Scilab Textbook Companion for Basic And Applied Thermodynamics by P. K. Nag[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

Scilab code Exa 1.1 Calculation of gas pressure

```
clc
d_r = 13640 // Density of mercury in kg/m^3
g = 9.79 // Acceleration due to gravity in m/s^2
z = 562e-03 // Difference in height in m
z0 = 761e-03 // Reading of barometer in m
P = (d_r*g*(z+z0))*(0.987/1e05) // Gas Pressure in atm

printf("\n Example 1.1\n")
printf("\n Gas Pressure is %f atm",P)
//The answers vary due to round off error
```

Scilab code Exa 1.2 Calculation of pressure

```
clc
d_r = 13.6e03 // Density of mercury in kg/m^3
g = 9.81 // Acceleration due to gravity in m/s^2
```

```
z = 710e-03 // Steam flow pressure in m
z0 = 772e-03 // Reading of barometer in m
P = 1.4e06 // Gauge pressure of applied steam in Pa
P0 = d_r*g*z0 // Atmospheric pressure in Pa
Pi = P+P0  // Inlet steam pressure in Pa
Pc = d_r*g*(z0-z) // Condenser pressure in Pa

printf("\n Example 1.2\n")
printf("\n Inlet steam pressure is %f MPa",Pi/1e6)
printf("\n Condenser pressure is %f kPa",Pc/1e3)
//The answers vary due to round off error
```

Chapter 2

Temperature

Scilab code Exa 2.1 Calculation of temperature

```
clc
d = 1 // Assumption
l = 1 // Assumption
A_ACDB = (%pi/4)*(1/3)*((1.05*d)^2)*10.5*l - (%pi/4)
    *(1/3)*d^2*10*l  // Area of ABCD
A_AEFB = (%pi/4)*(1/3)*((1.1*d)^2)*11*l - (%pi/4)
    *(1/3)*d^2*10*l // Area of AEFB
t = 100*(A_ACDB/A_AEFB)
printf("\n Example 2.1")
printf("\n The straight bore thermometer reading
    will be  %f degree Celsius.",t)
//The answers vary due to round off error
```

Scilab code Exa 2.2 Calculation of temperature

```
clc
t = poly(0,'t')
```

```
e = (0.2*t)-(5e-04*t^2) // e.m.f. as a function of temperature in mV
e0 = horner(e, 0) // e.m.f. at t = 0 degree
e100 = horner(e, 100) // e.m.f. at t = 100 degree
e50 = horner(e, 50) // e.m.f. at t = 50 degree
r = (100/e100)*e50 // Reading of thermocouple at t = 50degree
printf("\n Example 2.2")
printf("\n Reading of thermocouple at t = 50 degree Celsius will be %f degree Celsius.",r)
//The answers vary due to round off error
```

Chapter 3

Work and heat transfer

Scilab code Exa 3.1 Calculation of work done

```
clc
dV = 0.5 // Change in volume in m^3
P = 101.325e03 // Atmospheric pressure in N/m^2
Wd = P*dV // Work done in J
printf("\n Example 3.1")
printf("\n The amount of work done upon the
    atmosphere by the balloon is %f kJ",Wd/1e3)
//The answers vary due to round off error
```

Scilab code Exa 3.2 Calculation of displacement work done

```
clc
dV = 0.6 // Volumetric change in m^3
P = 101.325e03 // Atmospheric pressure in N/m^2
Wd = P*dV // Work done in J
printf("\n Example 3.2")
```

```
printf("\n The displacement work done by the air is
   %f kJ",Wd/1e3)
//The answers vary due to round off error
```

Scilab code Exa 3.3 Calculation of net work transfer

```
clc
// Given that
T = 1.275 // Torque acting against the fluid in mN
N = 10000 // Number of revolutions
W1 = 2*%pi*T*1e-3*N // Work done by stirring device
   upon the system
P = 101.325e03 // Atmospheric pressure in kN/m^2
d = 0.6 // Piston diameter in m
A = (%pi/4)*(d)^2 // Piston area in m
L = 0.80 // Displacement of diameter in m
W2 = (P*A*L)/1000 // Work done by the system on the
   surroundings i KJ
W = -W1+W2 // net work transfer for the system

printf("\n Example 3.3")
printf("\n The net work transfer for the system is
   %f kJ",W)
//The answers vary due to round off error
```

Scilab code Exa 3.4 Calculation of rate of work transfer

```
clc
// Given that
```

```
ad = 5.5e-04 // Area of indicator diagram in m^2
ld = 0.06 // Length of diagram in m
k = 147 // Spring value in MPa/m
w = 150 // Speed of engine in revolution per minute
L = 1.2 // Stroke of piston in m
d = 0.8 // Diameter of the cylinder in m
A = (%pi/4)*(0.8^2) // Area of cylinder
Pm = (ad/ld)*k // Effective pressure in MPa
W1 = Pm*L*A*w // Work done in 1 minute MJ
W = (12*W1)/60 // The rate of work transfer gas to the piston in MJ/s

printf("\n Example 3.4")
printf("\n The rate of work transfer from gas to the piston is %d kW",W*1e3)
//The answers vary due to round off error
```

Scilab code Exa 3.5 Calculation of rating of furnace and diameter of furnace and length of furnace

```
clc
//Given that
m = 5 // mass flow rate in tones/h
Ti = 15 // Initial temperature in degree Celsius
tp = 1535 // Phase change temperature in degree Celsius
Tf = 1650 // Final temperature in degree Celsius
Lh = 270 // Latent heat of iron in kJ/Kg
ml = 29.93 // Specific heat of iron in liquid phase in kJ/Kg
ma = 56 // Atomic weight of iron
sh = 0.502 // Specific heat of iron in solid phase in kJ/Kg
```

```
d = 6900 // Density of molten metal in kg/m^3
n=0.7 // furnace efficiency
l_d_ratio = 2 // length to diameter ratio
printf("\n Example 3.5")
h1 = sh*(tp-Ti) // Heat required to raise
    temperature
h2 = Lh // Heat consumed in phase change
h3 = ml*(Tf-tp)/ma // Heat consumed in raising
    temperature of molten mass
h = h1+h2+h3 // Heat required per unit mass
Hi = h*m*1e3 // Ideal heat requirement
H = Hi/(n*3600) // Actual heat requirement
V = (3*m)/d // Volume required in m^3
d = (4*V/(%pi*l_d_ratio))^(1/3) // Diameter of
    furnace
l = d*l_d_ratio // Length of furnace
printf("\n Rating of furnace would be %f *1e3 kW",H
    /1e3)
printf("\n Diameter of furnace is %f m",d)
printf("\n Length of furnace is %f m",l)
//The answer provided in the textbook is wrong
```

Scilab code Exa 3.6 Calculation of melting rate and mass

```
clc
// Given that
SH = 0.9 // Specific heat of aluminium in solid
    state in kJ/kgK
L = 390 // Latent heat in kJ/kg
aw = 27 // Atomic weight
D = 2400 // Density in molten state in kg/m^3
Tf = 700 // Final temperature in degree Celsius
Tm = 660 // Melting point of aluminium in degree
```

```
Celsius
Ti = 15 // Initial temperature in degree Celsius
HR = SH*(Tm-Ti)+L+(29.93/27)*(Tf-Tm) // Heat requirement
HS = HR/0.7  // Heat supplied
RM = 2.17e3*3600/HS  // From the data of problem 3.7
V = 2.18 // Volume in m^3
M = V*D
printf("\n Example 3.6")
printf("\n Rate at which aluminium can be melted is %f tonnes/h",RM/1e3)
printf("\n Mass of aluminium that can be held in furnace is %f tonnes",M/1e3)
```

Chapter 4

First law of thermodynamics

Scilab code Exa 4.1 Calculation of decrease in internal energy of gas

```
clc
V1 = 0.3 // Initial volume in m^3
V2 = 0.15 // Final volume in m^3
P = 0.105 // Initial Pressure in MPa
Q = -37.6 // Heat transferred in kJ
W = P*(V2-V1)*1e6 // Work done
U = Q*1e3-W // Internal energy change
printf("\n Example 4.1")
printf("\n The internal energy of the gas decrease
   by %f kJ in the process.",abs(U)/1e3)
```

Scilab code Exa 4.2 Calculation of heat flow and heat liberated and heat absorbed

```
clc
Qacb = 84 // Heat transfer along the path acb in kJ
Wacb = 32 // Work done along the path acb in kJ
```

```
Uba = Qacb-Wacb // Ub-Ua
// Part (a)
Wadb = 10.5 // Work done along the path adb in kJ
Qadb = Uba+Wadb // Heat flow into the system along the path adb
printf("\n Example 4.2")
printf("\n The heat flow into the system along the path adb is %f kJ.",Qadb)


// Part (b)
Wb_a = -21 // work done along the path ba in kJ
Uab = - Uba // Change in internal energy along the path ab in kJ
Qb_a = Uab+Wb_a // Heat liberated along the path b-a
printf("\n The heat liberated along the path b-a is %d kJ.",Qb_a)

// Part (c)
Wdb = 0 // Constant volume
Wad = 10.5 // work done along the path ad in kJ
Wadb = Wdb-Wad // work done along the path adb in kJ
Ud = 42
Ua = 0
Qad = Ud-Ua+Wad // Heat flow into the system along the path ad in kJ
Qdb = Qadb-Qad  //Heat flow into the system along the path db in kJ
printf("\n The heat absorbed in the path ad and db are %f kJ nd %d kJ respectively.",Qad,Qdb)
```

Scilab code Exa 4.3 Calculation of net rate of work output

```
clc
// Process a-b
Qab = 0 // Heat transfer along the path ab in kJ/min
Wab = 2170 // Work transfer along the path ab in kJ/min
Eab = Qab-Wab // Change in internal energy along the path ab in kJ/min
// Process b-c
Qbc = 21000 // Heat transfer along the path bc in kJ/ min
Wbc = 0 // Work transfer along the path bc in kJ/min
Ebc = Qbc-Wbc // Change in internal energy along the path bc in kJ/min
// Process c-d
Qcd = -2100 // Heat transfer along the path cd in kJ/ min
Ecd = -36600  // Change in internal energy along the path cd in kJ/min
Wcd = Qcd-Ecd  // Work transfer along the path cd in kJ/min
// Process d-a
Q = -17000  // Total heat transfer in kJ/min
Qda = Q-Qab-Qbc-Qcd // Heat transfer along the path da in kJ/ min
Eda = -Eab-Ebc-Ecd  // Change in internal energy along the path da in kJ/min
Wda = Qda-Eda // Work transfer along the path da in kJ/min
printf("\n Example 4.3")

M = [Qab Wab Eab ; Qbc Wbc Ebc; Qcd Wcd Ecd; Qda Wda Eda];
disp(M,"The completed table is:")
W = Qab+Qbc+Qcd+Qda
printf("\n Net rate of work output is %f kW",W/60)
```

Scilab code Exa 4.4 Calculation of heat transfer and internal energy and work transfer

```
clc
// Part (a)
m = 3 // mass of substance in kg
V1 = 0.22 // Initial volume of system in m^3
P1 = 500 // Initial pressure of system in kPa
P2 = 100 // Final pressure of system in kPa
V2 = V1*(P1/P2)^(1/1.2) // Final volume of system
dU = 3.56*(P2*V2-P1*V1) // Change in internal energy of substance in kJ/kg
n = 1.2 // polytropic index
W = (P2*V2-P1*V1)/(1-n) // work done in process
Q = dU+W // Heat addition in process

printf("\n Example 4.4")
printf("\n Part A:")
printf("\n For the quasi static process is: \n ")
printf("Q:    %fkJ",Q)
printf("\n dU: %fkJ",dU)
printf("\n W: %fkJ",W)
//The provided in the textbook is wrong
// Part (b)
printf("\n\n Part B:")
Qb = 30 // heat transfer in kJ
Wb = Qb-dU // Work done in kJ
printf("\n Work transfer for the process is %fkJ.",Wb)
//The answers vary due to round off error
// Part (c)
printf("\n\n Part C:")
```

```
printf("\n Wb is not equal to integral(p*dv) since
    the process is not quasi static.")
```

Scilab code Exa 4.5 Calculation of work done by the system and heat flow rate into the system

```
clc
V1 = 0.03 // initial volume in m^3
P1 = 170 // Initial pressure in kPa
P2 = 400 // Final pressure in kPa
V2 = 0.06 // Final volume in m^3
U = 3.15*(P2*V2-P1*V1) // internal energy in kJ
B = [P1 P2]'
A = [1 V1 ; 1 V2]
x = inv(A)*B
a = x(1) ; b = x(2)
function P=pressure(V)
  P = a+b*V
endfunction
W = intg(V1,V2,pressure)
Q = U+W // heat flow into the system in kJ

printf("\n Example 4.5")
printf("\n The work done by the system is %f kJ",W)
printf("\n The heat flow into the system is %f kJ",Q
    )
```

Chapter 5

First law applied to flow process

Scilab code Exa 5.1 Calculation of rate of work input and ratio of the inlet pipe and outlet pipe diameter

```

clc
// Part(a)
V1 = 0.95 // Inlet volume flow rate in m^3/kg
P1 = 100 // Pressure at inlet in kPa
v1 = 7 // velocity of flow at inlet in m/s
V2 = 0.19 // Exit volume flow rate in m^3/kg
P2 = 700 // Pressure at exit in kPa
v2 = 5 // velocity of flow at exit in m/s
w = 0.5 // mass flow rate in kg/s
u21 = 90  // change in internal energy in kJ/kg
Q = -58  // Heat transfer in kW
W =  - w*( u21 + (P2*V2-P1*V1) + ((v2^2-v1^2)/2) ) +
    Q  // W = dW/dt
printf("\n Example 5.1")
printf("\n The rate of work input is %d kW",abs(W))
//The answers given in textbook is wrong
// Part (b)
```

```
A = (v2/v1)*(V1/V2)  // A = A1/A2
d_ratio = sqrt(A)  // d = d1/d2

printf("\n The ratio of the inlet pipe diameter and
    outlet pipe diameter is %f ",d_ratio)

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

Scilab code Exa 5.2 Calculation of decrease in internal energy

```
clc
V1 = 0.37 // volume flow rate at inlet in m^3/kg
P1 = 600// Inlet pressure in kPa
v1 = 16 // Inlet velocity of flow in m/s
V2 = 0.62 // volume flow rate at exit in m^3/kg
P2 = 100// Exit pressure in kPa
v2 = 270 // Exit velocity of flow in m/s
Z1 = 32 // Height of inlet port from datum in m
Z2 = 0 //Height of exit port from datum in m
g = 9.81  // Acceleration due to gravity
Q = -9  // Heat transfer in kJ/kg
W = 135  // Work transfer in kJ/kg
U12 = (P2*V2-P1*V1) + ((v2^2-v1^2)/2000) + (Z2-Z1)*g
    *1e-3 + W - Q  // Change in internal energy in kJ

printf("\n Example 5.2")
printf("\n The internal energy decreases by %f kJ",
    U12)
//The answers vary due to round off error
```

Scilab code Exa 5.3 Calculation of steam flow rate

```
clc
P1 = 4 // Boiler pressure in MPa
t1 = 400 // Exit temperature at boiler in degree Celsius
h1 = 3213 // Enthalpy at boiler exit in kJ/kg
V1 = 0.073 // specific volume at boiler exit in m^3/kg
P2 = 3.5 // Pressure at turbine end in MPa
t2 = 392 // Turbine exit temperature in degree Celsius
h2 = 3202 // Enthalpy at turbine exit in kJ/kg
V2 = 0.084 // specific volume at turbine exit in m^3/kg
Q = -8.5 // Heat loss from pipeline in kJ/kg
v1 = sqrt((2*(h1-h2+Q)*1e3)/(1.15^2-1)) // velocity of flow in m/s
A1 = (%pi/4)*0.2^2 // Area of pipe in m^2
w = (A1*v1)/V1 // steam flow rate in Kg/s

printf("\n Example 5.3")
printf("\n The steam flow rate is %f Kg/s",w)
//The answers vary due to round off error
```

Scilab code Exa 5.4 Calculation of heat supplied

```
clc
```

```
h1 = 313.93 // Enthalpy of water at heater inlet in kJ/kg
h2 = 2676 // Enthalpy of hot water at temperature 100.2 degree Celsius
h3 = 419 //Enthalpy of water at heater inlet in kJ/kg
w1 = 4.2 // mass flow rate in kg/s

printf("\n Example 5.4")
w2 = w1*(h3-h1)/(h2-h3)// Steam rate
printf("\n The amount of heat that should be supplied is %d Kg/h", w2*3600)

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

Scilab code Exa 5.5 Calculation of rete of heat transfer and power output from turbine and velocity at the exit of nozzle

```
clc
t1 = 15 // Heat exchanger inlet temperature in degree Celsius
t2 = 800 // Heat exchanger exit temperature in degree Celsius
t3 = 650 // Turbine exit temperature in degree Celsius
t4 = 500 // Nozzle exit temperature in degree Celsius
v1 = 30 // Velocity of steam at heat exchanger inlet in m/s
v2 = 30// Velocity of steam at turbine inlet in m/s
v3 = 60 // Velocity of steam at nozzle inlet in m/s
w = 2 // mass flow rate in kg/s
cp = 1005 // Specific heat capacity of air in kJ/kgK
```

```

printf("\n Example 5.5")
Q1_2 = w*cp*(t2-t1) // rate of heat transfer
printf("\n The rate of heat transfer to the air in the heat exchanger is %d kJ/s",Q1_2/1e3)

W_T = w*( ((v2^2-v3^2)/2) + cp*(t2-t3)) // power output from the turbine
printf("\n The power output from the turbine assuming no heat loss is %f kW",W_T/1000)
v4 = sqrt( (v3^2) + (2*cp*(t3-t4)) ) // velocity at the exit of the nozzle
printf("\n The velocity at the exit of the nozzle is %d m/s",v4)
//The answers vary due to round off error
```

Scilab code Exa 5.6 Calculation of velocity of exhaust gas

```
clc
ha = 260  // Enthalpy of air in kJ/kg
hg = 912  // Enthalpy of gas in kJ/kg
Va = 270  // Velocity of air in m/s
wf = 0.0190  // mass of fuel in Kg
wa = 1 // mass of air in Kg
Ef = 44500  // Chemical energy of fuel in kJ/kg
Q = 21  // Heat loss from the engine in kJ/kg

printf("\n Example 5.6")
Eg = 0.05*wf*Ef/(1+wf)  // As 5% of chemical energy is not released in reaction
wg = wa+wf // mass of flue gas
Vg = sqrt(2000*(((ha+(Va^2*0.001)/2+(wf*Ef)-Q)/(1+wf))-hg-Eg))
```

```
printf("\n Velocity of exhaust gas is %d m/s",Vg)
//Answer given in textbook is wrong
```

Scilab code Exa 5.8 Calculation of air flow rate

```
clc
// Given that
V = 0.12 // Volume of tank in m^3
p = 1 // Pressure in MPa
T = 150 // Temperature in degree centigrade
P = 0.1 // Power to peddle wheel in kW
printf("\n Example 5.8")
u0 = 0.718*273 // Internal energy at 0 degree
    Celsius
// Function for internal energy of gas
t=poly(0,"t")
u = u0+(0.718*t)
pv = 0.287*(273+t)
U=horner(u,T)
PV = horner(pv,T)
hp = U+PV // At 150 degree centigrade
m_a = P/hp
printf("\n The rate at which air flows out of the
    tank is %f kg/h",m_a*3600)
//The answers vary due to round off error
```

Chapter 6

Second law of thermodynamics

Scilab code Exa 6.1 Calculation of rate of heat rejection

```
clc
T1 = 800 // Source temperature in degree Celsius
T2 = 30 // Sink temperature in degree Celsius
e_max = 1-((T2+273)/(T1+273)) // maximum possible efficiency
Wnet = 1  // in kW
Q1 = Wnet/e_max // Least rate of heat required in kJ/s
Q2 = Q1-Wnet  // Least rate of heat rejection kJ/s

printf("\n Example 6.1")
printf("\n Least rate of heat rejection is %f kW",Q2)
//The answers vary due to round off error
```

Scilab code Exa 6.2 Calculation of power required to pump heat out

```
clc
T1 = -15 // Source temperature in degree Celsius
T2 = 30 // Sink temperature in degree Celsius
Q2 = 1.75  // in kJ/sec
printf("\n Example 6.2")
W= Q2*((T2+273)-(T1+273))/(T1+273) // Least Power
    necessary to pump the heat out
 printf("\n Least Power necessary to pump the heat
     out is %f kW",W)
//The answers vary due to round off error
```

Scilab code Exa 6.3 Calculation of heat transfer to refrigerant and heat rejection to the reservoir

```
clc
//Given
T1 = 600 // Source temperature of heat engine in
    degree Celsius
T2 = 40 // Sink temperature of heat engine in degree
     Celsius
T3 = -20 // Source temperature of refrigerator in
    degree Celsius
Q1 = 2000  // Heat transfer to heat engine in kJ
W = 360  // Net work output of plant in kJ
// Part (a)
e_max = 1-((T2+273)/(T1+273)) // maximum efficiency
W1 = e_max*Q1 // maximum work output
COP = (T3+273)/((T2-273)-(T3-273)) // coefficient of
     performance of refrigerator
W2 = W1-W // work done to drive refrigerator
Q4 = COP*W2 // Heat extracted by refrigerator
Q3 = Q4+W2 // Heat rejected by refrigerator
Q2 = Q1-W1 // Heat rejected by heat engine
```

```
Qt = Q2+Q3 // combined heat rejection by heat engine and refrigerator
printf("\n Example 6.3")
printf("\n\n Part A:")
printf("\n The heat transfer to refrigerant is %d kJ",Q2)
printf("\n The heat rejection to the 40 degree reservoir is %f kJ",Qt)

// Part (b)
printf("\n\n Part B:")
e_max_ = 0.4*e_max // maximum efficiency
W1_ = e_max_*Q1 // maximum work output
W2_ = W1_-W // work done to drive refrigerator
COP_ = 0.4*COP // coefficient of performance of refrigerator
Q4_ = COP_*W2_  // Heat extracted by refrigerator
Q3_ = Q4_+W2_ // Heat rejected by refrigerator
Q2_ = Q1-W1_ // Heat rejected by heat engine
QT = Q2_+Q3_// combined heat rejection by heat engine and refrigerator
printf("\n The heat transfer to refrigerant is %f kJ",Q2_)
printf("\n The heat rejection to the 40 degree reservoir is %f kJ",QT)
//The answers vary due to round off error
```

Scilab code Exa 6.5 Calculation of multiplication factor

```
clc
T1 = 473 // Boiler temperature in K
T2 = 293 // Home temperature in K
T3 = 273 // Outside temperature in K
```

```
printf("\n Example 6.5")
MF = (T2*(T1-T3))/(T1*(T2-T3))
printf("\n  The multiplication factor is %f ",MF)
//The answers vary due to round off error
```

Scilab code Exa 6.6 Calculation of area of collector plate

```
clc
T1 = 90 // Operating temperature of power plant in degree Celsius
T2 = 20 // Atmospheric temperature in degree Celsius
W = 1  // Power production from power plant in kW
E = 1880  // Capability of energy collection in kJ/m^2 h

printf("\n Example 6.6")
e_max = 1-((T2+273)/(T1+273))  // maximum efficiency
Qmin = W/e_max  // Minimum heat requirement per second
Qmin_ = Qmin*3600 // Minimum heat requirement per hour
Amin = Qmin_/E  // Minimum area requirement
printf("\n Minimum area required for the collector plate is %d m^2",ceil(Amin))
```

Scilab code Exa 6.7 Calculation of area of the panel

```
clc
T1 = 1000 // Temperature of hot reservoir in K
```

```
W = 1000 // Power requirement in kW
K = 5.67e-08 // constant
printf("\n Example 6.7")
Amin = (256*W)/(27*K*T1^4) // minimum area required
printf("\n Area of the panel %f m^2",Amin)
```

Chapter 7

Entropy

Scilab code Exa 7.1 Calculation of change in entropy

```
clc
T1 = 37 // Final water temperature in degree Celsius
T2 = 35// Initial water temperature in degree
    Celsius
m = 1  // Mass of water in kg
cv = 4.187 // Specific heat capacity of water in kJ/
    kgK
printf("\n Example 7.1")
S = m*cv*log((T1+273)/(T2+273))  // Change in
    entropy of the water
printf("\n Change in entropy of the water is %f kJ/K
    ",S)
//The answer provided in the textbook is wrong
```

Scilab code Exa 7.2 Calculation of change in entropy of universe

```
clc
// Part (a)
T1 = 273 // Initial temperature of water in Kelvin
T2 = 373 // Temperature of heat reservoir in Kelvin
m = 1 // Mass of water in kg
cv = 4.187 // Specific heat capacity of water

printf("\n Example 7.2")
Ss = m*cv*log(T2/T1) // entropy change of water
Q = m*cv*(T2-T1) // Heat transfer
Sr = -(Q/T2) // Entropy change of universe
S = Ss+Sr // Total entropy change

printf("\n The entropy change of the universe is %f kJ/K",S)

// Part (b)
T3 = 323 // Temperature of intermediate reservoir in K
Sw = m*cv*(log(T3/T1)+log(T2/T3)) // entropy change of water
Sr1 = -m*cv*(T3-T1)/T3 // Entropy change of universe
Sr2 = -m*cv*(T2-T3)/T2 // Entropy change of universe
Su = Sw+Sr1+Sr2 // Total entropy change
printf("\n The entropy change of the universe is %f kJ/K",Su)
//The answers vary due to round off error
```

Scilab code Exa 7.3 Calculation of entropy change and work required

```
clc
// Part (a)
m = 1 // Mass of ice in kg
```

```
T1 = -5 // Initial temperature of ice in degree
    Celsius
T2 = 20// Atmospheric temperature in degree Celsius
T0 = 0// Phase change temperature of ice in degree
    Celsius
cp = 2.093 // Specific heat capacity of ice in kJ/
    kgK
cv = 4.187 // Specific heat capacity of water in kJ/
    kgK
lf = 333.3 // Latent heat of fusion in kJ/kgK

printf("\n Example 7.3")
Q = m*cp*(T0-T1)+1*333.3+m*cv*(T2-T0) // Net heat
    transfer
Sa = -Q/(T2+273) // Entropy change of surrounding
Ss1 = m*cp*log((T0+273)/(T1+273)) // entropy change
    during
Ss2 = lf/(T0+273) // Entropy change during phase
    change
Ss3 = m*cv*log((T2+273)/(T0+273)) // entropy change
    of water
St = Ss1+Ss2+Ss3 // total entropy change of ice to
    convert into water at atmospheric temperature
Su = St+Sa // Net entropy change of universe
printf("\n The entropy change of the universe is %f
    kJ/K",Su)

//The answer provided in the textbook is wrong
// Part (b)
S = St  // Entropy change of system
Wmin = (T2+273)*(S)-Q // minimum work required
printf("\n The minimum work required is %f kJ",Wmin)
//The answers vary due to round off error
```

Scilab code Exa 7.5 Calculation of temperature

```
clear
clc
T = poly(0,'T'); // T = Tf
Tf_ = 700-2*T; // Tf_ = Tf'
// Bisection method to solve for the polynomial

printf("\n Example 7.5")


function [x] = Temperature(a,b,f)
  N = 100;
  eps = 1e-5;
  if((f(a)*f(b))>0) then
    error('no root possible f(a)*f(b)>0');
    abort;
  end;
  if(abs(f(a))<eps) then
    error('solution at a');
    abort;
  end
  if(abs(f(b))<eps) then
    error('solution at b');
    abort;
  end
  while(N>0)
    c = (a+b)/2
    if(abs(f(c))<eps) then
      x = c ;
      x;
      return;
    end;
    if((f(a)*f(c))<0 ) then
      b = c ;
    else
      a = c ;
    end
```

```
    N = N-1;
  end
  error('no convergence');
  abort;
endfunction
deff('[y]=p(T)',['y = 2*T^3-700*T^2+9000000 '])
T = Temperature(100,200,p);

Tf_ = horner(Tf_,T);
printf("\n The final temperature of the body C is %d
    K",Tf_)
//The answers vary due to round off error
```

Scilab code Exa 7.6 Calculation of maximum work recovered

```
clc
T1 = 200 // Initial temperature of system in K
T2 = 100 // Final temperature of system in K
A = 0.042 // Constant
Q1 = integrate('A*T^2','T',T1,T2)
S =  integrate('A*T^2/T','T',T1,T2)
W = poly(0,'W')
Z = (-Q1-W)/T2 + S  // Polynomial to be solved for W
// Bisection method to solve for the Work
function [x] =Work(a,b,f),
  N = 100
  eps = 1e-5
  if((f(a)*f(b))>0) then
    error('no root possible f(a)*f(b)>0')
    abort
  end
  if(abs(f(a))<eps) then
    error('solution at a')
```

```
    abort
  end
  if(abs(f(b))<eps) then
    error('solution at b')
    abort
  end
  while(N>0)
    c = (a+b)/2
    if(abs(f(c))<eps) then
      x = c
      x
      return
    end
    if((f(a)*f(c))<0 ) then
      b = c
    else
      a = c
    end
    N = N-1
  end
  error('no convergence')
  abort
endfunction
deff('[y]=p(W)',['y = 350-0.01*W'])
W =Work(34000,36000,p)
printf("\n Example 7.6")
printf("\n The maximum work that can be recovered is
    %dkJ", W/1000 )
```

Scilab code Exa 7.7 Calculation of change in enthalpy and internal energy and entropy and heat transfer and work transfer

```
clc
```

```
P1 = 0.5 // Initial pressure in MPa
V1 = 0.2  // Initial volume in m^3
V2 = 0.05 // Final volume in m^3
n = 1.3 // Polytropic index


printf("\n Example 7.7")
P2 = P1*(V1/V2)^n
function y = f(p)
  y = ((P1*V1^n)/p)^(1/n)
endfunction
H = integrate('f','p',P1,P2)  // H = H2−H1
U = H-(P2*V2-P1*V1)
W12 = -U
printf("\n Change in enthalpy is %f kJ",H*1e3)
printf("\n Change in internal energy is %f kJ",U*1000)
printf("\n The change in entropy and heat transfer are is %d kJ",0)
printf("\n The work transfer during the process is %f kJ",W12*1000)
//The answers vary due to round off error
```

Scilab code Exa 7.8 Calculation of entropy and direction of flow

```
clc
Pa = 130 // Pressure at station A in kPa
Pb = 100// Pressure at station B in kPa
Ta = 50 // Temperature at station A in degree Celsius
Tb = 13// Temperature at station B in degree Celsius
cp = 1.005  // Specific heat capacity of air in kJ/kgK
```

```

printf("\n Example 7.8")
Ss = integrate('cp/T','T',Ta,Tb)-integrate('0.287/p','p',Pa,Pb)
Ssur = 0
Su = Ss+Ssur
printf("\n Change in the entropy of the universe is %f kJ/Kg K",Su)
//The answers given in the book is wrong
printf("\n As the change in entropy of the universe in the process A-B is negative \n so the flow must be from B-A")
```

Scilab code Exa 7.9 Calculation of entropy generation

```
clc
T1 = 300  // Inlet temperature of air in K
T2 = 330  // Exit temperature of first air stream in K
T3 = 270 // Exit temperature of second air stream in K
P1 = 4  // Pressure of inlet air stream in bar
P2 =1   // Pressure of first exit air stream in bar
P3 =1  // Pressure of second exit air stream in bar
cp = 1.0005  // Specific heat capacity of air in kJ/kgK
R = 0.287 // Gas constant

printf("\n Example 7.9")
S21 = cp*log(T2/T1)-R*log(P2/P1)  // Entropy generation
S31 = cp*log(T3/T1)-R*log(P3/P1) // Entropy generation
```

```
Sgen = 1*S21 + 1*S31 // Total entropy generation
printf("\n The entropy generated during the process is %f kW/K",Sgen)
//The answers vary due to round off error

printf("\n As the entropy generated is positive so such device is possible")
```

Scilab code Exa 7.10 Calculation of rate of heat transfer and entropy and total entropy generation

```
clc
A = 5*7 // Area of wall in m^2
k = 0.71// Thermal conductivity in W/mK
L = 0.32 // Thickness of wall in m
Ti = 21 // Room temperature in degree Celsius
To = 6 // Surrounding temperature in degree Celsius
printf("\n Example 7.10")
Q = k*A*(Ti-To)/L  // Heat transfer
Sgen_wall = Q/(To+273) - Q/(Ti+273)  // Entropy generation in wall
printf("\n The rate of heat transfer through the wall is %f W",Q)
printf("\n The rate of entropy through the wall is %f W/K",Sgen_wall)
Tr = 27 // Inner surface temperature of wall in degree Celsius
Ts = 2 // Outer surface temperature of wall in degree Celsius
Sgen_total = Q/(Ts+273)-Q/(Tr+273) // Total entropy generation in process
printf("\n The rate of total entropy generation with this heat transfer process is %f W/K",Sgen_total
```

)

Chapter 8

Available energy Exergy and Irreversibility

Scilab code Exa 8.1 Calculation of fraction of energy lost due to irreversible heat transfe

```
clc
T0 = 35 // Heat rejection temperature in degree Celsius
T1 = 420 //  Vapor condensation temperature in degree Celsius
T1_ = 250 // water vapor temperature in degree Celsius
printf("\n Example 8.1")
f = ((T0+273)*((T1+273)-(T1_+273)))/((T1_+273)*((T1+273)-(T0+273)))// fraction of energy lost
printf("\n The fraction of energy that becomes unavailable due to irreversible heat transfer is %f ",f)
//The answers vary due to round off error
```

Scilab code Exa 8.2 Calculation of change in entropy and increase in unavailable energy

```

clc
lhw = 1858.5 // Latent heat of water in kJ/kg
Tew = 220 // Water evaporation temperature in degree
    Celsius

Tig = 1100 // Initial temperature of the gas in
   degree Celsius
Tfg = 550 // Final temperature of the gas in degree
   Celsius
T0 = 303 // Atmospheric temperature in degree
   Celsius
Tg2 = 823
Tg1 = 1373
printf("\n Example 8.2")
Sw = lhw/(Tew+273) // Entropy generation in water
Sg = integrate('3.38/T','T',Tg1,Tg2)
St = Sg+Sw
printf("\n Total change in entropy is %f kJ/K",St)

printf("\n Increase in unavailable energy is %d kJ",
   T0*St)
//The answers vary due to round off error
```

