Scilab Textbook Companion for Engineering Thermodynamics Fundamental And Advanced Topics by Kavati Venkateswarlu[1]

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Book Description

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

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

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

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

Contents

List of Scilab Codes

Chapter 1

Introduction and Basic Concepts

Scilab code Exa 1.1 Determine the absolute pressure

```
//Example 1.1
//Determine the  absolute pressure
clear
clc
//P_abs = P_atm + P_Gauge
  rho_mercury = 13600;   // [kg/m^3]
  g = 9.81; //[m/s^2]  acceleration due to gravity
  z = 760; //[mm]
  z1 = z*10^-3; //[m]
  P_atm = (rho_mercury*g*z1)/10^3 ;   //[kPa]
     atmospheric pressure
  rho_oil = 800; //[kg/m^3]
  z2 = 5; //[m]
  P_gauge = (rho_oil*g*z2)/10^3 ; // [kPa]  gauge
     pressure
  P_abs = P_atm + P_gauge; // [kPa]  absolute
     pressure
```

```
Console

 "Absolute Pressure ="

  140.63616

 "kPa"
```

Figure 1.1: Determine the absolute pressure

```
Console

 "850 mm Hg gauge = "

  113.4036

 " kPa "

 "50 cm Hg vacuum ="

  66.708

 "kPa"

 "1.3 m H2O ="

  12.753

 " kPa "

 " 2.5 bar ="

  250.

 " kPa "
```

Figure 1.2: Convert the following into kPa

```
disp('Absolute Pressure =',P_abs,'kPa');
```

Scilab code Exa 1.2 `Convert the following into kPa`

```
//Example 1.2
// Convert the following into kPa
clear
clc
```

```
//(i) Convert 850mm Hg gauge into kPa
z = 850*10^-3; //[m]
rho_mercury = 13600; //[kg/m^3]
g = 9.81; //[m/s^2]  acceleration due to gravity
P1 = (rho_mercury*g*z)/10^3; // [kPa]
disp('850 mm Hg gauge = ', P1, ' kPa ');
//(ii) Convert 50 cm Hg vacuum into kPa
 h = 50*10^-2; //[m]
P2 = (rho_mercury*g*h)/10^3; //[kPa]
disp('50 cm Hg vacuum =', P2, 'kPa');
//(iii) Convert 1.3 m H2O into kPa
 l = 1.3; //[m]
 rho_H2O = 1000; //[kg/m^3]   density of H2O
P3 = (rho_H2O*g*l)/10^3; //[kPa]
disp('1.3 m H2O =', P3, ' kPa ');
//(iv) Convert 2.5 bar into kPa
P4 = 2.5*100; //[kPa]  1 bar = 100 kPa
disp(' 2.5 bar =',P4 ,' kPa ');
```

Scilab code Exa 1.3 Find gauge and absolute pressure and depth

```
//Example 1.3
// Find gauge and absolute pressure and depth
clear
clc
//(i) Find gauge pressure and absolute pressure
rho_oil = 782; //[kg/m^3]   density of oil
 P_atm = 101.32; //[kPa]    atmospheric pressure
 h = 32; //[m]  height
 g = 9.81; //[m/s^2]    acceleration due to gravity
 P_gauge = (rho_oil*g*h)/10^3; //[kPa]  gauge
    pressure
     disp('Gauge Pressure =',P_gauge,'kPa');
```

```
Console

 "Gauge Pressure = "
  245.48544
 "kPa"
 "Absolute Pressure = "
  346.80544
 "kPa "
 "Depth = "
  17.206723
 "m"
```

Figure 1.3: Find gauge and absolute pressure and depth

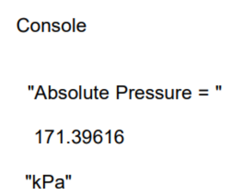

Figure 1.4: Determine the absolute pressure

```
P_abs = P_atm + P_gauge; //[kPa]   absolute
    pressure
    disp('Absolute Pressure =' , P_abs ,'kPa ');
//(ii) Compute the depth
P_gauge_1 = 132; //[kPa]
P_gauge_2 = (P_gauge_1)*10^3;
z = P_gauge_2/(rho_oil*g);  //[m]
    disp('Depth =' , z ,'m');
```

Scilab code Exa 1.4 Determine the absolute pressure

```
//Example 1.4
// Determine the absolute pressure
clear
clc
 z = 760; //[mm]
 z1 = z*10^-3; //[m]  height
 rho = 13600; //[kg/m^3]   Density of mercury
 g = 9.81; //[m/s^2]  acceleration due to gravity
 P_atm = (rho*g*z1)/10^3; //[kPa]   Atmospheric Pressure
 P_gauge = 70; //[kPa]   Gauge Pressure
 P_abs = P_atm + P_gauge; //[kPa]    Absolute Pressure
 disp('Absolute Pressure =' , P_abs , 'kPa');
```

Scilab code Exa 1.5 Determine the absolute pressure

```
//Example 1.5
// Determine the absolute pressure
clear
clc
//P_abs = P_atm - P_gauge
//P_gauge is the vaccum pressure
rho = 13600; //[kg/m^3]
 g = 9.8; //[m/s^2]  acceleration due to gravity
 z  = 760; //[mm]
 z1 = z*10^-3; //[m]
 P_atm = (rho*g*z1)/10^3; //[kPa]   Due to barometer
```

```
Console

 "Absolute Pressure = "

  14.660800

 "kPa"
```

Figure 1.5: Determine the absolute pressure

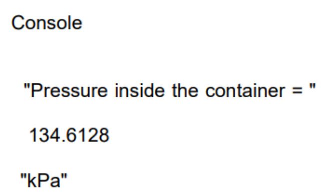

Figure 1.6: Determine the pressure inside the container

```
z2 = 650; //[mm]
z3 = z2*10^-3; //[m]
P_gauge = (rho*g*z3)/10^3; //[kPa]
P_abs = P_atm - P_gauge;
disp('Absolute Pressure =',P_abs,'kPa');
```

Scilab code Exa 1.6 `Determine the pressure inside the container`

```
//Example 1.6
//Determine the pressure inside the container
clear
clc
//P = P0 + P1
 rho = 13600; //[kg/m^3]
 g  = 9.8; //[m/s^2]
 z0 = 760; //[mm]  Barometric height
 z1 = z0*10^-3; //[m]
 z = 250; //[mm]    Difference between height of two
     columns of manometer
 z2 = z*10^-3; //[m]
 P0 = rho*g*z1; //[Pa]   atmospheric pressure
 P1 = rho*g*z2; //[Pa]
 P = (P0 + P1)/10^3; //[kPa]Pressure inside the
    container
 disp('Pressure inside the container = ',P,'kPa');
```

Chapter 2

Temperature Zeroth Law of Thermodynamics

Scilab code Exa 2.1 Express the Fahrenheit temperature change in Celsius and Kelvi

```
//Example2.1
// Express the fahrenheit temperature change in
   celsius and kelvin and rankine unit
clear
clc
T1 = 20; //[ F ]   temp change in fahrenhite
//Temp changes are identical in fahrenheit and
   rankine
T2  = T1; //[R]  temp change in rankine
T3 = T2/1.8; //[K] temp change in kelvin
//temp changes are identical in kelvin and celsius
   scale
T4 = T3; // C  //temp change in celsius scale
disp('Temp change in Celsius scale is = ' ,T4, ' C '
   )
disp('Temp change in Kelvin scale is =' ,T3, 'K')
disp('Temp change in Rankine scale is =' ,T2, 'R')
```

```
Console

 "Temp change in Celsius scale is = "

  11.111111

"°C"

 "Temp change in Kelvin scale is = "

  11.111111

"K"

 "Temp change in Rankine scale is = "

 20.

"R"
```

Figure 2.1: Express the Fahrenheit temperature change in Celsius and Kelvin and Rankine unit

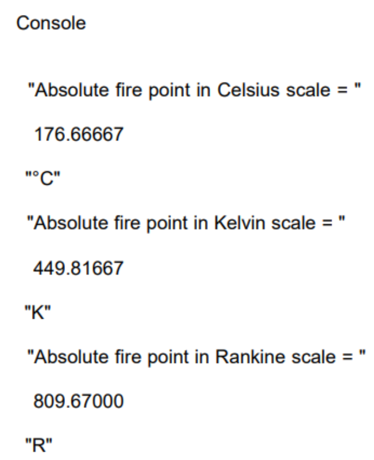

Figure 2.2: Find absolute fire point in Celsius and Kelvin and Rankine unit

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Scilab code Exa 2.2 `Find absolute fire point in Celsius and Kelvin and Rankine uni`

```
//Example 2.2
//Find absolute fire point in Celsius and Kelvin and
    Rankine unit
```

```
clear
clc
T1 = 350; // [ F ]  temperature in fahrenheit
T2 = T1 + 459.67; //[R]  Temperature in Rankine
T3 = T2/1.8; //[K]  Temperature in Kelvin
T4 = T3 - 273.15;  //[ C ]Temperature in Celsius
disp('Absolute fire point in Celsius scale = ' , T4,
    ' C ' )
disp('Absolute fire point in Kelvin scale = ' , T3,
    'K' )
disp('Absolute fire point in Rankine scale = ' , T2,
    'R' )
```

Scilab code Exa 2.3 Determine temperature corresponding to thermometric property v

```
//Example 2.3
//Determine temperature corresponding to
   thermometric property value given
clear
clc
t1 = 0;  //[ C ]  ice point temperature
t2 = 100; //[ C ]  steam point temperature
k1 = 1.75; //thermometric property at ice point
k2 = 8.5; //thermometric property at steam point
// given a equation t= x*log(k) + y
//we first need to find x and y and temp
   corresponding to thermometric property value of
   4.25
 //from given value two equatins are formed
 //x*log(k1) + y = 0
 //x*log(k2) + y = 100
 //solving the equations
 A = [log(k1) , 1 ;  log(k2) , 1];
```

Console

```
"On solving the equation value of x is"
 63.273103
"On solving the equation value of y is"
-35.408628
"Temperature corresponding to thermometric property value of 4.25 is "
 56.142427
"°C"
```

Figure 2.3: Determine temperature corresponding to thermometric property value given

```
B = [t1 ; t2];
C= inv(A)*B;
x = C(1,1);
y = C(2,1);
disp('On solving the equation value of x is' , x)
disp('On solving the equation value of y is' , y)
k3 = 4.25;
t = x*log(k3) + y; //[ C ]
disp('Temperature corresponding to thermometric property value of 4.25 is ' , t , ' C ')
//The answer vary due to round off error
```

Scilab code Exa 2.4 Determine the constants A and B in R

```
//Example2.4
//Determine the constants A and B in R
clear
clc
t1 = 0; //[ C ]     ice point temperature
t2 = 100; //[ C ]    steam point temperature
t3 = 444.6; //[ C ]    sulfur point temperature
R1 = 10.805; //[   ]   resistance at t1
R2 = 14.583;    //[   ]   resistance at t2
R3 = 29.332;   //[   ]     resistance at t3
//given equation R = R0(1 + At + Bt^2)
//we need to find value of Aand B
R0 = R1;  // solving equation at t1 = 0 C
// 14.583 = 10.805(1 + A*100 + B*100^2)  // at t2 = 100 C
// 29.332 = 10.805(1 + A*444.6 + B*444.6^2)  // at t3 = 444.6 C
//1080.5*A + 1080.5*100*B = 3.778
//4803.903*A + 10.805*444.6^2*B = 18.527
```

```
Console

 "Value of A is"
  0.0033920
 "Value of B is "
  0.0000010
```

Figure 2.4: Determine the constants A and B in R

```
X = [1080.5 , 108050; 4803.903 , 2135815.27];
Y = [3.778 ; 18.527];
Z = inv(X)*Y;
A = Z(1,1);
B = Z(2,1);
disp('Value of A is' , A)
disp('Value of B is ' , B)
//The answer given in book is wrong
```

Chapter 3

Energy and the First Law of Thermodynamics

Scilab code Exa 3.1 Estimate the work done by the gas on the piston

```
//Example 3.1
//Estimate the work done by the gas on the piston
clear
clc
P1 = 1600; //KPa
P2 = 175;  //KPa
A = 0.118; //m*m  //area of cylinder
l = 0.25; //m  //stroke of piston
V = A*l; //volume
//work done = area of PV diagram
W = (1/2)*(P1 + P2)*V;
disp('Work done by the gas on the piston = ' , W , '
    kJ ')
```

```
Console

 "Work done by the gas on the piston = "

  26.18125

 " kJ "
```

Figure 3.1: Estimate the work done by the gas on the piston

```
Console

 "Third work transfer is "
  10.
 "kJ "
 " from the fluid"
```

Figure 3.2: Determine the magnitude and direction of third work transfer

Scilab code Exa 3.2 Determine the magnitude and direction of third work transfer

```
//Example 3.2
//Determine the magnitude and direction of third work transfer
clear
clc
Q1 = 50; //kJ
Q2 = -20; //kJ
W1 = -20; //kJ
W2 = 40; //kJ
W3 = (Q1 + Q2) - (W1 + W2);
disp('Third work transfer is ' , W3 , 'kJ ' , ' from the fluid')
```

Scilab code Exa 3.3 Determine the specific heat Cp and Cv

```
//Example 3.3
//Determine the specific heat Cp and Cv
clear
clc
//u = 205 + 0.827t
u = poly([205 0.827] , 't', 'coeff');
Cv = derivat (u); //[kJ/kg K]  specific heat at constant volume
// pv = 0.279(t + 273)
//h = u+pv = 281.167 + 1.106t
h = poly([281.167 1.106], 't', 'coeff');
Cp = derivat (h); //[kJ/kg K]  specific heat at constant pressure
```

```
Console

 "Value of Cp is"

 1.106

 "kJ/kg K"

 "Value of Cv is"

 0.827

 "kJ/kg K"
```

Figure 3.3: Determine the specific heat Cp and Cv

```
disp('Value of Cp is' , Cp , 'kJ/kg K' )
disp('Value of Cv is' , Cv , 'kJ/kg K' )
```

Scilab code Exa 3.4 Estimate the net heat transfer

```
//Example 3.4
//Estimate the net heat transfer
clear
clc
P1 = 1200; //[kPa]    Initial pressure
P2 = 250; //[kPa]    Final pressure
V1 = 0.25; //[m^3]    Initial volume
V2 = 1.35; //[m^3]    Final volume
//given a equation p = a + 2bV
//from given value two equation are formed
// a + 2*V1*b = 1200;
// a + 2*V2*b = 250;
X = [1 , 2*V1; 1 , 2*V2];
Y = [P1; P2];
Z = inv(X)*Y;
a = Z(1,1);
b = Z(2,1);
disp('a = ' , a) //value of a given in book is wrong
disp('b = ', b)
//now we need to find the value of work transfer
function w = f (V)
    w = a +2*b*V;
endfunction
W = intg(V1, V2, f);
disp('Work transfer = ' , W , 'kJ')
// next we have to find change in internal energy
del_U = 2*(P2*V2) - 2*(P1*V1); //change in internal
    energy
```

```
Console

 "a = "

  1415.9091

 "b = "

 -431.81818

 "Work transfer = "

  797.50000

 "kJ"

  "Change in internal energy"

  75.

 "kJ"

 "Net heat transfer = "

  872.50000

 " kJ "
```

Figure 3.4: Estimate the net heat transfer

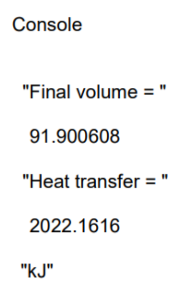


Figure 3.5: Determine the heat transfer

```
disp('Change in internal energy',del_U,'kJ')
Q = W + del_U; //net heat transfer
disp('Net heat transfer = ' , Q , ' kJ ')
// The answer provided in the textbook is wrong
```

Scilab code Exa 3.5 Determine the heat transfer

```
//Example 3.5
```

```
//Determine the heat transfer
clear
clc
P1 = 980; //[kPa]   initial pressure
P2 = 2.5;  //[kPa]   final pressure
V1 = 0.93;  //[m^3]   initial volume
n = 1.3;
m = 5; //[kg]
V2 = ((P1/P2)*(V1^n))^(1/n);
disp('Final volume = ', V2)
W1_2 = (P1*V1 -P2*V2)/(n-1);  //[kJ]
del_u = 50; //kJ/kg
del_U = m*(del_u);  //[kJ]
Q1_2 = W1_2 - del_U; //[kJ]
disp('Heat transfer = ' , Q1_2, 'kJ')
//The answer vary due to round off error
```

Scilab code Exa 3.6 Find total heat to be removed from fish and total latent heat

```
//Example 3.6
//Find total heat to be removed from fish and total
   latent heat to be removed
clear
clc
m = 700; //[kg]  mass of fish
t1 = 7; //[ C ]   initial temperature
t2 = -15; //[ C ]   temperature required
tf = -2;  //[ C ]   freezing point
Cp1 = 3.2;  //[kJ/kg K]    specific heat of fish
   above freezing point
Cp2  = 1.699;  //[kJ/kg K]   specific heat of fish
   below freezing point
hfg = 232; //[kJ/kg]    latent heat
```

```
Console

 "Total heat to be removed from fish"

  198020.9

"kJ"

 "Total latent heat to be removed"

  162400.

"kJ"
```

Figure 3.6: Find total heat to be removed from fish and total latent heat to be removed

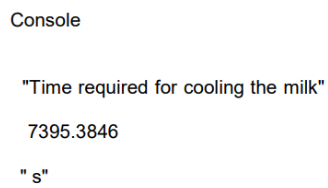


Figure 3.7: Estimate the time required for cooling milk

```
// Q = m*Cp*del_t   //heat removal
Q = m*(Cp1*(t1-tf) + hfg + Cp2*(tf - t2)); //[kJ]
disp('Total heat to be removed from fish', Q , 'kJ')
H = m*hfg; //total latent heat to be removed
disp('Total latent heat to be removed' , H , 'kJ')
```

Scilab code Exa 3.7 `Estimate the time required for cooling milk`

```
//Example 3.7
//Estimate time required for cooling milk
clear
clc
m = 1000; //[kg]    mass of milk
cp = 4.18; //[kJ/kg K]     specific heat of milk
t1 = 30; //[ C ]    initial temperature
t2 = 7; //[ C ]    final temperature
del_t = t1-t2; //[ C ]
Q = m*cp* del_t; //total heat to be removed from
   milk
C1 = 15; //[kJ/s]    capacity of milk chilling unit
   to remove heat from milk
C2 = 2; //[kJ/s]    rate of heat leakage into the
   milk
Net_Capacity = C1 - C2; //[kJ/s]    net capacity of
   the plant
Time_req = Q/Net_Capacity; //[s]
disp('Time required for cooling the milk' , Time_req
    , ' s')
```

Scilab code Exa 3.8 Estimate the work done for given conditions

```
//Example 3.8
//Estimate the work done for given conditions
clear
clc
P1 = 250; //[kPa]
m = 1; //[kg]
V1 = 0.035; //[m^3]
V2 = 0.09;  //[m^3]
//(i) Gas expands to 0.09 m^3 when pressure is
   constant
```

```
Console

 "Work done in isobaric process = "

  13.750000

 "kJ"

 "Work done in isothermal process = "

  8.2640391

 "kJ"

 "Work done in polytropic process = "

  6.8823544

 "kJ"
```

Figure 3.8: Estimate the work done for given conditions

```
function W = f(V)
    W = P1;
endfunction
w = intg(V1, V2, f); //[kJ]
disp('Work done in isobaric process = ', w ,'kJ' )
//(ii) Gas expands isothermally when the weights are
    removed
W1 = P1*V1*log(V2/V1); //[kJ]
disp('Work done in isothermal process = ', W1, 'kJ')
//(iii) Expansion follows P*(V^1.4) = Constant
n = 1.4;
P2 = P1*(V1/V2)^n; //[kPa]
W2 = (P1*V1-P2*V2)/(n-1); //[kJ]
disp('Work done in polytropic process = ' , W2 , 'kJ
    ')
//The answer vary due to round off error
```

Scilab code Exa 3.9 Calculate net work done and heat transfer and show Qcycle and

```
//Example 3.9
//Calculate net work done and heat transfer and show
    Qcycle and Wcycle are equal
clear
clc
//first ques is to sketch cycle of p-V diagram
// (ii) Calculate Wnet
p1 = 1.4; //[bar]
p2 = p1; //[bar]   pressure is constant during
    process 1-2
V1 = 0.028; //[m^3]
V3 = V1; //[m^3]    volume is constant during
    process 1-3
W1_2 = 10.5; //[kJ]
```

```
Console

 "Net workdone for the cycle = "

 -8.2824030

"kJ"

"Q1_2 = "

  36.9

"kJ"

"Qcycle = "

 -8.2824030

" kJ"

"Therefore  Qcycle = Wcycle"
```

Figure 3.9: Calculate net work done and heat transfer and show Qcycle and Wcycle are equal

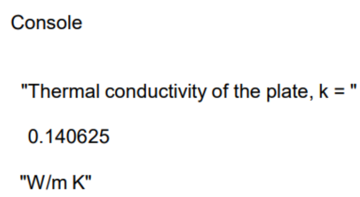
```
//W1_2 = p1*(V2-V1)
V2 = (W1_2/(p1 *100))+V1;
W2_3 = p2*100*V2*log(V3/V2); //[kJ]
U1_U3 = -26.4; //[kJ]   U1-U3
 //U3 = U2;
//U3-U2 = 0;
//   Q2_3 = W2_3 + U3 - U2;
Q2_3 = W2_3; //[kJ]
 W3_1 = 0; //[kJ]
 Q3_1 = -26.4; //[kJ]
 Wnet = W1_2 + W2_3 + W3_1;
 disp('Net workdone for the cycle = ' , Wnet , 'kJ')
 //(iii) Calculate Q1_2
 U2_U1 = -(U1_U3); //U2-U1=U3-U1 since U3 = U2
 Q1_2 = W1_2 + U2_U1; //[kJ]
 disp('Q1_2 = ',Q1_2, 'kJ')
 //(iv) Show Qcycle = Wnet
 Qcycle = Q1_2 + Q2_3 +Q3_1; //[kJ]
 disp('Qcycle = ' , Qcycle , ' kJ')
 disp('Therefore  Qcycle = Wcycle')
//Answer varies due to round off error
```

Scilab code Exa 3.10 Determine the outer surface temperature

```
//Example 3.10
//Determine the outer surface temperature
clear
clc
Q = 1500; //[W]   heat loss through wall
k = 1.7; //[W/m K]
L = 0.20; //[m]
A = 0.5*1.5; //m^2]
T1 = 1273; //[K]     inner surface temperature
```

```
Console

 "Outer surface temperature  t2 = "

   764.56588

 "°C"
```

Figure 3.10: Determine the outer surface temperature


Console

"Thermal conductivity of the plate, k = "

0.140625

"W/m K"

Figure 3.11: Find the thermal conductivity of the plate

```
//Q = (k*A*del_T)/L
del_T = (Q*L)/(k*A);//[K]
T2 = T1 - del_T; //[K]
t2 = T2 - 273.14; //[ C ]
disp('Outer surface temperature t2 = ' , t2 , ' C '
   )
```

