

Scilab Textbook Companion for
Fundamental Of Engineering Thermodynamics
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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.

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Chapter 2

Energy and the first law of thermodynamics

Scilab code Exa 2.1 Example 1

```
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  $p \cdot (v^n) = \text{constant}$ . 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)  $n
   =0$ .
2
3 // solution
4
5 // variable initialization
6 p1 = 3*(10^5) // initial pressure of gas in pascal
7 v1 = .1 // initial volume of gas in meter^3
8 v2 = .2 // final volume of gas in meter^3
9
10 // part (a) i.e.  $n=1.5$ 
11 funcprot(0);
12 function [constant] = f1(n)
```

```

13     constant = p1*(v1^n);                                //p*(
        v^n) = constant
14 endfunction;
15
16 function [p] = f2(v,n)
17     p = f1(n)/(v^n);                                     //
        expressing pressure as function of volume
18 endfunction;
19
20 function [work1] = f3(n)
21     work1 = intg(v1,v2,f2);                               //
        integrating pdv from initial to final volume
22 endfunction;
23
24 w1 = f3(1.5)/1000;                                       //
        divided by 1000 to convert to KJ
25 disp(w1,"the work done for n=1.5 in KJ is");
26
27 //part(b) i.e. n = 1
28
29 w2 = f3(1)/1000;
30 disp(w2,"the work done for n=1 in KJ is");
31
32 //part(c) i.e. n=0
33
34 w3 = f3(0)/1000;
35 disp(w3,"the work done for n=0 in KJ is");

```

Scilab code Exa 2.2 Example 2

```

1 // (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 $u_2 - u_1 = -4.6$ kJ/kg. There are no significant changes in kinetic or potential energy. Determine the net heat transfer for the process, in kJ.

```

2
3 // solution
4
5 //variable initialization
6 p1 = 3*(10^5) // initial pressure in pascal
7 v1 = .1      // initial volume in m3
8 v2 = .2      // initial volume in m3
9 m = 4        //mass of the gas in kg
10 deltaU = -4.6 // change in specific internal energy
    in KJ/Kg
11
12
13 funcprot(0);
14 function [constant] = f1(n)
15     constant = p1*(v1^n); //p*(
        v^n) = constant
16 endfunction;
17
18 function [p] = f2(v,n)
19     p = f1(n)/(v^n); //
        expressing pressure as function of volume
20 endfunction;
21
22 function [work] = f3(n)
23     work = intg(v1,v2,f2); //
        integrating pdv from initial to final volume
24 endfunction;
25
26 w = f3(1.5)/1000; //
        divided by 1000 to convert to KJ
27
28 deltaU = m*deltaU; //

```

```

    change in internal energy in KJ
29 Q = deltaU + w; //
    neglecting kinetic and potential energy changes
30
31 disp(Q,"net heat transfer for the process in KJ")

```

Scilab code Exa 2.3 Example 3

```

1 // (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 can be ignored, and the
    local acceleration of gravity is  $g = 9.81 \text{ m/s}^2$ .
    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.
2
3 // solution
4
5 // variable initialization
6 patm = 10^5 // atmospheric pressure in
    pascal.
7 mp = 45 // mass of piston in Kg
8 A = .09 // face area of piston in m2
9 deltaV = .045 // increment of the volume of

```

```

    air in m3
10 m = .27 // mass of air in kg
11 deltau = 42 // specific internal energy
    increase of air in kJ/kg
12 g = 9.81 // local acceleration of
    gravity
13
14
15 //part (a) i.e. air is system
16
17 p = (mp*g)/A + patm ; //constant pressure
    of air obtained from equilibrium of piston
18 w = (p*deltaV)/1000; //work done in KJ
19 deltaU = m*deltau; // internal energy
    change of air in KJ
20 Q = w + deltaU; // applying first
    with air as system
21
22 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);
23
24 // the answer given in book is incorrect. deltaU is
    incorrect in book.
25
26 //part(b) i.e. (air+piston) is system
27
28 wd = (patm*deltaV)/1000; // work done
    in KJ
29 deltaz = (deltaV)/A; // change in
    elevation of piston
30 deltaPE = (mp*g*deltaz)/1000; //
    change in potential energy of piston in KJ
31 Qt = wd + deltaPE + deltaU; // applying
    first law with air plus piston as system
32
33 printf('\n\nthe answer given in book is incorrect.

```

They have miscalculated ΔU . The correct heat transfer from resistor to air in KJ for air + piston as system is: $\int_{t_i}^{t_f} \dot{Q} dt$;

Scilab code Exa 2.4 Example 4

```
1 // (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  $\dot{Q} = -hA(T_b - T_f)$  where
   $h = 0.171 \text{ kW/m}^2\cdot\text{K}$  is the heat transfer
  coefficient,  $A = 1.0 \text{ m}^2$  is the outer surface
  area of the gearbox,  $T_b = 300 \text{ K}$  is the temperature
  at the outer surface, and  $T_f = 293 \text{ K}$  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.
2
3 // solution
4
5 // initializing variables
6 wldot = -60 // input work rate in KW
7 h = .171 // heat transfer
  coefficient, unit in KW/m2 .K
8 A = 1 // outer surface area of
  gearbox, unit in m2
9 Tb = 300 // outer surface
  temperature in kelvin
10 Tf = 293 // temperature of the
  surrounding
11
12 Qdot = -h*A*(Tb-Tf); // rate of energy
```

```

    transfer by heat
13 wdot = Qdot;           // steady state energy
    equation
14 w2dot = wdot-w1dot;
15
16 printf('the heat transfer rate in KW is:\n\tQdot =
    %f', Qdot);
17 printf('\n\nthe power delivered through output shaft
    in KW is:\n\tw2dot = %f', w2dot);

```

Scilab code Exa 2.5 Example 5

```

1 // (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.
2
3 // solution
4
5 // variable initialization
6
7 s=5*(10-3);           // measurement on a
    side in meter
8 wdot = -.225           // power input in
    watt
9 Tf = 293               // coolant
    temprature in kelvin
10 h = 150               // heat transfer

```



```

        coefficient in w/m2 k
11
12 A = s^2; //surface area
13 Tb = ((-wdot/(h*A)) + Tf - 273) ; //surface
        temperature in degree
14
15 printf('the surface temperature of the chip in
        degree celcius is:\n\t Tb = %f',Tb);

```

Scilab code Exa 2.6 Example 6

```

1 // (2.6) The rate of heat transfer between a certain
    electric motor and its surroundings varies with
    time as  $Q_{dot} = -0.2[1 - e^{-0.05t}]$  where  $t$  is in
    seconds and  $Q_{dot}$  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  $Q_{dot}$  and  $W_{dot}$ , each in kW, and the
    change in energy  $\Delta E$  in kJ, as functions of
    time from  $t = 0$  to  $t = 120$  s.
2
3 //solution
4
5 //initializing variables
6  $\omega = 100$ ; // motor rotation
    speed in rad/s
7  $\tau = 18$ ; //torque applied
    by shaft in N.m
8  $W_{elec_{dot}} = -2$ ; // electric power

```

```

    input in KW
9
10 funcprot(0);
11 Wshaftdot = (tau*omega)/1000;           //shaft work rate
    in KW
12 Wdot = Welecdot + Wshaftdot;           //net work rate in
    KW
13
14 function [Qdot]=f(t)
15     Qdot = (-.2)* [1-%e^(-.05*t)];
16 endfunction
17
18 function [Edot]=f1(t)                   //function for
    rate of change of energy
19     Edot =(-.2)* [1-%e^(-.05*t)] - Wdot ;
20 endfunction;
21
22 function [deltaE] =f2(t)                //function for
    change in energy
23     deltaE = intg(0,t,f1);
24 endfunction;
25
26 t = linspace(0,120,100);
27 for i = 1:100
28     Qdt(1,i)= f((120/99)*(i-1));
29     Wdt(1,i)= Wdot;
30     dltaE(1,i)= f2((120/99)*(i-1));
31 end
32 plot2d(t,Qdt,rect=[0,-.25,120,0]);
33 plot2d(t,Wdt,style=5,rect=[0,-.25,120,0]);
34 xtitle("", "time , s" , "Qdot , Wdot ,KW");
35 legend("Qdot" , "Wdot");
36 xset('window',1);
37 plot2d(t,deltaE);
38 xtitle("deltaE versus time" , "Time, s" , "deltaE , KJ");

```

Chapter 3

Evaluating properties

Scilab code Exa 3.1 Example 1

```
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  $p_1 = 1$ 
  bar with a quality of 0.5. After heating, the
  pressure in the container is  $p_2 = 1.5$  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.
2
3 // solution
4
5 //initializing variables
6 p1 = 10^5 // initial pressure in
  pascal
7 x1 = .5 // initial quality
8 p2 = 1.5*10^5 // pressure after
  heating in pascal
```

```

9  v = .5 // volume of container
    in m3
10
11  vf1 = 1.0432*10^(-3) // specific volume of
    fluid in state 1 in m3/Kg(from table A-3)
12  vg1 = 1.694 // specific volume of
    gas in state 1 in m3/kg(from table A-3)
13
14  v1 = vf1 + x1*(vg1-vf1) // specific volume in
    state 1 in m3/Kg
15  v2 = v1 // specific volume in
    state 2 in m3/Kg
16  vf2 = 1.0582*10^(-3) // specific volume of
    fluid in state 2 in m3/Kg(from table A-3)
17  vg2 = 1.159 // specific volume of
    gas in state 2 in m3/Kg(from table A-3)
18
19  // part (a)
20  T1 = 99.63 // temperature in
    degree celcius in state 1, from table A-3
21  T2 = 111.4 // temperature in
    degree celcius in state 2, from table A-3
22  printf('the temperature in degree celcius in state 1
    is:\n\t T1 = %f',T1);
23  printf('\nthe temperature in degree celcius in state
    2 is:\n\t T2 = %f',T2);
24
25  // part (b)
26  m = v/v1 // total mass in Kg
27  mg1 = x1*m // mass of vapour in
    state 1 in Kg
28  printf('\nthe mass of vapor in state 1 in Kg is:\n\t
    mg1 = %f',mg1 );
29  x2 = (v1-vf2)/(vg2-vf2) // quality in state 2
30  mg2 = x2*m // mass of vapor in
    state 2 in Kg
31  printf('\nthe mass of vapor in state 2 in Kg is:\n\t
    mg2 = %f',mg2 );

```

```

32
33 //part(c)
34 p3 = 2.11 // pressure in state 3
    from table A-3
35 printf('\nthe pressure corresponding to state 3 in
    bar is:\n\t p3 = %f',p3 );

```

Scilab code Exa 3.2 Example 2

```

1 // (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.
2
3 // solution
4
5 // variable initialization
6
7 m = .05 // mass of ammonia in
    kg
8 p1 = 1.5*105 // initial
    pressure of ammonia in pascal
9 T2 = 25 // final temperature
    in degree celcius
10
11 //part (a)
12 v1 = .7787 // specific volume in

```

```

state 1 in m3/kg from table A-14
13 V1 = m*v1 // volume occupied by
    ammonia in state 1 in m3
14 v2 = .9553 // specific volume in
    state 2 in m3/kg from table A-15
15 V2 = m*v2 // volume occupied by
    ammonia in state 2 in m3
16
17 printf('the volume occupied by ammonia in state 1 in
    m3 is:\n\t V1 = %f',V1);
18 printf('\nthe volume occupied by ammonia in state 2
    in m3 is:\n\t V2 = %f',V2);
19
20 // part (b)
21 w = (p1*(V2-V1))/1000 // work in KJ
22 printf('\nthe work done for the process in KJ is:\n\t
    W = %f',w)

```

Scilab code Exa 3.3 Example 3

```

1 // (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.
2
3 //solution
4
5 //variable initialization
6 V = .25 // volume of tank in
    m3
7 T1 = 100 // initial temperature
    in degree celcius
8 p2 = 1.5 // final pressure in

```

```

        bars
9
10 v = 1.673 // specific volume in
    m3/kg obtained using table A-2
11 u1 = 2506.5 // specific internal
    energy in state 1 in KJ/Kg obtained from table A
    -2
12 T2 = 273 // temperature in state
    2 in degree celcius obtained from table A-4
13 u2 = 2767.8 // specific internal
    energy in state 2 in KJ/Kg obtained from table A
    -4
14 m = V/v // mass of the system
    in kg
15 DeltaU = m*(u2-u1) // change in internal
    energy in KJ
16 W = - DeltaU // from energy balance
17 printf('the temperature at the final state in degree
    celcius is:\n T2 = %f',T2);
18 printf('\nthe work during the process in KJ is:\n\tW
    = %f',W);

```

Scilab code Exa 3.4 Example 4

```

1 // (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.

```

```

2
3 //solution
4
5 //variable initialization
6 P1 = 10*(10^5) //
   initial pressure in pascal
7 T1 = 400 // initial
   temperature in degree celcius
8
9 v1 = .3066 // specific
   volume in state 1 in m3/kg obtained from table A
   -4
10 u1 = 2957.3 // specific
   internal energy in state 1 in KJ/Kg obtained from
   table A-4
11 v2 = .1944 // specific
   volume in state 2 in m3/kg obtained from table A
   -3
12 w1to2 = (P1*(v2-v1))/1000 // work in KJ/Kg
   in process 1-2
13 w2to3 = 0 // work in
   process 2-3
14 W = w1to2 + w2to3 // net work
   in KJ/kg
15
16 v3 = v2
17 vf3 = 1.0905*10^(-3) // specific
   volume of fluid in state 3 from table A-2
18 vg3 = .3928 // specific
   volume of gas in state 3 from table A-2
19 x3 = (v3-vf3)/(vg3-vf3)
20 uf3 = 631.68 // specific
   internal energy for fluid in state 3 from table A
   -2
21 ug3 = 2559.5 // specific
   internal energy for gas in state 3 from table A-2
22 u3 = uf3+x3*(ug3-uf3) // specific
   internal energy in state 3 in Kj/Kg

```



```

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

```

Scilab code Exa 3.5 Example 5

```

1 //(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 .
2
3 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

```

1 //(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.
2
3 //solution
4
5 //variable initialization

```

```

6 p1 = 20 //initial pressure in
  MPa
7 T1 = 520 // initial
  temperature in degree celcius
8 T2 = 400 // final temperature
  in degree celcius
9
10 //part(a)
11 //from table A-1
12 Tc = 647.3 //critical
  temperature in kelvin
13 pc = 22.09 //critical pressure
  in MPa
14
15 Tr = (T1+273)/Tc //reduced temperature
16 Pr = p1/pc //reduced pressure
17 Z1 = .83 //compressibility
  factor
18 R = 8.314 //universal gas
  constant in SI unit
19 n = 1000/18.02 //number of moles in
  a kg of water
20 v1 = (Z1*n*R*(T1+273))/(p1*10^6)
21 printf('the specific volume in state1 in m3/Kg is:\n
  \t v1 = %f',v1)
22 printf('\n and the corresponding value obtained from
  table A-4 is .01551 m^3/Kg')
23
24 //part(b)
25 vr = v1*(pc*10^6)/(n*R*Tc)
26 Tr2 = (T2+273)/Tc
27 //at above vr and Tr2
28 PR = .69
29 P2 = pc*PR
30 printf('\n\n the pressure in MPa in the final state
  is: \n\t P2 = %f',P2)
31 printf('\n and the corresponding value from the
  table is 15.16Mpa')

```

Scilab code Exa 3.7 Example 7

```
1 // (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.
2
3 //solution
4
5 //variable initialization
6 T1 = 300 //
  temperature in state 1 in kelvin
7 P1 = 1 //pressure
  in state 1 in bar
8 P2 = 2 //pressure
  in state 2 in bar
9
10 R = 287 //gas
  constant of air in SI units
11 v1 = (R*T1)/(P1*10^5) //
  specific volume in state 1
12 P = linspace(1,2,100)
13 for i = 1:100
14     v(1,i) = v1
15 end
```

```

16
17 plot2d(v,P,rect=[0,0,5,2.5]);
18
19 T2 = (P2*10^5*v1)/R
20 v3 = (R*T2)/(P1*10^5)
21 vv = linspace(v1,v3,100)
22 plot(vv,P1)
23
24 function[out]= f(inp)
25     out = (R*T2)/inp
26 endfunction
27
28 VV = linspace(v1,v3,100)
29 for j = 1:100
30     pp(1,j) = f(VV(1,j))/(10^5)
31 end
32 plot2d(VV,pp)
33 xtitle("","v","p(bar)")
34
35 printf('the temperature in kelvin in state 2 is:\n\t
        T2 = %f',T2)
36 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

```

1 // (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.

```

2

```

3 //solution
4
5 //variable initialization
6 m = .9 // mass of air
   in kg
7 T1 = 300 // initial
   temperature in kelvin
8 P1 = 1 // initial
   pressure in bar
9 T2 = 470 // final
   temperature in kelvin
10 P2 = 6 // final
   pressure in bar
11 Q = -20 // heat transfer
   in kj
12
13 //from table A-22
14 u1 = 214.07 // in KJ/kg
15 u2 = 337.32 // in KJ/Kg
16 deltaU = m*(u2-u1) // change in
   internal energy in kj
17 W = Q - deltaU // in KJ/kg
18 printf('the work during the process in KJ is \n\t W
   = %f',W)

```

Scilab code Exa 3.9 Example 9

```

1 // (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.
2
3 //solution
4
5 //variable initialization
6
7 m1 = 2                                //initial mass of
    gas in tank 1 in kg
8 T1 = 350                              //initial
    temperature in kelvin in tank1
9 p1 = .7                                //initial pressure
    in bar in tank 1
10 m2 = 8                                //initial mass of
    gas in tank 2 in kg
11 T2 = 300                              //initial
    temperature in kelvin in tank 2
12 p2 = 1.2                              //initial pressure
    in bar in tank 2
13 Tf = 315                              //final equilibrium
    temperature in kelvin
14
15 pf = ((m1+m2)*Tf)/((m1*T1/p1)+(m2*T2/p2))
16
17 printf('the final equilibrium pressure in bar is: \n
    \t pf = %f',pf)
18
19 //from table A-20
20 Cv = .745                             //in KJ/Kg.k
21 Ui = (m1*Cv*T1)+(m2*Cv*T2)
22 Uf = (m1+m2)*Cv*Tf
23 deltaU = Uf-Ui
24 Q = deltaU
25 printf('\n\nthe heat transfer for the process in KJ
    is :\n\t Q = %f',Q)

```

Scilab code Exa 3.10 Example 10

```
1 //(3.10) One kmol of carbon dioxide gas (CO2) in a
  p i s t o n 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
  .
2
3 printf('This is solved by the referred software ')
```

Scilab code Exa 3.11 Example 11

```
1 //(3.11) Air undergoes a polytropic compression in
  a p i s t o n 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.
2
3 //solution
4
5 //variable initialization
6 p1 = 1 //initial
  pressure in bar
7 T1 = 295 //initial
  temperature in kelvin
8 p2 = 5 //final
  pressure in bar
```

```

9  n=1.3                                //polytropic
    constant
10 R = 8314/28.97                        // gas
    constant for air in SI units
11
12 T2 = T1*(p2/p1)^((n-1)/n)
13 w = R*(T2-T1)/(1-n)
14 printf('the work done per unit mass in KJ/Kg is :\n\
    tW = %f',w/1000)
15
16 //from table A-22
17 u2 = 306.53
18 u1 = 210.49
19 Q = u2-u1+w/1000
20
21 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

```
1 //(4.1) A feedwater heater operating at steady
   state has two inlets and one exit. At inlet 1,
   water vapor enters at  $p_1 = 7$  bar,  $T_1 = 200^\circ\text{C}$  with
   a mass flow rate of 40 kg/s. At inlet 2, liquid
   water at  $p_2 = 7$  bar,  $T_2 = 40^\circ\text{C}$  enters through an
   area  $A_2 = 25$  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.
2
3 //solution
4
5 //variable initialization
6 P1 = 7 //pressure
   at inlet 1 in bar
7 T1 = 200 //
   temperature at inlet 1 in degree celcius
8 m1dot = 40 //mass flow
```

```

    rate in Kg/s at inlet 1
9  P2 = 7 //pressure
    in bar at inlet 2
10 T2 = 40 //
    temperature at inlet 2 in degree celcius
11 A2 = 25 //area of
    inlet 2 in cm^2
12 P3 = 7 //exit
    pressure in bar
13 AV3 = .06 //
    volumetric flow rate through exit in m^3/s
14
15 //from table A-3
16 v3 = 1.108*10^(-3) //specific
    volume at the exit in m^3/Kg
17 m3dot = AV3/v3 //mass flow
    rate at the exit
18 m2dot = m3dot-m1dot //mass flow
    rate at inlet 2
19 //from table A-2
20 v2 = 1.0078*10^(-3) //specific
    volume in state 2 in m^3/kg
21 V2 =m2dot*v2/(A2*10^(-4))
22 printf('\n the mass flow rate at the inlet 2 in kg/s is
    \n\t m2dot = %f',m2dot)
23 printf('\n the mass flow rate at the exit in kg/s is
    \n\t m3dot =%f',m3dot)
24 printf('\n\nthe velocity at inlet 2 in m/s is \n\t
    V2 = %f',V2)

```

Scilab code Exa 4.2 Example 2

```

1 // (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: $\dot{m} = 1.4L$, 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.

```

2
3 //solution
4
5 //variable initialization
6 m_dot = 7 //inlet
    mass flow rate in kg/s
7 A = .2 //area of
    base in m^2
8 d = 1000 //density
    of water in kg/m^3
9
10 function Ldot = f(t,L)
11     Ldot = (m_dot/(d*A)) - ((1.4*L)/(d*A))
12 endfunction
13
14 t=0:.01:1000
15 L = ode(0,0,t,f)
16 plot2d(t,L)
17 xtitle("", "time", "height")

```

Scilab code Exa 4.3 Example 3

```

1 // (4.3) Steam enters a converging diverging
    nozzle operating at steady state with  $p_1 = 40$  bar
    ,  $T_1 = 400$ C, 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.
2
3 //solution
4
5 //variable initialization
6 p1 = 40 //entry
    pressure in bar
7 T1 = 400 //entry
    temperature in degree celcius
8 V1 = 10 //entry
    velocity in m/s
9 P2 = 15 //exit
    pressure in bar
10 V2 =665 //exit
    velocity in m/s
11 mdot = 2 //mass flow
    rate in kg/s
12
13 //from table A-4
14 h1 = 3213.6 //specific
    enthalpy in in kj/kg
15
16 h2 = h1+((V1^2-V2^2)/2)/1000
17
18 //from table A-4
19 v2 = .1627 //specific
    volume at the exit in m^3/kg
20 A2 = mdot*v2/V2
21 printf('the exit area of the nozzle in m^2 is \n\t
    A2 = %e',A2)

```

Scilab code Exa 4.4 Example 4

```

1  //(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.
2
3  //solution
4
5  //variable initialization
6  m1dot = 4600           //mass flow
      rate in Kg/h
7  Wcvdot = 1000        //turbine power
      output in kw
8  P1 = 60              //inlet
      pressure in bar
9  T1 = 400            //inlet
      temperature in degree celcius
10 V1 = 10             //inlet
      velocity in m/s
11 P2 = .1             //exit pressure
      in bar
12 x2 = .9            //the quality
      at the exit
13 V2 = 50            //exit velocity
      in m/s
14
15 //from table A-4
16 h1 = 3177.2        //specific
      enthalpy at the inlet in kj/kg
17 //from table A-3
18 hf2 = 191.83
19 hg2 = 2584.63
20
21 h2 = hf2+x2*(hg2-hf2) //specific

```

```

enthalpy at the exit in kj/kg
22 Qcvdot = Wcvdot + m1dot*((h2-h1)+(V2^2-V1^2)
    /(2*1000))/3600
23 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

```

1 //(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.
2
3 //solution
4
5 //variable initialization
6 P1 = 1 //entry
    pressure in bar
7 T1 = 290 //entry
    temperature in kelvin
8 V1 = 6 //entry
    velocity in m/s
9 A1 = .1 //inlet area in
    m^2
10 P2 = 7 //exit pressure
    in bar
11 T2 = 450 //exit
    temperature in kelvin

```

```

12 V2 = 2 //exit velocity
    in m/s
13 Qcvdot = -180 //heat transfer
    rate in KJ/min
14
15 R = 8.314 //univsersal
    gas constant in SI units
16 v1 = (R*1000*T1)/(28.97*P1*10^5) //specific
    volume
17 mdot = (A1*V1)/v1 //mass flow
    rate
18
19 //from table A-22
20 h1 = 290.16 //specific
    enthalpy in KJ/kg
21 h2 = 451.8 //specific
    enthalpy in Kj/Kg
22 Wcvdot = Qcvdot/60 + mdot*((h1-h2)+(v1^2-V2^2)
    /(2*1000));
23 printf('the power input to the compressor in kw is
    :\n\tWcvdot = %f',Wcvdot)

```

Scilab code Exa 4.6 Example 6

```

1 // (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  $g = 9.81 \text{ m/s}^2$ . Determine the
    power input to the motor, in kW.