Scilab code Exa 8.3 Calculation of available energy

```
clc
Tw_ = 75 // Initial temperature of water in degree
    Celsius
Ts_ = 5 // Atmospheric temperature in degree Celsius
m = 40 // mass of water in kg
cp = 4.2 // Specific heat capacity of water in kJ/
    kgK
printf("\n Example 8.3")
Tw= Tw_+273 // Initial temperature of water in K
Ts = Ts_+273 // Atmospheric temperature in K
Q1 = m*cp*(Tw-Ts) // Heat transfer

W = integrate('m*cp*(1-(Ts/T))','T',Ts,Tw)
UE = Q1-W // Available energy
printf("\n Available energy is %d kJ",UE)
//The answers vary due to round off error
```

Scilab code Exa 8.4 Calculation of decrease in the available energy

```
clc
Ts_ = 15 // Ambient temperature in degree Celsius
Tw1_ = 95 // Temperature of water sample 1 in degree
     Celsius
Tw2_ = 35// Temperature of water sample 2 in degree
    Celsius
m1 = 25 // Mass of water sample 1 in kg
m2 = 35 // Mass of water sample 2 in kg
cp = 4.2 // Specific heat capacity of water in kJ/
    kgK
printf("\n Example 8.4")
Ts = Ts_+273// Ambient temperature in K
Tw1 = Tw1_+273 // Temperature of water sample 1 in K
Tw2 = Tw2_+273// Temperature of water sample 2 in K
```

```
AE25 = integrate('m1*cp*(1-(Ts/T))','T',Ts,Tw1)
AE35 = integrate('m2*cp*(1-(Ts/T))','T',Ts,Tw2)
AEt = AE25 + AE35
Tm = (m1*Tw1+m2*Tw2)/(m1+m2) // Temperature after mixing
AE60 = integrate('(m1+m2)*cp*(1-(Ts/T))','T',Ts,Tm)
AE = AEt - AE60
printf("\n The decrease in the available energy is %f kJ",AE)
```

Scilab code Exa 8.5 Calculation of final rpm of flywheel

```
clc
N1 = 3000 // Speed of rotation of flywheel in RPM
I = 0.54 // Moment of inertia of flywheel in kgm^2
ti_ = 15 // Temperature of insulated system in degree Celsius
m = 2 // Water equivalent of shaft
printf("\n Example 8.5")
w1 = (2*%pi*N1)/60 // Angular velocity of rotation in rad/s
Ei = 0.5*I*w1^2 // rotational kinetic energy
dt = Ei/(1000*2*4.187) // temperature change
ti = ti_+273// Temperature of insulated system in Kelvin
tf = ti+dt // final temperature
AE = integrate('m*4.187*(1-(ti/T))','T',ti,tf)
UE = Ei/1000 - AE // Unavailable enrgy
w2 = sqrt(AE*1000*2/I) // Angular speed in rad/s
N2 = (w2*60)/(2*%pi) // Speed of rotation in RPM
printf("\n The final RPM of the flywheel would be %d RPM",N2)
```

Scilab code Exa 8.6 Calculation of maximum work and change in availability and irreversibility

```
clc
T1_ = 80 // Initial temperature of air in degree Celsius
T2_ = 5 // Final temperature of air in degree Celsius
V2 = 2 // Assumed final volume
V1 = 1 // Assumed initial volume
P0 = 100 // Final pressure of air in kPa
P1 = 500 // Initial pressure of air in kPa
R = 0.287 // Gas constant
cv = 0.718 // Specific heat capacity at constant volume for gas in kJ/kg K
m = 2 // Mass of gas in kg
printf("\n Example 8.6")
T1= T1_+273 // Initial temperature of air in K
T2 = T2_+273 // Final temperature of air in K
S = integrate('(m*cv)/T','T',T1,T2) + integrate('(m*R)/V','V',V1,V2) // Entropy change
U = m*cv*(T1-T2)// Change in internal energy
Wmax = U-(T2*(-S)) // Maximum possible work
V1_ = (m*R*T1)/P1 // volume calculation
CA = Wmax-P0*(V1_) // Change in availability
I = T2*S // Irreversibility
printf("\n The maximum work is %f kJ",Wmax)
printf("\n Change in availability is %f kJ",CA)
printf("\n Irreversibility is %f kJ",I)
//The answers vary due to round off error
```

Scilab code Exa 8.7 Calculation of decrease in availability and maximum work and irreversibility

```
clc
P1 = 500 // Initial pressure of steam in kPa
P2 = 100// Final pressure of steam in kPa
T1_ = 520 //Initial temperature of steam in degree Celsius
T2_ = 300 //Final temperature of steam in degree Celsius
cp = 1.005 // Specific heat capacity of steam in kJ/kgK
t0 = 20 // Atmospheric temperature in degree Celsius
R = 0.287 // Gas constant
Q = -10 // Heat loss to surrounding in kJ/kg
printf("\n Example 8.7")
T1 = T1_+273 //Initial temperature of steam in degree Celsius
T2 = T2_+273 //Final temperature of steam in degree Celsius
S21 = (R*log(P2/P1))-(cp*log(T2/T1))
T0 = t0+273
CA = cp*(T1-T2)-T0*S21 // Change in availability
Wmax = CA // Maximum possible work
W = cp*(T1-T2)+Q // net work
I = Wmax-W // Irreversibility
// Altenatively
Ssystem = -Q/T0
Ssurr = -S21
I1 = T0*(Ssystem+Ssurr)
printf("\n The decrease in availability is %f kJ/kg",CA)
```

```
printf("\n The maximum work is %f kJ/kg",Wmax)
printf("\n The irreversibility is %f kJ/kg",I)
printf("\n Alternatively , The irreversibility is %f kJ/kg",I1)
```

Scilab code Exa 8.8 Calculation of availability and irreversibility and total power generated

```

clc
T0 = 300 // Atmospheric temperature in K
Tg1_ = 300 // Higher temperature of combustion product in degree Celcius
Tg2_ = 200 // Lower temperature of combustion product in degree Celcius
Ta1 = 40 // Initial air temperature in K
cpg = 1.09 // Specific heat capacity of combustion gas in kJ/kgK
cpa = 1.005// Specific heat capacity of air in kJ/kgK
mg = 12.5 // mass flow rate of product in kg/s
ma = 11.15// mass flow rate of air in kg/s

printf("\n Example 8.8")
Tg1 = Tg1_+273 // Higher temperature of combustion product in K
Tg2 = Tg2_+273 // Lower temperature of combustion product in K
f1 = cpg*(Tg1-T0)-T0*cpg*(log(Tg1/T0)) // Initial availability of product
f2 = cpg*(Tg2-T0)-T0*cpg*(log(Tg2/T0)) // Final availability of product
printf("\n The initial and final availability of the
```

```
products are %f kJ/Kg and %f kJ/Kg respectively",f1,f2)
//The answer provided in the textbook is wrong

// Part (b)
Dfg = f1-f2 // Decrease in availability of products
Ta2 = (Ta1+273) + (mg/ma)*(cpg/cpa)*(Tg1-Tg2) // Exit temperature of air
Ifa = cpa*(Ta2-(Ta1+273))-T0*cpa*(log(Ta2/(Ta1+273))) // Increase in availability of air
I = mg*Dfg-ma*Ifa // Irreversibility
printf("\n The irreversibility of the process is %f kW",I)
////The answer provided in the textbook contains round off error

// Part (c)
Ta2_ = (Ta1+273)*(Tg1/Tg2)^((12.5*1.09)/(11.5*1.005))
Q1 = mg*cpg*(Tg1-Tg2) // Heat supply rate from gas to working fluid
Q2 = ma*cpa*(Ta2_-(Ta1+273))// Heat rejection rate from the working fluid in heat engine
W = Q1-Q2 // Power developed by heat engine
printf("\n Total power generated by the heat engine is %f kW",W)
//The answer provided in the textbook contains round off error
```

Scilab code Exa 8.9 Calculation of irreversibility rate

```
clc
T2 = 790 // Final temperature of gas in degree
```

```
Celsius
T1 = 800 // Initial temperature of gas in degree Celsius
m = 2 // Mass flow rate in kg/s
cp = 1.1 // Specific heat capacity in kJ/KgK
T0 = 300 // Ambient temperature in K

printf("\n Example 8.9")
I = m*cp*(((T1+273)-(T2+273))-T0*(log((T1+273)/(T2+273)))) // irreversibility rate
printf("\n The irreversibility rate is %f kW",I)

// At lower temperature
T1_ = 80 // Initial temperature of gas in degree Celsius
T2_ = 70 // Initial temperature of gas in degree Celsius
I_ = m*cp*(((T1_+273)-(T2_+273))-T0*(log((T1_+273)/(T2_+273)))) // irreversibility rate
printf("\n The irreversibility rate at lower temperature is %f kW",I_)
//The answers vary due to round off error
```

Scilab code Exa 8.10 Calculation of rate of energy loss

```
clc
m = 3 // Mass flow rate in kg/s
R = 0.287 // Gas constant
T0 = 300 // Ambient temperature in K
k = 0.10 // Fractional pressure drop
printf("\n Example 8.10")
Sgen = m*R*k // Entropy generation
I = Sgen*T0 // Irreversibility Calculation
```

```
printf("\n The rate of energy loss because of the
   pressure drop due to friction %f kW",I)
```

Scilab code Exa 8.11 Calculation of rate of entropy generation and rate of energy loss due to mixing

```
clc
m1 = 2 // Flow rate of water in kg/s
m2 = 1 // Flow rate of another stream in kg/s
T1 = 90 // Temperature of water in degree Celsius
T2 = 30// Temperature of another stream in degree
   Celsius
T0 =300 // Ambient temperature in K
cp = 4.187 // Specific heat capacity of water in kJ/
   kgK

printf("\n Example 8.11")
m = m1+m2 // Net mass flow rate
x = m1/m // mass fraction
t = (T2+273)/(T1+273) // Temperature ratio
Sgen = m*cp*log((x+t*(1-x))/(t^(1-x))) // Entropy
   generation
I = T0*Sgen // Irreversibility production
// Alternatively
T  = (m1*T1+m2*T2)/(m1+m2) // equilibrium
   temperature
Sgen1 = m1*cp*log((T+273)/(T1+273))+m2*cp*log((T
   +273)/(T2+273))// Entropy generation
I1 = T0*Sgen1 // Irreversibility production
printf("\n The rate of entropy generation is %f kW/K
   ",Sgen)
printf("\n The rate of energy loss due to mixing is
   %f kW",I)
```

```
printf("\n The rate of energy loss due to mixing is %f kW",I1) // Calculation from alternative way
//The answers vary due to round off error
```

Scilab code Exa 8.12 Calculation of first law and second law efficiency

```
clc
Qr = 500 // Heat release in kW
Tr = 2000 // Fuel burning temperature in K
T0 = 300 // Ambient temperature in K
// Part (a)
printf("\n Example 8.12")
Qa = 480 // Energy absorption by furnace in kW
Ta = 1000 // Furnace temperature in K
n1a = (Qa/Qr) // first law efficiency
n2a = n1a*(1-(T0/Ta))/(1-(T0/Tr)) //second law efficiency

//The answers vary due to round off error
printf(" \n\n PART (A)")
printf("\n The first law efficiency is %d percent" , n1a*100)
printf("\n The second law efficiency is %d percent", n2a*100)

// Part (b)
Qb = 450 // Energy absorption in steam generation in kW
Tb = 500// steam generation temperature in K
n1b = (Qb/Qr)// first law efficiency
n2b = n1b*(1-(T0/Tb))/(1-(T0/Tr))//second law efficiency
printf(" \n\n PART (B)")
```

```
printf("\n The first law efficiency is %d percent" ,n1b*100)
printf("\n The second law efficiency is %f percent",n2b*100)
// Part (c)
Qc = 300 // Energy absorption in chemical process in kW
Tc = 320 // chemical process temperature in K
n1c = (Qc/Qr) // first law efficiency
n2c = n1c*(1-(T0/Tc))/(1-(T0/Tr))//second law efficiency
printf(" \n\n PART (C)")
printf("\n The first law efficiency is %d percent",n1c*100)
printf("\n The second law efficiency is %f  percent",n2c*100)
// Part (d)
Qd = 450
n1d = (Qd/Qr)
n2a_= n1d*(1-(T0/Ta))/(1-(T0/Tr))
n2b_= n1d*(1-(T0/Tb))/(1-(T0/Tr))
n2c_= n1d*(1-(T0/Tc))/(1-(T0/Tr))
printf(" \n\n PART (D)")
printf("\n The First law efficiency for all the three cases would remain same and here is %d percent",n1d*100) //The answer provided in the textbook is wrong

printf("\n The Second law efficiency of part (a) is %f percent",n2a_*100)

printf("\n The Second law efficiency of part (b) is %f percent",n2b_*100)

printf("\n The Second law efficiency of part (c) is %f percent",n2c_*100)
```

Scilab code Exa 8.14 Calculation of power input and second law efficiency

```
clc
cp = 1.005 // Specific heat capacity of air in kJ/
    kgK
T2 = 160 // Compressed air temperature in degree
    Celsius
T1 = 25 // Ambient temperature
T0 = 25 // Ambient temperature
R = 0.287 // Gas constant
P2 = 8 // Pressure ratio
P1 = 1 // Initial pressure of gas in bar
Q = -100 // Heat loss to surrounding in kW
m = 1 // Mass flow rate in kg/s

printf("\n Example 8.14")
W = Q + m*cp*((T1+273)-(T2+273)) // power input
AF = cp*((T2+273)- (T1+273))-(T0+273)*((cp*log((T2
    +273)/(T1+273))-(R*log(P2/P1)))  // Availability
e = AF/-W // efficiency
printf("\n The power input is %f kW",W)
printf(" \n The second law efficiency of the
    compressor is %f percent",e*100)
//The answers vary due to round off error
```

Scilab code Exa 8.15 Calculation of exergy

```
clc
```

```
// Since vacuum has zero mass
U = 0 // Initial internal energy in kJ/kg
H0 = 0 // Initial enthalpy in kJ/kg
S = 0 // Initial entropy in kJ/kgK
// If the vacuum has reduced to dead state
U0 = 0 // Final internal energy in kJ/kg
H0 = 0  // Final enthalpy in kJ/kg
S0 = 0 // Final entropy in kJ/kgK
V0 = 0 // Final volume in m^3
P0 = 1 // Pressure in bar
V = 1 // Volume of space in m^3
fi = P0*1e5*V

printf("\n Example 8.15")
printf("\n The exergy of the complete vacuum is %d kJ",fi/1e3)
```

Scilab code Exa 8.16 Calculation of exergy

```
clc
m = 1000 // Mass of fish in kg
T0 = 300 // Ambient temperature in K
P0 = 1 // Ambient pressure in bar
T1 = 300 // Initial temperature of fish in K
T2_ = -20 // Final temperature of fish in degree Celsius
Tf_ = -2.2 // Freezing point temperature of fish in degree Celsius
Cb = 1.7 // Specific heat of fish below freezing point in kJ/kg
Ca = 3.2 // Specific heat of fish above freezing point in kJ/kg
Lh = 235 // Latent heat of fusion of fish in kJ/kg
```

```
printf("\n Example 8.16")
T2 = T2_+273 // Final temperature of fish in K
Tf = Tf_+273 // Freezing point temperature of fish in K
H12 = m*((Cb*(Tf-T2))+Lh+(Ca*(T1-Tf))) // Enthalpy change
H21 = -H12 // Enthalpy change
S12 = m*((Cb*log(Tf/T2))+(Lh/Tf)+(Ca*log(T1/Tf))) // Entropy change
S21 = -S12 // Entropy change
E = H21-T0*S21 //Exergy produced
printf("\n Exergy produced is %f MJ or %f kWh",E/1e3,E/3600)
//The answers vary due to round off error
```

Scilab code Exa 8.17 Calculation of irreversibility

```
clc
cv = 0.718 // Specific heat capacity of air in kJ/kg
T2 = 500 // Final temperature of air in K
T1 = 300// Initial temperature of air in K
m = 1 // Mass of air in kg
T0 = 300 // Ambient temperature
// Case (a)
printf("\n Example 8.17")
Sua = cv*log(T2/T1) // Entropy change of universe
Ia = T0*Sua // irreversibility
printf("\n The irreversibility in case a is %f kJ/kg",Ia)

// Case (b)
Q = m*cv*(T2-T1) // Heat transfer
```

```
T = 600 // Temperature of thermal reservoir in K
Sub = Sua-(Q/T) // Entropy change of universe
Ib = T0*Sub // irreversibility
printf("\n The irreversibility in case b is %f kJ/kg",Ib)
//The answers vary due to round off error
```

Scilab code Exa 8.18 Calculation of irreversibility per unit mass and second law efficiency of turbine

```
clc
h1 = 3230.9 // Enthalpy of steam at turbine inlet in kJ/kg
s1 = 6.69212// Entropy of steam at turbine inlet in kJ/kgK
V1 = 160 // Velocity of steam at turbine inlet in m/s
T1 = 400 // Temperature of steam at turbine inlet in degree Celsius
h2 = 2676.1 // Enthalpy of steam at turbine exit in kJ/kg
s2 = 7.3549 // Entropy of steam at turbine exit in kJ/kgK
V2 = 100 // Velocity of steam at turbine exit in m/s
T2 = 100 // Temperature of steam at turbine exit in degree Celsius
T0 = 298 // Ambient temperature in K
W = 540 // Work developed by turbine in kW
Tb = 500 // Average outer surface temperature of turbine in K

printf("\n Example 8.18")
Q = (h1-h2)+((V1^2-V2^2)/2)*1e-03-W // Heat loss
```

```
I = 151.84-Q*(0.404) // Irreversibility
AF = W + Q*(1-(T0/Tb)) + I // Exergy transfer
n2 = W/AF // second law efficiency

printf("\n Irreversibility per unit mass is %f kJ/kg
    ",I)
printf("\n The second law efficiency of the turbine
    is %d percent",n2*100)
```

Scilab code Exa 8.19 Calculation of rate of availability transfer with heat

```
clc
T0 = 300 // Ambient temperature in K
T = 1500 // Resistor temperature in K
Q = -8.5 // Power supply in kW

// Case (a)
W = -Q // work transfer
I = Q*(1-T0/T) + W // Irreversibility
R = Q*(1-T0/T) // availability

printf("\n Example 8.19")
printf("\n Case A:")
printf("\n Rate of availability transfer with heat
    and the irreversibility rate are \n  %f kW and %f
     kW respectively.",I,R)
// Case (b)
T1 = 500 // Furnace wall temperature
Ib = - Q*(1-T0/T) + Q*(1-T0/T1) // Irreversibility
printf("\n Case B:")
printf("\n Rate of availability in case b is %f kW "
    ,Ib)
```

Scilab code Exa 8.20 Calculation of heat loss and polytropic index and isothermal efficiency and minimum work input and second law efficiency

```
clc
p1 = 1 // Air pressure at compressure inlet in bar
t1 = 30 // Air temperature at compressure inlet in degree Celsius
p2 = 3.5 // Air pressure at compressure exit in bar
t2 = 141 // Air temperature at compressure exit in degree Celsius
v = 90 // Air velocity at compressure exit in m/s
cp = 1.0035 // Specific heat capacity of air in kJ/kg
y = 1.4 // Heat capacity ratio
R = 0.287 // Gas constant
printf("\n Example 8.20\n")
T2s = (t1+273)*(p2/p1)^((y-1)/y)
if T2s>(t2+273) then
    printf("\n Part A:")
    printf("\n There is heat loss to surrounding.")
end
n =(1/(1-((log((t2+273)/(t1+273)))/(log(p2/p1)))))
printf("\n\n Part B:")
printf("\n The polytropic index is %f ",n)
Wa = cp*(t1-t2)-(v^2)/2000 // Actual work
Wt = -R*(t1+273)*log(p2/p1) - (v^2)/2000 // Isothermal work
nt =Wt/Wa // Isothermal efficency
printf("\n\n Part C:")
printf("\n Isothermal efficiency is %f percent ",nt*100)
df = cp*(t1-t2) + (t1+273)*(R*log(p2/p1) - cp*log((
```

```
   t2+273)/(t1+273))) -(v^2)/2000
Wm = df // Minimum work input
I = Wm-Wa // Irreversibility

printf("\n\n Part D:")
printf("\n The minimum work input is %f kJ/kg, and
   irreversibility is %f kJ/kg",Wm,I)
// The answers given in the book contain round off
   error

neta = Wm/Wa
printf("\n\n Part E:")
printf("\n Second law efficiency is %d percent",ceil
   (neta*100))
```

Chapter 9

Properties of pure substances

Scilab code Exa 9.1 Calculation of equilibrium pressure and heat transferred and final temperature

```
clc
// At 1 MPa
tsat = 179.91 // Saturation temperature in degree
   Celsius
vf = 0.001127 // Specific volume of fluid in m^3/kg
vg = 0.19444 // Specific volume of gas in m^3/kg
sf = 2.1387 // Specific entropy of fluid in kJ/kgK
sg = 6.5865// Specific entropy of gas in kJ/kgK
printf("\n Example 9.1")
vfg = vg-vf // Change in specific volume due to
   evaporation
sfg = sg-sf// Change in specific entropy due to
   evaporation
hfg = 2015.3
printf("\n At 1 MPa, \n saturation temperature is %f
    degree celcius",tsat)
printf("\n Changes in specific volume is %f m^3/kg",
   vfg)
printf("\n Change in entropy during evaporation is
   %f kJ/kg K",sfg)
```

```
printf("\n The latent heat of vaporization is %f kJ/
    kg",hfg)
// Data is given in the table A.1(b) in Appendix in
    the book
```

Scilab code Exa 9.2 Calculation of gas constant and molecular weight and work done and change in internal energy

```
clc
// Given that
s = 6.76 // Entropy of saturated steam in kJ/kgK
printf("\n Example 9.2")
// From the table A.1(b) given in the book at s=
    6.76 kJ/kgK
p = 0.6
t=158.85
v_g=0.3156
h_g=2756.8
printf("\n pressure = %f Mpa\n Temperature = %f
    degree centigrade\n Specific volume = %f m^3/kg\n
     enthalpy = %f kJ/kg",p,t,v_g,h_g)
```

Scilab code Exa 9.3 Calculation of work done in expansion

```
clc
v = 0.09  // Specific volume of substance at a point
     in m^3/kg
vf = 0.001177 // Specific volume of fluid in m^3/kg
vg = 0.09963  // Specific volume of gas in m^3/kg
```

```
hf = 908.79 // Specific enthalpy of fluid in kJ/kg
hfg = 1890.7 // Latent heat of substance in kJ/kg
sf = 2.4474 // Specific entropy of fluid in kJ/kgK
sfg = 3.8935 // Entropy change due to vaporization

printf("\n Example 9.3")
x = (v-vf)/(vg-vf) // steam quality
h = hf+(x*hfg) // Specific enthalpy of substance at a point in kJ/kg
s = sf+(x*sfg) // Specific entropy of substance at a point in kJ/kgK

printf("\n The enthalpy and entropy of the system are\n %f kW and %f kJ/kg and kJ/kg K respectively.",h,s)
//The answers vary due to round off error
```

Scilab code Exa 9.4 Calculation of enthalpy and entropy and volume

```
clc
// for T = 350 degree
T1 = 350 // Temperature in degree Celsius
v1 = 0.2003 // specific volume in m^3/kg
h1 = 3149.5 // Specific enthalpy in kJ/kgK
s1 = 7.1369 // Entropy in kJ/kgK
// for T = 400 degree
T2 = 400 // Temperature in degree Celsius
v2 = 0.2178 // specific volume in m^3/kg
h2 = 3257.5 // Specific enthalpy in kJ/kgK
s2 = 7.3026// Entropy in kJ/kgK
// Interpolation for T = 380

printf("\n Example 9.4")
```

```
T = [T1 T2]
v = [v1 v2]
h = [h1 h2]
s = [s1 s2]
v3 = interpln([T;v],380)
h3 = interpln([T;h],380)
s3 = interpln([T;s],380)

printf("\n The entropy, enthalpy and volume of steam at 1.4MPa and 380 degree are \n %f kJ/kg K, %fkJ/kg, %fm3/kg respectively",s3,h3,v3)
//The answers vary due to round off error
```

Scilab code Exa 9.5 Calculation of work transfer and heat transfer

```
clc
Psat = 3.973 // Saturation pressure in MPa
vf = 0.0012512 // specific volume of fluid in m^3/kg
vg = 0.05013 // Specific volume of gas in m^3/kg
hf = 1085.36  // Specific enthalpy of fluid in kJ/kg
hfg = 1716.2 // Latent heat of vaporization in kJ/kg
sf = 2.7927 // Specific entropy of fluid in kJ/kgK
sfg = 3.2802 // Entropy change due to vaporization in kJ/kgK
mf = 9 // Mass of liquid in kg
V = 0.04 // Volume of vessel in m^3
// at T = 250
uf = 1080.39 //Specific internal energy in kJ/kg
ufg = 1522// Change in internal energy due to vaporization in kJ/kg

printf("\n Example 9.5")
Vf = mf*vf // volume of fluid
```

```
Vg = V-Vf // volume of gas
mg = Vg/vg // mass of gas
m = mf+mg // mass if mixture
x = mg/m // quality of steam
v = vf+x*(vg-vf) // specific volume of mixture
h = hf+x*hfg // enthalpy of mixture
s = sf+(x*sfg) // entropy of mixture
u = h-Psat*1e6*v*1e-03 // Internal energy of mixture
u_ = uf+x*ufg // Internal energy at 250 degree Celsius
printf("\n The pressure is %f MPa",Psat)
printf("\n The total mass of mixture is %f kg",m)
printf("\n Specific volume is %f m3/kg",v)
printf("\n Enthalpy is is %f kJ/kg",h)
printf("\n The entropy is %f kJ/kg K",s)
printf("\n The internal energy is %f kJ/kg",u)
printf("\n At 250 degree Celsius, internal energy is %fkJ/kg",u_) //The answer provided in the textbook is wrong

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

Scilab code Exa 9.6 Calculation of heat received and heat rejected and efficiency of cycle

```
clc
// Part (a)
vg1_ = 0.8919
T1 = 120
vg2_ = 0.77076
T2 = 125
vg_ = [vg1_ vg2_]
T_ = [T1 T2]
```

```
v1 = 0.7964
h1 = 2967.6
P1 = 0.3e03 // in Kpa
printf("\n Example 9.6\n\n")
T1 = interpln([vg_;T_],v1)
printf("Steam will become saturated vapour at %f
   degree centigrade",T1)
// Part (b)
vf = 0.001029
vg = 3.407
hf = 334.91
hfg = 2308.8
Psat = 47.39 // In kPa
v2 = v1
x2 = (v1-vf)/(vg-vf)
h2 = hf+x2*hfg
P2 = Psat
Q12 = (h2-h1)+v1*(P1-P2)
disp(x2,"The quality factor at t=80 degree is")
disp("kJ/kg",Q12,"The heat transfered per kg of
   steam in cooling from 250 degree to 80 degree")
```

Scilab code Exa 9.7 Calculation of heat capacities of gas and increase in entropy

```
clc
// At T = 40 degree
Psat = 7.384 // Saturation pressure in kPa
sf = 0.5725 // Entropy of fluid in kJ/kgK
sfg = 7.6845 // Entropy change due to vaporization
   in kJ/kgK
hf = 167.57 // Enthalpy of fluid in kJ/kg
hfg = 2406.7 // Latent heat of vaporization in kJ/kg
```

```
s1 = 6.9189 // Entropy at turbine inlet in kJ/kgK
h1 = 3037.6 // Enthalpy at turbine inlet in kJ/kg
printf("\n Example 9.7")
x2 = (s1-sf)/sfg // Steam quality
h2 = hf+(x2*hfg) // Enthalpy at turbine exit
W = h1-h2 // Net work done
printf("\n The ideal work output of the turbine is %f kJ/Kg",W)
//The answers vary due to round off error
```

Scilab code Exa 9.8 Calculation of mole fraction and equivalent molecular weight and equivalent gas constant and partial pressure and total volume of mixture and heat capacities of mixture and change in internal energy and enthalpy and entropy

```
clc
w3 = 2.3 // net flow rate in kg/s
w1 = 1.0 // flow rate from stream 1 in m/s
h1 = 2950.0 // Enthalpy of stream 1
p = 0.8 // Pressure in MPa
// At 0.8MPa, 0.95 dry
x = 0.95 // Quality fraction
hf = 721.11 // Enthalpy of fluid in kJ/kg
hfg = 2048 // Latent heat of vaporization in kJ/kg
s3 = 6.7087  // entropy at turbine inlet in kJ/kgK


printf("\n Example 9.8")
w2 = w3-w1 // flow rate from second stream
h2 = hf + (x*hfg) // enthalpy of stream 2
h3 = ((w1*h1)+(w2*h2))/w3 // enthalpy of mixed stream
// Interpolation
```

```
H = [2769.1 2839.3]
T = [170.43 200]
t3 = interpln([H;T],2790)

s4 = s3
x4 = (s3-1.7766)/5.1193
h4 = 604.74+(x4*2133.8)
V4 = sqrt(2000*(h3-h4))
printf("\n Condition of steam after mixing is - \n
    pressure = %f MPa, temperature = %f degree
    centigrade",p,t3)

printf("\n The velocity of steam leaving the nozzle
    is %f m/sec",V4)
//The answers vary due to round off error
```

Scilab code Exa 9.9 Calculation of increase in entropy

```
clc
h2 = 2716.2 // Enthalpy at turbine inlet in kJ/kg
hf = 844.89 // Enthalpy of fluid in kJ/kg
hfg = 1947.3 // Latent heat of vaporization in kJ/kg
h3 = 2685.5 // Enthalpy at turbine exit in kJ/kg
printf("\n Example 9.9")
x1 = (h2-hf)/hfg
x4 = (h3-hf)/hfg
printf("\n The quality of steam in pipe line is %f "
    ,x1) //The answers vary due to round off error
printf("\n Maximum moisture content that can be
    determined is %f percent",100-(x4*100))//The
    answer provided in the textbook is wrong
```

Scilab code Exa 9.10 Calculation of specific volume and specific temperature and specific pressure and reduced volume

```
clc
// At 0.1Mpa, 110 degree
h2 = 2696.2 // Enthalpy at turbine inlet in kJ/kg
hf = 844.89 // Enthalpy of fluid in kJ/kg
hfg = 1947.3 // Latent heat of vaporization in kJ/kg
vf = 0.001023 // at T = 70 degree
V = 0.000150 // In m3
m2 = 3.24 // mass of condensed steam in kg

printf("\n Example 9.10")
x2 = (h2-hf)/hfg // Quality of steam at turbine
    inlet
m1 = V/vf // mass of moisture collected in separator
x1 = (x2*m2)/(m1+m2) // quality of the steam
printf("\n The quality of the steam in the pipe line
     is %f",x1)
//The answers vary due to round off error
```

Scilab code Exa 9.11 Calculation of heat transfer

```
clc
// P = 1MPa
vf = 0.001127 // specific volume of fluid in m^3/kg
vg = 0.1944// specific volume of gas in m^3/kg
hg = 2778.1 // specific enthalpy of gas in kJ/kg
```

```
uf = 761.68 // Specific internal energy of fluid in kJ/kg
ug = 2583.6 // Specific internal energy of gas in kJ/kg
ufg = 1822 // Change in specific internal energy due to phase change in kJ/kg
// Initial anf final mass
Vif = 5 // Initial volume of water in m^3
Viw = 5// Initial volume of gas in m^3
Vff = 6  // Final volume of gas in m^3
Vfw = 4 // Final volume of water in m^3


printf("\n Example 9.11")
ms = ((Viw/vf)+(Vif/vg)) - ((Vfw/vf)+(Vff/vg))
U1 =  ((Viw*uf/vf)+(Vif*ug/vg))
Uf =  ((Vfw*uf/vf)+(Vff*ug/vg))
Q = Uf-U1+(ms*hg)
printf("\n The heat transfer during the process is %f MJ",Q/1e3)
//The answer provided in the textbook is wrong
```

Scilab code Exa 9.12 Calculation of polytropic index and work done and heat transfer

```
clc
m = 0.02 // Mass of steam in Kg
d = 280 // diameter of piston in mm
l = 305 // Stroke length in mm
P1 = 0.6 // Initial pressure in MPa
P2 = 0.12 // Final pressure in MPa
// At 0.6MPa, t = 200 degree
v1 = 0.352 // Specific volume in m^3/kg
```

```
h1 = 2850.1 // Specific enthalpy in kJ/kg
vf = 0.0010476 // specific volume of fluid in m^3/kg
vfg = 1.4271 // Specific volume change due to vaporization in m^3/kg
uf = 439.3 // specific enthalpy of fluid
ug = 2512.0 // Specific enthalpy of gas
printf("\n Example 9.12")
V1 = m*v1 // total volume at point 1
Vd = (%pi/4)*(d*1e-3)^2*l*1e-3 // displaced volume
V2 = V1+Vd  // Total volume at point 2
n = log(P1/P2)/log(V2/V1) // polytropic index
W12 = ((P1*V1)-(P2*V2))*1e6/(n-1) // work done
printf("\n The value of n is %f ",n)
printf("\n The work done by the steam is %fkJ ",W12/1e3)
//The answers vary due to round off error
v2 = V2/m // specific volume
x2 = (v2-vf)/vfg  // Steam quality
// At 0.12MPa
u2 = uf + (x2*(ug-uf)) // Internal energy
u1 = h1-(P1*1e6*v1*1e-03) // Internal energy
Q12 = m*(u2-u1)+ (W12/1e3) // Heat transfer
printf("\n The heat transfer is %fkJ ",Q12)
//The answers vary due to round off error
```

Scilab code Exa 9.13 Calculation of pressure and steam quality and entropy change

```
clc
x1 = 1 // Steam quality in first vessel
x2 = 0.8 // Steam quality in second vessel
// at 0.2MPa
vg = 0.8857 // Specific volume of gas in m^3/kg
```