Scilab code Exa 3.11 `Find the thermal conductivity of the plate`

```
//Example 3.11
//Find the thermal conductivity of the plate
clear
clc
q = 450; //[W/m^2]    heat flux through the plate
T1 = 0; //[ C ]
T2 = 80; //[ C ]
del_T = T2-T1;
L = 0.025; //[m]
k = q*L/del_T; //[W/m K]
disp('Thermal conductivity of the plate, k = ', k , 'W/m K')
```

Scilab code Exa 3.12 Find the rate of heat transfer

```
//Example 3.12
//Find the rate of heat transfer
clear
clc
T_alpha = 100; //[ C ]   temperature of air
Ts = 25; //[ C ]   surface temperature of plate
h = 50; //   [W/m^2 K]   convective heat transfer coefficient
A = 1.5*3; //[m^2] area
Q_conv = [h*A*(T_alpha - Ts)]/1000; //[kW]
disp('Heat transfer by convection , Q_conv = ' , Q_conv , 'kW')
```

```
Console

 "Heat transfer by convection , Q_conv = "

  16.875

 "kW"
```

Figure 3.12: Find the rate of heat transfer

Chapter 4

Properties of Pure Substances

Scilab code Exa 4.1 Determine specific volume temperature enthalpy and entropy and

```
//Example 4.1
//Determine specific volume, temperature, enthalpy, entropy, internal energy
clear
clc
//(i) Determine specific volume
V = 50*10^-3 //[m^3]
m = 5; //[kg]
v = V/m; //[m^3/kg]     specific volume
disp('Specific volume v, = ', v , 'm^3/kg')
//(ii) Determine temperature
//From steam table at 150 kPa
vf = 0.00109; //[m^3/kg]
vg = 0.3749; //[m^3/kg]
t = 151.86; // C     since vf<v<vg , water is in saturated mixture region, the temperature must be the saturated temperature at pressure 150 kPa
disp('Temperature = ' , t , ' C ')
//(iii) Determine enthalpy
```

```
Console

 "Specific volume v, = "
  0.01
 "m^3/kg"
 "Temperature = "
  151.86
 "°C"
 "Enthalpy, h  = "
  690.47687
 "kJ/kg"
 "Entropy, s = "
  2.0232872
 "kJ/kg K"
 "Internal energy, u = "
  688.97687
 "kJ/kg"
```

Figure 4.1: Determine specific volume temperature enthalpy and entropy and internal energy

```
vfg = vg - vf;  //[m^3/kg]
x = (v-vf)/vfg;
// At 500 kPa
hf = 640.23;  //[kJ/kg] //value of hf is mentioned
   wrong in book
hfg = 2108;  //[kJ/kg]
sf = 1.8607; //[kJ/kg K]
sfg = 6.821; //[kJ/kg K]
h = hf + x*hfg; //[kJ/kg]
disp('Enthalpy, h  = ', h ,'kJ/kg')
//(iv) Determine entropy
s = sf +x*sfg; //[kJ/kg K]
disp('Entropy, s = ', s , 'kJ/kg K')
//(v) Determine internal energy
p = 150; //[kPa]
v1 = 0.01;
u = h - p*v1; // [kJ/kg]
disp('Internal energy, u = ', u ,'kJ/kg')
//The answer vary due to round off error
```

Scilab code Exa 4.2 Determine change in enthalpy entropy internal energy and volum

```
//Example 4.2
//Determine change in enthalpy, entropy, internal
   energy and volume
clear
clc
m = 15; //kg
//At state 1, water is saturated water, so from
   saturated steam table at 55 C
hf = 230.26; //  kJ/kg
h1 = hf; //  kJ/kg
vf = 0.00101;  // m^3/kg
```

```
Console

 "Change in enthalpy = "
  43736.1
 "kJ"
 "Change in entropy = "
  94.551
 "kJ/K"
 "Change in internal energy = "
  39545.400
 "kJ"
 "Change in volume = "
  2.6023500
 "m^3"
```

Figure 4.2: Determine change in enthalpy entropy internal energy and volume

```
v1 = vf; // m^3/kg
uf = 230.24;  // kJ/kg
u1 = uf; // kJ/kg
sf = 0.7679;  //  kJ/kg K
s1 = sf;  //  kJ/kg K
//At state 2, water becomes superheated, so from
   superheated steam tables at 16 bar and 350 C
h2 = 3146.0; //  kJ/kg
v2 = 0.1745;  //m^3/kg
u2 = 2866.6;  //  kJ/kg
s2 = 7.0713;  // kJ/kg K
//(i) Determine the change in enthalpy
enthalpy = m*(h2-h1); //kJ
disp('Change in enthalpy = ' , enthalpy , 'kJ')
//(ii) Determine change in entropy
entropy = m*(s2-s1); // kJ/K
disp('Change in entropy = ',entropy,'kJ/K')
//(iii) Determine change in internal energy
del_U = m*(u2-u1); //kJ
disp('Change in internal energy = ', del_U,'kJ')
//(iv) Determine change in volume
del_V = m*(v2-v1); //m^3
disp('Change in volume = ',del_V, 'm^3')
```

Scilab code Exa 4.3 Compute ideal power of turbine

```
//Example 4.3
//Compute ideal power of turbine
clear
clc
m = 5; //[kg/s]
//from superheated steam table
h1 = 3137.0; //[kJ/kg]
```

```
Console

 "Power of turbine, (dW/dt) = "

  2585.

 "kJ/s or kW"
```

Figure 4.3: Compute ideal power of turbine

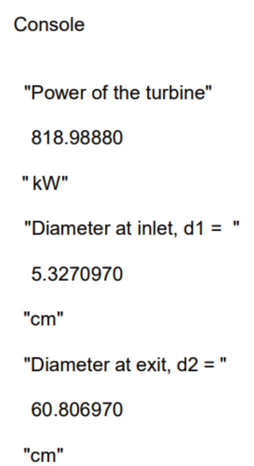


Figure 4.4: Determine power of turbine and diameter at inlet and exit

```
//from h—s diagram
h2 = 2620;   //[kJ/kg]
P = m*(h1-h2);   //[kJ/s or kW]     power of turbine(dW/dt)
disp('Power of turbine, (dW/dt) = ' , P , 'kJ/s or kW')
```

Scilab code Exa 4.4 `Determine power of turbine and diameter at inlet and exit`

```
//Example 4.4
//Determine power of turbine and diameter at inlet and exit
clear
clc
m = 2;  //  [kg/s]
V1 = 100; //[m/s]    velocity of steam at inlet
V2 = 50;  //[m/s]    velocity of steam at exit
z1_z2 = 3; //[m]   difference in height of inlet and exit(z1-z2)
//From superheated steam table
//At state 1 at 20 bar and 250 C
h1 = 2902.5;  //[kJ/kg]
s1 = 6.5453;  //[kJ/kg K]
v1 = 0.11144  //[m^3/kg]
//At state 2 at 0.2 bar and 5% moisture
hf2 = 251.40; //[kJ/kg]
hfg2 = 2358.3;  //[kJ/kg]
vf2 = 0.00101; //[m^3/kg]
sf2 = 7.64;  //[kJ/kg]
x = 0.95; // Quality or drynes fraction
h2 = hf2 + x*hfg2; //[kJ/kg]   enthalpy at state 2
q = -10; //[kJ/s]  rate of heat loss(dQ/dt)
g = 9.8; //[m/s^2]
//(i) Determine power of turbine when heat loss is at rate of 10 kJ/s
P = m*[(h1 - h2) + (V1^2 - V2^2)/(2*1000) + (z1_z2)*g/1000] + q;//[kW] power(dW/dt)
disp('Power of the turbine' , P , ' kW')
//(ii) Determine the diameters at inlet and exit
A1 = (m*v1)/V1; //[m^2]   inlet area
v2 = 7.26; //[m^3/kg]
A2 = (m*v2)/V2;  //[m^2]    exit area
d1 = sqrt((A1*4)/%pi); //[m]   inlet diameter
d2 = sqrt((A2*4)/%pi);  //[m]   exit diameter
disp('Diameter at inlet, d1 =  ' , d1*100 , 'cm')
disp('Diameter at exit, d2 = ' , d2*100 , 'cm')
//Answer vary due to round off error
```

```
Console

 "Heat required to produce 1 kg of steam with x1 = 0.9, q1 = "

  2422.005

 "kJ/kg"

 "Heat required to produce 1 kg of dry saturated steam, q2 = "

  2611.085

 "kJ/kg"

 "Heat required to produce 1 kg of superheated steam, q3 = "

  2674.085

 "kJ/kg"
```

Figure 4.5: Calculate amount of heat required to produce 1kg of steam under 3 condition

---

Scilab code Exa 4.5 `Calculate amount of heat required to produce 1kg of steam unde`

```
//Example 4.5
//Calculate the amount of heat required to produce 1
    kg steam under 3 condition
```

```
clear
clc
t = 45; //[ C ]   temperature of feed water
Cpw = 4.187; //[kJ/kg K]
Cp_steam = 2.1; //[kJ/kg]
hf = Cpw*(t-0); //[kJ/kg]    sensible heat of feed
    water
//from steam table at 20 bar
hf1 = 908.79; //[kJ/kg]
hfg1 = 1890.7;  //[kJ/kg]
hg1 = 2799.5; //[kJ/kg]
//(i)Calculate amount of  heat required to produce 1
     kg steam with x1 = 0.9
x1 = 0.9;
h1 = hf1 + x1*hfg1; //[kJ/kg]
q1 = h1 - hf; //[kJ/kg]
disp('Heat required to produce 1 kg of steam with x1
     = 0.9, q1 = ',q1,'kJ/kg')
// (ii)Calculate amount of heat required to produce
    1 kg of dry saturated steam
q2 =  hg1-hf; //[kJ/kg]
disp('Heat required to produce 1 kg of dry saturated
     steam, q2 = ' , q2 , 'kJ/kg')
// (iii)Calculate amount of heat required to produce
     1 kg of superheated steam with 30 C  of
    superheat
//from steam table at 20 bar t_sat = 212.42 C
t_sat = 212.42; //[ C ]
t2 = 30; //[ C ]   given in ques 3
t_sup = t_sat + t2;  //[ C ]
h3 = hg1 + Cp_steam*(t_sup - t_sat); //[kJ/kg]
q3 = h3 - hf; //[kJ/kg]
disp('Heat required to produce 1 kg of superheated
    steam, q3 = ',q3, 'kJ/kg')
```

```
Console

 "Quality (dryness fraction) of steam = "

  96.810934

 "%"

 "Maximum moisture allowed is"

  4.8595292

 "%"
```

Figure 4.6: Determine dryness fraction and maximum moisture

Scilab code Exa 4.6 `Determine dryness fraction and maximum moisture`

```
//Example 4.6
//Determine dryness fraction and maximum moisture
clear
clc
p1= 10; //[MPa]
p2 = 0.05; //[MPa]
t = 100; //[ C ]
//(i) Calculate dryness fraction of steam
h2 = 2682; //[kJ/kg]    when p2 = 0.05 MPa and t = 100 C  from superheated steam tables
hf1 = 1407; //[kJ/kg]    at p1 = 10 MPa
hfg1 = 1317; //[kJ/kg]    at p1 = 10MPa
h1 = h2;  //for throttling process   (h1 = h2 = hf1 + x*hfg1)
x = (h2 - hf1)/hfg1;
dryness_fraction = x*100; //[%]
disp('Quality (dryness fraction) of steam = ',dryness_fraction,'%')
//(ii) Calculate the maximum moisture
t2 = 5; //[ C ]   superheat reuired after throttling
t_sat = 81; //[ C ]    at p2=0.05 MPa
T = t_sat + t2; //[ C ]
//from superheated steam tables
h3 = 2660; //[kJ/kg]
h4 = h3; //[kJ/kg]
hf4 = hf1;//[kJ/kg]
hfg4 = hfg1;//[kJ/kg]
// h4 = hf4 + x4*hfg4
x4 = (h4-hf4)/hfg4;
max_moisture = (1-x4)*100;
disp('Maximum moisture allowed is', max_moisture , '%')
```

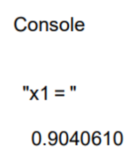


Figure 4.7: Determine the quality of steam in the main

```
//The answer vary due to round off error
```

Scilab code Exa 4.7 `Determine the quality of steam in the main`

```
//Example 4.7
//Determine the quality of steam in the main
clear
clc
```

```
h3 = 2768.8; //[kJ/kg]   From superheated steam
   tables , at 2 bar and 150 C
h2 = h3; //enthalpy before throttling = enthalpy
   after throttling
hf2 = 798.65; //[kJ/kg]   From saturated steam table
    at 12 bar
hfg2 = 1986.2; //[kJ/kg]  From saturated steam table
    at 12 bar
// h2 = hf2 + x2*hfg2
x2 = (h2-hf2)/hfg2;
V = 0.2*10^-3; //[m^3]
v = 0.001029; //[m^3/kg]   From saturated steam
   table at 80 C  (v = vf = 0.001029)
m1 = V/v; //[kg]
m2 = 2; //[kg]   Mass of steam condensed after
   throttling
x1 = (x2 *m2)/(m1 +m2);
disp('x1 = ', x1)
```

Chapter 5

First Law Analysis of Control Volumes

Scilab code Exa 5.1 Find Velocity and Mass flow rate and Area

```
//Example 5.1
//Find Velocity and Mass flow rate and Area
clear
clc
//At inlet
h1 = 2670; //   [kJ/kg]
V1 = 72;  //[m/s]
A1 = 0.098; //[m^2]
v1 = 0.179;  // [m^3/kg]
//At exit
h2 = 2580; //   [kJ/kg]
v2 = 0.503;  // [m^3/kg]
heat_loss = 0;  //(dQ/dt = 0)  heat loss is
    negligible
work_done = 0;  //work done is zero for nozzle
//(i) Find the velocity at the exit of the nozzle
// final equation is [h1 + (V1^2)/2] = [h2 + (V2^2)
```

```
Console

 "Velocity at the exit of the nozzle, V2 = "

   430.33011

 "m/s"

 "Mass flow rate, m ="

   39.418994

 "kg/s"

 "Area at the exit of nozzle, A2 = "

   0.0460757

 "m^2"
```

Figure 5.1: Find Velocity and Mass flow rate and Area

```
    /2]
V2 = sqrt(2*1000*(h1-h2) + V1^2); // [m/s ]
disp('Velocity at the exit of the nozzle, V2 = ', V2
    , 'm/s')
//(ii) Find the mass flow rate of gas at A1 and v1
m = (A1*V1)/v1;  //  [kg/s]
disp('Mass flow rate, m =' , m , 'kg/s')
//(iii)Find the area at the exit of the nozzle
A2 = (m*v2)/V2;  //[m^2]
disp('Area at the exit of nozzle, A2 = ', A2 , 'm^2'
    )
```

Scilab code Exa 5.2 Estimate the power output for steady flow conditions

```
//Example 5.2
//Estimate the power output for steady flow
    conditions
clear
clc
//At turbine inlet
p1 = 110; //[bar]
h1 = 2900; //[kJ/kg]
V1 = 36; //[m/s]
z1 = 3.3; //[m]
//At turbine outlet
p2 = 30; //[kPa]
h2 = 2490; //[kJ/kg]
V2 = 110; //[m/s]
z2 = 0; //[m]
heat_loss = -0.32; //[kJ/s]  rate of heat loss(dQ/dt
    )
m = 0.393;  //[kg/s]
g = 9.8;  //[m/s^2]
```

```
Console

 "Power output of turbine = "

  158.69972

 "kW"
```

Figure 5.2: Estimate the power output for steady flow conditions

```
Console

 "Power required to drive the compressor, P = "

  95.487062

 "kW"

 "Inlet cross sectional area, A1 = "

  0.05625

 "m^2"

 "Outlet cross sectional area, A2 = "

  0.0207143

 "m^2"
```

Figure 5.3: Calculate power and inlet and outlet cross sectional area

```
P = m*[(h1-h2) + (V1^2 - V2^2)/(2*1000 )+ ((z1-z2)*g
    )/1000] + heat_loss;//[kW]
disp('Power output of turbine = ', P , 'kW')
```

Scilab code Exa 5.3 Calculate power and inlet and outlet cross sectional area

```
// Example 5.3
```

```
//Calculate power and inlet and outlet cross
    sectional area
clear
clc
p1 = 1.5; //[bar]
v1 = 0.9; // [m^3/kg]     specific volume while
    entering
V1 = 8; //   [m/s]
p2 = 8;  //[bar]
v2 = 0.145; //  [m^3/kg]     specific volume while
    leaving
V2 = 3.5; //[m/s]
z1_z2 = 0; //difference in height at inlet and
    outlet  (z1-z2)
heat_rate = -55;  //[kW]   rate at which cooling
    water absorbs heat from air
u1_u2 = -100; //[kJ]   difference in internal energy
     of air entering and leav
m = 30/60;  //  [kg/s]
//[h1-h2 = u1_u2 + (p1*v1 - p2*v2)*10^5 ] [kJ/kg]  (
    difference in enthalpy)
g = 9.8; // [m/s^2]  acceleration due to gravity
//(i) Calculate power required to drive the
    compressor
P  = m*[(u1_u2) + ((p1*v1-p2*v2)*10^5)/1000+ (V1^2 -
     V2^2)/(2*1000) + (z1_z2)*g ] + heat_rate; //[kW]
disp('Power required to drive the compressor, P = '
    , -P , 'kW')
//(ii) Calculate inlet and outlet cross sectional
    area
A1 = (m*v1)/V1; // [m^2]
A2 = (m*v2)/V2; // [m^2]
disp('Inlet cross sectional area, A1 = ' , A1 , 'm^2
    ')
disp('Outlet cross sectional area, A2 = ' , A2 , 'm
    ^2')
```

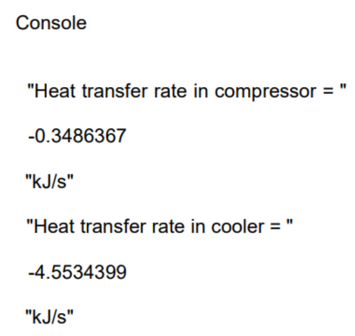


Figure 5.4: Estimate heat transfer rate in compressor and cooler

Scilab code Exa 5.4 `Estimate heat transfer rate in compressor and cooler`

```
//Example 5.4
//Estimate heat transfer rate in compressor and
   cooler
clear
clc
```

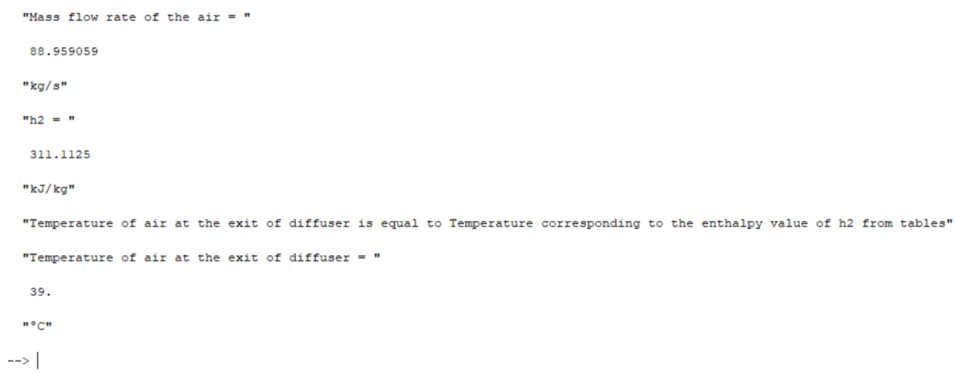
```
p1 = 1; //  [bar]
P1 = 100; //[kPa]
t1 = 25; //[ C ]
V1 = 2.5; //  [m^3/min]  volumetric flow rate of air
p2 = 2; //  [bar]
t2 = 120; //[ C ]
t3 = 27; //[ C ]
dW_by_dt_1 = -5;  //[kW]  Work input required for compressor
T1 = t1 + 273; //[K]
T2 = t2 + 273; //[K]
T3 = t3 + 273; //[K]
R = 0.287;
v1 = (R*T1)/P1; //[m^3/kg]
m = V1/v1; //[kg/min]   mass flow rate in kg/min
m2 = m/60; //[kg/s]    mass flow rate in kg/s
//(i) Estimate heat transfer rate in compressor
cp = 1.005;  //[kJ/kg K]
h1_h2 = cp*(T1 - T2); //  [kJ/kg]
Q1 = dW_by_dt_1 - m2*[h1_h2]; //[kJ/s] //heat transfer rate in compressor
disp('Heat transfer rate in compressor = ', Q1 , 'kJ/s' )
//(ii) Estimate  heat transfer rate in cooler
h2_h3 = cp*(T2-T3); //[kJ/kg]
dW_by_dt_2 = 0; // since no work is involved in cooler dW/dt = 0
Q2 = dW_by_dt_2 - m2*(h2_h3) ;  // heat transfer rate in cooler
disp('Heat transfer rate in cooler = ', Q2 , 'kJ/s')
//Answer vary due to round off error
```

Scilab code Exa 5.5 Estimate velocity of air stream leaving the nozzle

```
Console

"Velocity of air stream leaving the nozzle at 30°C = "

 447.21508

"m/s"
```

Figure 5.5: Estimate velocity of air stream leaving the nozzle

```
//Example 5.5
//Estimate velocity of air stream leaving the nozzle
clear
clc
p1 = 1.2; //[bar]
t1 = 30; //[ C ]
V1 = 25; //[m/s]
p2 = 6; //[bar]
t2 = 230; //[ C ]
V2 = 45; // [m/s]
Q = -80; // [kJ/s] Rate at which heat is removed
    from chamber
t4 = 30; // [ C ]
t3 = (t1 + t2)/2;  //[ C ]  Final temperature after
    mixing
// From tables of ideal gas properties of air
h1 = 303; //[kJ/kg]  At 303 K
h2 = 503; //[kJ/kg]  At 503 K
h3 = 403; //[kJ/kg]  At 403 K
// for mixing chamber m1*[h1 + V1^2/2] + m2*[h2 + V2
    ^2/2] = m3*[h3 + V3^2]+Q
// Also m1 = m2 = m and from mass balance m1+m2 = m3
    = 2*m
// Final eq  =  [m*[h1 + V1^2/2 + h2 + V2^2/2] = 2*m
    *[h3 + V3^2/2]+Q]
V3 = sqrt(h1 + V1^2/(2*1000) + h2 + V2^2/(2*1000) -
    2*h3); //[m/s]
// For nozzle mass flow rate remain constant so
    final equation is
// m3*[h3 + V3^2/2] = m3*[h4 + V4^2/2]
h4 = h1;
V4 = sqrt(2*1000*[h3 + V3^2/(2*1000)-h4]);
disp('Velocity of air stream leaving the nozzle at
    30 C = ' , V4 , 'm/s')
// The answer vary due to round off error
```


"Mass flow rate of the air = "

88.959059

"kg/s"

"h2 = "

311.1125

"kJ/kg"

"Temperature of air at the exit of diffuser is equal to Temperature corresponding to the enthalpy value of h2 from tables"

"Temperature of air at the exit of diffuser = "

39.