```

```

2
3
4 //solution
5
6 //variable initialization
7 T1 = 20 //entry
   temperature in degree celcius
8 P1 = 1 //entry
   pressure in atm
9 AV1 = .1 //entry
   volumetric flow rate in litre/s
10 D1 = 2.5 //diameter of
   the hose in cm
11 T2 = 23 //exit
   temperature in degree celcius
12 P2 = 1 //exit
   pressure in atm
13 V2 =50 //exit
   velocity in m/s
14 Z2 = 5 //elevation in
   m
15 g = 9.81 //acceleration
   due to gravity in m/s^2
16
17 //from table A-2
18 v = 1.0018*10^(-3) //specific
   volume in m^3/kg
19
20 mdot = (AV1/1000)/v //mass flow
   rate in kg/s
21 V1 = (AV1/1000)/(%pi*(D1/(2*100))^2) //entry
   velocity in m/s
22 c = 4.18 //from table A
   -19
23 deltah = c*(T2-T1)+v*(P2-P1)
24 Wcvdot = (mdot/.9)*[-deltah+(V1^2-V2^2)/(2*1000)+g
   *(0-Z2)/1000]
25 printf('the power input to the motor in KW is :\n\t

```


= %f',Wcvdot)

Scilab code Exa 4.7 Example 7

```
1 // (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 steam. (b) the rate of
  energy transfer from the condensing steam to the
  cooling water, in kJ per kg of steam passing
  through the condenser.
2
3 //solution
4
5 //variable initialization
6 P1 = .1 //
  pressure of steam entering in bar
7 x1 = .95 //quality
  of steam entering
8 P2 = .1 //
  pressure of exiting condensate in bar
9 T2 = 45 //
  temperature of exiting condensate in degree
  celcius
10 T3 = 20 //
  temperature of cooling entry water in degree
  celcius
```

```

11 T4 = 35 //
    temperature of cooling exit water in degree
    celcius
12
13 //part (a)
14 //from table A-3
15 hf = 191.83 //in KJ/kg
16 hg = 2584.7 //in Kj/kg
17 h1 = hf + x1*(hg-hf) //in kj/kg
18
19 h2 = 188.45 //by
    assumption At states 2, 3, and 4, h is
    approximately equal to hf(T), in kj/kg
20 deltah4_3= 62.7 //by
    assumption 4,in kj/kg
21 ratio = (h1-h2)/(deltah4_3)
22 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/mldot = %f',
    ratio)
23
24 //part(b)
25 Qrate = (h2-h1)
26 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
    t Qrate = %f',Qrate)

```

Scilab code Exa 4.8 Example 8

```

1 // (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.

```

2
3 //solution
4
5 //variable initialization
6 T1 = 293 //temperature
   of entering air in kelvin
7 P1 = 1.01325*(10^5) //pressure
   of entering air in pascal
8 V1max = 1.3 //maximum
   velocity of entering air in m/s
9 T2max = 305 //maximum
   temperature at the exit in kelvin
10 Pec = -80 //power
   received by electronic components in watt
11 Pf = -18 //power
   received by fan in watt
12
13 R = 8.314 //universal
   gas constant in SI units
14 M = 28.97*(10^(-3)) //
   molar mass of air in kg
15 Qcvdot = 0 //Heat
   transfer from the outer surface of the
   electronics enclosure to the surroundings is
   negligible.
16 Cp = 1.005*(10^3) //in j/
   Kg.k
17
18 Wcvdot = Pec + Pf //total
   electric power provided to the electronic
   components and fan in watt

```

```

19 mdotmin = (-Wcvdot)/(Cp*(T2max-T1))    //minimum mass
    flow rate
20 v1 = ((R/M)*T1)/P1                    //specific
    volume
21 A1min = (mdotmin*v1)/V1max
22 D1min = sqrt(4*A1min/(%pi))
23 printf('the smallest fan inlet diameter in cm is:\n\
    t D1min = %f',D1min*100)

```

Scilab code Exa 4.9 Example 9

```

1 // (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.
2
3 //solution
4
5 //variable initialization
6 P1 = 20                                //pressure in
  supply line in bars
7 P2 = 1                                  //exhaust
  pressure in bar
8 T2 = 120                                //exhaust
  temperature in degree celcius
9
10 //from table A-3 at 20 bars
11 hf1 = 908.79                            //in kj/kg
12 hg1 = 2799.5                            //in kj/kg
13
14 //from table A-4, at 1 bar and 120 degree celcius

```

```

15 h2 = 2766.6 //in kj/kg
16 h1 = h2 //from throttling
    process assumption
17 x1 = (h1-hf1)/(hg1-hf1)
18 printf('the quality of the steam in the supply line
    is:\n\tx1 = %f',x1)

```

Scilab code Exa 4.10 Example 10

```

1 //(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.
2
3 //solution
4
5 //variable initialization
6 P1 = 1 //pressure of industrial
    discharge in bar

```

```

7 T1 = 478 //temperature of
  industrial discharge in kelvin
8 m1dot = 69.78 //mass flow rate of
  industrial discharge in kg/s
9 T2 = 400 //temperature of exit
  products from steam generator in kelvin
10 P2 = 1 //pressure of exit
  products from steam generator in bar
11 P3 = .275 //pressure of water
  stream entering the generator in Mpa
12 T3 = 38.9 //temperature of water
  stream entering the generator in degree celcius
13 m3dot = 2.079 //mass flow rate of
  water stream entering in kg/s
14 P5 = .07 //exit pressure of the
  turbine in bars
15 x5 = .93 //quality of turbine exit
16
17 //part (a)
18 m2dot = m1dot //since gas and water
  streams do not mix
19 m5dot = m3dot //--DO
20
21 //from table A-22,
22 h1 = 480.3 //in kj/kg
23 h2 = 400.98 //in Kj/kg
24
25 //from table A-2,
26 h3 = 162.9 //assumption: h3 = hf(T3),
  units in Kj/kg
27
28 //from table A-3
29 hf5 = 161 //in kj/kg
30 hg5 = 2571.72 //in kj/kg
31
32 h5 = hf5 + x5*(hg5-hf5)
33 Wcvdot = m1dot*h1 + m3dot*h3 - m2dot*h2 - m5dot*h5
34

```

```

35 printf('the power developed by the turbine in kj/s
      is: \n\t Wcvdot = %f',Wcvdot)
36
37 //part(b)
38 P4 = P3 //from the assumption that
      there is no pressure drop for water flowing
      through the steam generator
39 h4 = h3 + (m1dot/m3dot)*(h1 -h2) //from steady
      state energy rate balance
40 //interpolating in table A-4, with these P4 and h4
41 T4 = 180 //in degree celcius
42 printf('\n\t turbine inlet temperature in degree
      celcius is :\n\t T4 = %f',T4)

```

Scilab code Exa 4.11 Example 11

```

1 // (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.
2
3
4 //solution
5
6 //variable initialization
7 V = .85 //volume of
      tank in m^3
8 T1 = 260 //initial

```

```

    temperature of the tank in degree celcius
9  X1 = .7 //initial
    quality
10
11 //from table A-2
12 uf1 = 1128.4 //in kg/kg
13 ug1 = 2599 //in kg/kg
14
15 vf1 = 1.2755e-3 //in m^3/kg
16 vg1 = .04221 //in m^3/kg
17
18 u1 = uf1 + X1*(ug1-uf1) //in kj/kg
19 v1 = vf1 + X1*(vg1-vf1) //in m^3/kg
20
21 m1 = V/v1 //initial mass
    in kg
22
23 //for final state , from table A-2,
24 u2 = 2599 // units in KJ/
    kg
25 v2 = 42.21e-3 //units in m^3/
    Kg
26 he = 2796.6 //units in KJ/
    kg
27 m2 = V/v2 //final mass in
    kg
28 U2 = m2*u2 //final
    internal energy in KJ
29 U1 = m1*u1 //initial
    internal energy in KJ
30 Qcv = (U2-U1) - he*(m2-m1)
31 printf('the amount of heat transfer in KJ is : \n\t
    Qcv = %f',Qcv)

```

Scilab code Exa 4.12 Example 12


```

1 // (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.
2
3
4 // solution
5
6 //variable initialization
7 Pv = 15
  //pressure in the vessel in bar
8 Tv = 320
  //temperature in the vessel in degree celcius
9 Vt = .6
  //volume of a tank in m^3
10 Tt = 400
  //temperature in the tank in degree celcius when
  the tank is full
11
12 //since the tank is initially empty
13 m1 = 0
14 u1 = 0
15
16 //from table A-4, at 15bar and 400 degree celcius
17 v2 = .203 //
  in m^3/kg
18 m2 = Vt/v2 //
  mass within the tank at the end of the process in
  kg
19 //from table A-4,

```

```

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

```

Scilab code Exa 4.13 Example 13

```

1 //(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  $pv^{1.4} = \text{constant}$ . 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  $m/m_1$ ,
    where  $m_1$  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  $m/m_1$ .
    Let  $m/m_1$  vary from 1 to 3.
2
3
4
5 //solution
6 printf('its an IT software problem')

```

Scilab code Exa 4.14 Example 14

```
1 // (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.
2
3
4 //solution
5
6 //variable initialization
7
8 funcprot(0)
9 mcv = 45 //
  initial mass of water in kg
10 Ti = 318 //
  initial temperature of water in kelvin
11 mdot = 270/3600 //mass
  flow rate in kg/s
12 Qcvdot = -7.6*10^3 //rate
  of energy removal by coil in Watt
13 Wcvdot = -.6*10^3
  //power input from the paddle in Watt
14
15 c = 4.2*10^3 //
  specific heat for liquid water in J/Kg.k
16
17 function Tdot= f(t,T)
18     Tdot = (Qcvdot-Wcvdot+mdot*c*(Ti-T))/(mcv*c)
19 endfunction
```

```
20
21 t = 0:.1:3600
22 T = ode(Ti,0,t,f)
23 plot2d(t/3600,T)
24 xtitle("", "time(h)", "water temperature(kelvin)")
```

Chapter 5

The second law of thermodynamics

Scilab code Exa 5.1 Example 1

```
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.
2
3 //solution
4
5 //variable initialization
6 W = 410 //
  net work output in kj claimed
7 Q = 1000 //
  energy input by heat transfer in kj
8 Tc = 300 //
  temperature of cold reservoir in kelvin
9 TH = 500 //
```

```

    temperature of hot reservoir in kelvin
10
11 eta = W/Q                                //
    thermal efficiency
12 etamax = 1-Tc/TH
13
14
15 printf('eta = %f',eta)
16 printf('\n etamax = %f',etamax)
17 printf('\n since eta is more than etamax, the claim
    is not authentic')

```

Scilab code Exa 5.2 Example 2

```

1 // (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.
2
3
4 //solution
5
6 //variable initialization
7 funcprot(0)
8 Qcdot = 8000                                //in kj/
    h

```

```

9 Wcycledot = 3200 //in kj/
  h
10 Tc = 268 //
   temperature of compartment in kelvin
11 TH = 295 //
   temperature of the surrounding air in kelvin
12
13 beta = Qcdot/Wcycledot //
   coefficient of performance
14 betamax = Tc/(TH-Tc) //
   reversible coefficient of performance
15 printf('coefficient of performance is : \n\t beta =
   %f',beta)
16 printf('\n\n coefficient of performance of a
   reversible cycle is :\n\t betamax = %f',betamax)

```

Scilab code Exa 5.3 Example 3

```

1 //(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.
2
3
4 //solution
5
6 //variable initialization
7 Tc = 283 //in kelvin
8 TH = 295 //in kelvin
9 QH = 5*10^5 //in kj per day
10
11 Wcyclemin = (1-Tc/TH)*QH
12 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

```
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.
2
3 //solution
4
5
6 T = 373.15 //
  temperature in kelvin
7 //from table A-2
8 p = 1.014*10^5 //pressure
  in pascal
9 vg = 1.673
10 vf = 1.0435e-3
```

```

11 sg = 7.3549
12 sf = 1.3069
13
14 w = p*(vg-vf)*10^(-3)
15 Q = T*(sg-sf)
16
17 printf('the work per unit mass in kj/kg is\n\t w =
        %f',w)
18 printf('\nthe heat transfer per unit mass in kj/kg
        is \n\t Q = %f',Q)

```

Scilab code Exa 6.2 Example 2

```

1 //(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
2
3 //solution
4
5 //Assumptions:
6 //1. The water in the piston cylinder assembly is
  a closed system .
7 //2. There is no heat transfer with the surroundings
  .
8 //3. The system is at an equilibrium state initially
  and finally . There is no change in kinetic or
  potential energy between these
9 //two states .

```

```

10
11 //from table A-2 at 100 degree celcius
12 ug = 2506.5 //in kj
    /kg
13 uf = 418.94 //in kj
    /kg
14 sg = 7.3549
15 sf = 1.3069
16
17 //from energy balance ,
18 W = -(ug-uf)
19 printf('the net work per unit mass in kj/kg is:\n\t
    w = %f ',W)
20
21 //from entropy balance
22 sigmabym = (sg-sf)
23 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

```

1 // (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.
2
3 //solution
4
5 //variable initialization
6 T1 = 273
    //initial temperature of saturated vapor in
    kelvin
7 P2 = .7*10^6

```

```

        //final pressure in pascal
8
9 //from table A-10,
10 u1 = 227.06
    //in kj/kg
11
12 //minimum theoretical work corresponds to state of
    isentropic compression
13 //from table A-12,
14 u2s = 244.32 //
    in kj/kg
15 Wmin = u2s-u1
16 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

```

1 //(6.4) Referring to Example 2.4, evaluate the
    rate of entropy production  $\dot{\sigma}$  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,  $T_f = 293$  K (20
    C).
2
3 //solution
4
5 //variable initialization
6 Qdot = -1.2 //in kilo watt
7 Tb = 300 //in kelvin
8 Tf = 293 //in kelvin
9
10

```

```

11 //part (a)
12 //from entropy balance
13 sigmadot = -Qdot/Tb
14 printf('the rate of entropy production in kw/k with
        gearbox as system is:\n\t sigmadot = %e',sigmadot
        )
15
16 //part(b)
17 //from entropy balance
18 sigmadt = -Qdot/Tf
19 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

```

1 //(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  $c_w = 4.2$  kJ/
    kg. K, and an appropriate value for the metal is
     $c_m = 0.42$  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.
2
3
4 //solution
5
6 //variable initialization
7 Tmi = 1200 //
    initial temperature of metal in kelvin

```

```

8 cm = .42 //
  specific heat of metal in KJ/kg.k
9 mm = .3 //mass
  of metal in kg
10 Twi = 300 //
  initial temperature of water in kelvin
11 cw = 4.2 //
  specific heat of water in KJ/Kg.k
12 mw = 9 //mass
  of water in kg
13
14
15 //part(a)
16 //solving energy balance equation yields
17 Tf = (mw*(cw/cm)*Twi+mm*Tmi)/(mw*(cw/cm)+mm)
18
19 //part (b)
20 //solving entropy balance equation yields
21 sigma = mw*cw*log(Tf/Twi)+mm*cm*log(Tf/Tmi)
22
23 printf('the final equilibrium temperature of the
  metal bar and the water in kelvin is :\n\t Tf =
  %f',Tf)
24 printf('\n\n the amount of entropy produced in kj/k
  is: \n\t sigma = %f ',sigma)

```

Scilab code Exa 6.6 Example 6

```

1 //(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

```

2
3 //solution
4
5 //variable initialization
6 P1 = 30 //
   pressure of steam entering the turbine in bar
7 T1 = 400 //
   temperature of steam entering the turbine in
   degree celcius
8 V1 = 160 //
   velocity of steam entering the turbine in m/s
9 T2 = 100 //
   temperature of steam exiting in degree celcius
10 V2 = 100 //
   velocity of steam exiting in m/s
11 Wcvdot = 540 //work
   produced by turbine in kJ/kg of steam
12 Tb = 350 //
   temperature of the boundary in kelvin
13
14 //from table A-4 and table A-2,
15 h1 = 3230.9 //
   specific enthalpy at entry in Kj/kg
16 h2 = 2676.1 //
   specific enthalpy at exit in kj/kg
17
18 //reduction in mass and energy balance equations
   results in
19 Qcvdot = Wcvdot + (h2 - h1)+ (V2^2-V1^2)/(2*10^3)
   //heat transfer rate
20
21 //from table A-2
22 s2 = 7.3549 //in kj/

```

```

    kg.k
23 //from table A-4
24 s1 = 6.9212 //in kj/
    kg.k
25
26 //from entropy and mass balance equations
27 sigmadot = -(Qcvdot/Tb) + (s2-s1)
28
29 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

```

1 //(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 inventors claim ,
    employing the ideal gas model for air and
    ignoring changes in the kinetic and potential
    energies of the streams from inlet to exit.
2
3 //solution
4
5 //variable initialization
6 T1 = 294 //entry
    temperature of air in kelvin

```



```

7 P1 = 5.1 //entry
  pressure of air in bars
8 T2 = 352 //exit
  temperature of hot stream in kelvin
9 P2 = 1 //exit
  pressure of hot stream in bars
10 T3 = 255 //exit
  temperature of cold stream in kelvin
11 P3 = 1 //exit
  pressure of cold stream in bars
12
13 cp = 1 //in kj/kg
  .k
14 R = 8.314/28.97
15 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
16
17 printf('specific entropy in kj/kg.k = %f',se)
18 printf('\n\nsince se > 0, the claim of the writer is
  true')

```

Scilab code Exa 6.8 Example 8

```

1 //(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).

```
2
3
4 //solution
5
6
7 //variable initialization
8 P1 = 3.5 //
   pressure of refrigerant entering the compressor
   in bars
9 T1 = 268 //
   temperature of refrigerant entering the
   compressor in kelvin
10 P2 = 14 //
   pressure of refrigerant entering the condenser in
   bars
11 T2 = 348 //
   temperature of refrigerant entering the condenser
   in kelvin
12 P3 = 14 //
   pressure of refrigerant exiting the condenser in
   bars
13 T3 = 301 //
   temperature of refrigerant exiting the condenser
   in kelvin
14 P4 = 3.5 //
   pressure of refrigerant after passing through
   expansion valve in bars
15 P5 = 1 //
```

```

    pressure of indoor return air entering the
    condenser in bars
16 T5 = 293 //
    temperature of indoor return air entering the
    condenser in kelvin
17 AV5 = .42 //
    volumetric flow rate of indoor return air
    entering the condenser in m^3/s
18 P6 = 1 //
    pressure of return air exiting the condenser in
    bar
19 T6 = 323 //
    temperature of return air exiting the condenser
    in kelvin
20
21 //part(a)
22
23 //from table A-9
24 s1 = .9572 //in
    kj/kg.k
25 //interpolating in table A-9
26 s2 = .98225 //in
    kj/kg.k
27 h2 = 294.17 //in
    kj/kg
28 //from table A-7
29 s3 = .2936 //in
    kj/kg.k
30 h3 = 79.05 //in
    kj/kg
31
32 h4 = h3 //
    since expansion through valve is throttling
    process
33
34 //from table A-8
35 hf4 = 33.09 //in
    kj/kg

```

```

36 hg4 = 246 //in
    kj/kg
37 sf4 = .1328 //in
    kj/kg.k
38 sg4 = .9431 //in
    kj/kg.k
39
40 x4 = (h4-hf4)/(hg4-hf4) //
    quality at state 4
41 s4 = sf4 + x4*(sg4-sf4) //
    specific entropy at state 4
42
43 //condenser!!
44 v5 = ((8314/28.97)*T5)/(P5*10^5) //
    specific volume at state 5
45 mairdot = AV5/v5
46 cp = 1.005 //in
    kj/kg.k
47 h6 = cp*T6
48 h5 = cp*T5
49 mrefdot = mairdot*(h6-h5)/(h2-h3)
50 deltaS65 = cp*log(T6/T5)-(8.314/28.97)*log(P6/P5)
    //change in specific entropy
51 sigmacond = (mrefdot*(s3-s2)) + (mairdot*(deltaS65))
52
53 //compressor!!
54 sigmacomp = mrefdot*(s2-s1)
55
56
57 //valve!!
58 sigmavalve = mrefdot *(s4-s3)
59
60 printf('\nthe rates of entropy production , in kW/K,
    for control volume enclosing the condenser is \n\
    t R1 = %e ',sigmacond)
61 printf('\nthe rates of entropy production , in kW/K,
    for control volume enclosing the compressor is \n\
    \t R2 = %e ',sigmacomp)

```

```

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

```

Scilab code Exa 6.9 Example 9

```

1 // (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.
2
3 //solution
4
5 //variable initialization
6 P1 = 1 //initial
  pressure in bar
7 T1 = 300 //initial
  temperature in kelvin
8 T2 = 650 //final
  temperature in kelvin
9
10 //part(a)
11 //from table A-22
12 pr2 = 21.86
13 pr1 = 1.3860
14 p2 = P1*(pr2/pr1)
15 printf('part(a) P2 in bar = %f ',p2)
16 //part(b)
17 printf('\n part(b) IT software problem')
18 //part(c)
19 k = 1.39 //from

```

```

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

```

Scilab code Exa 6.10 Example 10

```

1  //(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.
2
3
4  //solution
5
6  //variable initialization
7  m1 = 5 //
   initial mass in kg
8  P1 = 5 //
   initial pressure in bar
9  T1 = 500 //
   initial temperature in kelvin
10 P2 = 1 //
   final pressure in bar
11
12 //from table A-22
13 pr1 = 8.411
14
15 pr2 = (P2/P1)*pr1
16
17 //using this value of pr2 and interpolation in table
   A-22
18 T2 = 317 //

```

```

    in kelvin
19
20 m2 = (P2/P1)*(T1/T2)*m1
21 printf('the amount of mass remaining in the tank in
    kg is :\n \t m2 = %f',m2)
22 printf('\n and its temperature in kelvin is : \n\t
    T = %f',T2)

```

Scilab code Exa 6.11 Example 11

```

1  //(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.
2
3
4  //solution
5
6  //variable initialization
7  P1 = 1
    //inlet pressure in bar
8  T1 = 593
    //inlet temperature in kelvin
9  P2 = 1
    //exit pressure in bar
10 eta = .75

```

```

    //turbine efficiency
11
12 //from table A-4
13 h1 = 3105.6

    //in Kj/kg
14 s1 = 7.5308

    //in kj/kg.k
15 //from table A-4 at 1 bar
16 h2s = 2743

    //in kj/kg
17 w = eta*(h1 - h2s)
18 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

```

1 // (6.12) A turbine operating at steady state
  receives air at a pressure of  $p_1 = 3.0$  bar and a
  temperature of  $T_1 = 390$  K. Air exits the turbine
  at a pressure of  $p_2 = 1.0$  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.

