 = Tnot/(1+((k-1)/2)*(M2^2))                    //exit temperature in kelvin
V2 = M2*sqrt(k*(R/M)*10^3*T2)
```

```
//exit velocity in m/s
mdot2 = (p2/((R/M)*T2))*A2*V2 //mass flow rate in kg/s
printf('\n\nthe mass flow rate at the exit in kg/s for back pressure of 784kpa is:  %f',mdot2)
printf('\nthe exit mach number for back pressure of 784 kpa is:  %f',M2)
```

Scilab code Exa 9.15 Example 15

```
//(9.15)  A converging diverging nozzle operating at steady state has a throat area of 6.25 cm2 and an exit area of 15 cm2. Air enters the nozzle with a negligible velocity at a pressure of 6.8 bars and a temperature of 280 K. For air as an ideal gas with k = 1.4, determine the mass flow rate, in kg/s, the exit pressure, in bars, and exit Mach number for each of the five following cases. (a) Isentropic flow with M = 0.7 at the throat. (b) Isentropic flow with M = 1 at the throat and the diverging portion acting as a diffuser. (c) Isentropic flow with M = 1 at the throat and the diverging portion acting as a nozzle. (d) Isentropic flow through the nozzle with a normal shock standing at the exit. (e) A normal shock stands in the diverging section at a location where the area is 12.5 cm2. Elsewhere in the nozzle, the flow is isentropic.

//solution

//part(a)
Mt = .7
```

```
                //mach mumber at the throat
At = 6.25                //throat area in cm^2
Ae = 15                //exit area in cm^2
//With Mt = 0.7, Table 9.1 gives
AtbyAstar = 1.09437

A2byAstar = (Ae/At)*AtbyAstar
//The flow throughout the nozzle, including the exit, is subsonic. Accordingly, with this value for A2byAstar, Table 9.1 gives
M2 = .24
//For M2 = 0.24,
T2byTnot = .988
p2bypnot = .959
k = 1.4
T0 = 280                //in kelvin
pnot = 6.8                //in bars

T2 = T2byTnot*T0                //in kelvin
p2 = p2bypnot*pnot                //in bars

V2 = M2*sqrt((k*(8.314/28.97)*T2*10^3))                //velocity at the exit in m/s
mdot = (p2/((8.314/28.97)*T2))*Ae*V2*10^-2                //mass flow
```

```
    rate in kg/s
printf('part(a)  the mass flow rate in kg/s is:  %f'
   ,mdot)
printf('\nthe exit pressure in bars is:  %f',p2)
printf('\nthe exit mach number is:  %f',M2)

//part(b)
Mt = 1

   //mach number at the throat
//from table 9.1
M2 = .26
T2byTnot = .986
p2bypnot = .953

T0 = 280

   //in kelvin
pnot = 6.8

   //in bars

T2 = T2byTnot*T0

   //in kelvin
p2 = p2bypnot*pnot

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

   //exit velocity in m/s
mdot = (p2/((8.314/28.97)*T2))*Ae*V2*10^-2
                                                    //mass
    flow rate in kg/s

printf('\n\n\npart(b)  the mass flow rate in kg/s is
   :  %f',mdot)
```

```
printf('\nthe exit pressure in bars is:  %f',p2)
printf('\nthe 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 = .0684

pnot = 6.8                                                  //in bars

p2 = p2bypnot*pnot                                          //in bars
//Since the nozzle is choked, the mass flow rate is the same as found in part (b).
printf('\n\n\npart(c)  the mass flow rate in kg/s is :  %f',mdot)
printf('\nthe exit pressure in bars is:  %f',p2)
printf('\nthe 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 = .465                                                   //in bars
//Then, from Table 9.2
My = .52
pybypx = 6.5533
//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).

printf('\n\n\npart(d) the mass flow rate in kg/s is : %f',mdot)
printf('\nthe exit pressure in bars is: %f',3.047)
printf('\nthe 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
//With Mx = 2.2, the ratio of stagnation pressures is obtained from Table 9.2 as
pnotybypnotx = .62812

A2byAystar = (Ae/Axstar)*pnotybypnotx
//Using this ratio and noting that the flow is subsonic after the shock, Table 9.1 gives
M2 = .43
//for M2 = .43,
p2bypnoty = .88

p2 = p2bypnoty*pnotybypnotx*pnot                                //in bars
//Since the flow is choked, the mass flow rate is the same as that found in part (b).
```

```
printf('\n\n\npart(e)  the mass flow rate in kg/s is :  %f',mdot)
printf('\nthe exit pressure in bars is:  %f',p2)
printf('\nthe exit mach number is:  %f',M2)
```

Chapter 10

Refrigeration and heat pump systems

Scilab code Exa 10.1 Example 1

```
//(10.1)  Refrigerant 134a is the working fluid in
   an ideal vapor-compression refrigeration cycle
   that communicates thermally with a cold region at
    0C and a warm region at 26C. Saturated vapor
   enters the compressor at 0C and saturated liquid
   leaves the condenser at 26C. The mass flow rate
   of the refrigerant is 0.08 kg/s. Determine (a)
   the compressor power, in kW, (b) the
   refrigeration capacity, in tons, (c) the
   coefficient of performance, and (d) the
   coefficient of performance of a Carnot
   refrigeration cycle operating between warm and
   cold regions at 26 and 0C, respectively.

//solution

//variable initialization

Tc = 273
```

```
   //temperature of cold region in kelvin
Th = 299

   //temperature of hot region in kelvin
mdot = .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 = .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:  %f',Wcdot)

//part(b)
Qindot = mdot*(h1-h4)*60/211

   //refrigeration capacity in ton
printf('\nthe refrigeration capacity in tons is:  %f
   ',Qindot)

//part(c)
funcprot(0)
beta = (h1-h4)/(h2s-h1)
printf('\nthe coefficient of performance is:  %f',
   beta)

//part(d)
betamax = Tc/(Th-Tc)
printf('\n the coefficient of performance of a
   Carnot refrigeration cycle operating between warm
    and cold regions at 26 and 0C, respectively is:
    %f',betamax)
```

Scilab code Exa 10.2 Example 2

```
//(10.2)  Modify Example 10.1 to allow for
   temperature differences between the refrigerant
   and the warm and cold regions as follows.
   Saturated vapor enters the compressor at 10C.
   Saturated liquid leaves the condenser at a
   pressure of 9 bar. Determine for the modified
   vapor-compression refrigeration cycle (a) the
```

```
compressor power, in kW, (b) the refrigeration capacity, in tons, (c) the coefficient of performance. Compare results with those of Example 10.1.

//solution
mdot = .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
printf('the compressor power in kw is:  %f',Wcdot)

//part(b)
```

```
Qindot = mdot*(h1-h4)*60/211

   //refrigeration capacity in tons
printf('\nthe refrigeration capacity in tons is:  %f
   ',Qindot)

//part(c)
beta = (h1-h4)/(h2s-h1)
printf('\nthe coefficient of performance is:  %f',
   beta)
```

Scilab code Exa 10.3 Example 3

```
//(10.3)  Reconsider the vapor-compression
   refrigeration cycle of Example 10.2, but include
   in the analysis that the compressor has an
   efficiency of 80%. Also, let the temperature of
   the liquid leaving the condenser be 30C.
   Determine for the modified cycle (a) the
   compressor power, in kW, (b) the refrigeration
   capacity, in tons, (c) the coefficient of
   performance, and (d) the rates of exergy
   destruction within the compressor and expansion
   valve, in kW, for T0 = 299 K (26C).

//solution
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: %f',Wcdot)

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

//part(c)
beta = (h1-h4)/(h2-h1)
    //coefficient of performance
printf('\n\nthe coefficient of performance is: %f',
    beta)

//part(d)
Eddotc = mdot*Tnot*(s2-s1)
    //in kw
Eddotv = mdot*Tnot*(s4-s3)
    //in kw
printf('\n\nthe rate of exergy destruction within
```

```
the compressor is: %f',Eddotc)
printf('\nthe rate of exergy destruction within the valve is: %f',Eddotv)
```

Scilab code Exa 10.4 Example 4

```
//(10.4) Air enters the compressor of an ideal Brayton refrigeration cycle at 1 bar, 270K, with a volumetric flow rate of 1.4 m3/s. If the compressor pressure ratio is 3 and the turbine inlet temperature is 300K, determine (a) the net power input, in kW, (b) the refrigeration capacity, in kW, (c) the coefficient of performance

//solution

//variable initialization
p1 = 1                                                  //in bar
T1 = 270                                                //in kelvin
AV = 1.4                                                //in m^3/s
r = 3                                                   //compressor pressure ratio
T3 = 300                                                //turbine inlet temperature in kelvin