"°C"

-->

Figure 5.6: Determine the mass flow rate of air and temperature of air at the exit of diffuser

Scilab code Exa 5.6 `Determine the mass flow rate of air and temperature of air at`

```
//Example 5.6
//Determine the mass flow rate of air and
   temperature of air at the exit of diffuser
clear
clc
T1 = 273 + 15; //[K]
V1 = 215; //[m/s]
p1 = 90; //[kPa]
R = 0.287;
```

```
v1 = (R*T1)/p1; //[m^3/kg]
A1 = 0.38; //[m^2]
//(i) Determine mass flow rate of air
m = (A1*V1)/v1; //[kg/s]
disp('Mass flow rate of the air = ',m,'kg/s')
//(ii)Determine the temperature of air at the exit of diffuser
//For diffuser , mass flow rate remains constant in steady flow so final equation is [h1 + V1^2/2] = [h2 +V2^2/2]
V2 = 0; //velocity of air leaving the diffuser is very small to vel at inlet
h1 = 288; //[kJ/kg]  from tables of ideal gas properties of air
h2 = h1 + V1^2/(2*1000) - V2^2/(2*1000);
disp('h2 = ',h2, 'kJ/kg')
disp('Temperature of air at the exit of diffuser is equal to Temperature corresponding to the enthalpy value of h2 from tables')
T2 = 39; //[ C ] From tables of ideal gas properties of air , temperature corresponding to h2
disp('Temperature of air at the exit of diffuser = ', T2 ,' C ')
// The answer vary due to round off error
```

Scilab code Exa 5.7 Determine mass flow rate of the cooling water

```
//Example 5.7
//Determine mass flow rate of the cooling water
clear
clc
//For a heat exchanger , SFEE is m1*h1+m2*h2 = m3*h3+m4*h4
```

```
Console

 "Mass flow rate of cooling water = "

  1.4374701

 "kg/s"
```

Figure 5.7: Determine mass flow rate of the cooling water

```
//For steady flow, mass flow rates are equal so eq
   is m_air(h1-h3)=m_water(h4-h2)
m_air = 1; //[kg/s]
h1 = 373; //[kJ/kg]  from tables of ideal gas
   properties of air at 373 K
h3 = 313; //[kJ/kg]  from tables of ideal gas
   properties of air at 313 K
h2 = 125.79; //[kJ/kg]  from saturated water
   temperature table at 30 C
h4 = 167.53; //[kJ/kg]  from saturated water
   temperature tables at 40 C
m_water = (m_air*(h1-h3))/(h4-h2); //[kg/s]
disp('Mass flow rate of cooling water = ',m_water,'
   kg/s')
```

Chapter 6

Second Law of Thermodynamics

Scilab code Exa 6.1 Determine the power required to drive the plant

```
//Example 6.1
//Determine the power required to drive the plant
clear
clc
T1 = 273 + 27; //[K] atmospheric temperature
T2 = 273 - 7; //[K]  store temperature
Q2 = 6; //[kW] heat transfer(removed) from store
COP = T2/(T1-T2); //coefficient of performance
Wnet_in = Q2/COP; //[kW]
disp('Power required to drive the plant = ' ,
   Wnet_in, 'kW')
//The answer vary due to round off error
```

```
Console

 "Power required to drive the plant = "

  0.7669173

 "kW"
```

Figure 6.1: Determine the power required to drive the plant

```
Console

 "Monthly bill of the refrigerator = "

 "Rs"

  4.2238267
```

Figure 6.2: Estimate the monthly bill of the refrigerator

Scilab code Exa 6.2 Estimate the monthly bill of the refrigerator

```
//Example 6.2
//Estimate the monthly bill of the refrigerator
clear
clc
T1 = 273 + 30;  //[K]
T2 = 273 + 4; //[K]
Ideal_COP = T2/(T1-T2);
Actual_COP = 0.20 * Ideal_COP;
 n = 12; // no. of times the door of refrigerator is opened in a day
 Q = 360; //[kJ]
 Q2 = Q*n; //[kJ]
 Wnet_in = Q2/Actual_COP; // [kJ]
 Cost_of_work = 0.25; //[Rs/kW h]
 // 1 kW h = 3600 kJ
 Wnet_in_1 = Wnet_in/3600; //[kW h]
  Cost = Wnet_in_1*Cost_of_work; //[Rs.]  Cost of work for Wnet_in_1
  Bill = 30*Cost; //[Rs] //Monthly bill of refrigerator
  disp('Monthly bill of the refrigerator = ', 'Rs' , Bill,)
```

Scilab code Exa 6.3 Determine the heat input required to heat engine and heat avai

```
//Example 6.3
//Determine the heat input required to heat engine and heat available for heating by the heat pump
clear
clc
COP_R= 4.5; //COP of refrigerator
```

```
Console

 "Heat input required to the engine is "

  793.65079

"kJ"

 "Heat available for heating by the heat pump is"

  1540.

"kJ"
```

Figure 6.3: Determine the heat input required to heat engine and heat available for heating by the heat pump

```
Q4 = 1000; //[kJ]   Heat removed from refrigerator
Wnet_in = Q4/COP_R; //[kJ]  Work need to remove 1MJ of heat
eta_thermal = 0.28; // Thermal efficiency of heat engine
Wnet_out_1 = Wnet_in; //[kJ] Work output of heat engine
//(i) Determine heat input required to the engine
Q1 = Wnet_out_1/eta_thermal; //[kJ] heat input required to the engine
disp('Heat input required to the engine is ', Q1 , ' kJ' )
//(ii) Determine the heat that is available for heating if above is used as heat pump for each MJ of heat input to the engine
q = 1000; //[kJ] Heat input to the Heat engine
Wnet_out_2 = eta_thermal*q; //[kJ] Work output
Wnet_in_2 = Wnet_out_2; //[kJ] Work input to heat pump
COP_HP = 1 + COP_R; // COP of heat pump
Q3 = COP_HP*Wnet_in_2; //[kJ]
disp('Heat available for heating by the heat pump is ', Q3, 'kJ')
// The answer provided in textbook is wrong
```

Scilab code Exa 6.4 Determine ratio between heat transfer to circulating water and

```
// Example 6.4
//Determine ratio between heat transfer to circulating water and heat input to engine
clear
clc
COP_HP = 3.5;
```

```
Console

 "The ratio between heat transfer to circulating water and heat input to engine is "

  1.625
```

Figure 6.4: Determine ratio between heat transfer to circulating water and heat input to engine

```
// COP_HP = Q3/Wnet
// therefore Wnet = Q3/COP_HP  --eq1
eta_thermal = 0.25;
// eta_thermal = Wnet/Q1
// therefore Wnet = eta_thermal*Q1  --eq2
// From eq1 & 2  [eta_thermal*Q1 = Q3/COP_HP]
// so Q3/Q1 = eta_thermal*COP_HP
Q3_1 = eta_thermal*COP_HP; // Q3/Q1
// Q2/Q1 = 1 - eta_thermal
Q2_1 = 1 - eta_thermal;
Ratio = Q3_1 + Q2_1; // (Q3/Q1) + (Q2/Q1) = (Q3 + Q2)/Q1
disp('The ratio between heat transfer to circulating water and heat input to engine is ', Ratio)
```

Scilab code Exa 6.5 Estimate heat rejected to the surroundings and the engine effi

```
//Example 6.5
//Estimate heat rejected to the surroundings and the engine efficiency
clear
clc
T1 = 800; //[K]
T2 = 298; //[K]
Q1 = 900; //[kW]
Wnet_out_1 = 400; //[kW]
eta_thermal = (Wnet_out_1/Q1)*100; //[%] Actual heat engine efficiency
Q2_1 = Q1 - Wnet_out_1; //[kW] Heat rejected to surrounding by actual heat engine
eta_carnot = 1 - (T2/T1); //Carnot heat engine efficiency
Wnet_out_2 = eta_carnot*Q1; //[kW]
```

```
Console

 "Heat rejected by actual heat engine = "
  500.
 "kW"
 "Heat rejected by carnot heat engine = "
  335.25
 "kW"
 "Actual heat engine efficiency = "
  44.444444
 "%"
 "Carnot heat engine efficiency = "
  62.750000
 "%"
```

Figure 6.5: Estimate heat rejected to the surroundings and the engine efficiency

```
Q2_2 = Q1 - Wnet_out_2; //[kW] Heat rejected to surrounding by carnot heat engine
//(i) Estimate heat rejected to the surroundings
disp('Heat rejected by actual heat engine = ',Q2_1,' kW')
disp('Heat rejected by carnot heat engine = ', Q2_2 , 'kW')
//(ii) Estimate the engine efficiency
disp('Actual heat engine efficiency = ', eta_thermal , '%')
disp('Carnot heat engine efficiency = ' , eta_carnot *100 , '%')
```

Scilab code Exa 6.6 Estimate minimum work input required

```
//Example 6.6
// Estimate minimum work input required
clear
clc
T1 = 20 + 273; //[K]
T2 = 0 + 273; //[K]
m = 1000; //[kg] Mass of ice
LH = 335; //[kJ/kg] Enthalpy of fusion of ice
Cp = 4.2; //[kJ/kg K] Specific heat capacity of water at constant pressure
COP_R_Rev = T2/(T1 - T2); // COP for reversible refrigerator
Q2 = m*LH + m*Cp*(T1 - T2); //[kJ] Heat removed by refrigerator from water to produce 1 ton ice
Wnet_in = Q2/COP_R_Rev;//[kJ]
W_min = Wnet_in/3600; //[kW h] Minimum work input required in kW h
disp('Minimum work input required in kW h to produce
```

```
Console

 "Minimum work input required in kW h to produce 1 ton of ice = "

  8.5266585

 "kW h"
```

Figure 6.6: Estimate minimum work input required

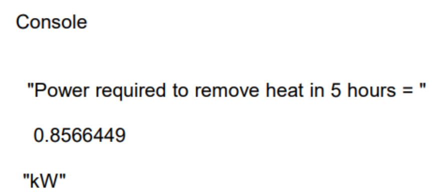


Figure 6.7: Evaluate the power required to remove heat in 5 hours

```
1 ton of ice = ', W_min,'kW h')
```

Scilab code Exa 6.7 Evaluate the power required to remove heat in 5 hours

```
//Example 6.7
// Evaluate the power required to remove heat in 5
   hours
clear
```

```
clc
m = 150; //[kg]
ti = 10; //[ C ] Initial temperature
tf = -2; //[ C ]  Freezing point
T1 = 35 + 273; //[K]  Ambient temperature
t2 = -5; //[ C ] Temperature required in celsius
T2 = 273 - 5; //[K] Temperature required in kelvin
Cp1 = 3.2; //[kJ/kg K] Specific heat of fish above
   freezing point
Cp2 = 1.699; //[kJ/kg K] Specific heat of fish below
    freezing point
hfg = 232; //[kJ/kg] Latent heat of fusion
COP_R_Rev = T2/(T1 - T2);
COP = 0.4*COP_R_Rev; // Actual COP
Q2 = m*[Cp1 *(ti - tf)+ hfg + Cp2*(tf - t2)]; //[kJ]
Wnet_in = Q2/COP; //[kJ]
del_t = 5*3600; //[s]
W = Wnet_in/del_t; //[kW]
disp('Power required to remove heat in 5 hours = ',W
   ,'kW')
```

Chapter 7

Entropy

Scilab code Exa 7.1 Determine the increase in entropy of water

```
//Example 7.1
//Determine the increase in entropy of water
clear
clc
m1 = 1.5; // [kg]
t1 = 75;  // [ C ]
T1 = 273 + t1; //[K]
m2 = 4;  // [kg]
t2 = 40;  // [ C ]
T2 = 273 + t2; //[K]
Cpw = 4.2;  //[kJ/kg K]
t = 0; // [ C ]
T = 273 + t; //[K]
m = m1+m2; //[kg]
E = m1*Cpw*(t1-t) + m2*Cpw*(t2-t); // total energy before mixing
// total energy after mixing = m*Cpw*(tf - t)
tm = E/(m*Cpw); //[ C ]  final equilibrium temperature of water
```

```
Console

 "Initial entropy of the system, s1 = "

  3.8262908

 "kJ/kg K"

 "Final entropy of the system, s2 = "

  3.8524396

 "kJ/kg K"

 "Increase in entropy of the system, del_s = "

  0.0261488

 "kJ/kg K"
```

Figure 7.1: Determine the increase in entropy of water

```
tf = 273 + tm; //[K]
s1 = m1*Cpw*log(T1/T) + m2*Cpw*log(T2/T); //[kJ/kg K
    ] Initial entropy of the system
disp('Initial entropy of the system, s1 = ',s1,'kJ/
    kg K')
s2 = m*Cpw*log(tf/T); // [kJ/kg K] Final entropy of
    the system
disp('Final entropy of the system, s2 = ',s2,'kJ/kg
    K')
del_s = s2 - s1; //[kJ/kg K]
disp('Increase in entropy of the system, del_s = ',
    del_s , 'kJ/kg K')
//The answer vary due to round off error
```

Scilab code Exa 7.2 Determine heat supplied and work done and steam flow rate

```
//Example 7.2
//Determine heat supplied and work done and steam
    flow rate
clear
clc
T1 = 600; //[K]
T2 = 320; //[K]
//(i) Determine the heat supplied
// Q1/T1 = Q2/T2 = del_s ( for a reversible cycle)
del_s = 1.5; //[kJ/kg K]
Q1 = del_s * T1; //[kJ/kg]
disp('Heat supplied = ', Q1 , 'kJ/kg')
//(ii) Determine the work done
eta = 1 - (T2/T1);
W = eta*Q1; //[kJ/kg]   Work done
disp('Work done = ',W, 'kJ/kg')
//(iii) Determine the steam flow rate
```

```
Console

 "Heat supplied = "

  900.

 "kJ/kg"

 "Work done = "

  420.

 "kJ/kg"

 "Steam flow rate = "

  0.0435714

 "kg/s"
```

Figure 7.2: Determine heat supplied and work done and steam flow rate

```
P = 18.3; //[kW]  Power output
m = P/W; //[kg/s]  mass flow
disp('Steam flow rate = ' , m , 'kg/s')
```

Scilab code Exa 7.3 Estimate the entropy change of the system

```
//Example 7.3
// Estimate the entropy change of the system
clear
clc
T1 = 273 + 25; //[K]
T2 = 273 + 0; //[K]
T3 = 273 + (-5); //[K]
m = 250; //[g]
Cp_water = 4.182; //[ J/g K]  Specific heat of water
Cp_ice = Cp_water/2; //[J/K]  Specific heat of ice
del_s_1 = m*Cp_water*log(T2/T1); //[J/K]  Entropy change of system when it is converted to ice from 25 C  to 0 C
// Answer of del_s_1 is given wrong as T2 is 298 and in book it is solved by taking T2 as 293
disp('Entropy change of the system(water) when it is converted to ice from 25 C  to 0 C ' , del_s_1,' J/K')
L = 335; //[J/g] latent heat of fusion at 0 C
Q = m*L; //[J]
del_s_2 = -Q/T2; //[J/K] entropy change of system when water freezes at 0 C
disp('Entropy change of the system (water) when water freezes at 0 C ',del_s_2,'J/K')
del_s_3 = m*Cp_ice*log(T3/T2); //[J/K] entropy change when ice is formed from 0 C  to -5 C
disp('Entropy change of system (water) when ice is
```

```
Console

 "Entropy change of the system(water) when it is converted to ice from 25°C to 0°C"

 -91.608478

"J/K"

 "Entropy change of the system (water) when water freezes at 0°C"

 -306.77656

"J/K"

 "Entropy change of system (water) when ice is formed from 0°C to -5°C"

 -9.6629369

"J/K"

 "Total entropy change of the system"

 -408.04797

"J/K"
```

Figure 7.3: Estimate the entropy change of the system

```
formed from 0 C to -5 C ',del_s_3, 'J/K')
del_s_total = del_s_1 + del_s_2 + del_s_3; //[J/K]
disp('Total entropy change of the system' , del_s_total, 'J/K')
//The answer for del_s_1 is provided wrong in textbook and value of del_s_2 and del_s_3 vary due to round off error due to this final answer vary
```

Scilab code Exa 7.4 Estimate the entropy change of the universe

```
//Example 7.4
//Estimate the entropy change of the universe
clear
clc
 m = 0.5; //[kg]
 Cp = 0.45; //[kJ/kg K]
 T1 = 273 + 120; //[K]
 T2 = 273 + 10; //[K]
 // Case 1 : Iron block is placed in lake at 10 C
 del_s_system = m*Cp*log(T2/T1); //[kJ/kg]
 Q = m*Cp*(T1-T2); //[kJ]
 del_s_surr = Q/T2; //[kJ/kg K]
 del_s_1 = del_s_system + del_s_surr; //[kJ/kg K]
 disp('Entropy change when iron block is placed in lake at 10 C ',del_s_1,'kJ/kg K')
 // Case 2: Iron block is dropped in lake from 150 m
 g = 9.8; //[m/s^2] Acceleration due to gravity
 h = 150; //[m]
 Q1 = m*g*h; //[kJ/kg K]
 del_s_2 = Q1/T2; //[kJ/kg K]
 disp('Entropy change when iron block is dropped from 150 m',del_s_2,'kJ/kg K')
```

```
Console

 "Entropy change when iron block is placed in lake at 10°C"
  0.0135742
 "kJ/kg K"
 "Entropy change when iron block is dropped from 150 m"
  2.5971731
 "kJ/kg K"
 "Entropy change when two blocks are joined"
  0.0060379
 "kJ/kg K"
```

Figure 7.4: Estimate the entropy change of the universe

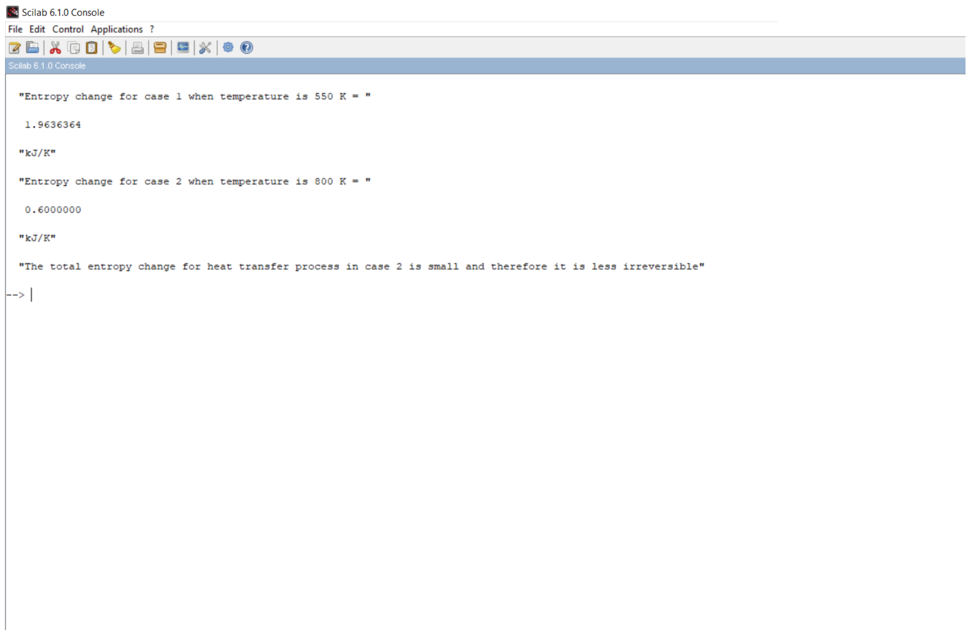


Figure 7.5: Find which of the heat transfer process is reversible

```
// Case 3: Two iron blocks are joined together
Tf = (T1 + T2)/2; //[K] Final temperature when both
    blocks are joined
del_s_block1 = m*Cp*log(Tf/T1); //[kJ/kg K]
del_s_block2 = m*Cp*log(Tf/T2); //[kJ/kg K]
del_s_3 = del_s_block1 + del_s_block2; //[kJ/kg K]
   Entropy change when two blocks are joined
disp('Entropy change when two blocks are joined',
   del_s_3,'kJ/kg K' )
//Value of del_s_1 vary due to round off error
```

Scilab code Exa 7.5 Find which of the heat transfer process is reversible

```
//Example 7.5
```

```
//Find which of the heat transfer process is reversible
clear
clc
T =1000; //[K]
Q = 2400; //[kJ]
// Case1: When temperature is 550 K
T1 = 550; //[K]
del_s_source_1 = -Q/T; //[kJ/K]
del_s_sink_1 = Q/T1; //[kJ/K]
del_s_total_1 = del_s_source_1 + del_s_sink_1; //[kJ/K]
disp('Entropy change for case 1 when temperature is 550 K = ',del_s_total_1,'kJ/K')
// Case 2: When temperature is 800 K
T2 = 800; //[K]
del_s_source_2 = -Q/T; //[kJ/K]
del_s_sink_2 = Q/T2; // [kJ/K]
del_s_total_2 = del_s_source_2 + del_s_sink_2; //[kJ/k]
disp('Entropy change for case 2 when temperature is 800 K = ',del_s_total_2,'kJ/K')
if (del_s_total_1 > del_s_total_2)
    then disp('The total entropy change for heat transfer process in case 2 is small and therefore it is less irreversible')
    else  disp('The total entropy change for heat transfer process in case 1 is small and therefore it is less reversible')
end
```

Scilab code Exa 7.6 `Determine the power of turbine`

```
Console

 "Power of the turbine, P = "

  1851.7300

 "kW"
```

Figure 7.6: Determine the power of turbine

```
//Example 7.6
//Determine the power of turbine
clear
clc
m = 2.3; //[kg/s] Stream flow rate
h1 = 3375.1; //[kJ/kg]  From Mollier diagram at 100
    bar and 500 C
s1 = 6.6; //[kJ/kg K]  from Mollier diagram at 100
    bar and 500 C
h2 = 2570; //[kJ/kg K] From Mollier diagram at 10
    bar and 500 C
s2 = s1; //Since stream flow isentropically
P = m*(h1-h2); //[kW] Power of the turbine
disp('Power of the turbine , P = ',P,'kW')
```

Scilab code Exa 7.7 Determine the entropy increase of the universe

```
//Example 7.7
//Determine the entropy increase of the universe
clear
clc
m = 2.5; //[kg]
P = 200; //[kPa]
s_fg = 5.597; //[kJ/kg K] From steam tables for
    saturated water vapour at 200 kPA
del_s_sys = -(m*s_fg); //[kJ/K] for system
T = 273 +30; //[K]
h_fg = 2202; //[kJ/kg] From steam tables
Q = m*h_fg; //[kJ]
del_s_surr = Q/T; //[kJ/K]  for surrounding
del_s_univ = del_s_sys + del_s_surr; //[kJ/K]  for
    universe
disp('Entropy increase of the universe = ',
```

```
Console

 "Entropy increase of the universe = "

  4.1758168

 "kJ/K"
```

Figure 7.7: Determine the entropy increase of the universe

```
del_s_univ,'kJ/K')
```