2
3 //solution
4
5 //variable initialization
6 P1 = 3 //

```



```

    pressure of air entering in bar
7 T1 = 390 //
    temperature of air entering in kelvin
8 P2 = 1 //
    pressure of exit air
9 Wcvdot = 74 //work
    developed in kj/kg
10
11 //from table A-22,at 390k
12 h1 = 390.88 //in
    kj/kg
13 pr1 = 3.481
14
15 pr2 = (P2/P1)*pr1
16
17 //from interpolation table A-22
18 h2s = 285.27 //in kj
    /kg
19
20 Wcvdots = h1 - h2s
21
22 eta = Wcvdot/Wcvdots
23
24 printf('the turbine efficiency is : \n\t eta = %f',
    eta)

```

Scilab code Exa 6.13 Example 13

```

1 //(6.13) Steam enters a nozzle operating at
    steady state at  $p_1 = 1.0$  MPa and  $T_1 = 320$ C with a
    velocity of 30 m/s. The pressure and temperature
    at the exit are  $p_2 = 0.3$  MPa and  $T_2 = 180$ C.
    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.
2
3
4 //solution
5
6 //variable initialization
7 P1 = 1

    //pressure of entering steam in Mpa
8 T1 = 593

    //temperature of entering steam in kelvin
9 V1 = 30

    //velocity of entering steam in m/s
10 P2 = .3

    //pressure of exit steam in Mpa
11 T2 = 453

    //temperature of exit steam in kelvin
12
13 //from table A-4, at T1 = 593 kelvin and P1 = 1 Mpa;
    T2 = 453 kelvin and P2 = .3 Mpa
14 h1 = 3093.9 //in
    kj/kg
15 s1 = 7.1962 //in
    kj/kg.k
16 h2 = 2823.9 //in
    kj/kg
17 V2squareby2 = h1 - h2 + (V1^2)/2000
18
19 //interpolating in table A-4
20 h2s = 2813.3 //in

```

```

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

```

Scilab code Exa 6.14 Example 14

```

1  //(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.
2
3
4  //solution
5
6  //part(a)
7  //from table A-9
8  h1 = 249.75
    kj/kg
9  h2 = 294.17
    //in
    //in
    kj/kg
10
11 mdot = .07
    //in
    kg/s
12
13 wcvdot = mdot*(h1-h2)
14 //from table A-9
15 s1 = .9572
    //in
    Kj/Kg.k

```

```

16 h2s = 285.58
                                     //in
    kj/kg
17
18 eta = (h2s-h1)/(h2-h1)
19
20 printf('the power in KW is: \n\t p = %f',wcvdot)
21 printf('\n the isentropic efficiency is : \n\t eta =
    %f',eta)

```

Scilab code Exa 6.15 Example 15

```

1  //(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.
2
3  //solution
4
5  //variable initialization
6  P1 = 1
    //pressure of entering air in bar
7  T1 = 293
    //temperature of entering air in kelvin
8  P2 = 5
    //pressure of exit air in bar
9  n = 1.3
10
11 T2 = T1*((P2/P1)^((n-1)/n))
    //in kelvin
12 R = 8.314/28.97

```

```
13 wcvdot=((n*R)/(n-1))*(T1-T2)           //
    in kj/kg
14
15 //from table A-22
16 h1 = 293.17                             //
    in kj/kg
17 h2 = 426.35                             //
    in kj/kg
18
19 Qcvdot= wcvdot + (h2-h1)                //
    in kj/kg
20 printf('the work per unit mass passing through the
    device in kj/kg is: w = %f',wcvdot)
21 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

```
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.
2
3
4 //solution
5
6
7 //variable initialization
8 v = 2450
   //volume of gaseous products in cm^3
9 P = 7
   //pressure of gaseous product in bar
10 T = 867
```

```

        //temperature of gaseous product in degree
        celcius
11 T0 = 300

        //in kelvin
12 P0 = 1.013

        //in bar
13
14 //from table A-22
15 u = 880.35

        //in kj/kg
16 u0 = 214.07

        //in kj/kg
17 s0(T) = 3.11883
                                                    //in
        kj/kg.k
18 s0(T0) = 1.70203
                                                    //in
        kj/kg.k
19
20 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
21 printf('the specific exergy of the gas, in kJ/kg is
        \n\t e = %f',e)

```

Scilab code Exa 7.2 Example 2

```

1 // (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 $T_0 = 293 \text{ K}$ (20C), $p_0 = 1 \text{ bar}$.

```

2
3 //solution
4
5 //variable initialization
6 mR = 1.11 //
   mass of the refrigerant in kg
7 T1 = -28 //
   initial temperature of the saturated vapor in
   degree celcius
8 P2 = 1.4 //
   final pressure of the refrigerant in bar
9 T0 = 293 //in
   kelvin
10 P0 = 1 //in
   bar
11
12 //part (a)
13 //from table A-10
14 u1 = 211.29 //in
   kj/kg
15 v1 = .2052 //in
   m^3/kg
16 s1 = .9411 //in

```



```

    kj/kg.k
17 //from table A-12
18 u0 = 246.67 //in
    kj/kg
19 v0 = .23349 //in
    m^3/kg
20 s0 = 1.0829 //in
    kj/kg.k
21
22 E1 = mR*[(u1-u0) + P0*10^5*(v1-v0)*10^(-3)-T0*(s1-s0
    )]
23
24 //from table A-12
25 u2 = 300.16 //in
    kj/kg
26 s2 = 1.2369 //in
    kj/kg.k
27 v2 = v1
28
29 E2 = mR*[(u2-u0) + P0*10^5*(v2-v0)*10^(-3)-T0*(s2-s0
    )]
30
31 printf('part(a)the initial exergy in kj is :\n\t E1
    = %f',E1)
32 printf('\nthe final exergy in kj is :\n\t E2 = %f',
    E2)
33 printf('\nthe change in exergy of the refrigerant in
    kj is \n\t deltaE = %f',E2-E1)
34
35
36 //part (b)
37 deltaU = mR*(u2-u1)
38 //from energy balance
39 deltaPE = -deltaU
40 //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
41 deltaE = deltaPE
42 printf('\n\n\ncpart(b)the change in exergy of the
    suspended mass, in kJ is :\n\t deltaE = %f',
    deltaE)
43
44
45 //part(c)
46 deltaEiso = (E2-E1) + deltaE
47 printf('\n\n\ncpart(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

```

1 //(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  $T_0 = 20\text{C}$ ,
 $p_0 = 1.014\text{ bar}$ . (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.

```

```

2
3
4 //solution
5
6 //variable initialization
7 T = 373.15
//
// initial temperature of saturated liquid in kelvin
8 T0 = 293.15
//in
kelvin
9 P0 = 1.014
//
in bar
10
11
12 //part(a)
13 //from table A-2
14 ug = 2506.5
//in
kj/kg
15 uf = 418.94
//in
kj/kg
16 vg = 1.673
//
in m^3/kg
17 vf = 1.0435*10^(-3)
//in
m^3/kg
18 sg = 7.3549
//in
kj/kg.k
19 sf = 1.3069
//in
kj/kg.k
20
21 deltae = ug-uf + P0*10^5*(vg-vf)/(10^3)-T0*(sg-sf)

```

```

22
23 //exergy transfer accompanying work
24 etaw = 0

    //since p = p0
25
26 //exergy transfer accompanying heat
27 Q = 2257

    //in kj/kg, obtained from example 6.1
28 etah = (1-(T0/T))*Q
29
30 //exergy destruction
31 ed = 0

    //since the process is accomplished without any
    irreversibilities
32
33 printf('part(a)the change in exergy in kj/kg is:\n\t
    deltae = %f ',deltae)
34 printf('\nthe exergy transfer accompanying work in
    kj/kg is:\n\t etaw = %f',etaw)
35 printf('\nthe exergy transfer accompanying heat in
    kj/kg is:\n\t etah = %f',etah)
36 printf('\nthe exergy destruction in kj/kg is:\n\t ed
    = %f',ed)
37
38
39 //part(b)
40 Deltae = deltae

    //since
    the end states are same
41 Etah = 0

    //since process is adiabatic
42 //exergy transfer along work
43 W = -2087.56

    //in

```

```

    kj/kg from example 6.2
44 Etaw = W- P0*10^5*(vg-vf)/(10^3)
45 //exergy destruction
46 Ed = -Deltae-Etaw
47
48 printf('\n\n\npart(b)the change in exergy in kj/kg
    is:\n\t Deltae = %f ',Deltae)
49 printf('\nthe exergy transfer accompanying work in
    kj/kg is:\n\t Etaw = %f',Etaw)
50 printf('\nthe exergy transfer accompanying heat in
    kj/kg is:\n\t Etah = %f',Etah)
51 printf('\nthe exergy destruction in kj/kg is:\n\t Ed
    = %f',Ed)

```

Scilab code Exa 7.4 Example 4

```

1  //(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.
2
3
4  //solution
5
6  //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.
7
8  T0 = 293

```

```

    in kelvin
9  Qdot = -1.2 //
    in KW, from example 6.4a
10 Tb = 300 //
    temperature at the outer surface of the gearbox
    in kelvin from example 6.4a
11 sigmadot = 4e-3 //
    rate of entropy production in KW/k from example
    6.4a
12
13 R = (1-T0/Tb)*Qdot //
    time rate of exergy transfer accompanying heat
14 Eddot = T0*sigmadot //
    rate of exergy destruction
15
16 printf('balance sheet')
17 printf('\nrate of exergy in:\n high speed shaft\t\t
    60Kw')
18 printf('\nDisposition of the exergy:\n Rate of
    exergy out\nlow-speed shaft\t\t 58.8Kw')
19 printf('\nheat transfer in kw\t\t%f',norm(R))
20 printf('\n Rate of exergy destruction in kw\t\t%f
    ',Eddot)

```

Scilab code Exa 7.5 Example 5

```

1 //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.
2
3 //solution
4

```

```

5 //variable initialization
6 p1 = 3
   //entry pressure in Mpa
7 p2 = .5
   //exit pressure in Mpa
8 T1 = 320
   //entry temperature in degree celcius
9 T0 = 25
   //in degree celcius
10 p0 = 1
    //in atm
11
12
13 //from table A-4
14 h1 = 3043.4
    //in kj/kg
15 s1 = 6.6245
    //in kj/kg.k
16
17 h2 = h1
    //from reduction of the steady-state mass and
    //energy rate balances
18
19 s2 = 7.4223
    //Interpolating at a pressure of 0.5 MPa with h2
    // = h1, units in kj/kg.k
20
21 //from table A-2
22 h0 = 104.89
    //in kj/kg
23 s0 = 0.3674
    //in kj/kg.k
24
25 ef1 = h1-h0-(T0+273)*(s1-s0)
    //flow exergy at the
    inlet
26 ef2 = h2-h0-(T0+273)*(s2-s0)
    //flow exergy at the

```

```

    exit
27
28 //from the steady-state form of the exergy rate
    balance
29 Ed = ef1-ef2
    //the exergy destruction per unit of mass flowing
    is
30
31 printf(' the specific flow exergy at the inlet in kj
    /kg is :\n\t ef1 =%f',ef1)
32 printf('\nthe specific flow exergy at the exit in kj
    /kg is:\n\t ef2 = %f',    ef2)
33 printf('\nthe exergy destruction per unit of mass
    flowing in kj/kg is:\n\t = %f',Ed)

```

Scilab code Exa 7.6 Example 6

```

1 //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  $T_0 = 300$  K,  $p_0 =$ 
    1 bar.

```

2


```

3
4 //solution
5
6 //variable initialization
7 T1 = 610

    //temperature of the air entering heat exchanger
    in kelvin
8 p1 = 10

    //pressure of the air entering heat exchanger in
    bar
9 T2 = 860

    //temperature of the air exiting the heat
    exchanger in kelvin
10 p2 = 9.7

    //pressure of the air exiting the heat exchanger
    in bar
11 T3 = 1020

    //temperature of entering hot combustion gas in
    kelvin
12 p3 = 1.1

    //pressure of entering hot combustion gas in bar
13 p4 = 1

    //pressure of exiting hot combustion gas in bar
14 mdot = 90

    mass flow rate in kg/s //
15 T0 = 300

    //in kelvin
16 p0 = 1

```

```

    //in bar
17
18 //part (a)
19 //from table A-22
20 h1 = 617.53
    //
    in kj/kg
21 h2 = 888.27
    //
    in kj/kg
22 h3 = 1068.89
    //in
    kj/kg
23
24 //from reduction of mass and energy rate balances
    for the control volume at steady state
25 h4 = h3+h1-h2
26
27 //using interpolation in table A-22 gives
28 T4 = 778
    //in kelvin
29 printf('the exit temperature of the combustion gas
    in kelvin is:\n\tT4 = %f',T4)
30
31
32 //part(b)
33 //from table A-22
34 s2 = 2.79783
    //in kj
    /kg.k
35 s1 = 2.42644
    //in kj
    /kg.k
36
37 deltaR = (mdot*((h2-h1)-T0*(s2-s1-(8.314/28.97)*log(
    p2/p1))))/1000
38

```

```

39 //from table A-22
40 s4 = 2.68769 //in kj/
    kg.k
41 s3 = 2.99034 //in kj/
    kg.k
42
43 deltRc = mdot*((h4-h3)-T0*(s4-s3-(8.314/28.97)*log(
    p4/p3)))/1000
44
45 printf('\nthe net change in the flow exergy rate
    from inlet to exit of compressed gas in MW is:\n\
    t deltaR = %f',deltaR)
46 printf('\nthe net change in the flow exergy rate
    from inlet to exit of hot combustion gas in MW is
    :\n\tdeltRc =%f ',deltRc)
47
48 //part(c)
49 //from an exergy rate balance
50 Eddot = -deltaR-deltRc
51
52 printf('\nthe rate exergy destroyed , in MW is:Eddot
    = %f',Eddot)

```

Scilab code Exa 7.7 Example 7

```

1 //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 $T_0 = 25\text{C}$, $p_0 = 1 \text{ atm}$.

```
2
3 //solution
4
5 //variable initialization
6 p1 = 30

   //pressure of entering steam in bar
7 t1 = 400

   temperature of entering steam in degree celcius //
8 v1 = 160

   velocity of entering steam in m/s //
9 t2 = 100

   temperature of exiting saturated vapor in degree //
   celcius
10 v2 = 100

   velocity of exiting saturated vapor in m/s //
11 W = 540

   //rate of work developed in kj per kg of steam
12 Tb = 350

   the temperature on the boundary where heat //
   transfer occurs in kelvin
13 T0 = 25

   //in degree celcius
14 p0 = 1

   //in atm
15
```

```

16 //from table A-4
17 h1 = 3230.9
                                     //in
    kj/kg
18 s1 = 6.9212
                                     //in
    kj/kg.k
19 //from table A-2
20 h2 = 2676.1
                                     //in
    kj/kg
21 s2 = 7.3549
                                     //in
    kj/kg.k
22
23 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
24
25 //from example 6.6
26 Q = -22.6
                                     //
    in kj/kg
27 Eq = (1-(T0+273)/Tb)*(Q)
                                     //exergy
    transfer accompanying heat in kj/kg
28
29 Ed = (1-(T0+273)/Tb)*(Q)-W+(DELTAef)
                                     //The exergy destruction
    determined by rearranging the steady-state form
    of the exergy rate balanceff
30
31 printf('balance sheet')
32 printf('\nNet rate of exergy in:\t%f',DELTAef)
33 printf('\nDisposition of the exergy:')
34 printf('\ n Rate of exergy out')
35 printf('\nwork\t%f',W)
36 printf('\nheat transfer\t%f',-Eq)

```

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

Scilab code Exa 7.8 Example 8

```
1 //(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.
2
3
4 //solution
5
6 //variable initialization
7 mldot = 69.78
   //in kg/s
8 p1 = 1
   //in bar
9 T1 = 478
   //in kelvin
10 T2 = 400
   //in kelvin
11 p2 = 1
   //in bar
12 p3 = .275
   //in Mpa
13 T3 = 38.9
```

```

//in degree celcius
14 m3dot = 2.08

//in kg/s
15 T4 = 180

//in degree celcius
16 p4 = .275

//in Mpa
17 p5 = .07

//in bar
18 x5 = .93
19 Wcvdot = 876.8

//in kW
20 T0 = 298

//in kelvin
21
22
23 //part(a)
24 //from table A-22
25 h1 = 480.35

//in kj/kg
26 h2 = 400.97

//in kj/kg
27 s1 = 2.173

//in kj/kg
28 s2 = 1.992

//in kj/kg
29

```

```

30 netRE = m1dot*(h1-h2-T0*(s1-s2-(8.314/28.97)*log(p1/
    p2))) //the net rate exergy carried
    into the control volume
31
32
33 //from table A-2E
34 h3 = 162.82
    //in kj/kg
35 s3 = .5598
    //in kj/kg.k
36 //Using saturation data at 0.07 bars from Table A-3
37 h5 = 2403.27
    //in kj/kg
38 s5 = 7.739
    //in kj/kg.k
39
40 netREout = m3dot*(h5-h3-T0*(s5-s3)) //the net rate
    exergy carried out by the water stream
41
42 //from table A-4
43 h4 = 2825
    //in kj/kg
44 s4 = 7.2196
    //in kj/kg.k
45
46 //from an exergy rate balance applied to a control
    volume enclosing the steam generator
47 Eddot = netRE + m3dot*(h3-h4-T0*(s3-s4)) //the rate exergy is
    destroyed in the heat-recovery steam generator
48

```



```

49 //from an exergy rate balance applied to a control
    volume enclosing the turbine
50 EdDot = -Wcvdot + m3dot*(h4-h5-T0*(s4-s5))
    //the rate exergy is
    destroyed in the tpurbine
51
52
53 printf('balance sheet')
54 printf('\nNet rate of exergy in:\t%f',netRE)
55 printf('\nDisposition of the exergy:')
56 printf('\ n   Rate of exergy out')
57 printf('\npower developed\t%f',1772.8-netREout-Eddot
    -EdDot)
58 printf('\nwater stream\t%f',netREout)
59 printf('\ n   Rate of exergy destruction')
60 printf('\nheat-recovery steam generator\t%f',Eddot)
61 printf('\nturbine\t%f',EdDot)

```

Scilab code Exa 7.9 Example 9

```

1 //(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.
2
3
4 //solution
5
6 T0 = 273

```

```

    //in kelvin
7  pricerate = .08
                                     //
    exergy value at $0.08 per kw.h
8
9  //from example 6.8
10 sigmadotComp = 17.5e-4
                                     //in kw/k
11 sigmadotValve = 9.94e-4
                                     //in kw/k
12 sigmadotcond = 7.95e-4
                                     //in kw/k
13
14 //The rates of exergy destruction
15 EddotComp = T0*sigmadotComp
                                     //in kw
16 EddotValve = T0*sigmadotValve
                                     //in kw
17 Eddotcond = T0*sigmadotcond
                                     //in kw
18
19 mCP = 3.11

    //From the solution to Example 6.14, the
    magnitude of the compressor power in kW
20
21 printf('Daily cost in dollars of exergy destruction
    due to compressor irreversibilities =\t %f',
    EddotComp*pricerate*24)
22 printf('\naDaily cost in dollars of exergy
    destruction due to irreversibilities in the
    throttling valve =\t %f',EddotValve*pricerate*24)
23 printf('\naDaily cost in dollars of exergy
    destruction due to irreversibilities in the
    condenser =\t %f',Eddotcond*pricerate*24)
24 printf('\naDaily cost in dollars of electricity to
    operate compressor =\t %f',mCP*pricerate*24)

```

Scilab code Exa 7.10 Example 10

```
1 //(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.
2
3
4 //solution
5
6 //variable initialization
7 Effdot = 100
```

```

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

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

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

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

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

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

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

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

//temperature of exiting steam from the turbine
in degree celcius
16 m2dot = 26.15

//mass flow rate of exiting steam from the
turbine in kg/s
17 T0 = 298

```

```

    //in kelvin
18
19
20 //part(a)
21 //from table A-4,
22 h1 = 3353.54

    //in kj/kg
23 h2 = 2865.96

    //in kj/kg
24 //from assumption, For each control volume,  $Q_{cv\dot{}} = 0$ 
    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
25  $\dot{W}_{edot} = \dot{m}_2 (h_1 - h_2) / 1000$ 
    //power in
    MW
26
27 //from table A-4
28 s1 = 6.8773

    //in kj/kg.k
29 s2 = 7.0806

    //in kj/kg.k
30
31  $\dot{E}_{f2dot} = \dot{E}_{f1dot} + \dot{m}_2 (h_2 - h_1 - T_0 (s_2 - s_1)) / 1000$ 
    //the rate exergy exits with
    the steam in MW
32 printf('for the turbine, the power in MW is:\t%f',
     $\dot{W}_{edot}$ )
33 printf('\nfor the turbine, the rate exergy exits with
    the steam in MW is:\t%f',  $\dot{E}_{f2dot}$ )
34
35 //part(b)
36 c1 = cF * ( $\dot{E}_{f\dot{}} / \dot{E}_{f1dot}$ ) + (( $\dot{Z}_{b\dot{}} / \dot{E}_{f1dot}$ ) / 10^3) * 100

```

```

//unit cost of exiting steam from
boiler in cents/Kw.h
37 c2 = c1

//Assigning the same unit cost to the steam
entering and exiting the turbine
38 ce = c1*((Ef1dot-Ef2dot)/Wedot) + ((Ztdot/Wedot)
/10^3)*100 //unit cost of power in cents/kw
.h
39
40 printf('\n\nthe unit costs of the steam exiting the
boiler in cents per kw.h of exergy is:\t%f',c1)
41 printf('\nthe unit costs of the steam exiting the
turbine in cents per kw.h of exergy is:\t%f',c2)
42 printf('\nunit cost of power in cents per kw.h is:\t
%f',ce)
43
44 //part(c)
45 C2dot = (c2*Ef2dot*10^3)/100 //cost rate
for low-pressure steam in dollars per hour
46 Cedot = (ce*Wedot*10^3)/100 //cost rate
for power in dollars per hour
47
48 printf('\n\nthe cost rate of the steam exiting the
turbine in dollars per hour is: %f',C2dot)
49 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

```
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,
    $\dot{Q}_{in}$ , into the working fluid as it passes
   through the boiler, in MW, (e) the rate of heat
   transfer,  $\dot{Q}_{out}$  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.
2
3
4 // solution
5
6 // variable initialization
7 p1 = 8
```

```

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

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

        //the net power output of the cycle in MW
10
11 //analysis
12 //from table A-3
13 h1 = 2758.0

        //in kj/kg
14 s1 = 5.7432

        //in kj/kg.k
15 s2 = s1
16 sf = .5926

        //in kj/kg.k
17 sg = 8.2287

        //in kj/kg.k
18 hf = 173.88

        //in kj/kg
19 hfg = 2403.1

        //in kj/kg
20 v3 = 1.0084e-3

        //in m^3/kg
21
22 x2 = (s2-sf)/(sg-sf)

```



```

    //quality at state 2
23 h2 = hf + x2*hfg
24 //State 3 is saturated liquid at 0.008 MPa, so
25 h3 = 173.88

    //in kj/kg
26
27 p4 = p1
28 h4 = h3 + v3*(p4-p3)*10^6*10^-3
    //in kj/
    kg
29
30 //part(a)
31 //Mass and energy rate balances for control volumes
    around the turbine and pump give, respectively
32 wtdot = h1 - h2
33 wpdot = h4-h3
34
35 //The rate of heat transfer to the working fluid as
    it passes through the boiler is determined using
    mass and energy rate balances as
36 qindot = h1-h4
37
38 eta = (wtdot-wpdot)/qindot
    //
    thermal efficiency)
39 printf('the thermal efficiency for the cycle is: %f
    ',eta)
40
41 //part(b)
42 bwr = wpdot/wtdot

    //back work ratio
43 printf('\n\nthe back work ratio is: %e',bwr)
44
45 //part(c)
46 mdot = (Wcycledot*10^3*3600)/((h1-h2)-(h4-h3))
    //mass flow rate in kg/h

```

```

47 printf('\n\nthe mass flow rate of the steam in kg/h
      is: %e',mdot)
48
49 //part(d)
50 Qindot = mdot*qindot/(3600*10^3)
                                     //in MW
51 printf('\n\nthe rate of heat transfer ,Qindot , into
      the working fluid as it passes through the boiler
      , in MW is: %f',Qindot)
52
53 //part(e)
54 Qoutdot = mdot*(h2-h3)/(3600*10^3)
                                     //in MW
55 printf('\n\nthe rate of heat transfer ,Qoutdot from
      the condensing steam as it passes through the
      condenser , in MW is: %f',Qoutdot)
56
57 //part(f)
58 //from table A-2
59 hcwout = 146.68
                                     //in kj/kg
60 hcwin = 62.99
                                     //in kj/kg
61 mcwdot = (Qoutdot*10^3*3600)/(hcwout-hcwin)
                                     //in kg/h
62 printf('\n\nthe mass flow rate of the condenser
      cooling water , in kg/ h is: %e',mcwdot)

```

Scilab code Exa 8.2 Example 2

```

1 // (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 \dot{Q}_{in} into the working fluid as it passes through the boiler, in MW, (d) the rate of heat transfer \dot{Q}_{out} from 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 15°C and exits as 35°C. Discuss the effects on the vapor cycle of irreversibilities within the turbine and pump.