//analysis
```

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

   //in kj/kg
pr1 = .9590
pr2 = r*pr1
//interpolating in Table A-22,
h2s = 370.1

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

   //in kj/kg
pr3 = 1.3860
pr4 = pr3/r
//Interpolating in Table A-22, we obtain
h4s = 219

   //in kj/kg

//part(a)
R = 8.314

   //universal gas constant , in SI units
M = 28.97

   //molar mass of air in grams
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:  %f',Wcycledot
   )

//part(b)
Qindot = mdot*(h1-h4s)
```

```
    //refrigeration capacity in kw
printf('\nthe refregeration capacity in kw is:  %f',
    Qindot)

//part(c)
beta = Qindot/Wcycledot
    //coefficient of performance
printf('\nthe coefficient of performance is:  %f',
    beta)
```

Scilab code Exa 10.5 Example 5

```
//(10.5)  Reconsider Example 10.4, but include in
    the analysis that the compressor and turbine each
     have an isentropic efficiency of 80%. Determine
    for the modified cycle (a) the net power input,
    in kW, (b) the refrigeration capacity, in kW, (c)
     the coefficient of performance, and interpret
    its value.

//solution
funcprot(0)

//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 = .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 = .8

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

   //actual turbine work in kw

Wdotcycle = Wcdot-Wtdot

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

//part(b)
h3 = 300.19

   //in kj/kg
h4 = h3 -Wtdot/mdot
//from table A-22
h1 = 270.11

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

   //refrigeration capacity in kw
printf('\nthe refrigeration capacity in kw is: %f',
   Qindot)

```

```
//part(c)
beta = Qindot/Wdotcycle    //coefficient of performance
printf('\nthe coefficient of performance is:  %f',beta)
```

Chapter 11

Thermodynamic relations

Scilab code Exa 11.1 Example 1

```
//(11.1) A cylindrical tank containing 4.0 kg of carbon monoxide gas at 50C has an inner diameter of 0.2 m and a length of 1 m. Determine the pressure, in bar, exerted by the gas using (a) the generalized compressibility chart, (b) the ideal gas equation of state, (c) the van der Waals equation of state, (d) the Redlich Kwong equation of state. Compare the results obtained.

//solution

//variable initialization
m = 4                                   //mass of carbon monoxide in kg
T = 223                                 //temperature of carbon monoxide in kelvin
D = .2                                  //inner diameter of cylinder in meter
```

```
L = 1
   //length of the cylinder in meter

//analysis
V = (%pi*D^2/4)*L
   //volume occupied by the gas in m^3
M = 28
   //molar mass in kg/kmol
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
vrdash = (vbar*Pc&10^5)/(Rbar*Tc)                                //
   pseudoreduced specific volume
Z = .9

p = (Z*Rbar*T/vbar)*10^-5
   //in bar
printf('part(a)the pressure in bar is: %f',p)
```

```
//part(b)
//The ideal gas equation of state gives
p = (Rbar*T/vbar)/10^5                                                        //in bar
printf('\npart(b)the pressure in bar is:  %f',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 = .0395                                                                     //in m^3/kmol

p = (Rbar*T/(vbar-b))/10^5 - a/vbar^2
printf('\npart(c)the pressure in bars is:  %f',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 = .02737                                                                    //in m^3/kmol

p = (Rbar*T/(vbar-b))/10^5 - a/[vbar*(vbar+b)*T^.5]
printf('\npart(d)the pressure in bar is:  %f',p)
```

Scilab code Exa 11.2 Example 2

```
printf('theoretical problem')
```

Scilab code Exa 11.3 Example 3

```
//(11.3)  Evaluate the partial derivative (dels/delv)T for water vapor at a state fixed by a temperature of 240C and a specific volume of 0.4646 m3/kg. (a) Use the Redlich Kwong equation of state and an appropriate Maxwell relation. (b) Check the value obtained using steam table data.

//solution

//part(a)
v = .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 = .0211                                             //in m^3/kmol
```

```

Rbar = 8314

   //universal gas constant in N.m/kmol.K
T = 513

   //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
printf('the value of delpbydelT in kj/(m^3*K) is:
   %f ',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

   //in degree celcius
//at p =1 bar
s(1,1) = 7.9949

   //in kj/kg.k
v(1,1) = 2.359

   //in m^3/kg
//at p= 1.5 bar
s(2,1) = 7.8052

   //in kj/kg.k
v(2,1) = 1.570

   //in m^3/kg
```

```
//at p = 3 bar
s(3,1) = 7.4774  //in kj/kg.k
v(3,1) = .781  //in m^3/kg
//at p = 5 bar
s(4,1) = 7.2307  //in kj/kg.k
v(4,1) = .4646  //in m^3/kg
//at p =7 bar
s(5,1) = 7.0641  //in kj/kg.k
v(5,1) = .3292  //in m^3/kg
//at p = 10 bar
s(6,1) = 6.8817  //in kj/kg.k
v(6,1) = .2275  //in m^3/kg
plot(v,s)
xtitle("","Specific volume, m3/kg","Specific entropy, kJ/kg K")
//The pressure at the desired state is 5 bar.The corresponding slope is
delsbydelv = 1  //in kj/m^3.K
printf('\n\nfrom the data of the table,delsbydelv = %f',delsbydelv)
```

Scilab code Exa 11.4 Example 4

```
//(11.4)Using p v T data for saturated water,
   calculate at 100C (a) hg - hf, (b) ug - uf, (c)
   sg - sf. Compare with the respective steam table
   value.

//solution

//analysis
//For comparison, Table A-2 gives at 100C,
hgf =2257

   //in kj/kg
ugf = 2087.6

   //in kj/kg
sgf = 6.048

   //in kj/kg.K
printf('from table, hg-hf = %f',hgf)
printf('\nfrom table, ug-uf = %f',ugf)
printf('\nfrom table, sg-sf = %f',sgf)

//(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
```

```
                                                    //in N/(m^2.K)

vg = 1.673                                          //in m^3/kg
vf = 1.0435e-3                                      //in m^3/kg
//from the Clapeyron equation
hgf = T*(vg-vf)*delpbydelT*10^-3                    //in kj/kg

printf('\n\npart(a)using Clapeyron equation, hg-hf = %f',hgf)
//(b)
psat = 1.014e5                                      //in N/m^2
hgf = 2256                                          //can be obtained using IT software in kj/kg
ugf = hgf - psat*(vg-vf)/10^3                       //in kj/kg
printf('\npart(b)ug-uf = %f',ugf)
//(c)
sgf =hgf/T                                          //in kj/kg.K
printf('\npart(c)sg-sf = %f',sgf)
```

Scilab code Exa 11.5 Example 5

```
printf('theoretical problem')
```

Scilab code Exa 11.6 Example 6

```
//(11.6)  For liquid water at 1 atm and 20C,
   estimate (a) the percent error in cv that would
   result if it were assumed that cp = cv, (b) the
   velocity of sound, in m/s.

//solution

//part(a)
funcprot(0)
v = 1/998.21

   //specific volume of water in m^3/kg
T = 293

   //given temperature in kelvin
beta = 206.6e-6

   //volume expansivity in /K
k = 45.90e-6

   //isothermal compressibility in /bar

cpv = (v*T*beta^2/k)*10^2

   //in kj/kg.k

//Interpolating in Table A-19
cp = 4.188

   //in kj/kg.k
cv = cp-cpv
```

```
//in kj/kg.k

errorPercentage = 100*(cp-cv)/cv
printf('the percentage error is:  %f', errorPercentage)

//part(b)

K = cp/cv //specific heat ratio
c = sqrt((K*v/k)*10^5) //velocity of sound in m/s
printf('\nthe velocity of sound in m/s is:  %f',c)
```

Scilab code Exa 11.7 Example 7

```
printf('theoretical problem')
```

Scilab code Exa 11.8 Example 8

```
//(11.8)  Nitrogen enters a turbine operating at steady state at 100 bar and 300 K and exits at 40 bar and 245 K. Using the enthalpy departure chart, determine the work developed, in kJ per kg of nitrogen flowing, if heat transfer with the surroundings can be ignored. Changes in kinetic and potential energy from inlet to exit also can be neglected.

//solution

```

```
//variable initialization
p1 = 100

   //in bar
T1 = 300

   //in kelvin
p2 = 40

   //in bar
T2 = 245

   //in kelvin


//from table A-23
h1starbar = 8723

   //in kj/kmol
h2starbar = 7121

   //in kj/kmol
//From Tables A-1
Tc = 126

   //critical temperature in kelvin
pc = 33.9

   //critical pressure in bar
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

M = 28                                         //molar mass in kg/kmol
Rbar = 8.314                                   //universal gas constant in kj/(kmol.K)

Term1 = .5
Term2 = .31

wcvdot = (1/M)*[h1starbar-h2starbar-Rbar*Tc*(Term1-Term2)]                  //in kj/kg
printf('the work developed, in kJ per kg of nitrogen flowing is :  %f',wcvdot)
```