Scilab code Exa 7.8 Find isentropic efficiency of turbine and mass flow rate of st

```
//Example 7.8
//Find isentropic efficiency of turbine and mass flow rate of steam
clear
clc
p1 = 50; //[bar]
T1 = 600; //[ C ]
h1 = 3666.5; //[kJ/kg] From superheated steam tables at p1 and T1
s1 = 7.259; //[kJ/kg K] From superheated steam tables at p1 and T1
p2 = 0.5; //[bar]
T2 = 150; //[ C ]
h2 = 2780.2; //[kJ/kg s] From superheated steam tables at p2 and T2
s2 = 7.9413; //[kJ/kg K] From superheated steam tables at p2 and T2
//From saturated steam tables at p2 = 0.5 bar
sf = 1.091; //[kJ/kg K]
sg = 7.593; //[kJ/kg K]
sfg = 6.502; //[kJ/kg K]
hf = 340.5; //[kJ/kg]
hfg = 2304.7; //[kJ/kg]
s2_1 = s1; //Entropy remains constant for isentropic process
x2_1 = (s2_1 - sf)/sfg;
h2_1 = hf + x2_1 * hfg; //[kJ/kg]
//(i) Find isentropic efficiency of the turbine
eta_T = ((h1 - h2)/(h1 - h2_1))*100;
```

```
Console

 "Isentropic efficiency of turbine = "

  77.766782

 "%"

 "Mass flow rate of steam flowing through the turbine = "

  5.6414307

 "kg/s"
```

Figure 7.8: Find isentropic efficiency of turbine and mass flow rate of steam

```
disp('Isentropic efficiency of turbine = ' , eta_T ,
    '%')
// (ii) Find the mass flow rate of steam flowing
   through the turbine
W_out = 5*1000; //[kW] Power output of the turbine
m = W_out/(h1-h2); //[kg/s] Mass flow rate of steam
disp('Mass flow rate of steam flowing through the
   turbine = ', m , 'kg/s' )
//The answer vary due to round off error
```

Scilab code Exa 7.9 Find isentropic efficiency of compressor and power required to

```
//Example 7.9
//Find isentropic efficiency of compressor and power
    required to drive compressor
clear
clc
m = 0.25; //[kg/s]
T1 = 273 + 17; //[k]
h1 = 290.16; //[kJ/kg] From table of ideal gas
   properties of air at 290 K
Pr1 = 1.2311; //From table of ideal gas properties
   of air at 290 K
T2 = 610; //[K]
h2 = 617.53; //[kJ/kg]  From tables of ideal gas
   properties at 610 K
P1 = 100; //[kPa]
P2 = 1000; //[kPa]
// Isentropic relation of ideal gas Pr2/Pr1 = P2/P1
Pr2 = (Pr1 * P2)/P1;
h2_1 = 559.23; //[kJ/kg] At Pr2
//(i) Find isentropic efficiency of compressor
eta_c = ((h2_1 - h1)/(h2 - h1))*100; //[%]
```

```
Console

 "Isentropic efficiency of compressor = "

  82.191404

"%"

 "Power required to run the compressor = "

  81.842500

"kW"
```

Figure 7.9: Find isentropic efficiency of compressor and power required to drive compressor

```
disp('Isentropic efficiency of compressor = ',eta_c,'%')
//(ii) Find the power required to drive the compressor
W = m*(h2-h1); //[kW] Power required to run the compressor
disp('Power required to run the compressor = ',W,'kW')
```

Scilab code Exa 7.10 Find Isentropic efficiency Exit temperature and Actual exit v

```
//Example 7.10
//Find Isentropic efficiency , Exit temperature and Actual exit velocity of air
clear
clc
T1 = 880; //[K]
T2 = 690; //[K]
P1 = 250; //[kPa]
P2 = 90; //[kPa]
//From tables of ideal gas specific heats
Cp_ave = 1.099; //[kJ/kg] Average specific heat
k = 1.354;
// Isentropic efficiency of nozzle = eta_N = (h1 - h2)/(h1 - h2_1) = (Cp_ave(T1-T2))/Cp_ave(T1 - T2_1)
T2_1 = T1*[(P2/P1)^( (k-1)/k)]; //[K] Exit temperature
eta_N = (T1 - T2)/(T1 - T2_1); //Isentropic efficiency of nozzle
V2_1 = sqrt(2*Cp_ave*(T1 - T2_1)*1000); //[m/s] Isentropic exit velocity of nozzle
V2 = V2_1*sqrt(eta_N); //[m/s] Actual exit velocity
```

```
Console

 " Isentropic efficiency of nozzle = "

   92.107539

 "%"

 " Exit temperature = "

   673.71938

 "K"

 " Actual exit velocity of air = "

   646.23525

 "m/s"
```

Figure 7.10: Find Isentropic efficiency Exit temperature and Actual exit velocity of air

```
    of air
disp(' Isentropic efficiency of nozzle = ',eta_N
    *100,'%')
disp(' Exit temperature = ',T2_1,'K')
disp(' Actual exit velocity of air = ',V2,'m/s')
//The answer vary due to round off error
```

Chapter 8

Properties of Gases and Gas Mixtures

Scilab code Exa 8.1 Determine the pressure exerted by N2 gas

```
//Example 8.1
//Determine the pressure exerted by N2 gas
clear
clc
m = 10; //[kg]
V = 8; //[m^3]
T = 273 + 25; //[K]
R = 8.314;  //[kJ/mol K]   Gas constant
mu_N2 = 28; //[kg/mol]  Molecular weight of nitrogen
R_N2 = R/mu_N2; //[kJ/kg K]  Gas constant of N2
// (i) Determine the pressure exerted by N2 gas when the gas obeys idel gas equation
p = (m*R_N2*T)/V; //[kPa]  Pressure
disp('Pressure exerted by N2 gas when gas obeys ideal gas equation = ',p,'kPa')
//(ii) Determine the pressure exerted by N2 gas when the gas follows Vander waals equation
```

```
Console

 "Pressure exerted by N2 gas when gas obeys ideal gas equation = "

  110.60589

 "kPa"

 "Pressure exerted by N2 gas when gas follows Vander waals equation"

  110.52438

 "kPa"
```

Figure 8.1: Determine the pressure exerted by N2 gas

```
// Vander waals equation (p1 + a/v^2 )*(v - b) = R*T
n = m/mu_N2; //[mol] Number of moles
v = V/n; //[m^3/ kg mol]  Molar volume
a = 136.7; //[kN m^4/(kg mol)^2]
b = 0.0386; // [m^3/ kg mol]
p1 = ((R*T)/(v - b)) - a/v^2; //[kPa]  Pressure
disp('Pressure exerted by N2 gas when gas follows
   Vander waals equation',p1,'kPa')
```

Scilab code Exa 8.2 Evaluate Mole fraction Mass fraction and Average gas constant

```
//Example 8.2
//Evaluate Mole fraction , Mass fraction and Average
   gas constant of mixture
clear
clc
m_O2 = 5; //[kg]
m_N2 = 8; //[kg]
m_CO2 = 10; //[kg]
Mol_wt_O2 = 32; //[kg]  molecular weight of O2
Mol_wt_N2 = 28; //[kg]  molecular weight of N2
Mol_wt_CO2 = 44; //[kg]  molecular weight of CO2
m_m = m_O2 + m_N2 + m_CO2; //[kg] total mass of
   mixture
//(i) Evaluate mole fraction of each gas
n_O2 = m_O2/Mol_wt_O2; //[kmol]  no. of mole of O2
n_N2 = m_N2/Mol_wt_N2; //[kmol] no. of mole of N2
n_CO2 = m_CO2/Mol_wt_CO2; //[kmol] no. of mole of
   CO2
n_m = n_O2 + n_N2 + n_CO2; //[kmol]  Total no. of
   moles
Mf_O2 = n_O2/n_m; //mole fraction of O2
Mf_N2 = n_N2/n_m; //mole fraction of N2
```

```
Console

 "Mole fraction of O2 ="

  0.2334748

 "Mole fraction of N2 ="

  0.4269254

 "Mole fraction of CO2 ="

  0.3395998

 "Mass fraction of O2 ="

  0.2173913

 "Mass fraction of N2 ="

  0.3478261

 "Mass fraction of CO2 ="

  0.4347826

 "Average gas constant of mixture = "

  0.2419146

 "kJ/kg K"
```

Figure 8.2: Evaluate Mole fraction Mass fraction and Average gas constant of mixture

```
Mf_CO2 = n_CO2/n_m; //mole fraction of CO2
disp('Mole fraction of O2 =',Mf_O2)
disp('Mole fraction of N2 =',Mf_N2)
disp('Mole fraction of CO2 =',Mf_CO2)
//(ii) Evaluate mass fraction of each gas
w_O2 = m_O2/m_m; //mass fraction of O2
w_N2 = m_N2/m_m; //mass fraction of N2
w_CO2 = m_CO2/m_m; //mass fraction of CO2
disp('Mass fraction of O2 =',w_O2)
disp('Mass fraction of N2 =',w_N2)
disp('Mass fraction of CO2 =',w_CO2)
//(iii) Evaluate average gas constant of the mixture
mu_m = m_m/n_m; //[kg/kmol] average molar mass of mixture
R_bar = 8.314; //[kJ/kmol K]  gas constant
R = R_bar/mu_m; //[kJ/kg K]average gas constant of mixture
disp('Average gas constant of mixture = ',R,'kJ/kg K')
```

Scilab code Exa 8.3 Find work done and heat transfer in isothermal and adiabatic p

```
//Example 8.3
//Find the work done and heat transfer in isothermal and adiabatic process
clear
clc
p1 = 6*100; //[kPa]
V1 = 0.2; //[m^3]
V2 = 1.1; //[m^3]
m = 1.5; //[kg]
//(i) Find the work done and heat transfer in isothermal process
```

```
Console

 "Work done in isothermal process ="

  204.56977

 "kJ"

 "Heat transfer in isothermal process ="

  204.56977

 "kJ"

 "Work done in adiabatic process ="

  148.30328

 "kJ"

 "Heat transfer in adiabatic process = "

  0.

 "kJ"
```

Figure 8.3: Find work done and heat transfer in isothermal and adiabatic process

```
W1_2 = p1*V1*log(V2/V1); //[kJ] work done
U2_U1 = 0; //Change in internal energy is zero (U2-U1=0)
Q1_2 = U2_U1 + W1_2; //[kJ] Heat transfer
disp('Work done in isothermal process =',W1_2,'kJ')
disp('Heat transfer in isothermal process =',Q1_2,'kJ')
//(ii) Find work done and heat transfer in adiabatic process
gama = 1.4;
p2 = p1*(V1/V2)^gama; //[kPa]
W_adia = (p1*V1 - p2*V2)/(gama - 1); //[kJ] work done
Q = 0; //Heat transfer is 0 since it is adiabatic process
disp('Work done in adiabatic process =',W_adia,'kJ')
 disp('Heat transfer in adiabatic process = ',Q,'kJ')
```

Scilab code Exa 8.4 Compute change in Enthalpy Work done Heat transferred and Fina

```
//Example 8.4
//Compute change in enthalpy, work done, heat transferred and final temperature
clear
clc
m = 2; //[kg]
p1 = 600; //[kPa]
T1 = 273 + 20; //[K]
p2 = 300; //[kPa]
gama = 1.4;
// For an ideal gas, for isentropic process, T2/T1 = (p2/p1)^( (gama- 1)/gama )
```

```
Console

 "Change in enthalpy ="

 -104.65178

"kJ"

"Work done = "

  74.751272

"kJ"

 "Heat transferred ="

 0.

 "Final temperature ="

  240.35826

"K"
```

Figure 8.4: Compute change in Enthalpy Work done Heat transferred and Final temperature

```
T2 = T1*( (p2/p1)^( (gama-1)/gama) ); //[K] final
    temperature
//(i) Compute the change in enthalpy
R = 0.284;
del_h =    ( (gama*m*R*T1)/(gama-1) )*[ (p2/p1)^( (
    gama-1)/gama ) - 1]; //[kJ]
disp('Change in enthalpy =',del_h,'kJ')
//(ii) Compute the work done
//dQ = dU + dW = 0, therefore dW = -dU = U1 - U2 = m
    (u1 - u2)
W1_2 = ( (m*R*T1)/(gama-1) )*[ 1 - (p2/p1)^( (gama
    -1)/gama )]; //[kJ]
disp('Work done = ',W1_2,'kJ')
//(iii) Compute the heat transferred
Q = 0; //heat transferred is 0, since the process is
     reversible adiabatic
disp('Heat transferred =',Q)
//(iv) Compute the final temperature
disp('Final temperature =',T2,'K')
//The answer vary due to round off error
```

Scilab code Exa 8.5 Calculate following question when heat is transferred to 5 kg

```
//Example 8.5
//Calculate following question when heat is
    tranferred to 5 kg gas
clear
clc
m = 5; //[kg]
V1 = 0.3; //[m^3]
t1 = 273+10; //[ C ]
t2 = 273 +120; //[ C ]
Cp = 1.88; //[kJ/kg K]
```

```
Console

 "Final Volume ="

  0.4166078

 "m^3"

 "Heat transferred = "

  1034.0000

 "kJ"

 "Work done = "

  247.5

 "kJ"

 "Change in enthalpy = "

  1034.0000

 "kJ"

 "Change in entropy = "

  0.6173219

 "kJ/K"

 "Gas constant"

  0.4500000

 "kJ/kg K"

 "Molecular weight ="

  18.475556

 "kg/kg mol"
```

Figure 8.5: Calculate following question when heat is transferred to 5 kg gas

```
Cv = 1.43; //[kJ/kg K]
R = Cp - Cv; // [kJ/kg K]  Gas constant
//(i) Calculate the final volume
p1 = m*R*t1/V1; //[kPa]
p2 = p1; //[kPa] pressure is constant
V2 = m*R*t2/p2; //[m^3]  //final volume
disp('Final Volume =',V2,'m^3')
//(ii) Calculate the heat transferred
Q1_2 = m*Cp*(t2-t1); //[kJ] heat transferred
disp('Heat transferred = ',Q1_2,'kJ')
//(iii) Calculate the work done
W1_2 = p1*(V2 - V1); //[kJ] work done
disp('Work done = ',W1_2,'kJ')
//(iv) Calculate the changes in enthalpy and entropy
U1_2 = Q1_2 - W1_2; //[kJ] Change in internal energy
del_H = m*Cp*(t2 - t1); //[kJ]  Change in enthalpy
del_s = Cp*log(t2/t1) - R*log(p2/p1); //[kJ/K]
   Change in entropy
disp('Change in enthalpy = ',del_H,'kJ')
disp('Change in entropy = ',del_s,'kJ/K')
//(v) Calculate the gas constant
disp('Gas constant',R,'kJ/kg K')
//(vi) Calculate the molecular weight
R_bar = 8.314; //[kJ/kg K]
mu = R_bar/R; //[kg/kg mol]
disp('Molecular weight =',mu,'kg/kg mol')
```

Scilab code Exa 8.6 Determine specific volume of superheated vapor

```
//Example 8.6
//Determine specific volume of superheated vapor
clear
clc
```

```
Console

 "Using ideal gas equation ,Specific volume = "

  0.0191676

 "m^3/kg"

 "Using generalized compressibility chart, Specific volume = "

  0.0124590

 "m^3/kg"

 "Error in case 1 = "

  66.950904

 "%"

 "Error in case 2 = "

  8.5180879

 "%"
```

Figure 8.6: Determine specific volume of superheated vapor

```
p = 15; //[MPa]
T = 273 + 350; //[K]
//From superheated steam tables at 15 MPa and 350 C
v = 0.011481; //[m^3/kg]  specific volume
//From data of water vapour
R = 0.4615; //[kJ/kg K]
pc = 22.06; //[MPa]
Tc = 647.1; //[K]
//(i) Determine specific volume of superheated vapor using ideal gas equation(pv = RT)
v_ideal = (R*T)/(p*1000); //[m^3/kg]
disp('Using ideal gas equation ,Specific volume = ',v_ideal,'m^3/kg')
//(ii) Determine specific volume using generalized compressibility chart
pr = p/pc;
Tr = T/Tc;
Z = 0.65; //From compressibility chart at pr and Tr
v_actual = Z *v_ideal; //[m^3/kg]  Z= actual v/ideal v
disp('Using generalized compressibility chart, Specific volume = ',v_actual,'m^3/kg')
error_in_case1 = ( (v_ideal - v)/v )*100; //[%] error in case 1
error_in_case2 = ( (v_actual - v)/v )*100; //[%] error in case 2
disp('Error in case 1 = ',error_in_case1,'%')
disp('Error in case 2 = ',error_in_case2,'%')
// The answer vary due to round off error
```

Scilab code Exa 8.7 Determine Volume Temperature Total Work and Heat transfer and

```
//Example 8.7
```

```
Console

 "Volume at the end of compression"

  0.4640549

 "m^3"

 "Temperature at the end of compression"

  560.16989

 "K"

 "Total work transfer ="

  491.45713

 "kJ"

 "Total heat transferred ="

  4108.0473

 "kJ"

 "Total change in entropy ="

  4.2018319

 "kJ/kg K"
```

Figure 8.7: Determine Volume Temperature Total Work and Heat transfer and Total entropy change

```
//Determine Volume, Temperature ,Total work and heat transfer and total entropy change
clear
clc
m = 2.5; //[kg]
V1 = 1.8; //[m^3]
p1 = 103; //[kPa]
T1 = 373; //[K]
p2 = 600; //[kPa]
n = 1.3;
R = (p1*V1)/(m*T1); //[kJ/kg K]  Gas constant
//(i) Determine the volume and temperature at the end of compression
// p1* (V1^n) = p2 * (V2^n)
V2 = V1*( (p1/p2)^(1/n) ); //[m^3] volume
disp('Volume at the end of compression',V2,'m^3')
//p2*V2 = m*R*T2
T2 = (p2*V2)/(m*R); //[K]  temperature
disp('Temperature at the end of compression',T2,'K')
//(ii) Determine the total work transfer
W1_2 = (p1*V1 - p2*V2)/(n-1); //[kJ]
V3 = V1; //[m^3]
W2_3 = p2*(V3 - V2); //[kJ]
W_tot = W1_2 + W2_3; //[kJ]  total work transfer
disp('Total work transfer =',W_tot,'kJ')
 //(iii) Determine total heat transfer
 Cv = 0.783; //[kJ/kg K]
 Cp = 1.005; //[kJ/kg K]
 Q1_2 = m*Cv*(T2 - T1) + W1_2; //[kJ]
 //(p2 V2)/T2 = (p3V3)/T3 & p3 = p2  & V3 = V1
 T3 = (T2*V1)/V2; //[K]
 Q2_3 = m*Cp*(T3 - T2); //[kJ]
 Q_tot = Q1_2 + Q2_3; //[kJ]
 disp('Total heat transferred =',Q_tot,'kJ')
 //(iv) Determine total change of entropy
S2_S1 = m*[Cv*log(T2/T1) + R*log(V2/V1)]; //[kJ/kg k] S2-S1
S3_S2 = m*[Cp*log(T3/T2) + R*log(V3/V2)]; //[kJ/kg K
```

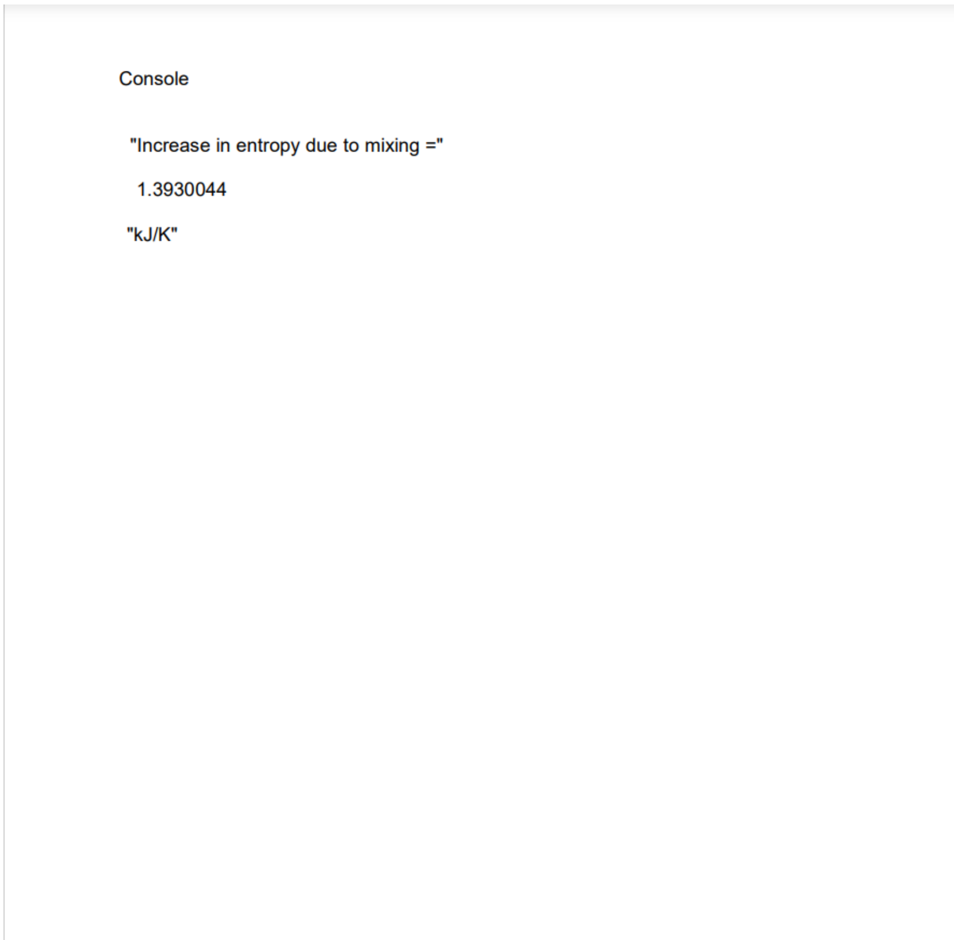


Figure 8.8: Estimate the increase in entropy due to mixing

```
    ] S3-S2
del_S_tot = S2_S1 + S3_S2; //[kJ/kg K]total change
    in entropy
disp('Total change in entropy =',del_S_tot,'kJ/kg K'
    )
//The answer provided in textbook is wrong
```

Scilab code Exa 8.8 Estimate the increase in entropy due to mixing

```
//Example 8.8
//Estimate the increase in entropy due to mixing
clear
clc
m_O2 = 5; //[kg]
m_H2 = 2; //[kg]
M_O2 = 32; //[kg/mol] molecular weight of O2
M_H2 = 2; //[kg/mol]  molecular weight of H2
n_O2 = m_O2/M_O2; //[mol]  no. of moles of O2
n_H2 = m_H2/M_H2; // [mol]  no. of moles of H2
x_O2 = n_O2/(n_O2 +n_H2); //mole fraction of O2
x_H2 = 1 - x_O2; // mole fraction of H2
R_bar = 8.314; //[kJ/mol K]
R_O2 = R_bar/M_O2; //[kJ/kg K]
R_H2 = R_bar/M_H2; //[kJ/kg K]
// Partial pressure of O2 and H2 is equal to their mole fraction
//p_O2/p = x_O2 and p_H2/p = x_H2
del_s =  -(m_O2 *R_O2* log(x_O2) - m_H2*R_H2*log(x_H2) ); //[kJ/K]  s2 - s1 (increase in entropy)
disp('Increase in entropy due to mixing =',del_s,'kJ/K')
```

Scilab code Exa 8.9 Compute Specific heats and change in Internal energy Enthalpy

```
//Example 8.9
//Compute Specific heats and change in Internal energy, Enthalpy and Entropy
```

```
Console

 "Specific heat at constant pressure of mixture = "

  0.8387143

"kJ/kg K"

 "Specific heat at constant volume of mixture = "

  0.5984286

"kJ/kg K"

 "Change in internal energy = "

  104.725

"kJ"

 "Change in enthalpy = "

  146.77500

"kJ"

 "Change in entropy = "

  0.4729609

"kJ/K"
```