```

2
3
4 //solution
5
6 etat= .85

    //given that the turbine and the pump each have
    an isentropic efficiency of 85%
7 //analysis
8 //State 1 is the same as in Example 8.1, so
9 h1 = 2758.0

    //in kj/kg
10 s1 = 5.7432

    //in kj/kg.k
11
12 //from example 8.1
13 h1 = 2758

    //in kj/kg
14 h2s = 1794.8

    //in kj/kg
15

```

```

16 h2 = h1 - etat*(h1-h2s)

    //in kj/kg
17 //State 3 is the same as in Example 8.1, so
18 h3 = 173.88

    //in kj/kg
19
20 //from solution to example 8.1
21 wpdot = 8.06/etat

    //where the value 8.06 is obtained from example
    8.1
22
23 h4 = h3 + wpdot
24
25 //part(a)
26 eta = ((h1-h2)-(h4-h3))/(h1-h4)

    //thermal efficiency
27 printf('thermal efficiency is: %f',eta)
28
29 //part(b)
30 Wcycledot = 100

    //given, a net power output of 100 MW
31 mdot = (Wcycledot*10^3*3600)/((h1-h2)-(h4-h3))
32 printf('\n\nthe mass flow rate of steam, in kg/h,
    for a net power output of 100 MW is: %e',mdot)
33
34 //part(c)
35 Qindot = mdot*(h1-h4)/(3600 * 10^3)
36 printf('\n\nthe rate of heat transfer Qindot into
    the working fluid as it passes through the boiler
    , in MW is: %f',Qindot)
37
38 //part(d)
39 Qoutdot = mdot*(h2-h3)/(3600*10^3)

```

```

40 printf('\n\nthe rate of heat transfer Qoutdotfrom
    the condensing steam as it passes through the
    condenser , in MW is:  %f',Qoutdot)
41
42 //part(e)
43 //from table A-2
44 hcwout = 146.68

    //in kj/kg
45 hcwin = 62.99

    //in kj/kg
46 mcwdot = (Qoutdot*10^3*3600)/(hcwout-hcwin)
47 printf('\n\nthe mass flow rate of the condenser
    cooling water , in kg/h is:  %e',mcwdot)

```

Scilab code Exa 8.3 Example 3

```

1 // (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.
2
3 //solution
4
5 //variable initialization

```

```

6 T1 = 480

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

    //pressure of steam entering the first stage
    turbine in MPa
8 p2 = .7

    //pressure of steam exiting the first stage
    turbine in MPa
9 T3 = 440

    //temperature of steam before entering the second
    stage turbine
10 Pcond = .008

    //condenser pressure in MPa
11 Wcycledot = 100

    //the net power output in MW
12
13 //analysis
14 //from table A-4
15 h1 = 3348.4

    //in kj/kg
16 s1 = 6.6586

    //in kj/kg.k
17 s2 = s1

    //isentropic expansion through the first-stage
    turbine
18 //from table A-3
19 sf = 1.9922

```

```

    //in kj/kg.k
20 sg = 6.708

    //in kj/kg.k
21 hf = 697.22

    //in kj/kg
22 hfg = 2066.3

    //in kj/kg
23
24 x2 = (s2-sf)/(sg-sf)
25 h2 = hf + x2*hfg
26 //State 3 is superheated vapor with p3 = 0.7 MPa and
    T3= 440C, so from Table A-4
27 h3 = 3353.3

    //in kj/kg
28 s3 = 7.7571

    //in kj/kg.k
29 s4 = s3

    //isentropic expansion through the second-stage
    turbine
30 //for determing quality at state 4,from table A-3
31 sf = 0.5926

    //in kj/kg.k
32 sg = 8.2287

    //in kj/kg.k
33 hf = 173.88

    //in kj/kg
34 hfg = 2403.1

    //in kj/kg

```

```

35
36 x4 = (s4-sf)/(sg-sf)
37 h4 = hf + x4*hfg
38
39 //State 5 is saturated liquid at 0.008 MPa, so
40 h5 = 173.88
41 //the state at the pump exit is the same as in
    Example 8.1, so
42 h6 = 181.94
43
44 //part(a)
45 eta = ((h1-h2)+(h3-h4)-(h6-h5))/((h1-h6)+(h3-h2))
46 printf('the thermal efficiency of the cycle is: %f',
    ,eta)
47
48 //part(b)
49 mdot = (Wcycledot*3600*10^3)/((h1-h2)+(h3-h4)-(h6-h5
    ))
50 printf('\n\nthe mass flow rate of steam, in kg/h is:
    %e',mdot)
51
52 //part(c)
53 Qoutdot = (mdot*(h4-h5))/(3600*10^3)
54 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

- 1 // (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 $\text{etat} = 85\%$, determine the thermal efficiency. (


```

    b) Plot the thermal efficiency versus turbine
       stage efficiency ranging from 85 to 100%.
2
3
4 //solution
5
6 //part (a)
7 etat = .85

    //given efficiency
8 //From the solution to Example 8.3, the following
   specific enthalpy values are known, in kJ/kg
9 h1 = 3348.4
10 h2s = 2741.8
11 h3 = 3353.3
12 h4s = 2428.5
13 h5 = 173.88
14 h6 = 181.94
15
16 h2 = h1 - etat*(h1 - h2s)

    //The specific enthalpy at the exit of the first-
   stage turbine in kJ/kg
17 h4 = h3 - etat*(h3-h4s)

    //The specific enthalpy at the exit of the second
   -stage turbine in kJ/kg
18
19 eta = ((h1-h2)+(h3-h4)-(h6-h5))/((h1-h6)+(h3-h2))
20 printf('the thermal efficiency is: %f',eta)
21
22
23 //part (b)
24 x = linspace(.85,1,50);
25 for i = 1: 50
26     h2(1,i) = h1 - x(1,i)*(h1 - h2s)

    //The specific enthalpy at the exit of the

```

```

                first-stage turbine in kj/kg
27 h4(1,i) = h3 - x(1,i)*(h3-h4s)

                //The specific enthalpy at the exit of the second
                -stage turbine in kj/kg
28 end
29
30 for i = 1:50
31     y(1,i) = ((h1-h2(1,i))+(h3-h4(1,i))-(h6-h5))/((
                h1-h6)+(h3-h2(1,i)))
32 end
33 plot2d(x,y)
34 xtitle("","isentropic turbine efficiency","cycle
                thermal efficiency")

```

Scilab code Exa 8.5 Example 5

```

1 //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.
2
3 //solution
4
5 //variable initialization

```

```

6 T1 = 480

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

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

    //condenser pressure in MPa
9 etat = .85

    //turbine efficiency
10 Wcycledot = 100

    //net power output of the cycle
11
12
13 //analysis
14 //with the help of steam tables
15 h1 = 3348.4

    //in kj/kg
16 h2 = 2832.8

    //in kj/kg
17 s2 = 6.8606

    //in kj/kg.k
18 h4 = 173.88

    //in kj/kg
19 //With s3s = s2, the quality at state 3s is x3s=
    //0.8208; using this, we get
20 h3s = 2146.3

    //in kj/kg
21 //The specific enthalpy at state 3 can be determined

```

```

    using the efficiency of the second-stage turbine
22 h3 = h2 - etat*(h2-h3s)
23 //State 6 is saturated liquid at 0.7 MPa. Thus,
24 h6 = 697.22

    //in kj/kg
25 //for determining specific enthalpies at states 5
    and 7 ,we have
26 p5 = .7

    //in MPa
27 p4 = .008

    //in MPa
28 p7 = 8

    //in MPa
29 p6 = .7

    //in MPa
30 v4 = 1.0084e-3

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

    //units in m^3/kg,obtained from steam tables
32
33 h5 = h4 + v4*(p5-p4)*10^6*10^-3

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

    //in kj/kg
35
36 //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

```

```

37 y = (h6-h5)/(h2-h5)
38
39 //part(a)
40 wtdot = (h1-h2) + (1-y)*(h2-h3)

    //the total turbine work output, units in KJ/Kg
41 wpdot = (h7-h6) + (1-y)*(h5-h4)                                //The
    total pump work per unit of mass passing through
    the first-stage turbine, in KJ/kg
42 qindot = h1 - h7

    //in kj/kg
43
44 eta = (wtdot-wpdot)/qindot
45 printf('the thermal efficiency is: %f',eta)
46
47 //part(b)
48 m1dot = (Wcycledot*3600*10^3)/(wtdot-wpdot)
49 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

```

1 // (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.

```

2
3
4 //solution
5
6 //analysis
7 //State 1 is the same as in Example 8.3, so
8 h1 = 3348.4

    //in kj/kg
9 s1 = 6.6586

    //in kj/kg.k
10 //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
11 h2 = 2963.5

    //in kj/kg
12 //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
13 h3 = 2741.8

    //in kj/kg

```

```

14 //State 4 is superheated vapor at 0.7 MPa, 440C.
    From Table A-4,
15 h4 = 3353.3

    //in kj/kg
16 s4 = 7.7571

    //in kj/kg.k
17 //interpolating in table A-4 at p5 = .3MPa and s5 =
    s4, the enthalpy at state 5 is
18 h5 = 3101.5

    //in kj/kg
19 //Using s6 = s4, the quality at state 6 is found to
    be
20 x6 = .9382
21 //using steam tables, for state 6
22 hf = 173.88

    //in kj/kg
23 hfg = 2403.1

    //in kj/kg
24
25 h6 = hf + x6*hfg
26
27 //at the condenser exit, we have
28 h7 = 173.88

    //in kj/kg
29 v7 = 1.0084e-3

    //in m^3/kg
30 p8 = .3

    //in MPa
31 p7 = .008

```

```

    //in MPa
32
33 h8 = h7 + v7*(p8-p7)*10^6*10^-3

    //The specific enthalpy at the exit of the first
    pump in kj/kg
34 //The liquid leaving the open feedwater heater at
    state 9 is saturated liquid at 0.3 MPa. The
    specific enthalpy is
35 h9 = 561.47

    //in kj/kg
36
37 //for the exit of the second pump,
38 v9 = 1.0732e-3

    //in m^3/kg
39 p10 = 8

    //in MPa
40 p9 = .3

    //in MPa
41 h10 = h9 + v9*(p10-p9)*10^6*10^-3
    //
    The specific enthalpy at the exit of the second
    pump in kj/kg
42 //The condensate leaving the closed heater is
    saturated at 2 MPa. From Table A-3,
43 h12 = 908.79

    //in kj/kg
44 h13 = h12

    //since The fluid passing through the trap
    undergoes a throttling process
45 //for the feedwater exiting the closed heater
46 hf = 875.1

```



```

47   //in kj/kg
vf = 1.1646e-3

48   //in m^3/kg
p11 = 8

49   //in MPa
psat = 1.73

50   //in MPa
h11 = hf + vf*(p11-psat)*10^6*10^-3
//in
kj/kg
51
52   ydash = (h11-h10)/(h2-h12)

//the fraction of the total flow diverted to the
closed heater
53   ydashdash = ((1-ydash)*h8+ydash*h13-h9)/(h8-h5)
//the fraction of
the total flow diverted to the open heater
54
55 //part(a)
56   wt1dot = (h1-h2) + (1-ydash)*(h2-h3)
//The
work developed by the first turbine per unit of
mass entering in kj/kg
57   wt2dot = (1-ydash)*(h4-h5) + (1-ydash-ydashdash)*(h5
-h6)
//The work developed
by the second turbine per unit of mass in kj/kg
58   wp1dot = (1-ydash-ydashdash)*(h8-h7)
//The
work for the first pump per unit of mass in kj/kg
59   wp2dot = h10-h9

//The work for the second pump per unit of mass
in kj/kg

```

```

60 qindot = (h1-h11) + (1-ydash)*(h4-h3)
//The total heat
    added expressed on the basis of a unit of mass
    entering the first turbine
61
62 eta = (wt1dot+wt2dot-wp1dot-wp2dot)/qindot
//thermal
    efficiency
63 printf('the thermal efficiency is: %f',eta)
64
65 //part(b)
66 Wcycledot = 100

//the net power output of the cycle in MW
67 m1dot = (Wcycledot*3600*10^3)/(wt1dot+wt2dot-wp1dot-
    wp2dot)
68 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

```

1 // (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.

```

```

2
3
4 //solution
5
6 //analysis
7 //The solution to Example 8.2 gives
8 h1 = 2758

    //in kj/kg
9 h4 = 183.36

    //in kj/kg
10 //from table A-22
11 hi = 1491.44

    //in kj/kg
12 he = 843.98

    //in kj/kg
13 //using the conservation of mass principle and
    energy rate balance, the ratio of mass flow rates
    of air and water is
14 madotbymdot = (h1-h4)/(hi-he)
15 //from example 8.2
16 mdot = 4.449e5

    //in kg/h
17 madot = madotbymdot*mdot

    //in kg/h
18
19 //part(a)
20 T0 = 295

    //in kelvin
21 //from table A-22
22 si = 3.34474

```

```

    //in kj/kg.k
23 se = 2.74504

    //in MW
24 Rin = m_dot*(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
25 printf(' the net rate at which exergy is carried
    into the heat exchanger unit by the gas stream,
    in MW is: %f',Rin)
26
27 //part(b)
28 //from table A-3
29 s1 = 5.7432

    //in kj/kg.k
30 //from interpolation in table A-5 gives
31 s4 = .5957

    //in kj/kg.k
32 Rout = m_dot*(h1-h4-T0*(s1-s4))/(3600*10^3)
    //in MW
33 printf('\n\n the net rate at which exergy is carried
    from the heat exchanger by the water stream, in
    MW is: %f',Rout)
34
35 //part(c)
36 Eddot = Rin-Rout

    //in MW
37 printf('\n\n the rate of exergy destruction , in MW is
    : %f',Eddot)
38
39 //part(d)
40 epsilon = Rout/Rin
41 printf('\n\n the exergetic efficiency is: %f',
    epsilon)

```

Scilab code Exa 8.8 Example 8

```
1  //(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  $T_0 = 22\text{C}$ ,
     $p_0 = 1 \text{ atm}$ 
2
3  //solution
4
5  T0 = 295
    //in kelvin
6  P0 = 1
    //in atm
7
8  //analysis
9  //from table A-3
10 s1 = 5.7432
    //in kJ/kg.k
11 //Using  $h_2 = 1939.3 \text{ kJ/kg}$  from the solution to
    Example 8.2, the value of  $s_2$  can be determined
    from Table A-3 as
12 s2 = 6.2021
    //in kJ/kg.k
13
14 mdot = 4.449e5
    //in kg/h
15 Eddot = mdot*T0*(s2-s1)/(3600*10^3)
```

```

//the
rate of exergy destruction for the turbine in MW
16 printf('the rate of exergy destruction for the
turbine in MW is: %f',Eddot)
17 //From the solution to Example 8.7, the net rate at
which exergy is supplied by the cooling
combustion gases is 231.28 MW
18 printf('\n\nThe turbine rate of exergy destruction
expressed as a percentage is: %f ',(Eddot
/231.28)*100)
19 //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
20 printf('\n\npercentage of the exergy entering the
plant with the fuel destroyed within the turbine
is: %f',.69*(Eddot/231.28)*100)
21
22 //from table A-3
23 s3 =.5926

//in kj/kg.k
24 //from solution of example 8.7
25 s4 = .5957

//in kj/kg.k
26 EddotP = mdot*T0*(s4-s3)/(3600*10^3)
//the
exergy destruction rate for the pump
27 printf('\n\nthe exergy destruction rate for the pump
in MW is: %f',EddotP)
28 printf(' and expressing this as a percentage of the
exergy entering the plant as calculated above,
we have %f',(EddotP/231.28)*69 )
29
30 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

```
1 //(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
   .
2
3
4 //solution
5 T0 = 295
   //in kelvin
6 //analysis
7 //from solution to Example 8.2.
8 mcwdot = 9.39e6
   //mass flow rate of the cooling water in kg/h
9
10 //With saturated liquid values for specific enthalpy
   and entropy from Table A-2
11 he = 146.68
```

```

    //in kj/kg
12 hi = 62.99

    //in kj/kg
13 se = .5053

    //in kj/kg.k
14 si = .2245

    //in kj/kg.k
15 Rout = mcwdot*(he-hi-T0*(se-si))/(3600*10^3)

    //
    The net rate at which exergy is carried out of
    the condenser in MW
16 printf(' the net rate at which exergy is carried
    from the condenser by the cooling water, in MW is
    : %f',Rout)
17 printf('. Expressing this as a percentage of the
    exergy entering the plant with the fuel, we get
    %f',(Rout/231.28)*69)
18 printf('percent')
19
20 //part(b)
21 //from table
22 s3 = .5926

    //in kj/kg.k
23 s2 = 6.2021

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

    //in kg/h
25 Eddot = T0*(mdot*(s3-s2)+mcwdot*(se-si))/(3600*10^3)
    //the rate of exergy
    destruction for the condenser in MW
26 printf('\n\nthe rate of exergy destruction for the
    condenser in MW is: %f',Eddot)

```



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

Chapter 9

Gas power systems

Scilab code Exa 9.1 Example 1

```
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, and 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.
2
3 //solution
4
5 //variable initialization
6 T1 = 300
   //The temperature at the beginning of the
   compression process in kelvin
7 p1 = 1
   //the pressure at the beginning of the
   compression process in bar
```

```

8  r = 8

    //compression ratio
9  V1 = 560

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

    //maximum temperature during the cycle in kelvin
11
12 //part(a)
13 //at T1 = 300k, table A-22 gives
14 u1 = 214.07

    //in kj/kg
15 vr1 = 621.2
16 //For the isentropic compression Process 1 2
17 vr2 = vr1/r
18 //Interpolating with vr2 in Table A-22, we get
19 T2 = 673

    //in kelvin
20 u2 = 491.2

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

    //in bars
23 //Since Process 2 3 occurs at constant volume, the
    ideal gas equation of state gives
24 p3 = p2*(T3/T2)

    //in bars
25 //At T3 = 2000 K, Table A-22 gives
26 u3 = 1678.7

```

```

    //in kj/kg
27 vr3 = 2.776
28 //For the isentropic expansion process 3 4
29 vr4 = vr3*(r)
30 //Interpolating in Table A-22 with vr4 gives
31 T4 = 1043

    //in kelvin
32 u4 = 795.8

    //in kj/kg
33 //the ideal gas equation of state applied at states
    1 and 4 gives
34 p4 = p1*(T4/T1)

    //in bars
35 printf('at state1, the pressure in bar is: %f',p1)
36 printf('\natstate1, the temperature in kelvin is %f
    ',T1)
37 printf('\n\nat state2, the pressure in bar is: %f',
    p2)
38 printf('\natstate2, the temperature in kelvin is %f
    ',T2)
39 printf('\n\nat state3, the pressure in bar is: %f',
    p3)
40 printf('\natstate3, the temperature in kelvin is %f
    ',T3)
41 printf('\n\nat state4, the pressure in bar is: %f',
    p4)
42 printf('\natstate4, the temperature in kelvin is %f
    ',T4)
43
44 //part(b)
45 eta = 1-(u4-u1)/(u3-u2)

    //thermal efficiency
46 printf('\n\n\nthe thermal efficiency is: %f',eta)
47

```

```

48 //part(c)
49 R = 8.314

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

    //molar mass of air in grams
51 m = ((p1*V1)/((R/M)*T1))*10^-6*10^5*10^-3
                                           //mass of
    the air in kg
52
53 Wcycle = m*((u3-u4)-(u2-u1))

    //the net work per cycle in KJ
54 mep = (Wcycle/(V1*(1-1/r)))*10^6*10^3*10^-5
                                           //in bars
55 printf('\n\nthe mean effective pressure, in atm.
    is:    %f',mep/1.01325)

```

Scilab code Exa 9.2 Example 2

```

1 // (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.
2
3 //solution
4
5 //variable initialization
6 r = 18

```

```

7      //compression ratio
7  T1 = 300

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

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

      //cutoff ratio
10
11 //part(a)
12 //With T1 = 300 K, Table A-22 gives
13 u1 = 214.07

      //in kj/kg
14 vr1 = 621.2
15 //For the isentropic compression process 1 2
16 vr2 = vr1/r
17 //Interpolating in Table A-22, we get
18 T2 = 898.3

      //in kelvin
19 h2 = 930.98

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

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

      //in kelvin
24 //From Table A-22,

```

```

25 h3 = 1999.1

    //in kj/kg
26 vr3 = 3.97
27
28 p3 = p2
29 //For the isentropic expansion process 3 4
30 vr4 = (r/rc)*vr3
31 //Interpolating in Table A-22 with vr4, we get
32 u4 = 664.3

    //in kj/kg
33 T4 = 887.7

    //in kelvin
34 //the ideal gas equation of state applied at states
    1 and 4 gives
35 p4 = p1*(T4/T1)

    //in MPa
36 printf('at state1, the pressure in bar is: %f',p1)
37 printf('\natstate1, the temperature in kelvin is %f
    ',T1)
38 printf('\n\nat state2, the pressure in bar is: %f',
    p2)
39 printf('\natstate2, the temperature in kelvin is %f
    ',T2)
40 printf('\n\nat state3, the pressure in bar is: %f',
    p3)
41 printf('\natstate3, the temperature in kelvin is %f
    ',T3)
42 printf('\n\nat state4, the pressure in bar is: %f',
    p4)
43 printf('\natstate4, the temperature in kelvin is %f
    ',T4)
44
45 //part(b)
46 eta = 1- (u4-u1)/(h3-h2)

```

```

47 printf('\n\nthe thermal efficiency is: %f',eta)
48
49 //part(c)
50 wcycle = (h3-h2)-(u4-u1)

    //The net work of the cycle in kj/kg
51 R = 8.314

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

    //molar mass of air in grams
53 v1 = ((R/M)*T1/p1)/10^3

    //The specific volume at state 1 in m^3/kg
54
55 mep = (wcycle/(v1*(1-1/r)))*10^3*10^-6 //in MPa
56 printf('\n\nthe mean effective pressure, in MPa is
: %f',mep)

```

Scilab code Exa 9.3 Example 3

```

1 // (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.
2
3
4 //solution

```



```

5
6 //variable initialization
7 T1 = 300

    //beginning temperature in kelvin
8 p1 = .1

    //beginning pressure in MPa
9 r = 18

    //compression ratio
10 pr = 1.5

    //The pressure ratio for the constant volume part
    //of the heating process
11 vr = 1.2

    // The volume ratio for the constant pressure
    //part of the heating process
12
13 //analysis
14 //States 1 and 2 are the same as in Example 9.2, so
15 u1 = 214.07

    //in kj/kg
16 T2 = 898.3

    //in kelvin
17 u2 = 673.2

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

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

```

```

22     //in kj/kg
    u3 = 1065.8

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

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

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

    //in kj/kg
32
33 //part(a)
34 eta = 1-(u5-u1)/((u3-u2)+(h4-h3))
35 printf('the thermal efficiency is: %f',eta)
36
37 //part(b)
38 //The specific volume at state 1 is evaluated in
    Example 9.2 as
39 v1 = .861

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

```

Scilab code Exa 9.4 Example 4

```
1  //(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.
2
3  //solution
4
5  //variable initialization
6  T1 = 300
      //in kelvin
7  AV = 5
      //volumetric flow rate in m3/s
8  p1 = 100
      //in kpa
9  pr = 10
      //compressor pressure ratio
10 T3 = 1400
      //turbine inlet temperature in kelvin
11
12 //analysis
13 //At state 1, the temperature is 300 K. From Table A
      -22,
14 h1 = 300.19
```

```

    //in kj/kg
15 pr1 = 1.386
16
17 pr2 = pr*pr1
18 //interpolating in Table A-22,
19 h2 = 579.9

    //in kj/kg
20 //from Table A-22
21 h3 = 1515.4

    //in kj/kg
22 pr3 = 450.5
23
24 pr4 = pr3*1/pr
25 //Interpolating in Table A-22, we get
26 h4 = 808.5

    //in kj/kg
27
28 //part(a)
29 eta = ((h3-h4)-(h2-h1))/(h3-h2)

    //thermal efficiency
30 printf('the thermal efficiency is: %f',eta)
31
32 //part(b)
33 bwr = (h2-h1)/(h3-h4)

    //back work ratio
34 printf('\nthe back work ratio is: %f',bwr)
35
36 //part(c)
37 R = 8.314

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

```

```

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

    //mass flow rate in kg/s
40
41 Wcycledot = mdot*((h3-h4)-(h2-h1))
//
    The net power developed
42 printf('\n the net power developed , in kW is: %f',
    Wcycledot)

```

Scilab code Exa 9.5 Example 5

```

1 printf('theoretical problem')

```

Scilab code Exa 9.6 Example 6

```

1 //(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.
2
3 //solution
4
5
6 etat = .8

    //turbine efficiency
7 etac = .8

    //compressor efficiency

```

```

8 //part(a)
9 wtdots = 706.9

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

    //in kj/kg
12
13 wcdots = 279.7

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

    //in kj/kg
16
17 h1 = 300.19

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

    //in kj/kg
19
20 h3 = 1515.4

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

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

    //thermal efficiency

```

```

23 printf('the thermal efficiency is: %f',eta)
24
25 //part(b)
26 bwr = wcdot/wtdot

    //back work ratio
27 printf('\nthe back work ratio is: %f',bwr)
28
29 //part(c)
30 mdot = 5.807

    //in kg/s, from example 9.4
31 Wcycledot = mdot*(wtdot-wcdot)

    //The net power developed by the cycle in kw
32 printf('\nthe net power developed, in kW. is: %f',
    Wcycledot)

```

Scilab code Exa 9.7 Example 7

```

1 // (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%.
2
3 //solution
4
5
6 //part(a)
7 etareg = .8

    //regenerator effectiveness of 80%.