Scilab code Exa 11.9 Example 9

```
//(11.9)  For the case of Example 11.8, determine (a) the rate of entropy production, in and (b) the isentropic turbine efficiency.

//solution

//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                                               //molar mass in kg/kmol
p2 = 40                                              //in bar
p1 = 100                                             //in bar

S2StarBarMinusS1StarBar = sT2bar-sT1bar-Rbar*log(p2/p1)                          //The change in specific entropy in kj/(kmol.K)

Term1 = .21
Term2 = .14

sigmacvdot = (1/M)*(S2StarBarMinusS1StarBar-Rbar*(Term2-Term1))
printf('the rate of entropy production in kj/kg.K is :  %f',sigmacvdot)

//part(b)
//From Table A-23,
h2starbar = 6654                                     //in kj/kmol
h1starbar = 8723                                     //in kj/kmol
Tc = 126                                             //critical temperature in kelvin
Term2 = .36
```

```
Term1 = .5

wcvdots = (1/M)*[h1starbar-h2starbar-Rbar*Tc*(Term1-Term2)]                              //isentropic work in kj/kg
wcvdot = 50.1                                                            //from example 11.8

etat = wcvdot/wcvdots                                                    //turbine efficiency
printf('\nthe isentropic turbine efficiency is: %f',etat)
```

Scilab code Exa 11.10 Example 10

```
//(11.10)  A mixture consisting of 0.18 kmol of methane (CH4) and 0.274 kmol of butane (C4H10) occupies a volume of 0.241 m3 at a temperature of 238C. The experimental value for the pressure is 68.9 bar. Calculate the pressure, in bar, exerted by the mixture by using (a) the ideal gas equation of state, (b) Kay s rule together with the generalized compressibility chart, (c) the van der Waals equation, and (d) the rule of additive pressures employing the generalized compressibility chart. Compare the calculated values with the known experimental value.

//solution

//analysis
V = .241
```

```
    //volume of the mixture in m^3
T = 511

    //temperature of the mixture in kelvin
n1 = .18

    //number of moles of methane in kmol
n2 = .274

    //number of moles of butane in kmol
n = n1 + n2

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

    //mole fraction of methane
y2 = n2/n

    //mole fraction of butane
Rbar = 8314

    //universal gas constant in (N.m)/(kmol.K)
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
printf('the pressure in bar obtained using ideal gas
    equation is:  %f',p)

//part(b)
//from table A-1
Tc1 = 191
```

```
   //critical temperature for methane in kelvin
Pc1 = 46.4
   //critical pressure for methane in bar
Tc2 = 425
   //critical temperature for butane in kelvin
Pc2 = 38
   //critical pressure for butane in bar

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)

Z = .88
p = ((Z*Rbar*T)/vbar)*10^-5
   //mixture pressure in bar
printf('\npressure obtained using Kay s rule
   together with the generalized compressibility
   chart , is:  %f',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 = .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 = .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('\nthe pressure in bar from van der Waals equation is: %f ',p)

//part(d)
//for methane
TR1 = T/Tc1
vR1dash = (.241/.18)*10^5*Pc1/(Rbar*Tc1)
Z1 = 1
//for butane
TR2 = T/Tc2
vR2dash = (.88*10^5*Pc2)/(Rbar*Tc2)
Z2 = .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
printf('\nthe pressure in bar obtained using the rule of additive pressures employing the
```

```
    generalized compressibility chart is: %f',p)
```

Chapter 12

Ideal gas mixture and psychrometric applications

Scilab code Exa 12.1 Example 1

```
//(12.1)  The molar analysis of the gaseous products of combustion of a certain hydrocarbon fuel is CO2, 0.08; H2O, 0.11; O2, 0.07; N2, 0.74. (a) Determine the apparent molecular weight of the mixture. (b) Determine the composition in terms of mass fractions (gravimetric analysis).

//solution

//variable initialization
n1 = .08                                    // mole fraction of CO2
n2 = .11                                    // mole fraction of H2O
n3 = .07                                    //mole fraction of O2
```

```
n4 = .74    //mole fraction of N2

//part(a)
M1 = 44    //molar mass of CO2 in kg/kmol
M2 = 18    //molar mass of H2O in kg/kmol
M3 = 32    //molar mass of O2 in kg/kmol
M4 = 28    //molar mass of N2 in kg/kmol

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

//part(b)
mf1 = (M1*n1/M)*100    //mass fraction of CO2 in percentage
mf2 = (M2*n2/M)*100    //mass fraction of H2O in percentage
mf3 = (M3*n3/M)*100    //mass fraction of O2 in percentage
mf4 = (M4*n4/M)*100    //mass fraction of N2 in percentage

```

```
printf('\n\nthe mass fraction of CO2 in percentage
   is:  %f',mf1)
printf('\nthe mass fraction of H2O in percentage is:
     %f',mf2)
printf('\nthe mass fraction of O2 in percentage is:
    %f',mf3)
printf('\nthe mass fraction of N2 in percentage is:
    %f',mf4)
```

Scilab code Exa 12.2 Example 2

```
//(12.2)   A gas mixture has the following
   composition in terms of mass fractions: H2, 0.10;
    N2, 0.60; CO2, 0.30. Determine (a) the
   composition in terms of mole fractions and (b)
   the apparent molecular weight of the mixture.

//solution

//variable initialization
mf1 = .1

   //mass fractiion of H2
mf2 = .6

   //mass fraction of N2
mf3 = .3

   //mass fraction of CO2

//part(a)
M1 = 2

   //molar mass of H2 in kg/kmol
M2 = 28
```

```
//molar mass of N2 in kg/kmol
M3 = 44                                         //molar mass of CO2 in kg/kmol

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

printf('the mole fraction of H2 in percentage is: %f',n1*100)
printf('\nthe mole fraction of N2 in percentage is: %f',n2*100)
printf('\nthe mole fraction of CO2 in percentage is: %f',n3*100)

//part(b)
M = n1*M1 + n2*M2 + n3*M3                       //in kg/kmol
printf('\n\nthe apparent molecular weight of the mixture in kg/kmol is:  %f',M)
```

Scilab code Exa 12.3 Example 3

```
//(12.3)  A mixture of 0.3 kg of carbon dioxide and 0.2 kg of nitrogen is compressed from p1 = 1 bar, T1 = 300 K to p2 = 3 bars in a polytropic
```

```
   process for which n=  1.25. Determine (a) the
   final temperature, in K, (b) the work, in kJ, (c)
    the heat transfer, in kJ, (d) the change in
   entropy of the mixture, in kJ/K.

//solution

//variable initialization
m1 = .3

   //mass of CO2 in kg
m2 = .2

   //mass of N2 in kg
p1 = 1

   //in bar
T1 = 300

   //in kelvin
p2 = 3

   //in bar
n = 1.25

//part(a)
T2 = T1*(p2/p1)^[(n-1)/n]

   //in kelvin
printf('the final temperature in Kelvin is:  %f',T2)

//part(b)
Rbar = 8.314

   //universal gas constant in SI units
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
printf('\nthe work in kj is:  %f',W)

//part(c)
//from table A-23
uCO2T1 = 6939                                                   //internal energy of CO2 on molar mass basis at temperature T1
uCO2T2 = 9198                                                   //internal energy of CO2 on molar mass basis at temperature T2
uN2T1 = 6229                                                    //internal energy of N2 on molar mass basis at temperature T1
uN2T2 = 7770                                                    //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
printf('\nthe 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

deltaS = (m1/44)*[sbarT2CO2-sbarT1CO2-Rbar*log(p2/p1)] + (m2/28)*[sbarT2N2-sbarT1N2-Rbar*log(p2/p1)]
printf('\nthe change in entropy of the mixture in kj/k is:  %f',deltaS)
```

Scilab code Exa 12.4 Example 4

```
//(12.4)   A gas mixture consisting of CO2 and O2 with mole fractions 0.8 and 0.2, respectively, expands isentropically and at steady state through a nozzle from 700 K, 5 bars, 3 m/s to an exit pressure of 1 bar. Determine (a) the temperature at the nozzle exit, in K, (b) the entropy changes of the CO2 and O2 from inlet to exit, in KJ/Kmol.K (c) the exit velocity, in m/s.

//solution

//variable initialization
y1 = .8                    //mole fraction of CO2
y2 = .2                    //mole fraction of O2
T1 = 700                   //in kelvin
p1 = 5
```

```
    //in bars
V1 = 3

    //in m/s
p2 = 1

    //in bars


//part(a)
//from table A-23
sO2barT1 = 231.358
sCO2barT1 = 250.663

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)
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

deltasbarO2 = sbarO2T2-sbarO2T1-8.314*log(p2/p1)                //in kj/kmol.K
deltasbarCO2 = sbarCO2T2-sbarCO2T1-8.314*log(p2/p1)             //in kj/kmol.K

printf('\n\nthe entropy changes of the CO2 from inlet to exit, in KJ/Kmol.K is: %f',deltasbarCO2)
printf('\nthe 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
h2barO2 = 15320
h1barCO2 = 27125
h2barCO2 = 18468

M = y1*44 + y2*32                                               //apparent molecular weight of the mixture in kg/kmol
deltah = (1/M)*[y2*(h1barO2-h2barO2) + y1*(h1barCO2-h2barCO2)]
V2 = sqrt(V1^2+ 2*deltah*10^3)
printf('\n\nthe exit velocity in m/s is: %f',V2)
```