```
h1 =  2706.7 // Enthalpy in first vessel  in kJ/kg
v1 = vg // Specific volume of gas in first vessel in m^3/kg
hg = h1 //  Enthalpy in first vessel  1 in kJ/kg
m1 = 5  // mass in first vessel in kg
V1 = m1*v1 // Volume of first vessel in m^3
// at 0.5MPa
m2 = 10 // mass in second vessel in kg
hf = 640.23 // Enthalpy in second vessel  in kJ/kg
hfg = 2108.5 // Latent heat of vaporization in kJ/kg
vf = 0.001093 // Specific volume of fluid in second vessel in m^3/kg
vfg = 0.3749 // Change in specific volume in second vessel due to evaporation of gas in m^3/kg
v2 = vf+(x2*vfg) // Specific volume of gas in second vessel
V2 = m2*v2 // Volume of second vessel in m^3
//
Vm = V1+V2 // Total volume
m = m1+m2 // Total mass
vm = Vm/m // net specific volume
u1 = h1 // Internal energy
h2 = hf+(x2*hfg) // Enthalpy calculation
u2 = h2 // Internal energy calculation
m3 = m // Net mass calculation
h3 = ((m1*u1)+(m2*u2))/m3 // Resultant enthalpy calculation
u3 = h3 // Resultant internal energy calculation
v3 = vm // resultant specific volume calculation
// From Mollier diagram
x3 = 0.870  // Steam quality
p3 = 3.5 // Pressure in MPa
s3 = 6.29 // Entropy at state 3  in kJ/kgK
s1 = 7.1271 // Entropy at state 1 in kJ/kgK
sf = 1.8607  // Entropy in liquid state  in kJ/kgK
sfg = 4.9606 // Entropy change due to vaporization in kJ/kgK
s2 = sf+(x2*sfg) // Entropy calculation
```

```
E = m3*s3-((m1*s1)+(m2*s2)) // Entropy change during process

printf("\n Example 9.13")
printf("\n Final pressure is %f bar",p3)
printf("\n Steam quality is %f ",x3)
printf("\n Entropy change during the process is %f kJ/K",E)
//The answers vary due to round off error
```

Scilab code Exa 9.14 Calculation of availability and work output

```
clc
// At 6 MPa, 400 degree
h1 = 3177.2 // Enthalpy in kJ/kg
s1 = 6.5408 //Entropy in kJ/kgK
// At 20 degree
h0= 83.96 // Enthalpy in kJ/kg
s0 = 0.2966//Entropy in kJ/kgK
T0 = 20 // Surrounding temperature in degree Celsius
f1 = (h1-h0)-(T0+273)*(s1-s0) // Availability before throttling
// By interpolation at P= 5MPa, h= 3177.2
s2 = 6.63 //Entropy in kJ/kgK
h2 = h1 // Throttling
f2 = (h2-h0)-(T0+273)*(s2-s0) // Availability after throttling
df = f1-f2 // Change in availability
x3s = (s2-1.5301)/(7.1271-1.5301) //Entropy at state 3 in kJ/kgK
h3s = 504.7+(x3s*2201.9) //Enthalpy at state 3 in kJ/kg
eis = 0.82 // isentropic efficiency
```

```
h3 = h2-eis*(h1-h3s) // Enthalpy at state 3 in kJ/kgK
x3 = (h3-504.7)/2201.7 // Steam quality at state 3
s3 = 1.5301+(x3*5.597) // Entropy at state 3
f3 = (h3-h0)-(T0+273)*(s3-s0) // Availability at state 3

printf("\n Example 9.14")
printf("\n The availability of the steam before the throttle valve %f kJ/kg",f1)
printf("\n The availability of the steam after the throttle valve %f kJ/kg",f2)
printf("\n The availability of the steam at the turbine exhaust %f kJ/kg",f3)
printf("\n The specific work output from the turbine is %f kJ/kg",h2-h3)
//The answers vary due to round off error
```

Scilab code Exa 9.15 Calculation of availability and work and irreversibility

```
clc
// At 25 bar, 350 degree
h1 = 3125.87 // Enthalpy in kJ/kg
s1 = 6.8481// Entropy in kJ/kgK
// 30 degree
h0 = 125.79 // Enthalpy in kJ/kg
s0 = 0.4369// Entropy in kJ/kgK
// At 3 bar, 200 degree
h2 = 2865.5 // Enthalpy in kJ/kg
s2 = 7.3115 //Entropy in kJ/kgK
// At 0.2 bar 0.95 dry
hf = 251.4 // Enthalpy of liquid in kJ/kg
```

```
hfg = 2358.3 // Latent heat of vaporization in kJ/kg
sf = 0.8320 // Entropy of liquid in kJ/kgK
sg = 7.0765// Entropy of liquid in kJ/kgK
h3 = hf+0.92*hfg // Enthalpy at state 3 in kJ/kg
s3 = sf+(0.92*sg) // Entropy at state 3 in kJ/kgK
// Part (a)
T0 = 30 // Atmospheric temperature in degree Celsius
f1 = (h1-h0)-((T0+273)*(s1-s0)) // Availability at steam entering turbine
f2 = (h2-h0)-((T0+273)*(s2-s0)) // Availability at state 2
f3 = (h3-h0)-((T0+273)*(s3-s0))// Availability at state 3

printf("\n Example 9.15")
printf("\n Availability of steam entering is %f kJ/kg",f1)
printf("\n Availability of steam leaving the turbine is %f kJ/kg",f2)

// Part (b)
m2m1 = 0.25  // mass ratio
m3m1 = 0.75 // mass ratio
Wrev = f1-(m2m1*f2)-(m3m1*f3) // Maximum work
printf("\n Maximum work is %f kJ/kg",Wrev)

// Part (c)
w1 = 600 // mass flow at inlet of turbine in kg/h
w2 = 150 // mass flow at state 2 in turbine in kg/h
w3 = 450// mass flow at state 2 in  turbine in kg/h
Q = -10  // Heat loss rate kJ/s
I = ((T0+273)*(w2*s2+w3*s3-w1*s1)-Q*3600)*103/600
printf("\n Irreversibility is %f kJ/kg",I/1e3)
//The answer provided in the textbook is wrong
```

Scilab code Exa 9.16 Calculation of exergy

```
clc
// At dead state of 1 bar, 300K
u0 = 113.1 // Internal energy in kJ/kg
h0 = 113.2 // Enthalpy in kJ/kg
v0 = 0.001005 // Specific volume in m^3/kg
s0 = 0.395 // Entropy in kJ/kg
T0 = 300 // Atmospheric temperature in K
P0 = 1 // Atmospheric pressure in bar
K = h0-T0*s0
// Part (a)
// At 1bar and 90 degree Celsius
u = 376.9 // Internal energy in kJ/kg
h = 377 // Enthalpy in kJ/kg
v = 0.001035 // specific volume in m^3/kg
s = 1.193 // Entropy in kJ/kgK
m = 3 // Mass of water in kg
fi = m*(h-(T0*s)-K)  //Energy of system

printf("\n Example 9.16")
printf("\n Energy of system in Part (a) is %f kJ",fi
    )
//The answers vary due to round off error

// Part (b)
// At P = 4 Mpa, t = 500 degree
u = 3099.8// Internal energy in kJ/kg
h = 3446.3 // Enthalpy in kJ/kg
v = 0.08637 // specific volume in m^3/kg
s = 7.090 // Entropy in kJ/kgK
m = 0.2 // Mass of steam in kg
```

```
fib = m*(u+P0*100*v-T0*s-K) // Energy of system
printf("\n Energy of system in Part (b) is %f kJ",
   fib)

// Part (c) // P = 0.1 bar
m = 0.4 // Mass of wet steam in kg
x = 0.85 // Quality
u = 192+x*2245 // Internal energy
h = 192+x*2392// Enthalpy
s = 0.649+x*7.499 // Entropy
v = 0.001010+x*14.67 // specific volume
fic = m*(u+P0*100*v-T0*s-K) // Energy of system
printf("\n Energy of system in Part (c) is %f kJ",
   fic)

// Part (d)
// P = 1 Bar, t = -10 degree Celsius
m = 3 // Mass of ice in kg
h = -354.1 // Enthalpy in kJ/kg
s = -1.298 // at 1000kPa, -10 degree
fid = m*((h-h0)-T0*(s-s0)) // Energy of system

printf("\n Energy of system in Part (d) is %f kJ",
   fid) //The answer provided in the textbook is
   wrong
```

Scilab code Exa 9.17 Calculation of second law efficiency and rate of exergy destruction

```
clc
// Given
th1 = 90 // Inlet temperature of hot water in degree
    Celsius
```

```
tc1 = 25// Inlet temperature of cold water in degree Celsius
tc2 = 50// Exit temperature of cold water in degree Celsius
mc = 1 // mass flow rate of cold water in kg/s
T0 = 300 // Atmospheric temperature in K
th2p = 60 // Temperature limit in degree Celsius for parallel flow
th2c = 35 // Temperature limit in degree Celsius for counter flow
mhp = (tc2-tc1)/(th1-th2p) // mass flow rate of hot water in kg/s for parallel flow
mhc = (tc2-tc1)/(th1-th2c) // mass flow rate of hot water in kg/s for counter flow
// At 300 K
h0 = 113.2 // ENthalpy in kJ/kg
s0 = 0.395 // ENtropy in kJ/kgK
T0 = 300 // temperature in K
// At 90 degree celsius
h1 = 376.92 // Enthalpy in kJ/kg
s1 = 1.1925 // Entropy in kJ/kgK
af1 = mhp*((h1-h0)-T0*(s1-s0)) // Availability
// Parallel Flow
// At 60 degree
h2 = 251.13 // Enthalpy in kJ/kg
s2 =0.8312  // Entropy in kJ/kgK
 // At 25 degree
h3 = 104.89 // Enthalpy in kJ/kg
s3 = 0.3674 // Entropy in kJ/kgK
// At 50 degree
h4 = 209.33 // Enthalpy in kJ/kg
s4 = 0.7038 // Entropy in kJ/kgK
REG = mc*((h4-h3)-T0*(s4-s3)) // Rate of energy gain
REL = mhp*((h1-h2)-T0*(s1-s2)) // Rate of energy loss
Ia = REL-REG // Energy destruction
n2a = REG/REL // Second law efficiency
```

```
printf("\n Example 9.17")
printf("\n In parallel flow")
printf("\n The rate of irreversibility is %f kW",Ia)
printf("\n The Second law efficiency is %f percent",n2a*100)
//The answers vary due to round off error


// Counter flow
h2_ = 146.68
sp = 0.5053 // At 35 degree
REG_b = REG // Rate of energy gain by hot water is same in both flows
REL_b = mhc*((h1-h2_)-T0*(s1-sp))
Ib = mhc*((h1-h2_)-(T0*(s1-sp))) // Energy destruction
n2b = REG_b/Ib // Second law efficiency
printf("\n\n In counter flow")
printf("\n The rate of irreversibility is %f kW",Ib)
printf("\n The Second law efficiency is %f percent",n2b*100)
//The answers vary due to round off error
```

Scilab code Exa 9.18 Calculation of cooling rate

```
clc
m = 50 // mass flow rate in kg/h
Th = 23 // Home temperature in degree Celsius
// State 1
T1 = 150 // Saturated vapor temperature in degree Celsius
h1 = 2746.4 // Saturated vapor enthalpy in kJ/kg
s1 = 6.8387 //Saturated vapor entropy in kJ/kgK
```

```
// State 2
h2 = 419.0 // Saturated liquid enthalpy in kJ/kg
s2 = 1.3071 //Saturated liquid entropy in kJ/kg
T0 = 45 //  Atmospheric temperature in degree Celsius
//
b1 = h1-((T0+273)*s1) // Availability at point 1
b2 = h2-((T0+273)*s2) // Availability at point 2
Q_max = m*(b1-b2)/((T0+273)/(Th+273)-1) // maximum cooling rate

printf("\n Example 9.18")
printf("\n The maximum cooling rate is %d kW",Q_max/3600)
```

Chapter 10

Properties of gases and gas mixtures

Scilab code Exa 10.1 Calculation of pressure and heat transfer and temperature

```
clc
Pa = 1.5 // Pressure in vessel A in MPa
Ta = 50  // Temperature in vessel A in K
ca = 0.5 // Content in vessel A in kg mol
Pb = 0.6 // Pressure in vessel B in MPa
Tb = 20 // Temperature in vessel B in K
mb = 2.5 // Content in vessel B in kg mol
R = 8.3143 // Universal gas constant
Va = (ca*R*(Ta+273))/(Pa*1e03) // volume of vessel A
ma = ca*28 // mass of gas in vessel A
Rn = R/28 // Gas content to of nitrogen
Vb = (mb*Rn*(Tb+273))/(Pb*1e03) // volume of vessel
    B
V = Va + Vb  // Total volume
m = ma + mb // Total mass
Tf = 27 // Equilibrium temperature in degree Celsius
P = (m*Rn*(Tf+273))/V // Equilibrium pressure
```

```
g = 1.4 // Heat capacity ratio
cv  = Rn/(g-1) // Heat capacity at constant volume
U1 = cv*(ma*Ta+mb*Tb) // Initial internal energy
U2 = m*cv*Tf// Final internal energy
Q = U2-U1 // heat transferred

printf("\n Example 10.1")
printf("\n\n The final equilibrium pressure is %f MPa",P/1e3)
printf("\n The amount of heat transferred to the surrounding is %f kJ",Q)
//The answers vary due to round off error

T_ = (ma*Ta+mb*Tb)/m  // final temperature
P_ = (m*Rn*(T_+273))/V // final pressure
printf(" \n\n If the vessel is perfectly insulated")
printf("\n The final temperature is %f degree Celsius",T_)
// Answer varies due to round off error.
printf("\n The final pressure is %f MPa",P_/1e3)
```

Scilab code Exa 10.2 Calculation of work done and molecular weight and heat transfer and change in internal energy and enthalpy and entropy

```
clc
cp = 1.968 // Heat capacity in kJ/kg
cv = 1.507 // Heat capacity in kJ/kg
R_ = 8.314 // Gas constant
V = 0.3 // Volume of chamber in m^3
m = 2 // mass of gas in kg
T1 = 5// Initial gas temperature in degree Celsius
T2 = 100 // Final gas temperature in degree Celsius
R = cp-cv // Universal gas constant
```

```
mu = R_/R // molecular weight
Q12 = m*cv*(T2-T1) // The heat transfer at constant volume
W12 = 0 // work done
U21 = Q12 // change in internal energy
H21= m*cp*(T2-T1) // change in  enthalpy
S21 = m*cv*log((T2+273)/(T1+273)) //change in entropy

printf("\n Example 10.2")
printf("\n\n Gas constant of the gas is %f kJ/kg K ",R)
printf("\n Molecular weight the gas is %f kg/kg mol",mu)
printf("\n The heat transfer at constant volume is %f kJ",Q12)
printf("\n Work done is %d kJ",0)
printf("\n The change in internal energy is %f kJ",U21)
printf("\n The change in  enthalpy is %f kJ",H21)
printf("\n The change in  entropy is %f kJ/k",S21)
//The answers vary due to round off error
```

Scilab code Exa 10.3 Calculation of work done

```
clc
m = 1.5 // Mass of gas in kg
P1 = 5.6 // Initial pressure of gas in MPa
V1 = 0.06 // Initial volume of gas in m^3
T2_ = 240 // Final temperature of gas in degree Celsius
a = 0.946 // Constant
b = 0.662 // Constant
```

```
k = 1e-4 // Constant
// Part (b)
R = a-b // constant
T2 = T2_+273 // Final temperature of gas in KK
T1 = (P1*1e03*V1)/(m*R) // Initial temperature
W12 = -integrate('m*(b+k*T)','T',T1,T2) // Work done

printf("\n Example 10.3")
printf("\n The work done in the expansion is %d kJ", W12)
//The answers vary due to round off error
```

Scilab code Exa 10.5 Calculation of heat transfer and work transfer

```
clc
m = 0.5 // mass of air in kg
P1 = 80 // Initial pressure kPa
T1 = 60 // Initial temperature in degree Celsius
P2 = 0.4 // Final pressure in MPa
R = 0.287 // Gas constant
V1 = (m*R*(T1+273))/(P1) // Volume of air at state 1
g = 1.4 // Heat capacity ratio
T2 = (T1+273)*(P2*1e3/P1)^((g-1)/g)// Final temperature
W12 = (m*R*(T1+273-T2))/(g-1) // Work done in
V2 = V1*((P1/(P2*1e3))^(1/g)) // Final volume
W23 = P2*(V1-V2)*1e3 // // Work done
W = W12+W23 // Net work done
V3 = V1 // constant volume
T3 = (T2)*(V3/V2) // Temperature at state 3
cp = 1.005 // Heat capacity at constant volume in kJ/kgK
Q = m*cp*(T3-T2)// Heat transfer
```

```
printf("\n Example 10.5")
printf("\n The work transfer for the whole path is
    %f kJ",W)
//The answers vary due to round off error
printf("\n The heat transfer for the whole path %f
    kJ",Q)
//The answer provided in the textbook is wrong
```

Scilab code Exa 10.6 Calculation of heat

```
clc
P1 = 700 // Initial pressure of gas in kPa
T1 = 260 // Initial temperature of gas in degree
    Celcius
T3 = T1 // Temperature at state 3
V1 = 0.028 // Initial volume of gas in m^3
V2 = 0.084 // Final volume of gas in m^3
R = 0.287 // Gas constant
m = (P1*V1)/(R*(T1+273)) // mass of gas
P2 = P1 // Pressure at state 2
T2 = (T1+273)*((P2*V2)/(P1*V1)) // Temperature at
    state 2
n  = 1.5 // polytropic index
P3 = P2*(((T3+273)/(T2))^(n/(n-1))) // Pressure at
    state 3
cp = 1.005 // COnstant pressure heat capacity in kJ/
    kgK
cv = 0.718 // COnstant volume heat capacity in kJ/
    kgK
Q12 = m*cp*(T2-T1-273) // HEat transfer
Q23 = m*cv*(T3+273-T2) + (m*R*(T2-T3-273))/(n-1) //
    Heat transfer
Q31 = m*R*(T1+273)*log(P3/P2) // Heat transfer
```

```
Q1 = Q12 // Heat equivalance
Q2 = -(Q23+Q31) // Net heat transfer
e = 1-(Q2/Q1) // First law efficiency

printf("\n Example 10.6")
printf("\n The heat received in the cycle is %f kJ",
    Q1)
printf("\n The heat rejected in the cycle %f kJ",Q2)
printf("\n The efficiency of the cycle is %d percent
    ",ceil(e*100))
//The answers vary due to round off error
```

Scilab code Exa 10.7 Calculation of cp and cv and increase in entropy

```
clc
P1 = 300 // Initial gas pressure in kPa
V1 = 0.07 // Initial volume of gas in m^3
m = 0.25 // Mass of gas in kg
T1 = 80 // Initial temperature of gas in degree
    Celsius
R = (P1*V1)/(m*(T1+273)) // constant
P2 = P1 // process condition
V2 = 0.1 // Final volume in m^3
T2 = (P2*V2)/(m*R) // Final temperature in K
W = -25 //Work done in kJ
cv = -W/(m*(T2-T1-273)) // Constant volume heat
    capacity in kJ/kg
cp = R+cv //Constant pressure heat capacity in kJ/kg
S21 = m*cp*log(V2/V1) // Entropy change
printf("\n Example 10.7")
printf("\n Cv of the gas is %f kJ/kg K",cv)
printf("\n Cp of the gas is %f kJ/kg K",cp)
printf("\n Increase in the entropy of the gas is %f
```

```
kJ/kg K",S21)
//The answers vary due to round off error
```

Scilab code Exa 10.8 Calculation of mole fraction and equivalent molecular weight and equivalent gas constant and partial pressure and partial volume and volume and density and cp and cv

```
clc
mn = 3 // Mass of nitrogen in kg
mc = 5 // mass of CO2 in kg
an = 28 // Atomic weight of nitrogen
ac = 44 // Atomic weight of CO2
// Part (a)
xn = (mn/an)/((mn/an)+(mc/ac)) // mole fraction of nitrogen
xc = (mc/ac)/((mn/an)+(mc/ac)) // mole fraction of carbon

printf("\n Example 10.8")
printf("\n\n Mole fraction of N2 is %f ",xn)
printf("\n Mole fraction of CO2 is %f" ,xc)
//The answers vary due to round off error

// Part (b)
M = xn*an+xc*ac // Equivalent molecular weight
printf("\n\n Equivalent molecular weight of mixture is %fkg/kg mol" ,M)

// Part (c)
R = 8.314 // Gas constant
Req = ((mn*R/an)+(mc*R/ac))/(mn+mc)
printf("\n\n The equivalent gas constant of the mixture is %f kJ/kg K" ,Req)
```

```

// Part (d)
P = 300 // Initial pressure in kPa
T = 20 // Initial temperature in degree Celsius
Pn = xn*P // Partial pressure of Nitrogen
Pc = xc*P // Partial pressure of CO2
Vn = (mn*R*(T+273))/(P*an) // Volume of nitrogen
Vc = (mc*R*(T+273))/(P*ac) // Volume of CO2
printf("\n\n Partial pressures of nitrogen and CO2 are \n %f kPa and %f kPa respectively",Pn,Pc)
printf("\n Partial volume of nitrogen and CO2 are \n %f kPa and %f kPa respectively",Vn,Vc)
// Part (e)
V = (mn+mc)*Req*(T+273)/P // Total volume
rho = (mn+mc)/V // mass density
printf("\n\n Total volume of mixture is %f m^3" ,V)
printf("\n Density of mixture is %f kg/m^3" ,rho)

// Part (f)
gn = 1.4 // Heat capacity ratio for nitrogen
gc = 1.286 // Heat capacity ratio for carbon dioxide
cvn = R/((gn-1)*an) // cp and cv of N2
cpn = gn*cvn  // Constant pressure heat capacity of nitrogen
cvc = R/((gc-1)*ac) // cp and cv of CO2
cpc = gc*cvc// COnstant pressure heat capacity of carbon dioxide
cp = (mn*cpn+mc*cpc)/(mn+mc)  // Constant pressure heat capacity ratio of mixture
cv = (mn*cvn+mc*cvc)/(mn+mc) // Constant volume Heat capacity ratio of mixture
printf("\n\n Cp and Cv of mixture are \n %fkJ/kg K and %fkJ/kg K respectively" ,cp,cv)
T1 = T
T2 = 40
U21 = (mn+mc)*cv*(T2-T1)
H21 = (mn+mc)*cp*(T2-T1)
S21v = (mn+mc)*cv*log((T2+273)/(T1+273)) // If
```

```
heated at constant volume
S21p = (mn+mc)*cp*log((T2+273)/(T1+273)) // If
    heated at constant Pressure

printf("\n\n Change in internal energy of the system
    heated at constant volume  is %fkJ" ,U21)
printf("\n Change in enthalpy of the system heated
    at constant volume  is %fkJ" ,H21)
printf("\n Change in entropy of the system heated at
    constant volume  is %f kJ/kg K",S21v)
printf("\n\n Change in entropy of the system heated
    at constant Pressure  is %fkJ/kgK" ,S21p)

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

Scilab code Exa 10.9 Calculation of increase in entropy

```
clc
mo = 2 // mass of oxygen in kg
mn = 6 // mass of nitrogen in kg
muo = 32 // molecular mass of oxygen
mun = 28 // molecular mass of nitrogen
o = mo/muo // mass fraction of oxygen
n = mn/mun // mass fraction of nitrogen
xo = o/(n+o) // mole fraction of oxygen
xn = n/(n+o) // mole fraction of nitrogen
R = 8.314 // Universal gas constant
Ro = R/muo // Gas constant for oxygen
Rn = R/mun // Gas constant for nitrogen
dS = -mo*Ro*log(xo)-mn*Rn*log(xn) // Increase in
    entropy

printf("\n Example 10.9")
```

```
printf("\n Increase in entropy is %f kJ/kg K",dS)
//The answers vary due to round off error
```

Scilab code Exa 10.10 Calculation of specific volume and pressure and temperature and volume

```
clc
an = 20.183 // molecular weight of neon
Pc = 2.73 // Critical pressure
Tc = 44.5 // Critical tmperature in Kelvin
Vc = 0.0416 // volume of gas in m^3
Pr = 2 // Reduced Pressure
Tr = 1.3 // Reduced temperature
Z = 0.7 // Compressibility factor
P = Pr*Pc // Corresponding Pressure
T = Tr*Tc // Corresponding temperature
R = 8.314 // Gas constant
v = (Z*R*T)/(P*an) // Corresponding volume
vr = (v*an)/(Vc*1e3)  // reduced volume

printf("\n Example 10.10")
printf("\n Specific volume is %f *10^-3 m3/kg",v)
printf("\n Specific temperature is %f K",T)
printf("\n Specific pressure is %f MPa",P)
printf("\n Reduced volume is %f m3/kg",vr)
//The answers vary due to round off error
```

Chapter 11

Thermodynamic relations equilibrium and third law

Scilab code Exa 11.3 Calculation of vapour pressure of benzene

```
clc
Tb = 353 // boiling point of benzene in K
T = 303 // Operational temperature in K
R = 8.3143 //Gas constant
P = 101.325*exp((88/R)*(1-(Tb/T)))

printf("\n Example 11.3")
printf("\n Vapour pressure of benzene is %f kPa",P)
//The answers vary due to round off error
```

Scilab code Exa 11.4 Calculation of temperature and pressure at triple point and latent heat of sublimation and vaporization and fusion

```
clc
```

```
T = (3754-3063)/(23.03-19.49) // Temperature at triple point in K
P = exp(23.03-(3754/195.2)) // Pressure at triple point
R = 8.3143 // Gas constant
Lsub = R*3754 // Latent heat of sublimation
Lvap = 3063*R // Latent heat of vaporisation
Lfu = Lsub-Lvap // Latent heat of fusion

printf("\n Example 11.4")
printf("\n Temperature at triple point is %f K",T)
printf("\n Pressure at triple point is %f mm Hg",P)
printf("\n\n Latent heat of sublimation is %d kJ/kg mol",Lsub)
printf("\n Latent heat of vapourization is is %d kJ/kg mol",Lvap)
printf("\n Latent heat of fusion is %d kJ/kg mol",Lfu)
//The answers vary due to round off error
```

Scilab code Exa 11.6 Calculation of energy and volume and pressure and temperature

```
clc
R = 8.3143 // Gas constant in kJ/kg-mol-K
N1 = 0.5 // Mole no. of first system
N2 = 0.75 // Mole no. of second system
T1 = 200 // Initial temperature of first system in K
T2 = 300 // Initial temperature of second system in K
v = 0.02 // Total volume in m^3
printf("\n Example 11.6\n")
Tf = (T2*N2+T1*N1)/(N1+N2)
```

```
Uf_1 = (3/2)*(R*N1*Tf)*(10^-3)
Uf_2 = (3/2)*(R*N2*Tf)*(10^-3)
pf = (R*Tf*(N1+N2)*(10^-3))/v
Vf_1 = R*N1*(10^-3)*Tf/pf
Vf_2 = v-Vf_1
printf("\n Energy of first system is %f kJ,\n Energy
    of second system is %f kJ,\n Volume of first
   system is %f m^3,\n Volume of second system is %f
    m^3,\n Pressure is %d kN/m^2,\n Temperature is
   %d K.",Uf_1,Uf_2,Vf_1,Vf_2,pf,Tf)
//The answers vary due to round off error
```

Scilab code Exa 11.10 Calculation of power and rate of heat removed

```
clc
R = 0.082 // Gas constant in litre-atm/gmol-K
m = 1.5 // Mass flow rate in kg/s
p1 = 1 // Pressure in atm
t2 = 300 // Temperature after compression in K
p2 = 400 // Pressure after compression in atm
Tc = 151 // For Argon in K
pc = 48 // For Argon in atm
printf("\n Example 11.10 ")
a = 0.42748*((R*1000)^2)*((Tc)^2)/pc
b = 0.08664*(R*1000)*(Tc)/pc
// By solving equation v2^2 - 49.24*v2^2 + 335.6*v2
   - 43440 = 0
v2 = 56.8 // In cm^3/g mol
v1 = (R*1000)*(t2)/p1
delta_h = -1790 // In J/g mol
delta_s = -57 // In J/g mol
Q = (t2*delta_s*(10^5)/39.8)/(3600*1000)
W = Q - (delta_h*(10^5)/39.8)/(3600*1000)
```

```
printf("\n Power required to run the compressor = %f
    kW, \n The rate at which heat must be removed
   from the compressor = %f kW",W,Q)
// Answers vary due to round off error.
```

Chapter 12

Vapour power cycles

Scilab code Exa 12.1 Calculation of work required

```
clc
// Part (a)
P1 = 1 // Initial pressure in bar
P2 = 10 // Final pressure in bar
vf = 0.001043 // specific volume of liquid in m^3/kg
Wrev = vf*(P1-P2)*1e5 // Work done

printf("\n Example 12.1")
printf("\n The work required in saturated liquid
   form is %f kJ/kg",Wrev/1000)
//The answers vary due to round off error

// Part (b)
h1 = 2675.5 // Enthalpy at state 1 in kJ/kg
s1 = 7.3594 // Entropy at state 1 kJ/kgK
s2 = s1 // Isentropic process
h2 = 3195.5 // Enthalpy at state 2 kJ/kg
Wrev1 = h1-h2 // Work done
printf("\n The work required in saturated vapor form
    is %d kJ/kg",Wrev1)
```

Scilab code Exa 12.2 Calculation of net work and cycle efficiency and percentage reduction in net work and percentage reduction in cycle efficiency

```
clc
h1 = 3159.3 // Enthalpy at state 1 in kJ/kg
s1 = 6.9917 // Entropy at state 1 in kJ/kgK
h3 = 173.88  // Enthalpy at state 3 in kJ/kg
s3 = 0.5926 // Entropy at state 3 in kJ/kgK
sfp2 = s3 // Isentropic process
hfp2 = h3 // Isenthalpic process
hfgp2 = 2403.1 // Latent heat of vaporization in kJ/
    kg
sgp2 = 8.2287 // Entropy of gas in kJ/kgK
vfp2 = 0.001008 // Specific volume in m^3/kg
sfgp2 = 7.6361// Entropy of liquid in kJ/kgK
x2s = (s1-sfp2)/(sfgp2)// Steam quality
h2s = hfp2+(x2s*hfgp2) // Enthalpy at state 2s
// Part (a)
P1 = 20 // Turbine inlet pressure in bar
P2 = 0.08 // Turbine exit pressure in bar
h4s = vfp2*(P1-P2)*1e2+h3  // Enthalpy at state 4s
Wp = h4s-h3 // Pump work
Wt = h1-h2s // Turbine work
Wnet = Wt-Wp // Net work
Q1 = h1-h4s // Heat addition
n_cycle = Wnet/Q1// Cycle efficiency
printf("\n Example 12.2")
printf("\n Net work per kg of steam is %f kJ/kg",
    Wnet)//The answer provided in the textbook is
    wrong

printf("\n Cycle efficiency is %f percent",n_cycle
```

```
*100)

// Part (b)
n_p = 0.8 // pump efficiency
n_t = 0.8// Turbine efficiency
Wp_ = Wp/n_p // Pump work
Wt_ = Wt*n_t // Turbine work
Wnet_ = Wt_-Wp_// Net work
P = 100*((Wnet-Wnet_)/Wnet) // Percentage reduction in net work
n_cycle_ = Wnet_/Q1 // cycle efficiency
P_ = 100*((n_cycle-n_cycle_)/n_cycle) //reduction in cycle
printf("\n\n Percentage reduction in net work per kg of steam is %f percent",P)
printf("\n Percentage reduction in cycle efficiency is %f percent",P_)

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

Scilab code Exa 12.3 Calculation of Rankine cycle efficiency and mean temperature of heat addition

```
clc
P1 = 0.08 // Exhaust pressure in bar
sf = 0.5926 // Entropy of fluid in kJ/kgK
x2s = 0.85 // Steam quality
sg = 8.2287 // Entropy of gas in kJ/kgK
s2s = sf+(x2s*(sg-sf)) // Entropy of mixture at state 2s in kJ/kgK
s1 = s2s // Isentropic process
P2 = 16.832 // by steam table opposite to s1 in bar
h1 = 3165.54 // Enthalpy at state 1 in kJ/kg
```

```
h2s = 173.88 + (0.85*2403.1) // Enthalpy at state 2s in kJ/kg
h3 = 173.88// Enthalpy at state 3 in kJ/kg
vfp2 = 0.001 // specific volume of liquid in m^3/kg
h4s = h3 + (vfp2*(P2-P1)*100)// Enthalpy at state 4s in kJ/kg
Q1 = h1-h4s // Heat addition
Wt = h1-h2s // Turbine work
Wp = h4s-h3 // Pump work
n_cycle = 100*((Wt-Wp)/Q1) // Cycle efficiency
Tm = (h1-h4s)/(s2s-sf) // Mean temperature of heat addition

printf("\n Example 12.3")
printf("\n The greatest allowable steam pressure at the turbine inlet is %f bar",P2)

printf("\n Rankine cycle efficiency is %f percent",n_cycle)

printf("\n Mean temperature of heat addition is %f degree celcius",Tm-273)
//The answers vary due to round off error
```

Scilab code Exa 12.4 Calculation of quality at turbine exhaust and cycle efficiency and steam rate

```
clc
h1 = 3465 // Enthalpy at state 1 in kJ/kgK
h2s = 3065 //Enthalpy at state 2s in kJ/kgK
h3 = 3565 //Enthalpy at state 3 in kJ/kgK
h4s = 2300 // Enthalpy at state 4s in kJ/kgK
x4s = 0.88 // Steam quality at state 4s
```

```
h5 = 191.83// Enthalpy at state 5 in kJ/kgK
v = 0.001 // specific volume in m^3/kg
P = 150 // Boiler outlet pressure in bar
Wp = v*P*100 // Pump work
h6s = 206.83 // Enthalpy at state 6s in kJ/kgK
Q1 = (h1-h6s)+(h3-h2s) // Heat addition
Wt = (h1-h2s)+(h3-h4s) // Turbine work
Wnet = Wt-Wp // Net work
n_cycle = 100*Wnet/Q1 // cycle efficiency
sr = 3600/Wnet //Steam rate

printf("\n Example 12.4 \n")
printf("\n Quality at turbine exhaust is %f ",0.88)
printf("\n Cycle efficiency is %f percent",n_cycle)
printf("\n Steam rate is %f kg/kW h",sr)
//The answers vary due to round off error
```

Scilab code Exa 12.5 Calculation of efficiency of cycle and steam rate and increase in temperature and increase in steam rate and increase in efficiency