```

```

8 //from example 9.4
9 h1 = 300.19

    //in kj/kg
10 h2 = 579.9

    //in kj/kg
11 h3 = 1515.4

    //in kj/kg
12 h4 = 808.5

    //in kj/kg
13
14 hx = etareg*(h4-h2)+h2

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

    //
    thermal efficiency
16 printf('the thermal efficiency is: %f',eta)
17
18 //part(b)
19 etareg = linspace(0,.8,50)
20 for i= 1:50
21     hx(1,i) = etareg(1,i)*(h4-h2)+h2
22 end
23 for i = 1:50
24     eta(1,i) = ((h3-h4) - (h2-h1))/(h3-hx(1,i))
25 end
26 plot(etareg,eta)
27 xtitle(""," Regenerator effectiveness"," Thermal
    efficiency")

```

Scilab code Exa 9.8 Example 8


```

1  //(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.

2
3
4  //solution
5
6  //analysis
7  //States 1, 2, and 3 are the same as in Example 9.4:
8  h1 = 300.19

    //in kj/kg
9  h2 = 579.9

    //in kj/kg
10 h3 = 1515.4

    //in kj/kg
11 //The temperature at state b is the same as at state
    3, so
12 hb = h3
13
14 pa = 300

    //in kpa
15 p3 = 1000

    //in kpa
16 //from table A-22
17 pr3 = 450.5

```

```

18 pra = pr3*(pa/p3)
19 //Interpolating in Table A-22, we get
20 ha = 1095.9

    //in kj/kg
21
22 p4 = 100

    //in kpa
23 pb = 300

    //in kpa
24 prb = pra
25 pr4 = prb*(p4/pb)
26 //Interpolating in Table A-22, we obtain
27 h4 = 1127.6

    //in kj/kg
28 //Since the regenerator effectiveness is 100%,
29 hx = h4
30
31 eta = ((h3-ha)+(hb-h4)-(h2-h1))/((h3-hx)+(hb-ha))
    //thermal
    efficiency
32 printf('the thermal efficiency is: %f',eta)

```

Scilab code Exa 9.9 Example 9

```

1 // (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

```
2
3
4 //solution
5
6 //variable initialization
7 T1 = 300

    //in kelvin
8 p1 = 100

    //in kpa
9 p2 = 1000

    //in kpa
10 p3 = p2
11 pc = 300

    //in kpa
12 pd = 300

    //in kpa
13 Td = 300

    //in kelvin
14
15
16 //part(a)
17 //from table A-22
18 prd = 1.386
19 pr2 = prd*(p2/pd)
20 //Interpolating in Table A-22, we get
```

```

21 T2 = 422

    //in kelvin
22 h2 = 423.8

    //in kj/kg
23 printf('the temperature at the exit of the second
    compressor stage is: %f',T2)
24
25 //part(b)
26 //From Table A-22 at T1 = 300
27 h1 = 300.19

    //in kj/kg
28 //Since Td = T1,
29 hd = 300.19

    //in kj/kg
30 //with pr data from Table A-22 together
31 pr1 = 1.386
32 prc = pr1*(pc/p1)
33 //Interpolating in Table A-22, we obtain
34 hc = 411.3

    //in kj/kg
35
36 wcdot = (hc-h1)+(h2-hd)

    //the total compressor work per unit of mass in
    kj/kg
37 printf('\n\nthe total compressor work input per unit
    of mass flow is: %f',wcdot)
38
39 //part(c)
40 pr3 = pr1*(p3/p1)
41 //Interpolating in Table A-22, we get
42 T3 = 574

```

```

//in kelvin
43 h3 = 579.9

//in kj/kg
44
45 wcdot = h3-h1

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

```

Scilab code Exa 9.10 Example 10

```

1 printf('theoretical problem')

```

Scilab code Exa 9.11 Example 11

```

1 //(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.
2
3
4 //solution
5
6 //variable initialization
7 T1 = 300

    //in kelvin
8 p1 = 100

    //in kpa
9 mdot = 5.807

    //in kg/s
10 p2 = 300

    //in kpa
11 p3 = p2
12 p4 = 1000

    //in kpa
13 p5 = p4
14 p6 = p4
15 T6 = 1400

    //in kelvin
16 T8 = T6
17 p7 = 300

    //in kpa
18 p8 = p7
19 etac = .8

    //isentropic efficiency of compressor
20 etat = .8

```

```

//isentropic efficiency of turbine
21 etareg = .8

//regenerator effectiveness
22 //analysis
23 //from example 9.9
24 h1 = 300.19

//in kj/kg
25 h3 = h1

//in kj/kg
26 h2s = 411.3

//in kj/kg
27 h4s = 423.8

//in kj/kg
28 //from example 9.8
29 h6 = 1515.4

//in kj/kg
30 h8 = h6
31 h7s = 1095.9

//in kj/kg
32 h9s = 1127.6

//in kj/kg
33
34 h4 = h3 + (h4s-h3)/etac

//in kj/kg
35 h2 = h1 + (h2s-h1)/etac

//in kj/kg
36
37 h9 = h8-etat*(h8-h9s)

```

```

38 //in kj/kg
   h7 = h6-etat*(h6-h7s)

   //in kj/kg
39
40 h5 = h4+etareg*(h9-h4)

   //in kj/kg
41
42 //part(a)
43 wtdot = (h6-h7)+(h8-h9)

   //The total turbine work per unit of mass flow in
   kj/kg
44 wcdot = (h2-h1)+(h4-h3)

   //The total compressor work input per unit of
   mass flow in kj/kg
45 qindot = (h6-h5)+(h8-h7)

   //The total heat added per unit of mass flow in
   kj/kg
46
47 eta = (wtdot-wcdot)/qindot

   //thermal efficiency
48 printf('the thermal efficiency is: %f',eta)
49
50 //part(b)
51 bwr = wcdot/wtdot

   //back work ratio
52 printf('\nthe back work ratio is: %f',bwr)
53
54 //part(c)
55 Wcycledot = mdot*(wtdot-wcdot)

```



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

Scilab code Exa 9.12 Example 12

```
1  //(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.
2
3  //solution
4
5  //variable initialization
6  Ta = 240
    //in kelvin
7  pa = .8
    //in bar
8  Va = 278
    //in m/s
9  PR = 8
```

```

    //pressure ratio across the compressor
10 T3 = 1200

    //in kelvin
11 p5 = .8

    //in bar
12
13 //from table A-22
14 ha = 240.02

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

    //in kj/kg
16 //Interpolating in Table A-22 gives
17 pr1 = 1.070
18 pra = .6355
19 p1 = (pr1/pr)*pa

    //in bars
20
21 p2 = PR*p1

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

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

    //in kj/kg
26 //using assumption 'There is no pressure drop for
    flow through the combustor',
27 p3 = p2
28 //with the help of assumption, 'The turbine work

```

```

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

        //in kj/kg
30 //Interpolating in Table A-22 with h4, gives
31 pr4 = 116.8
32 //pr data from table A-22 gives
33 pr4 = 116
34 pr3 = 238
35
36 p4 = p3*(pr4/pr3)

        //in bars
37
38 //The expansion through the nozzle is isentropic to
39 p5 = .8

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

        //in kj/kg
43
44 V5 = sqrt(2*(h4-h5)*10^3)

        //the velocity at the nozzle exit in m/s
45
46 printf('the velocity at the nozzle exit in m/s is:
        %f',V5)
47 printf('\npa in bars = %f',pa)
48 printf('\np1 in bars = %f',p1)
49 printf('\np2 in bars = %f',p2)
50 printf('\np3 in bars = %f',p3)
51 printf('\np4 in bars = %f',p4)
52 printf('\np5 in bars = %f',p5)

```

Scilab code Exa 9.13 Example 13

```
1 // (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  $T_0 = 300$  K,  $p_0 = 100$  kPa.
2
3 //solution
4 Wnetdot = 45
   //in MW
5 T1 = 300
   //in kelvin
6 p1 = 100
```

```

//in kpa
7 etac = .84

//The isentropic efficiency of the compressor
8 T3 = 1400

//in kelvin
9 p2 = 1200

//in kpa
10 p3 = p2
11 etat = .88

//isentropic efficiency of the turbine
12 T5 = 400

//in kelvin
13 p4 = 100

//in kpa
14 p5 = p4
15 T7 = 400

//in degree celcius
16 p7 = 8

//in MPa
17 etatw = .9

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

//in kpa
19 p9 = p8
20 etap = .8

```

```

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

        //in kelvin
22  p0 = 100

        //in kpa
23
24  //analysis
25  //with procedure similar to that used in the
        examples of chapters 8 and 9,we can determine
        following property data
26  h1 = 300.19

        // in kj/kg
27  h2 = 669.79

        // in kj/kg
28  h3 = 1515.42

        // in kj/kg
29  h4 = 858.02

        // in kj/kg
30  h5 = 400.98

        // in kj/kg
31  h6 = 183.96

        // in kj/kg
32  h7 = 3138.30

        // in kj/kg
33  h8 = 2104.74

        // in kj/kg
34  h9 = 173.88

```

```

35     // in kj/kg
s1 = 1.7020

36     //in kj/kg.k
s2 = 2.5088

37     //in kj/kg.k
s3 = 3.3620

38     //in kj/kg.k
s4 = 2.7620

39     //in kj/kg.k
s5 = 1.9919

40     //in kj/kg.k
s6 = 0.5975

41     //in kj/kg.k
s7 = 6.3634

42     //in kj/kg.k
s8 = 6.7282

43     //in kj/kg.k
s9 = 0.5926

44
45 //part(a)
46 //by applying mass and energy rate balances
47 mvdotbymgdot = (h4-h5)/(h7-h6)

48
49 //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
50 mvdot = mvdotbymgdot*mgdot

    //mass flow rate of vapor in kg/s
51
52 Wgasdot = mgdot*((h3-h4)-(h2-h1))*10^-3           //net
    power developed by gas turbine in MW
53 Wvapdot = mvdot*((h7-h8)-(h6-h9))*10^-3         //net
    power developed by vapor cycle in MW
54
55 printf('mass flow rate of air in kg/s is:  %f',mgdot
    )
56 printf('\nmass flow rate of vapor in kg/s is:  %f',
    mvdot)
57 printf('\nnet power developed by gas turbine in MW
    is:  %f',Wgasdot)
58 printf('\nnet power developed by vapor cycle in MW
    is:  %f',Wvapdot)
59
60
61 //part(b)
62 //The net rate of exergy increase of the air passing
    through the combustor is
63 Edotf32 = mgdot*(h3-h2-T0*(s3-s2))*10^-3           //in MW
64 //The net rate exergy is carried out by the exhaust
    air stream at 5 is
65 Edotf51 = mgdot*(h5-h1-T0*(s5-s1))/10^3           //in MW
66 //The net rate exergy is carried out as the water
    passes through the condenser is
67 Edotf89 = mvdot*(h8-h9-T0*(s8-s9))*10^-3         //in MW
68
69 R = 8.314

```



```

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

//molar mass of air in grams
71 //the rate of exergy destruction for air turbine is
72 Eddott = mgdot*T0*(s4-s3-(R/M)*log(p4/p3))/10^3
//in MW
73 //the rate of exergy destruction for compressor is
74 Eddotc = mgdot*T0*(s2-s1-(R/M)*log(p2/p1))/10^3
//in MW
75 //the rate of exergy destruction for steam turbine
is
76 Eddotst = mvdot*T0*(s8-s7)/10^3

//in MW
77 //the rate of exergy destruction for pump is
78 Eddotp = mvdot*T0*(s6-s9)/10^3

//in MW
79 //for heat exchanger
80 EddotHE = T0*(mgdot*(s5-s4)+mvdot*(s7-s6))/10^3
//in MW

81
82 printf('\n\nbalance sheet')
83 printf('\nNet exergy increase of the gas passing')
84 printf('\nthrough the combustor:\t%f',Edotf32)
85 printf('\nDisposition of the exergy:')
86 printf('\n Net power developed')
87 printf('\ngas turbine cycle\t%f',Wgasdot)
88 printf('\nvapor cycle\t%f',Wvapdot)
89 printf('\n Net exergy lost')
90 printf('\nwith exhaust gas at state 5\t%f',Edotf51)
91 printf('\nfrom water passing through condenser\t%f',
Edotf89)
92 printf('\n Exergy destruction')
93 printf('\nair turbine\t%f',Eddott)
94 printf('\ncompressor\t%f',Eddotc)
95 printf('\nsteam turbine\t%f',Eddotst)

```

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

Scilab code Exa 9.14 Example 14

```
1  //(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.
2
3  //solution
4
5  //variable initialization
6  Tnot = 360
    //in kelvin
7  pnot = 1
    //in MPa
8  A2 = .001
    //in m^2
9  k = 1.4
10
11  pstarbypnot = (1+(k-1)/2)^(k/(1-k))
12  pstar = pstarbypnot*pnot
13  //part(a)
14  //since back pressure of 500 kpa is less than
    critical pressure pstar(528kpa in this case)
    found above, the nozzle is choked
15  //at the exit
16  M = 1
```

```

17 p2 = pstar

    //in MPa
18 printf('the exit mach number for back pressure of
    500kpa is: %f',M)
19 T2 = Tnot/(1+((k-1)/2)*(M^2))

    //exit temperature in kelvin
20 R = 8.314

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

    //molar mass of air in grams
22 V2 = sqrt(k*(R/M)*T2*10^3)

    //exit velocity in m/s
23 mdot = (p2/((R/M)*T2))*A2*V2*10^3

    //
    mass flow rate in kg/s
24 printf('\nthe mass flow rate in kg/s for back
    pressure of 500kpa is: %f',mdot)
25
26 //part(b)
27 //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 ,
28 p2 = 784

    //exit pressure in kpa
29 M2 = {(2/(k-1))*[(pnot*10^3/p2)^((k-1)/k)-1]}^.5
    //exit mach number
30 T2 = Tnot/(1+((k-1)/2)*(M2^2))

    //exit temperature in kelvin
31 V2 = M2*sqrt(k*(R/M)*10^3*T2)

```

```

    //exit velocity in m/s
32 mdot2 = (p2/((R/M)*T2))*A2*V2

    //mass flow rate in kg/s
33 printf('\n\nthe mass flow rate at the exit in kg/s
    for back pressure of 784kpa is: %f',mdot2)
34 printf('\nthe exit mach number for back pressure of
    784 kpa is: %f',M2)

```

Scilab code Exa 9.15 Example 15

```

1 // (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.
2
3 //solution
4
5 //part(a)
6 Mt = .7

```

```

    //mach number at the throat
7  At = 6.25

    //throat area in cm^2
8  Ae = 15

    //exit area in cm^2
9  //With Mt = 0.7, Table 9.1 gives
10 AtbyAstar = 1.09437
11
12 A2byAstar = (Ae/At)*AtbyAstar
13 //The flow throughout the nozzle, including the exit
    , is subsonic. Accordingly, with this value for
    A2byAstar, Table 9.1 gives
14 M2 = .24
15 //For M2 = 0.24,
16 T2byTnot = .988
17 p2bypnot = .959
18 k = 1.4
19 T0 = 280

    //in kelvin
20 pnot = 6.8

    //in bars
21
22 T2 = T2byTnot*T0

    //in kelvin
23 p2 = p2bypnot*pnot

    //in bars
24
25 V2 = M2*sqrt((k*(8.314/28.97)*T2*10^3)) //
    velocity at the exit in m/s
26 mdot = (p2/((8.314/28.97)*T2))*Ae*V2*10^-2 //mass flow

```

```

    rate in kg/s
27 printf('part(a)  the mass flow rate in kg/s is:  %f'
    ,mdot)
28 printf('\nthe exit pressure in bars is:  %f',p2)
29 printf('\nthe exit mach number is:  %f',M2)
30
31 //part(b)
32 Mt = 1

    //mach number at the throat
33 //from table 9.1
34 M2 = .26
35 T2byTnot = .986
36 p2bypnot = .953
37
38 T0 = 280

    //in kelvin
39 pnot = 6.8

    //in bars
40
41 T2 = T2byTnot*T0

    //in kelvin
42 p2 = p2bypnot*pnot

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

    //exit velocity in m/s
45 mdot = (p2/((8.314/28.97)*T2))*Ae*V2*10^-2
                                                    //mass
    flow rate in kg/s
46
47 printf('\n\n\npart(b)  the mass flow rate in kg/s is
    :  %f',mdot)

```

```

48 printf('\nthe exit pressure in bars is: %f',p2)
49 printf('\nthe exit mach number is: %f',M2)
50
51 //part(c)
52 //from part (b), the exit Mach number in the present
    part of the example is
53 M2 = 2.4
54 //Using this, Table 9.1 gives
55 p2bypnot = .0684
56
57 pnot = 6.8

    //in bars
58
59 p2 = p2bypnot*pnot

    //in bars
60 //Since the nozzle is choked, the mass flow rate is
    the same as found in part (b).
61 printf('\n\n\nc) the mass flow rate in kg/s is
    : %f',mdot)
62 printf('\nthe exit pressure in bars is: %f',p2)
63 printf('\nthe exit mach number is: %f',M2)
64
65 //part(d)
66 //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),
67 Mx = 2.4
68 px = .465

    //in bars
69 //Then, from Table 9.2
70 My = .52
71 pybypx = 6.5533
72 //The pressure downstream of the shock is thus 3.047
    bars. This is the exit pressure

```

```

73 //The mass flow is the same as found in part (b).
74
75 printf('\n\n\npart(d)  the mass flow rate in kg/s is
       : %f',mdot)
76 printf('\nthe exit pressure in bars is: %f',3.047)
77 printf('\nthe exit mach number is: %f',My)
78
79 //part(e)
80 //a shock stands in the diverging portion where the
       area is
81 Ax = 12.5

       //in cm^2
82 //Since a shock occurs, the flow is sonic at the
       throat, so
83 Axstar = 6.25

       //in cm^2
84 At = Axstar
85 //The Mach number Mx can then be found from Table
       9.1, by using AxbyAxstar as
86 Mx = 2.2
87 //With Mx = 2.2, the ratio of stagnation pressures
       is obtained from Table 9.2 as
88 pnotybypnotx = .62812
89
90 A2byAystar = (Ae/Axstar)*pnotybypnotx
91 //Using this ratio and noting that the flow is
       subsonic after the shock, Table 9.1 gives
92 M2 = .43
93 //for M2 = .43,
94 p2bypnoty = .88
95
96 p2 = p2bypnoty*pnotybypnotx*pnot

//
       in bars
97 //Since the flow is choked, the mass flow rate is
       the same as that found in part (b).

```



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

Chapter 10

Refrigeration and heat pump systems

Scilab code Exa 10.1 Example 1

```
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.
2
3 //solution
4
5 //variable initialization
6
7 Tc = 273
```

```

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

      //temperature of hot region in kelvin
9  mdot = .08

      //mass flow rate in kg/s
10
11 //analysis
12 //At the inlet to the compressor, the refrigerant is
      a saturated vapor at 0C, so from Table A-10
13 h1 = 247.23

      //in kj/kg
14 s1 = .9190

      //in kj/kg.k
15
16 //The pressure at state 2s is the saturation
      pressure corresponding to 26C, or
17 p2 = 6.853

      //in bars
18 //The refrigerant at state 2s is a superheated vapor
      with
19 h2s = 264.7

      //in kj/kg
20 //State 3 is saturated liquid at 26C, so
21 h3 = 85.75

      //in kj/kg
22 h4 = h3

      //since The expansion through the valve is a
      throttling process
23

```

```

24 //part(a)
25 Wcdot = mdot*(h2s-h1)

    //The compressor work input in KW
26 printf('the compressor power, in kW, is:  %f',Wcdot)
27
28 //part(b)
29 Qindot = mdot*(h1-h4)*60/211

    //refrigeration capacity in ton
30 printf('\nthe refrigeration capacity in tons is:  %f
    ',Qindot)
31
32 //part(c)
33 funcprot(0)
34 beta = (h1-h4)/(h2s-h1)
35 printf('\nthe coefficient of performance is:  %f',
    beta)
36
37 //part(d)
38 betamax = Tc/(Th-Tc)
39 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

```

1 //(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.
2
3 //solution
4 mdot = .08

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

    //in kj/kg
8 s1 = .9253

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

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

    //in kj/kg
13 h4 = h3

    //since The expansion through the valve is a
    throttling process
14
15 //part(a)
16 Wcdot = mdot*(h2s-h1)

    //The compressor power input in KW
17 printf('the compressor power in kw is: %f',Wcdot)
18
19 //part(b)

```

```

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

    //refrigeration capacity in tons
21 printf('\nthe refrigeration capacity in tons is: %f
    ',Qindot)
22
23 //part(c)
24 beta = (h1-h4)/(h2s-h1)
25 printf('\nthe coefficient of performance is: %f',
    beta)

```

Scilab code Exa 10.3 Example 3

```

1 // (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  $T_0 = 299$  K (26C).
2
3 //solution
4 Tnot = 299

    //in kelvin
5 etac = .8

    //compressor efficiency of 80 percent
6 mdot = .08

    //mass flow rate in kg/s

```

```

7 //analysis
8 //State 1 is the same as in Example 10.2, so
9 h1 = 241.35

    //in kj/kg
10 s1 = .9253

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

    //in kj/kg
13 h2 = (h2s-h1)/etac + h1

    //in kj/kg
14 //Interpolating in Table A-12,
15 s2 = .9497

    //in kj/kg.k
16
17 h3 = 91.49

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

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

    //in kj/kg
22 hg4 = 241.36

    //in kj/kg
23 sf4 = .1486

    //in kj/kg.k