Scilab code Exa 12.5 Example 5

```
//(12.5)  Two rigid, insulated tanks are interconnected by a valve. Initially 0.79 kmol of
```

```
  nitrogen at 2 bars and 250 K fills one tank. The
  other tank contains 0.21 kmol of oxygen at 1 bar
  and 300 K. The valve is opened and the gases are
  allowed to mix until a final equilibrium state
  is attained. During this process, there are no
  heat or work interactions between the tank
  contents and the surroundings. Determine (a) the
  final temperature of the mixture, in K, (b) the
  final pressure of the mixture, in atm, (c) the
  amount of entropy produced in the mixing process,
  in kJ/K

//solution

//variable initialization
nN2 = .79
                                      //initial moles of nitrogen in kmol
pN2 = 2
                                      //initial pressure of nitrogen in bars
TN2 = 250
                                      //initial temperature of nitrogen in kelvin
nO2 = .21
                                      //initial moles of oxygen in kmol
pO2 = 1
                                      //initial pressure of oxygen in bars
TO2 = 300
                                      //initial temperature of oxygen in kelvin
//part(a)
MN2 = 28.01
                                      //molar mass of nitrogen in kg/kmol
MO2 = 32
```

```
   //molar mass of oxygen in kg/kmol

//with the help of table A-20
cvbarN2 = MN2*.743

   //in kj/kmol.K
cvbarO2 = MO2*.656

   //in kj/kmol.K

T2 = (nN2*cvbarN2*TN2+nO2*cvbarO2*TO2)/(nN2*cvbarN2+
   nO2*cvbarO2)
printf('the final temperature of the mixture in
   kelvin is: %f',T2)

//part(b)
p2 = [(nN2+nO2)*T2]/[nN2*TN2/pN2 + nO2*TO2/pO2]
printf('\n\nthe final pressure of the mixture in bar
    is: %f',p2)

//part(c)
Rbar = 8.314

   //universal gas constant
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
   ))
```

```
printf('\n\nthe amount of entropy produced in the
    mixing process, in kJ/K is: %f',sigma)
```

Scilab code Exa 12.6 Example 6

```
//(12.6) At steady state, 100 m3/min of dry air at
    32C and 1 bar is mixed adiabatically with a
    stream of oxygen (O2) at 127C and 1 bar to form a
     mixed stream at 47C and 1 bar. Kinetic and
    potential energy effects can be ignored.
    Determine (a) the mass flow rates of the dry air
    and oxygen, in kg/min, (b) the mole fractions of
    the dry air and oxygen in the exiting mixture,
    and (c) the time rate of entropy production, in
    kJ/K . min

//solution

//variable initialization
T1 = 32

    //temperature of dry air in degree celcius
p1 = 1

    //pressure of dry air in bar
AV1 = 100

    //volume rate of dry air in m^3/min
T2 = 127

    //temperature of oxygen stream in degree celcius
p2 = 1

    //pressure of oxygen stream in bar
T3 = 47
```

```
    //temperature of mixed stream in degree celcius
p3 = 1

    //pressure of mixed stream in bar

//part(a)
Rbar = 8314

    //universal gas constant
Ma = 28.97

    //molar mass of air
Mo = 32

    //molar mass of oxygen

va1 = (Rbar/Ma)*(T1+273)/(p1*10^5)
                                                      //
    specific volume of air in m^3/kg
ma1dot = AV1/va1

    //mass flow rate of dry air in kg/min

//from table A-22 and A-23
haT3 = 320.29

    //in kj/kg
haT1 = 305.22

    //in kj/kg
hnotT2 = 11711

    //in kj/kmol
hnotT1 = 9325

    //in kj/kmol

```

```
modot = ma1dot*(haT3-haT1)/[(1/Mo)*(hnotT2-hnotT1)]      //in kg/min
printf('the mass flow rate of dry air in kg/min is: %f',ma1dot)
printf('\nthe 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

printf('\n\nthe mole fraction of dry air in the exiting mixture is: %f',ya)
printf('\nthe 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

sigmadot = ma1dot*[sanotT3-sanotT1-(8.314/Ma)*log(ya
    )] + (modot/Mo)*[sbarT3-sbarT2-8.314*log(yo)]
printf('\n\nthe time rate of entropy production, in
    kJ/K. min is: %f',sigmadot)
```

Scilab code Exa 12.7 Example 7

```
//(12.7)  A 1 kg sample of moist air initially at 21
    C, 1 bar, and 70% relative humidity is cooled to
    5C while keeping the pressure constant. Determine
     (a) the initial humidity ratio, (b) the dew
    point temperature, in C, and (c) the amount of
    water vapor that condenses, in kg.

//solution

//variable initialization
m =1
    //mass of sample in kg
T1 = 21
    //initial temperature in degree celcius
psi1 = .7
    //initial relative humidity
T2 = 5
    //final temperature in degree celcius

//part(a)
```

```
//from table A-2
pg = .02487

   //in bar

pv1 = psi1*pg

   //partial pressure of water vapor in bar

omega1 = .622*(.2542)/(14.7-.2542)
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
printf('\n\nthe dew point temperature in degree
   celcius is:  %f',T)

//part(c)
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

//the partial pressure of the water vapor remaining
   in the system at the final state is the
   saturation pressure corresponding to 5C:
pg = .00872

   //in bar
omega2 = .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
printf('\n\n the amount of water vapor that
    condenses, in kg. is:  %f',mw)
```

Scilab code Exa 12.8 Example 8

```
//(12.8)  An air water vapor mixture is contained
    in a rigid, closed vessel with a volume of 35 m3
    at 1.5 bar, 120C, and psi =  10%. The mixture is
    cooled at constant volume until its temperature
    is reduced to 22C. Determine (a) the dew point
    temperature corresponding to the initial state,
    in C, (b) the temperature at which condensation
    actually begins, in C, and (c) the amount of
    water condensed, in kg.

//solution

//variable initialization
V = 35
    //volume of the vessel in m^3
p1 = 1.5
    //in bar
T1 = 120
    //in degree celcius
```

```
psi1 = .1
T2 = 22                                                 //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
pv1 = psi1*pg1                                          //partial pressure in bar
//Interpolating in Table A-2 gives the dew point temperature as
T = 60                                                  //in degree celcius
printf('the dew point temperature corresponding to the initial state, in degee celcius is: %f',T)

//part(b)
Rbar = 8314                                             //universal gas constant
Mv = 18                                                 //molar mass of vapor in kj/kmol
vv1 =((Rbar/Mv)*(T1+273))/(pv1*10^5)                    //the specific volume of the vapor at state 1 in m^3/kg
//Interpolation in Table A-2
Tdash = 56                                              //in degrees
```

```
printf('\n\nthe temperature at which condensation actually begins in degree celcius is: %f',Tdash)

//part(c)
mv1 = V/vv1                                        //initial amount of water vapor present in kg
//from table
vf2 = 1.0022e-3
vg2 = 51.447
vv2 = vv1                                          //specific volume at final state

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
printf('\n\n the amount of water condense in kg is: %f',mw2)
```

Scilab code Exa 12.9 Example 9

```
//(12.9) An air water vapor mixture is contained in a rigid, closed vessel with a volume of 35 m3 at 1.5 bar, 120C, and psi = 10%. The mixture is cooled until its temperature is reduced to 22C. Determine the heat transfer during the process, in kJ.

//solution
```

```

//variable initialization
V = 35

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

    //initial pressure in bar
T1 = 120

    //initial temperature in degree celcius
psi = .1
T2 = 22

    //in degree celcius

Rbar = 8314

    //universal gas constant
Ma = 28.97

    //molar mass of air

pv1 = .1985

    //in bar, from example 12.8
mv2 = .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

ma =( [(p1-pv1)*10^5]*V)/[(Rbar/Ma)*(T1+273)]
                                        //mass of dry
```

```
   air in kg

//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

Q = ma*(ua2-ua1) + mv2*ug2 + mw2*uf2 - mv1*ug1
printf(' the heat transfer during the process, in kJ
    is:  %f',Q)
```

Scilab code Exa 12.10 Example 10

```
//(12.10)  Moist air enters a duct at 10C, 80%
   relative humidity, and a volumetric flow rate of
   150 m3/min. The mixture is heated as it flows
   through the duct and exits at 30C. No moisture is
    added or removed, and the mixture pressure
   remains approximately constant at 1 bar. For
   steady-state operation, determine (a) the rate of
    heat transfer, in kJ/min, and (b) the relative
   humidity at the exit. Changes in kinetic and
```

```
   potential energy can be ignored.

//solution

//variable initialization
AV1 = 150                                    //entry volumetric flow rate in m^3/min
T1 = 10                                      //entry temperature in degree celcius
psi1 = .8
T2 = 30                                      //exit temperature in degree celcius
p = 1                                        //in bar

//part(a)
Rbar = 8314                                  //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 = .01228                                          //in bar
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 = .622*(pv1/(p-pv1))                            //humidity ratio

Qcvdot = madot*[(ha2-ha1)+omega*(hv2-hv1)]            //in kj/min
printf('rate of heat transfer, in kJ/min is: %f', Qcvdot)

//part(b)
//from Table A-2 at 30C
pg2 = .04246                                          //in bar
pv2 = pv1
psi2 = pv2/pg2
```

```
    //relative humidity at the exit
printf('\n\nthe relative humidity at the exit is:
    %f',psi2)
```

