Scilab Textbook Companion for Engineering Thermodynamics: A Computer Approach (SI Units Version) by R. K. Rajput[1]

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Book Description

Title: Engineering Thermodynamics: A Computer Approach (SI Units Version)

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

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

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

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

Contents

List of Scilab Codes

Chapter 2

Basic Concepts Of Thermodynamics

Scilab code Exa 2.1 1

```
clc
rho_Hg=13596; //kg/m^3
g=9.806; //m/s^2
h=0.76; //m

P=rho_Hg*g*h/1000; //kPa

disp("(i) Pressure of 80 cm of Hg")
h1=0.80; //m
P1=h1/h*P;
disp(P1)
disp("kPa")

disp("(ii) 30 cm Hg vacuum")
H2=0.30; //cm Hg vacuum
h2=h-H2; //cm of Hg absolute
disp("Pressure due to 46 cm of Hg")
P2=h2/h*P;
disp(P2)
```

```
disp("kPa")

disp("(iii) Pressure due to 1.35 m H2O gauge")
rho_H2O=1000; //kg/m^3
h3=1.35; //m
P3=rho_H2O*g*h3/1000;
disp(P3)
disp("kPa")

disp("(iv) 4.2 bar")
P4=4.2*10^2;
disp(P4)
disp("kPa")
```

Scilab code Exa 2.2 2

```
clc
d=0.1; //m
F=1000; //N
A=%pi/4*d^2; //m^2
P=F/A/10^3;
disp("Pressure on the piston=")
disp(P)
disp("kN/m^2")
```

Scilab code Exa 2.3 3

```
clc
SG=0.9;
h=1.2; //m
g=9.81; //m/s^2
rho_w=1000; //kg/m^3
rho=SG*rho_w; //kg/m^3
```

```
P=rho*g*h/10^3;
disp("Gauge pressure P=")
disp(P)
disp("kN/m^2")
```

Scilab code Exa 2.4 4

```
clc
Vacuum_recorded=740; //mm of Hg
Barometric_reading=760; //mm of Hg

Absolute_pressure=(Barometric_reading-Vacuum_recorded)*133.4;
disp("Absolute pressure in the condenser=")
disp(Absolute_pressure)
disp("Pa")
```

Scilab code Exa 2.5 5

```
clc
d=0.5; //m
h=0.75; //m
m=4; //kg
Manometer_reading=620; //mm of Hg above atmosphere
Barometer_reading=760; //mm of Hg
V=%pi/4*d^2*h; //m^3
disp("(i) Total pressure in the vessel")

P=(Barometer_reading+Manometer_reading)*133.4/10^5; //bar
disp("P=")
disp(P)
disp("bar")
```

```
disp("(ii) Specific volume and density")
SV=V/m;
disp("Specific volume=")
disp(SV)
disp("m^3/kg")
D=m/V;
disp("Density=")
disp(D)
disp("kg/m^3")
```

Scilab code Exa 2.6 6

```
clc
h0=.761; //m
h=.55; //m
g=9.79; //m/s^2
rho=13640; //kg/m^3
P=rho*g*(h0+h); //N/m^2
disp("Gas pressure=")
disp(P/10^5)
disp("bar")
```

Scilab code Exa 2.7 7

```
clc
h_H2O=34; //mm of Hg
g=9.81; //m/s^2
rho=13600; //kg/m^3
P_Hg=97.5; //mm of Hg
P_atm=760; //mm of Hg
P_H2O=h_H2O/13.6; //mm of Hg
Pabs=rho*g*(P_Hg+P_atm-P_H2O)/10^8; //bar
disp("absolute pressure =")
```

```
disp(Pabs)
disp("bar")
```

Scilab code Exa 2.8 8

```
clc
SG=0.8;
rho_H2O=1000; //kg/m^3
g=9.81; //ms^2
h=0.17; //m
Patm=1.01325; //bar
rho=SG*rho_H2O; //kg/m^3
P_liq=rho*g*h/10^5; //bar
P_gas=Patm - P_liq;
disp("gas pressure= ")
disp(P_gas)
disp("bar")
```