```

```

24 sg4 = .9253

    //in kj/kg.k
25 x4 = (h4-hf4)/(hg4-hf4)

    //quality at state 4
26 s4 = sf4 + x4*(sg4-sf4)

    //specific entropy at state 4 in kj/kg.k
27
28 //part(a)
29 Wcdot = mdot*(h2-h1)

    //compressor power in kw
30 printf('the compressor power in kw is: %f',Wcdot)
31
32 //part(b)
33 Qindot = mdot*(h1-h4)*60/211

    //refrigeration capacity in ton
34 printf('\n\nthe refrigeration capacity in ton is:
    %f',Qindot)
35
36 //part(c)
37 beta = (h1-h4)/(h2-h1)

    //coefficient of performance
38 printf('\n\nthe coefficient of performance is: %f',
    beta)
39
40 //part(d)
41 Eddotc = mdot*Tnot*(s2-s1)

    //in kw
42 Eddotv = mdot*Tnot*(s4-s3)

    //in kw
43 printf('\n\nthe rate of exergy destruction within

```



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

Scilab code Exa 10.4 Example 4

```
1 //(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
2
3 //solution
4
5 //variable initialization
6 p1 = 1
//in bar
7 T1 = 270
//in kelvin
8 AV = 1.4
//in m3/s
9 r = 3
//compressor pressure ratio
10 T3 = 300
//turbine inlet temperature in kelvin
11
12 //analysis
```

```

13 //From Table A-22,
14 h1 = 270.11

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

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

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

    //in kj/kg
25
26 //part(a)
27 R = 8.314

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

    //molar mass of air in grams
29 mdot = (AV*p1)/((R/M)*T1)*10^2

    //mass flow rate in kg/s
30
31 Wcycledot = mdot*((h2s-h1)-(h3-h4s))
32 printf('the net power input in kw is: %f',Wcycledot
    )
33
34 //part(b)
35 Qindot = mdot*(h1-h4s)

```

```

    //refrigeration capacity in kw
36 printf('\nthe refregeration capacity in kw is: %f',
    Qindot)
37
38 //part(c)
39 beta = Qindot/Wcycledot

    //coefficient of performance
40 printf('\nthe coefficient of performance is: %f',
    beta)

```

Scilab code Exa 10.5 Example 5

```

1 // (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.
2
3 //solution
4 funcprot(0)
5
6 //part(a)
7 wcdots = 99.99

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

    //mass flow rate in kg/s from 10.4
9 etac = .8

```

```

    //isentropic efficiency of compressor
10 Wcdot = mdot*wcdots/etac

    //The power input to the compressor in kw
11
12 //Using data form the solution to Example 10.4 gives
13 wtdots =81.19

    //in kj/kg
14 etat = .8

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

    //actual turbine work in kw
16
17 Wdotcycle = Wcdot-Wtdot

    //The net power input to the cycle in kw
18 printf('the net power input in kw is: %f',Wdotcycle
    )
19
20 //part(b)
21 h3 = 300.19

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

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

    //refrigeration capacity in kw
26 printf('\nthe refrigeration capacity in kw is: %f',
    Qindot)
27

```

```
28 //part(c)
29 beta = Qindot/Wdotcycle

    //coefficient of performance
30 printf('\nthe coefficient of performance is: %f',
    beta)
```

Chapter 11

Thermodynamic relations

Scilab code Exa 11.1 Example 1

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

```

9 L = 1

    //length of the cylinder in meter
10
11 //analysis
12 V = (%pi*D^2/4)*L

    //volume occupied by the gas in m^3
13 M = 28

    //molar mass in kg/kmol
14 vbar = M*(V/m)

    //The molar specific volume in m^3/kmol
15
16 //part(a)
17 //From Table A-1 for CO
18 Tc = 133

    //in kelvin
19 Pc = 35

    //in bar
20 Tr = T/Tc

    //reduced temperature
21 Rbar = 8314

    //universal gas constant in N.m/kmol.K
22 vrdash = (vbar*Pc&10^5)/(Rbar*Tc)

    pseudoreduced specific volume //
23 Z = .9
24
25 p = (Z*Rbar*T/vbar)*10^-5

    //in bar
26 printf('part(a)the pressure in bar is: %f',p)

```

```

27
28 //part(b)
29 //The ideal gas equation of state gives
30 p = (Rbar*T/vbar)/10^5

    //in bar
31 printf('\npart(b)the pressure in bar is: %f',p)
32
33 //part(c)
34 //For carbon monoxide, the van der Waals constants a
    and b can be read directly from Table A-24
35 a = 1.474

    //in (m^3/kmol)^2
36 b = .0395

    //in m^3/kmol
37
38 p = (Rbar*T/(vbar-b))/10^5 - a/vbar^2
39 printf('\npart(c)the pressure in bars is: %f',p)
40
41 //part(d)
42 //For carbon monoxide, the RedlichKwong constants
    can be read directly from Table A-24
43 a = 17.22

    //in m^6*K^.5/kmol^2
44 b = .02737

    //in m^3/kmol
45
46 p = (Rbar*T/(vbar-b))/10^5 - a/[vbar*(vbar+b)*T^.5]
47 printf('\npart(d)the pressure in bar is: %f',p)

```

Scilab code Exa 11.2 Example 2


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

Scilab code Exa 11.3 Example 3

```
1 //(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 RedlichKwong
   equation of state and an appropriate Maxwell
   relation. (b) Check the value obtained using
   steam table data.
2
3 //solution
4
5 //part(a)
6 v = .4646
   //specific volume in in m^3/kg
7 M = 18.02
   //molar mass of water in kg/kmol
8 //At the specified state, the temperature is 513 K
   and the specific volume on a molar basis is
9 vbar = v*M
   //in m^3/kmol
10 //From Table A-24
11 a = 142.59
   //(m^3/kmol)^2 * K^.5
12 b = .0211
   //in m^3/kmol
```

```

13
14 Rbar = 8314

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

    //in kelvin
16 delpbydelT = (Rbar/(vbar-b) + a/[2*vbar*(vbar+b)*T
    ^1.5]*10^5)/10^3           //in kj/(m^3*K)
17
18 //by The Maxwell relation
19 delsbydelv = delpbydelT
20 printf('the value of delpbydelT in kj/(m^3*K) is :
    %f ',delpbydelT)
21
22 //part(b)
23 //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
24 T = 240

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

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

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

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

    //in m^3/kg

```

```

31 //at p = 3 bar
32 s(3,1) = 7.4774

    //in kj/kg.k
33 v(3,1) = .781

    //in m^3/kg
34 //at p = 5 bar
35 s(4,1) = 7.2307

    //in kj/kg.k
36 v(4,1) = .4646

    //in m^3/kg
37 //at p =7 bar
38 s(5,1) = 7.0641

    //in kj/kg.k
39 v(5,1) = .3292

    //in m^3/kg
40 //at p = 10 bar
41 s(6,1) = 6.8817

    //in kj/kg.k
42 v(6,1) = .2275

    //in m^3/kg
43 plot(v,s)
44 xtitle(""," Specific volume, m3/kg", " Specific entropy
    , kJ/kg K")
45 //The pressure at the desired state is 5 bar.The
    corresponding slope is
46 delvbydelv = 1

    //in kj/m^3.K
47 printf('\n\nfrom the data of the table, delvbydelv =
    %f', delvbydelv)

```

Scilab code Exa 11.4 Example 4

```
1  //(11.4)Using p vT data for saturated water ,
    calculate at 100C (a) hg - hf, (b) ug - uf, (c)
    sg - sf. Compare with the respective steam table
    value.
2
3  //solution
4
5  //analysis
6  //For comparison , Table A-2 gives at 100C,
7  hgf =2257

    //in kj/kg
8  ugf = 2087.6

    //in kj/kg
9  sgf = 6.048

    //in kj/kg.K
10 printf('from table , hg-hf = %f',hgf)
11 printf('\nfrom table , ug-uf = %f',ugf)
12 printf('\nfrom table , sg-sf = %f',sgf)
13
14 //(a)
15 T = 373.15

    //in kelvin
16 //If we plot a graph between temperature and
    saturation pressure using saturation
    pressure temperature data from the steam tables
    , the desired slope is:
17 delpbydelT = 3570
```

```

    //in N/(m^2.K)
18
19 vg = 1.673

    //in m^3/kg
20 vf = 1.0435e-3

    //in m^3/kg
21 //from the Clapeyron equation
22 hgf = T*(vg-vf)*delrho/delT*10^-3
//
    in kj/kg
23
24 printf('\n\npart(a) using Clapeyron equation , hg-hf =
    %f', hgf)
25 //(b)
26 psat = 1.014e5

    //in N/m^2
27 hgf = 2256

    //can be obtained using IT software in kj/kg
28 ugf = hgf - psat*(vg-vf)/10^3

    //in kj/kg
29 printf('\n\npart(b) ug-uf = %f', ugf)
30 //(c)
31 sgf = hgf/T

    //in kj/kg.K
32 printf('\n\npart(c) sg-sf = %f', sgf)

```

Scilab code Exa 11.5 Example 5

```

1 printf('theoretical problem')

```

Scilab code Exa 11.6 Example 6

```
1 //(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.  
2  
3 //solution  
4  
5 //part(a)  
6 funcprot(0)  
7 v = 1/998.21  
  
    //specific volume of water in m^3/kg  
8 T = 293  
  
    //given temperature in kelvin  
9 beta = 206.6e-6  
  
    //volume expansivity in /K  
10 k = 45.90e-6  
  
    //isothermal compressibility in /bar  
11  
12 cpv = (v*T*beta^2/k)*10^2  
  
    //in kj/kg.k  
13  
14 //Interpolating in Table A-19  
15 cp = 4.188  
  
    //in kj/kg.k  
16 cv = cp-cpv
```

```

    //in kj/kg.k
17
18 errorPercentage = 100*(cp-cv)/cv
19 printf('the percentage error is: %f',
    errorPercentage)
20
21 //part(b)
22
23 K = cp/cv

    //specific heat ratio
24 c = sqrt((K*v/k)*10^5)

    //velocity of sound in m/s
25 printf('\nthe velocity of sound in m/s is: %f',c)

```

Scilab code Exa 11.7 Example 7

```

1 printf('theoretical problem')

```

Scilab code Exa 11.8 Example 8

```

1 //(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.
2
3 //solution
4

```

```

5 //variable initialization
6 p1 = 100

    //in bar
7 T1 = 300

    //in kelvin
8 p2 = 40

    //in bar
9 T2 = 245

    //in kelvin
10
11
12 //from table A-23
13 h1starbar = 8723

    //in kj/kmol
14 h2starbar = 7121

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

    //critical temperature in kelvin
17 pc = 33.9

    //critical pressure in bar
18 TR1 = T1/Tc

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

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

    //reduced temperature at the exit

```



```

21 PR2 = p2/pc
    //reduced pressure at the exit
22
23 M = 28
    //molar mass in kg/kmol
24 Rbar = 8.314
    //universal gas constant in kj/(kmol.K)
25
26 Term1 = .5
27 Term2 = .31
28
29 wcvdot = (1/M)*[h1starbar-h2starbar-Rbar*Tc*(Term1-
    Term2)] //in kj/kg
30 printf('the work developed, in kJ per kg of nitrogen
    flowing is : %f',wcvdot)

```

Scilab code Exa 11.9 Example 9

```

1 // (11.9) For the case of Example 11.8, determine (a
    ) the rate of entropy production, in and (b) the
    isentropic turbine efficiency.
2
3 //solution
4
5 //part(a)
6 //With values from Table A-23
7 sT2bar = 185.775
    //in kj/(kmol.K)
8 sT1bar = 191.682
    //in kj/(kmol.K)

```

```

9
10 Rbar = 8.314

    //universal gas constant
11 M = 28

    //molar mass in kg/kmol
12 p2 = 40

    //in bar
13 p1 = 100

    //in bar
14
15 S2StarBarMinusS1StarBar = sT2bar-sT1bar-Rbar*log(p2/
    p1) //The change in
    specific entropy in kj/(kmol.K)
16
17 Term1 = .21
18 Term2 = .14
19
20 sigmacvdot = (1/M)*(S2StarBarMinusS1StarBar-Rbar*(
    Term2-Term1))
21 printf('the rate of entropy production in kj/kg.K is
    : %f',sigmacvdot)
22
23 //part(b)
24 //From Table A-23,
25 h2starbar = 6654

    //in kj/kmol
26 h1starbar = 8723

    //in kj/kmol
27 Tc = 126

    //critical temperature in kelvin
28 Term2 = .36

```

```

29 Term1 = .5
30
31 wcvdots = (1/M)*[h1starbar-h2starbar-Rbar*Tc*(Term1-
    Term2)] //isentropic work in
    kj/kg
32 wcvdot = 50.1

    //from example 11.8
33
34 etat = wcvdot/wcvdots

    //turbine efficiency
35 printf('\nthe isentropic turbine efficiency is: %f',
    etat)

```

Scilab code Exa 11.10 Example 10

```

1 // (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) Kays 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.
2
3 //solution
4
5 //analysis
6 V = .241

```

```

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

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

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

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

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

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

    //mole fraction of butane
13 Rbar = 8314

    //universal gas constant in (N.m)/(kmol.K)
14 vbar = V/(n)

    //The specific volume of the mixture on a molar
    basis in m^3/kmol
15
16 //part(a)
17 p = (Rbar*T/vbar)*10^-5

    //in bar
18 printf('the pressure in bar obtained using ideal gas
    equation is: %f',p)
19
20 //part(b)
21 //from table A-1
22 Tc1 = 191

```

```

    //critical temperature for methane in kelvin
23 Pc1 = 46.4

    //critical pressure for methane in bar
24 Tc2 = 425

    //critical temperature for butane in kelvin
25 Pc2 = 38

    //critical pressure for butane in bar
26
27 Tc = y1*Tc1 + y2*Tc2

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

    //critical pressure in bar
29
30 TR = T/Tc

    //reduced temperature of the mixture
31 vRdash= vbar*Pc/(Rbar*Tc)
32
33 Z = .88
34 p = ((Z*Rbar*T)/vbar)*10^-5

    //mixture pressure in bar
35 printf('\npressure obtained using Kay's rule
    together with the generalized compressibility
    chart, is: %f',p)
36
37 //part(c)
38 //Table A-24 gives the following van der Waals
    constants values for methane
39 a1 = 2.293

    //in (m^3/kmol)^2
40 b1 = .0428

```

```

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

//in (m^3/kmol)^2
43 b2 = .1162

//in m^3/kmol
44
45 a = (y1*a1^.5 + y2*a2^.5)^2

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

//in m^3/kmol
47 //from van der Waals equation
48 p = ((Rbar*T)/(vbar-b))*10^-5 - a/(vbar^2)
49 printf('\nthe pressure in bar from van der Waals
    equation is: %f ',p)
50
51 //part(d)
52 //for methane
53 TR1 = T/Tc1
54 vR1dash = (.241/.18)*10^5*Pc1/(Rbar*Tc1)
55 Z1 = 1
56 //for butane
57 TR2 = T/Tc2
58 vR2dash = (.88*10^5*Pc2)/(Rbar*Tc2)
59 Z2 = .8
60 Z = y1*Z1 + y2*Z2
61 //Accordingly, the same value for pressure as
    determined in part (b) using Kays rule results
    :
62 p = 70.4
63 printf('\nthe pressure in bar obtained using the
    rule of additive pressures employing the

```

generalized compressibility chart is: $z = z(p_r, T_r)$

Chapter 12

Ideal gas mixture and psychrometric applications

Scilab code Exa 12.1 Example 1

```
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).
2
3 //solution
4
5 //variable initialization
6 n1 = .08
   // mole fraction of CO2
7 n2 = .11
   // mole fraction of H2O
8 n3 = .07
   //mole fraction of O2
```



```

9  n4 = .74

    //mole fraction of N2
10
11 //part(a)
12 M1 = 44

    //molar mass of CO2 in kg/kmol
13 M2 = 18

    //molar mass of H2O in kg/kmol
14 M3 = 32

    //molar mass of O2 in kg/kmol
15 M4 = 28

    //molar mass of N2 in kg/kmol
16
17 M = M1*n1 + M2*n2 + M3*n3 + M4*n4

    //
    in kg/kmol
18 printf('the apparent molecular weight of the mixture
    in kg/kmol is: %f',M)
19
20 //part(b)
21 mf1 = (M1*n1/M)*100

    //mass fraction of CO2 in percentage
22 mf2 = (M2*n2/M)*100

    //mass fraction of H2O in percentage
23 mf3 = (M3*n3/M)*100

    //mass fraction of O2 in percentage
24 mf4 = (M4*n4/M)*100

    //mass fraction of N2 in percentage
25

```

```

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

```

Scilab code Exa 12.2 Example 2

```

1  //(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.
2
3  //solution
4
5  //variable initialization
6  mf1 = .1
    //mass fraction of H2
7  mf2 = .6
    //mass fraction of N2
8  mf3 = .3
    //mass fraction of CO2
9
10 //part(a)
11 M1 = 2
    //molar mass of H2 in kg/kmol
12 M2 = 28

```

```

13     //molar mass of N2 in kg/kmol
M3 = 44

    //molar mass of CO2 in kg/kmol
14
15 n1 = (mf1/M1)/(mf1/M1 + mf2/M2 + mf3/M3) //mole
    fraction of H2
16 n2 = (mf2/M2)/(mf1/M1 + mf2/M2 + mf3/M3) //mole
    fraction of N2
17 n3 = (mf3/M3)/(mf1/M1 + mf2/M2 + mf3/M3) //mole
    fraction of CO2
18
19 printf('the mole fraction of H2 in percentage is:
    %f',n1*100)
20 printf('\nthe mole fraction of N2 in percentage is:
    %f',n2*100)
21 printf('\nthe mole fraction of CO2 in percentage is:
    %f',n3*100)
22
23 //part(b)
24 M = n1*M1 + n2*M2 + n3*M3

    //in kg/kmol
25 printf('\n\nthe apparent molecular weight of the
    mixture in kg/kmol is: %f',M)

```

Scilab code Exa 12.3 Example 3

```

1 // (12.3) A mixture of 0.3 kg of carbon dioxide and
    0.2 kg of nitrogen is compressed from  $p_1 = 1$  bar,
     $T_1 = 300$  K to  $p_2 = 3$  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.
2
3 //solution
4
5 //variable initialization
6 m1 = .3
    //mass of CO2 in kg
7 m2 = .2
    //mass of N2 in kg
8 p1 = 1
    //in bar
9 T1 = 300
    //in kelvin
10 p2 = 3
    //in bar
11 n = 1.25
12
13 //part(a)
14 T2 = T1*(p2/p1)^[(n-1)/n]
    //in kelvin
15 printf('the final temperature in Kelvin is: %f',T2)
16
17 //part(b)
18 Rbar = 8.314
    //universal gas constant in SI units
19 M = (m1+m2)/(m1/44 + m2/28)
    //molar mass of mixture in kg/kmol

```

```

20
21 W = [(m1+m2)*(Rbar/M)*(T2-T1)]/(1-n)                                     //in
    kj
22 printf('\nthe work in kj is: %f',W)
23
24 //part(c)
25 //from table A-23
26 uC02T1 = 6939
    //internal energy of CO2 on molar mass basis at
    temperature T1
27 uC02T2 = 9198
    //internal energy of CO2 on molar mass basis at
    temperature T2
28 uN2T1 = 6229
    //internal energy of N2 on molar mass basis at
    temperature T1
29 uN2T2 = 7770
    //internal energy of N2 on molar mass basis at
    temperature T2
30 deltaU = (m1/44)*[uC02T2-uC02T1] + (m2/28)*[uN2T2-
    uN2T1] //internal energy
    change of the mixture in KJ
31
32 //with assumption, The changes in kinetic and
    potential energy between the initial and final
    states can be ignored
33 Q = deltaU + W
34 printf('\nthe heat transfer in kj is: %f',Q)
35
36 //part(d)
37 //from table A-23
38 sbarT2C02 = 222.475
39 sbarT1C02 = 213.915

```

```

40 sbarT2N2 = 198.105
41 sbarT1N2 = 191.682
42 Rbar = 8.314

    //universal gas constant
43
44 deltaS = (m1/44)*[sbarT2CO2-sbarT1CO2-Rbar*log(p2/p1
    )] + (m2/28)*[sbarT2N2-sbarT1N2-Rbar*log(p2/p1)]
45 printf('\nthe change in entropy of the mixture in kj
    /k is:  %f',deltaS)

```

Scilab code Exa 12.4 Example 4

```

1 // (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.
2
3 //solution
4
5 //variable initialization
6 y1 = .8

    //mole fraction of CO2
7 y2 = .2

    //mole fraction of O2
8 T1 = 700

    //in kelvin
9 p1 = 5

```

```

10     //in bars
    V1 = 3

    //in m/s
11    p2 = 1

    //in bars
12
13
14    //part(a)
15    //from table A-23
16    sO2barT1 = 231.358
17    sCO2barT1 = 250.663
18
19    RHS = y2*sO2barT1 + y1*sCO2barT1 + 8.314*log(p2/p1)
20
21    //using table A-23
22    LHSat510K = y2*221.206 + y1*235.7
23    LHSat520K = y2*221.812 + y1*236.575
24    //using linear interpolation ,
25    T2 = 510 +[(520-510)/(LHSat520K-LHSat510K)]*(RHS-
        LHSat510K)
26    printf('the temperature at the nozzle exit in K is:
        %f',T2)
27
28    //part(b)
29    //from table A-23
30    sbarO2T2 = 221.667

    //in kj/kmol.K
31    sbarO2T1 = 231.358

    //in kj/kmol.K
32    sbarCO2T2 = 236.365

    //in kj/kmol.K
33    sbarCO2T1 = 250.663

```

```

    //in kj/kmol.K
34
35 deltasbarO2 = sbarO2T2-sbarO2T1-8.314*log(p2/p1)
    //in kj/kmol.K
36 deltasbarCO2 = sbarCO2T2-sbarCO2T1-8.314*log(p2/p1)
    //in kj/kmol.K
37
38 printf('\n\nthe entropy changes of the CO2 from
    inlet to exit , in KJ/Kmol.K is:  %f',deltasbarCO2
    )
39 printf('\n\nthe entropy change of the O2 from inlet to
    the exit in kj/kmol.k is:  %f',deltasbarO2)
40
41 //part(c)
42 //from table A-23, the molar specific enthalpies of
    O2 and CO2 are
43 h1barO2 = 21184
44 h2barO2 = 15320
45 h1barCO2 = 27125
46 h2barCO2 = 18468
47
48 M = y1*44 + y2*32

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

```

Scilab code Exa 12.5 Example 5

```

1 // (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

```
2
3 //solution
4
5 //variable initialization
6 nN2 = .79

    //initial moles of nitrogen in kmol
7 pN2 = 2

    //initial pressure of nitrogen in bars
8 TN2 = 250

    //initial temperature of nitrogen in kelvin
9 nO2 = .21

    //initial moles of oxygen in kmol
10 pO2 = 1

    //initial pressure of oxygen in bars
11 TO2 = 300

    //initial temperature of oxygen in kelvin
12 //part(a)
13 MN2 = 28.01

    //molar mass of nitrogen in kg/kmol
14 MO2 = 32
```

```

    //molar mass of oxygen in kg/kmol
15
16 //with the help of table A-20
17 cvbarN2 = MN2*.743

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

    //in kj/kmol.K
19
20 T2 = (nN2*cvbarN2*TN2+nO2*cvbarO2*T02)/(nN2*cvbarN2+
    nO2*cvbarO2)
21 printf('the final temperature of the mixture in
    kelvin is: %f',T2)
22
23 //part(b)
24 p2 = [(nN2+nO2)*T2]/[nN2*TN2/pN2 + nO2*T02/pO2]
25 printf('\n\nthe final pressure of the mixture in bar
    is: %f',p2)
26
27 //part(c)
28 Rbar = 8.314

    //universal gas constant
29 cpbarN2 = cvbarN2 + Rbar
30 cpbarO2 = cvbarO2 + Rbar
31
32 yN2 = nN2/(nN2+nO2)

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

    //mole fraction of O2
34
35 sigma = nN2*(cpbarN2*log(T2/TN2)-Rbar*log(yN2*p2/pN2
    )) + nO2*(cpbarO2*log(T2/T02)-Rbar*log(yO2*p2/pO2
    ))

```

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

Scilab code Exa 12.6 Example 6