Scilab code Exa 12.11 Example 11

```
//(12.11)  Moist air at 30C and 50% relative
    humidity enters a dehumidifier operating at
    steady state with a volumetric flow rate of 280
    m3/min. The moist air passes over a cooling coil
    and water vapor condenses. Condensate exits the
    dehumidifier saturated at 10C. Saturated moist
    air exits in a separate stream at the same
    temperature. There is no significant loss of
    energy by heat transfer to the surroundings and
    pressure remains constant at 1.013 bar. Determine
     (a) the mass flow rate of the dry air, in kg/min
    , (b) the rate at which water is condensed, in kg
     per kg of dry air flowing through the control
    volume, and (c) the required refrigerating
    capacity, in tons.

//solution

//variable initialization
T1 = 30

    //in degree celcius
AV1 = 280

    //in m^3/min
psi1 = .5

    //relative humidity at the inlet
```

```
T2 = 10 //in degree celcius
p = 1.013 //pressure in bar

//part(a)
//from table A-2
pg1 = .04246 //in bar
pv1 = psi1*pg1 //in bar

pa1 = p-pv1 //partial pressure of the dry air in bar

Rbar = 8314 //universal gas constant
Ma = 28.97 //molar mass of air
madot = AV1/[(Rbar/Ma)*((T1+273)/(pa1*10^5))] //common mass flow rate of the dry air in kg/min
printf('the mass flow rate of the dry air in kg/min is: %f',madot)

//part(b)
omega1 = .622*[pv1/(p-pv1)]

//from table A-2
pv2 = .01228
```

```
    //in bar

omega2 = .622*[pv2/(p-pv2)]

mwdotbymadot = omega1-omega2
printf('\n\nthe rate at which water is condensed, in
     kg per kg of dry air flowing through the control
     volume is:  %f',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

Qcvdot = madot*[(ha2-ha1)-omega1*hg1+omega2*hg2+(
    omega1-omega2)*hf2]                //in kj/min
printf('\n\nthe required refrigerating capacity, in
    tons is:  %f',Qcvdot/211)
```

Scilab code Exa 12.12 Example 12

```
//(12.12)  Moist air with a temperature of 22C and a
```

```
wet-bulb temperature of 9C enters a steam-spray
humidifier. The mass flow rate of the dry air is
90 kg/min. Saturated water vapor at 110C is
injected into the mixture at a rate of 52 kg/h.
There is no heat transfer with the surroundings,
and the pressure is constant throughout at 1 bar.
 Using the psychrometric chart, determine at the
exit (a) the humidity ratio and (b) the
temperature, in C.

//solution

//variable initialization
T1 = 22

   //entry temperature of moist air in degree
   celcius
Twb = 9

   //wet-bulb temperature of entering moist air in
   degree celcius
madot = 90

   //mass flow rate of dry air in kg/min
Tst = 110

   //temperature of injected saturated water vapor
   in degree celcius
mstdot = 52

   //mass flow rate of injected saturated water
   vapor in kg/h
p = 1

   //pressure in bar

//part(a)
//by inspection of the psychrometric chart
```

```
omega1 = .002
omega2 = omega1 + mstdot/(madot*60)
printf('the humidity ratio at the exit is:  %f',
   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
printf('\n\nthe temperature at the exit in degree
   celcius is:  %f',T2)
```

Scilab code Exa 12.13 Example 13

```
//(12.13)   Air at 38C and 10% relative humidity
   enters an evaporative cooler with a volumetric
   flow rate of 140 m3/min. Moist air exits the
   cooler at 21C. Water is added to the soaked pad
   of the cooler as a liquid at 21C and evaporates
   fully into the moist air. There is no heat
   transfer with the surroundings and the pressure
   is constant throughout at 1 atm. Determine (a)
   the mass flow rate of the water to the soaked pad
   , in lb/h, and (b) the relative humidity of the
   moist air at the exit to the evaporative cooler.

//solution

```

```
//variable initialization
T1 = 38

   //temperature of entering air in degree celcius
psi1 = .1

   //relative humidity of entering air
AV1 = 140

   //volumetric flow rate of entering air in m^3/min
Tw = 21

   //temperature of added water in degree celcius
T2 = 21

   //temperature of exiting moist air in degree
   celcius
p = 1

   //pressure in atm

//part(a)
//from table A-2
pg1 = .066

   //in bar
pv1 = psi1*pg1

   //the partial pressure of the moist air entering
   the control volume in bar
omega1 = .622*[pv1/(p*1.01325-pv1)]
//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
```

```
madot = AV1/va1                                       //mass flow rate of the dry air in kg/min
//from table A-2
hf = 88.14
hg1 = 2570.7
hg2 = 2539.94

omega2 = [cpa*(T1-T2)+omega1*(hg1-hf)]/(hg2-hf)
mwdot = madot*60*(omega2-omega1)                                          //in kg/h
printf('the mass flow rate of the water to the soaked pad in kj/h is:  %f',mwdot)

//part(b)
pv2 = (omega2*p*1.01325)/(omega2+.622)                                    //in bars
//At 21C, the saturation pressure is
pg2 = .02487
psi2 = pv2/pg2
printf('\n the relative humidity of the moist air at the exit to the evaporative cooler is:  %f',psi2)
```

Scilab code Exa 12.14 Example 14

```
//(12.14)  A stream consisting of 142 m3/min of moist air at a temperature of 5C and a humidity ratio of 0.002 kg(vapor)kg(dry air) is mixed adiabatically with a second stream consisting of 425 m3/min of moist air at 24C and 50% relative humidity. The pressure is constant throughout at 1 bar. Using the psychrometric chart, determine (
```

```
   a) the humidity ratio and (b) the temperature of
   the exiting mixed stream, in C.

//solution

//variable initialization
AV1 = 142

   //in m^3/min
T1 = 5

   //in degree celcius
omega1 = .002
AV2 = 425

   //in m^3/min
T2 = 24

   //in degree celcius
psi2 = .5
p = 1

   //in bar


//part(a)
//from the psychrometric chart, Fig. A-9.
va1 = .79

   //in m^3/kg
va2 = .855

   //in m^3/kg
omega2 = .0094

ma1dot = AV1/va1

   //in kg/min
```

```
ma2dot = AV2 /va2                                    //in kg/min

omega3 = (omega1*ma1dot+omega2*ma2dot)/(ma1dot + ma2dot)
printf('the humidity ratio is:  %f',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                                              //in degree celcius
printf('\n\nthe temperature of the exiting mixed stream in degree celcius is:  %f',T3)
```

Scilab code Exa 12.15 Example 15

```
//(12.15)  Water exiting the condenser of a power plant at 38C enters a cooling tower with a mass flow rate of 4.5 X  107 kg/h. A stream of cooled water is returned to the condenser from a cooling tower with a temperature of 30C and the same flow rate. Makeup water is added in a separate stream at 20C. Atmospheric air enters the cooling
```

```
    tower at 25C and 35% relative humidity. Moist
   air exits the tower at 35C and 90% relative
   humidity. Determine the mass flow rates of the
   dry air and the makeup water, in kg/h. The
   cooling tower operates at steady state. Heat
   transfer with the surroundings and the fan power
   can each be neglected, as can changes in kinetic
   and potential energy. The pressure remains
   constant throughout at 1 atm.


//solution

//variable initialization
T1 = 38

   //in degree celcius
m1dot = 4.5e7

   //in kg/h
T2 = 30

   //in degree celcius
m2dot = 4.5e7

   //in kg/h
T3 = 25

   //in degree celcius
psi3 = .35
T4 = 35

   //in degree celcius
psi4 = .9
T5 = 20

   //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 =.00688
omega4 = .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

madot = [m1dot*(hf1-hf2)]/[ha4-ha3+omega4*hg4-omega3*hg3-(omega4-omega3)*hf5]    //in kg/h
m5dot = madot*(omega4-omega3)                    //in kg/h
printf('the mass flow rate of dry air in kg/h is: %e',madot)
printf('\nthe mass flow rate of makeup water in kg/h is:  %e',m5dot)
```