```
clc
h1 = 3230.9 // Enthalpy at state 1 in kJ/kg
s1 = 6.9212 // Entropy at state 1 in kJ/kgK
s2 = s1 // Isentropic process
s3 = s1 // Isentropic process
h2 = 2796  // Enthalpy at state 2 in kJ/kg
sf = 0.6493 // ENtropy of fluid onkJ/kgK
sfg = 7.5009 // Entropy change due to vaporization
x3 = (s3-sf)/sfg // steam quality
h3 = 191.83 + x3*2392.8 // Enthalpy at state 3
h4 = 191.83 // Enthalpy at state 4 in kJ/kg
h5 = h4 // Isenthalpic process
h6 = 640.23 // Enthalpy at state 6 in kJ/kg
```

```
h7 = h6 // Isenthalpic process
m = (h6-h5)/(h2-h5) // regenerative mass
Wt = (h1-h2)+(1-m)*(h2-h3) // turbine work
Q1 = h1-h6 // Heat addition
n_cycle = 100*Wt/Q1 // Cycle efficiency
sr = 3600/Wt // Steam rate
s7 = 1.8607  // Entropy at state 7 in kJ/kgK
s4 = 0.6493 // Entropy at state 4 in kJ/kgK
Tm = (h1-h7)/(s1-s7) // Mean temperature of heat
    addition with regeneration
Tm1 = (h1-h4)/(s1-s4) // Mean temperature of heat
    addition without regeneration
dT = Tm-Tm1 // Change in temperature
Wt_ = h1-h3 // Turbine work
sr_ = 3600/Wt_ // Steam rate
dsr = sr-sr_// Change in steam rate
n_cycle_ = 100*(h1-h3)/(h1-h4) // Cycle effciency
dn = n_cycle-n_cycle_// Change in efficiency
printf("\n Example 12.5\n")
printf("\n Efficiency of the cycle is %f percent",
    n_cycle)

printf("\n Steam rate of the cycle is %f kg/kW h",sr
    )//The answer provided in the textbook is wrong

printf("\n Increase in temperature due to
    regeneration is %f degree centigrade",dT)
printf("\n Increase in steam rate due to
    regeneration is %f kg/kW h",dsr)//The answer
    provided in the textbook is wrong

printf("\n Increase in Efficiency of the cycle due
    to regeneration is %f percent",dn)

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

Scilab code Exa 12.6 Calculation of steam quality and net work per kg and cycle efficiency and steam rate

```
clc
h1 = 3023.5  // Enthalpy of steam at state 1 in kJ/
    kg
s1 = 6.7664 // Enthalpy of steam at state 1 in kJ/
    kgK
s2 = s1 // Isentropic process
s3 = s1 //Isentropic process
s4 = s1 //Isentropic process
t_sat_20 = 212 // Saturation temperature at 20 bar
    in degree Celsius
t_sat_1 = 46 // Saturation temperature at 1 bar in
    degree Celsius
dt = t_sat_20-t_sat_1 // Change in temperature
n =3 // number of heaters
t = dt/n // temperature rise per heater
t1 = t_sat_20-t // Operational temperature of first
    heater
t2 = t1-t// Operational temperature of second heater
// 0.1 bar
hf = 191.83 // Enthalpy of fluid in kJ/kg
hfg = 2392.8 // Latent heat of vaporization in kJ/kg
sf = 0.6493// Entropy of fluid in kJ/kgK
sg = 8.1502// Entropy of gas in kJ/kgK
// At 100 degree
hf100 = 419.04 // Enthalpy of fluid in kJ/kg
hfg100 = 2257.0// Latent heat of vaporization in kJ/
    kg
sf100 = 1.3069 // Entropy of fluid in kJ/kgK
sg100 = 7.3549 // Entropy of gas in kJ/kgK
```

```
// At 150 degree
hf150 = 632.20 // Enthalpy of fluid in kJ/kg
hfg150 = 2114.3// Latent heat of vaporization in kJ/kg
sf150 = 1.8418 // Entropy of fluid in kJ/kgK
sg150 = 6.8379// Entropy of gas in kJ/kgK
x2 = (s1-sf150)/4.9961 // Steam quality
h2 = hf150+(x2*hfg150) // Enthalpy at state 2 in kJ/kg
x3 = (s1-sf100)/6.0480 // Steam quality
h3 = hf100+(x3*hfg100) // Enthalpy at state 3 in kJ/kg
x4 = (s1-sf)/7.5010 // Steam quality
h4 = hf+(x4*hfg)//Enthalpy at state 4 in kJ/kg
h5 = hf // Enthalpy at state 5 in kJ/kg
h6 = h5 //Enthalpy at state 6 in kJ/kg
h7 = hf100 // Enthalpy at state 7 in kJ/kg
h8 = h7 // Enthalpy at state 8 in kJ/kg
h9 = 632.2  // Enthalpy at state 9 in kJ/kg
h10 = h9 // Enthalpy at state 10 in kJ/kg
m1 = (h9-h7)/(h2-h7) // regenerative mass
m2 = ((1-m1)*(h7-h6))/(h3-h6) // regenerative mass
Wt = 1*(h1-h2)+(1-m1)*(h2-h3)+(1-m1-m2)*(h3-h4) // Turbine work
Q1 = h1-h9 // Heat addition
Wp = 0  // Pump work is neglected
n_cycle = 100*(Wt-Wp)/Q1 // Cycle efficiency
sr = 3600/(Wt-Wp)  // Steam rate

printf("\n Example 12.6\n")
printf("\n Steam quality at turbine exhaust is %f ",x3)
printf("\n Net work per kg of stem is %f kJ/kg",Wt)
printf("\n Cycle efficiency is %f percent",n_cycle)
printf("\n Stream rate is %f kg/kW h",sr)
//The answers vary due to round off error
```

Scilab code Exa 12.7 Calculation of the second law of efficiency

```
clc
Ti = 2000 // Hot gas inlet temperature in K
Te = 450 // Hot gas exhaust temperature in K
T0 = 300 // Ambient temperature in K
Q1_dot = 100 // Heating rate provided by steam in kW
cpg = 1.1 // Heat capacity of gas in kJ/kg
wg = Q1_dot/(cpg*(Ti-Te)) // mass flow rate of hot gas
af1 = wg*cpg*T0*((Ti/T0)-1-log(Ti/T0)) // Availability at inlet
af2 = wg*cpg*T0*((Te/T0)-1-log(Te/T0)) // Availability at exit
afi = af1-af2 // Change in availability
h1 = 2801 // Enthalpy at state 1 in kJ/kg
h3 = 169 //Enthalpy at state 3 in kJ/kg
h4 = 172.8 //Enthalpy at state 4 in kJ/kg
h2 = 1890.2 // Enthalpy at state 2 in kJ/kg
s1 = 6.068 // Entropy at state 1 in kJ/kgK
s2 = s1 // Isentropic process
s3 = 0.576 // Entropy at state 3 in kJ/kgK
s4 = s3 // Isentropic process
Wt = h1-h2 // Turbine work
Wp = h4-h3 // Pump work
Q1 = h1-h4 // Heat addition
Q2 = h2-h3// Heat rejection
Wnet = Wt-Wp // Net work
ws = Q1_dot/2628 // steam mass flow rate
afu = 38*(h1-h4-T0*(s1-s3)) // availability loss
I_dot = afi-afu // Rate of exergy destruction
Wnet_dot = ws*Wnet// Mechanical power rate
```

```
afc = ws*(h2-h3-T0*(s2-s3)) // Exergy flow rate of
    of wet steam
n2 = 100*Wnet_dot/af1 // second law efficiency

printf("\n Example 12.7\n")
printf("\n The second law efficiency is %f percent",
    n2)
//The answers vary due to round off error
```

Scilab code Exa 12.8 Calculation of first law of efficiency and second law of efficiency

```
clc
// Part (a)
h1 = 2758 // Enthalpy at state 1 in kJ/kg
h2 = 1817 // Enthalpy at state 2 in kJ/kg
h3 = 192 // Enthalpy at state 3 in kJ/kg
h4 = 200// Enthalpy at state 4 in kJ/kg
Wt = h1-h2 // turbine work
Wp = h4-h3 // Pump work
Q1 = h1-h4 // Heat addition
Wnet = Wt-Wp // Net work doen
n1 = Wnet/Q1 // First law efficiency
WR = Wnet/Wt // Work ratio
Q1_ = 100 // Heat addition rate in MW
PO = n1*Q1_ // power output
cpg = 1000 // Specific heat capacity in J/kg
wg = (Q1_/(833-450)) // mass flow rate of gas
EIR = wg*cpg*((833-300)-300*(log(833/300)))/1000 //
    Exergy input
n2 = PO/EIR // Second law efficiency

printf("\n Example 12.8\n")
```

```
printf("\n Part (a)")
printf("\n The first law efficiency n1 is %f",n1*100)
printf("\n The second law efficiency n2 is %f",n2*100)
printf("\n The work ratio is %f",WR)
// Part (b)
h1b = 3398 // Enthalpy at state 1 in kJ/kg
h2b = 2130 // Enthalpy at state 2 in kJ/kg
h3b = 192 // Enthalpy at state 3 in kJ/kg
h4b = 200// Enthalpy at state 4 in kJ/kg
Wtb = 1268 // turbine work in kJ/kg
Wpb = 8  // Pump work in kJ/kg
Q1b = 3198// Heat addition rate in kW
n1b = (Wtb-Wpb)/Q1b //first law efficiency
WRb = (Wtb-Wpb)/Wtb // WOrk ratio
EIRb = 59.3 // Exergy input rate in MW
Wnetb = Q1_*n1b // net work done

n2b = Wnetb/EIRb // Second law efficiency
printf("\n Part (b)")
printf("\n The first law efficiency n1 is %f",n1b*100)
printf("\n The second law efficiency n2 is %f",n2b*100)
printf("\n The work ration is %f",WRb)

// Part (c)
h1c = 3398 // Enthalpy at state 1 in kJ/kg
h2c = 2761 // Enthalpy at state 2 in kJ/kg
h3c = 3482 // Enthalpy at state 3 in kJ/kg
h4c = 2522 // Enthalpy at state 4 in kJ/kg
h5c = 192 // Enthalpy at state 5 in kJ/kg
h6c = 200// Enthalpy at state 6 in kJ/kg
Wt1 = 637 // Turbine work in kJ/kg
Wt2 = 960 // Turbine work in kJ/kg
Wtc = Wt1+Wt2  // Net turbine work in kJ/kg
Wp = 8 // Pump work in kJ/kg
```

```
Wnetc = Wtc-Wp // net work done
Q1c = 3198+721 // Heat addition
n1c = Wnetc/Q1c// First law efficiency
WRc = Wnetc/Wtc// Work ratio
POc = Q1_*n1c// Power output
EIRc = 59.3// Exergy input in MW
n2c = POc/EIRc // Second law efficiency
printf("\n Part (c)")
printf("\n The first law efficiency n1 is %f",n1c
    *100)
printf("\n The second law efficiency n2 is %f",n2c
    *100)
printf("\n The work ration is %f",WRc)

// Part (d)
T3 = 45.8 // saturation temperature at 0.1 bar in
    degree celsius
T1 = 295 // saturation temperature at 80 bar in
    degree celsius
n1d = 1-((T3+273)/(T1+273)) // First law efficiency
Q1d = 2758-1316 // Heat addition
Wnet = Q1d*n1d // Net work output
Wpd = 8 // Pump work in kJ/kg
Wtd = 641// Turbine work in kJ/kg
WRd = (Wt-Wp)/Wt // Work ratio
POd = Q1_*0.439// Power output
EIRd = (Q1_/(833-593))*cpg*((833-300)-300*(log
    (833/300)))/1000 //Exergy Input rate in MW
n2d = POd/EIRd // Second law efficiency
printf("\n Part (d)")
printf("\n The first law efficiency n1 is %f",n1d
    *100)
printf("\n The second law efficiency n2 is %f",n2d
    *100)
printf("\n The work ration is %f",WRd)
//The answers vary due to round off error
```

Scilab code Exa 12.9 Calculation of temperature of steam and pressure of the steam

```
clc
hfg = 2202.6 // Latent heat of fusion in kJ/kg
Qh = 5.83 // Heat addition in MJ/s
ws = Qh/hfg // steam flow rate
eg = 0.9 // efficiency of generator
P = 1000 // Power generation rate in kW
Wnet = 1000/eg // Net output
nbrake = 0.8 // brake thermal efficiency
h1_2s = Wnet/(ws*nbrake) // Ideal heat addition
n_internal = 0.85 // internal efficiency
h12 = n_internal*h1_2s // Actual heat addition
hg = 2706.3 // Enthalpy of gas in kJ/kg
h2 = hg //Isenthalpic process
h1 = h12+h2 // Total enthalpy
h2s = h1-h1_2s // Enthalpy change
hf = 503.71 // Enthalpy of fluid in kJ/kg
x2s = (h2s-hf)/hfg // Quality of steam
sf = 1.5276  // entropy of fluid in kJ/kgK
sfg = 5.6020 // Entropy change due to vaporization in kJ/kgK
s2s = sf+(x2s*sfg) // Entropy at state 2s
s1 = s2s // Isentropic process
P1 = 22.5 // Turbine inlet pressure in bar from Mollier chart
t1 = 360 // Temperature of the steam in degree Celsius from Mollier chart

printf("\n Example 12.9\n")
printf("\n Temperature of the steam is %d degree
```

```
    celcius",t1)
printf("\n Pressure of the steam is %f bar",P1)
//The answers vary due to round off error
```

Scilab code Exa 12.10 Calculation of pressure and steam flow and cycle efficiency

```
clc
h1 = 3037.3 // Enthalpy at state 1 in kJ/kg
x = 0.96 // Steam quality
h2 = 561+(x*2163.8) // Enthalpy at state 2
s2 = 1.6718+(x*5.3201)// Entropy at state 2
s3s = s2 // Isentropic process
x3s = (s3s-0.6493)/7.5009 // Quality at state 3s
h3s = 191.83+(x3s*2392.8) // Enthalpy at state 3s
h23 = 0.8*(h2-h3s) // Enthalpy change in process 23
h3 = h2-h23 // Enthalpy at state 3
h5 = 561.47  // Enthalpy at state 5
h4 = 191.83// Enthalpy at state 4
Qh = 3500 // Heat addition in kJ/s
w = Qh/(h2-h5) // mass flow rate
Wt = 1500 // Turbine work
ws = (Wt+w*(h2-h3))/(h1-h3) // Steam flow rate
ws_ = 3600*ws  // Steam flow rate  in kg/h
h6 = ((ws-w)*h4+w*h5)/ws  //Enthalpy at state 6
h7 = h6// Enthalpy at state 7
n_boiler = 0.85 // Boiler efficiency
CV = 44000 // Calorific value of fuel in kJ/kg
wf = (1.1*ws_*(h1-h7))/(n_boiler*CV) // Fuel
    consumption rate

printf("\n Example 12.10\n")
printf("\n Fuel burning rate is %f tonnes/day",wf
```

```
*24/1000)
//The answers vary due to round off error
```

Scilab code Exa 12.11 Calculation of overall efficiency and flow and useful work done and overall efficiency

```
clc
h1 = 3285  // Enthalpy at state 1 in kJ/kg
h2s = 3010 // Enthalpy at state 2s in kJ/kg
h3 = 3280 // // Enthalpy at state 3 in kJ/kg
h4s = 3030 // // Enthalpy at state 4s in kJ/kg
// Saturation pressure at temperature 180 degree centigrade
psat = 10 // In bar
h4 = h3-0.83*(h3-h4s) // // Enthalpy at state 4
h5s = 2225 // // Enthalpy at state 5s in kJ/kg
h5 = h4-0.83*(h4-h5s) // // Enthalpy at state 5
h6 = 162.7 // Enthalpy at state 6 in kJ/kg
h7 = h6 // // Enthalpy at state 7
h8 = 762.81// Enthalpy at state 8 in kJ/kg
h2 = h1-0.785*(h1-h2s) //Enthalpy at state 2
m = (h8-h7)/(h4-h7) // regenerative mass flow
n_cycle = ((h1-h2)+(h3-h4)+(1-m)*(h4-h5))/((h1-h8)+(h3-h2)) // Cycle efficiency

printf("\n Example 12.11\n")
printf("\n The minimum pressure at which bleeding is neccessary is %d bar",psat)
printf("\n Steam flow at turbine inlet is %f kg/s",m)
printf("\n Cycle efficiency is %f percent",n_cycle*100)
//The answers vary due to round off error
```

```
// Part A and Part B are theoretical problems
```

Scilab code Exa 12.12 Calculation of efficiency and flow rate and work done

```
clc
// From table
h1 = 2792.2 // Enthalpy at state 1 in kJ/kg
h4 = 122.96// Enthalpy at state 4 in kJ/kg
hb = 254.88 // Enthalpy at state b in kJ/kg
hc = 29.98// Enthalpy at state c in kJ/kg
ha = 355.98 // Enthalpy at state a in kJ/kg
hd = hc // Isenthalpic process
h2 = 1949.27 // // Enthalpy at state 2 in kJ/kg
//
m = (h1-h4)/(hb-hc) // Amount of mercury circulating
Q1t = m*(ha-hd) // Heat addition
W1t = m*(ha-hb) + (h1-h2) // Turbine work
n = W1t/Q1t // first law efficiency

printf("\n Example 12.12 \n")
printf("\n Overall efficiency of the cycle is %f
    percent",n*100)
//The answers vary due to round off error

S = 50000 // Stem flow rate through turbine in kg/h
wm = S*m // mercury flow rate
printf("\n Flow through the mercury turbine is %e kg
    /h",wm)

Wt = W1t*S/3600 // Turbine work
printf("\n Useful work done in binary vapor cycle is
    %f MW",Wt/1e3)
```

```
nm = 0.85 // Internal efficiency of mercury turbine
ns = 0.87 // Internal efficiency of steam turbine
WTm = nm*(ha-hb) // turbine work of mercury based cycle
hb_ = ha-WTm // Enthalpy at state b in kJ/kg
m_ = (h1-h4)/(hb_-hc) // mass flow rate of mercury
h1_ = 3037.3 // Enthalpy at state 1 in kJ/kg
Q1t = m_*(ha-hd)+(h1_-h1) // Heat addition
x2_ = (6.9160-0.4226)/(8.47-0.4226) // steam quality
h2_ = 121+(0.806*2432.9) // Enthalpy at state 2 in kJ/kg
WTst = ns*(h1_-h2_) // Turbine work
WTt = m_*(ha-hb_)+WTst // Total turbine work
N = WTt/Q1t //Overall efficiency
printf("\n Overall efficiency is %f percent",N*100)
// The answers vary due to round off error
```

Chapter 13

Gas power cycles

Scilab code Exa 13.1 Calculation of cycle efficiency and maximum temperature and maximum pressure and mean effective pressure

```
clc
T1 = 35 // Air inlet temperature in degree Celsius
P1 = 0.1 // Air inlet pressure in MPa
Q1 = 2100 // Heat supply in kJ/kg
R = 0.287 // gas constant
rk = 8 // Compression ratio
g = 1.4 // Heat capacity ratio
n_cycle = 1-(1/rk^(g-1)) // cycle efficiency
v1 = (R*(T1+273))/(P1*1e3) // Initial volume
v2 = v1/8 // Volume after compression
T2 = (T1+273)*(v1/v2)^(g-1) // Temperature after compression
cv = 0.718 // Constant volume heat capacity in kJ/kg
T3 = Q1/cv + T2 // Temperature at after heat addition
P21 = (v1/v2)^g // Pressure ratio
P2 = P21*P1 // Pressure after compression
P3 = P2*(T3/T2) // Pressure after heat addition
Wnet = Q1*n_cycle // Net work output
Pm = Wnet/(v1-v2) // Mean pressure
```

```
printf("\n Example 13.1\n")
printf("\n Cycle efficiency is %f percent",n_cycle
    *100)
printf("\n Maximum temperature in the cycle is %d K"
    ,T3)
printf("\n Maximum pressure in the cycle is %f MPa",
    P3)
printf("\n Mean effective pressure is %f MPa",Pm/1e3
    )
//The answers vary due to round off error
```

Scilab code Exa 13.2 Calculation of air standard efficiency

```
clc
rk = 14 // Compression ratio
k = 6 // cutoff percentage ratio
rc = k/100*(rk-1)+1
g = 1.4 // Heat capacity ratio
n_diesel = 1-((1/g))*(1/rk^(g-1))*((rc^(g-1))/(rc-1)
    ) // Cycle efficiency
printf("\n Example 13.2\n")
printf("\n Air standard efficiency is %f percent",
    n_diesel*100)
//The answers vary due to round off error
```

Scilab code Exa 13.3 Calculation of cutoff ratio and heat supplied and cycle efficiency and mean effective pressure

```
clc
```

```
rk = 16 // Compression ratio
T1 = 15 // Air inlet temperature in degree Celsius
P1 = 0.1 // Air inlet pressure in MPa
T3 = 1480 // Highest temperature in cycle in degree Celsius
g = 1.4 // Heat capacity ratio
R = 0.287 // Gas constant
T2 = (T1+273)*(rk^(g-1)) // Temperature after compression
rc =  (T3+273)/T2 // cut off ratio
cp = 1.005 // Constant pressure heat constant
cv = 0.718 // Constant volume heat constant
Q1 = cp*(T3+273-T2) // Heat addition
T4 = (T3+273)*((rc/rk)^(g-1)) // Temperature after heat addition
Q2 = cv*(T4-T1-273) // Heat rejection
n = 1-(Q2/Q1) // cycle efficiency
n_ = 1-((1/g))*(1/rk^(g-1))*((rc^(g-1))/(rc-1)) // cycle efficiency from another formula
Wnet = Q1*n // Net work
v1 = (R*(T1+273))/(P1*1e3) // Volume before compression
v2 = v1/rk // Volume after compression
Pm = Wnet/(v1-v2) // Mean pressure
printf("\n Example 13.3\n")
printf("\n Cut-off ratio is %f ",rc)
printf("\n Heat supplied per kg of air is %f kJ/kg",Q1)
printf("\n Cycle efficiency is %f percent",n*100)
printf("\n Mean effective pressure is %f kPa",Pm)
//The answers vary due to round off error
```

Scilab code Exa 13.4 Calculation of efficiency of cycle and mean effective pressure

```
clc
T1 = 50 // Temperature before compression stroke in
   degree Celsius
rk = 16 // Compression ratio
g = 1.4 // Heat capacity ratio
P3 = 70 // Maximum cycle pressure in bar
cv = 0.718 // Constant volume heat addition capacity
cp = 1.005 // Constant pressure heat addition
   capacity
R = 0.287 // Gas constant
T2 = (T1+273)*((rk^(g-1))) //Temperature after
   compression stroke
P1 = 1 // Pressure before compression in bar
P2 = P1*(rk)^g // Pressure after compression
T3 = T2*(P3/P2) // Temperature after constant volume
    heat addition
Q23 = cv*(T3-T2) // Constant volume heat added
T4 = (Q23/cp)+T3 // Temperature after constant
   pressure heat addition
v43 = T4/T3 // cut off ratio
v54 = rk/v43 // Expansion ratio
T5 = T4*(1/v54)^(g-1) // Temperature after expansion
P5 = P1*(T5/(T1+273)) // Pressure after expansion
Q1 = cv*(T3-T2)+cp*(T4-T3) // Total heat added
Q2 = cv*(T5-T1-273) // Heat rejected
n_cycle = 1-(Q2/Q1) // Cycle efficiency
v1 = (R*(T1+273))/(P1*1e2) // Volume before
   compression
v2 = (1/16)*v1 // Swept volume
Wnet = Q1*n_cycle // Net work done
Pm = Wnet/(v1-v2) // Mean pressure
printf("\n Example 13.4\n")
printf("\n Efficiency of the cycle is %f percent",
   n_cycle*100)
printf("\n Mean effective pressure is %f bar",Pm
```

```
/100)
//The answers vary due to round off error
```

Scilab code Exa 13.5 Calculation of percentage increase in cycle efficiency

```
clc
P1 = 0.1 // Air pressure at turbine inlet in MPa
T1 = 30 // Air temperature at turbine inlet in degree Celsius
T3 = 900 // Maximum cycle temperature at turbine inlet in degree Celsius
rp = 6 // Pressure ratio
nt = 0.8 // Turbine efficiency
nc = 0.8// Compressor efficiency
g = 1.4 // Heat capacity ratio
cv = 0.718 // Constant volume heat capacity
cp = 1.005 // Constant pressure heat capacity
R = 0.287 // Gas constant
T2s = (T1+273)*(rp)^((g-1)/g)
T4s = (T3+273)/((rp)^((g-1)/g))
T21 = (T2s-T1-273)/nc  // Temperature raise due to compression
T34 = nt*(T3+273-T4s) // Temperature drop due to expansion
Wt = cp*T34 // Turbine work
Wc = cp*T21 // Compressor work
T2 = T21+T1+273 // Temperature after compression
Q1 = cp*(T3+273-T2) // Heat added
n = (Wt-Wc)/Q1 // First law efficiency
T4 = T3+273-T34 // Temperature after expansion
T6 = 0.75*(T4-T2) + T2 // Regeneration temperature
Q1_ = cp*(T3+273-T6)// Heat added
n_ = (Wt-Wc)/Q1_ //cycle efficiency
```

```
I = (n_-n)/n // Fractional increase in cycle efficiency
printf("\n Example 13.5\n")
printf("\n The percentage increase in cycle efficiency \n due to regeneration is %f percent", I*100)
//The answers vary due to round off error
```

Scilab code Exa 13.6 Calculation of maximum work done and cycle efficiency and ratio of Brayton and Carnot efficiency

```
clc
cp = 1.005 // Constant pressure heat capacity
Tmax = 1073 // Maximum cycle temperature in K
Tmin = 300// Minimum cycle temperature in K
Wnet_max = cp*(sqrt(Tmax)-sqrt(Tmin))^2 // maximum work
n_cycle = 1-sqrt(Tmin/Tmax) // cycle efficiency
n_carnot = 1-(Tmin/Tmax) // Carnot efficiency
r = n_cycle/n_carnot // Efficiency ratio
printf("\n Example 13.6\n")
printf("\n Maximum work done per kg of air is %f kJ/kg",Wnet_max)
printf("\n Cycle efficiency is %d percent",n_cycle*100)
printf("\n Ratio of Brayton and Carnot efficiency is %f",r)
//The answers vary due to round off error
```

Scilab code Exa 13.7 Calculation of thermal efficiency and work ratio and power output and energy flow rate

```
clc
rp = 6 // pressure ratio
g = 1.4 // Heat capacity ratio
cv = 0.718 // Constant volume heat capacity
cp = 1.005 //Constant pressure heat capacity
R = 0.287 // Gas constant
T1 = 300 // Minimum temperature in K
T3 = 1100 // Maximum cycle temperature in K
T0 = 300 // Atmospheric temperature in K
n_cycle = 1-(1/rp^((g-1)/g)) // cycle efficiency
T2 = (T1)*(rp^((g-1)/g)) // Temperature after
    compression
T4 = (T3)/(rp^((g-1)/g)) // Temperature after
    expansion
Wc = cp*(T2-T1) // Compressor work
Wt = cp*(T3-T4) // Turbine work
WR = (Wt-Wc)/Wt // Work ratio
Q1 = 100 // Heat addition in MW
PO = n_cycle*Q1 // Power output
m_dot = (Q1*1e06)/(cp*(T3-T2)) // Mass flow rate
R = m_dot*cp*T0*((T4/T0)-1-log(T4/T0)) // Exergy
    flow rate
printf("\n Example 13.7\n")
printf("\n The thermal efficiency of the cycle is %f
     percent",n_cycle*100)
printf("\n Work ratio is %f ",WR)
printf("\n Power output is %f MW",PO)
printf("\n Energy flow rate of the exhaust gas
    stream is %f MW",R/1e6)
//The answers vary due to round off error
```

Scilab code Exa 13.8 Calculation of percentage of air taken by the compressor

```
clc
nc = 0.87 // Compressor efficiency
nt = 0.9 // Turbine efficiency
T1 = 311 // Compressor inlet temperature in K
rp = 8 // compressor pressure ratio
P1 = 1 // Initial pressure in atm
T3 = 1367 // Turbine inlet temperature
P2 = P1*rp // Final pressure
P3 = 0.95*P2 // Actual pressure after compression
P4 = 1 // Atmospheric pressure
g = 1.4 // Heat capacity ratio
cv = 0.718 // Constant volume heat capacity
cp = 1.005 // Constant pressure heat capacity
R = 0.287 // Gas constant
// With no cooling
T2s = T1*((P2/P1)^((g-1)/g)) // Ideal temperature
    after compression
T2 = T1 + (T2s-T1)/0.87 // Actual temperature after
    compression
T4s = T3*(P4/P3)^((g-1)/g) // Ideal temperature
    after expansion
n = (((T3-T4s)*nt)-((T2s-T1)/nc))/(T3-T2) // cycle
    efficiency
// With cooling
n_cycle = n-0.05
x = 0.13 // Fluid quality
r = x/(x+1) //
printf("\n Example 13.8\n")
printf("\n Percentage of air that may be taken from
    the compressor is %f percent",r*100)
//The answers vary due to round off error
```

Scilab code Exa 13.9 Calculation of optimum specific output

```
clc
//Given that
nc = 0.85 // Compressor efficiency
nt = 0.9 // Turbine efficiency
r = 3.5 // Ratio of max and min temperature
gama = 1.4 // Ratio of heat capacities for air
printf("\n Example 13.9 \n")
x = (gama-1)/gama
r_opt = ((nc*nt*r)^(2/3))^(1/x)
printf("\n Optimum specific output is %f ",r_opt)
//The answers vary due to round off error
```

Scilab code Exa 13.10 Calculation of temperature and pressure and velocity and propulsive efficiency

```
clc
//Given that
v = 300 // Aircraft velocity in m/s
p1 = 0.35 // Pressure in bar
t1 = -40 // Temperature in degree centigrade
rp = 10 // The pressure ratio of compressor
t4 = 1100 // Temperature of gases at turbine intlet
   in degree centigrade
ma = 50 // Mass flow rate of air at the inlet of
   compressor in kg/s
```

```
cp = 1.005 // Heat capacity of air at constant pressure in kJ/kg-K
gama=1.4 // Ratio of heat capacities for air
printf("\n Example 13.10 \n")
T1 = t1+273
T4 = t4+273
T2 = T1 + (v^2)/(2*cp)*(10^-3)
p2 = p1*(100)*((T2/T1)^(gama/(gama-1)))
p3 = rp*p2
p4 =p3
T3 = T2*((p3/p2)^((gama-1)/gama))
T5 = T4-T3+T2
p5 = ((T5/T4)^(gama/(gama-1)))*(p4)
p6 = p1*100
T6 = T5*((p6/p5)^((gama-1)/gama))
V6 = (2*cp*(T5-T6)*1000)^(1/2)
Wp = ma*(V6-v)*v*(10^-6)
Q1 = ma*cp*(T4-T3)*(10^-3)
np = Wp/Q1
printf("\n The temperature of the gases at the turbine exit is %f K,\n The pressure of the gases at the turbine exit is %f kN/m^2,\n The velocity of gases at the nozzle exit is %f m/sec,\n The propulsive efficiency of the cycle is %f percent",T5,p5,V6,np*100)
//The answers vary due to round off error
```

Scilab code Exa 13.11 Calculation of air fuel ratio and overall efficiency of combined plant

```
clc
Ta = 15 // Atmospheric temperature in degree Celsius
rp = 8 // pressure ratio
```

```
g = 1.33 // heat capacity ratio for gas
g1 = 1.40 // heat capacity ratio for air
cv = 0.718 // Constant volume heat capacity
cpa = 1.005 // Constant pressure heat capacity for air
cpg = 1.11 // Constant pressure heat capacity for gas
R = 0.287 // Gas constant
Tb = (Ta+273)*(rp)^((g1-1)/g1) // Temperature after compression
Tc = 800  // Temperature after heat addition in degree Celsius
Td = (Tc+273)/((rp)^((g-1)/g)) // Temperature after expansion
Wgt = cpg*(Tc+273-Td)-cpa*(Tb-Ta-273)
Q1 = cpg*(Tc+273-Tb)
Q1_ = cpg*(Tc+273-Td)
h1 = 3775  // Enthalpy at state 1 in kJ/kg
h2 = 2183 // Enthalpy at state2 in kJ/kg
h3 = 138 // Enthalpy at state3 in kJ/kg
h4 = h3 // Isenthalpic process
Q1_st = h1-h3 // Total heat addition
Q_fe = cpg*(Tc-100) // Heat transfer by steam
was = Q1_st/Q_fe // air steam mass ratio
Wst = h1-h2// work done by steam turbine
PO = 190e03 // Power output in kW
ws = PO/(was*Wgt+Wst)// steam flow rate
wa = was*ws // Air flow rate
CV = 43300 // Calorific volume of fuel in kJ/kg
waf = CV/(Q1+Q1_) // Air fuel ratio
FEI = (wa/waf)*CV // Fuel energy input
noA = PO/FEI // combined cycle efficiency

printf("\n Example 13.11 \n")
printf("\n Air fuel ratio is %f ",waf)
printf("\n Overall efficiency of combined plant is %f percent ",noA*100)
//The answers vary due to round off error
```

Chapter 14

Refrigeration cycles

Scilab code Exa 14.1 Calculation of power required to drive the plane

```
clc
T2 = -5 // Cold storage temperature in degree
   Celsius
T1 = 35 // Surrounding temperature in degree Celsius
COP = (T2+273)/((T1+273)-(T2+273))
ACOP = COP/3 // Actual COP
Q2 = 29 // Heat leakage in kW
W = Q2/ACOP
printf("\n Example 14.1\n")
printf("\n Power required to drive the plane is %f
   kW",W)
//The answers vary due to round off error
```