```
1 //(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
2
3 //solution
4
5 //variable initialization
6 T1 = 32
    //temperature of dry air in degree celcius
7 p1 = 1
    //pressure of dry air in bar
8 AV1 = 100
    //volume rate of dry air in m^3/min
9 T2 = 127
    //temperature of oxygen stream in degree celcius
10 p2 = 1
    //pressure of oxygen stream in bar
11 T3 = 47
```

```

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

     //pressure of mixed stream in bar
13
14 //part(a)
15 Rbar = 8314

     //universal gas constant
16 Ma = 28.97

     //molar mass of air
17 Mo = 32

     //molar mass of oxygen
18
19 va1 = (Rbar/Ma)*(T1+273)/(p1*10^5)
                                     //
     specific volume of air in m^3/kg
20 ma1dot = AV1/va1

     //mass flow rate of dry air in kg/min
21
22 //from table A-22 and A-23
23 haT3 = 320.29

     //in kj/kg
24 haT1 = 305.22

     //in kj/kg
25 hnotT2 = 11711

     //in kj/kmol
26 hnotT1 = 9325

     //in kj/kmol
27

```

```

28 modot = ma1dot*(haT3-haT1)/[(1/Mo)*(hnotT2-hnotT1)]
                                     //in kg/min
29 printf('the mass flow rate of dry air in kg/min is:
        %f',ma1dot)
30 printf('\nthe mass flow rate of oxygen in kg/min is:
        %f',modot)
31
32 //part(b)
33 nadot = ma1dot/Ma

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

        //molar flow rate of oxygen in kmol/min
35
36 ya = nadot/(nadot+nodot)

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

        //mole fraction of oxygen
38
39 printf('\n\nthe mole fraction of dry air in the
        exiting mixture is: %f',ya)
40 printf('\n\nthe mole fraction of dry oxygen in the
        exiting mixture is: %f',yo)
41
42 //part(c)
43 //with the help of tables A-22 and A-23
44 sanotT3 = 1.7669

        //in kj/kg.K
45 sanotT1 = 1.71865

        //in kj/kg.K
46 sbarT3 = 207.112

        //in kj/kmol.K

```

```

47 sbarT2 = 213.765

    //in kj/kmol.K
48
49 sigmadot = maldot*[sanotT3-sanotT1-(8.314/Ma)*log(ya
    )] + (modot/Mo)*[sbarT3-sbarT2-8.314*log(yo)]
50 printf('\n\nthe time rate of entropy production, in
    kJ/K . min is: %f',sigmadot)

```

Scilab code Exa 12.7 Example 7

```

1  //(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.
2
3  //solution
4
5  //variable initialization
6  m =1

    //mass of sample in kg
7  T1 = 21

    //initial temperature in degree celcius
8  psi1 = .7

    //initial relative humidity
9  T2 = 5

    //final temperature in degree celcius
10
11 //part(a)

```

```

12 //from table A-2
13 pg = .02487

    //in bar
14
15 pv1 = psi1*pg

    //partial pressure of water vapor in bar
16
17 omega1 = .622*(.2542)/(14.7-.2542)
18 printf('the initial humidity ratio is: %f',omega1)
19
20 //part(b)
21 //The dew point temperature is the saturation
    temperature corresponding to the partial pressure
    , pv1. Interpolation in Table A-2 gives
22 T = 15.3

    //the dew point temperature in degree celcius
23 printf('\n\nthe dew point temperature in degree
    celcius is: %f',T)
24
25 //part(c)
26 mv1 = 1/[(1/omega1)+1]

    //initial amount of water vapor in the sample in
    kg
27 ma = m-mv1

    //mass of dry air present in kg
28
29 //the partial pressure of the water vapor remaining
    in the system at the final state is the
    saturation pressure corresponding to 5C:
30 pg = .00872

    //in bar
31 omega2 = .622*(pg)/(1.01325-pg)

```

```

    //humidity ratio after cooling
32
33 mv2 = omega2*ma

    //The mass of the water vapor present at the
    final state
34 mw = mv1-mv2
35 printf('\n\n the amount of water vapor that
    condenses , in kg. is:  %f',mw)

```

Scilab code Exa 12.8 Example 8

```

1 // (12.8) An a i r 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.
2
3 //solution
4
5 //variable initialization
6 V = 35

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

    //in bar
8 T1 = 120

    //in degree celcius

```



```

9  psi1 = .1
10 T2 = 22

    //in degree celcius
11
12 //part(a)
13 //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
14 pg1 = 1.985
15 pv1 = psi1*pg1

    //partial pressure in bar
16 //Interpolating in Table A-2 gives the dew point
    temperature as
17 T = 60

    //in degree celcius
18 printf('the dew point temperature corresponding to
    the initial state , in degee celcius is: %f',T)
19
20 //part(b)
21 Rbar = 8314

    //universal gas constant
22 Mv = 18

    //molar mass of vapor in kj/kmol
23 vv1 = ((Rbar/Mv)*(T1+273))/(pv1*10^5)

    //the
    specific volume of the vapor at state 1 in m^3/
    kg
24 //Interpolation in Table A-2
25 Tdash = 56

    //in degrees

```

```

26 printf('\n\nthe temperature at which condensation
    actually begins in degree celcius is: %f',Tdash)
27
28 //part(c)
29 mv1 = V/vv1

    //initial amount of water vapor present in kg
30 //from table
31 vf2 = 1.0022e-3
32 vg2 = 51.447
33 vv2 = vv1

    //specific volume at final state
34
35 x2 = (vv2-vf2)/(vg2-vf2)

    //quality
36 mw2 = x2*mv1

    //the mass of the water vapor contained in the
    system at the final state
37 mw2 = mv1-mv2
38 printf('\n\n the amount of water condense in kg is:
    %f',mw2)

```

Scilab code Exa 12.9 Example 9

```

1 //(12.9) An a i r 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.
2
3 //solution

```

```

4
5 //variable initialization
6 V = 35

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

    //initial pressure in bar
8 T1 = 120

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

    //in degree celcius
11
12 Rbar = 8314

    //universal gas constant
13 Ma = 28.97

    //molar mass of air
14
15 pv1 = .1985

    //in bar, from example 12.8
16 mv2 = .681

    //in kg, from examples 12.8
17 mv1 = 3.827

    //in kg, from example 12.8
18 mw2 = 3.146

    //in kg, from example 12.8
19
20 ma =( [(p1-pv1)*10^5]*V)/[(Rbar/Ma)*(T1+273)]
    //mass of dry

```

```

    air in kg
21
22 //evaluating internal energies of dry air and water
    from Tables A-22 and A-2, respectively
23 ua2 = 210.49

    //in kj/kg
24 ua1 = 281.1

    //in kj/kg
25 ug2 = 2405.7

    //in kj/kg
26 uf2 = 92.32

    //in kj/kg
27 ug1 = 2529.3

    //in kj/kg
28
29 Q = ma*(ua2-ua1) + mv2*ug2 + mw2*uf2 - mv1*ug1
30 printf(' the heat transfer during the process , in kJ
    is: %f',Q)

```

Scilab code Exa 12.10 Example 10

```

1 // (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.
2
3 //solution
4
5 //variable initialization
6 AV1 = 150

    //entry volumetric flow rate in m^3/min
7 T1 = 10

    //entry temperature in degree celcius
8 psi1 = .8
9 T2 = 30

    //exit temperature in degree celcius
10 p = 1

    //in bar
11
12 //part(a)
13 Rbar = 8314

    //universal gas constant
14 Ma = 28.97

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

    //in kj/kg
17 ha2 = 303.2

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

```

```

19 hv1 = 2519.8
    //in kj/kg
20 hv2 = 2556.3
    //in kj/kg
21 //from table A-2
22 pg1 = .01228
    //in bar
23 pv1 = psi1*pg1
    //the partial pressure of the water vapor in bar
24 pa1 = p-pv1
25 va1 = (Rbar/Ma)*(T1+273)/(pa1*10^5)
    //
    specific volume of the dry air in m^3/kg
26
27 madot = AV1/va1
    //mass flow rate of the dry air in kg/min
28
29 omega = .622*(pv1/(p-pv1))
    //humidity ratio
30
31 Qcvdot = madot*[(ha2-ha1)+omega*(hv2-hv1)]
    //in kj/min
32 printf('rate of heat transfer , in kJ/min is: %f',
    Qcvdot)
33
34 //part(b)
35 //from Table A-2 at 30C
36 pg2 = .04246
    //in bar
37 pv2 = pv1
38 psi2 = pv2/pg2

```

```

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

```

Scilab code Exa 12.11 Example 11

```

1 //(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.
2
3 //solution
4
5 //variable initialization
6 T1 = 30
7
8 //in degree celcius
9 AV1 = 280
10
11 //in m^3/min
12 psi1 = .5
13
14 //relative humidity at the inlet

```

```

9 T2 = 10

    //in degree celcius
10 p = 1.013

    //pressure in bar
11
12 //part(a)
13 //from table A-2
14 pg1 = .04246

    //in bar
15 pv1 = psi1*pg1

    //in bar
16
17 pa1 = p-pv1

    //partial pressure of the dry air in bar
18
19 Rbar = 8314

    //universal gas constant
20 Ma = 28.97

    //molar mass of air
21 madot = AV1/[(Rbar/Ma)*((T1+273)/(pa1*10^5))]
    //common mass
    flow rate of the dry air in kg/min
22 printf('the mass flow rate of the dry air in kg/min
    is: %f',madot)
23
24 //part(b)
25 omega1 = .622*[pv1/(p-pv1)]
26
27 //from table A-2
28 pv2 = .01228

```



```

        //in bar
29
30 omega2 = .622*[pv2/(p-pv2)]
31
32 mwdotbymadot = omega1-omega2
33 printf('\n\nthe rate at which water is condensed, in
        kg per kg of dry air flowing through the control
        volume is: %f',mwdotbymadot)
34
35 //part(c)
36 //from table A-2 and A-22
37 ha2 = 283.1

        //in kg/kj
38 ha1 = 303.2

        //in kg/kj
39 hg1 = 2556.3

        //in kg/kj
40 hg2 = 2519.8

        //in kg/kj
41 hf2 = 42.01

        //in kg/kj
42
43 Qcvdot = madot*[(ha2-ha1)-omega1*hg1+omega2*hg2+(
        omega1-omega2)*hf2] //in kj/min
44 printf('\n\nthe required refrigerating capacity, in
        tons is: %f',Qcvdot/211)

```

Scilab code Exa 12.12 Example 12

```

1 // (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.

```

2
3 //solution
4
5 //variable initialization
6 T1 = 22

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

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

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

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

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

    //pressure in bar
12
13 //part(a)
14 //by inspection of the psychrometric chart

```

```

15 omega1 = .002
16 omega2 = omega1 + mstdot/(madot*60)
17 printf('the humidity ratio at the exit is: %f',
        omega2)
18
19 //part(b)
20 // the steady-state form of the energy rate balance
    can be rearranged as
21 //(ha + omega*hg)2 = (ha + omega*hg)1 + (omega2-
    omega1)*hg3
22 //on putting values in the above equation from
    tables and figures , temperature at the exit can
    then be read directly from the chart
23 T2 = 23.5

    //in degree celcius
24 printf('\n\nthe temperature at the exit in degree
    celcius is: %f',T2)

```

Scilab code Exa 12.13 Example 13

```

1 //(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.
2
3 //solution
4

```

```

5 //variable initialization
6 T1 = 38

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

    //relative humidity of entering air
8 AV1 = 140

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

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

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

    //pressure in atm
12
13 //part(a)
14 //from table A-2
15 pg1 = .066

    //in bar
16 pv1 = psi1*pg1

    //the partial pressure of the moist air entering
    the control volume in bar
17 omega1 = .622*[pv1/(p*1.01325-pv1)]
18 //The specific volume of the dry air can be
    evaluated from the ideal gas equation of state.
    The result is
19 va1 = .887

    //in m^3/kg
20 cpa = 1.005

```

```

21 madot = AV1/va1

    //mass flow rate of the dry air in kg/min
22 //from table A-2
23 hf = 88.14
24 hg1 = 2570.7
25 hg2 = 2539.94
26
27 omega2 = [cpa*(T1-T2)+omega1*(hg1-hf)]/(hg2-hf)
28 mwdot = madot*60*(omega2-omega1)

    //
    in kg/h
29 printf('the mass flow rate of the water to the
    soaked pad in kj/h is: %f',mwdot)
30
31 //part(b)
32 pv2 = (omega2*p*1.01325)/(omega2+.622)

    //in
    bars
33 //At 21C, the saturation pressure is
34 pg2 = .02487
35 psi2 = pv2/pg2
36 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

```

1 // (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.
2
3 //solution
4
5 //variable initialization
6 AV1 = 142

    //in m^3/min
7 T1 = 5

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

    //in m^3/min
10 T2 = 24

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

    //in bar
13
14
15 //part(a)
16 //from the psychrometric chart, Fig. A-9.
17 va1 = .79

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

    //in m^3/kg
19 omega2 = .0094
20
21 ma1dot = AV1/va1

    //in kg/min

```

```

22 ma2dot = AV2 /va2

    //in kg/min
23
24 omega3 = (omega1*ma1dot+omega2*ma2dot)/(ma1dot +
    ma2dot)
25 printf('the humidity ratio is: %f',omega3)
26
27 //part(b)
28 //Reduction of the energy rate balance gives
29 //(ha + omega*hv)3 = [ma1dot*(ha + omega*hv)1 +
    ma2dot*(ha + omega*hv)2]/(ma1dot+ma2dot)
30 //with (ha + omega*hv)1 = 10kj/kg and (ha + omega*hv
    )2 = 47.8kj/kg from figure A-9
31 LHS = (ma1dot*10+ma2dot*47.8)/(ma1dot + ma2dot)
32
33 //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,
34 T3 = 19

    //in degree celcius
35 printf('\n\nthe temperature of the exiting mixed
    stream in degree celcius is: %f',T3)

```

Scilab code Exa 12.15 Example 15

```

1 //(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.

```
2
3
4 //solution
5
6 //variable initialization
7 T1 = 38

    //in degree celcius
8 m1dot = 4.5e7

    //in kg/h
9 T2 = 30

    //in degree celcius
10 m2dot = 4.5e7

    //in kg/h
11 T3 = 25

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

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

    //in degree celcius
16
```



```

17 //analysis
18 //The humidity ratios omega3 and omega4 can be
    determined using the partial pressure of the
    water vapor obtained with the respective relative
    humidity
19 omega3 =.00688
20 omega4 = .0327
21 //from tables A-2 and A-22
22 hf1 = 159.21
23 hf2 = 125.79
24 ha4 = 308.2
25 ha3 = 298.2
26 hg4 = 2565.3
27 hg3 = 2547.2
28 hf5 = 83.96
29
30 madot = [m1dot*(hf1-hf2)]/[ha4-ha3+omega4*hg4-omega3
    *hg3-(omega4-omega3)*hf5] //in kg/h
31 m5dot = madot*(omega4-omega3)
    //in kg/h
32 printf('the mass flow rate of dry air in kg/h is:
    %e',madot)
33 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

```
1 // (13.1) Determine the a i r 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
   ).
2
3 // solution
4
5 // part (a)
6 // the combustion equation can be written in the form
   of
7 //  $C_8H_{18} + a(O_2 + 3.76N_2) \rightarrow b CO_2 + c H_2O + d N_2$ 
8 // using conservation of mass principle
9 b = 8
10 c = 18/2
11 a = (2*b+c)/2
12 d = 3.76*a
13
14 // The a i r fuel ratio on a molar basis is
```

```

15 AFbar = a*(1+3.76)/1
16
17 Ma = 28.97

    //molar mass of air
18 MC8H18 = 114.22

    //molar mass of C8H18
19 //The a i r fuel ratio expressed on a mass basis is
20 AF = AFbar*[Ma/MC8H18]
21
22 printf('The a i r fuel ratio on a molar basis is:
    %f',AFbar)
23 printf('\nThe a i r fuel ratio expressed on a mass
    basis is: %f',AF)
24
25 //part(b)
26 //For 150% theoretical air, the chemical equation
    for complete combustion takes the form
27 //c8H18 + 1.5*12.5*(O2 + 3.76N2) ----> b CO2 + c H2O
    + d N2 + e O2
28 //using conservation of mass
29 b = 8
30 c =18/2
31 e = (1.5*12.5*2 - c -2*b)/2
32 d = 1.5*12.5*3.76
33 //The a i r fuel ratio on a molar basis is
34 AFbar = 1.5*12.5*(1+3.76)/1
35 //The a i r fuel ratio expressed on a mass basis is
36 AF = AFbar*[Ma/MC8H18]
37 printf('\n\nThe a i r fuel ratio on a molar basis is
    : %f',AFbar)
38 printf('\n\nThe a i r fuel ratio expressed on a mass
    basis is: %f',AF)

```

Scilab code Exa 13.2 Example 2

```
1  //(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 a i r 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.
2
3  //solution
4
5  //part(a)
6  //The chemical equation
7  //a CH4 + b*(O2 + 3.76N2) ----> 9.7CO2 + .5CO +
    2.95O2 + 86.85N2 + cH2O
8
9  //applying conservation of mass
10 a = 9.7 + .5
11 c = 2*a
12 b = [9.7*2+.5+2*2.95+c]/2
13
14 Ma = 28.97
    //molar mass of air
15 MCH4 = 16.04
    //molar mass of methane
16 //On a molar basis , the a i r fuel ratio is
17 AFbar = b*(1+3.76)/a
18 //On a mass basis
19 AF = AFbar*(Ma/MCH4)
20
21 printf('the air-fuel ratio on a molar basis is: %f'
    ,AFbar)
22 printf('\nthe air-fuel ratio on a mass basis is: %f
    ',AF)
```

```

23
24 //part(b)
25 //The balanced chemical equation for the complete
    combustion of methane with the theoretical amount
    of air is
26 //CH4 + 2(O2 + 3.76N2) ----> CO2 + 2H2O + 7.52N2
27 //The theoretical a i r fuel ratio on a molar basis
    is
28 AFbartheo = 2*(1+3.76)/1
29 //The percent theoretical air is
30 Ta = AFbar/AFbartheo
31 printf('\n\nthe percent theoretical air is: %f',Ta
    *100)
32
33 //part(c)
34 //the mole fraction of the water vapor is
35 yv = 20.4/(100+20.4)
36 pv = yv*1
37 //Interpolating in Table A-2,
38 T = 57

    //in degree celcius
39 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

```

1 // (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 a i r 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.

```

2
3 //solution
4
5 //part(a)
6 //The chemical equation
7 //(.8062CH4 + .0541C2H6 + .0187C3H8 + .0160C4H10 +
  .1050N2) + a(O2 + 3.76N2) ----> b(.078CO2 +
  .002CO + .07O2 + .85N2) + c H2O
8
9 //using mass conservation
10 b = [.8062 + 2*.0541 + 3*.0187 + 4*.0160]/(.078 +
  .002)
11 c = [4*.8062 + 6*.0541 + 8*.0187 + 10*.0160]/2
12 a = {b*[2*.078+.002+2*.07] + c}/2
13
14 //The a i r fuel ratio on a molar basis is
15 AFbar = a*(1+3.76)/1
16 printf('the air-fuel ratio on a molar mass basis is:
  %f',AFbar)
17
18 //part(b)
19 p = 1
20
  //in bar
20 V = 100
21
  //in m^3
21 Rbar = 8314
22
  //in N.m/kmol.K
22 T = 300
23
  //in kelvin
23 //The amount of fuel in kmol

```

```

24 nF = (p*10^5*V)/(Rbar*T)
25 //the amount of product mixture that would be formed
    from 100 m3 of fuel mixture is
26 n = nF*(b+c)
27 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)
28
29 //part(c)
30 //The balanced chemical equation for the complete
    combustion of the fuel mixture with the
    theoretical amount of air is
31 //(10.8062CH4 + 0.0541C2H6 + 0.0187C3H8 + 0.0160
    C4H10 + 0.1050N2) + 2(O2 + 3.76N2)  ----> 1.0345
    CO2 + 1.93H2O + 7.625N2
32 //The theoretical air fuel ratio on a molar basis
    is
33 AFbartheo = 2*(1+3.76)/1
34 //The percent theoretical air is
35 Ta = AFbar/AFbartheo
36 printf('\n\nthe percent of theoretical air is: %f',
    Ta*100)

```

Scilab code Exa 13.4 Example 4

```

1 //(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.

```

```

2
3
4 //solution
5 //The balanced chemical equation for complete
   combustion with the theoretical amount of air is
   obtained from the solution to Example 13.1 as
6 //C8H18 +12.5O2 + 47N2 -----> 8CO2 + 9H2O + 47N2
7 //from tabel A-25
8 hRbar = -249910

   //in kj/kmol

9
10 //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
11 hpbar = 8*[-393520 + (36876 - 9364)] + 9*[-241820 +
   (31429 - 9904)] + 47*[(26568 - 8669)]
12
13 mfdot = 1.8e-3

   //mass flow rate of liquid octane in kg/s
14 M = 114.22

   //molar mass of octane
15 nFdot = mfdot/M

   //molar flow rate of the fuel in kmol/s
16
17 Wcvdot = 37

   //power output of the engine in kw
18
19 Qcvdot = Wcvdot + nFdot*(hpbar-hRbar)
   //in kw
20 printf('the rate of heat transfer from the engine ,
   in kW is: %f',Qcvdot)

```

Scilab code Exa 13.5 Example 5

```
1  //(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.
2
3
4  //solution
5
6  //When expressed on a per mole of fuel basis, the
    balanced chemical equation obtained in the
    solution to Example 13.2 takes the form
7  //CH4 + 2.265O2 + 8.515N2 -----> .951CO2 + .049CO
    + .289O2 + 8.515N2 + 2H2O
8  cpbar = 38
    //specific heat in KJ/kmol.K
9  //from table A-25
10 hfnotbar = -74850
    //enthalpy of formation for methane
11 //from table A-23
12 deltahbarO2 = 14770-8682
13 deltahbarN2 = 14581-8669
14
15 hRbar = hfnotbar + cpbar*(400-298) + 2.265*
```

```

    deltabarO2 + 8.515*deltahbarN2      //in kj/kmol
16 //With enthalpy of formation values for CO2, CO, and
    H2O(g) from Table A-25 and enthalpy values from
    Table A-23
17 hpbar = .951*[-393520 + (88806 - 9364)] +
    .049*[-110530 + (58191 - 8669)] + .289*(60371 -
    8682) + 8.515*(57651 - 8669) + 2*[-241820 +
    (72513 - 9904)]
18
19 Qcvdot = hpbar - hRbar

    //in kj/kmol
20 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

```

1 //(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.
2
3
4 //solution
5
6 //variable initialization
7 nCH4 = 1

    //moles of methane in kmol
8 nO2 = 2

```

```

9      //moles of oxygen in kmol
T1 = 25

      //in degree celcius
10 p1 = 1

      //in atm
11 T2 = 900

      //in kelvin
12 Rbar = 8.314

      //universal gas constant
13 //The chemical reaction equation for the complete
      combustion of methane with oxygen is
14 //CH4 + 2O2  ---->  CO2 + 2H2O
15
16 //part(a)
17 //with enthalpy of formation values from table A-25
18 hfbarCO2 = -393520
19 hfbarH2O = -241820
20 hfbarCH4 = -74850
21 //with enthalpy values from table A-23
22 deltahbarCO2 = 37405-9364
23 deltahbarH2O = 31828-9904
24
25 Q = ((hfbarCO2 + deltahbarCO2)+2*(hfbarH2O +
      deltahbarH2O) - hfbarCH4) + 3*Rbar*(T1+273-T2)
26 printf('the amount of heat transfer in kJ is:  %f',Q
      )
27
28 //part(b)
29 p2 = p1*(T2/(T1+273))

      //in atm
30 printf('\nthe final pressure in atm is:  %f',p2)