Figure 8.9: Compute Specific heats and change in Internal energy Enthalpy and Entropy

```
clear
clc
m_O2 = 5; //[kg]
m_CO2 = 2; //[kg]
T1 = 298; //[K]
T2 = 323; //[K]
Cp_O2 = 0.9094; //[kJ/kg K]
Cp_CO2 = 0.662; //[kJ/kg K]
Cv_O2 = 0.649; //[kJ/kg K]
Cv_CO2 = 0.472;  //[kJ/kg K]
P1 = 250; //[kPa]
//(i) Compute the specific heats
Cp = (m_O2*Cp_O2 + m_CO2*Cp_CO2)/(m_O2 + m_CO2); //[
   kJ/kg K] at constant pressure
Cv = (m_O2*Cv_O2 + m_CO2*Cv_CO2)/(m_O2 + m_CO2); //[
   kJ/kg K] at constant volume
disp('Specific heat at constant pressure of mixture
   = ',Cp,'kJ/kg K')
disp('Specific heat at constant volume of mixture =
   ',Cv,'kJ/kg K')
//(ii) Compute internal energy, enthalpy and entropy
    of the mixture
m = m_O2 + m_CO2; //[kg]
del_U = m*Cv*(T2 - T1); //[kJ] change in internal
   energy
del_H = m*Cp*(T2 - T1); //[kJ] change in enthalpy
// del_s = m*[Cp*log(T2/T1) - R*log(P2/P1)] , but P2
    = P1 so R*log(P2/P1)=0
del_s = m*Cp*log(T2/T1); // [kJ/K] change in entropy
disp('Change in internal energy = ',del_U,'kJ')
disp('Change in enthalpy = ',del_H,'kJ')
disp('Change in entropy = ',del_s,'kJ/K')
```

```
Console

 "Final temperature = "

  468.00900

"K"

 "Final partial pressure of N2 = "

  242.64706

"kPa"

 "Final partial pressure of CO2 = "

  257.35294

"kPa"

 "Change in internal energy of the mixture = "

  780.15362

"kJ"
```

Figure 8.10: Compute Final temperature Final partial pressure of components and change in internal energy

Scilab code Exa 8.10 Compute Final temperature Final partial pressure of component

```
//Example 8.10
//Compute Final temperature, Final partialpressure of components and change in internal energy
clear
clc
m_N2 = 3; //[kg]
m_CO2 = 5; //[kg]
m = m_N2 + m_CO2; //[kg]
M_N2 = 28; //[kg/mol] mol. wt. of N2
M_CO2 = 44; //[kg/mol] mol. wt. of CO2
P1 = 103; //[kPa]
P2 = 500; //[kPa]
T1 = 273 +25; //[K]
R_bar = 8.314; //[kJ/mol K] gas constant
R_N2 = R_bar/M_N2; //[kJ/kg K]
R_CO2 = R_bar/M_CO2; //[kJ/kg K]
gamma_N2 = 1.4;
Cv_N2 = R_N2/(gamma_N2 - 1); //[kJ/kg K]
Cp_N2 = gamma_N2*Cv_N2; //[kJ/kg K]
gamma_CO2 = 1.286;
Cv_CO2 = R_CO2/(gamma_N2-1); //[kJ/kg K]
Cp_CO2 = gamma_CO2*Cv_CO2; //[kJ/kg K]
Cp = (m_N2*Cp_N2 + m_CO2*Cp_CO2)/(m_N2 + m_CO2); //[kJ/kg K]
Cv = (m_N2*Cv_N2 + m_CO2*Cv_CO2)/(m_N2 + m_CO2); //[kJ/kg K]
//(i) Compute the final temperature
T2 = T1 *(P2/P1)^( (gamma_N2 - 1) /gamma_N2 ); //[K]
disp('Final temperature = ', T2 , 'K')
//(ii) Compute the final partial pressure of component
x_N2 = (m_N2/M_N2)/[ (m_N2/M_N2) + (m_CO2/M_CO2) ]; //Mole fraction of N2
x_CO2 = (m_CO2/M_CO2)/[ (m_N2/M_N2) + (m_CO2/M_CO2) ]; //Mole fraction of CO2
p_N2 = x_N2*P2; //[kPa]
```

```
p_CO2 = x_CO2*P2; //[kPa]
disp('Final partial pressure of N2 = ', p_N2 ,'kPa')
disp('Final partial pressure of CO2 = ', p_CO2,'kPa')
//(iii) Compute the change in internal energy of mixture during the process
del_U = m*Cv*(T2 - T1); //[kJ]
disp('Change in internal energy of the mixture = ', del_U,'kJ')
//The answer of (iii) is provided wrong in textbook due to calculation mistake
// Total mass should be 8 but it is taken as 7
```

Chapter 9

Concept of Available Energy Exergy

Scilab code Exa 9.1 Determine reversible power input and irreversibility for the p

```
//Example 9.1
//Determine reversible power input  and irreversibility for the process
clear
clc
T1 = 273 + 27; //[K]
T2 = 273 + (-5); //[K]
COP_R_Rev = T2/(T1 - T2);
Q2 = 7.8;//[kJ/s]  Rate of heat transfer
//(i) Determine the reversible power input required to drive the plant
W_in_rev = Q2/COP_R_Rev; //[kW] Minimum power required to drive the plant when it is run on reversible conditions
disp('The reversible power input required to drive the plant = ',W_in_rev,'kW')
W_in_u = 2.2; //[kJ/s]  power required to drive the
```

```
Console

 "The reversible power input required to drive the plant = "

  0.9313433

"kW"

 "Irreversibility for the process ="

  1.2686567

"kW"
```

Figure 9.1: Determine reversible power input and irreversibility for the process

```
   plant
I = W_in_u - W_in_rev; //[kW] Irreversibility for the process
disp('Irreversibility for the process =',I,'kW')
```

Scilab code Exa 9.2 `Calculate Actual work required Minimum work required and Irrev`

```
//Example 9.2
//Calculate actual work required , minimum work required and irreversibility of process
clear
clc
p1 = 140; //[kPa]
T1 = 273 + 17; //[K]
V1 = 70; //[m/s]
p2 = 350; //[kPa]
T2 = 273 + 127; //[K]
V2 = 110; //[m/s]
T0 = 273+7; //[K]
Cp = 1.005; //[kJ/kg K]
R = 0.287;
//(i) Calculate actual amount of work required
Win_u = Cp*(T2 - T1) + (V2^2 - V1^2)/(2*1000); //[kJ] Actual work input required
//(ii) Calculate the minimum work required
//TdS = dh - vdp
// s2 - s1 = Cplog(T2/T1) - Rlog(p2/p1)
// 1 - 2 = del = Win_rev = (h1 - T0*s1)-(h2 - T0*s2)+(V1^2 - V^2)/2
Win_rev = -[Cp*(T1 - T2) - T0*[R*log(p2/p1) - Cp*log(T2/T1)]+(V1^2 - V2^2)/(2*1000)]; //[kJ] Minimum work required
//(iii) Calculate the irreversibility of the process
```

```
Console

 "Actual amount of work required = "

  114.15000

"kJ"

 "Minimum work required = "

  97.289491

"kJ"

 "Irreversibility of process = "

  16.860509

"kJ"
```

Figure 9.2: Calculate Actual work required Minimum work required and Irreversibility of process

```
I = Win_u - Win_rev;//[kJ] Irreversibility of process
disp('Actual amount of work required = ',Win_u,'kJ')
disp('Minimum work required = ', Win_rev,'kJ')
disp('Irreversibility of process = ',I,'kJ')
```

Scilab code Exa 9.3 Calculate Availability at states 1 and 2 Irreversibility and S

```
//Example 9.3
//Calculate Availability at state 1 and 2, Irreversibility and Second law efficiency
clear
clc
p1 = 500; //[kPa]
p2 = 100; //[kPa]
p0 = 100; //[kPa]
V1 = 150; //[m/s]
V2 = 70;  //[m/s]
T1 = 400; //[K]
T2 = 300; //[K]
T0 = 290; //[K]
Cp = 1.005; //[kJ/kg K]
R = 0.287;
//(i) Calculate the availability at states 1 and 2
//psi_1 = Cp*(T1 - T0) - T0*(s1 - s2) + V1^2/2
psi_1 = Cp*(T1 - T0) - T0*[R*log(p0/p1) - Cp*log(T0/T1)] + V1^2/(2*1000); //[kJ]
disp('Availability at state 1 = ',psi_1,'kJ')
//psi_2 = Cp*(T2 - T0) - T0*(s2 - s0) + V2^2/2
psi_2 = Cp*(T2 - T0) - T0*[R*log(p0/p2) - Cp*log(T0/T2)] + V2^2/(2*1000); //[kJ]
disp('Availability at state 2 = ',psi_2,'kJ')
//(ii) Calculate irreversibility or energy
```

```
Console

 "Availability at state 1 = "

  162.02797

 "kJ"

 "Availability at state 2 = "

  2.6193928

 "kJ"

 "Irreversibility = "

  50.108577

 " kJ "

 "The second-law efficiency = "

  68.565947

 " % "
```

Figure 9.3: Calculate Availability at states 1 and 2 Irreversibility and Second law efficiency

```
destruction
// W_act = (h1 - h2) + (V1^2 - V2^2)/2
W_act = Cp*(T1 - T2) + (V1^2 - V2^2)/(2*1000); //[kJ] Actual work output of turbine
//W_max = (h1 - h2) - T0*(s1 - s2) +(V1^2 - V2^2)/2 = psi_1 - psi_2
W_max = psi_1 - psi_2; //[kJ] Maximum work output of turbine
I = W_max - W_act; //[kJ]  Irreversibility
disp('Irreversibility = ',I,' kJ ')
//(iii) Calculate the second-law efficiency
eta_pi = (W_act/W_max)*100; //[%]
disp('The second-law efficiency = ',eta_pi,' % ')
//The answer vary due to round off error
```

Scilab code Exa 9.4 Determine Exergy of steam Exergy destruction and Efficiency

```
//Example 9.4
//Determine Exergy of steam, Exergy destruction and Efficiency
clear
clc
m = 0.052; //[kg]
p1 = 12; //[bar]
T1 = 273 +350; //[K]
// At p1 and T1 value of u1, v1 and s1 are
u1 = 2872.7; //[kJ/kg]
v1 = 0.2345; //[m^3/kg]
s1 = 7.2139; //[kJ/kg K]
p2 = 3; //[bar]
T2 = 273 + 200; //[K]
// At p2 and T2 value of u2, v2 and s2 are
u2 = 2651; //[kJ/kg ]
```

```
Console

 "Exergy of steam at state 1 = "
  39.048381
"kJ"
 "Exergy of steam at state 2 = "
  28.490207
"kJ"
"Exergy destroyed ="
  3.7356536
"kJ"
 " Therefore, the work potential of the steam is "
  64.618373
"%"
```

Figure 9.4: Determine Exergy of steam Exergy destruction and Efficiency

```
v2 = 0.7164; //[m^3/kg]
s2 = 7.313; //[kJ/kg K]
p0 = 1; //[bar]
T0 = 273 + 25; //[K]
// At p0 and T0 value of u0, v0 and T0 are
u0 = 104.8;  //[kJ/kg]
v0 = 0.00103; //[m^3/kg]
s0 = 0.3672; //[kJ/kg K]
Q = 2.2; //[kJ]  Heat lost to the surrounding
// (i) Determine the exergy of steam at the initial and final states
X1 = m*[ (u1 - u0) - T0*(s1 - s0) + p0*100*(v1 - v0) ]; //[kJ]  Exergy of steam at state 1
X2 = m*[ (u2 - u0) - T0*(s2 - s0) + p0*100*(v2 - v0) ]; //[kJ]   Exergy of steam at state 2
disp('Exergy of steam at state 1 = ',X1,'kJ')
disp('Exergy of steam at state 2 = ', X2, 'kJ')
//(ii) Determine the exergy destruction
del_X = (X1-X2); //[kJ]
del_s_sys = m*(s2 - s1); //[kJ/K]
del_s_surr = Q/T0; //[kJ/K]
s_gen = del_s_sys + del_s_surr; //[kJ/K]
X_destroyed = T0 * s_gen; //[kJ]   exergy destroyed
disp('Exergy destroyed =',X_destroyed,'kJ')
//(iii) Determine the second law efficiency
X_expended = del_X; //[kJ]
eta_pi = (1 - (X_destroyed/X_expended) )*100; //[%] efficiency
// work potential of the steam is called second law efficiency
disp(' Therefore, the work potential of the steam is ', eta_pi,'%')
// The answer vary due to round off error
```

```
Console

 "W_max = "

  121.66698

"kJ"

"W_act = "

 71.8

"kJ"

 "Change in availability = "

  58.666981

"kJ"

 "Irreversibility = "

  49.866981

"kJ"

"Efficiency = "

  59.013546

"%"
```

Figure 9.5: Calculate following question on air expansion in turbine

Scilab code Exa 9.5 Calculate following question on air expansion in turbine

```
//Example 9.5
//Calculate following question on air expansion in turbine
clear
clc
m = 1; //[kg]
Cv = 0.718; //[kJ/kg K]
T1 = 400; //[kPa]
T2 = 300; //[kPa]
p1 = 500; //[kPa]
p2 = 100; //[kPa]
p0 = 100; //[kPa]
T0 = 273 +17; //[K]
Cv = 0.718; //[kJ/kg K]
R = 0.287;
v1 = 0.23; //[m^3/kg] At p1 and T1
v2 = 0.86; //[m^3/kg]  At P2 and T2
//(i) Calculate W_max(maximum work done)
//W_max = (u1 - u2) - T0(s1 - s2), where s2 - s1 = Cv*log(T2/T1) + R*log(v2/v1)
// (u1 - u2) = Cv(T1 - T2)
W_max = Cv*(T1 - T2) + T0*[ Cv*log(T2/T1) + R*log(v2/v1)];//[kJ]
disp('W_max = ',W_max,'kJ')
//(ii) Calculate W_act(actual work done)
//W_act = Q - del_U => -del_U = m*Cv*(T1 - T2)
W_act = m*Cv*(T1 - T2); //[kJ]
disp('W_act = ',W_act,'kJ')
//(iii) Calculate change in availability
Wu_max = W_max - p0*(v2 - v1); //[kJ]
disp('Change in availability = ',Wu_max,'kJ')
//(iv) Calculate irreversibility
I = W_max - W_act; //[kJ]    irreversibility
disp('Irreversibility = ',I,'kJ')
//(v) Calculate second-law efficiency
eta_pi = (W_act/W_max)*100; //[%]
```

```
disp('Efficiency = ',eta_pi,'%')
//The answer vary due to round off error
```

Scilab code Exa 9.6 Determine temperature and rate of exergy destruction

```
//Example 9.6
//Determine temperature and rate of exergy
   destruction
clear
clc
mh = 800; //[kg/h]  mass flow rate of oil
Cph = 2.1; //[kJ/kg K]  specific heat of oil at
   constant pressure
Th1 = 440; //[K]
Th2 = 320; //[K]
mc = 3200; //[kg/h]  mass flow rate of water
Cpc = 4.2; //[kJ/kg K]  specific heat of water at
   constant pressure
Tc1 = 290; //[K]
//(i) Calculate temperature T
//Energy balance between oil and water,  mh*Cph*(Th1
    - Th2)=mc*Cpc*(Tc2 - Tc1)
T = [ ( mh*Cph*(Th1 - Th2) )/(mc*Cpc) ] + Tc1; //[K]
disp('The final temperature of water after heating ,
    T = ' , T , 'K')
//(ii) Calculate the rate of exergy destruction
// del_S_total = del_s_oil + del_s_water
function s = f (T)
    s = (mh*Cph)/T;
endfunction
del_s_oil = intg(Th1, Th2, f);  //[kJ/K]
function s1= f1 (T)
    s1 = (mc*Cpc)/T;
```

```
Console

 "The final temperature of water after heating , T = "

  305.

 "K"

 "Rate of exergy destruction = "

  41.408637

 "MJ/h"
```

Figure 9.6: Determine temperature and rate of exergy destruction

```
endfunction
del_s_water = intg(Tc1, T, f1); //[kJ/K]
del_S_total = del_s_oil + del_s_water;
X_destroyed = (Tc1 * del_S_total)/1000; //[MJ/h]
disp('Rate of exergy destruction = ',X_destroyed,'MJ/h')
```

Scilab code Exa 9.7 Estimate the increase in unavailable energy

```
//Example 9.7
//Estimate the increase in unavailable energy
clear
clc
m = 1; //[kg]
L = 1404; //[kJ/kg]  latent heat of vapourization of water
Tw = 273 + 300; //[K]
Tg_1 = 273 + 1500; //[K]  initial temperature of combustion gas
Tg_2 = 273 + 350; //[K]    final temperature of combustion gas
Cpg = 1.2; //[kJ/kg K]   specific heat of combustion gas at constant pressure
Ts = 273 + 25; //[K]
//Heat lost by combustion = Heat gained by water = Latent heat L
// mg*Cpg*del_T_g = mw*Cpw*del_T_w  = 1 * 1404 kJ/kg
mg = (m * L)/(Cpg *(Tg_1 - Tg_2) ); //[kg]  mass of gas
del_s_water = (m*L)/Tw; //[kJ/kg K]  entropy increase of water due to evaporation
function s = f(T)
    s = (mg*Cpg)/T;
```

```
Console

 "Loss in (available energy) exergy = "

  349.66621

 "kJ"
```

Figure 9.7: Estimate the increase in unavailable energy

```
endfunction
del_s_gas = intg(Tg_1, Tg_2, f); //[kJ/kg K] entropy decrease of combustion gas as it is cooled
del_s_total = del_s_water + del_s_gas; //[kJ/kg K]
E_loss = Ts * del_s_total; //[kJ] loss in exergy
disp('Loss in (available energy) exergy = ',E_loss,' kJ')
```

Scilab code Exa 9.8 Estimate the exergy destroyed

```
//Example 9.8
//Estimate the exergy destroyed
clear
clc
mI = 10; //[kg]
CpI = 0.55; //[kJ/kg K]
t1_I = 300; //[ C ]
T1_I = 273 + t1_I; //[K]
mw = 80; //[kg]
Cpw = 4.18; //[kJ/kg K]
t1_w = 27; //[kJ/kg K]
T1_w = 273 + 27; //[K]
T0 = 273 + 25; //[K]
// dQ = dW + dU and dU = 0 & dW = 0, therefore dQ = 0
// so the equation is, m1*Cp1*(tf - t1_1) + mw*Cpw*(tf - t1_w) = 0
tf = (mI*CpI*t1_I + mw*Cpw*t1_w)/(mI*CpI + mw*Cpw); //[ C ] final equilibrium temperature
Tf = 273 + tf; //[K]
CvI = CpI; //[kJ/kg K]
E_loss_iron = mI*CvI*(T1_I - Tf) - mI*CvI*T0*log(T1_I/Tf); //[kJ] exergy loss of iron block
```

```
Console

 "Exergy loss of the system ="

  461.10633

 "kJ"
```

Figure 9.8: Estimate the exergy destroyed

```
Cvw = Cpw; //[kJ/kg K]
E_gain_water = mw*Cvw*(T1_w - Tf) - T0*mw*Cvw*log(
    T1_w/Tf);//[kJ] exergy gain of water
E_loss_system = E_loss_iron - E_gain_water; //[kJ]
    exergy loss of system
disp('Exergy loss of the system =',E_loss_system,'kJ
    ')
//The answer provided in textbook is wrong
```

Chapter 10

Vapor and Advanced Power Cycles

Scilab code Exa 10.1 `Determine cycle efficiency and thermal efficiency in both cas`

```
//Example 10.1
// Determine cycle efficiency and thermal efficiency in both case
clear
clc
//(i) Determine cycle efficiency
p1 = 2.5*10^3; //[kPa]
t1 = 300; //[K]
//From superheated stem tables at p1 and t1
h1 = 3009.6; //[kJ/kg]
s1 = 6.645; //[kJ/kg K]
p2 = 15; //[kPa]
//From saturated steam tables at p2
sf2 = 0.7549; //[kJ/kg K]
sfg2 = 7.252; //[kJ/kg K]
vf = 0.001014; //[m^3/kg]
hf2 = 225.94; //[kJ/kg]
```

```
Console

 "Cyle efficiency = "

  30.693123

 "%"

 "Therml efficiency if steam is superheated to 500°C  ="

  33.473725

 "%"

 "Thermal efficiency if boiler pressure is raised to 5MPa and turbine inlet temp is 500°(

  36.341206

 "%"
```

Figure 10.1: Determine cycle efficiency and thermal efficiency in both case

```
hfg2 = 2373.2; //[kJ/kg]
s2 = s1; //[kJ/kg K]
x2 = [(s2 - sf2)/sfg2 ]; //[%]
 h2 = hf2 + x2*hfg2; //[kJ/kg]
 h3 = 225.94; //[kJ/kg]
 v3 = vf; //[m^3/kg]
 wp = v3*(p1 - p2); //[kJ/kg]
 h4 = wp + h3; //[kJ/kg]
 q1 = h1 - h4; //[kJ/kg]
 q2 = h2 - h3; //[kJ/kg]
 eta_cycle = [1 - (q2/q1)]*100; //[%] cycle efficiency
 disp('Cycle efficiency = ',eta_cycle,'%')
 //(ii) Determine thermal efficiency if steam is superheated to 500 C
 p1_1 = 2.5*1000; //[kPa]
 t1_1 = 500; //[ C ]
 // at p1_1 and t1_1
h1_1 = 3462.8; //[kJ/kg]
s1_1 = 7.33; //[kJ/kg K]
s2_1 = s1_1; //[kJ/kg K]
x2_1 =  [(s2_1 - sf2)/sfg2]; //[%]
h2_1 = hf2 + x2_1*hfg2; //[kJ/kg]
q1_1 = h1_1 - h4; //[kJ/kg]
q2_1 = h2_1 - h3; //[kJ/kg]
eta_cycle_1 = [1 - (q2_1/q1_1)]*100; //[kJ/kg]
disp('Thermal efficiency if steam is superheated to 500 C  =',eta_cycle_1,'%')
//(iii) Determine thermal efficiency if boiler pressure is raised to 5 MPa and turbine inlet temperature is at 500 C
p1_2 = 5*1000; //[kPa]
t1_2 = 500; //[ C ]
// at p1_2 and t1_2
h1_2 = 3434.7; //[kJ/kg]
s1_2 = 6.987; //[kJ/kg K]
s2_2 = s1_2; //[kJ/kg K]
x2_2 = [(s2_2 - sf2)/sfg2];
```

```
h2_2 = hf2 + x2_2*hfg2; //[kJ/kg]
wp_2 = v3*(p1_2 - p2); //[kJ/kg]
h4_2 = wp_2 + h3; //[kJ/kg]
q1_2 = h1_2 - h4_2; //[kJ/kg]
q2_2 = h2_2 - h3; //[kJ/kg]
eta_cycle_2 = [1 - (q2_2/q1_2)]*100; //[%]
disp('Thermal efficiency if boiler pressure is
    raised to 5MPa and turbine inlet temp is 500 C =
    ',eta_cycle_2,'%')
//The answer vary due to round off error
```