Scilab code Exa 14.2 Calculation of rate of heat removal and power input and heat rejection rate and COP

```
clc
// At P = .14 MPa
h1 = 236.04 // Enthalpy at state 1 in kJ/kg
s1 = 0.9322 // Entropy at state 2 in kJ/kgK
s2 = s1 // Isenthalpic process
// At P = 0.8 MPa
h2 = 272.05 // Enthalpy at state 2 in kJ/kg
h3 = 93.42 // Enthalpy at state 3 in kJ/kg
h4 = h3 // Isenthalpic process
m = 0.06 // mass flow rate in kg/s
Q2 = m*(h1-h4) // Heat absorption
Wc = m*(h2-h1) // Compressor work
Q1 = m*(h2-h4) // Heat rejection in evaporator
COP = Q2/Wc // coefficient of performance

printf("\n Example 14.2\n")
printf("\n The rate of heat removal is %f kW",Q2)
printf("\n Power input to the compressor is %f kW",Wc)
printf("\n The heat rejection rate in the condenser is %f kW",Q1)
printf("\n COP is %f kW",COP)
//The answers vary due to round off error
```

Scilab code Exa 14.3 Calculation of refrigerant flow rate and volume flow rate compressor discharge temperature and pressure ratio and heat rejected to the condenser and flash gas percentage and COP and power required and ratio of COP of cycle with Carnot refrigerator

```
clc
h1 = 183.19 // Enthalpy at state 1 in kJ/kg
h2 = 209.41 // Enthalpy at state 2 in kJ/kg
h3 = 74.59 // Enthalpy at state 3 in kJ/kg
```

```
h4 = h3 // Isenthalpic process
T1 = 40 // Evaporator temperature in degree Celsius
T2 = -10 // Condenser temperature in degree Celsius
W = 5 // Plant capacity in tonnes of refrigeration
w = (W*14000/3600)/(h1-h4) // Refrigerant flow rate
v1 = 0.077 // Specific volume of vapor in m^3/kg
VFR = w*v1 // volume flow rate
T = 48 // Compressor discharge temperature in degree Celsius
P2 = 9.6066 // Pressure after compression
P1 = 2.1912 // Pressure before compression
rp = P2/P1 // Pressure ratio
Q1 = w*(h2-h3) // Heat rejected in condenser
hf = 26.87 // Enthalpy of fluid in kJ/kg
hfg = 156.31// Latent heat of vaporization in kJ/kg
x4 = (h4-hf)/hfg // quality of refrigerant
COP_v = (h1-h4)/(h2-h1) // Actual coefficient of performance of cycle
PI = w*(h2-h1) // Power input
COP = (T2+273)/((T1+273)-(T2+273)) // Ideal coefficient of performance
r = COP_v/COP
printf("\n Example 14.3\n")
printf("\n Refrigerant flow rate is %f kg/s",w)
printf("\n Volume flow rate is %f m^3/s",VFR)
printf("\n Compressor discharge temperature is %d degree Celsius ",T)
printf("\n Pressure ratio is %f ",rp)
printf("\n Heat rejected to the condenser is %f kW",Q1)
printf("\n Flash gas percentage is %f percent",x4*100)
printf("\n COP is %f kW",COP_v)
printf("\n Power required to drive the compressor is %f kW",PI)
printf("\n Ratio of COP of cycle with  Carnot refrigerator is %f",r)
//The answers vary due to round off error
```

Scilab code Exa 14.4 Calculation of sub cooling and flow rate and dimensions and COP and power

```
clc
h3 = 882 // Enthalpy at state 3 in kJ/kg
h2 = 1034 // Enthalpy at state 2 in kJ/kg
h6 = 998 // Enthalpy at state 6 in kJ/kg
h1 = 1008 // Enthalpy at state 1 in kJ/kg
v1 = 0.084 // Specific volume at state 1 in m^3/kg
t4 = 25 // Temperature at state 4 in degree Celsius
m = 10 // mass flow rate in kg/s
h4 = h3-h1+h6
h5 = h4 // isenthalpic process
w = (m*14000)/((h6-h5)*3600) // in kg/s
VFR = w*3600*v1 // Volume flow rate in m^3/h
ve = 0.8 // volumetric efficiency
CD = VFR/(ve*60) // Compressor displacement in m^3/min
N = 900 // Number of strokes per minute
n = 2 // number of cylinder

D = ((CD*4)/(%pi*1.1*N*n))^(1/3) // L = 1.1D L = length D = diameter
L = 1.1*D
COP = (h6-h5)/(h2-h1) // coefficient of performance
PI = w*(h2-h1) // Power input

printf("\n Example 14.4\n")
printf("\n Refrigeration effect is %d kJ/kg",h6-h5)
printf("\n Refrigerant flow rate is %f kg/s",w)
printf("\n Diameter of cylinder is %f cm",D*100)
printf("\n Length of cylinder is %f cm",L*100)
```

```
printf("\n COP is %f ",COP)
printf("\n Power required to drive the compressor is
    %f kW",PI)

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

Scilab code Exa 14.5 Calculation of work and COP and increase in work and increase in COP

```
clc
P2 = 1554.3 // Pressure at state 2 in kPa
P1 = 119.5// Pressure at state 1 in kPa
Pi = sqrt(P1*P2)
h1 = 1404.6 // Enthalpy at state1 in kJ/kg
h2 = 1574.3 // Enthalpy at state2 in kJ/kg
h3 = 1443.5 // Enthalpy at state3 in kJ/kg
h4 = 1628.1// Enthalpy at state4 in kJ/kg
h5 = 371.7 // Enthalpy at state5 in kJ/kg
h6 = h5 // Isenthalpic process
h7 = 181.5// Enthalpy at state7 in kJ/kg
w = 30 // capacity of plant in tonnes of
   refrigeration
m2_dot = (3.89*w)/(h1-h7) // mass flow rate in upper
    cycle
m1_dot = m2_dot*((h2-h7)/(h3-h6))// mass flow rate
   in lower cycle
Wc_dot = m2_dot*(h2-h1)+m1_dot*(h4-h3) // Compressor
    work
COP = w*3.89/Wc_dot // Coefficient of performance of
    cycle
// single stage
h1_ = 1404.6 //Enthalpy at state1 in kJ/kg
h2_ = 1805.1 // Enthalpy at state2 in kJ/kg
```

```
h3_ = 371.1 // Enthalpy at state3 in kJ/kg
h4_ = h3_ // Isenthalpic process
m_dot = (3.89*30)/(h1_-h4_) // mass flow rate in cycle
Wc = m_dot*(h2_-h1_) // Compressor work
COP_ = w*3.89/Wc // Coefficient of performance of cycle
IW = (Wc-Wc_dot)/Wc_dot // Increase in compressor work
ICOP = (COP-COP_)/COP_ // Increase in COP for 2 stage compression
printf("\n Example 14.5\n")
printf("\n Increase in work of compression for single stage  is %f percent",IW*100)
printf("\n Increase in COP for 2 stage compression is %f percent",ICOP*100)
//The answers vary due to round off error
```

Scilab code Exa 14.6 Calculation of COP and mass flow rate

```
clc
// Given that
te = -10 // Evaporator temperature in degree celsius
pc = 7.675 // Condenser pressure in bar
pf = 4.139 // Flash chamber pressure in bar
P = 100 // Power input to compressor in kW
printf("\n Example 14.6\n")
// From the property table of R-134a,
h7 = 140.96 // In kJ/kg
hf = 113.29 // In kJ/kg
hfg = 300.5-113.29 // In kJ/kg
hg = 300.5 // In kJ/kg
h1 = 288.86 // In kJ/kg
```

```
s1 = 1.17189 // // In kJ/kgK
s2 =s1
//By interpolation
h2 = 303.468 // In kJ/kg
x8 = (h7-hf)/hfg
m1=x8
h5 = (1-m1)*h2 + m1*hg
// By interpolation
s5 = 1.7174 // In kJ/kgK
s6=s5
h6 = 315.79 // In kJ/kg
m = P/((h6-h5) + (1-m1)*(h2-h1))
m_e = (1-m1)*m
COP = m_e*(h1-hf)/P
printf("\n The COP of the plant is %f, \n The mass flow rate of refrigerant in the evaporator is %f kg/s",COP,m_e)
```

Scilab code Exa 14.7 Calculation of COP and flow rate

```
clc
tsat = 120.2 // Saturation temperature in degree Celsius
hfg = 2201.9 // Latent heat of fusion in kJ/kg
T1 = 120.2 // Generator temperature in degree Celsius
T2 = 30 // Ambient temperature in degree Celsius
Tr = -10 // Operating temperature of refrigerator in degree Celsius
COP_max = (((T1+273)-(T2+273))*(Tr+273))/(((T2+273)-(Tr+273))*(T1+273)) // Ideal coefficient of performance
ACOP = 0.4*COP_max // Actual COP
```

```
L =  20 // Refrigeration load in tonnes
Qe = (L*14000)/3600 // Heat extraction in KW
Qg = Qe/ACOP // Heat transfer from generator
x = 0.9 // Quality of refrigerant
H = x*hfg // Heat extraction
SFR = Qg/H // Steam flow rate
printf("\n Example 14.7\n")
printf("\n Steam flow rate required is %f kg/s",SFR)
//The answers vary due to round off error
```

Scilab code Exa 14.8 Calculation of COP

```
clc
// Given that
tf = 5 // Temperature of flash chamber in degree celsius
x = 0.98 // Quality of water vapour living the evaporator
t2 = 14 // Returning temperature of chilled water in degree celsius
t0 = 30 // Make up water temperature in degree celsius
m = 12 // Mass flow rate of chilled water in kg/s
nc = 0.8 // Compressor efficiecy
pc = 0.1 // Condenser pressure in bar
printf("\n Example 14.8\n")
//From the steam table
hf = 58.62 // In kJ/kg at 14 degree celsius
hf_ = 20.93 // In kJ/kg at 5 degree celsius
hf__ = 125.73 // In kJ/kg at 30 degree celsius
hv = x*2510.7
Rc = m*(hf-hf_)/3.5
m_v = Rc*3.5/(hv-hf__)
```

```
// At 0.10 bar
hg = 2800 // In kJ/kg
Win = m_v*(hg-hv)/nc
COP = Rc*3.5/Win
printf("\nCOP of the system is %f",COP)
```

Scilab code Exa 14.9 Calculation of COP and power

```
clc
T1 = 4 // Compressor inlet temperature in degree Celsius
T3 = 55 // Cooling limit in heat exchanger in degree Celsius
rp = 3 // Pressure ratio
g = 1.4 // Heat capacity ratio
cp = 1.005 // Constant volume heat capacity
L = 3 // Cooling load in tonnes of refrigeration
nc = 0.72 // compressor efficiency
T2s = (T1+273)*(rp^((g-1)/g)) // Ideal temperature after compression
T2 = (T1+273)+(T2s-T1-273)/nc // Actual temperature after compression
T4s = (T3+273)/(rp^((g-1)/g)) // Ideal temperature after expansion
T34 = 0.78*(T3+273-T4s) // Change in temperature during expansion process
T4 = T3+273-T34 // Actual temperature after expansion
COP = (T1+273-T4)/((T2-T1-273)-(T3+273-T4)) // Coefficient of performance of cycle
P = (L*14000)/(COP*3600) // Driving power required
m = (L*14000)/(cp*(T1+273-T4)) // Mass flow rate of air
```

```
printf("\n Example 14.9\n")
printf("\n COP of the refrigerator is %f",COP)
printf("\n Driving power required is %f kW",P)
printf("\n Mass flow rate is %f kg/s",m/3600)
//The answers vary due to round off error
```

Scilab code Exa 14.10 Calculation of power and heating capacity and COP and efficiency

```
clc
P1 = 2.4  //Compressor inlet pressure in bar
T1 = 0 // Compressor inlet temperature in degree Celsius
h1 = 188.9 // Enthalpy of refrigerant at state 1 in kJ/kg
s1 = 0.7177 // Entropy of refrigerant at state 1 in kJ/kgK
v1 = 0.0703 // Specific volume at state 1 in m^3/kg
P2 = 9 // Compressor outlet pressure in bar
T2 = 60 // Compressor outlet pressure in degree Celsius
h2 = 219.37 // Actual compressor outlet enthalpy in kJ/kgK
h2s = 213.27 // Ideal compressor outlet enthalpy in kJ/kgK
h3 = 71.93 // Enthalpy of refrigerant at state 3 in kJ/kg
h4 = h3 // Isenthalpic process

A1V1 = 0.6/60 // volume flow rate in kg/s
m_dot = A1V1/v1 // mass flow rate
Wc_dot = m_dot*(h2-h1) // Compressor work
Q1_dot = m_dot*(h2-h3) // Heat extracted
```

```
COP = Q1_dot/Wc_dot // Coefficient of performance
nis = (h2s-h1)/(h2-h1) // Isentropic compressor efficiency
printf("\n Example 14.10\n")
printf("\n Power input is %f kW",Wc_dot)
printf("\n Heating capacity is %f kW",Q1_dot)
printf("\n COP is %f",COP)
printf("\n The isentropic compressor efficiency is %f percent",nis*100)
//The answers vary due to round off error
```

Scilab code Exa 14.11 Calculation of pressure ratio and COP

```

clc
T1 = 275 // Temperature of air at entrance to compressor in K
T3 = 310 // Temperature of air at entrance to turbine in K
P1 = 1  // Inlet pressure in bar
P2 = 4 // Outlet pressure in bar
nc = 0.8 // Compressor efficiency
T2s = T1*(P2/P1)^(.286) // Ideal temperature after compression
T2 = T1 + (T2s-T1)/nc // Actual temperature after compression
pr1 = 0.1 // Pressure loss in cooler in bar
pr2 = 0.08 //Pressure loss in condenser in bar
P3 = P2-0.1 // Actual pressure in condenser
P4 = P1+0.08 // Actual pressure in evaporator
PR = P3/P4 // Pressure ratio
T4s = T3*(1/PR)^(0.286) // Ideal temperature after expansion
```

```
nt = 0.85 // turbine efficiency
T4 = T3-(T3-T4s)*nt // Actual temperature after
    expansion
COP = (T1-T4)/((T2-T3)-(T1-T4)) // Coefficient of
    performance
printf("\n Example 14.11\n")
printf("\n Pressure ratio for the turbine is %f ",PR
    )
printf("\n COP is %f ",COP)
//The answers vary due to round off error
```

Scilab code Exa 14.12 Calculation of flow rate and COP

```
clear
clc
// Given that
L = 60 // Cooling load in kW
p = 1 // Pressure in bar
t = 20 // Temperature in degree celsius
v = 900 // Speed of aircraft in km/h
p1 = 0.35 // Pressure in bar
T1 = 255 // Temperature in K
nd = .85 // Diffuser efficiency
rp = 6 // Pressure ratio of compressor
nc = .85 // Copressor efficiency
E = 0.9 // Effectiveness of air cooler
nt = 0.88 // Turbine efficiency
p_ = 0.08 // Pressure drop in air cooler in bar
p5 =  1.08 // Pressure in bar
cp = 1.005 // Heat capacity of air at constant
    pressure in kJ/kgK
gama = 1.4 // Ratio of heat capacities of air
printf("\n Example 14.12\n")
```

```
V = v*(5/18)
T2_ = T1 + (V^2)/(2*cp*1000)
T2 = T2_
p2_ = p1*((T2_/T1)^((gama/(gama-1))))
p2 = p1 + nd*(p2_-p1)
p3 = rp*p2
T3_ = T2*((p3/p2)^((gama-1)/gama))
T3 = T2 + (T3_-T2)/nc
P = cp*(T3-T2)
p4 = p3 - p_
T4 = T3 - E*(T3-T2)
T5_ = T4/((p4/p5)^(.286))
T5 = T4 - (T4-T5_)/nt
RE = cp*(t+273 - T5)
m = L/51.5
Pr = m*P
COP = L/Pr
printf("\n Mass flow rate of air flowing through the
    cooling system is %f kg/s",m)
printf("\n COP is %f ",COP)
//The answers vary due to round off error
```

Chapter 15

Psychrometrics and air conditioning systems

Scilab code Exa 15.1 Calculation of specific humidity and partial pressure and dew point temperature and relative humidity and degree of saturation and density of dry air and density of water vapor and enthalpy of the mixture

```
clc
Ps = 0.033363 //Saturation pressure in bar
P = 1.0132 // Atmospheric pressure in bar
W2 = (0.622*Ps)/(P-Ps) // mass fraction of moisture
hfg2 = 2439.9 // Latent heat of vaporization in kJ/kg
hf2 = 109.1 // Enthalpy of liquid moisture in kJ/kg
cpa = 1.005 // Constant pressure heat capacity in kJ/kg
hg = 2559.9 // Enthalpy of gas moisture in kJ/kg
hw1 = hg // constant enthalpy
T2 = 26 // wbt in degree Celsius
T1 = 32 // dbt in degree Celsius
W1 = (cpa*(T2-T1)+(W2*hfg2))/(hw1-hf2)
Pw = ((W1/0.622)*P)/(1+(W1/0.622))

Psat = 0.048 // Saturation pressure in bar at 32
```

```
degree
fi = Pw/Psat // Relative humidity

mu = (Pw/Psat)*((P-Psat)/(P-Pw)) // Degree of Saturation
Pa = P-Pw // Air pressure
Ra = 0.287 // Gase constant
Tdb = T1+273 //  dbt in K
rho_a = (Pa*100)/(Ra*Tdb) // Density of air
rho_w = W1*rho_a // Water vapor density
ta = 32 // air temperature in degree Celsius
tdb = 32 // dbt in degree Celsius
tdp = 24.1// Dew point temperature in degree Celsius
h = cpa*ta + W1*(hg+1.88*(tdb-tdp))
printf("\n Example 15.1\n")
printf("\n Specific humidity is %f kg vap./kg dry air",W1)
printf("\n Partial pressure of water vapour is %f bar",Pw)
printf("\n Dew point temperature is %f degree celcius",tdp)
printf("\n Relative humidity is %f percent ",fi*100)
printf("\n Degree of saturation is %f ",mu)
printf("\n Density of dry air is %f kg/m^3",rho_a)
printf("\n Density of water vapor is %f kg/m^3",rho_w)
printf("\n Enthalpy of the mixture is %f kJ/kg",h)
//The answers vary due to round off error
```

Scilab code Exa 15.2 Calculation of humidity ratio and relative humidity

```
clc
Ps = 2.339 // Satutation pressure in kPa
```

```
P = 100 // Atmospheric pressure in kPa
W2 = (0.622*Ps)/(P-Ps) // Specific humidity
hfg2 = 2454.1 // Latent heat of vaporization in kJ/kg
hf2 = 83.96 // Enthalpy of fluid in kJ/kg
cpa = 1.005 // COnstant pressure heat capacity of air
hw1 = 2556.3// ENthalpy of water
T2 = 20  // Exit tempeature of mixture in degree Celsius
T1 = 30 // Inlet tempeature of mixture in degree Celsius
W1 = (cpa*(T2-T1)+(W2*hfg2))/(hw1-hf2) // Specific humidity at inlet
Pw1 = ((W1/0.622)*P)/(1+(W1/0.622)) // pressure due to moisture
Ps1 = 4.246 // Saturation pressure in kPa
fi = (Pw1/Ps1) // Humidity ratio

printf("\n Example 15.2\n")
printf("\n Humidity ratio of inlet mixture is %f kg vap./kg dry air",W1)
printf("\n Relative humidity is %f percent",fi*100)
//The answers vary due to round off error
```

Scilab code Exa 15.3 Calculation of mass and temperature

```
clc
Psat = 2.339 // Saturation pressure in kPa
fi3 = 0.50 // Humidity ratio
P = 101.3 // Atmospheric pressure in kPa
cp = 1.005 // Constant pressure heat addition in kJ/kg
```

```
Pw3 = fi3*Psat // Vapor pressure
Pa3 = P-Pw3 // Air pressure
W3 = 0.622*(Pw3/Pa3) // Specific humidity
Psa1_1 = 0.7156 // Saturation pressure in kPa
Pw1 = 0.7156 // moister pressure in kPa
Pa1 = P-Pw1 // Air pressure
W1 = 0.622*(Pw1/Pa1)  // Specific humidity
W2 = W1 // Constant humidity process
T3 = 293 // Temperature at state 3 in K
Ra = 0.287 // Gas constant
Pa3 = 100.13 // Air pressure at state 3
va3 = (Ra*T3)/Pa3 // volume of air at state 3
SW = (W3-W1)/va3 // spray water
tsat = 9.65 // Saturation temperature in K
hg = 2518 // Enthalpy of gas in kJ/kg
h4 = 10 // Enthalpy at state 4 in kJ/kg
t3 = T3-273
t2 = ( W3*(hg+1.884*(t3-tsat))-W2*(hg-1.884*tsat) + cp*t3 - (W3-W2)*h4 )/ (cp+W2*1.884)
printf("\n Example 15.3\n")
printf("\n Mass of spray water required is %f kg moisture/m^3",SW)
printf("\n Temperature to which air must be heated is %f degree celcius",t2)
//The answers vary due to round off error
```

Scilab code Exa 15.4 Calculation of capacity of coils and rate of water vapor removal

```
clc
h1 = 82 // Enthalpy at state 1 in kJ/kg
h2 = 52 // Enthalpy at state 2 in kJ/kg
h3 = 47 // Enthalpy at state 3 in kJ/kg
```

```
h4 = 40// Enthalpy at state 4 in kJ/kg
W1 = 0.020 // Specific humidity at state 1
W2 = 0.0115// Specific humidity at state 2
W3 = W2 // Constant humidity process
v1 = 0.887 // Specific volume at state 1
v = 3.33 // amount of free sir circulated
G = v/v1 // air flow rate
CC = (G*(h1-h3)*3600)/14000 // Capacity of the heating Cooling coil
R = G*(W1-W3) // Rate of water vapor removal
HC = G*(h2-h3) //Capacity of the heating coil
printf("\n Example 15.4\n")
printf("\n Capacity of the cooling coil is %f tonnes ",CC)
printf("\n Capacity of the heating coil is %f kW",HC)
printf("\n Rate of water vapor removal is %f kg/s",R)
//The answers vary due to round off error
```

Scilab code Exa 15.5 Calculation of specific humidity and enthalpy

```
clc
W1 = 0.0058 // Humidity ratio for first stream
W2 = 0.0187 // Humidity ratio for second stream
h1 = 35 // Enthalpy of first stream in kJ/kg
h2 = 90// Enthalpy of second stream in kJ/kg
G12 = 1/2 //ratio
W3 = (W2+G12*W1)/(1+G12) // Final humidity ratio of mixture
h3 = (2/3)*h2 + (1/3)*h1// Final enthalpy of mixture

printf("\n Example 15.5 \n")
```

```
printf("\n Final condition of air is given by")
printf("\n W3 = %f kg vap./kg dry air",W3)
printf("\n h3 =  %f kJ/kg dry air",h3)
//The answers vary due to round off error
```

Scilab code Exa 15.6 Calculation of temperature and heat rejected and relative humidity and dew point temperature and moisture removed

```
clc
// Given that
t = 21 // Temperature in degreee celsius
w = 20 // Relative humidity in percentage
t_ = 21 // Final temperature of air in degree
    celsius
printf("\n Example 15.6 \n")
// From the psychrometric chart
T2 = 38.5 // In degree celsius
h1_3 = 60.5-42 // In kJ/kg
fi3 = 53 // In percentage
t4 = 11.2 // In degree celsius
W1_2 = 0.0153-0.0083 // In kg vap /kg dry air
printf("\n The temperature of air at the end of the
    drying process is %f degree celsius,\n Heat
    rejected during the cooling process is %f kJ/kg,\
    n The relative humidity is %f percent,\n The dew
    point temperature at the end of drying process is
     %f degree celsius,\n The moisture removed during
     the drying process is %f kg vap/kg dry air",T2,
    h1_3,fi3,t4,W1_2)
```

Scilab code Exa 15.7 Calculation of capacity of coil and humidifier

```
clc
h1 = 57 // Enthalpy at state 1 in kJ/kg
h2 = h1 // Isenthalpic process
h3 = 42 // Enthalpy at state 3 in kJ/kg
W1 = 0.0065 // Humidity ratio at sate 1
W2 = 0.0088 // Humidity ratio at sate 2
W3 = W2 // Constant humidity ratio process
t2 = 34.5 // Temperature at state 2
v1 = 0.896// Specific volume at state 1 in m^3/kg
n = 1500 // seating capacity of hall
a = 0.3 // amount of outdoor air supplied m^3 per
    person
G = (n*a)/0.896  // Amount of dry air supplied
CC = (G*(h2-h3)*60)/14000 // Cooling capacity
R = G*(W2-W1)*60 // Capacity of humidifier

printf("\n Example 15.7 \n")
printf("\n Capacity of the cooling coil is %f tonnes
    ",CC)
printf("\n Capacity of humidifier is %f kg/h",R)
//The answers vary due to round off error
```

Scilab code Exa 15.8 Calculation of temperature and range of cooling water and approach of cooling water and fraction of water evaporated

```
clc
```

```
twb1 = 15.2// Wbt in degree Celsius
twb2 = 26.7// Wbt in degree Celsius
tw3 = 30  // Temperature at state 3 in degree Celsius
h1 = 43 // Enthalpy at state 1 in kJ/kg
h2 = 83.5 // Enthalpy at state 2 in kJ/kg
hw = 84 // Enthalpy of water in kJ/kg
mw = 1.15 // mass flow rate of water in kg/s
W1 = 0.0088 // Humidity ratio of inlet stream
W2 = 0.0213 // Humidity ratio of exit stream
hw3 = 125.8 // Enthalpy of water entering tower in kJ/kg
hm = 84 // Enthalpy of make up water in kJ/kg
G = 1 // mass flow rate of dry air in kg/s
hw34 = (G/mw)*((h2-h1)-(W2-W1)*hw)  // Enthalpy change
tw4 = tw3-(hw34/4.19) // Temperature of water leaving the tower
A = tw4-twb1 //Approach of cooling water
R = tw3-tw4 //Range of cooling water
x = G*(W2-W1) //Fraction of water evaporated

printf("\n Example 15.8\n")
printf("\n Temperature of water leaving the tower is %f degree celcius",tw4)
printf("\n Range of cooling water is %f degree Celsius",R)
printf("\n Approach of cooling water is %f degree celcius",A)
printf("\n Fraction of water evaporated is %f kg/kg dry air",x)
//The answers vary due to round off error
```

Scilab code Exa 15.9 Calculation of bypass factor

```
clc
// Given that
DBT = 40 // Dry bulb temperature in degree celsius
DBT_ = 25 // Dry bulb temperature after cooling and
   dehumidification in degree celsius
RH = 70 // Relative humidity in percentage
f = 30 // Air flow rate in cmm
printf("\n Example 15.9 \n")
// From the psychrometric chart
v1 = 0.9125 // In m^3/kg
G = f/v1
h5 = 41.5 // In kJ/kg
W1 = 0.0182 // In kg vapor/kg dry air
h1 = 86 // In kJ/kg d.a.
W2 = 0.0136 // In kg vapor/kg dry air
h2 = 60 // In kJ/kg
L = G*(h1-h2)/3.5
Mo = G*(W1-W2)
x = (h2-h5)/(h1-h5)
printf("\n Bypass factor of coolin coil is  %f ",x)
// Answer veries due to round off error
```

Scilab code Exa 15.10 Calculation of capacity of heating coil and surface temperature and capacity of humidifier

```
clc
// Given that
c = 75 // Capacity of classroom in no of perasons
DBT1 = 10 // Outdoor Dry bulb temperature in degree
   celsius
WBT1 = 8 // Outdoor Wet bulb temperature in degree
```

```
celsius
DBT2 = 20 // Indoor Dry bulb temperature in degree celsius
RH2 = 50 // Relative humidity in percentage
x =0.5 // Bypass factor
f = 0.3 // Air flow rate per person in cmm
printf("\n Example 15.10 \n")
// From the psychrometric chart
W1 = 0.0058 // In kg moisture/kg d.a.
h1 = 24.5 // In kJ/kg
h2 = 39.5 // In kJ/kg
h3 = h2
W3 = 0.0074 // In kg moisture/kg d.a.
t2 = 25 // In degree celsius
v1 = .81 // In m^3/kg d.a.
G = f*c/v1
C = G*(h2-h1)/60
t4 = (t2-x*DBT1)/(1-x)
ts = t4
C_H = G*(W3-W1)*60
printf("\n Capacity of heating coil is %f kW,\n Surface temperature of heating coil is %d degree celsius ,\n Capacity of humidifier is %f kg/h ",C,ts,C_H)
```

Scilab code Exa 15.11 Calculation of DBT and WBT and coil bypass factor

```

clc
// Given that
DBT = 31 // Dry bulb temperature in degree celsius
WBT = 18.5 // Wet bulb temperature in degree celsius
```

```
t = 4.4 // Effective surface temperature of coil in
    degree celsius
RE = 12.5 // Refrigeration effect by the coil in kW
f= 39.6 // Air flow rate in cmm
printf("\n Example 15.11 \n")
// From the fig. given in the example
ws = 5.25 //In g/kg d.a.
hs = 17.7 //In kJ/kg d.a.
v1 = 0.872 // In m^3/kg d.a.
h1 = 52.5 // In kJ/kg d.a.
w1 = 8.2 // In g/kg d.a.
G = f/v1
h2 = h1-(RE*60)/G
w2 = w1-((h1-h2)/(h1-hs))*(w1-ws)
// From the psychrometric chart
t2 = 18.6 // In degree celsius
t_ = 12.5 // In degree celsius
x = (h2-hs)/(h1-hs)
printf("\n DBT of air leaving the coil is %f degree
    celsius,\n WBT of air leaving the coil is %f
    degree celsius,\n Coil bypass factor is %f ",t2,
    t_,x)
// Answer varies due to round off error
```

Scilab code Exa 15.12 Calculation of capacity and bypass factor and mass of water vapor removed

```

clc
// Given that
c = 75 // Capacity of classroom in no of persons
DBT1 = 35 // Outdoor Dry bulb temperature in degree
    celsius
```

```
RH1 = 70 // Outdoor relative humidity in percentage
DBT2 = 20 // Indoor Dry bulb temperature in degree celsius
RH1 = 60 // Indoor relative humidity in percentage
DPT = 10 // Cooling coil dew point temperature in degree celsius
x =0.25 // Bypass factor
f = 300 // Air flow rate in cmm
printf("\n Example 15.12 \n")
// From the psychrometric chart
W1 = 0.0246 // In kg vap./kg d.a.
h1 = 98 // In kJ/kg
v1 = .907 // In m^3/kg d.a.
h3 = 42 // In kJ/kg
W3 = 0.0088 // In kg moisture/kg d.a.
h2 = 34 // In kJ/kg
hs = 30 // In kJ/kg
t2 = 12 // In degree celsius
G = f/v1
C = G*(h1-h2)/(60*3.5)
X = (h2-hs)/(h1-hs)
C_ = G*(h3-h2)/60
t4 = (DBT2-x*t2)/(1-x)
C_H = G*(W1-W3)
printf("\n Capacity of cooling coil is %f tonnes,\n Bypass factor of cooling coil is %f,\n Capacity of heating coil is %f kW,\n Surface temperature of heating coil is %f degree celsius,\n Mass of water vapor removed is %f kg/min ",C,X,C_,t4,C_H)
//Answers varies due to round off error
```

Scilab code Exa 15.13 Calculation of make up water flow rate and volume flow rate

```
clc
// at 15 degree Celsius
Psat1 = 0.01705  // Saturation pressure in bar
hg1 = 2528.9 // Enthalpy in kJ/kg
// At 35 degree Celsius
Psat2 = 0.05628 // Saturation pressure in bar
hg2 = 2565.3 // Enthalpy in kJ/kg
fi1 = 0.55// Humidity ratio at state 1
Pw1 = fi1*Psat1 // water vapor pressure at state 1
fi2 = 1 // Humidity ratio at state 2
Pw2 = fi2*Psat2 // water vapor pressure at state 2
P = 0.1 // Atmospheric pressure in MPa
W1 = (0.622*Pw1)/(P*10-Pw1)
W2 = (0.622*Pw2)/(P*10-Pw2)
MW = W2-W1 // unit mass flow rate of water
t2 = 35 // Air exit temperature in degree Celsius
t1 = 14 // make up water inlet temperature in degree
    Celsius
m_dot = 2.78 // water flow rate in kg/s
cpa = 1.005 // Constant pressure heat capacity ratio
    in kJ/kg
h43 = 35*4.187 // Enthalpy change
h5 = 14*4.187 // Enthalpy at state 5in kJ/kg
m_dot_w = (-(W2-W1)*h5 - W1*hg1 + W2*hg2 + cpa*(t2-
   t1))/(h43)
R = m_dot/m_dot_w
MW = (W2-W1)*R //Make up water flow rate
RWA = R*(1+W1)
R = 0.287 // Gas constant
V_dot = (RWA*R*(t1+273))/(P*1e03)  // Volume flow
   rate of air
printf("\n Example 15.13\n")
printf("\n Make up water flow rate is %f kg/s",MW)
printf("\n Volume flow rate of air is %f m^3/s",
   V_dot)
//The answers vary due to round off error
```

Chapter 16

Reactive systems

Scilab code Exa 16.2 Calculation of heat of reaction

```
clc
eps_e = 0.27  // Constant
P = 1 // Atmospheric pressure in bar
K = (4*eps_e^2*P)/(1-eps_e^2)
P1 = 100/760 // Pressure in Pa
eps_e_1 = sqrt((K/P1)/(4+(K/P1)))
T1 = 318 // Temperature in K
T2 = 298// Temperature in K
R = 8.3143 // Gas constant
K1 = 0.664 // dissociation constant at 318K
K2 = 0.141// dissociation constant at 298K
dH = 2.30*R*((T1*T2)/(T1-T2))*(log10(K1/K2))
printf("\n Example 16.2\n")
printf("\n K is %f atm",K)
printf("\n Epsilon is %f ",eps_e_1)
printf("\n The heat of reaction is %d kJ/kg mol",dH)
//The answers vary due to round off error
```

Scilab code Exa 16.3 Calculation of equilibrium constant and Gibbs function change

```
clc
v1 = 1 // Assumed
v2 = v1// Assumed
v3 = v2 // Assumed
v4 = v2// Assumed
e = 0.56 // Degree of reaction
P = 1 // Dummy
T = 1200 // Reaction temperature in K
R = 8.3143 // Gas constant
x1 = (1-e)/2 //
x2 = (1-e)/2
x3 = e/2
x4 = e/2
K = (((x3^v3)*(x4^v4))/((x1^v1)*(x2^v2)))*P^(v3+v4-
    v1-v2) // Equilibrium constant
dG = -R*T*log(K) //Gibbs function change

printf("\n Example 16.3\n")
printf("\n Equilibrium constant is %f",K)
printf("\n Gibbs function change is %fJ/gmol",dG)
//The answers vary due to round off error
```

Scilab code Exa 16.5 Calculation of equilibrium constant