```

Scilab code Exa 13.7 Example 7

```
1  //(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.
2
3
4  //solution
5
6  //The combustion equation is
7  //CH4 + 2O2 + 7.52N2 ----> CO2 + 2H2O + 7.52N2
8
9  //part(a)
10 //With enthalpy of formation values from Table A-25
11 hfbarcO2 = -393520
    //in kj/kmol
12 hfbarcH2O = -285830
    //in kj/kmol
13 hfbarcCH4 = -74850
    //in kj/kmol
14
15 hRPbar = hfbarcO2 + 2*hfbarcH2O - hfbarcCH4
    //in kj/
    kmol
16 M = 16.04
    //molar mass of CH4 in kg/kmol
17 hRP = hRPbar/M
```

```

    //in kj/kg
18 printf('part(a)the enthalpy of combustion of gaseous
    methane, in kJ per kg of fuel is: %f',hRP)
19
20 //part(b)
21 hfbarC02 = -393520

    //in kj/kmol
22 hfbarH20 = -241820

    //in kj/kmol
23 hfbarCH4 = -74850

    //in kj/kmol
24
25 hRPbar = hfbarC02 + 2*hfbarH20 - hfbarCH4
    //in kj/
    kmol
26 hRP = hRPbar/M

    //in kj/kg
27 printf('\n\npart(b)the enthalpy of combustion of
    gaseous methane, in kJ per kg of fuel is: %f',
    hRP)
28
29 //part(c)
30 //from table A-23
31 deltahbar02 = 31389-8682

    //in kj/kmol
32 deltahbarH20 = 35882-9904

    //in kj/kmol
33 deltahbarC02 = 42769-9364

    //in kj/kmol
34
35 //using table A-21

```

```

36 function cpbar = f(T)
37     cpbar = (3.826 - (3.979e-3)*T + 24.558e-6*T^2 -
              22.733e-9*T^3 + 6.963e-12*T^4)*8.314
38 endfunction
39
40 deltahbarCH4 = intg(298,1000,f)
41 var = deltahbarCH4
42
43 hRPbar = hRPbar + (deltahbarCO2 + 2*deltahbarH2O -
                    var -2*deltahbarO2)
44 hRP = hRPbar/M

    //in kj/kg
45 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

```

1 // (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.
2
3 //solution
4
5 //part(a)
6 //For combustion of liquid octane with the
  theoretical amount of air, the chemical equation
  is
7 //C8H18(l) + 12.5 O2 + 47N2 -----> 8 CO2 + 9 H2O

```

```

      (g) + 47N2
8 //with enthalpy of formation data from Table A-25
9 hfbarc8H18 = -249910

      //in kj/kmol
10 hfbarcO2 = -393520
11 hfbarcH2O = -241820
12
13 RHS = hfbarc8H18 -(8*hfbarcO2 + 9*hfbarcH2O)
                                           //in kj/kmol
14
15 //at temperature 2400k
16 LHS1 = 5089337

      //in kj/kmol
17 //at temperature 2350 k
18 LHS2 = 4955163

      //in kj/kmol
19 //Interpolation between these temperatures gives
20 Tp = 2400 + [(2400-2350)/(LHS1-LHS2)]*(RHS-LHS1)
21 printf('the temperature in kelvin with theoretical
      amount of air is: %f',Tp)
22
23 //part(b)
24 //For complete combustion of liquid octane with 400%
      theoretical air, the chemical equation is
25 //C8H18(l) + 50O2 + 188N2 -----> 8CO2 + 9H2O +
      37.5O2 + 188N2
26
27 //proceeding iteratively as part(a)
28 Tp = 962

      //in kelvin
29 printf('\n\nthe temperature in kelvin using 400
      percent theoretical air is: %f',Tp)

```

Scilab code Exa 13.9 Example 9

```
1  //(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.
2
3  //solution
4
5  //part(a)
6  Tp = 2395
    //in kelvin, from example 13.8
7  //For combustion of liquid octane with the
    theoretical amount of air, the chemical equation
    is
8  //C8H18(l) + 12.5O2 + 47N2  ---->  8CO2 + 9H2O(g) +
    47N2
9
10 //from table A-25
11 sFbar = 360.79
    //absolute entropy of liquid octane in kj/kmol.K
12
13 //from table A-23
14 //for reactant side
15 sbarO2atTref = 205.03
    //in kj/kmol.K
```



```

16 sbarN2atTref = 191.5
    //in kj/kmol.K
17
18 Rbar = 8.314
    //universal gas constant in SI units
19
20 yO2 = .21
21 yN2 = .79
22
23 sbarO2 = sbarO2atTref - Rbar*log(yO2)
    //in kj
    /kmol.K
24 sbarN2 = sbarN2atTref - Rbar*log(yN2)
    //in kj
    /kmol.K
25
26 //for product side
27 yCO2 = 8/64
28 yH2O = 9/64
29 yN2p = 47/64
30
31 //with the help from table A-23
32 sbarCO2 = 320.173 - Rbar*log(yCO2)
33 sbarH2O = 273.986 - Rbar*log(yH2O)
34 sbarN2p = 258.503 - Rbar*log(yN2p)
35
36 sigmadot = (8*sbarCO2 + 9*sbarH2O + 47*sbarN2p) -
    sFbar - (12.5*sbarO2 + 47*sbarN2)
37 printf(' the rate of entropy production , in kJ/K per
    kmol of fuel with theoretical amount of air is:
    %f',sigmadot)
38
39 //part(b)
40 //The complete combustion of liquid octane with 400%
    theoretical air is described by the following
    chemical equation:

```

```

41 //C8H18(1) + 50 O2 + 188N2 -----> 8 CO2 + 9H2O(g)
    + 37.5O2 + 188N2
42
43 //for product side
44 yCO2 = 8/242.5
45 yH2O = 9/242.5
46 yO2 = 37.5/242.5
47 yN2p = 188/242.5
48
49 //with help from table A-23
50 sbarCO2 = 267.12 - Rbar*log(yCO2)
51 sbarH2O = 231.01 - Rbar*log(yH2O)
52 sbarO2p = 242.12 - Rbar*log(yO2)
53 sbarN2p = 226.795 - Rbar*log(yN2p)
54
55 sigmadot = (8*sbarCO2 + 9*sbarH2O + 37.5*sbarO2p
    +188*sbarN2p) -sFbar - (50*sbarO2 + 188*sbarN2)
56 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

```

1 //(13.10) Determine the change in entropy of the
    system of Example 13.6 in kJ/K.
2
3
4 //solution
5 Rbar = 8.314

    //universal gas constant in SI units
6 //The chemical equation for the complete combustion
    of methane with oxygen is
7 //CH4 + 2O2 -----> CO2 + 2H2O
8 yCH4 = 1/3

```

```

9 yO2 = 2/3
10 yCO2 = 1/3
11 yH2O = 2/3
12 //from table A-25
13 sbarCH4atTref = 186.16

    //in kj/kmol.K
14 sbarO2atTref = 205.03

    //in kj/kmol.K
15
16 sbarCH4 = sbarCH4atTref - Rbar*log(yCH4)
17 sbarO2 = sbarO2atTref - Rbar*log(yO2)
18
19 p2 = 3.02

    //in atm
20 pref = 1

    //in atm
21 //with help from table A-23
22 sbarCO2 = 263.559 - Rbar*log(yCO2*p2/pref)
    //in kj/kmol
    .K
23 sbarH2O = 228.321 - Rbar*log(yH2O*p2/pref)
    //in kj/kmol
    .K
24
25 deltaS = sbarCO2 + 2*sbarH2O - sbarCH4 -2*sbarO2
    //in kj/K
26 printf('the change in entropy of the system in kJ/K
    is: %f',deltaS)

```

Scilab code Exa 13.11 Example 11

```

1  //(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.
2
3
4
5  //solution
6
7  //Methane is formed from carbon and hydrogen
    according to
8  //C + 2H2 -----> CH4
9
10 //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
11 hCbar = 0
12 hH2bar = 0
13 gRbar = 0
14 //With enthalpy of formation and absolute entropy
    data from Table A-25
15 hfbarCH4 = -74850
16 sbarCH4 = 186.16
17 sbarC = 5.74
18 sbarH2 = 130.57
19
20 Tref = 298.15

    //in kelvin
21
22 gfbarCH4 = hfbarCH4 -Tref*(sbarCH4-sbarC-2*sbarH2)
    //in kJ/kmol
23 printf('the gibbs function of formation of methane
    at the standard state is: %f',gfbarCH4)

```

Scilab code Exa 13.12 Example 12

```
1  //(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).
2
3
4
5  //solution
6
7  //Complete combustion of liquid octane with O2 is
   described by
8  //C8H18(l) + 12.5O2  ----->  8CO2 + 9H2O
9
10 //part(a)
11 Rbar = 8.314

   //universal gas constant in SI units
12 Tnot = 298.15

   //in kelvin
13 //from table A-25
14 gbarC8H18 = 6610
15 gbarO2 = 0
16 gbarCO2 = -394380
17 gbarH2O = -228590
18
```

```

19 yO2 = .2035
20 yCO2 = .0003
21 yH2O = .0312
22
23 M = 114.22

    //molecular weight of liquid octane
24
25 ech = ((gbarC8H18 + 12.5*gbarO2 -8*gbarCO2 -9*
    gbarH2O) + Rbar*Tnot*log(yO2^12.5/(yCO2^8*yH2O^9
    )))/M
26 printf('part(a) the chemical exergy obtained on a
    unit mass basis is: %f',ech)
27
28 //part(b)
29 //With data from Table A-25 and Model II of Table A
    -26
30 gbarH2O = -237180
31 ebarCO2 = 19870
32 ebarH2O = 900
33 ebarO2 = 3970
34
35 ech = ((gbarC8H18 + 12.5*gbarO2 -8*gbarCO2 - 9*
    gbarH2O) + 8*ebarCO2 + 9*ebarH2O - 12.5*ebarO2)/M
36 printf('\n\npart(b) chemical exergy on a unit mass
    basis is: %f',ech)

```

Scilab code Exa 13.13 Example 13

```

1 // (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
2

```

```

3
4 //solution
5 Rbar = 8.314

    //universal gas constant in SI units
6 Tnot = 298

    //in kelvin
7 //With data from the steam tables
8 h = 2939.9

    //in kj/kg
9 hnot = 104.9

    //in kj/kg
10 s = 7.2307

    //in kj/kg
11 snot = .3674

    //in kj/kg
12 //With data from Table A-25
13 gbarH20liq = -237180
14 gbarH20gas = -228590
15 yeH20 = .0303
16 M =18

    //molar mass of steam
17
18 ech = (1/M)*(gbarH20liq-gbarH20gas + Rbar*Tnot*log
    (1/yeH20)) //in kj/kg
19
20 ef = h-hnot-Tnot*(s-snot) + ech

    //in kj/kg
21 printf(' the flow exergy of the steam , in kJ/k is:
    %f ',ef)

```

Scilab code Exa 13.14 Example 14

```
1  //(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.
2
3
4
5  //solution
6
7  //For 140% theoretical air, the reaction equation
    for complete combustion of methane is
8  //CH4 + 2.8(O2 + 3.76N2) -----> CO2 + 2H2O +
    10.53N2 + .8O2
9
10 //for product side
11 yCO2p = 1/(1+2+10.53+.8)
12 yH2Op = 2/(1+2+10.53+.8)
13 yN2p = 10.53/(1+2+10.53+.8)
14 yO2p = .8/(1+2+10.53+.8)
15
16 Rbar = 8.314

    //universal gas constant in SI units
17 Tnot = 298.15

    //in kelvin
```



```

18
19 yeN2 = .7567
20 yeO2 = .2035
21 yeH2O = .0303
22 yeCO2 = .0003
23
24 ebarch = Rbar*Tnot*(log(yCO2p/yeCO2) + 2*log(yH2Op/
    yeH2O) + 10.53*log(yN2p/yeN2) + .8*log(yO2p/yeO2)
    )
25
26 //with data from tables A-23 at 480 and 1560 kelvin ,
    the thermomechanical contribution to the flow
    exergy , per mole of fuel , is
27 contri480 = 17712

    //kJ per kmol of fuel
28 contri1560 = 390853

    //kJ per kmol of fuel
29
30 efbar480 = contri480 + ebarch

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

    //kJ per kmol of fuel
32
33 printf('at T= 480k, the flow exergy of the
    combustion products , in kJ per kmol of fuel is:
    %f',efbar480)
34 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

```

1  //(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).
2
3
4  //solution
5
6  mFdot = 1.8e-3
      //fuel mass flow rate in kg/s
7  ech = 47346
      //in kJ/kg, from example 13.12(a)
8  Wcvdot = 37
      //power developed by the engine in kw
9
10 Efdot = mFdot*ech
      //rate at which exergy enters with the fuel in kw
11
12 epsilon = Wcvdot/Efdot
      //exergetic efficiency
13 printf('the exergetic efficiency is:  %f',epsilon)

```

Scilab code Exa 13.16 Example 16

```

1  //(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).
2
3
4 //solution
5
6 Tnot = 298

    //in kelvin
7
8 //For the case of complete combustion with the
    theoretical amount of air
9 sigmadot = 5404

    //rate of entropy production from example 13.9,
    in kj/kmol.K
10 Eddot = Tnot*sigmadot

    //in kj/kmol
11 Efdot = 5407843

    //rate at which exergy enters with the fuel from
    example 13.12, in kj/kmol
12 epsilon = 1-Eddot/Efdot
13 printf('the exergetic efficiency with theoretical
    amount of air is: %f',epsilon)
14
15 //for the case of combustion with 400% theoretical
    air
16 sigmadot = 9754

    //rate of entropy production from example 13.9,
    in kj/kmol.K
17 Eddot = Tnot*sigmadot

    ////in kj/kmol
18 epsilon = 1-Eddot/Efdot
19 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

```
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.  
2  
3  
4  //solution  
5  
6  //The reaction is CO + .5O2  ---->  CO2  
7  
8  //part(a)  
9  T = 298  
  
    //in kelvin  
10 Rbar = 8.314  
  
    //universal gas constant in SI units  
11 //from table A-25  
12
```

```

13 hfbarC02 = -393520
    //in kj/kmol
14 hfbarC0 = -110530
    //in kj/kmol
15 hfbarO2 = 0
    //in kj/kmol
16 deltahbarC02 = 0
    //in kj/kmol
17 deltahbarC0 = 0
    //in kj/kmol
18 deltahbarO2 = 0
    //in kj/kmol
19 sbarC02 = 213.69
    //in kj/kmol.K
20 sbarC0 = 197.54
    //in kj/kmol.K
21 sbarO2 = 205.03
    //in kj/kmol.K
22
23 deltaG = [hfbarC02-hfbarC0-.5*hfbarO2] + [
    deltahbarC02-deltahbarC0-.5*deltahbarO2] - T*(
    sbarC02-sbarC0-.5*sbarO2)
24 lnK = -deltaG/(Rbar*T)
25 logK = (1/log(10))*lnK
26 //from table A-27
27 logKtable = 45.066
28 printf('part(a) the value of equilibrium constant
    expressed as log10K is: %f',logK)
29 printf('\nthe value of equilibrium constant

```

```

    expressed as log10K from table A-27 is: %f',
    logKtable)
30
31 //part(b)
32 T = 2000

    //in kelvin
33 //from table A-23
34 hfbarC02 = -393520

    //in kj/kmol
35 hfbarC0 = -110530

    //in kj/kmol
36 hfbarO2 = 0

    //in kj/kmol
37 deltahbarC02 = 100804-9364

    //in kj/kmol
38 deltahbarC0 = 65408 - 8669

    //in kj/kmol
39 deltahbarO2 = 67881 - 8682

    //in kj/kmol
40 sbarC02 = 309.210

    //in kj/kmol.K
41 sbarC0 = 258.6

    //in kj/kmol.K
42 sbarO2 = 268.655

    //in kj/kmol.K
43
44 deltaG = [hfbarC02-hfbarC0-.5*hfbarO2] + [
    deltahbarC02-deltahbarC0-.5*deltahbarO2] - T*(

```

```

    sbarCO2-sbarCO-.5*sbarO2)
45 lnK = -deltaG/(Rbar*T)
46 logK = (1/log(10))*lnK
47 //from table A-27
48 logKtable = 2.884
49 printf('\n\npart(b) the value of equilibrium
    constant expressed as log10K is: %f',logK)
50 printf('\nthe value of equilibrium constant
    expressed as log10K from table A-27 is: %f',
    logKtable)

```

Scilab code Exa 14.2 Example 2

```

1 // (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
2
3
4 //solution
5
6 //Applying conservation of mass, the overall
    balanced chemical reaction equation is
7 //CO + .5O2 -----> zCO + (z/2)O2 + (1-z)CO2
8
9 //At 2500 K, Table A-27 gives
10 log10K = -1.44
11 K = 10^log10K

    //equilibrium constant
12 //part(a)
13 p = 1

```



```

    //in atm
14 //solving equation  $K = (z/(1-z))*(2/(2+z))^{.5} *(p$ 
    //1)^.5 gives
15 z = .129
16 yCO = 2*z/(2 + z)
17 yO2 = z/(2 + z)
18 yCO2 = 2*(1 - z)/(2 + z)
19 printf('part(a) mole fraction of CO is: %f',yCO)
20 printf('\nmole fraction of O2 is: %f',yO2)
21 printf('\nmole fraction of CO2 is: %f',yCO2)
22
23 //part(b)
24 p = 10

    //in atm
25 //solving equation  $K = (z/(1-z))*(2/(2+z))^{.5} *(p$ 
    //1)^.5 gives
26 z = .062
27 yCO = 2*z/(2 + z)
28 yO2 = z/(2 + z)
29 yCO2 = 2*(1 - z)/(2 + z)
30 printf('\n\npart(b) mole fraction of CO is: %f',yCO
    )
31 printf('\nmole fraction of O2 is: %f',yO2)
32 printf('\nmole fraction of CO2 is: %f',yCO2)

```

Scilab code Exa 14.3 Example 3

```

1 //(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  $y_{CO} = 0.298, y_{O2} = .149, y_{CO2} = .553$ .
    Determine the temperature T of the mixture, in K.
2
3

```

```

4 //solution
5 yCO = .298
6 //solving yCO = 2z/(2 + z)
7 z = 2*yCO/(2 - yCO)
8
9 p = 1

    //in atm
10 pref = 1

    //in atm
11
12 K = (z/(1-z))*(z/(2 + z))^.5*(p/pref)^.5
13
14 //with this value of K, table A-27 gives
15 T = 2881
16 printf('the temperature T of the mixture in kelvin
    is: %f',T)

```

Scilab code Exa 14.4 Example 4

```

1 //(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.
2
3
4
5 //solution
6
7 //For a complete reaction of CO with the theoretical
  amount of air
8 //CO + .5 O2 + 1.88N2 -----> CO2 + 1.88N2

```

```

9 //Accordingly , the reaction of CO with the
    theoretical amount of air to form CO2, CO, O2,
    and N2 is
10 //CO + .5O2 + 1.88N2 ----> zCO + z/2 O2 + (1-z)CO2 +
    1.88N2
11
12 K = .0363

    //equilibrium constant the solution to Example
    14.2
13 p =1

    //in atm
14 pref = 1

    //in atm
15
16 //solving  $K = (z*z^{.5}/(1-z))*((p/pref)*2/(5.76+z))^{.5}$  gives
17 z = .175
18 yCO = 2*z/(5.76 + z)
19 yO2 = z/(5.76 + z)
20 yCO2 = 2*(1-z)/(5.76 + z)
21 yN2 = 3.76/(5.76 + z)
22 printf('the mole fraction of CO is: %f',yCO)
23 printf('\nthe mole fraction of O2 is: %f',yO2)
24 printf('\nthe mole fraction of CO2 is: %f',yCO2)
25 printf('\nthe mole fraction of N2 is: %f',yN2)

```

Scilab code Exa 14.5 Example 5

```

1 //(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
2
3
4
5 //solution
6
7 //Applying the conservation of mass principle , the
    overall dissociation reaction is described by
8 //CO2 ----> zCO2 + (1-z)CO + ((1-z)/2)O2
9
10 p = 1

    //in atm
11 pref = 1

    //in atm
12 //At 3200 K, Table A-27 gives
13 log10k = -.189
14 k = 10^log10k
15 //solving k = ((1-z)/2)*((1-z)/(3-z))^0.5 gives
16 z = .422
17
18 //from tables A-25 and A-23
19 hfbarCO2 = -393520

    //in kj/kmol
20 deltahbarCO2 = 174695-9364

    //in kj/kmol
21 hfbarCO = -110530

    //in kj/kmol
22 deltahbarCO = 109667-8669

    //in kj/kmol
23 hfbarO2 = 0

```

```

    //in kj/kmol
24 deltabar02 = 114809-8682

    //in kj/kmol
25 hfbarc02r = -393520

    //in kj/kmol
26 deltabarc02r = 0

    //in kj/kmol
27
28 Qcvdot = .422*(hfbarc02 + deltabarc02) + .578*(
    hfbarc0 + deltabarc0) + .289*(hfbarc02 +
    deltabarc02)- (hfbarc02r + deltabarc02r)
29 printf('the heat transfer to the reactor, in kJ per
    kmol of CO2 entering is: %f',Qcvdot)

```

Scilab code Exa 14.6 Example 6

```

1  //(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.
2
3
4  //solution
5
6  //The overall reaction is
7  //CO + .5O2 + 1.88N2 -----> zCO + (z/2)O2 + (1-

```

```

      z)CO2 + 1.88N2
8  p =1

      //in atm
9  pref = 1

      //in atm
10
11 //solving equations  $K = (z/(1-z))*(z/(5.76+z))^{.5}$ 
      and  $z*\text{deltahbarCO} + (z/2)*\text{deltahbarO2} + (1-z)*$ 
       $\text{deltahbarCO2} + 1.88\text{deltahbarN2} + (1-z)*[\text{hfbarCO2}-$ 
       $\text{hfbarCO}] = 0$ 
12 z = .125
13 T = 2399

      //in kelvin
14 printf('the temperature of the exiting mixture in
      kelvin is: %f',T)
15 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

```

1  printf('IT software problem')

```

Scilab code Exa 14.8 Example 8

```

1 // (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
2 //      Cs <--> Cs+ + e-
3 //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.

4
5
6
7 //solution
8 //The ionization of cesium to form a mixture of Cs,
        Cs+, and e- is described by
9 //Cs  ----> (1-z)Cs + zCs+ + Ze-
10
11 K = 15.63
12 z = .95
13 pref =1

        //in atm
14 p = pref*K*((1-z^2)/z^2)
15 printf('the pressure in atm if the ionization of CS
        is 95 percent complete is: %f',p)
16
17 x = linspace(0,10,100)
18 for i = 1:100
19     y(1,i) = 100*sqrt(1/(1+x(1,i)/K))
20 end
21 plot(x,y)
22 xtitle(""," p(atm)" ," z(%)" )

```

Scilab code Exa 14.9 Example 9

```

1 //(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.

```

2
3
4
5 //solution
6
7 //The overall reaction can be written as
8 //CO2 + .5O2 + .5N2  ---->  aCO + bNO + (1-a)CO2 +
   .5(1+a-b)O2 + .5(1-b)N2
9
10 //At 3000 K, Table A-27 provides
11 log10K1 = -.485

   //equilibrium constant of the reaction CO2 <-->
   CO + .5O2
12 log10K2 = -.913

   //equilibrium constant of the reaction .5O2 + .5
   N2 <-->NO
13
14 K1 = 10^log10K1
15 K2 = 10^log10K2
16
17 //solving equations K1 = (a/(1-a))*((1+a-b)/(4+a))
   ^.5 and K2 = 2b/((1+a-b)*(1-b))^.5
18 a = .3745
19 b = .0675
20 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

```
1  //(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.
2
3
4
5  //solution
6  //With data from Table A-2 at 20C,
7  vf = 1.0018e-3
    //in m^3/kg
8  psat = .0239
    //in bar
9  p = 1
    //in bar
10 T = 293.15
    //in kelvin
11
12 Rbar = 8.314
    //universal gas constant in SI units
13 M = 18.02
    //molat mass of water in kg/kmol
14
```

```
15 pvbypsat = %e^(vf*(p-psat)*10^5/[(1000*Rbar/M)*T])
16
17 percent = (pvbypsat-1)*100
18 printf('the departure, in percent, of the partial
    pressure of the water vapor from the saturation
    pressure of water at 20 is: %f',percent)
```