Scilab code Exa 10.2 Estimate reheat pressure and efficiency and steam rate

```
//Example 10.2
//Estimate reheat pressure and efficiency and steam
    rate
clear
clc
p1 = 150; // [bar]
T1 = 550; //[ C ]
h1 = 3448; //[kJ/kg] At p1 and T1
h2 = 2740; //[kJ/kg] From Mollier chart
//At state 4
p4 = 0.1; //[bar]
x4 = 0.95;
sf4 = 0.1; //[bar]
sfg4 = 7.602; //[kJ/kg K]
hf4 = 191.83; //[kJ/kg]
hfg4 = 2392.8; //[kJ/kg K]
s4 = sf4 + x4*sfg4; //[kJ/kg K]
// At state 3
T3 = 550;//[ C ]
s3 = s4; //[kJ/kg K]
```

```
Console

 "Reheat pressure = "
  13.
 "bar"
 "eta_cycle = "
  43.397694
 "%"
 "Steam rate = "
  2.0655703
 "kg/kW h"
```

Figure 10.2: Estimate reheat pressure and efficiency and steam rate

```
p3 = 13; //[bar] By interpolation  //(i)
h3 = 3500; //[kJ/kg]
sg = 5.3; //[kJ/kg K]
h4 = hf4 + x4*hfg4; //[kJ/kg K]
h5 = hf4; //[kJ/kg K]
v5 = 0.001; //[m^3/kg]
wp = v5*(p1 - p4); //[kJ/kg]
h6 = wp+h5; //[kJ/kg]
wT = (h1 - h2) + (h3 - h4); //[kJ/kg]
w_net_out = wT - wp; //[kJ/kg]
q1 = (h1 - h6) + (h3 - h2); //[kJ/kg]
eta_cycle = [(wT - wp)/q1]*100; //[%]  //(ii)
Steam_rate = 3600/w_net_out; //[kg/kW h]  //(iii)
disp('Reheat pressure = ', p3 ,'bar')
disp('eta_cycle = ',eta_cycle,'%')
disp('Steam rate = ', Steam_rate ,'kg/kW h')
//The answer vary due to round off error
```

Scilab code Exa 10.3 Compute thermal efficiency of plant

```
//Example 10.3
//Compute thermal efficiency of plant
clear
clc
s1 = 6.569; //[kJ/kg K]   s1 = s2 = s3 = s4

p = 3.5; //[bar]
// At p = 3.5 bar
sg = 6.9; //[kJ/kg K]
s2 = s1; //[kJ/kg K]
sf = 1.7275; //[kJ/kg K]
sfg = 5.213; //[kJ/kg K]
hf2 = 584; //[kJ/kg K]
```

```
Console

 "Thermal efficiency of plant ="

  36.044793

 "%"
```

Figure 10.3: Compute thermal efficiency of plant

```
hfg2 = 2148; //[kJ/kg K]
x2 = (s2 - sf)/sfg;
h2 = hf2 + x2*hfg2; //[kJ/kg K]

p1 = 0.7; //[bar]
// At p1 = 0.7 bar
sf3 = 1.2; //[kJ/kg K]
sfg3 = 6.2; //[kJ/kg K]
hf3 = 384; //[kJ/kg]
hfg3 = 2278; //[kJ/kg]
s3 = s1; //[kJ/kg K]
x3 = (s3 - sf3)/sfg3;
h3 = hf3 + x3*hfg3; //[kJ/kg]

p2 = 0.08; //[bar]
// At p2 = 0.08 bar
sf4 = 0.576; //[kJ/kg K]
sfg4 = 7.67; //[kJ/kg K]
hf4 = 168; //[kJ/kg]
hfg4 = 2406; //[kJ/kg]
s4 = s1; //[kJ/kg K]
x4 = (s4 - sf4)/sfg4; //[kJ/kg]
h4 = hf4 + x4*hfg4; //[kJ/kg]
h5 = 168; //[kJ/kg]  // h5 = hf4 at 0.08 bar
h6 = h5; //[kJ/kg K]
h7 = 375; //[kJ/kg K] at pressure 0.7 bar
h8 = h7; //[kJ/kg K]  at pressure 0.7 bar
h9 = 584.34; //[kJ/kg K]  at pressure 3.5 bar
h10 = h9; //[kJ/kg]  at pressure 3.5 bar
m1 = (h9 - h8)/(h2 - h8); //[kg]
h1 = 2993; //[kJ/kg K]
m2 = [(1 - m1)*(h7 - h6)]/(h3 - h6); //[kg]
wT = (h1 - h2) + (1 - m1)*(h2 - h3) + (1 - (m1 + m2)
    )*(h3 - h4); //[kJ/kg] work of turbine
q1 = h1 - h9; //[kJ/kg]  heat input
wp = 0; //pump work is negligible
eta = [(wT - wp)/q1]*100; //[%]
disp('Thermal efficiency of plant =',eta,'%')
```

```
// The answer vary due to round off error
```

Scilab code Exa 10.4 Calculate following question on regenerative cycle

```
//Example 10.4
//Calculate following question on regenerative cycle
clear
clc
//From steam tables at 50 bar and 350 C
h1 = 3068; //[kJ/kg]
s1 = 6.45; //[kJ/kg K]   s1 = s2 = s3
s2 = s1;
// At 7 bar
sg = 6.708; //[kJ/kg K]
hf2 = 697.22; //[kJ/kg]
hfg2 = 2066.3; //[kJ/kg]
sf2 = 1.992; //[kJ/kg K]
sfg2 = sg - sf2; //[kJ/kg K]
x2 = (s2 - sf2)/sfg2;
h2 = hf2 + x2*hfg2;
//At 0.5 bar
sf3 = 1.091; //[kJ/kg K]
sg3 = 7.593; //[kJ/kg K]
sfg3 = 6.502; //[kJ/kg K]
s3 = s1; //[kJ/kg K]
x3 = (s3 - sf3)/sfg3;
hf3 = 340.49; //[kJ/kg]
hfg3 = 2305.4; //[kJ/kg]
h3 = hf3 + x3*hfg3; //[kJ/kg]
h4 = hf3; //[kJ/kg] at 0.5 bar
h5 = h4; //[kJ/kg]
s4 = sf3; // at 0.5 bar
h6 = 697.22; // at 7 bar
```

```
Console

 "Efficiency of cycle with regeneration = "

  34.570558

 "%"

 "Efficiency of cycle without  regeneration = "

  30.334665

 "%"

 "Steam rate with regeneration = "

  4.3924300

 "kg/kW h"

 "Steam rate without  regeneration = "

  4.3510788

 "kg/kW h"

 "Mean temperature of heat addition with regeneration = "

  531.80350

 "K"

 "Mean temperature of heat addition without regeneration = "

  508.95876

 "K"

 "Increase in Tm with regeneration = "

  22.844738

 "K"

 "Increase in steam rate with regeneration = "

  0.0413513

 "kg/kW h"
```

Figure 10.4: Calculate following question on regenerative cycle

```
h7 = h6; //[kJ/kg]
// Energy balance for heater => m1*h2 + (1 - m1)*h5 = h6
m1 = (384.39 - h5)/(h2 - h5); //[kg]
q1_with_reg = h1 - h6; //[kJ/kg]  with regeneration
q1_without_reg= h1 - h4; //[kJ/kg]  without regeneration
wT_with_reg = (h1 - h2) + (1 - m1)*(h2 - h3); //[kJ/kg]   with regeneration
wT_without_reg = h1 - h3; //[kJ/kg]   without regeneration
s7 = sf2;
//(i) Find efficiency of cycle
eta_with_reg = (wT_with_reg/q1_with_reg)*100; //[%]  Efficiency of cycle with regeneration
disp('Efficiency of cycle with regeneration = ',eta_with_reg,'%')
eta_without_reg = (wT_without_reg/q1_without_reg)*100; //[%]  Efficiency of cycle without regeneration
disp('Efficiency of cycle without  regeneration = ',eta_without_reg,'%')
// (ii)Find steam rate
S_rate_with_reg = 3600/wT_with_reg; //[kg/kW h]  Steam rate with regeneration
disp('Steam rate with regeneration = ',S_rate_with_reg,'kg/kW h')
S_rate_without_reg = 3600/wT_without_reg; //[kg/kW h] Steam rate without regeneration
disp('Steam rate without  regeneration = ',S_rate_without_reg,'kg/kW h')
//(iii)Find the mean temperature of the heat addition
Tm_with_reg = (h1 - h7)/(s1 - s7); //[K]  with regeneration
disp('Mean temperature of heat addition with regeneration = ',Tm_with_reg,'K')
Tm_without_reg = (h1 - h4)/(s1 - s4); //[K]  without
```

```
regeneration
disp('Mean temperature of heat addition without regeneration = ',Tm_without_reg,'K')
//(iv)Find increase in Tm and steam rate with regeneration
del_Tm = Tm_with_reg - Tm_without_reg; //[ C ] Increase in Tm with regeneration
disp('Increase in Tm with regeneration = ',del_Tm,'K')
S_rate_inc = S_rate_with_reg - S_rate_without_reg; //[kg/kW h] Increase in steam rate with regeneration
disp('Increase in steam rate with regeneration = ',S_rate_inc,'kg/kW h')
// The answer vary due to round off error
```

Scilab code Exa 10.5 Compute kg of Hg per kg of cycle and efficiency of combined c

```
//Example 10.5
//Compute kg of Hg per kg of water and efficiency of combined cycle
clear
clc
//(i) Compute kg of Hg per kg of water
p = 10; //[bar]
t = 515; //[ C ]
// at p1 and t1
hg = 363; //[kJ/kg]  hg = ha
ha = hg; //[kJ/kg]
sa = 0.5167;//[kJ/kg K]
sb = sa; //[kJ/kg K]
p1 = 0.2; //[bar]
// at p1 = 0.2 bar
```

```
Console

 "Mass of mercury per kg of water = "

   11.906451

 "kg"

 "Overall efficiency of  cycle ="

  -760.67551

 "%"
```

Figure 10.5: Compute kg of Hg per kg of cycle and efficiency of combined cycle

```
// sb = sf_1 + xm*sfg1
sf_1 = 0.0967; //[kJ/kg K]
sg_1 = 0.6385; //[kJ/kg K]
sfg_1 = sg_1 - sf_1; //[kJ/kg K]
xm =  (sb - sf_1)/sfg_1;
hf_1 = 38.35; //[kJ/kg]
hfg_1 = 336.5; //[kJ/kg K]
hb = hf_1+ xm*hfg_1; //[kJ/kg]
hc = hf_1; //[kJ/kg]
hd = hc; //[kJ/kg]
q1 = ha - hd; //[kJ/kg]
W_net_out_m = ha - hb; //[kJ/kg]
eta_m = (W_net_out_m/q1)*100; //[%]  Efficiency of mercury cycle
// For steam cycle at 40 bar and 400 C
h1 = 3273.4; //[kJ/kg]
hf = 167.57; //[kJ/kg]
s1 = 6.77; //[kJ/kg]
sf = 0.5725; //[kJ/kg K]
sfg = 8.257; //[kJ/kg K]
hfg = 2406.7; //[kJ/kg]
s2 = s1; //[kJ/kg K]
xw = (s2 - sf)/sfg;
h2 = hf + xw*hfg; //[kJ/kg]
h3 = hf; //[kJ/kg]
h4 = h3; //[kJ/kg]
q2 = h1 - h4; //[kJ/kg] Heat rejected by topping cycle and recieved by bottoming cycle
W_net_out_st = h1 - h2; //[kJ/kg]
m = (h1 - h4)/(hb - hc); //[kg]  Mass of mercury per kg of water
disp('Mass of mercury per kg of water = ',m,'kg')
//(ii) Efficiency of combined cycle
eta_st = (W_net_out_st/q2)*100; //[%] Efficiency of steam cycle
eta_o =  eta_m +eta_st - (eta_m*eta_st); //[%] Overall efficiency of cycle
disp('Overall efficiency of  cycle =',eta_o,'%')
```

```
// The answer provided in textbook is wrong
```

Scilab code Exa 10.6 Calculate Work Efficiency of cycle Steam rate and Isentropic

```
//Example 10.6
//Calculate Work, Efficiency of cycle, Steam rate
   and Isentropic efficiency
clear
clc
p1 = 2.5; //[bar]
// From steam tables at p1 = 2.5 bar
h1 = 2716.9; //[kJ/kg]
sg = 7.052; //[kJ/kg K]
s1 = sg; //[kJ/kg]
s2 = s1;
hf = 125.77; //[kJ/kg]  at 30 C
hfg = 2430.5; //[kJ/kg]  at 30 C
x = 0.85; //given in question
h2 = hf + x*hfg; //[kJ/kg]
h3 = hf; //[kJ/kg]  at 30 C
p2 = 0.0562; //[bar]  Saturation pressure at 30 C
vf = 1.006*10^-3; //[m^3/kg]  value of vf at  p2 =
   0.0562 bar at 30 C
wp = vf*(p1 - p2); //[kJ/kg]  // wp = h4 - h3 = vf
   *(p1 - p2)
 s2_dash = s1;
 sf = 0.4369; //[kJ/kg K]  at 30 C
 sfg = 8.0164; //[kJ/kg K]  at 30 C
 x2_dash = (s2_dash - sf)/sfg;
 h2_dash = hf + x2_dash*hfg; //[kJ/kg K]
 h4 = wp + h3; //[kJ/kg K]
 q1 = h1 - h4; //[kJ/kg]
 wT = h1 - h2; //[kJ/kg]
```

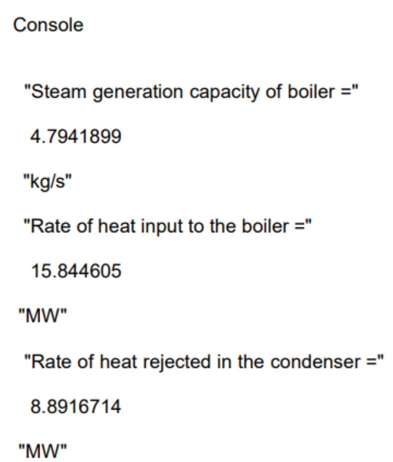
```
Console

 "w_net_out = "
  525.20254
 "kJ/kg"
 "eta_cycle = "
  20.269266
 "%"
 "Steam rate = "
  6.8544984
 "kJ/kW h"
 "Isentropic efficiency of turbine = "
  89.703268
 "%"
```

Figure 10.6: Calculate Work Efficiency of cycle Steam rate and Isentropic efficiency

```
//(i) Estimate w_net_out
w_net_out = wT - wp; //[kJ/kg K]
disp('w_net_out = ',w_net_out,'kJ/kg')
//(ii) Estimate eta_cycle
eta_cycle = (w_net_out/q1)*100; //[%]
disp('eta_cycle = ',eta_cycle,'%')
//(iii) Estimate steam rate
St_rate = 3600/w_net_out; //[kg/kW h]
disp('Steam rate = ',St_rate,'kJ/kW h')
//(iv) Estimate isentropic efficiency of turbine
eta_isentropic = [(h1 - h2)/(h1 - h2_dash)]*100; //
    [%]
disp('Isentropic efficiency of turbine = ',
    eta_isentropic,'%')
```

Scilab code Exa 10.7 Compute steam generation capacity and rate of heat input and

```
//Example 10.7
//Compute steam generation capacity  and rate of
    heat input and rejected
clear
clc
WT= 5600; //[kW]  Power of cogeneration plant
p1 = 40; //[bar]
t1 = 500; //[ C ]
h1 = 3450; //[kJ/kg] at 40 bar and 500 C
h2 = 2700; //[kJ/kg]  enthalpy at state 2 , from
    mollier diagram by drawing line from 40 bar to 2
    bar
h3 = 2230; //[kJ/kg] extending same line from 2 bar
    to 0.06 bar
// From saturated steam tables , at 0.06 bar
p4 = 0.06; //[bar]
```



```
Console

 "Steam generation capacity of boiler ="

  4.7941899

 "kg/s"

 "Rate of heat input to the boiler ="

  15.844605

"MW"

 "Rate of heat rejected in the condenser ="

  8.8916714

"MW"
```

Figure 10.7: Compute steam generation capacity and rate of heat input and rejected

```
h4 = 145; //[kJ/kg]  h4 = hf at 0.06 bar
v4 = 0.0010055; //[m^3/kg]
// From saturated steam tables at 2 bar
p6 = 2; //[bar]
h6 = 504; //[kJ/kg]  h6 = hf at 2 bar
v6 = 0.001061; //[m^3/kg]  v6 = vf at 2bar
// pump work
p5 = p1;
p7 = p1;
 wp1 = v4*(p5 - p4); //[kJ/kg]
 wp2 = v6*(p7 - p6); //[kJ/kg]
 h5 = h4 + wp1; //[kJ/kg]
 QH = 1.163*1000; //[kW]  Heat input
 m1 = QH/(h2 - h6); //[kg/s]  rate of steam flow
 //(i) Compute steam generation capacity of boiler
 // WT = m*(h1 - h2) +(m - m1)*(h2 - h3)
 // final equation becomes => m = [WT + m1(h2 - h3)]/(h1 - h3)
 m = [WT + m1*(h2 - h3)]/(h1 - h3);  //[kg/s]  steam generation capacity of boiler
disp('Steam generation capacity of boiler =',m,'kg/s')
 //(ii) Compute rate of heat input to boiler
 h8 = h5; //[kJ/kg]
 Q1 = m*(h1 - h8); //[kW] Rate of heat input to boiler
 disp('Rate of heat input to the boiler =',Q1/1000,'MW')
 //(iii) Compute rate of heat rejected in the condenser
 Q2 = (m - m1)*(h3 - h4); //[kW]  Rate of heat rejected in condenser
 disp('Rate of heat rejected in the condenser =',Q2/1000,'MW')
```

```
Console

 "Exergy destruction ="

  855.36743

 "kJ/kg"

 "The second law efficiency is ="

  50.022528

 "%"
```

Figure 10.8: Calculate exergy destruction and second law efficiency

Scilab code Exa 10.8 Calculate exergy destruction and second law efficiency

```
//Example 10.8
//Calculate exergy destruction and the second law efficiency
clear
clc
p1 = 2.5*1000; //[kPa]
t1 = 300; //[ C ]
//From superheated steam tables at p1 and t1
h1 = 3009.6; //[kJ/kg]
s1 = 6.645; //[kJ/kg K]
p2 = 15; //[kPa]
// From saturated steam tables at p2 = 15 kPa
sf2 = 0.7549; //[kJ/kg K]
sfg2 = 7.252; //[kJ/kg K]
hf2 = 225.94; //[kJ/kg]
hfg2 = 2373.2; //[kJ/kg]
// s1 = s2 = sf2 + x2 * sfg2
s2 = s1;
x2 = (s2 - sf2)/sfg2;
h2 = hf2 + x2*hfg2; //[kJ/kg]
h3 = 225.93; //[kJ/kg]  at p2 = 15 kPa hf3 = 225.94
s3 = sf2;
s4 = sf2;
v3 = 0.001014; //[m^3/kg]
wp = v3*(p1 - p2); //[kJ/kg]
h4 = wp + h3; //[k/kg]
wT = h1 - h2; //[kJ/kg]
q1 = h1 - h4; //[kJ/kg]
q2 = h2 - h3; //[kJ/kg]
T0 = 298; //[K]
T2 = T0; //[K]
T1 = 773; //[K]
```

```
//(i) Calculate the exergy destruction
X_destroyed_23 = T0*[s3 - s2 + (q2/T2)]; //[kJ/kg]
X_destroyed_41 = T0*[s1 - s4 - (q1/ T1) ]; //[kJ/kg]
// X_desroted=X_destroyed_12+X_destroyed_23+X_destroyed_34+X_destroyed_41
//X_destroyed_12 = 0 & X_destroyed_34 = 0
X_destroyed = X_destroyed_23 + X_destroyed_41; //[kJ/kg]
disp('Exergy destruction =',X_destroyed,'kJ/kg')
//(ii) Calculate the second law efficiency
X_heat_in = (q1 - q2) + X_destroyed;
X_pump_in =  wp; //[kJ/kg]
X_supplied = X_heat_in + X_pump_in; //[kJ/kg]
eta_pi = [1 - (X_destroyed/X_supplied)]*100; //[%]
disp('The second law efficiency is =',eta_pi,'%')
//The answer vary due to round off error
```

Chapter 11

Gas Power Cycles

Scilab code Exa 11.1 Calculation on air standard Otto cycle

```
//Example 11.1
//Calculation on air standard Otto cycle
clear
clc
p1 = 1.1*100; //[kPa] pressure before start of
   compression
T1 = 323; //[K]  temperature before start of
   compression
eta_cycle = 0.45; // 45%
q2 = 800; //[kJ/kg]
q1 = q2/(1 -eta_cycle); //[kJ/kg]  eta_cycle = 1 -
   q2/q1
//(i) Determine the work done per kg of air
W_net = eta_cycle*q1;//[kJ/kg]  net work done
disp('Work done per kg of air =',W_net,'kJ/kg')
//(iii) Determine the compression ratio
// eta_otto = eta_cycle = 1 - [1/(rk^(gama-1))]
gama = 1.4;
rk = [1/(1-eta_cycle)]^(1/(gama-1)); //compression
```

```
Console

 "Work done per kg of air ="

  654.54545

 "kJ/kg"

 "Compression ratio = "

  4.4575198

 "Temperature at the end of compression="

  587.27273

 "K"

 "Pressure at the end of compression ="

  891.50395

 "kPa"

 "The maximum pressure in the cycle ="

  214.13947

 "kPa"
```

Figure 11.1: Calculation on air standard Otto cycle

```
ratio
disp('Compression ratio = ',rk)
//(iii) Determine the pressure and temperature at the end of compression
// rk =  (v1/v2)
//   T2/T1 = (v1/v2)^(gama-1)
T2 = T1*((rk)^(gama-1)); //[K]
disp('Temperature at the end of compression=',T2,'K')
// Also p2/p1 = (v1/v2)^gama
p2 = p1*(rk^gama); //[kPa]
disp('Pressure at the end of compression =',p2,'kPa')
//(iv) Determine the maximum pressure in the cycle
Cv = 0.783;
T3 = (q1/Cv) + T2; //[K]  since q1 = Cv*(T3 - T2)
// For process 2-3 (p2*v2)/T2 = (p3*v3)/T3  where v2 = v3
p3 = (p2*T2)/T3; //[kPa]
disp('The maximum pressure in the cycle =',p3,'kPa')
// The answer provided in textbook is wrong
// eta_cycle given in question is 0.45 but in book it is taken as 0.50 then it is solved
```

Scilab code Exa 11.2 Calculation on air standard Diesel cycle

```
//Example 11.2
//Calculation on air standard Diesel cycle
clear
clc
p1 = 1.1*100; //[kPa]
T1 = 273 + 35; //[K]
// Compression ratio rk = 17:1 and rk = v1/v2
```

```
Console

 "The maximum temperature of the cycle = "

  2747.6446

 "K"

 "The work done per kg of air = "

  1052.4256

 "kJ/kg"

 "The maximum pressure = "

  5.8079273

 "MPa"

 "eta_cycle = "

  58.468090

 "%"

 "The temperature at the end of isentropic expansion = "

  1349.1899

 "K"

 "Cutoff ratio = "

  2.8723031

 "The MEP of cycle = "

  1.4111588

 "MPa"
```