Chapter 13

Reacting mixtures and combustion

Scilab code Exa 13.1 Example 1

```
//(13.1)  Determine the air fuel ratio on both a
   molar and mass basis for the complete combustion
   of octane, C8H18, with (a) the theoretical amount
    of air, (b) 150% theoretical air (50% excess air
   ).

//solution

//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
c = 18/2
a = (2*b+c)/2
d = 3.76*a

//The air fuel ratio on a molar basis is
```

```
AFbar = a*(1+3.76)/1

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]

printf('The air fuel ratio on a molar basis is: %f',AFbar)
printf('\nThe air fuel ratio expressed on a mass basis is: %f',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
b = 8
c =18/2
e = (1.5*12.5*2 - c -2*b)/2
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]
printf('\n\nThe air fuel ratio on a molar basis is: %f',AFbar)
printf('\nThe air fuel ratio expressed on a mass basis is: %f',AF)
```

Scilab code Exa 13.2 Example 2

```
//(13.2) Methane, CH4, is burned with dry air. The molar analysis of the products on a dry basis is CO2, 9.7%; CO, 0.5%; O2, 2.95%; and N2, 86.85%. Determine (a) the air fuel ratio on both a molar and a mass basis, (b) the percent theoretical air, (c) the dew point temperature of the products, in C, if the mixture were cooled at 1 atm.

//solution

//part(a)
//The chemical equation
//a CH4 + b*(O2 + 3.76N2) ---> 9.7CO2 + .5CO + 2.95O2 + 86.85N2 + cH2O

//applying conservation of mass
a = 9.7 + .5
c = 2*a
b = [9.7*2+.5+2*2.95+c]/2

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)

printf('the air-fuel ratio on a molar basis is: %f',AFbar)
printf('\nthe air-fuel ratio on a mass basis is: %f',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
AFbartheo = 2*(1+3.76)/1
//The percent theoretical air is
Ta = AFbar/AFbartheo
printf('\n\nthe percent theoretical air is: %f',Ta*100)

//part(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
printf('\n\nthe 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 3

```
//(13.3) A natural gas has the following molar analysis: CH4, 80.62%; C2H6, 5.41%; C3H8, 1.87%; C4H10, 1.60%; N2, 10.50%. The gas is burned with dry air, giving products having a molar analysis on a dry basis: CO2, 7.8%; CO, 0.2%; O2, 7%; N2, 85%. (a) Determine the air fuel ratio on a molar basis. (b) Assuming ideal gas behavior for
```

```
    the fuel mixture, determine the amount of
    products in kmol that would be formed from 100 m3
     of fuel mixture at 300 K and 1 bar. (c)
    Determine the percent of theoretical air.

//solution

//part(a)
//The chemical equation
//(.8062CH4 + .0541C2H6 + .0187C3H8 + .0160C4H10 +
    .1050N2) + a(O2 + 3.76N2)  ---->  b(.078CO2 +
    .002CO + .07O2 + .85N2) + c H2O

//using mass conservation
b = [.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
printf('the air-fuel ratio on a molar mass basis is:
      %f',AFbar)

//part(b)
p = 1

    //in bar
V = 100

    //in m^3
Rbar = 8314

    //in N.m/kmol.K
T = 300

    //in kelvin
//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)
printf('\n\nthe amount of products in kmol that would be formed from 100 m3 of fuel mixture at 300 K and 1 bar is: %f',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 + 0.0160 C4H10 + 0.1050N2) + 2(O2 + 3.76N2)  ----> 1.0345 CO2 + 1.93H2O + 7.625N2
//The theoretical air fuel ratio on a molar basis is
AFbartheo = 2*(1+3.76)/1
//The percent theoretical air is
Ta = AFbar/AFbartheo
printf('\n\nthe percent of theoretical air is: %f',Ta*100)
```

Scilab code Exa 13.4 Example 4

```
//(13.4)  Liquid octane enters an internal combustion engine operating at steady state with a mass flow rate of 1.8  103 kg/s and is mixed with the theoretical amount of air. The fuel and air enter the engine at 25C and 1 atm. The mixture burns completely and combustion products leave the engine at 890 K. The engine develops a power output of 37 kW. Determine the rate of heat transfer from the engine, in kW, neglecting kinetic and potential energy effects.
```

```


//solution
//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

//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)]

mfdot = 1.8e-3                                       //mass flow rate of liquid octane in kg/s
M = 114.22                                           //molar mass of octane
nFdot = mfdot/M                                      //molar flow rate of the fuel in kmol/s

Wcvdot = 37                                          //power output of the engine in kw

Qcvdot = Wcvdot + nFdot*(hpbar-hRbar)                //in kw
printf('the rate of heat transfer from the engine, in kW is: %f',Qcvdot)
```

Scilab code Exa 13.5 Example 5

```
//(13.5)  Methane gas at 400 K and 1 atm enters a combustion chamber, where it is mixed with air entering at 500 K and 1 atm. The products of combustion exit at 1800 K and 1 atm with the product analysis given in Example 13.2. For operation at steady state, determine the rate of heat transfer from the combustion chamber in kJ per kmol of fuel. Neglect kinetic and potential energy effects. The average value for the specific heat cpbar of methane between 298 and 400 K is 38 kJ/kmol K.


//solution

//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                                             //specific heat in KJ/kmol.K
//from table A-25
hfnotbar = -74850                                      //enthalpy of formation for methane
//from table A-23
deltahbarO2 = 14770-8682
deltahbarN2 = 14581-8669

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

Scilab code Exa 13.6 Example 6

```
//(13.6)   A mixture of 1 kmol of gaseous methane and 2 kmol of oxygen initially at 25C and 1 atm burns completely in a closed, rigid container. Heat transfer occurs until the products are cooled to 900 K. If the reactants and products each form ideal gas mixtures, determine (a) the amount of heat transfer, in kJ, and (b) the final pressure, in atm.


//solution

//variable initialization
nCH4 = 1      //moles of methane in kmol
nO2 = 2
```

```
    //moles of oxygen in kmol
T1 = 25
    //in degree celcius
p1 = 1
    //in atm
T2 = 900
    //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
//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)
printf('the amount of heat transfer in kJ is:  %f',Q)

//part(b)
p2 = p1*(T2/(T1+273))
    //in atm
printf('\nthe final pressure in atm is:  %f',p2)
```

Scilab code Exa 13.7 Example 7

```
//(13.7)   Calculate the enthalpy of combustion of gaseous methane, in kJ per kg of fuel, (a) at 25C, 1 atm with liquid water in the products, (b) at 25C, 1 atm with water vapor in the products. (c) Repeat part (b) at 1000 K, 1 atm.


//solution

//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

hRPbar = hfbarCO2 + 2*hfbarH2O - hfbarCH4                 //in kj/kmol
M = 16.04                                                 //molar mass of CH4 in kg/kmol
hRP = hRPbar/M
```

```
    //in kj/kg
printf('part(a)the enthalpy of combustion of gaseous methane, in kJ per kg of fuel is:  %f',hRP)

//part(b)
hfbarCO2 = -393520                  //in kj/kmol
hfbarH2O = -241820                  //in kj/kmol
hfbarCH4 = -74850                   //in kj/kmol

hRPbar = hfbarCO2 + 2*hfbarH2O - hfbarCH4                          //in kj/kmol
hRP = hRPbar/M                      //in kj/kg
printf('\n\npart(b)the enthalpy of combustion of gaseous methane, in kJ per kg of fuel is:  %f',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
```

```
function cpbar = f(T)
    cpbar = (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,f)
var = deltahbarCH4

hRPbar = hRPbar + (deltahbarCO2 + 2*deltahbarH2O - var -2*deltahbarO2)
hRP = hRPbar/M                                    //in kj/kg
printf('\n\npart(c)the enthalpy of combustion of gaseous methane, in kJ per kg of fuel is:  %f', hRP)
```

Scilab code Exa 13.8 Example 8

```
//(13.8)  Liquid octane at 25C, 1 atm enters a well-insulated reactor and reacts with air entering at the same temperature and pressure. For steady-state operation and negligible effects of kinetic and potential energy, determine the temperature of the combustion products for complete combustion with (a) the theoretical amount of air, (b) 400% theoretical air.

//solution

//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                                        //in kj/kmol
hfbarCO2 = -393520
hfbarH2O = -241820

RHS = hfbarC8H18 -(8*hfbarCO2 + 9*hfbarH2O)                 //in kj/kmol

//at temperature 2400k
LHS1 = 5089337                                              //in kj/kmol
//at temperature 2350 k
LHS2 = 4955163                                              //in kj/kmol
//Interpolation between these temperatures gives
Tp = 2400 + [(2400-2350)/(LHS1-LHS2)]*(RHS-LHS1)
printf('the temperature in kelvin with theoretical amount of air is: %f',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
printf('\n\nthe temperature in kelvin using 400 percent theoretical air is: %f',Tp)
```