```
clc
```

```
Veo = 1.777 // Ve/Vo
e = 1-Veo // Degree of dissociation
P = 0.124 // in atm
K = (4*e^2*P)/(1-e^2)

printf("\n Example 16.5\n")
printf("\n The value of equillibrium constant is %f
    atm",K)
```

Scilab code Exa 16.6 Calculation of heat capacity

```
clc
v1 = 1 // Assumed
v2 = 0 // Assumed
v3 = 1 // Assumed
v4 = 1/2// Assumed
dH = 250560 // Enthalpy change in j/gmol
e = 3.2e-03 // Constant
R = 8.3143 // Gas constant
T = 1900 // Reaction temperature
Cp = ((dH^2)*(1+e/2)*e*(1+e))/(R*T^2*(v1+v2)*(v3+v4)
    )
printf("\n Example 16.6\n")
printf("\n Cp is %f J/g mol K",Cp)
//The answers vary due to round off error
```

Scilab code Exa 16.7 Calculation of composition of fuel and air fuel ratio

```
clc
```

```
a = 21.89 // stochiometric coefficient
y = 18.5 // stochiometric coefficient
x = 8.9 // stochiometric coefficient
PC = 100*(x*12)/((x*12)+(y)) // Carbon percentage
PH = 100-PC // Hydrogen percentage
AFR = ((32*a)+(3.76*a*28))/((12*x)+y) //Air fuel ratio
EAU = (8.8*32)/((21.89*32)-(8.8*32)) // Excess air used

printf("\n Example 16.7\n")
printf("\n The composition of fuel is %f percent Hydrogen and %f percent Carbon",PH,PC) //The answer provided in the textbook is wrong
printf("\n Air fuel ratio is %f ",AFR)
printf("\n Percentage of excess air used is %f percent",EAU*100)
//The answers vary due to round off error
```

Scilab code Exa 16.8 Calculation of heat transfer

```
clc
hf_co2 = -393522 // Enthalpy of reaction in kJ/kg mol
hf_h20 = -285838// Enthalpy of reaction in kJ/kg mol
hf_ch4 = -74874// Enthalpy of reaction in kJ/kg mol
D = hf_co2 + (2*hf_h20) //Heat transfer
QCV = D-hf_ch4 // Q_cv

printf("\n Example 16.8\n")
printf("\n Heat transfer per kg mol of fuel is %d kJ",D)
printf("\n Q_cv is %d kJ",QCV)
```

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

Scilab code Exa 16.9 Calculation of fuel consumption rate

```
clc
// Below values are taken from table
Hr = -249952+(18.7*560)+(70*540)
Hp = 8*(-393522+20288)+9*(-241827+16087)
   +6.25*14171+70*13491
Wcv = 150 // Energy out put from engine in kW
Qcv = -205 // Heat transfer from engine in kW
n = (Wcv-Qcv)*3600/(Hr-Hp)
printf("\n Example 16.9 \n")
printf("\n Fuel consumption rate is %f kg/h",n*114)
//The answers vary due to round off error
```

Scilab code Exa 16.10 Calculation of adiabatic flame temperature

```
clc
Hr1 = -249952 // For octane
Hp1 = Hr1
// Below values are calculated using value from
   table
T2 = 1000  // Assumed reaction temperature in K
Hp2 = -1226577 // Enthalpy of reaction products
T3 = 1200  // Assumed reaction temperature in K
Hp3 = 46537// Enthalpy of reaction products
T4 = 1100// Assumed reaction temperature in K
Hp4 = -595964 // Enthalpy of reaction products
```

```
Hp = [Hp2 Hp3 Hp4]
T = [T2 T3 T4]
T1 = interpln([Hp;  T],Hp1) // Interpolation to find
    temperature at Hp1
printf("\n Example 16.10 \n")
printf("\n The adiabatic flame temperature is %f K",
   T1)
//The answer provided in the textbook is wrong
```

Scilab code Exa 16.11 Calculation of reversible work and increase in entropy and irreversibility and availability

```
clc
// Refer table 16.4 for values
T0 = 298 // Atmospheric temperature in K
Wrev = -23316-3*(-394374)-4*(-228583) // Reversible
   work in kJ/kg mol
Wrev_ = Wrev/44 // Reversible work in kJ/kg
Hr = -103847 // Enthalpy of reactants in kJ/kg
T = 980 // Through trial and error
Sr = 270.019+20*205.142+75.2*191.611 // Entropy of
   reactants
Sp = 3*268.194 + 4*231.849 + 15*242.855 +
   75.2*227.485 // Entropy of products
IE = Sp-Sr // Increase in entropy
I = T0*3699.67/44 // Irreversibility
Si = Wrev_ - I// Availability of products of
   combustion

printf("\n Example 16.11 \n")
printf("\n Reversible work is %f kJ/kg",Wrev_)
printf("\n Increase in entropy during combustion is
   %f kJ/kg mol K",Sp-Sr)
```

```
printf("\n Irreversibility of the process %f kJ/kg",I)
printf("\n Availability of products of combustion is %f kJ/kg",Si)
//The answers vary due to round off error
```

Scilab code Exa 16.12 Calculation of chemical energy

```

clc
T0 = 298.15 // Environment temperature in K
P0 = 1 // Atmospheric pressure in bar
R = 8.3143// Gas constant
xn2 = 0.7567  // mole fraction of nitrogen
xo2 = 0.2035 // mole fraction of oxygen
xh2o = 0.0312 // mole fraction of water
xco2 = 0.0003// mole fraction of carbon dioxide
// Part (a)
g_o2 = 0 // Gibbs energy of oxygen
g_c = 0 // Gibbs energy of carbon
g_co2 = -394380  // Gibbs energy of carbon dioxide
A = -g_co2 + R*T0*log(xo2/xco2) // Chemical energy

// Part (b)
g_h2 = 0 // Gibbs energy of hydrogen
g_h2o_g = -228590// // Gibbs energy of water
B = g_h2 + g_o2/2 - g_h2o_g + R*T0*log(xo2^0.5/xh2o)
// Chemical energy
// Part (c)
g_ch4 = -50790 // Gibbs energy of methane
C = g_ch4 + 2*g_o2 - g_co2 - 2*g_h2o_g + R*T0*log((xo2^2)/(xco2*xh2o))
// Chemical energy
```

```
// Part (d)
g_co = -137150// // Gibbs energy of carbon mono oxide
D =  g_co + g_o2/2 - g_co2 + R*T0*log((xo2^0.5)/xco2)
// Chemical energy
// Part (e)
g_ch3oh = -166240 // Gibbs energy of methanol
E = g_ch3oh + 1.5*g_o2 - g_co2 - 2*g_h2o_g + R*T0*log((xo2^1.5)/(xco2*(xh2o^2)))
// Chemical energy
// Part (f)
F = R*T0*log(1/xn2)
// Chemical energy
// Part (g)
G = R*T0*log(1/xo2)
// Chemical energy
// Part (h)
H = R*T0*log(1/xco2)
// Chemical energy
// Part (i)
g_h2o_l = -237180 //  Gibbs energy of liquid water
I = g_h2o_l - g_h2o_g + R*T0*log(1/xh2o)
// Chemical energy
printf("\n Example 6.12\n")
printf("\n The chemical energy of carbon is  %d kJ/k mol",A)
printf("\n The chemical energy of hydrogen is  %d kJ/k mol",B)
printf("\n The chemical energy of methane is  %d kJ/k mol",C)
printf("\n The chemical energy of Carbon monoxide is  %d kJ/k mol",D)
printf("\n The chemical energy of liquid methanol is  %d kJ/k mol",E)
printf("\n The chemical energy of nitrogen is  %d kJ/k mol",F)
printf("\n The chemical energy of Oxygen is  %d kJ/k
```

```
    mol",G)
printf("\n The chemical energy of Carbon dioxide is
    %d kJ/k mol",H)
printf("\n The chemical energy of Water is  %d kJ/k
    mol",I)
//The answers vary due to round off error
```

Scilab code Exa 16.13 Calculation of rate of heat transfer and second law of efficiency

```

clc
// Environment
T0 = 298.15 // Environment temperature in K
P0 = 1 // Atmospheric pressure in atm
R = 8.3143// Gas constant
xn2 = 0.7567  // mole fraction of nitrogen
xo2 = 0.2035 // mole fraction of oxygen
xh2o = 0.0312 // mole fraction of water
xco2 = 0.0003// mole fraction of carbon dioxide
xother = 0.0083 // Mole fraction of other gases
// Liquid octane
t1 = 25 // Temperature of liquid octane in degree
    centigrade
m = 0.57 // Mass flow rate in kg/h
T2 = 670 // Temperature of combustion product at
    exit in K
x1 = 0.114 // Mole fraction of CO2
x2 = .029 // Mole fraction of CO
x3 = .016 // Mole fraction of O2
x4 = .841 // Mole fraction of N2
Wcv = 1 // Power developed by the engine in kW
printf("\n Example 6.13\n")
```

```
// By carbon balance
b = 55.9
// By hydrogen balance
c=9
// By oxygen balance
a = 12.58
Qcv = Wcv- 3845872*(.57/(3600*114.22))
E = 5407843 // Chemical exergy of C8H18
nII = Wcv/(E*.57/(3600*114.22))
printf("\n The rate of heat transfer from the engine
    = %f kW,\n The second law of efficiency of the
    engine = %f percent",Qcv,nII*100)
```

Chapter 17

Compressible fluid flow

Scilab code Exa 17.1 Calculation of Mach no and velocity and pressure

```
clc
t0 = 37 // Stangnation temperature in degree Celsius
P = 40 // Duct static pressure in kPa
g = 1.4 // Heat capacity ratio
function [x] = speed(a,b,f)
  N = 100
  eps = 1e-5;
  if((f(a)*f(b))>0) then
    error('no root possible f(a)*f(b)>0');
    abort;
  end;
  if(abs(f(a))<eps) then
    error('solution at a');
    abort;
  end
  if(abs(f(b))<eps) then
    error('solution at b');
    abort;
  end
  while(N>0)
    c = (a+b)/2
```

```
    if(abs(f(c))<eps) then
      x = c ;
      x;
      return;
    end;
    if((f(a)*f(c))<0 ) then
      b = c ;
    else
      a = c ;
    end
    N = N-1;
  end
  error('no convergence');
  abort;
endfunction

deff('[y]=p(x)',['y = x^4 + (5*(x^2)) - 3.225 '])
x = speed(0.5,1,p);
T0 = t0+273;
M = x; // Mach number
g = 1.4; // gamma
R = 0.287;
T = T0/(1+((g-1)/2)*M^2);
c = sqrt(g*R*T*1000);
V = c*M;
P0 = P*((T0/T)^(g/(g-1)));

printf("\n Example 17.1\n")
printf("\n Mach number is %f ",M)
printf("\n Velocity is %f m/s",V)
printf("\n Stagnation pressure is %f kPa",P0)
//The answers vary due to round off error
```

Scilab code Exa 17.2 Calculation of mass flow rate and Mach no and temperature and pressure

```
clc
P1 = 0.18 // Diffuser static pressure in MPa
R = 0.287 // Gas constant
T1 = 37 // Static temperature
P0 = 0.1// Atmospheric pressure in MPa
A1 = 0.11 // intake area in m^2
V1 = 267 // Inlet velocity in m/s
w = (P1*1e3/(R*(T1+273)))*A1*V1 // mass flow rate
g = 1.4 // Heat capacity ratio
c1 = sqrt(g*R*(T1+273)*1000) // velocity
M1 = V1/c1 // Mach number
A1A_ = 1.0570 // A1/A* A* = A_
P1P01 = 0.68207 // pressure ratio
T1T01 = 0.89644// Temperature ratio
F1F_ = 1.0284// Impulse function ratio
A2A1 = 0.44/0.11  // Area ratio
A2A_ = A2A1*A1A_// Area ratio
M2 = 0.135 // Mach number
P2P02 = 0.987 // Pressure ratio
T2T02 = 0.996 // Temperature ratio
F2F_ = 3.46// Impulse function ratio
P2P1 = P2P02/P1P01 // Pressure ratio
T2T1 = T2T02/T1T01// Temperature ratio
F2F1 = F2F_/F1F_ // Impulse function ratio
P2 = P2P1*P1 // Outlet  pressure
T2 = T2T1*(T1+273) // Outlet temperature
A2 = A2A1*A1 // Exit area
F1 = P1*A1*(1+g*M1^2) // Impulse function
F2 = F2F1*F1 // Impulse function
Tint = F2-F1 // Internal thrust
Text = P0*(A2-A1) // External thrust
NT = Tint - Text  // Net thrust

printf("\n Example 17.2 \n")
printf("\n Mass flow rate of air through diffuser is
```

```
%f Kg/s",w)
printf("\n  Mach number of leaving air is %f ",M2)
printf("\n  Temperature of leaving air is %f degree celcius",T2-273)
printf("\n  Pressure of leaving air is %f MPa ",P2)
printf("\n Net thrust is %f kN",NT*1e3)

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

Scilab code Exa 17.3 Calculation of flow rate and temperature and pressure and velocity

```
clc
M2 = 2.197 // Mach number
P2P0 = 0.0939 // pressure ratio
T2T0 = 0.5089 // Temperature ratio
P0 = 1 // Stagnation pressure in MPa
T0 = 360 // Stagnation temperature in K
g = 1.4 // Heat capacity ratio
R = 0.287 // Gas constant
P2 = P2P0*P0*1e3 // Static Pressure
T2 = T2T0*T0 // Static temperature
c2 = sqrt(g*R*T2*1000)
V2 = c2*M2 //velocity at the exit from the nozzle
// for air
P_P0 = 0.528 // pressure ratio
T_T0 = 0.833 // Temperature ratio
P_ = P_P0*P0*1e3 // Static Pressure
T_ = T_T0*T0 //Static temperature
rho_ = P_/(R*T_) // density
V_ = sqrt(g*R*T_*1000) // Velocity at the exit from the nozzle
At = 500e-06 // throat area
```

```
w = At*V_*rho_// Maximum flow rate of air

printf("\n Example 17.3\n")
printf("\n When divergent section act as a nozzle")
printf("\n Maximum flow rate of air is %f kg/s",w)
printf("\n Static temperature is %f K",T2)
printf("\n Static Pressure is %f kPa",P2)
printf("\n Velocity at the exit from the nozzle is
    %f m/s",V2)
//The answers vary due to round off error

// Part (b)
Mb = 0.308  // Mach number
P2P0b = 0.936 // Pressure ratio
T2T0b = 0.9812 // Temperature ratio
P2b = P2P0b*P0*1e3//Static Pressure
T2b = T2T0b*T0 // Static temperature
c2b = sqrt(g*R*T2b*1000) // Velocity
V2b = c2b*Mb //Velocity at the exit from the nozzle
printf("\n\n When divergent section act as a
    diffuser")
printf("\n Maximum flow rate of air is %f kg/s",w)
printf("\n Static temperature is %f K",T2b)
printf("\n Static Pressure is %d kPa",P2b)
printf("\n Velocity at the exit from the nozzle is
    %d m/s",V2b)
```

Scilab code Exa 17.4 Calculation of Mach no

```
clc
Px = 16 // pressure in kPa
Poy = 70 //pressure in kPa
Mx = 1.735 // Mach number
```

```
Pyx = 3.34 // Pressure ratio
rho_yx = 2.25 // Density ratio
Tyx = 1.483  // Temperature ratio
Poyox = 0.84 // pressure ratio
My = 0.631 // Mach number
g = 1.4 // Ratio of heat capacities
Tox = 573 // stagnation temperature in K
Toy = Tox // temperature equivalence
Tx = Tox/(1+((g-1)/2)*Mx^2) // temperature at x
Ty = Tyx*Tx // temperature at y
Pox = Poy/Poyox  // total pressure
// From table
Mx = 1.735

printf("\n Example 17.4\n")
printf("\n Mach number of the tunnel is %f ",Mx)
```

Scilab code Exa 17.5 Calculation of Mach no and pressure and entropy increase

```
clc
Ax = 18.75 // cross sectional area in divergent part
    in m^2
A_ = 12.50 // throat area in m^2
AA_ = 1.5 // Area ratio
Pxox = 0.159 // pressure ratio from table
R = 0.287 // Gas constant
Pox = 0.21e03 // pressure in kPa
Px = Pxox*Pox // pressure calculation
// from the gas table on normal shock
Mx = 1.86
My = 0.604
Pyx = 3.87
```

```
Poyx = 4.95
Poyox = 0.786
Py = Pyx*Px
Poy = Poyx*Px
My = 0.604
Ay_ = 1.183
A2 = 25
Ay = 18.75
A2_ = (A2/Ay)*Ay_
// From isentropic table
M2 = 0.402
P2oy = 0.895
P2 = P2oy*Poy
syx = -R*log(Poy/Pox) // sy-sx

printf("\n Example 17.5\n")
printf("\n Exit Mach number is %f ",M2)
printf("\n Exit pressure is %f kPa",P2)
printf("\n Exit Stagnation pressure is %f kPa",Pox-Poy)
printf("\n Entropy increase is %f kJ/kg K",syx)
//The answers vary due to round off error
```

Chapter 18

Elements of heat transfer

Scilab code Exa 18.1 Calculation of rate of heat removal and temperature

```
clc
ho = 12 // Outside convective heat transfer
   coefficient in W/m^2K
x1 = 0.23// Thickness of brick in m
k1 = 0.98 // Thermal conductivity of brick in W/mK
x2 = 0.08 // Thickness of foam in m
k2 = 0.02// Thermal conductivity of foam in W/mK
x3 = 1.5// Thickness of wood in cm
k3 = 0.17// Thermal conductivity of wood in W/cmK
hi = 29// Inside convective heat transfer
   coefficient in W/m^2K
A = 90 // Total wall area in m^2
to = 22// outside air temperature in degree Celsius
ti = -2 // Inside air temperature in degree Celsius
printf("\n Example 18.1\n")
U = (1/((1/ho)+(x1/k1)+(x2/k2)+(x3*1e-2/k3)+(1/hi)))
   // Overall heat transfer coefficient
Q = U*A*(to-ti) // Rate of heat transfer
R = (1/ho)+(x1/k1)
t2 = to-Q*R/A // Temperature at inside surface of
   brick
```

```
printf("\n The rate of heat removal is %f W",Q)

printf("\n Temperature at inside surface of brick is %f degree celcius",t2)

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

Scilab code Exa 18.2 Calculation of thermal conductivity

```
clc
r1 = 5 // Inner radius of steel pipe in cm
r2 = 10 // Extreme radius of inner insulation in cm
r3 = 13// Extreme radius of outer insulation in cm
K1 = 0.23 // Thermal conductivity of inner insulation in W/mK
K2 = 0.37 // Thermal conductivity of outer insulation in W/mK
hi = 58 // Inner heat transfer coefficient in W/m^2K
h0 = 12 // Inner heat transfer coefficient in W/m^2K
ti = 60 // Inner temperature in degree Celsius
to = 25 // Outer temperature in degree Celsius
L = 50 // Length of pipe in m

printf("\n Example 18.2\n")
Q =((2*%pi*L*(ti-to))/((1/(hi*r1*1e-2))+(log(r2/r1)/(K1))+(log(r3/r2)/(K2))+(1/(h0*r3*1e-2))))
// Rate of heat transfer
printf("\n Heat transfer rate is %f kW",Q/1e3)
//The answers vary due to round off error
```

Scilab code Exa 18.3 Calculation of temperature and heat loss rate

```
clc
to = 20 // Environment temperature in degree Celsius
t = 100// Temperature of steam path in degree Celsius
ta1 =  26.76 // Temperature at other end in degree Celsius for rod A
d = 10 // diameter of rod in mm
L = 0.25 // length of rod in m
h = 23 // heat transfer coefficient in W/m^2 K
tb1 =  32.00 // Temperature at other end in degree Celsius for rod B
tc1 =  36.93 // Temperature at other end in degree Celsius for rod C

printf("\n Example 18.3\n")
A = %pi/4 * (d*1e-3)^2 //Area of rod
p = %pi*d*1e-3 // perimeter of rod
// For rod A
a = (ta1-to)/(t-to)
ma = (acosh(1/a))/L

Ka = (h*p)/(ma^2*A) // Thermal conductivity of rod A
printf("\n Thermal conductivity of rod A is %f W/mK",Ka)
// For rod B
b = (tb1-to)/(t-to)
mb = (acosh(1/b))/L

Kb = (h*p)/(mb^2*A) // Thermal conductivity of rod B
printf("\n Thermal conductivity of rod B is %f W/mK"
```

```
    ,Kb)
c = (tc1-to)/(t-to)
mc = (acosh(1/c))/L

Kc = (h*p)/(mc^2*A) // Thermal conductivity of rod A
printf("\n Thermal conductivity of rod C is %d W/mK"
    ,ceil(Kc))
//The answers vary due to round off error
```

Scilab code Exa 18.4 Calculation of time and temperature

```
clc
h = 17.4 // Convective heat transfer coefficient in
    W/m^2K
K = 52.2 // Thermal conductivity in W/mK
t = 120 // Heat reservoir wall temperature in degree
    celcius
t0 = 35 // Ambient temperature in degree celcius
L = 0.4 // Lenght of rod in m
b  = .050 // width of rod in mm
H = .050 // Heigth of rod in mm

printf("\n Example 18.4\n")
l= L/2
A = b*H
m = sqrt(4*h*b/(K*b*H))
t1 = (t-t0)/cosh(m*l) + t0 // Midway temperature of
    rod
Q1 = 2*5.12*K*A*(t-t0)*tanh(m*l) // Heat loss rate
printf("\n Midway temperature of rod is %f degree
    Celcius",t1)
printf("\n Heat loss rate is %fW",Q1)
//The answers vary due to round off error
```

Scilab code Exa 18.5 Calculation of time and temperature

```
clc
d = 8 // Average diameter in mm
r = 750 // Density in Kg/m^3
t = 2 // Intermediate temperature in degree celcius
t_inf = 1 // Ambient temperature in degree celcius
t0 = 25 // Initial temperature in degree celcius
c = 3.35 // Specific heat in kJ/KgK
h = 5.8 // Heat transfer coeeficient in W/m^2K
T1 = 10 // time period in minutes
T2 = 30 // time period in minutes
t1 = 5 // Intermediate temperature in degree celcius
printf("\n Example 18.5\n")
tau1 = c*1e3*log((t0-t_inf)/(t-t_inf))/(h*60) //
    Time to cool down to 2 degree celcius
tau2 = (t0-t_inf)*(exp(-(c*T1*60)/(c*1e3))) //
    Temperature of peas after 10 minutes
Y = exp(-1*(c*T2*60)/(c*1e3))
tau3 = (t0*Y-t1)/(Y-1)

printf("\n Time to cool down to 2 degree celcius is
    %f min",tau1)
printf("\n Temperature of peas after 10 minutes is
    %f degree celcius",tau2)
printf("\n Temperature of peas after 30 minutes is
    %f degree celcius",tau3)
//The answers given in book are incorrect
```

Scilab code Exa 18.6 Calculation of surface area of heat exchanger

```
clc
mh =  1000 // mass flow rate of hot fluid in Kg/h
mc = 1000 // mass flow rate of cold fluid in Kg/h
ch = 2.09 // Specific heat capacity of hot fluid in
    kJ/kgK
cc = 4.187 //Specific heat capacity of cold fluid in
    kJ/kgK
th1 = 80// Inlet temperature of hot fluid in degree
    celcius
th2 = 40 // Exit temperature of hot fluid in degree
    Celsius
tc1 = 30 // Inlet temperature of cold fluid in
    degree Celsius
U = 24 // heat transfer coefficient in W/m^2K

printf("\n Example 18.6\n")
Q = mh*ch*(th1-th2)
tc2 = Q/(mc*cc) + tc1// outlet temperature of cold
    fluid
te = th2-tc1 // Exit end temperature difference in
    degree Celsius
ti = th1 - tc2 // Inlet end temperature  difference
    in degree Celsius
t_lm = (ti-te)/(log(ti/te))
A = Q / (U*t_lm*3.6) // Surface are of heat
    exchanger

printf("\n Surface area of heat exchanger is %f m^2"
    ,A)
```

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

Scilab code Exa 18.7 Calculation of surface area of heat exchanger

```
clc
Hfg = 2257 // Latent heat at 100 degree Celsius

ma =  500 // mass flow rate of air in Kg/h
ch = 1.005 // Specific heat capacity of hot air in kJ/kgK
ta1 = 260 // Inlet temperature of hot air in degree Celsius
ta2 = 150 // Inlet temperature of cold air in degree Celsius
tc1 = 100 // Inlet temperature of steam
tc2 = tc1 // Exit temperature of steam
U = 46 // heat transfer coefficient in W/m^2K

printf("\n Example 18.7\n")
Q = ma*ch*(ta1-ta2)
m = Q/Hfg // mass flow rate of steam
te = ta2-tc1 // Exit end temperature difference in degree Celsius
ti = ta1 - tc2 // Inlet end temperature  difference in degree Celsius
t_lm = (ti-te)/(log(ti/te))
A = Q / (U*t_lm*3.6) // Surface are of heat exchanger

printf("\n Surface area of heat exchanger is %f m^2",A)

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

Scilab code Exa 18.8 Calculation of temperature and rate of heat transfer

```
clc
mh =  20.15 // mass flow rate of hot fluid in Kg/s
mc = 5.04 // mass flow rate of cold fluid in Kg/h
ch = 2.094 // Specific heat capacity of hot fluid in kJ/kgK
cc = 4.2 //Specific heat capacity of cold fluid in kJ/kgK
th1 = 121// Inlet temperature of hot fluid in degree Celsius
th2 = 40 // Exit temperature of hot fluid in degree Celsius
tc1 = 10 // Inlet temperature of cold fluid in degree Celsius
U = 0.34 // heat transfer coefficient in kW/m^2K
n = 200 // total number of tubes
l = 4.87 // length of tube in m
d = 1.97 // Outer diameter in cm
printf("\n Example 18.8\n")
A = %pi*n*d*1e-2*l // Total surface area
mc_oil = mh*ch
mc_water = mc*cc
 c_min = mc_water
    c_max =mc_oil

if mc_oil<mc_water then
    c_min = mc_oil
    c_max =mc_water
end

R = c_min/c_max
```

```
NTU = U*A/c_min
e = (1-exp(-1*NTU*(1-R)))/(1-R*exp(-1*NTU*(1-R)))
t_larger = e*(th1-tc1)
t_water = t_larger
t_oil = t_water*mc_water/mc_oil
th2 = th1 - t_oil // Exit temperature of oil
Q = mh*ch*(th1-th2) // Rate of heat transfer

printf("\n Exit temperature of oil is %f degree celcius",th2)
printf("\n Rate of heat transfer is %d kW",Q)
//The answers vary due to round off error
```

Scilab code Exa 18.9 Calculation of heat transfer coefficient and rate of heat transfer

```
clc
u_m = 0.8 // mean velocity in m/s
D = 5 // Diameter in cm
v = 4.78e-7 // dynamic coefficient of viscosity
Pr = 2.98 // Prantl number
K = 0.66 // Thermal conductivity in W/mK
l = 3 // length of pipe in m
tw = 70 // Wall temperature
tf = 50 // mean water temperature
printf("\n Example 18.9\n")
Re = u_m*D*1e-2/v // Reynold number
Nu = 0.023*(Re^0.8)*(Pr^0.4)
h = K*Nu/(D*1e-2) // Heat transfer coefficient
A = %pi*D*1e-2*l // Surface area
Q = h*A*(tw-tf) // Rate of heat transfer
printf("\n Heat transfer coefficient is %d W/m^2K",h)
```

```
printf("\n Rate of heat transfer is %f kW",Q/1e3)
//The answers vary due to round off error
```

Scilab code Exa 18.10 Calculation of rate of heat dissipation

```
clc
b = 10 // width of plate in cm
h = 15 // Height of plate in cm
hr = 8.72 // Radiative heat transfer coefficient in
    W/m^2K
tw = 140 // temperature of wall in degree Celsius
tf = 20 // Atmospheric temperature in degree Celsius
v = 2.109e-5 // Coefficient of dynamic viscosity in
    m^2/s
Pr = 0.692 // Prantl number
K = 0.0305 // Thermal conductivity in W/mK
L = 0.15 // characteristic length in m
g = 9.81 // Gravitational acceleration in m/s^2

printf("\n Example 18.10\n")
A = 2*b*1e-2*h*1e-2 // total area of plate
t_mean = (tw+tf)/2 +273
B = 1/t_mean
del_t = tw-tf
Gr = g*B*del_t*L^3/v^2 // Grashoff number
x = Gr*Pr
if x<1e9 then
    Nu = 0.59*(Gr*Pr)^0.25
end
hc = Nu*K/L
Q = (hc+hr)*A*del_t // Rate of heat dissipation
printf("\n Rate of heat dissipation is %f W",Q)
//The answers vary due to round off error
```

Scilab code Exa 18.11 Calculation of time

```
clc
d1 = 2 // Diameter of steel rod in cm
d2 = 16 // Diameter of cylindrical furnace in cm
e1 = 0.6 // emissivity of inner surface
e2 = 0.85 // emissivity of rod surface
T = 1093 // Inner surface temperature of furncae in degree celcius
Tr1 = 427 // Initial temperature of rod in degree celcius
Tr2 = 538 // Initial temperature of rod in degree celcius
sigma = 5.67e-8 // Constant
rho = 7845 // density in kg/ m^3
c = 0.67 // Specific heat capacity in kJ/kgK
printf("\n Example 18.11\n")
A_ratio = d1/d2 // Surface area ratio of cylindrical bodies
F12 = (1/((1/e1)+(A_ratio*(1/e2 -1))))
A1 = %pi*d1*1e-2*1 // Surface area of rod
T1 = Tr1+273
T2 = T +273
T3 = Tr2 +273
Qi = sigma*A1*F12*(T1^4-T2^4)
Qe = sigma*A1*F12*(T3^4-T2^4)

Q_avg = abs((Qi+Qe)/2)
tau = rho*c*(1e-4)*%pi*(Tr2-Tr1)/(Q_avg*(1e-3))

// Time required for heating operation
printf("\n Time required for heating operation is %f
```

```
s",tau)

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

Scilab code Exa 18.12 Calculation of net heat transfer

```
clc
d1 = 10 // Diameter of inner cylinder in cm
d2 = 20 // Diameter of outer cylinder in cm
e1 = 0.65 // emissivity of inner surface
e2 = 0.4 // emissivity of outer surface
T1 = 1000 // Inner surface temperature in K
T2 = 500 // outer suface temperature in K
sigma = 5.67e-8 // Constant
printf("\n Example 18.12\n")
A1 = %pi*d1*1e-2
A2 = %pi*d2*1e-2
R =(((1-e1)/(e1*A1))+((1-e2)/(e2*A2))+(1/(A1*1)))
Eb1 = sigma*T1^4
Eb2 = sigma*T2^4
Q = (Eb1-Eb2)/R // Net heat transfer between two cylinders
printf("\n Net heat transfer between two cylinders is %d W/m length",Q)

//The answers vary due to round off error
clc
d1 = 10 // Diameter of inner cylinder in cm
d2 = 20 // Diameter of outer cylinder in cm
e1 = 0.65 // emissivity of inner surface
e2 = 0.4 // emissivity of outer surface
T1 = 1000 // Inner surface temperature in K
T2 = 500 // outer surface temperature in K
```

```
sigma = 5.67e-8 // Constant
printf("\n Example 18.12\n")
A1 = %pi*d1*1e-2
A2 = %pi*d2*1e-2
R =(((1-e1)/(e1*A1))+((1-e2)/(e2*A2))+(1/(A1*1)))
Eb1 = sigma*T1^4
Eb2 = sigma*T2^4
Q = (Eb1-Eb2)/R // Net heat transfer between two
    cylinders
printf("\n Net heat transfer between two cylinders
    is %d W/m length",Q)

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

Chapter 19

Gas compressors

Scilab code Exa 19.1 Calculation of pressure ratio and indicated power and shaft power and mass flow rate and second stage bore

```

clc
T2 = 488
T1 = 298
n = 1.3
R =8314/44
rp = (T2/T1)^(n/(n-1))

b = 0.12 // Bore of compressor
L = 0.15 // Stroke of compressor
V1 = (%pi/4)*(b)^2*L
P1 = 120e03 // in kPa
W = ((n*P1*V1)/(n-1))*(((rp)^((n-1)/n))-1)
P = (W*1200*0.001)/60

V1_dot = V1*(1200/60)
m_dot = (P1*V1_dot)/(R*T1)

rp_1 = rp^2
V2 = (1/rp)^(1/n)*V1
```

```
d = sqrt((V2*4)/(L*%pi))
printf("\n Example 19.1\n")
printf("\n Pressure ratio is %f ",rp)
printf("\n Indicated power is %f kW",P)
printf("\n Shaft power is %f kW",P/0.8)
printf("\n Mass flow rate is %f kg/s",m_dot)
printf("\n Pressure ratio when second stage is added is %f",rp_1)
printf("\n Volume derived per cycle is V2 %f m^3",V2)
printf("\n Second stage bore would be %f mm",d*1000)
//The answers vary due to round off error
```

Scilab code Exa 19.2 Calculation of volumetric efficiency

```

clc
c = 0.05 // Clearance volume
p1 = 96 // Inlet pressure in bar
p2 = 725 // Outlet pressure in bar
pa = 101.3 // Atmospheric pressure
Ta = 292 // Atmospheric temperature in kelvin
T1 = 305 // Inlet temperature in Kelvin
n = 1.3 // polytropic index
printf("\n Example 19.2 \n ")
n_v = (1+c-c*((p2/p1)^(1/n)))*(p1/pa)*(Ta/T1)
printf("\n Volumetric efficiency of system is %f percent", n_v*100)
// Answer is not mentioned in book
```