Figure 11.2: Calculation on air standard Diesel cycle

```
rk = 17;
q1 = 1.8*1000;//[kJ/kg]
Cp = 1.005; //[kJ/kg K]
Cv = 0.718; //[kJ/kg K]
// T2/T1 = (v1/v2)^(gama - 1)
gama = 1.4;
T2 = T1*[rk^(gama -1)]; //[K]
// Estimate maximum temperature of the cycle
T3 = (q1/Cp) + T2; //[K] Maximum temperature of the cycle Tmax = T3
// Estimate the cutoff ratio
// For process 2-3 (p2*v2)/T2 = (p3*v3)/T3 & p2 =p3
// Cut off ratio (v3/v2) = T3/T2
C_R = T3/T2; //C_R = v3/v2 cutoff ratio
// Estimate the temperature at the end of isentropic expansion
//For process 3-4 T3/T4 = (v4/v3)^(gama-1) = [(v1/v2)*(v2/v3)]^(gama-1)
T4 = T3/[(rk/C_R)^(gama-1)]; //[K] where rk=v1/v2 and C_R = v3/v2
q2 = Cv*(T4 - T1); //[kJ/kg]
// Estimate the work done per kg of air
W_net = q1 - q2; //[kJ/kg]
// Estimate eta_cycle
eta_cycle = [1-(q2/q1)]*100;
R = 0.283;
v1 = (R*T1)/p1; //[m^3/kg] p1*v1=R*T1
v2 = v1/rk; //[m^3/kg]
// Estimate the maximum pressure
p2 = (R*T2)/v2; //[kPa]
// Estimate the MEP of cycle
MEP = W_net/(v1 - v2);//[kPa]
disp('The maximum temperature of the cycle = ',T3,'K') //(i)
disp('The work done per kg of air = ',W_net,'kJ/kg') //(ii)
disp('The maximum pressure = ',p2/1000,'MPa') //(iii)
```

```
disp('eta_cycle = ',eta_cycle,'%') //(iv)
disp('The temperature at the end of isentropic expansion = ',T4,'K')  //(v)
disp('Cutoff ratio = ',C_R)  //(vi)
disp('The MEP of cycle = ',MEP/1000,'MPa') //(vii)
// The answer vary due to round off error
```

Scilab code Exa 11.3 Calculate following question on Brayton cycle gas turbine pla

```
//Example 11.3
// Calculate following question on Brayton cycle gas turbine plant
clear
clc
p1 = 1; //[bar]
T1 = 298; //[K]
rp = 8; //pressure ratio rp = p2/p1
eta_T = 0.85; //turbine efficiency
eta_c = 0.85; //compressor efficiency
// For process1-2 T2_1/T1 = (p2/p1)^((gama-1)/gama)
gama = 1.4
T2_1 = T1*[(rp)^((gama-1)/gama)];//[K]
T3 = 273+950;//[K]  maximum temperature
// For process 3-4  T4_1/T3 = (p4/p3)^((gama-1)/gama) & p4/p3 = p1/p2 = 1/rp
T4_1 = T3*[(1/rp)^((gama -1)/gama)]; //[K]
T2 = [(T2_1 - T1)/eta_c]+T1; //[K]  eta_c = (T2_1 - T1)/(T2 - T1)
Cp = 1.005;
//Compute compressor work per kg of air
wc = Cp*(T2 - T1); //[kJ/kg]  work input to compressor
//Compute turbine exhaust temperature
```

```
Console

 "The turbine work per kg of air = "
  468.00023
"kJ/kg"
 "The compressor work per kg of air = "
  285.90631
"kJ/kg"
"Cycle efficiency = "
  28.287811
"%"
 "Heat supplied per kg of air = "
  643.71869
"kJ/kg"
 "Turbine exhaust temperature = "
  757.32813
"K"
 "Black work ratio = "
  61.091061
"%"
```

Figure 11.3: Calculate following question on Brayton cycle gas turbine plant

```
T4 = T3 - eta_T*(T3 - T4_1);//[K]
// Compute turbine work per kg of air
wT = Cp*(T3 - T4); //[kJ/kg]  work output of turbine
//Compute heat supplied per kg of air
 Q1 = Cp*(T3 - T2); //[kJ/kg]
 // Compute cycle efficiency
 eta_cycle = [(wT - wc)/Q1]*100;
 //Compute the black work ratio
 B_wr = (wc/wT)*100; //[%] black work ratio
 disp('The turbine work per kg of air = ',wT,'kJ/kg') //(i)
 disp('The compressor work per kg of air = ',wc,'kJ/kg') //(ii)
 disp('Cycle efficiency = ',eta_cycle,'%')  //(iii)
 disp('Heat supplied per kg of air = ',Q1,'kJ/kg') //(iv)
 disp('Turbine exhaust temperature = ',T4,'K') //(v)
 disp('Black work ratio = ',B_wr,'%')  //(vi)
```

Scilab code Exa 11.4 Calculate maximum temperature and percentage increase in effi

```
//Example 11.4
//Calculate maximum temperature and percentage increase in efficiency
clear
clc
p1 = 103; //[kPa]
T1 = 300; //[K]
q1 = 700; //[kJ/kg]
rp = 5; // pressure ratio (rp) = p2/p1
eta_T = 0.75; //turbine efficiency
eta_c = 0.75; //compressor efficiency
Cp = 1.005;
```

```
Console

 "Maximum temperature in the cycle = "

  1230.0453

 "K"

 "The percentage increase in efficiency of cycle due to regeneration = "

  69.324213

 "%"
```

Figure 11.4: Calculate maximum temperature and percentage increase in efficiency

```
gama = 1.4;
// Without regenerator
//For process1-2     T2_1/T1 = (p2/p1)^(gama -1/gama)
T2_1= T1*[(rp)^((gama -1)/gama)]; //[K]
T2 = [(T2_1 - T1)/eta_c] + T1; //[K] since eta_c = (T2_1 - T1)/(T2 - T1)
//(i) Compute maximum temperature in the cycle
T3 = (q1/Cp) + T2; //[K]   as q1 = Cp*(T3 - T2) max temp
disp('Maximum temperature in the cycle = ',T3,'K')
//For process 3-4   T3/T4_1 = (p2/p1)^(gama -1/gama)
T4_1 = T3/[(rp)^((gama -1)/gama)]; //[K]
T4 = T3 - [eta_T*(T3 - T4_1)]; //[K]
wT = Cp*(T3  - T4); //[kJ/kg]  turbine work
wc = Cp*(T2 - T1); //[kJ/kg]   work input of compressor
eta_cycle = [(wT - wc)/q1]*100; //[%]  cycle efficiency
//With regenerator
eta_r = 0.80; //regenerator effectiveness
T6 = eta_r*(T4 - T2) + T2; //[K]  eta_r = (T6 - T2)/(T4 - T2)
q1_1 = Cp*(T3 - T6); //[kJ/kg]
eta_cycle_1 = [(wT - wc)/q1_1]*100; //[%]
//(ii)Compute the percentage increase in efficiency of cycle due to regeneration
percent_inc = [(eta_cycle_1 - eta_cycle)/eta_cycle]*100; //[%]
disp('The percentage increase in efficiency of cycle due to regeneration = ',percent_inc,'%')
//The answer vary due to round off error
```

```
Console

 "The efficiency of the cycle = "

  25.444596

 "%"
```

Figure 11.5: Compute the efficiency of the cycle

Scilab code Exa 11.5 Compute the efficiency of the cycle

```
//Example 11.5
//Compute the efficiency of the cycle
clear
clc
p1 = 101.32; //[kPa]
T1 = 300; //[K]
T3 = 1023; //[K]
T5 = T3; //[K]
rp = 7; // rp = p2/p1
eta_THP = 0.85;
eta_TLP = 0.85;
eta_c = 0.80;
gama = 1.4;
Cp = 1.005;
T2_1 = T1*[(rp)^((gama -1)/gama)]; //[K]  For
    process 1-2 T2_1/T1 = (rp)^(gama -1/gama)
T2 = [(T2_1 - T1)/eta_c] + T1;//[K]  eta_c = (T2_1 -
    T1)/(T2 - T1)
wc = Cp*(T2 - T1); //[kJ/kg]  work of compression
w_out_HP = wc; //[kJ/kg]  work output of high
    pressure turbine
T4 = T3 - w_out_HP/Cp; //[K]
T4_1 = T3 - (T3 - T4)/eta_THP; //[K]
p2 = rp*p1; //[kPa]
p3 = p2; //[kPa]
p4 = p3/[(T3/T4)^(gama/(gama -1))]; //For process3-4
p5 = p4; //[kPa]
p6 = p1; //[kPa]
T6_1 = T5/[ (p5/p6)^( (gama -1)/gama) ]; //[K]  For
    process 5-6
T6 = T5 - eta_TLP*(T5 - T6_1); //[K]
w_out_LP = Cp*(T5 - T6); //[kJ/kg]
q1 = Cp*[(T3 - T2) + (T5 - T4)]; //[kJ/kg]
eta = (w_out_LP/q1)*100; //[%]
disp('The efficiency of the cycle = ',eta,'%')
// The answer provided in textbook is wrong
```

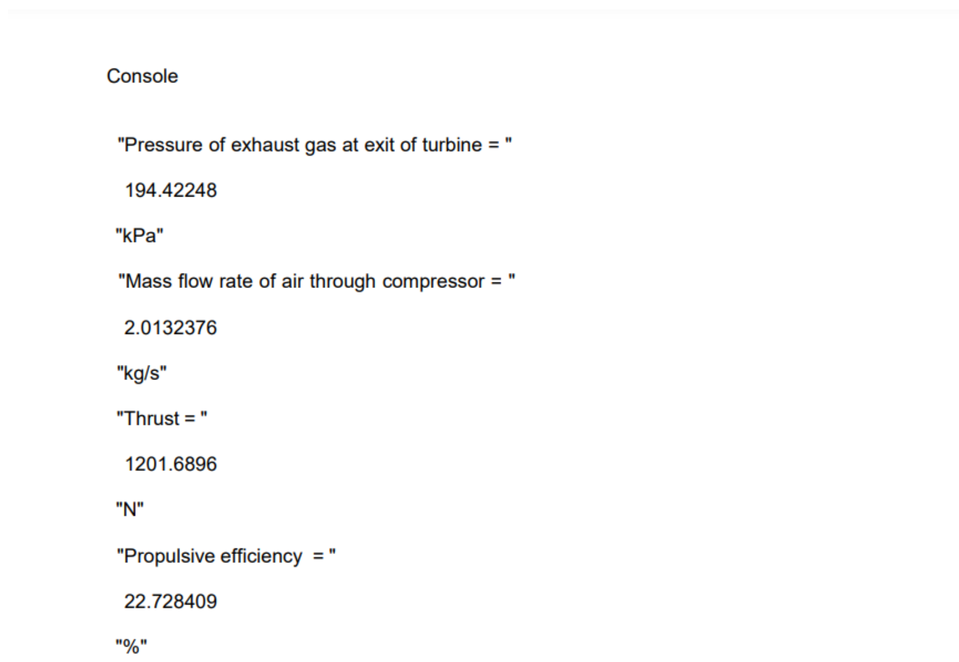
```
// Due to round off error  in initial calculations there is large difference in final solution
```

Scilab code Exa 11.6 Determine efficiency of the plant

```
//Example 11.6
// Determine efficiency of the plant
clear
clc
m = 1.2; //[kg/s]
T1 = 273 + 27; //[K]
T3 = T1; //[K]
T5 = 273 + 723; //[K] Tmax
pr = 6; //pressure ratio P4/P1
P2_1 = sqrt(pr); // P2/P1 = P4/P3
gama = 1.4;
Cp = 1.005;
T2_1 = T1*(P2_1)^( (gama -1)/gama ); //[K]
eta_comp_LP = 0.85;
T2 = ( (T2_1 - T1)/eta_comp_LP ) + T1; //[K]
Wc = 2*m*Cp*(T2 - T1); //[kW]
P5_6 = pr; // P5/P6
T6_1 = T5/[P5_6^( (gama -1)/gama )]; //[K]
eta_T = 0.90;
T6 = T5 - [(T5 - T6_1)/eta_T];  //[K]
WT = m*Cp*(T5 - T6); //[kW]
Wnet = WT - Wc; //[kW]
T4_1 = T2; //[K]
T4 =  ( (T4_1 - T3)/eta_comp_LP ) + T3; //[K]
Q1 = m*Cp*(T5 - T4); //[kJ/s]
eta = (Wnet/Q1)*100; //[%]
disp('Cycle efficiency = ',eta,'%')
// The answer provided in textbook is wrong
```

```
Console

 "Cycle efficiency = "

   41.311323

 "%"
```

Figure 11.6: Determine efficiency of the plant


Console

"Pressure of exhaust gas at exit of turbine = "

194.42248

"kPa"

"Mass flow rate of air through compressor = "

2.0132376

"kg/s"

"Thrust = "

1201.6896

"N"

"Propulsive efficiency = "

22.728409

"%"

Figure 11.7: Calculate following question on turbojet aircraft

---

Scilab code Exa 11.7 `Calculate following question on turbojet aircraft`

```
//Example 11.7
//Calculate following question on turbojet aircraft
```

```
clear
clc
P1 = 35; //[kPa]
P2 = 45;//[kPa]
T1 = 240; //[K]
P3 = 400; //[kPa]
P4 = P3; //[kPa]
P6 = P1; //[kPa]
T4 = 1200; //[K]
gama = 1.4;
Cp = 1.005;
vi = 275; //[m/s]
// For process 1-2 [ T2/T1 = (P2/P1)^(gama -1/gama) ]
T2 = T1*[(P2/P1)^( (gama -1)/gama )]; //[K]
//For process2-3 [ T3/T1 = (P3/P2)^(gama -1/gama) ]
T3 = T2*[(P3/P2)^( (gama -1)/gama )]; //[K]
// work of compression = work of turbine
//Cp*(T3 - T2) = Cp*(T4 - T5)
T5 = T4 - T3 + T2; //[K]
//(i) Find pressure of exhaust gas at exit of turbine
//For process 4-5  [ P5/P4 = (T5/T4)^(gama/(gama -1)) ]
P5 = P4*[(T5/T4)^(gama/(gama -1))]; //[kPa]
disp('Pressure of exhaust gas at exit of turbine = ',P5,'kPa')
//(ii) Find mass flow rate of air through compressor
 Wc = 450; //[kW] work of compressor
 m = Wc/(T3 - T2); //[kg/s]  Mass flow rate of air
 disp('Mass flow rate of air through compressor = ',m,'kg/s')
 //(iii) Find Thrust
 // For process 5-6  T6/T5 = (P5/P6)^(gama -1/gama)
 T6 = T5*[(P6/P5)^((gama -1)/gama)]; //[K]
 //Also  h6 + v6^2/2 = h5 + v5^2/2, where v5 = 0
 v6 = sqrt(2*Cp*(T5 - T6)*1000);//[m/s]  Velocity at nozzle exit
```

```
F = m*(v6 - vi); //[N]  Thrust
disp('Thrust = ',F,'N')
//(iv) Find propulsive efficiency
Wp = [m*(v6 - vi)*vi]/1000; //[kW]  propulsive power
Q1 = m*Cp*(T4 - T3); //[kW]  Rate of heat input
eta_p = (Wp/Q1)*100; //[%]  propulsive efficiency
disp('Propulsive efficiency = ',eta_p,'%' )
// The answer vary due to round off error
```

Scilab code Exa 11.8 Calculate following question on simple Brayton cycle

```
//Example 11.8
//Calculate following question on simple Brayton cycle
clear
clc
T1 = 300; //[K]
T0 = T1; //[K]
T3 = 1250; //[K]
rp = 10; // pressure ratio rp = P2/P1
Cp = 1.005;  //[kJ/kg K]specific heat
gama = 1.4
T_source = 1550; //[K]
T_sink = 310; //[K]
R = 0.287; //[kJ/kg K]
//For process 1-2 T2/T1 = (P2/P1)^(gama -1/gama)
T2 = T1*[(rp)^( (gama -1)/gama)]; //[K]
T4 = T3*[(1/rp)^( (gama -1)/gama )]; //[K]
q1 = Cp*(T3 - T2); //[kJ/kg]
q2 = Cp*(T4 - T1); //[kJ/kg]
s2 = 2.363; //[kJ/kg K] From ideal gas properties of air at T2
```

```
Console

 "Exergy destruction in process 1-2 = "
  0.
 "Exergy destruction in process 2-3 = "
   128.42039
 "kJ/kg"
 "Exergy destruction in process 3-4 = "
  0.
 "Exergy destruction in process 4-1 = "
   79.007910
 "kJ/kg"
 "Total exergy destruction = "
   207.42830
 "kJ/kg"
 "Second-law efficiency of the cycle = "
   61.846304
 "%"
```

Figure 11.8: Calculate following question on simple Brayton cycle

```
s3 = 3.226; //[kJ/kg K] From ideal gas properties of air at T3
s1 = s2; //[kJ/kg K]
s4 = s3; //[kJ/kg K]
// For process 2-3 (s3_1 - s2_1)= del_s_32 = s3 -s2 - R*log(P3/P2) where P3 = P2
del_s_32 = s3 - s2 - R*log(1); //s3_1 - s2_1 = del_s_32
del_s_14 = -del_s_32; // s1_1 - s4_1 = del_s_14
//(i) Find exergy destruction associated with each process of the cycle
X_destroyed_12 = 0;
X_destroyed_34 = 0;
X_destroyed_23 = T0*[(del_s_32) - (q1/T_source) ]; //[kJ/kg]
X_destroyed_41 = T0*[(del_s_14) + (q2/T_sink)]; //[kJ/kg]
disp('Exergy destruction in process 1-2 = ',X_destroyed_12)
disp('Exergy destruction in process 2-3 = ',X_destroyed_23,'kJ/kg')
disp('Exergy destruction in process 3-4 = ',X_destroyed_34)
disp('Exergy destruction in process 4-1 = ',X_destroyed_41,'kJ/kg')
X_heat_in = [1 - (T0/T_source)]*q1; //[kJ/kg]
X_supplied = X_heat_in; //[kJ/kg]
//(ii) Find total exergy destruction of the cycle
X_destroyed = X_destroyed_12+X_destroyed_23+X_destroyed_34+X_destroyed_41; //[kJ/kg]
disp('Total exergy destruction = ',X_destroyed,'kJ/kg')
//(iii) Find the second law efficiency of the cycle
eta_pi = [1 - (X_destroyed/X_supplied)]*100; //[%]
disp('Second-law efficiency of the cycle = ',eta_pi,'%')
```

Chapter 12

Refrigeration Cycles

Scilab code Exa 12.1 Determine COP and volume and power required

```
//Example 12.1
// Determine COP and volume and power required
clear
clc
p1 = 2.1912; //[bar]
h1 = 183.19; //[kJ/kg]
s1 = 0.7019; //[kJ/kg K]
v1 = 0.077; //[m^3/kg]
p2 = 7.067; //[bar]
s2 = s1; //[kJ/kg K]
h2 = 207; //[kJ/kg]
h4 = 62.63; //[kJ/kg]
h3 = h4; //[kJ/kg]
t2 = 40;//[ C ]
eta_v = 0.76; //volumetric efficiency
Ref_load = 2; //[kW]
m = Ref_load/(h1 - h4); //[kg/s]
//(i) Determine COP
COP = (h1 - h4)/(h2 - h1);
```

```
Console

 "COP = "

  5.0634187

 "Swept volume of the compressor = "

  0.0016808

 "m^3/s"

 "Power required to drive the compressor = "

  0.3949900

 "kW"
```

Figure 12.1: Determine COP and volume and power required

```
disp('COP = ',COP)
//(ii) Determine swept volume of compressor
va = m*v1; //[m^3/s]
vs = va/eta_v; //[m^3/s]
disp('Swept volume of the compressor = ',vs,'m^3/s')
//(iii) Determine power required to drive the
   compressor
P = m*(h2 - h1); //[kW]
disp('Power required to drive the compressor = ',P,'
   kW')
//The answer vary due to round off error
```

Scilab code Exa 12.2 Calculate following question on gas refrigerating system

```
//Example 12.2
//Calculate following question on gas refrigerating
   system
clear
clc
T1 = 273 - 12; //[K]  Temperature at inlet to
   compressor
T3 = 273 + 27; //[K]  Temperature at inlet to
   turbine
rp = 5; // pressure ratio (rp) = p2/p1
gama = 1.4;
Cp = 1.005;
R = 0.287;
p1 = 100; //[kPa]
Load = (10*14000)/3600; //[kJ/h]  1 ton = 14000 kJ/s
T2 = T1*[(rp)^( (gama -1)/gama )]; //[K]
T4 = T3*[(1/rp)^( (gama -1)/gama )]; //[K] since p4
   = p1 and p3 = p2
RE = Cp*(T1 - T4);//[kJ/kg]  Refrigerating effect
```

```
Console

 "COP = "
  1.7128579
 "Air flow rate = "
  0.5405558
 "kg/s"
 "Volume rate entering compressor = "
  0.4049141
 "m^3/s"
 "Minimum temperature = "
 -83.584489
 "°C"
 "Maximum temperature = "
  140.37692
 "°C"
```

Figure 12.2: Calculate following question on gas refrigerating system

```
W_net_in = Cp*[(T2 - T1) - (T3 - T4)]; //[kJ/kg] Net work input
//(i) Compute COP
COP = RE/W_net_in;
disp('COP = ',COP)
//(ii) Compute air flow rate in kg/s
m = Load/RE; //[kg/s] Mass flow rate of refrigerant
disp('Air flow rate = ',m,'kg/s')
//(iii) Compute volume rate entering compressor in m^3/s
vi = (R*T1)/p1; //[m^3/kg]
va = m*vi; //[m/s]
disp('Volume rate entering compressor = ',va,'m^3/s')
//(iv) Maximum and Minimum temperature
disp('Minimum temperature = ',T4-273,' C ')
disp('Maximum temperature = ',T2-273,' C ')
//The answer vary due to round off error
```

Scilab code Exa 12.3 Calculate following question on food freezing system

```
//Example 12.3
// Calculate following question on food freezing system
clear
clc
// From saturated tables of refrigerant R-12
//At temperature -35 C
T1 = 273 - 35;//[K]
h1 = 175; //[kJ/kg]    h1 = hg
v1 = 0.1954; //[m^3/kg]
s1 = 0.72; //[kJ/kg K]  s1 = sg
// At temperature 25 C
```

```
Console

 "Refrigerating effect = "
  118.232
 "kJ/kg"
 "Flow rate of R-12 ="
  0.6578403
 "kg/s"
 "Length and diameter of cylinder are same"
 "Length = "
  0.1108982
 "m"
 "Diameter ="
  0.1108982
 "m"
 "Power required to drive the compressor ="
  22.712051
 "kW"
 "COP ="
  3.4245158
```