Scilab code Exa 13.9 Example 9

```
//(13.9) Liquid octane at 25C, 1 atm enters a well-insulated reactor and reacts with air entering at the same temperature and pressure. The products of combustion exit at 1 atm pressure. For steady-state operation and negligible effects of kinetic and potential energy, determine the rate of entropy production, in kJ/K per kmol of fuel, for complete combustion with (a) the theoretical amount of air, (b) 400% theoretical air.

//solution

//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 = .21
yN2 = .79

sbarO2 = sbarO2atTref - Rbar*log(yO2)                   //in kj/kmol.K
sbarN2 = sbarN2atTref - Rbar*log(yN2)                   //in kj/kmol.K

//for product side
yCO2 = 8/64
yH2O = 9/64
yN2p = 47/64

//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)
printf(' the rate of entropy production, in kJ/K per kmol of fuel with theoretical amount of air is: %f',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 = 8/242.5
yH2O = 9/242.5
yO2 = 37.5/242.5
yN2p = 188/242.5

//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*sbarCO2 + 9*sbarH2O + 37.5*sbarO2p +188*sbarN2p) -sFbar - (50*sbarO2 + 188*sbarN2)
printf('\n\nthe rate of entropy production, in kJ/K per kmol of fuel with 400 percent theoretical air is:  %f',sigmadot)
```

Scilab code Exa 13.10 Example 10

```
//(13.10)  Determine the change in entropy of the system of Example 13.6 in kJ/K.


//solution
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 = 1/3
```

```
yO2 = 2/3
yCO2 = 1/3
yH2O = 2/3
//from table A-25
sbarCH4atTref = 186.16                                        //in kj/kmol.K
sbarO2atTref = 205.03                                        //in kj/kmol.K

sbarCH4 = sbarCH4atTref - Rbar*log(yCH4)
sbarO2 = sbarO2atTref - Rbar*log(yO2)

p2 = 3.02                                        //in atm
pref = 1                                        //in atm
//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
printf('the chenge in entropy of the system  in kJ/K is:  %f',deltaS)
```

Scilab code Exa 13.11 Example 11

```
//(13.11)  Determine the Gibbs function of formation of methane at the standard state, 25C and 1 atm, in kJ/kmol, and compare with the value given in Table A-25.



//solution

//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

gfbarCH4 = hfbarCH4 -Tref*(sbarCH4-sbarC-2*sbarH2)             //in kj/kmol
printf('the gibbs function of formation of methane at the standard state is:  %f',gfbarCH4)
```

Scilab code Exa 13.12 Example 12

```
//(13.12)  Determine the chemical exergy of liquid octane at 25C, 1 atm, in kJ/kg. (a) Using Eq. 13.36, evaluate the chemical exergy for an environment consisting of a gas phase at 25C, 1 atm obeying the ideal gas model with the following composition on a molar basis: N2, 75.67%; O2, 20.35%; H2O, 3.12%; CO2, 0.03%; other, 0.83%. (b) Evaluate the chemical exergy using Eq. 13.44b and standard chemical exergies from Table A-26 (Model II).



//solution

//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
gbarO2 = 0
gbarCO2 = -394380
gbarH2O = -228590

```

```
yO2 = .2035
yCO2 = .0003
yH2O = .0312

M = 114.22 //molecular weight of liquid octane

ech = ((gbarC8H18 + 12.5*gbarO2 -8*gbarCO2 -9*gbarH2O) + Rbar*Tnot*log(yO2^12.5/(yCO2^8*yH2O^9)))/M
printf('part(a) the chemical exergy obtained on a unit mass basis is: %f',ech)

//part(b)
//With data from Table A–25 and Model II of Table A–26
gbarH2O = -237180
ebarCO2 = 19870
ebarH2O = 900
ebarO2 = 3970

ech = ((gbarC8H18 + 12.5*gbarO2 -8*gbarCO2 - 9*gbarH2O) + 8*ebarCO2 + 9*ebarH2O - 12.5*ebarO2)/M
printf('\n\npart(b) chemical exergy on a unit mass basis is: %f',ech)
```

Scilab code Exa 13.13 Example 13

```
//(13.13) Steam at 5 bar, 240C leaks from a line in a vapor power plant. Evaluate the flow exergy of the steam, in kJ/kg, relative to an environment at 25C, 1 atm in which the mole fraction of water vapor is yeH2O = 0.0303

```

```

//solution
Rbar = 8.314 //universal gas constant in SI units
Tnot = 298 //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 = .3674 //in kj/kg
//With data from Table A-25
gbarH2Oliq = -237180
gbarH2Ogas = -228590
yeH2O = .0303
M =18 //molar mass of steam

ech = (1/M)*(gbarH2Oliq-gbarH2Ogas + Rbar*Tnot*log(1/yeH2O)) //in kj/kg

ef = h-hnot-Tnot*(s-snot) + ech //in kj/kg
printf(' the flow exergy of the steam, in kJ/k is: %f',ef)
```

Scilab code Exa 13.14 Example 14

```
//(13.14)  Methane gas enters a reactor and burns completely with 140% theoretical air. Combustion products exit as a mixture at temperature T and a pressure of 1 atm. For T = 480 and 1560 K, evaluate the flow exergy of the combustion products, in kJ per kmol of fuel. Perform calculations relative to an environment consisting of an ideal gas mixture at 25C, 1 atm with the molar analysis, yeN2 = 0.7567, yeO2 = 0.2035, yeH2O = 0.0303, yeCO2 = 0.0003.



//solution

//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/(1+2+10.53+.8)
yH2Op = 2/(1+2+10.53+.8)
yN2p = 10.53/(1+2+10.53+.8)
yO2p = .8/(1+2+10.53+.8)

Rbar = 8.314                              //universal gas constant in SI units
Tnot = 298.15                             //in kelvin
```

```

yeN2 = .7567
yeO2 = .2035
yeH2O = .0303
yeCO2 = .0003

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

   //kJ per kmol of fuel
contri1560 = 390853

   //kJ per kmol of fuel

efbar480 = contri480 + ebarch

   //kJ per kmol of fuel
efbar1560 = contri1560 + ebarch

   //kJ per kmol of fuel

printf('at T= 480k, the flow exergy of the combustion products, in kJ per kmol of fuel is: %f',efbar480)
printf('\nat T = 1560K, the flow exergy of the combustion products, in kJ per kmol of fuel is: %f',efbar1560)
```

Scilab code Exa 13.15 Example 15

```
//(13.15)  Devise and evaluate an exergetic
   efficiency for the internal combustion engine of
   Example 13.4. For the fuel, use the chemical
   exergy value determined in Example 13.12(a).


//solution

mFdot = 1.8e-3
   //fuel mass flow rate in kg/s
ech = 47346
   //in kj/kg, from example 13.12(a)
Wcvdot = 37
   //power developed by the engine in kw

Efdot = mFdot*ech
   //rate at which exergy enters with the fuel in kw

epsilon = Wcvdot/Efdot
   //exergetic efficiency
printf('the exergetic efficiency is:  %f',epsilon)
```

Scilab code Exa 13.16 Example 16

```
//(13.16)   For the reactor of Example 13.9,
   determine the exergy destruction, in kJ per kmol
   of fuel, and devise and evaluate an exergetic
   efficiency. Consider (a) complete combustion with
    the theoretical amount of air (b) complete
   combustion with 400% theoretical air. For the
```

```
fuel, use the chemical exergy value determined in Example 13.12(a).


//solution

Tnot = 298                                                  //in kelvin

//For the case of complete combustion with the theoretical amount of air
sigmadot = 5404                                             //rate of entropy production from example 13.9, in kj/kmol.K
Eddot = Tnot*sigmadot                                       //in kj/kmol
Efdot = 5407843                                             //rate at which exergy enters with the fuel from example 13.12, in kj/kmol
epsilon = 1-Eddot/Efdot
printf('the exergetic efficiency with theoretical amount of air is: %f',epsilon)

//for the case of combustion with 400% theoretical air
sigmadot = 9754                                             //rate of entropy production from example 13.9, in kj/kmol.K
Eddot = Tnot*sigmadot                                       ////in kj/kmol
epsilon = 1-Eddot/Efdot
printf('\nthe exergetic efficiency with 400 percent
```

```
   theoretical amount of air is: %f',epsilon)
```

Chapter 14

Chemical and phase equilibrium

Scilab code Exa 14.1 Example 1

```
//(14.1)  Evaluate the equilibrium constant,
   expressed as log10K, for the reaction at (a) 298
   K and (b) 2000 K. Compare with the value obtained
    from Table A-27.


//solution

//The reaction is CO + .5O2  ---->   CO2

//part(a)
T = 298

   //in kelvin
Rbar = 8.314

   //universal gas constant in SI units
//from table A-25

```

```
hfbarCO2 = -393520
   //in kj/kmol
hfbarCO = -110530
   //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

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 = 45.066
printf('part(a) the value of equilibrium constant
   expressed as log10K is: %f',logK)
printf('\nthe value of equilibrium constant
```

```
   expressed as log10K from table A-27 is:  %f',
   logKtable)

//part(b)
T = 2000

   //in kelvin
//from table A-23
hfbarCO2 = -393520

   //in kj/kmol
hfbarCO = -110530

   //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

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
printf('\n\npart(b) the value of equilibrium
   constant expressed as log10K is:  %f',logK)
printf('\nthe value of equilibrium constant
   expressed as log10K from table A-27 is:  %f',
   logKtable)
```