Scilab code Exa 19.3 Calculation of indicated power and volumetric efficiency and mass flow rate and free air delivery and isothermal efficiency and input power

```
clc
P1 = 101.3e03
P4 = P1 // in Pa
P2 = 8*P1
P3 = P2
T1 = 288
Vs = 2000
V3 = 100
Vc = V3
V1 = Vs + Vc
n = 1.25
R = 287
V4 = ((P3/P4)^(1/n))*V3
W = ((n*P1*(V1-V4)*1e-06)/(n-1))*(((P2/P1)^((n-1)/n)
    )-1)
P = (W*800*0.001)/60

m = (P1*(V1-V4)*1e-06)/(R*T1)
m_dot = m*800

FAD = (V1-V4)*1e-06*800

Wt = P1*(V1-V4)*1e-06*log(P2/P1)
n_isothermal = (Wt*800*0.001)/(P*60)

Pi = P/0.85
n_v =100*(V1-V4)/Vs
printf("\n Example 19.3\n")
```

```
printf("\n Indicated poer is %f kW",P)
printf("\n Volumetric efficiency is %f percent",n_v)
printf("\n Mass flow rate is %f kg/min",m_dot)
printf("\n Free air delivery is %f m^3/min",FAD)
printf("\n Isothermal efficiency is %f percent",100*
    n_isothermal)
printf("\n Input power is %f kW",Pi)

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

Scilab code Exa 19.4 Calculation of power input and volumetric efficiency and bore and stroke of cylinder

```
clc
// Given that
m = 3 // Mass flow rate in kg/min
p1 = 1 // Initial pressure in bar
T1 = 300 // Initial temperature in K
p3 = 6 // Pressure after compression in bar
p5 = 15 // Maximum pressure in bar
N = 300 // Rpm of compressure
n = 1.3 // Index of compression and expansion
r = 1.5 // Stroke to bore ratio
R = 287 // Gas constant of air
t = 15 // Temperature in degree centigrade
printf("\n Example 19.4\n")
T = t+273
Wc = (n/(n-1))*(m/60)*(R*(1e-3)*T1)*(((p3/p1)^((n-1)
    /n))-1)
r1 = (p5/p1)^(1/n)// Where r1 = V1/Vc
r2 = r1-1 // Where r2 = Vs/Vc
r3 = (p3/p1)^(1/n)
n_vol = (r1-r3)*(T/T1)/r2
```

```
V = m*R*T/(2*(1e5)*N)
Vs = V/n_vol
d = (Vs*4/(%pi*r))^(1/3)
l = r*d
printf("\n Power input is %f kW, \n Volumetric
   efficiency is %f percent , \n Bore of the cylinder
    is %f m, \n Stroke of the cylinder is %f m",Wc,
   n_vol*100,d,l)
//The answers vary due to round off error
```

Scilab code Exa 19.5 Calculation of power and isothermal efficiency and mechanical efficiency

```
clc
// Given that
d = 15 // Diameter in cm
l = 18 // Stroke in cm
C = 0.04 // Ratio of clearance volume and sweft
   volume
p1 = 1 // Pressure in bar
t1 = 25 // Temperature in degree centigrade
p2 = 8// Pressure in bar
N = 1200 // Rpm of compressure
W = 18 // Actual power input in kW
m = 4 // Mass flow rate in kg/min
R = 0.287
printf("\n Example 19.5\n")
T1 = t1+273
v = R*T1/(p1*100)
V = m*v
Vs = (%pi/4)*((d*(1e-2))^2)*(l*1e-2)*N
n_vol = V/Vs
n = (log(p2/p1))/(log((1+C-n_vol)/C))
```

```
// The value of n given in the example is wrong
n = 1.573
T2 = T1*(p2/p1)^((n-1)/n)
Wc = (n/(n-1))*(m*R/60)*(T2-T1)
n_mech = Wc/W
W_isothermal = m*R*T1*log(p2/p1)/60
n_iso = W_isothermal/W
printf("\n Power required to drive the unit is %f kW ,\n Isothermal efficiency is %f percent ,\n Mechanical efficiency is %f percent",Wc,n_iso*100,n_mech*100)
//The answers vary due to round off error
```

Scilab code Exa 19.6 Calculation of power required

```
clc
// Given that
d = 40 // Diameter in cm
l = 50 // Stroke in cm
D = 5 // Piston rod diameter in cm
C = 0.04 // Ratio of clearance volume and sweft volume
p1 = 1 // Pressure in bar
t1 = 15 // Temperature in degree centigrade
p2 = 7.5// Pressure in bar
N = 300 // Rpm of compressure
n_vol = 0.8 // Volumetric efficiency
n_mech = 0.95 // Mechanical efficiency
n_iso = .7 // Isothermal efficiency
R = 0.287
printf("\n Example 19.6\n")
Vs = (%pi/4)*((d*(1e-2))^2)*(l*(1e-2))
Vs_ = (%pi/4)*(((d*(1e-2))^2)-(D*(1e-2))^2)*(l*1e-2)
```

```
Vs_min = (Vs+Vs_)*2*N
V1 = Vs_min*n_vol
W_iso = p1*V1*(log(p2/p1))
Win = W_iso/n_iso
Wc = Win/n_mech
printf("\n Power required to drive the compressure
    is %f kW",Wc)
//The answers vary due to round off error
```

Scilab code Exa 19.7 Calculation of work done and heat rejected

```
clc
// Given that
p1 = 1 // Pressure in bar
t1 = 27 // Temperature in degree centigrade
n = 1.3 // Index of the compression process
p3 = 9// Pressure in bar
R = 0.287
printf("\n Example 19.7\n")
T1 = t1+273
p2 = sqrt(p1*p3)
Wc = ((2*n*R*T1)/(n-1))*(((p2/p1)^((n-1)/n))-1)
T2 = T1*((p2/p1)^((n-1)/n))
H = 1.005*(T2-T1)
printf("\n Minimum work done is %f kJ/kg,\n Heat
    rejected to intercooler is %f kJ/kg",Wc,H)
//The answers vary due to round off error
```

Scilab code Exa 19.8 Calculation of power and bore and stroke

```
clc
// Given that
V = 4 // Volume flow rate in m^3/min
p1 = 1.013 // Pressure in bar
t1 = 15 // Temperature in degree centigrade
N = 250 // Speed in RPM
p4 = 80// Delivery pressure in bar
v = 3 //Speed of piston in m/sec
n_mech = .75 // Mechanical efficiency
n_vol = .8 // Volumetric efficiency
n = 1.25 // Polytropic index
printf("\n Example 19.8\n")
T1 = t1+273
p2 = sqrt(p1*p4)
W = (2*n/(n-1))*(p1*100/n_mech)*(V/60)*((p2/p1)^((n-1)/n) - 1)
L = v*60/(N*2)
Vs = V/N
D_LP = sqrt(Vs*V/(%pi*L*n_vol))
D_HP = D_LP*sqrt(p1/p2)
printf("\n Minimum power required by the compressure is %f kW,\n Bore of the compressure in low pressure side is %f cm,\n Bore of the compressure in high pressure side is %f cm,\n Stroke of the compressure is %d cm",W,D_LP*100,D_HP*100,L*100)
//The answers vary due to round off error
```

Scilab code Exa 19.9 Calculation of compressor work and heat transfer

```
clc
// Given that
p1 = 1 // Pressure in bar
T1 = 300 // Temperature in K
```

```
p4 = 9// Compressed pressure in bar
n = 1.3 // Polytropic index
R = 0.287 // Gas constant in kJ/kgK
cp = 1.042 // Heat capapcity in kJ/kgK
printf("\n Example 19.9\n")
p2 = sqrt(p1*p4)
T2 =T1*((p2/p1)^((n-1)/n))
Wc = (2*n/(n-1))*R*1*(T2-T1)
Wc_ = Wc/2
Q = 1*cp*(T2-T1)
Q_ = cp*(T1-T2)+Wc_
H = Q+2*Q_
printf("\n Compressor work = %f kJ/kg,\n Total heat transfer to the surrounding = %f kJ/kg",Wc_,H)
//The answers given in the book contain calculation error
```

Scilab code Exa 19.10 Calculation of power and diameter and stroke and efficiency

```
clc
// Given that
N = 300 // Speed in RPM
// Intake condition of compressor
p1 = 0.98 // Pressure in bar
T1 = 305 // Temperature in K

p6 = 20// Delivery pressure in bar
p3 = 5 // Intermediate pressure in bar
C = .04 // Ratio of clearance volume to the stroke volume
v = 3 // Volume flow rate of compressure in m^3/min
p = 1 // pressure in bar
```

```
t = 25 // Temperautre in degree centigrade
n = 1.3 // Polytropic index
R = 0.287 // Gas constant in kJ/kgK
printf("\n Example 19.10\n")
T = t+273
r0 = 1+C // Where r0 = v1/vs
r1 = C*(p3/p1)^(1/n)// Where r1 = v4/vs
r2=r0-r1//Where r2 is the ratio of volume of air
    taken at 0.98 bar,305 k and vs
r3 = r2*(T/T1)*p1/p // Where r3 is the ratio of
    volume of air taken at free air conditions and vs
n_vol = r3
m = p*(1e5)*(v/60)/(R*1000*T)
T2 = T1*((p3/p1)^((n-1)/n))
// For perfect intercooling
T5 = T1
p5 = p3
T6 = T5*((p6/p5)^((n-1)/n))
Wc = (n/(n-1))*m*R*((T2-T1)+(T6-T5))
m_a_s = m*60/N
v_fa_s = m_a_s *(R*1000)*T/(p*1e5)
d = ((v_fa_s/n_vol)*(4/%pi))^(1/3)
l = d // As given in the question
P_iso = m*R*T1*(log(p6/p1))
n_iso = P_iso/Wc
printf("\n The power required to drive the
    compressor = %f kW,\n Diameter of cylinder = %f
    cm, \n Storke of the cylinder = %f cm,\n
    Isothermal efficiency = %f percent",Wc,d*100,l
    *100,n_iso*100)
//The answers given in the book contain calculation
    error
```

Scilab code Exa 19.11 Calculation of no of stage and power and temperature

```
clc
// Given that
p1 = 1 // Intake pressure of compressor in bar
T1 = 298 // Intake temperature in K
p_d = 36 // Delivery pressure in bar
T2 = 390 // Maximum temperature in any stage in K
n = 1.3 // Polytropic index
R = 0.287
printf("\n Example 19.11\n")
r = (T2/T1)^(n/(n-1))
N = ceil(r)
p2 = (p_d/p1)^(1/N)
p3 = (p_d/p1)^(2/N)
p4 = (p_d/p1)^(3/N)
Wc = (N*n*R*T1/(n-1))*((p_d/p1)^((n-1)/(N*n))-1)
Wc_ = (n/(n-1))*(1*R*T1)*((p_d/p1)^((n-1)/n)- 1)
T = T1*((p2/p1)^((n-1)/n))
printf("\n No of stages for min power input = %d,\n Power required = %f kW/kg air,\n The power required for a single stage compressor = %f kW,\n Maximum temperature in any stage = %f K",N,Wc,Wc_,T)
//The answers given in the book contain round off error
```

Scilab code Exa 19.12 Calculation of indicated output

```
clc
// Given that
p1 = 700 // Intake pressure of compressor in kPa
```

```
t1 = 38 // Intake temperature in degree centigrade
c = 0.4 // Ratio of cutoff volume to stroke volume
p3 = 112 // Back pressure in kPa
r = 0.85 // Ratio of area of actual indicator diagram to the outlined in the question
n = 1.3 // Polytropic index
R = 0.287
m = 1.25 // Air mass in kg
printf("\n Example 19.12\n")
T1 = t1+273
T2 = T1/((1/c)^(n-1))
p2 = p1*(c^n)
V2 = m*R*T2/p2
v2 = V2/m
A = R*T1 + R*(T1-T2)/(n-1) - p3*v2
Io = A*r*m
printf("\n Indicated output = %f kJ",Io)
// The answer given in the book vary due to round off error
```

Scilab code Exa 19.13 Calculation of pressure and volume and work done

```

clc
// Given that
d = 450 // Bore of low pressure cylinder in mm
l = 300 // Stroke in mm
c = 0.05 // Ratio of clearance volume to swept volume
p1 = 1 // Intake pressure in bar
t1 = 18 // Intake temperature in degree centigrade
p4 = 15 // Delivery pressure in bar
n = 1.3 // Compression and expansion index
```

```
R = 0.29 // Gas constant in kJ/kgK
printf("\n Example 19.13\n")
T1 = t1+273
r = (p4/p1)^(1/3)
p2 = p1*r
p3 = p2*r
Vs = (%pi/4)*((d*1e-3)^2)*(l*1e-3)
V11 = c*Vs
V1 = Vs +V11
V12 = V11*((r)^(1/n))
Vs_e = V1 - V12
T3 = T1
T5 = T3
T6 = T1*(r^((n-1)/n))
t6 = T6-273
V6_7 = (p1/p4)*(T6/T1)*(V1 - V12)
W = (3*n*R*T1/(n-1))*((p2/p1)^((n-1)/n)-1)
printf("\n The intermediate pressure are - \n p2 =
    %f bar,\n p3 = %f bar,\n The effective swept
    volume = %f m^3,\n Temperature of air delivered
    per stroke at 15 bar = %f degree centigrade,\n
    The work done per kg of air = %f kJ",p2,p3,Vs,t6,
    W)
// The answers given in the book vary due to round
    off error
```

Scilab code Exa 19.14 Calculation of work input

```
clc
// Given that
p1 = 1.013 // Inlet pressure in bar
r = 1.5 // Pressure ratio
Vs = 0.03 // Induce volume of air in m^3/rev
```

```
gama = 1.4
printf("\n Example 19.14\n")
p2 = p1*r
W = (p2-p1)*Vs*100
pi = (p1+p2)/2
A_A = (gama/(gama-1))*(p1*Vs)*((pi/p1)^((gama-1)/gama)-1)*100
Vb = Vs *((p1/pi)^(1/gama))
A_B = (p2-pi)*Vb*100
Wr = A_A + A_B
printf("\n Work input = %f kJ/rev,\n Work input for a vane-type compressor = %f kJ/rev",W,Wr)
// The answers given in the book vary due to round off error
```

Scilab code Exa 19.15 Calculation of power required

```
clc
// Given that
m = 1 // Mass flow rate in kg/s
r = 2 // Prssure ratio of blower
t1 = 70 // Inlet temperature in degree centigrade
p1 = 1 // Inlet pressure in bar
R = 0.29 // Gas constant in kJ/kgK
x = 0.7 // Reduction in pressure ratio and intake volume
gama = 1.4
printf("\n Example 19.15\n")
T1 = t1+273
V = m*R*T1/(p1*100)
P = V*(p1*r-p1)*100
p2 = p1*((1/x)^(gama))
V2 = x*V
```

```
P_ = (gama/(gama-1))*(p1*100*V)*((p2/p1)^((gama-1)/
    gama)-1) + V2*(p1*r-p2)*100

printf("\n Power required to drive the blower = %f
    kW,\n Power required = %f kW",P,P_)
// The answers given in the book vary due to round
    off error
```

Scilab code Exa 19.16 Calculation of temperature and power

```
clc
// Given that
r1 = 2.5 // Pressure ratio of compressor for first
    stage
r2 = 2.1 // Pressure ratio of compressor for second
    stage
m = 5 // Mass flow rate of air in kg/s
t1 = 10 // Inlet temperature in degree centigrade
p1 = 1.013 // Inlet pressure in bar
td = 50 // Temperature drop in intercooler in degree
     centigreade
n_iso = .85 // Isentropic efficiency
cp = 1.005 // Heat capacity of air in kJ/kgK
x = 0.7 // Reduction in pressure ratio and intake
    volume
gama = 1.4 // Ratio of heat capacities for air
printf("\n Example 19.16\n")
T1 = t1+273
T2s = T1*((r1)^((gama-1)/gama))
T2 = T1 + (T2s-T1)/n_iso
T3 = T2 - td
T4s = T3*((r2)^((gama-1)/gama))
T4 = T3 + (T4s-T3)/n_iso
```

```
P = m*cp*((T2-T1)+(T4-T3))
printf("\n Actual temperature at the end of first
    stage = %f K,\n Actual temperature at the end of
    second stage = %f K,\n The total compressor power
     = %f kW",T2,T4,P)
// The answers given in the book vary due to round
    off error
```

Scilab code Exa 19.17 Calculation of power and pressure and temperature

```
clc
// Given that
r = 2.5 // Static pressure ratio of supercharger
p1 = 0.6 // Static inlet pressure in bar
t1 = 5 // Static inlet temperature in degree
    centigrade
A_r = 13 // Air-fuel ratio
m = 0.04 // The rate of fuel consumed by the engine
    in kg/s
gama= 1.39 // For air-fuel mixture
cp = 1.005 // Heat capacity for air-fuel mixture in
    kJ/kgk
n_iso = .84 // Isentropic efficiency of compressor
v = 120 // Exit velocity from the compressor in m/s
printf("\n Example 19.17\n")
T1 = t1+273
T2s = T1*((r)^((gama-1)/gama))
T2 = T1 +(T2s-T1)/n_iso
m_g = m*(A_r+1)
P = m_g*cp*(T2-T1)
T02 = T2 + (v^2)/(2*cp*1000)
t02 = T02-273
```

```
p02 = p1*r*((T02/T2)^(gama/(gama-1)))*100
printf("\n Power required to drive the compressor =
    %f kW,\n Stagnatio temperature = %f degree
    centigrade,\n Stagnation pressure = %f kPa",P,t02
    ,p02)
// The answers given in the book vary due to round
    off error
```

Scilab code Exa 19.18 Calculation of temperature and power input and diameter and blade inlet angle and diffuser inlet angle

```
clc
// Given that
N = 10000 // Speed in RPM
V = 1.2 // Volume flow rate of free air in m^3/s
p1 = 1 // Inlet pressure in bar
t1 = 27 // Inlet temperature in degree centigrade
r = 5 // Pressure ratio
vf = 60 // Velocity flow rate in m/s
sigma = 0.9 // Slip factor
n_iso = 0.85 // Isentropic efficiency
gama = 1.4
R = 0.287
cp = 1.005
printf("\n Example 19.18\n")
T1 = t1+273
T2s = T1*((r)^((gama-1)/gama))
T2 = T1 +(T2s-T1)/n_iso
m = p1*100*V/(R*288)
Wc = m*cp*(T2-T1)
Vb2 = (Wc*1000/(m*sigma))^(1/2)
D = Vb2*60/(%pi*N)
Vb1 = Vb2/2
```

```
beta1 = atand(vf/Vb1)
alpha = atand(vf/(sigma*Vb2))
printf("\n The temperature of air at outlet = %f
    degree centigrade,\n Power input = %f kW,\n
    Diameter of impeller = %f m, \n Blade inlet angle
     = %d degree,\n Diffuser inlet angle = %f degree
    ",T2-273,Wc,D,beta1,alpha)
// The answers given in the book vary due to round
    off error
```

Scilab code Exa 19.19 Calculation of total head pressure ratio and power and angle

```
clc
// Given that
N = 264 // Speed in RPS
sigma = 0.91 // Slip factor
d = 0.482 // Impeller diameter in m
D = 0.306 // Impeller eye diameter
D_ = 0.153 // Impeller root eye diameter in m
vf = 138 // Uniform axial inlet velocity in m/s
V = 1.2 // Volume flow rate of free air in m^3/s
m = 9.1 // Air mass flow rate in kg/s
T1 = 294 // Inlet air stagnation temperature in K
n_iso = 0.8 // Total head isentropic efficiency
n_mech = 0.98 // Mechanical efficiency
gama = 1.4 // Ratio of heat capacities
cp = 1.006 // Heat capacity in kJ/kgK
printf("\n Example 19.19\n")
Wc = m*sigma*(2*%pi*d*N/2)/1000
P_e = Wc/n_mech
delta_T = Wc/(m*cp)
delta_T_ideal = delta_T*n_iso
```

```
T2_i = delta_T_ideal + T1
r = (T2_i/T1)^(gama/(gama-1)) // Where r = p02/p01
Vb = 2*%pi*N*D/2
V_er = (2*%pi*N*D_/2)
beta1 = atand(vf/Vb)
beta2 = atand(vf/V_er)
beta1_ = (beta1 - floor(beta1))*60
beta2_ = (beta2 - floor(beta2))*60
printf("\n Total head pressure ratio = %f, \n The
    required power at input shaft = %f kW,\n Inlet
    angle at the root = %d degree and %d minute,\n
    Inlet angle at the tip = %d degree and %d minute"
    ,r,P_e,floor(beta1),beta1_,floor(beta2),beta2_)
// The answers given in the book for total head
    pressure ratio and required power at input shaft
    contain calculation error
```

Scilab code Exa 19.20 Calculation of diameter

```
clc
// Given that
N = 16000 // Speed in RPM
t1 = 17 // Intake tempertur of gas in degree
    centigrade
rp = 4 // Pressure ratio
sigma = 0.85// Slip factor
n_iso = 0.82 // Isentropic efficiency
alpha_wirl = 20 // Pre-wirl angle in degree
d1 = 200 // Mean diameter of impeller eye in mm
V1 = 120 //Absolute air velocity in m/s
gama = 1.4 // Ratio of heat capacities
cp = 1.005 // Heat capacity in kJ/kgK
printf("\n Example 19.20\n")
```

```
T1 = t1 + 273
T2s = T1*((rp)^((gama-1)/gama))
delta_Ts = T2s-1
delta_T = delta_Ts/n_iso
Wc = 1 *cp*delta_T
Vb1 = (%pi*d1*(1e-3)*N)/60
Vw1 = V1*sind(alpha_wirl)
Vb2 = 459.78 // By solving quadratic equation 172.81
    e3=0.85*Vb2^2-167.55*41.05
d2 = Vb2*60/(%pi*N)

printf("\n Impeller tip diameter = %f mm",d2*1000)
// The answer given in the book varies due to round
    off error
```

Scilab code Exa 19.21 Calculation of pressure and no of stages and internal efficiency

```
clc
// Given that
m = 2.5 // Mass flow rate in kg/s
p1 = 1 // Inlet pressure in bar
T1 = 300 // Inlet temperature in bar
n_s = 0.88 // Stage efficiency
Wc = 600 // Power input in kW
delta_t = 21 // Temperature rise in first stage in
    degree centigrade
gama = 1.4 // Ratio of heat capacities
cp = 1.005 // Heat capacity in kJ/kgK
printf("\n Example 19.21\n")
x = n_s*gama/(gama-1)// Where x = (n/(n-1))
T = Wc/(m*cp)+T1
p = p1*((T/T1)^(x))
```

```
T2 = T1 + n_s*delta_t
r = ((T2/T1)^(gama/(gama-1)))// Where r = p2/p1
N = log(p/p1)/log(r)
N_ = ceil(N)
Ts = T1*(p/p1)^((gama-1)/gama)
n_inter = (Ts-T1)/(T-T1)
printf("\n The delivery pressure = %f bar,\n The no
    of stages = %d,\n The internal efficiency = %f ",
    p,N_,n_inter)
```

Scilab code Exa 19.22 Calculation of angle and power input and degree of reaction

```
clc
// Given that
D = 0.5 // Mean diameter of impeller in m
N = 15000 // Speed in RPM
Vf = 230 // Velocity of flow in m/s
p1 = 1  // Inlet pressure in bar
T1 = 300 // Inlet temperature in K
Vw1 = 80 // Velocity of whirl at inlet in m/s
n_s = 0.88 // Stage efficiency
rp = 1.5 // Pressure ratio
gama = 1.4
cp = 1.0005
printf("\n Example 19.22\n")
Vb = (%pi*D*N/60)
Ts = T1*((rp)^((gama-1)/gama))
T = T1 + (Ts-T1)/n_s
Wc = cp*(T-T1)
Vw2 = Vw1 + (Wc*1000)/(Vb)
beta1 = atand(Vf/(Vb-Vw1))
beta2 =  atand(Vf/(Vb-Vw2))
```

```
theta = beta2-beta1
R = 1-((Vw1+Vw2)/(2*Vb))

printf("\n Fluid deflection angle = %f degree,\n Power input = %f kJ/kg,\n The degree of reaction = %d percent",theta,Wc,R*100)
// The answers given in the book vary because of round off error
```

Scilab code Exa 19.23 Calculation of angle

```
clc
// Given that
v = 5 // Volume flow rate in m^3/s
d = 1 // Mean impeller diameter in m
D = 0.6 // Hub diameter in m
N = 600 // Rotational speed in RPM
h = 35 // Theoretical head in mm
rho = 1.2 // Density of air in kg/m^3
rho_w = 1000 // Density of water in kg/m^3
printf("\n Example 19.23\n")
Vf = v*4/(%pi*(d^2 - D^2))
Vb = (%pi*d*N/60)
Vb_ = (%pi*D*N/60)
H = h/rho
Vw2 = H*9.81/(Vb)
Vw2_ = H*9.81/(Vb_)
beta_tip = atand(Vf/(Vb-Vw2))
beta_hub = atand(Vf/(Vb_-Vw2_))
printf("\n Blade angle at the tip = %f degree,\n Blade angle at the hub = %f degree",beta_tip,beta_hub)
// The answers given in the book vary because of
```

```
round off error
```

Scilab code Exa 19.24 Calculation of speed and width

```
clc
// Given that
N0 = 9000 // Rotational speed in RPM
Q = 6 // Volume flow rate in m^3/s
p1 = 1 // Initial pressure in bar
t1 = 25 // Initial temperature in degree centigrade
p2 = 2.2 // Compressed pressure in bar
n = 1.33 // Compression index
Vf = 75 // Velocity of flow in m/s
beta1 = 30 // Blade angle at inlet in degree
beta2 = 55 // Blade angle at outlet in degree
d = 0.75 // Diameter of impeller in m
cp = 1.005
printf("\n Example 19.24\n")
T1 = t1+273
T2 = T1*(p2/p1)^((n-1)/n)
Wc = cp*(T2-T1)
x = Wc // Where x = Vw2*Vb2
y = Vf/tand(beta2)// Where y = Vb2-Vw2(Equation 1)
z = (y^2 +4*x*1000)^(0.5) // Where z = Vw2+Vb2(Equation 2)
// By solving Equation 1 and Equation 2
Vb2 = (y+z)/2
Vw2 = ((z-y)/2)
N = Vb2*60/(%pi*d)
Vb1 = Vf/tand(beta1)
D1 = Vb1*60/(%pi*N)
b1 = Q/(%pi*D1*Vf)
Q_ = Q* (1/p2)*(T2/T1)
```

```
b2 = Q_/(%pi*d*Vf)
printf("\n Speed of impeller = %f RPM,\n Impeller
    width at inlet = %f cm,\n Impeller width at
    outlet = %f cm,",N,b1*100,b2*100)
// The answers given in the book vary because of
    round off error
```

Chapter 20

Internal combustion engines

Scilab code Exa 20.1 Calculation of fuel consumption and bmep

```
clc
// Given that
d = 6.5// Diametre in cm
L = 9.5 // Stroke in cm
T = 64 // Torque in Nm
N = 3000 // Speed in rpm
V_c = 63 // Clearance volume in cm^3
r = 0.5 // Brake efficiency ratio
c_v = 42 // Calorific value of gasoline in MJ/kg
printf("\n Example 20.1\n")
V_s = (%pi/4)*(d^2)*(L)
r_k = (V_s+V_c)/V_c
n_as = 1- (1/(r_k^(0.4)))
n_b = r*n_as
BP = (2*%pi*T*N)/60000
m_f = (BP*3600)/(n_b*c_v*1000)// in kg/h
BMEP = BP*60*2/((%pi/4)*4*(d^2)*L*N*10^(-6))
printf("\n Fuel consumption of the engine = %f Kg/h\
   n BMEP=%f kN/m^2",m_f,BMEP)
//The answers vary due to round off error
```

Scilab code Exa 20.2 Calculation of diameter and stroke and brake specific fuel consumption

```
clc
// Given that
// Four cylinder engine
BP = 30 // Power developed by engine in kW
N = 2500 // Speed in rpm
P_m = 800 // Mean effective pressure for each
    cylinder in kN/m^2
n_m = 0.8 // Mechanical efficiency
r = 1.5 // Stroke to bore ratio
n_b = 0.28 // Brake thermal efficiency
c_v = 44 // Heating value of petrol in MJ/kg
printf("\n Example 20.2\n")
IP = BP/n_m
d = ((IP*1000*60)/(P_m*1000*r*(%pi/4)*N*4))^(1/3)
L = r*d
m_f = BP/(c_v*1000*n_b)
bsfc = m_f*3600/BP
printf("\n Diameter of cylinder = %f cm\n Stroke of
    each cylinder = %f cm\n Brake specific fuel
    consumption = %f kg/kWh",d*10^2,L*100,bsfc)
```

Scilab code Exa 20.3 Calculation of power and pressure and fuel consumption

```
clc
```

```
// Given that
F = 680 // Net brake load in N
N = 360 //
d = 10// Bore in cm
L = 15 // Stroke in cm
T = 58 // Torque in Nm
v = 300 // Speed in m/min
n_m = 0.8 // Mechanical efficiency
n_th = 0.4 // Indicated thermal efficiency
c_v = 44 // Calorific value of gasoline in MJ/kg
printf("\n Example 20.3\n")
N = v/(2*L*(10^(-2)))
BP = (2*%pi*T*N)/60000
IP = BP/n_m
p_m = (IP*60)/(L*(%pi/4)*(d^2)*N*10^(-6))
m_f = (IP*3600)/(n_th*c_v*1000)
bsfc = m_f/BP
printf("\n Indicated power = %f kW\n Indicate mean effective pressure = %f kN/m^2\n  Fuel consumption per kWh on brake power output = %f Kg/kWh",IP,p_m,bsfc)
```

Scilab code Exa 20.4 Calculation of power

```
clc
// Given that
T = 20 // Time in minute
F = 680 // Net brake load in N
N = 360 // Speed in rpm
mep = 3 // Mean effective pressure in bar
f = 1.56 // Fuel consumption in kg
m_w = 160 // Cooling water in kg
t = 57 // Water inlet temperature in degree
```

```
centigrade
r = 30 // Air used per kg of fuel
t_r = 27 // Room temperature in degree centigrade
t_e = 310 // Exhaust gas temperature in degree centigrade
d = 210 // Bore in mm
L = 290 // Stroke in mm
D = 1 // Brake diameter in m
cv = 44 // Calorific value in MJ/kg
m_s = 1.3 // Steam formed per kg fuel in the exhaust in kg
s = 2.093 // Specific heat of steam in the exhaust in kJ/kgK
s_d = 1.01 // Specific heat of dry exhaust gases in kJ/kgK
printf("\n Example 20.4\n")
i_p = mep*100*L*(10^-3)*(%pi/4)*((d*(10^-3))^2)*N/60
b_p = (2*%pi*(F*(D/2))*N)/60000
n_m = b_p / i_p
h = f*cv*1000
i_pe = i_p*T*60
e_w = m_w * 4.187*(t-32)
m_t = f*r + f
m_s_ = m_s*f
m_d = m_t - m_s_
e_d = m_d * s_d * (t_e-t_r)
e_s = m_s_*(4.187*(100-t_r) + 2257.9 +s*(t_e-100))
e_t = e_s + e_d
e_Un = h - (i_pe + e_w + e_t)
printf("\n Indicated power = %f kW\n Brake power = %f kW",i_p,b_p)
printf("\n Energy release by combustion of fuel is %f kJ \n 1. Energy equivalent of ip is %f kJ (%f percent)\n 2. Energy carried away by cooling water is %f kJ (%f percent),\n 3. Energy carried away by exhaust gases is %f kJ (%f percent),\n 4. Unaccounted energy loss (by difference) is %f kJ (%f percent)",h,i_pe,(i_pe/h)*100,e_w,(e_w/h)
```

```
*100,e_t,(e_t/h)*100,e_Un,(e_Un/h)*100)
```

Scilab code Exa 20.5 Calculation of power and efficiency

```
clc
// Given that
F = 610 // Net brake load in N
N = 350 // Speed in rpm
d = 20 // Bore in cm
L = 30 // Stroke in cm
imep = 275 // Mean effective pressure in kN/m^2
D = 1 // Brake diameter in m
m_o = 4.25 // Oil consumption in kg/h
cv = 44 // Calorific value in MJ/kg
printf("\n Example 20.5\n")
i_p = imep*1000*L*(10^-2)*(%pi/4)*((d*(10^-2))^2)*N
   /60000
b_p = (2*%pi*(F*(D/2))*N)/60000
n_m = b_p / i_p
n_th = i_p *3600/(m_o*cv*1000)
n_br = n_th*n_m
printf("\n Indicated power = %f kW\n Brake power =
   %f kW\n Mechanical efficiency = %f percent,\n
   Indicated thermal efficiency = %f percent,\n
   Brake thermal efficiency = %f percent",i_p,b_p,
   n_m*100,n_th*100,n_br*100)
```

Scilab code Exa 20.6 Calculation of no of misfires

```
clc
// Given that
no = 6 // No of cylinders
Vs = 1.75 // Stroke volume in litres
P = 26.25 // Power developed in kW
N = 506 // Speed in rpm
mep = 600 // Mean effectine pressure in kN/m^2
printf("\n Example 20.6\n")
n = P*60000/(no*mep*1000*Vs*(10^-3))
n_e = N/2
n_m = n_e - n
printf("\nAvg no of misfire = %d",n_m)
```

Scilab code Exa 20.7 Calculation of mass of fuel

```
clc
// Given that
Bp = 110 // Brake power in kW
n_m = 0.8 // Mechanical efficiency of the engine
m_f = 50 // Fuel required for engine in kg/h
r_f = 5 // Reduced engine friction in kW
printf("\n Example 20.7\n")
Ip = Bp/n_m
Fp = Ip-Bp
Fp_n = Fp-r_f
Ip_new = Bp + Fp_n
m_f_new = Ip_new * m_f/ Ip
s_f = m_f- m_f_new
printf("\nSaving in fuel = %f kg/h",s_f)
```

Scilab code Exa 20.8 Calculation of efficiency

```
clc
// Given that
Bp = 14.7 // Brake power when all cylinder operating
    in kW
Bp1 = 10.14 // Brake power with cylinder no. 1 cut
   out in kW
Bp2 = 10.3 // Brake power with cylinder no. 2 cut
   out in kW
Bp3 = 10.36 // Brake power with cylinder no. 3 cut
   out in kW
Bp4 = 10.21 // Brake power with cylinder no. 4 cut
   out in kW
m_f = 5.5 // Fuel consumption in kg/h
cv = 42 // Calorific value MJ/kg
d = 8 // Diameter of cylinder in cm
L = 10 // Stroke of cylinder in cm
Vc = 0.1 // Clearance volume in litre
printf("\n Example 20.8\n")
Ip1 = Bp-Bp1
Ip2 = Bp-Bp2
Ip3 = Bp-Bp3
Ip4 = Bp-Bp4
Ip = Ip1+Ip2+Ip3+Ip4
n_m = Bp/Ip
Vs = (%pi/4)*((d*(10^-2))^2)*(L*(10^-2))
r_k = (Vs+(Vc*(10^-3)))/(Vc*(10^-3))
n_ase = 1- (1/(r_k^(1.4-1)))
n_th = Ip*3600/(m_f*cv*1000)
R_e = n_th/n_ase
printf("\n Mechanical efficiency = %f percent ,\n
```