Figure 12.3: Calculate following question on food freezing system

```
T2 = 273 + 25; //[K]
h2 = 197.73; //[kJ/kg]  h2 = hg
s2 = 0.6868; //[kJ/kg K] s2 = sg
h3 = 59.7; //[kJ/kg K]  h3 = hf
del_T1 = 5; //Tsup - Tsat
Cpg = 1.235; //[kJ/kg K]
Cpl = 0.733; //[kJ/kg K]
eta_v = 0.80; //volumetric efficiency
N = 1500; //[rpm]
n = 6; //six cylinders
Load = (20*14000)/3600; //[kJ/s]
h1_1 = h1 + Cpg*(del_T1); //[kJ/kg]
T1_1 = T1 + 5;//[K]
 s1_1 = s1 + Cpg*log(T1_1/T1); //[kJ/kg K]
 s2_1 =s1_1;//[kJ/kg K]  s2_1 = s2 + Cpg*log(T2_1/T2)
 L_T2_1 = [(s2_1 - s2)/Cpg] + log(T2);
 T2_1 = exp(L_T2_1); //[K]
 // Entahlpy of subcooled liquid refrigerant  = h3_1 = h3 + Cpl*(T3 - T3_1)
 h3_1 = h3 - Cpl*(4); //[kJ/kg]
 h2_1 = h2 + Cpg*(T2_1 - T2); //[kJ/kg]
 //(i) Determine refrigerating effect
 RE = h1 - h3_1; //[kJ/kg]  Refrigerating effect , h1 - h1 = h1 - h3_1
 disp('Refrigerating effect = ',RE,'kJ/kg')
 h4 = h3_1;//[kJ/kg]
 //(ii) Determine flow rate of R-12
 m = Load/RE; //[kg/s]
 disp('Flow rate of R-12 =',m,'kg/s')
 //(iii) Determine cylinder dimension
 va = m*v1; //[m^3/s]
 vs = (va/eta_v)*60; //[m^3/min]
 // Swept volume vs = (pi/4)*d^2*L*N*n, L = d
 d = [(vs *4)/(%pi *N*n)]^(1/3);
  disp('Length and diameter of cylinder are same')
  disp('Length = ',d,'m')
  disp('Diameter =',d,'m')
```

```
//(iv) Determine the power required to drive the
    compressor
 P = m*(h2_1 - h1_1); //[kW]
 disp('Power required to drive the compressor =',P,
    'kW')
 //(v) Determine COP
COP = (h1 - h4)/(h2_1 - h1_1);
disp('COP =',COP)
// The answer for question (iv) and (v) are
    provided wrong in textbook due to calculation
    mistake in h2_1
```

Scilab code Exa 12.4 Determine the steam flow rate

```
//Example 12.4
//Determine the steam flow rate
clear
clc
//From steam tables at 1.5 bar and 0.85 dry
Tsat = 111.37;//[ C ]
hfg = 2265.5; //[kJ/kg]
x = 0.85;
T1 = 273 + 111.37; //[K] Generator temperature
T2 = 273 + 25; //[K] Codenser or absorber
    temperature
Tr = 273 - 20; //[K]  Evaporator temperature
Load = (10*14000)/3600; //[kJ/s]
 COP_max = [(T1 - T2)*Tr]/[(T2 - Tr)*T1];
 Q_E = Load/COP_max; //[kW] Refrigerating effect
 // Q = m*(h2 - h1), where h2 - h1 = hf - x*hfg - hf
      = h2_h1
 h2_h1= x*hfg;//[kJ/kg]  Heat transfered by 1 kg
    steam on condensation
```

```
Console

 "The rate of steam flow ="

  0.0159853

 "kg/s"
```

Figure 12.4: Determine the steam flow rate

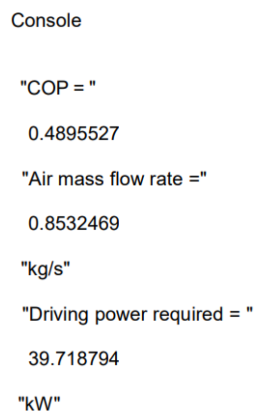


Figure 12.5: Determine COP and air mass flow rate and power

```
m = Q_E/h2_h1;//[kg/s] steam flow rate
disp('The rate of steam flow =',m,'kg/s')
```

Scilab code Exa 12.5 `Determine COP and air mass flow rate and power`

```
//Example 12.5
//Determine COP and air mass flow rate and power
```

```
clear
clc
T1 = 273 +5; //[K]
T3 = 273 + 40; //[K]
 p1 = 100; //[kPa]
 p2 = 250; //[kPa]
 eta_comp = 0.80; // Isentropic efficiency of compressor
 eta_Turbine = 0.80; // Isentropic efficiency of turbine
 Cp = 1.005; //[kJ/kg K]
 Load = (5*14000)/3600; //[kJ/s]
 gama = 1.4;
 T2 = T1*[(p2/p1)^( (gama -1)/gama )]; //[K] For process 1-2
 p3 = p2; //[kPa]
 p4 =p1; //[kPa]
 T4 = T3/[(p3/p4)^( (gama -1)/gama )]; //[K]
 T2_1 = [(T2 - T1)/eta_comp] + T1; //[K]
 T4_1 = T3 - [eta_Turbine*(T3 - T4)]; //[K]
 //(i) Determine COP
 Q2 = Cp*(T1 - T4_1); //[kJ/kg]
 W_net_in = Cp*[(T2_1 - T1) - (T3 - T4_1)];//[kJ/kg]
 COP = Q2/W_net_in;
 disp('COP = ',COP)
 //(ii) Determine air mass flow rate
 m = Load/Q2; //[kg/s]
 disp('Air mass flow rate =',m,'kg/s')
 //(iii) Determine driving power required
 P = m*W_net_in;//[kW]
 disp('Driving power required = ',P,'kW')
```

Scilab code Exa 12.6 Find total exergy destruction and in each process and efficie

```
Console

 "Exergy destruction in process 1-2 ="
  0.5088000
"kW"
 "Exergy destruction in process 2-3 ="
  0.5834353
"kW"
 "Exergy destruction in process 3-4 ="
  1.0800000
"kW"
 "Exergy destruction in process 4-1 ="
  0.8169490
"kW"
 "Second-law efficiency ="
  32.252381
"%"
 "Total exergy destruction ="
  2.9891843
"kW"
```

Figure 12.6: Find total exergy destruction and in each process and efficiency

```
//Example 12.6
//Find  total exergy destruction and in each process and efficiency
clear
clc
//From properties table of R-134 a
T1 = 273 - 26.4; //[K]
h1 = 234.44; //[kJ/kg]
s1 = 0.9518; //[kJ/kg k]
P2 = 1017.1; //[kPa]
s2_1 = s1; //[kJ/kg K]
h2_1 = 281.32; //[kJ/kg]
P3 = P2; //[kPa]
h3 = 108; //[kJ/kg]
s3 = 0.392; //[kJ/kg K]
P4 = 100; //[kPa]
h4 = h3; //[kJ/kg]
s4 = 0.437; //[kJ/kg K]
m = 0.08; //[kg/s]
T0 = 273 + 27; //[K] surrounding temperature
T2 = 273 - 10; //[K]
eta_c = 0.85; // Isentropic efficienccy
h2 = [(h2_1 - h1)/eta_c] + h1; //[kJ/kg]
s2 = 0.973; ///[kJ/kg K] at h2 and P2
Q1 = m*(h2 - h3); //[kW]
Q2 =  m*(h1 - h4); //[kW]
W_in = m*(h2 - h1); //[kW]
//(i) Find exergy destruction in each process
X_destroyed_12 = T0*m*(s2 - s1); //[kW]
X_destroyed_23 = T0*[m*(s3 - s2) + (Q1/300)]; //[kW]
X_destroyed_34 = T0*m*(s4 - s3); //[kW]
X_destroyed_41 = T0*[m*(s1 - s4) - (Q2/T2)]; //[kW]
disp('Exergy destruction in process 1-2 =', X_destroyed_12,'kW')
disp('Exergy destruction in process 2-3 =', X_destroyed_23,'kW')
disp('Exergy destruction in process 3-4 =', X_destroyed_34,'kW')
```

```
disp('Exergy destruction in process 4-1 =',X_destroyed_41,'kW')
//(ii) Find second-law efficiency
W_min_in = Q2*[(T0 - T2)/T2]; //[kW]
eta_pi = (W_min_in/W_in)*100; //[%]
disp('Second-law efficiency =',eta_pi,'%')
//(iii) Find Total exergy destruction
X_destroyed=X_destroyed_12+X_destroyed_23+X_destroyed_34+X_destroyed_41;//[kW]
disp('Total exergy destruction =',X_destroyed,'kW')
// The answer of exergy destruction in process 2-3 is provided wrong in textbook due to this value of total exergy destruction differs
```

Chapter 13

Thermodynamic Relations

Scilab code Exa 13.1 `Verify the 4th Maxwell relation`

```
//Example 13.1
//Verify the 4th Maxwell relation
clear
clc
P1 = 500; //[kPa]
P2 = 700; //[kPa]
T1 = 20; //[ C ]
T2 = 40; //[ C ]
s1 = 0.9713; //[kJ/kg K] At 500 kPa and 30 C
s2 = 0.9313; //[kJ/kg K]  At 700 kPa and 30 C
v1 = 0.0343; //[m^3/kg] At 600 kPa and 20 C
v2 = 0.0378; //[m^3/kg] At 600 kPa and 40 C
del_s = s2 - s1; //[kJ/kg K]
del_P = P2 - P1; //[kPa]
del_T = T2 - T1; //[ C ]
del_v = v2 - v1; //[m^3/kg]
del_s_P = del_s/del_P;
del_v_T = -(del_v/del_T);
disp('The change in entropy with pressure at
```

```
Console

 "The change in entropy with pressure at constant temperature ="
 -0.0002000
 "The change in specific volume with temperature at constant pressure="
 -0.0001750
 "Since both values are in close agreement with each other"
 "The refrigerant R-134a satisfies 4th Maxwell relation at specified state"
```

Figure 13.1: Verify the 4th Maxwell relation

```
    constant temperature =',del_s_P)
disp('The change in specific volume with temperature
     at constant pressure=',del_v_T)
disp('Since both values are in close agreement with
    each other')
disp('The refrigerant R-134a satisfies 4th Maxwell
    relation at specified state')
//The answer vary due to round off error
```

Scilab code Exa 13.2 Evaluate enthalpy of vaporization of water

```
//Example 13.2
//Evaluate enthalpy of vaporization of water
clear
clc
//From steam tables at 50 C
vf = 0.001012; //[m^3/kg]
vg = 12.026; //[m^3/kg]
vfg = vg - vf;
T = 273 + 50;//[K]
T1 = 45; //[ C ]
T2 = 55; //[ C ]
P1 = 9.595; //[kPa] At 45 C
P2 = 15.763; //[kPa] At  55 C
del_P = P2 - P1;
del_T = T2 - T1;
hfg = T*vfg*(del_P/del_T);//[kJ/kg] Value of hfg
    from clapeyron equation
hfg1 = 2382.0; //[kJ/kg] Value of hfg from steam
    tables
disp('The enthalpy of vapourization from Clapeyron
    equation = ',hfg,'kJ/kg' )
disp('The value of hfg from steam tables is ',hfg1,'
```

```
Console

 "The enthalpy of vapourization from Clapeyron equation = "

  2395.6951

 "kJ/kg"

 "The value of hfg from steam tables is "

  2382.

 "kJ/kg"

 "The difference between two values is around = "

  0.5716533

 "%"
```

Figure 13.2: Evaluate enthalpy of vaporization of water

```
    kJ/kg')
x = [(hfg - hfg1)/hfg]*100; //[%]
disp('The difference between two values is around =
    ',x,'%')
//The answer vary due to round off error
```

Scilab code Exa 13.3 Develop an expression for entropy change of a gas that follow

```
//Example 13.3
// Develop an expression for entropy change of a gas
    that follows van der waals equation

clear
clc

// The given example is theoretical and does not
    involve any numerical computation
//end
```

Scilab code Exa 13.4 Determine the saturation pressure of the refrigerant R 134a

```
//Example 13.4
//Determine the saturation pressure of the
    refrigerant R 134a
clear
clc
//The Clausius-Clapeyron equation for determing
    saturation pressure is
// log(p2/p1) = (hfg/R)*( (T2 - T1)/T1*T2 )
T1 = 273 - 50;//[K]
T2 = 273 - 40; //[K]
```

```
Console

 "Saturation pressure of the refrigerant R-134a at -50°C ="
  30.062831
 "kPa"
```

Figure 13.3: Determine the saturation pressure of the refrigerant R 134a

```
hfg = 225.86; //[kJ/kg K] From R-134a tables at -40
    C
R = 0.08149; //[kJ/kg K]
p2 = 51.25; //[kPa]
ln_p1 = log(p2) - [(hfg/R)*( (T2 - T1)/(T1*T2) )];
p1 = exp(ln_p1); //[kPa]
disp('Saturation pressure of the refrigerant R-134a
    at -50 C  =',p1,'kPa')
```

Chapter 14

Psychrometry

Scilab code Exa 14.1 `Determine amount of heat transferred and amount of steam adde`

```
//Example 14.1
//Determine amount of heat transferred and amount of
    steam added to air
clear
clc
Cp = 1.005; //[kJ/kg K]
R = 0.287; //[kJ/kg K]
h1 = 31.5; //[kJ/kg]
h2 = 37; //[kJ/kg]
T1 = 15; //[ C ]
T2 = 20; //[ C ]
ma = 1; //[kg/s]
//From the psychrometric chart in Figure EX 14.1
// 1  = 0.00653;//[kg vapor/kg dry air]
// 2  =  1 ;//[kg vapor/kg dry air]
// 3  = 0.01308; //[kg vapor/kg dry air]
pg1 = 1.757; //[kPa] p_sat of water at 15 C
pg3 = 3.1698; //[kPa] p_sat of water at 25 C
hg1= 2528.3; //[kJ/kg] Enthalpy of saturated water
```

```
Console

 "The amount of heat transferred to the air in the heating section = "
  5.1080506
 "kJ/s"
 "The amount of steam added to air = "
  0.0063710
 "kg/s"
```

Figure 14.1: Determine amount of heat transferred and amount of steam added to air

```
    vapor at 15 C
hg2 = 2541; //[kJ/kg] Enthalpy of saturated water
    vapor at 22 C
   = 0.60;
pw1 =   *pg1; //[kPa]
p1 = 101.325; //[kPa]
pa1 = p1 - pw1; //[kPa]
 1  = (0.622*pw1)/(p1 - pw1);
 2  =  1 ;
h1 = Cp*T1 +  1 *hg1; //  kJ/kg dry air
h2 = Cp*T2 +  2 *hg2; //  kJ/kg dry air
//(i) Determine amount of heat transferred to air in
     heating section
Q_in = ma*(h2 - h1); //[kJ/s]
disp('The amount of heat transferred to the air in
    the heating section = ',Q_in,'kJ/s')
//(ii) Determine amount of steam added to air
 3  = 0.65;
p3 = p1; //[kPa]
 3  = (0.622* 3 *pg3)/(p3 -  3 *pg3);
mw = ma*( 3  -  2 ); //[kg/s]
disp('The amount of steam added to air = ',mw,'kg/s'
    )
```

Scilab code Exa 14.2 Determine capacity of cooling and heating coil and amount of

```
// Example 14.2
// Determine capacity of cooling and heating coil
    and amount of water vapor removed
clear
clc
//From psychrometric chart in Figure Ex 14.2
h1 = 61; //kJ/kg of dry air
```

```
Console

 "Cooling coil capacity = "

  68.373245

 "Tonnes"

 "Capacity of heating coil = "

  80.924855

"kW"

 "Amount of water vapor removed = "

  0.0578035

 "kg/s"
```

Figure 14.2: Determine capacity of cooling and heating coil and amount of water vapor removed

```
h2 = 45; //kJ/kg of dry air
h3 = 38; //kJ/kg of dry air
h4 = 35; //kJ/kg of dry air
v1 = 0.865; // m^3/kg dry air
V = 10;//[m^3/s]
 1  = 0.014;//kg vapor/kg dry air
 2  = 0.009; //kg vapor/kg dry air
 3  =  2 ;
ma = V/v1; //[kg/s] Mass flow rate of air
//(i)
Cool_cap = ma*(h1 - h3); //[kJ/s] Cooling coil capacity
disp('Cooling coil capacity = ',(Cool_cap*3600)/14000,'Tonnes')
//(ii)
Heat_cap = ma*(h2 - h3); //[kW]  Capacity of heating coil
disp('Capacity of heating coil = ',Heat_cap,'kW')
//(iii)
W_removed = ma*( 1  -  3 ); //[kg/s] Amount of water vapor removed
disp('Amount of water vapor removed = ',W_removed,' kg/s')
```

Scilab code Exa 14.3 Estimate Partial pressure Specific humidity Enthalpy and Mass

```
//Example 14.3
// Estimate Partial pressure, Specific humidity, Enthalpy and Mass
clear
clc
T = 273 + 27; //[K]
Va = 100; //[m^3] Volume of dry air
```

```
Console

 "Partial pressure of dry air = "

  99.2718

 "kPa"

 "Specific humidity = "

  0.0128646

 "kg vapor/kg of dry air"

 "Enthalpy of dry air = "

  27.135000

 "kJ/kg"

 "Mass of dry air = "

  115.29826

 "kg"

 "Mass of water vapor = "

  1.4817060

 "kg"
```

Figure 14.3: Estimate Partial pressure Specific humidity Enthalpy and Mass

```
Vw = Va; //[m^3]  Volume of water vapor
p = 101.325; //[kPa]
  = 0.60; //Relative humidity
//From steam tables for water at 27 C
p_sat = 3.422; //[kPa]
hfg = 2551; //[kJ/kg]
//(i) Estimate partial pressure of dry air
pw =   *p_sat; //[kPa]
pa = p - pw; //[kPa]
disp('Partial pressure of dry air = ',pa,'kPa')
//(ii) Estimate specific humidity
  = 0.622*pw/(p - pw); //[kg vapor/kg of dry air] Specific humidity
disp('Specific humidity = ',  ,'kg vapor/kg of dry air')
//(iii) Estimate enthalpy of dry air
//Enthalpy of air-vapor mixture is Gh = Gha + m*hw or h = ha +   hw
ha = 1.005* 27; //[kJ/kg]
hw = hfg; //[kJ/kg]
h = ha +   *hw;//[kJ/kg] Enthalpy of air-vapor mixture
disp('Enthalpy of dry air = ',ha,'kJ/kg')
//(iv) Estimate mass of dry air and water vapor
Ra = 0.287;
ma = (pa*Va)/(Ra*T);//[kg] Mass of dry air
Rw = 0.4619;
mw = (pw*Vw)/(Rw*T); //[kg] Mass of water vapor
disp('Mass of dry air = ',ma,'kg')
disp('Mass of water vapor = ',mw,'kg')
```

Scilab code Exa 14.4 Using psychometric chart evaluate the following

```
//Example 14.4
//Using psychometric chart evaluate the following
```

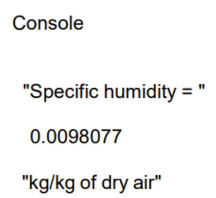


Figure 14.4: Determine the specific humidity

```

clear
clc

//The given example is theoretical and does not
   involve any numerical computation
//end
```

Scilab code Exa 14.5 Determine the specific humidity

```
//Example 14.5
//Determine the specific humidity
clear
clc
p = 101.32; //[kPa]
T1 = 273+20; //[K]
T2 = 273 + 25; //[K]
 1  = 0.25; // Relative humidity of 1st stream
 2  = 0.75; //Relative humidity of 2nd stream
ps1 = 2.339; //[kPa]
ps2 = 3.169; //[kPa]
pw1 =  1 *ps1; //[kPa]
 1  = (0.622*pw1)/(p - pw1);
pw2 =  2 *ps2; //[kPa]
 2  = (0.622*pw2)/(p - pw2);
v1 = 20; //[m^3/min]
v2 = 25; //[m^3/min]
Ra = 0.287;
pa1 = p - pw1;//[kPa]
pa2 = p - pw2; //[kPa]
ma1 = (pa1*v1)/(Ra*T1); //[kg/min]
ma2 = (pa2*v2)/(Ra*T2); //[kg/min]
 3  = ( 1 *ma1 +  2 *ma2)/(ma1 + ma2); //kg/kg of dry air
disp('Specific humidity = ', 3 ,'kg/kg of dry air')
```

Scilab code Exa 14.6 Calculate following question when air water vapor mixture is

```
//Example 14.6
//Calculate following question when air water vapor mixture is heated at constant pressure
```

```
Console

 "Initial specific humidity of mixture = "

  0.00625

 "kg/kg of dry air"

 "Final specific humidity of mixture = "

  0.0048

 "kg/kg of dry air"

 "Final relative humidity = "

  24.5

 "%"

 "Dew point temperature = "

  8.

 "°C"

 "Amount of heat transferred per kg of dry air = "

  15.400000

 "kJ/kg of dry air"

 "Amount of water vapor condensed = "

  0.0014500

 "kg/kg of dry air"
```

Figure 14.5: Calculate following question when air water vapor mixture is heated at constant pressure

```
clear
clc
//From psychrometric chart in Figure EX 14.6
 1 = 0.00625; // [kg/kg of dry air]    Initial specific humidity
 2 =  1 ; //kg/kg of dry air
 3 = 0.0048; // kg/kg of dry air
h1 = 32.6; //[kJ/kg of dry air]
h2 = 48; //[kJ/kg of dry air]
t_db = 8; //[ C ]   Dew point temperature
 2 = 24.5; //[%]  Final relative humidity
Q = h2 - h1; // [kJ/kg of dry air]      Heat transferred
m =  1  -  3 ; // [kg/kg of dry air]     Mass of vapor condensed
disp('Initial specific humidity of mixture = ', 1 ,' kg/kg of dry air')
disp('Final specific humidity of mixture = ', 3 ,'kg/kg of dry air')
disp('Final relative humidity = ', 2 ,'%')
disp('Dew point temperature = ',t_db,' C ')
disp('Amount of heat transferred per kg of dry air = ',Q,'kJ/kg of dry air')
disp('Amount of water vapor condensed = ',m,'kg/kg of dry air')
```

Scilab code Exa 14.7 Determine mass flow rate and heat removed

```
//Example 14.7
//Determine mass flow rate and heat removed
clear
clc
//From psychrometric chart in Figure Ex 14.7
```

```
Console

 "Mass flow rate of water vapor removed per hour = "

  0.7522124

 "kg/h"

 "Heat removed in the cooler per hour = "

  2925.2704

 "kJ/h"
```

Figure 14.6: Determine mass flow rate and heat removed

```
// At 27 C  and 65% relative humidity
h1 = 65; //kJ/kg of dry air
 1  = 0.017; //kg/kg of dry air
// At 23 C  and 45% relative humidity
ha = 30; // kJ/kg of dry air
 2  = 0.008; // kg/kg of dry air
m_aw = 85; //[kg/h] Mass flow rate of atmospheric air including moisture
m_a = m_aw/(1 +  1 ); //[kg/h] Mass flow rate of air
//(i) Determine mass flow rate of water vapor removed per hour
m_w = m_a*( 1  -  2 ); //[kg/h]  Mass flow rate of water vapor removed per hour
disp('Mass flow rate of water vapor removed per hour = ',m_w,'kg/h')
//(ii) Determine heat removed in cooler per hour
Q = m_a*(h1 - ha); //[kJ/h]
disp('Heat removed in the cooler per hour = ',Q,'kJ/h')
```