Scilab code Exa 14.2 Example 2

```
//(14.2)  One kilomole of carbon monoxide, CO,
   reacts with .5kmol of oxygen, O2, to form an
   equilibrium mixture of CO2, CO, and O2 at 2500 K
   and (a) 1 atm, (b) 10 atm. Determine the
   equilibrium composition in terms of mole
   fractions


//solution

//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
K = 10^log10K

   //equilibrium constant
//part(a)
p = 1
```

```
//in atm
//solving equation K = (z/(1-z))*(2/(2 + z))^.5 *(p/1)^.5 gives
z = .129
yCO = 2*z/(2 + z)
yO2 = z/(2 + z)
yCO2 = 2*(1 - z)/(2 + z)
printf('part(a) mole fraction of CO is:  %f',yCO)
printf('\nmole fraction of O2 is:  %f',yO2)
printf('\nmole fraction of CO2 is:  %f',yCO2)

//part(b)
p = 10
//in atm
//solving equation K = (z/(1-z))*(2/(2 + z))^.5 *(p/1)^.5 gives
z = .062
yCO = 2*z/(2 + z)
yO2 = z/(2 + z)
yCO2 = 2*(1 - z)/(2 + z)
printf('\n\npart(b) mole fraction of CO is:  %f',yCO)
printf('\nmole fraction of O2 is:  %f',yO2)
printf('\nmole fraction of CO2 is:  %f',yCO2)
```

Scilab code Exa 14.3 Example 3

```
//(14.3)  Measurements show that at a temperature T and a pressure of 1 atm, the equilibrium mixture for the system of Example 14.2 has the composition yCO = 0.298,yO2 = .149, yCO2 = .553. Determine the temperature T of the mixture, in K.


```

```
//solution
yCO = .298
//solving yCO = 2z/(2 + z)
z = 2*yCO/(2 - yCO)

p = 1           //in atm
pref = 1        //in atm

K = (z/(1-z))*(z/(2 + z))^.5*(p/pref)^.5

//with this value of K, table A-27 gives
T = 2881
printf('the temperature T of the mixture in kelvin is: %f',T)
```

Scilab code Exa 14.4 Example 4

```
//(14.4) One kilomole of carbon monoxide reacts with the theoretical amount of air to form an equilibrium mixture of CO2, CO, O2, and N2 at 2500 K and 1 atm. Determine the equilibrium composition in terms of mole fractions, and compare with the result of Example 14.2.



//solution

//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 = .0363 //equilibrium constant the solution to Example 14.2
p =1 //in atm
pref = 1 //in atm

//solving K = (z*z^.5/(1-z))*((p/pref)*2/(5.76+z))^.5 gives
z = .175
yCO = 2*z/(5.76 + z)
yO2 = z/(5.76 + z)
yCO2 = 2*(1-z)/(5.76 + z)
yN2 = 3.76/(5.76 + z)
printf('the mole fraction of CO is: %f',yCO)
printf('\nthe mole fraction of O2 is: %f',yO2)
printf('\nthe mole fraction of CO2 is: %f',yCO2)
printf('\nthe mole fraction of N2 is: %f',yN2)
```

Scilab code Exa 14.5 Example 5

```
//(14.5) Carbon dioxide at 25C, 1 atm enters a reactor operating at steady state and dissociates, giving an equilibrium mixture of CO2, CO, and O2 that exits at 3200 K, 1 atm. Determine the
```

```
    heat transfer to the reactor, in kJ per kmol of
    CO2 entering. The effectsof kinetic and potential
     energy can be ignored and Wcvdot = 0



//solution

//Applying the conservation of mass principle, the
    overall dissociation reaction is described by
//CO2 ---->  zCO2 + (1-z)CO + ((1-z)/2)O2

p = 1

    //in atm
pref = 1

    //in atm
//At 3200 K, Table A-27 gives
log10k = -.189
k = 10^log10k
//solving k = ((1-z)/2)*((1-z)/(3-z))^.5 gives
z = .422

//from tables A-25  and A-23
hfbarCO2 = -393520

    //in kj/kmol
deltahbarCO2 = 174695-9364

    //in kj/kmol
hfbarCO = -110530

    //in kj/kmol
deltahbarCO = 109667-8669

    //in kj/kmol
hfbarO2 = 0
```

```
    //in kj/kmol
deltahbarO2 = 114809-8682
    //in kj/kmol
hfbarCO2r =  -393520
    //in kj/kmol
deltahbarCO2r = 0
    //in kj/kmol

Qcvdot = .422*(hfbarCO2 + deltahbarCO2) + .578*(
    hfbarCO + deltahbarCO) + .289*(hfbarO2 +
    deltahbarO2)- (hfbarCO2r + deltahbarCO2r)
printf('the heat transfer to the reactor, in kJ per
    kmol of CO2 entering is:  %f',Qcvdot)
```

Scilab code Exa 14.6 Example 6

```
//(14.6)  Carbon monoxide at 25C, 1 atm enters a
    well-insulated reactor and reacts with the
    theoretical amount of air entering at the same
    temperature and pressure. An equilibrium mixture
    of CO2, CO, O2, and N2 exits the reactor at a
    pressure of 1 atm. For steady-state operation and
     negligible effects of kinetic and potential
    energy, determine the composition and temperature
     of the exiting mixture in K.


//solution

//The overall reaction is
//CO + .5O2 + 1.88N2  ------->  zCO + (z/2)O2 + (1-
```

```
z)CO2 + 1.88N2
p =1  //in atm
pref = 1  //in atm

//solving equations K = (z/(1-z))*(z/(5.76+z))^.5 and  z*deltahbarCO + (z/2)*deltahbarO2 + (1-z)*deltahbarCO2 + 1.88deltahbarN2 + (1-z)*[hfbarCO2-hfbarCO]= 0
z = .125
T = 2399  //in kelvin
printf('the temperature of the exiting mixture in kelvin is: %f',T)
printf('\ncomposition of the equilibrium mixture, in kmol per kmol of CO entering the reactor, is then 0.125CO, 0.0625O2, 0.875CO2, 1.88N2.')
```

Scilab code Exa 14.7 Example 7

```
printf('IT software problem')
```

Scilab code Exa 14.8 Example 8

```
//(14.8)  Consider an equilibrium mixture at 2000K consisting of Cs, Cs+, and e-, where Cs denotes neutral cesium atoms, Cs+ singly ionized cesium
```

```
ions, and e- free electrons. The ionization-equilibrium constant at this temperature for
//     Cs <--> Cs+ + e-
//is K = 15.63. Determine the pressure, in atmospheres, if the ionization of Cs is 95% complete, and plot percent completion of ionization versus pressure ranging from 0 to 10 atm.



//solution
//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 = .95
pref =1                                        //in atm
p = pref*K*((1-z^2)/z^2)
printf('the pressure in atm if the ionization of CS is 95 percent complete is:  %f',p)

x = linspace(0,10,100)
for i = 1:100
    y(1,i) = 100*sqrt(1/(1+x(1,i)/K))
end
plot(x,y)
xtitle("","p(atm)","z(%)")
```

Scilab code Exa 14.9 Example 9

```
//(14.9)  As a result of heating, a system
```

```
consisting initially of 1 kmol of CO2,.5 kmol of O2, and  5 kmol of N2 forms an equilibrium mixture of CO2, CO, O2, N2, and NO at 3000 K, 1 atm. Determine the composition of the equilibrium mixture.



//solution

//The overall reaction can be written as
//CO2 + .5O2 + .5N2  ---->  aCO + bNO + (1-a)CO2 + .5(1+a-b)O2 + .5(1-b)N2

//At 3000 K, Table A-27 provides
log10K1 = -.485          //equilibrium constant of the reaction CO2 <--> CO + .5O2
log10K2 = -.913          //equilibrium constant of the reaction .5O2 + .5N2 <-->NO

K1 = 10^log10K1
K2 = 10^log10K2

//solving equations K1 = (a/(1-a))*((1+a-b)/(4+a))^.5  and  K2 = 2b/((1+a-b)*(1-b))^.5
a = .3745
b = .0675
printf('The composition of the equilibrium mixture, in kmol per kmol of CO2 present initially, is then 0.3745CO, 0.0675NO, 0.6255CO2, 0.6535O2, 0.4663N2.')
```

Scilab code Exa 14.10 Example 10

```
//(14.10)  A closed system at a temperature of 20C and a pressure of 1 bar consists of a pure liquid water phase in equilibrium with a vapor phase composed of water vapor and dry air. Determine the departure, in percent, of the partial pressure of the water vapor from the saturation pressure of water at 20C.



//solution
//With data from Table A-2 at 20C,
vf = 1.0018e-3                                    //in m^3/kg
psat = .0239                                      //in bar
p = 1                                             //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

```

```
pvbypsat = %e^(vf*(p-psat)*10^5/[(1000*Rbar/M)*T])

percent = (pvbypsat-1)*100
printf('the departure, in percent, of the partial pressure of the water vapor from the saturation pressure of water at 20 is:  %f',percent)
```