```
    Relative efficiency on indicated power basis = %f
     percent",n_m*100,R_e*100)
//The value of  answer is different because of round
     off error
```

Scilab code Exa 20.9 Calculation of efficiency and bmep

```
clc
// Given that
Bp = 28.35 // Brake power in kW
N = 1500 // Speed in rpm
x = 20 // Rich percent of mixture
t = 15.5 // Temperature in degree centrigrde
p = 760 // Pressure in mm of mercury
f = 0.7 // Fraction of volume of air in th cylinder
    relative to swept volume
R = 14.8 // Theoratical Air fuel ratio
d = 82 // Diameter of cylinder in mm
L = 130 // Stroke of cylinder in mm
cv = 44 // Heating value of petrol in MJ/kg
n_m = 0.9 // Mechanical efficiency of the engine
printf("\n Example 20.9\n")
Ip = Bp/n_m
p_ = 101.325 // In kN/m^2 as p = 760 mm mercury
v_a = f*(%pi/4)*((d*(10^-3))^2)*(L*(10^-3))*(N/2)*4
m = p_*(v_a)/(0.287*(t+273))
m_f = (m/R)*(1+x/100)
n_th = Ip*3600/(m_f*cv*1000*60)
bmep = Bp*60/((%pi/4)*((d*(10^-3))^2)*(L*10^-3)*(N
    /2)*4)
printf("\n Indicated thermal efficiency = %f percent
    ,\n Brake mean effective preassure = %f kN/m^2",
    n_th*100,bmep)
```

```
//The value of  answer is different because of round
    off error
```

Scilab code Exa 20.10 Calculation of velocity

```
clc
// Given that
d = 25 // Throat diameter in mm
D = 1.2 // Main jet diameter in mm
c_d = 0.85 // Cofficient of discharge for the
   venturi
C_d = 0.65 // Cofficient of discharge for fuel jet
h = 6 // Height of the throat from gasoline surface
   in mm
p_1 = 1 // Ambient pressure in bar
T = 300 // Ambient temperature in K
Ro_f = 760 // Density in kg/m^3
printf("\n Example 20.10\n")
delta_p = h*(10^-3)*Ro_f*9.81
p_2 = p_1-delta_p*(10^-5)
Ro_air = p_1*(10^5)/(287*T)
v  = (2*delta_p/Ro_air)^(1/2)
printf("\n Minimum velocity of air required to start
    the flow = %f m/s",v)
//The value of  answer is different because of round
    off error
```

Scilab code Exa 20.11 Calculation of efficiency and bmep

```
clc
// Given that
Bp = 40 // Brake power when all cylinder operating in kW
N = 2000 // Speed in rpm
Bp1 = 32.2 // Brake power with cylinder no. 1 cut out in kW
Bp2 = 32 // Brake power with cylinder no. 2 cut out in kW
Bp3 = 32.5 // Brake power with cylinder no. 3 cut out in kW
Bp4 = 32.4 // Brake power with cylinder no. 4 cut out in kW
Bp5 = 32.1 // Brake power with cylinder no. 5 cut out in kW
Bp6 = 32.3 // Brake power with cylinder no. 6 cut out in kW
d = 100 // Diameter of cylinder in mm
L = 125 // Stroke of cylinder in mm
Vc = 0.000123 // Clearance volume in m^3
m_f = 9 // Fuel consumption in kg/h
cv = 40 // Heating value in MJ/kg
printf("\n Example 20.11\n")
Ip1 = Bp-Bp1
Ip2 = Bp-Bp2
Ip3 = Bp-Bp3
Ip4 = Bp-Bp4
Ip5 = Bp-Bp5
Ip6 = Bp-Bp6
Ip = Ip1+Ip2+Ip3+Ip4+Ip5+Ip6
n_m = Bp/Ip
bmep = Bp*2*60/(L*(10^-3)*((d*(10^-3))^2)*(%pi/4)*N)
Vs = (%pi/4)*((d*(10^-3))^2)*(L*(10^-3))
r_k = (Vs+Vc)/Vc
n_ase = 1- (1/(r_k^(1.4-1)))
n_th = Ip*3600/(m_f*cv*1000)
R_e = n_th/n_ase
printf("\n Mechanical efficiency = %d percent,\n
```

```
Brake mean effective pressure = %f bar\n Air standard ratio = %f percent,\n Brake thermal efficiency is %f percent,\n Relative efficiency = %f percent",n_m*100,bmep*(10^-2),n_ase*100,n_th*100,R_e*100)
//The value of  answer for air standard efficiency is different because of round off error
// Answer given in the book for bmep is 3.055 bar which is wrong.
// Answer given in the book for brake thermal efficiency is 40 percent which is wrong.
// Answer given in the book for relative efficiency is 68.6 percent which is wrong.
```

Scilab code Exa 20.12 Calculation of power

```
clc
// Given that
p1 = 0.95 // Pressure in bar
t1 = 25 // Temperature in degree centigrade
p2 = 2 // Delivery pressure in bar
r = 18 // Air fuel ratio
t3 = 600 // Temperature of gasses leaving the engine in degree centigrade
p3 = 1.8 // Pressure of gasses leaving the engine in bar
p4 = 1.04 // Pressure at the inlet of turbine in bar
n_c = 0.75 // Efficiency of compresor
n_t = 0.85 // Efficiency of turbine
Cp = 1.005 // Heat capacity of air in kJ/kgK
Cp_ = 1.15 // Heat capacity of gasses in kJ/kgK
gama = 1.4 // Adiabatic index for air
printf("\n Example 20.12\n")
```

```
T2_s = (t1+273)*(p2/p1)^((gama-1)/gama)
T2 = (t1+273)+((T2_s-(t1+273))/n_c)
Wc = Cp*(T2-(t1+273))
T4_s = (t3+273)*((p4/p3)^((gama-1)/gama))
T4 = (t3+273)-((t3+273)-T4_s)*n_t
Wt = (1+(1/r))*Cp_*((t3+273)-T4)
n = (Wt-Wc)/Wt
printf("\n Power lost as a percentage of the power
   produced by the turbine = %f percent",n*100)
```

Scilab code Exa 20.13 Calculation of area

```
clc
// Given that
Bp = 250 // Power developed by the engine in kW
n = 6 // No of cylinders
N = 2000 // Speed in rpm
bsfc = 0.2 // Specific fuel consumption in kg/kWh
P = 35 // Pressure at the begining of the injection
   in bar
p_max = 55 // Maximum cylinder pressure in bar
p = 180 // Expected pressure for injection in bar
P_max = 520 // Maximum pressure at the injection in
   bar
c_d = 0.78 // Cofficient of discharge
s = 0.85 // Specific gravity of fuel oil
p_atm = 1 // Atmospheric pressure in bar
theta = 18 // Crank angle in degree
printf("\n Example 20.13\n")
Bp_cy = Bp/n
m_f = Bp_cy*bsfc/60 // in kg/min
f_c = m_f*(2/N)
T = theta/(360*(N/60))
```

```
delta_p = p-P
delta_p_ = P_max-p_max
avg_delta_p = (delta_p+delta_p_)/2
v = c_d*sqrt((2*(avg_delta_p)*(10^5))/(s*1000))
V = m_f*(10^-3)/(s*1000)
A = V/(v*T)
printf("\n Total orifice area per injector = %f mm^2 ",A*10^6)
```

Scilab code Exa 20.14 Calculation of efficiency and gas consumption

```

clc
// Given that
n=1.3 // Polytropic index
p1 = 140 // Pressure at point one in kN/m^2
p2 = 360 // Pressure at point two in kN/m^2
r_e = 0.4 // Relative efficiency
cv = 18840 // Calorific value in kJ/m^2
printf("\n Example 20.14\n")
r = (((p2/p1)^(1/n))-1)/((0.75-0.25*((p2/p1)^(1/n))))
r_k  = r+1
n_ase = 1-(1/((r_k)^(0.4)))
n_th = r_e*n_ase
V_f = n_th*cv/3600
printf("\n Thermal efficiency = %f percent ,\n Gas consumption per kWh on indicated power basis = %f m^3/kWh",n_th*100,V_f)
//The value of answer is different because of round off error
```

Scilab code Exa 20.15 Calculation of efficiency

```
clc
// Given that
d = 180 // Bore in mm
L = 200 // Stroke in mm
Bp = 245 // Brake power in kW
N = 1500 // Speed in rpm
mep = 8 // Mean effective pressure in bar
m_f = 70 // Fuel consumption in kg/h
cv = 42 // Heating value of fuel in MJ/kg
m_h = 0.12 // Fraction of hydrogen content by mass
m_a = 26 // Air consumption in kg/min
m_w = 82 // Mass of cooling water in kg/min
delta_t = 44 // Cooling water temperature rise in
    degree centigrade
m_o = 50 // Cooling oil circulated through the
    engine in kg/min
delta_T = 24 // Cooling oil temperature rise in
    degree centigrade
s_o = 2.1 // Specific heat of cooling oil in kJ/kgK
t = 30 // Room temperature in degree centigrade
t_e = 400 // Exhaust gas temperature on degree
    centigrade
c_p_de = 1.045 // Heat capacity of dry exhaust gas
    in kJ/kgK
p = 0.035 // Partial pressure of steam in exhaust
    gas in bar
printf("\n Example 20.15\n")
h = m_f*cv*1000/3600
Ip = mep*(10^5)*L*(10^-3)*(%pi/4)*((d*(10^-3))^2)*N
    *6/(2*60000)
```

```
n_m = Bp/Ip
h_w = (m_w/60)*(4.187*delta_t)
h_o = (m_o/60)*(s_o*delta_T)
m_e = m_f/60 + m_a
m_v = m_h*9*(m_f/60)
m_de = (m_e-m_v)/60
H = 3060 // From the steam table the enthalpy of steam at the exhaust condition (0.035 bar) in kJ/kg
h_s = (m_v/60)*H
h_de = (m_de)*(c_p_de)*(t_e-t)
h_su = h - (Bp+h_w+h_s+h_o+h_de)
printf("\n Mechanical efficiency = %f percent",n_m*100)
printf("\n                    Energy Balance")
printf("\n                                   Input            Output")
printf("\n Heat supplied by fuel            %f kW    -",h)
printf("\n Useful work(BP)                    -       %d kW",Bp)
printf("\n Heat carried by cooling water      -       %f kW",h_w)
printf("\n Heat carried by steam              -       %f kW",h_s)
printf("\n Heat carried by cooling oil        -       %f kW",h_o)
printf("\n Heat carried by dry exhaust gas    -       %f kW",h_de)
printf("\n Heat transferred to surroundings   -       %f kW",h_su)
```

Scilab code Exa 20.16 Calculation of fuel consumption and bmep

```
clc
// Given that
N = 3000 // Speed in rpm
T = 66.5 // Torque in Nm
d = 60 // Bore in mm
L = 100 // Stroke in mm
Vc = 60 // Clearance volume in cc
r_e = 0.5 // Relative efficiency
cv = 42 // Calorific value in MJ/kg
printf("\n Example 20.16\n")
Vs = (%pi/4)*((60*(10^-3))^2)*(L*(10^-3))
r_k = (Vs+(Vc*(10^-6)))/(Vc*(10^-6))
n_ase = 1-(1/(r_k^(0.4)))
n_br = n_ase*r_e
Bp = (2*(%pi)*T*N)/(60000)
m_f = Bp*3600/(cv*1000*n_br)
bmep = Bp*60000/(Vs*(N/2))
printf("\n Fuel consumption = %f kg/h,\n Brake mean effective pressure = %f bar",m_f,bmep*(10^-5))
//The answer given in the book for bmep has calculation error
// The answer has round off error for fuel consumption
```

Chapter 21

Gas turbines and propulsion systems

Scilab code Exa 21.1 Calculation of power output and overall efficiency

```
clc
// Given that
r_c = 3.5 // Compression ratio
n_c = 0.85 // Efficiency of compressor
p1 = 1 // Pressure in bar
t1 = 300 // Temperature in K
t3 = 310 // Temperature at the exit of the
    intercooler in K
r_c_ = 3.5 // Compression ratio for high pressure
    compressor
n_c_ = 0.85 // Efficiency of H.P. compressor
e = 0.8 // Effectiveness of regenerator
n_t = 0.88 // Efficiency of H.P. tubine
t6 = 1100 // Temperature in H.P. tubine in K
t8 = 1050 // Temperature at the entrance of L.P.
    turbine in K
n_t_ = 0.88 // Efficiency of L.P. turbine
Cp = 1.005 // Heat capacity of air in kJ/kgK
Cp_ = 1.15 // Heat capacity of gases in kJ/kgK
```

```
gama = 1.4 // Heat capacity ratio for air
gama_ = 1.33 // Heat capacity ratio for gases
printf("\n Example 21.1\n")
p2 = r_c*p1
p4 = p2*r_c_
t2_s = t1*((r_c)^((gama-1)/gama))
t2 = t1+((t2_s-t1)/n_c)
t4_s = t3*((r_c_)^((gama-1)/gama))
t4 = t3+((t4_s-t3)/n_c_)
Wc = Cp*((t2-t1)+(t4-t3))
t7 = t6 - (Wc/Cp_)
t7_s = t6 - (t6-t7)/n_t
r_p = (t6/t7_s)^(gama_/(gama_-1))
p7 = p4/r_p
t9_s = t8/((p7/p1)^((gama_-1)/gama_))
t9 = t8-(t8-t9_s)*n_t_
Wt_LP = Cp_*(t8-t9)
W_T = Wt_LP+Wc
Rw = Wt_LP/W_T
Q1 = (Cp_*t6-Cp*t4)+Cp_*(t8-t7)
n_plant = Wt_LP/Q1
printf("\n Power output = %f kJ/kg,\n The overall
    efficiency = %f percent",W_T,n_plant*100)
//The answers given in the book have round off error
```

Scilab code Exa 21.2 Calculation of flow velocity and blade angle at the root and at the tip and degree of reaction at the root and at the tip

```
clc
// Given that
v_bm = 360 // Blade velocity at the mean diameter of
    a gas turbine stage in m/s
beta1 = 20 // Blade angle at inlet in degree
```

```
beta2 = 52 // Blade angle at exit in degree
r = 0.5 // Degree of reaction
Dm = 0.45 // Mean diameter of blade in m
h = 0.08 // Mean height of blade in m
printf("\n Example 21.2\n")
v_f = v_bm/((tand(beta2))-tand(beta1))
r_r = (Dm/2)-h/2
r_t = Dm/2 +h/2
delta_v_wm = v_f*((tand(beta1))+(tand(beta2)))
v_br = v_bm*(r_r/(Dm/2))
delta_v_wr = delta_v_wm*v_bm/v_br

v_bt = (r_t/(Dm/2))*v_bm
v_w_1m = v_f*(tand(beta2))
v_w_1t = v_w_1m*(Dm/2)/r_t
delta_v_wt = v_f*((tand(beta1))+(tand(beta2)))*v_bm/
    v_bt
v_w_1r = v_w_1m*((Dm/2)/r_r)
alpha_1r = atand(v_w_1r/v_f)
alpha_2r = atand((delta_v_wr-v_w_1r)/v_f)
beta_1r = atand((v_w_1r-v_br)/v_f)
beta_2r = atand((v_br+v_f*(tand(alpha_2r)))/v_f)
alpha_1t = atand(v_w_1t/v_f)
alpha_2t = atand((delta_v_wt-v_w_1t)/v_f)
beta_1t = atand((v_w_1t-v_bt)/v_f)
beta_2t = atand((v_bt+(v_f*tand(alpha_2t)))/v_f)
Rt = v_f*((tand(beta_2t))-(tand(beta_1t)))/(2*v_bt)
Rr = v_f*((tand(beta_2r))-(tand(beta_1r)))/(2*v_br)
printf("\n Flow velocity = %d m/s,\n The blade angle
     at the root = %f degree,and at the tip = %f
    degree,\n The degree of reaction at the root = %f
     percent, and at the tip = %d percent",v_f,
    alpha_1r,alpha_2r,Rt*100,Rr*100)
```

Scilab code Exa 21.3 Calculation of blade angle and efficiency

```
clc
// Given that
p1 = 8 // Pressure of entrance in bar
t1 = 1125 // Temperature of entrance in K
p2 = 1.5 // Pressure of exit in bar
n = 11 // No of stages
Vf = 110 // Axial velocity of flow in m/s
n_p = 0.85 // Polytropic efficiency
Vb = 140 // Mean velocity in m/s
gama = 1.33 // Heat capacity ratio for gases
Cp = 1.15 // Heat capacity of gases in kJ/kgK
r = 0.5 // Fraction of reaction
printf("\n Example 21.3\n")
t2 = t1*((p2/p1)^((gama-1)*n_p/gama))
t2_s = t1*((p2/p1)^((gama-1)/gama))
n_s = (t1-t2)/(t1-t2_s)
Wt = Cp*(t1-t2)
Wt_s = Wt/n
V_w1 = (((Wt_s*1000)/Vb) + Vb)/2
alpha1 = atand(Vf/V_w1)
alpha2 = alpha1
beta1 = atand(Vf/(V_w1-Vb))
h_s = Wt_s
t_s = h_s/Cp
t1_ = t1-t_s
t1_s = t1*((t1_/t1)^(gama/((gama-1)*n_p)))^((gama-1)/gama)
n_st = (t1-t1_)/(t1-t1_s)
printf("\n The blade angle at the inlet = %f degree, and at the exit = %f degree,\n The overall efficiency of the turbine = %f percent\n The stage efficiency = %f percent",alpha1,beta1,n_s*100,n_st*100)
// The answers given in the book contain round off error.
```

Scilab code Exa 21.4 Calculation of total thrust developed and specific fuel consumption

```
clc
// Given that
v = 800 // Speed of aircraft in km/h
h = 10700 // Height of aircraft in m
p0 = 0.24 // Pressure in bar
t0 = -50 // Temperature in degree centigrade
r_p = 10 // Compressor pressure ratio
t03 = 1093 // Max cycle temperature in K
n_ed = 0.9 // Entry duct efficiency
n_c = 0.9 // Isentropic efficiency of compressure
p_ = 0.14 // Stagnation pressure loss in combustion
    chamber in bar
cv = 43.3 // Calorific value of fuel in MJ/kg
n_C = 0.98 // Combustion efficiency
n_t = 0.92 // Isentropic efficiency of turbine
n_m = 0.98 // Mechanical efficiency of drive
n_j = 0.92 // Jet pipe efficiency
a = 0.08 // Nozzle outlet area in m^2
Cp = 1.005 // Heat capacity of air in kJ/kgK
gama = 1.4 // Ratio of heat capacities for air
Cp_ = 1.15 // Heat capacity for gases in kJ/kgK
gama_ = 1.333 // Ratio of heat capacities for gases
printf("\n Example 21.4\n")
KE = (1/2)*(v*5/18)^2
tr = KE/(1000*Cp)
t01 = tr + (273+t0)
t01_s = (t0+273)+(n_ed*(t01-(t0+273)))
p01 = p0*((t01_s/(t0+273))^(gama/(gama-1)))
t02_s = t01*((r_p)^((gama-1)/gama))
```

```
t02 = (t01) + (t02_s-t01)/n_c
p02 = p01*r_p
p03 = p02-p_
t04 = t03 - (Cp*(t02-t01)/(Cp_*n_m))
t04_s = t03-(t03-t04)/n_t
p04 = p03/((t03/t04_s)^(gama_/(gama_-1)))
p_cr = p04*((2/(gama_+1))^(gama_/(gama_-1)))
t05 = t04*(2/(gama_+1))
t05_s = t04-((t04-t05)/n_j)
p05 = p04/((t04/t05_s)^(gama_/(gama_-1)))
R = Cp_*(gama_-1)/gama_
v5 = R*t05/(p05*100)
Vj = sqrt(gama_*R*1000*t05)
m = a*Vj/v5
Mt = m*(Vj-v*(5/18))
Pt = (p05-p0)*a*10^5
Tt = Mt+Pt
Q1 = m*(t03-t02)*Cp_
m_f = Q1/(cv*1000*n_C)
m_sf = m_f*1000/Tt
printf("\n Total thrust developed = %f N,\n The specific fuel consumption = %f kg/kNs",Tt,m_sf)
// The answers given in the book contain round off error.
```

Scilab code Exa 21.5 Calculation of power and efficiency

```
clc
// Given that
v = 850 // Speed of turbojet in km/h
m = 50 // Air mass flow rate in kg/s
s = 200 // Entropy drop across the nozzle in kJ/kg
n_n = 0.9 // Nozzle efficiency
```

```
r = 80 // Air fuel ratio
cv = 40 // Heating value of fuel in MJ/kg
Cp = 1005 // Heat capacity of air in J/kgK
printf("\n Example 21.5\n")
Vo = v*(5/18)
m_f = m/r
Ve = sqrt(2*Cp*s*n_n)
T = (m+m_f)*Ve-m*Vo
TP = T*Vo
PP = (1/2)*(m+m_f)*(Ve^2)-(1/2)*(m*Vo^2)
n_p = TP/PP
n_t = PP/(m_f*cv*1000000)
n = n_t*n_p
printf("\n Propulsive power = %f MW,\n Thrust power = %f kW,\n Propulsive efficiency = %f percent\n Thermal efficiency = %f percent,\n Overall efficiency = %f percent ",PP*(10^-6),TP*(10^-3),n_p*100,n_t*100,n*100)
```

Scilab code Exa 21.6 Calculation of air fuel ratio and thrust power and thrust and mass flow rate

```
clc
// Given that
p1 = 0.56 // Ambient pressure in bar
t1 = 260 // Ambient temperature in K
r_p = 6 // Pressure ratio of compressor
n_c = 0.85 // Efficiency of compressor
v = 360 // Speed of aircraft in km/h
d = 3 // Propeller diameter in m
n_p = 0.8 // Propeller efficiency
n_g = 0.95 // Gear reduction efficiency
r_e = 5 // Expansion ratio
```

```
n_t = 0.88 // Turbine efficiency
t3 = 1100 // Temperature at the entrance of turbine in K
n_n = 0.9 // Nozzle efficiency
cv = 40 // Calorific value in MJ/kg
printf("\n Example 21.6\n")
gama = 1.4 // Heat capacities ratio for air
Vo = v*(5/18)
p2 = p1*r_p
t2_s = t1*((r_p)^(0.286))
t2 = t1+((t2_s-t1)/n_c)
Cp = 1.005 // The value of heat capacity of air as given in the book in kJ/kgK
Wc = Cp*(t2-t1)
m_f = (t3-t2)/((cv*1000/Cp)-t3)
m_a = 1/m_f
p3=p2
p4 = p3/r_e
t4_s = t3/((r_e)^(0.286))
t4 = t3-((t3-t4_s)*n_t)
Wt = (1+m_f)*(t3-t4)*Cp
Pp = Wt-Wc
p5 = p1
t5_s = t4/((p4/p5)^((gama-1)/gama))
Vj = sqrt(2*Cp*1000*(t4-t5_s)*n_n)
Ft = (1+m_f)*Vj-1*Vo
V = Vo/n_p
V4 = 2*V-Vo
Q = (%pi/4)*(d^2)*V
Pt = (1/2)*(p1*(10^5)/(287*t1))*Q*((V4^2)-(Vo^2))/1000
PT = Pt/n_g
ma_c = PT/Pp
Fp = Pt*n_p/V
printf("\n Air-fuel ratio = %f,\n Thrust power of the propeller = %f kJ/s ,\n Thrust by the propeller = %f kN,\n Mass flow rate of air flowing through the compressor = %f kg/s,",m_a,Pt
```

```
,Fp,ma_c)
// The answers are given in the book contain calculation error.
```

Scilab code Exa 21.7 Calculation of velocity and height

```
clc
// Given that
m = 15000 // Initial mass of rocket in kg
m_b = 125 // Burning rate of propellent in kg/s
v = 2000 // Relative velocity of gases with respect to the rocket in m/s
T = 70 // Time in second
printf("\n Example 21.7\n")
V = (-v*log(1-(m_b*T/m)))-(9.81*T)
function y=f(t),y = (-v*log(1-(m_b*t/m))-9.81*t),
endfunction
h1 = intg(0,T,f)
h2 = (V^2)/(2*9.81)
hmax = h2 + h1
printf("\n Velocity attain by the rocket in 70 seconds = %f m/s ,\n The maximum height that the rocket will attain = %f km",V,hmax*0.001)
```

Scilab code Exa 21.8 Calculation of thrust and specific impulse

```

clc
// Given that
```

```
Pc = 2.4 // Pressure in combustion chamber in MPa
Tc = 3170 // Temperature in combustion chamber in K
Pj = 55 // Atmospheric pressure in kPa
Pe = 85 // Pressure at the exit of nozzle in kPa
At = 0.06 // Area at the nozzle throat in m^2
n_n = 0.91 // Nozzle efficiency
Cd = 0.98 // Coefficient of discharge
gama = 1.25 // Heat capacities ratio for gases
R = 0.693 // Value of gas constant in kJ/kgK
theta = 12 // Half angle of divergence in degree
printf("\n Example 21.8\n")
Vj = sqrt((2*gama*R*1000*Tc/(gama-1))*(1-(Pj/(Pc*1000))^((gama-1)/gama)))
Vj_act = ((1+cosd(12))/2)*Vj*sqrt(n_n)
m = At*Pc*(10^6)*((gama/(R*1000*Tc))*(2/(gama+1))^((gama+1)/(gama-1)))^(1/2)
m_act = Cd*m
Ae = m/(Pe*Vj)
Ft = m*Vj+Ae*(Pe-Pj)*1000
SIm = Ft/m_act
printf("\n Thrust produced = %f kN,\n Specific impulse = %f Ns/kg",Ft*0.001,SIm)
// The answers are given in the book contain calculation error.
```

Chapter 22

Transport processes in gas

Scilab code Exa 22.1 Calculation of mean free path and percentage of molecules

```
clc
// Given that
p = 1.013e5 // Pressure in Pa
t = 300 // Temperature in K
d = 3.5 // Effective diameter of oxygen molecule in
    Angstrom
r = 2 // Ratio of free path of molecules with the
    lambda
printf("\n Example 22.1 \n")
sigma = %pi*(d*(10^-10))^2
n = p/(t*1.38*(10^-23))
lambda = 0.707/(sigma*n)
R = exp(-r)
printf("\n Mean free path = %e m,\n The fraction of
    molecules have free path longer than 2*lambda =
    %f percent",lambda,R*100)
// Answer given in the book contain round off error
    for mean free path.
```

Scilab code Exa 22.2 Calculation of pressure and no of collisions

```
clc
// Given that
lambda = 2.63e-5 // Mean free path of the molecules
    of the gas in m
t = 25 // Temperature in degree centigrade
r = 2.56e-10 // Radius of the molecules in m
printf("\n Example 22.2 \n")
sigma = 4*%pi*r^2
n = 0.707/(sigma*lambda)
p = n*(t+273)*(1.38*10^-23)
N = 1/lambda
printf("\n Pressure of the gas = %f Pa,\n No of
    collisions made by a molecule per meter of path =
    %e",p,N)
```

Scilab code Exa 22.3 Calculation of no of free paths

```
clc
// Given that
lambda = 10 // Mean free path of the gas in cm
N0 = 10000 // No of free paths
x1 = 10 // In cm
x2 = 20 // In cm
x3 = 50 // In cm
x4 = 5 // In cm
x5 = 9.5 // In cm
```

```
x6 = 10.5 // In cm
x7 = 9.9 // In cm
x8 = 10.1 // In cm
printf("\n Example 22.3 \n")
// For x>10 cm
N1 = N0*(exp(-1))
// For x>20 cm
N2 = N0*(exp(-2))
// For x>50 cm
N3 = N0*(exp(-5))
function y=f(x), y = (-N0/lambda)*(exp((-x)/lambda))
    ,
endfunction
// For 5>x>10 cm
N4 = intg(x4,x1,f)
// For 9.5>x>10.5 cm
N5 = intg(x5,x6,f)
// For 9.9>x>10.1 cm
N6 = intg(x7,x8,f)
// For x=10 cm
N7 = intg(x1,x1,f)
printf("\n The no of free paths which are longer
    than, \n 10 cm = %d,\n 20 cm = %d,\n 50 cm = %d,\
    n\n The no of free paths which are between,\n 5
    cm and 10 cm = %d,\n 9.5 cm and 10.5 cm = %d,\n
    9.9 cm and 10.1 cm = %d,\n\n The no of free paths
     which are exactly 10 cm = %d",ceil(N1),ceil(N2),
    ceil(N3),floor(N4),floor(N5),floor(N6),N7)
```

Scilab code Exa 22.4 Calculation of coefficient of viscosity

```
clc
// Given that
```

```
p = 1 // Pressure in atm
t = 300 // Temperature in K
printf("\n Example 22.4 \n")
// From previous example, we have
m = 5.31e-26 // In kg/molecule
v = 445 // In m/s
sigma = 3.84e-19 // In m^2
// Therefore
mu = (1/3)*(m*v/sigma)
printf("\n Coefficient of viscosity = %e Ns/m^2",mu)
```

Scilab code Exa 22.5 Calculation of thermal conductivity

```
clc
// Given that
p = 1 // Pressure in atm
t = 300 // Temperature in K
F = 5 // For oxygen gas degree of freedom
printf("\n Example 22.5 \n")
v = 445 // In m/s as given in the book
m = 5.31e-26 // Mass of oxygen molecule in kg
sigma = 3.84e-19 // As given in the book in m^2
k = (1/6)*(v*F*(1.38*10^-23))/sigma
// If the gas has Maxwellian velocity distribution,
k_ = (1/3)*(F*(1.38*10^-23)/sigma)*((1.38*10^-23)*t
    /(%pi*m))^(1/2)
printf("\n Thermal conductivity  = %f W/mK,\n If the
    gas has Maxwellian velocity distribution,\n
    Thermal conductivity = %f W/mK",k,k_)
```

Scilab code Exa 22.6 Calculation of pressure

```
clc
// Given that
F = .90 // Fraction of electrons leaving the cathode
    ray reach the anode without making a collision
x = 0.2 // Distance between cathode ray and anode in
    m
d = 3.6e-10 // Diameter of ion in m
t = 2000 // Temperature of electron in K
printf("\n Example 22.6 \n")
lambda = x/(log(1/F))
sigma = %pi*(d^2)
n = 4/(sigma*lambda)
p = n*(1.38*10^-23)*(t)
printf("\n Pressure in the cathode ray tube = %f Pa"
    ,p)
```

Scilab code Exa 22.7 Calculation of no of collisions and no of the molecules strike the flask and no of molecules in the flask

```
clc
// Given that
V = 1 // Volume of the flask in litre
p = 1 // Pressure in atm
t = 300 // Temperature in K
r = 1.8e-10 // Radius of oxygen gas molecule in m
m = 5.31e-26 // Mass of oxygen molecule in kg
```

```
printf("\n Example 22.7 \n")
n = (p*(1.013e5))/((1.38e-23)*(t)*1000)
sigma = 4*%pi*(r^2)
v = ((8*(1.38e-23)*t)/(%pi*m))^(1/2)
z = sigma*n*v*1000
N = (1/4)*(n*0.1*v)
printf("\n No of collisions per sec are made by one
    molecule with the other molecule = %e,\nThe no of
     molecules strike the flask per sq. cm = %e,\n No
     of molecules in the flask = %e",z,N,n)
```

Scilab code Exa 22.8 Calculation of time

```
clc
// Given that
lambda = 2 // Mean free path in cm
T = 300 // Temperature in K
r = 0.5 // As half of the molecules did not make any
     collision
printf("\n Example 22.8 \n")
x = lambda*(log(1/r))
v = 445.58 // For oxygen at 300K in m/s
t = x/(v*100)
printf("\n Time = %e s",t)
```

Scilab code Exa 22.9 Calculation of pressure

```
clc
// Given that
```

```
f = 0.9 // Fraction of electrons leaving the cathode ray and reaching the anode without making any collision
x = 20 // Distance between cathode ray tube and anode in cm
sigma = 4.07e-19 // Collision cross section of molecules in m^2
T = 2000 // Temperature in K
printf("\n Example 22.9 \n")
lambda = (x*0.01)/(log(1/f))
n = 1/(sigma*lambda)
p = n*(1.38e-23)*T
printf("\n Pressure = %e N/m^2",p)
// The answer given in the book contains round off error.
```

Scilab code Exa 22.10 Calculation of initial concentration gradient and no of reactive molecules and rate of diffusion

```
clc
// Given that
l = 2 // Length of tube in m
a = 1e-4 // Cross section of the tube in m^2
p = 1 // Pressure in atm
t = 0 // Temperature in degree centigrade
r = 0.5 // Fraction of the carbon atoms which are radioactive C14
sigma = 4e-19 // Collision cross section area in m^2
printf("\n Example 22.10 \n")
n = (p*1.01325e+5)/((1.38e-23)*(t+273))
C_g = -n/l
m = (46/6.023)*10^-26 // In kg/molecule
v = (2.55*(1.38e-23)*(t+273)/m)^(1/2)
```

```
lambda = (1/(sigma*n))
gama = (1/4)*(v*n) - (1/6)*(v*lambda*(C_g))
gama_ = (1/4)*(v*n) + (1/6)*(v*lambda*(C_g))
x = (1/4)*(v*n)
y = (1/6)*(v*lambda*(C_g))
d = (1/6)*(v*lambda*(-1*C_g))*2*(m)
printf("\n Initial concentration gradient of reactive molecules = %e molecules/m^4, \n The no of reactive molecules per sec cross a cross section at the mid point of the tube from left to right = %e - (%e) molecules/m^2,\n The no of reactive molecules per sec cross a cross section at the mid point of the tube from right to left = %e + (%e) molecule/m^2,\n Initial net rate of diffusion = %fg/m^2-s",C_g,x,y,x,y,d*1000)
// The answer for lambda given in the book conatains calculation error
// The answers contains calculation error
```