Scilab code Exa 2.9 9

```
clc
d=0.2; //m
g=9.81; //m/s^2
h=0.117; //m
rho=13600; //kg/m^3
p=rho*g*h;
m=(p*%pi/4*d^2)/g;
disp("mass=")
disp(m)
disp("kg")
```

Scilab code Exa 2.10 10

```
clc
v=800; //m/s
g=9; //m/s^2
F=3600; //N
m=F/g;
KE=1/2*m*v^2/10^6;
disp("Kinetic Energy=")
disp(KE)
disp("MJ")
```

Scilab code Exa 2.11 11

```
clc
m=6; //kg
T1=25; //0C
T2=125; //0C

disp("(i) Heat transferred")
Q=integrate('m*(0.4+0.004*T)','T',T1,T2);
disp("heat tranferred=")
disp(Q)
disp("kJ")

disp("(ii) Mean specific heat of the gas")
c_n=Q/m/(T2-T1);
disp("Mean specific heat=")
disp(c_n)
disp("kJ/kg.0C")
```

Scilab code Exa 2.12 12

```
clc
Ice_point=0;
Steam_point=100;
// t=a*log(p)+b
// from given conditions equations formed are
// a*log(1.5)+b=0
// a*log(7.5)+b=100
// solving equations
P=[log(1.5),1;log(7.5),1];
Q=[0;100];
X=inv(P)*Q;
a=X(1,1);
b=X(2,1);
p=3.5;
t=a*log(p)+b;
disp("The value of temperature is given by")
disp(t)
disp(" C ")
```

Scilab code Exa 2.13 13

```
clc
deff("[e]=func(t)","e=0.20*t-5*10^(-4)*t^2")
t1=0; //0C
e1=func(t1);
t2=100; //0C
e2=func(t2);
t3=70; //0C
e3=func(t3);
t=e3*(t2-t1)/e2-e1;
disp("thermocouple will read")
disp(t)
disp(" C ")
```

Scilab code Exa 2.15 15

```
clc
p=101.325; //kPa
V2=0.6; //m^3
V1=0; //m^3
W=p*(V2-V1);
disp("work done by atmosphere=")
disp(-W)
disp("kJ")
```

Scilab code Exa 2.16 16

```
clc
p=1.013*10^5; //N/m^2
V1=1.5; //m^3
V2=0; //m^3
W=p*(V2-V1);
disp("W=")
disp(W/10^3)
disp("kJ")
```

Scilab code Exa 2.17 17

```
clc
T=1.25; //N.m
N=9500;
W1=2*%pi*N*T/1000; //kJ
p=101.3; //kPa
```

```
d=0.65; //m
A=%pi/4*d^2; //m^2
L=0.6; //m
W2=p*A*L; //kJ
Wnet=(-W1)+W2;
disp("The net work transfer for the system=")
disp(Wnet)
disp("kJ")
```

Scilab code Exa 2.18 18

```
clc
A=45*10^(-4); //m^2
P=0.9*10^5; //N/m^2
Patm=1.013*10^5; //N/m^2
L=0.05; //m
dV=300*10^(-6); //m^3
W=P*A*L-Patm*dV;
disp("net work done =")
disp(W)
disp("J")
```

Scilab code Exa 2.19 19

```
clc
p1=1.5; //bar
p2=7.5; //bar
V1=3/p1;
V2=3/p2;
W=integrate('3/V*10^2', 'V', V1, V2);
disp("Work done=")
disp(W)
disp("kJ")
```

Scilab code Exa 2.20 20

```
clc
W=150; //kJ
V1=0.6; //m^3

// p=8-4*V
// W=integration of p*dV from V1 to V2
// Solving above equation we get

V2=0.354; //m^3
disp("Final volume =")
disp(V2)
disp("m^3")

p2=8-4*V2;
disp("Final pressure =")
disp(p2)
disp("bar")
```

Scilab code Exa 2.21 21

```
clc
p1=3*10^5; //Pa
v1=0.18; //m^3/kg
C=p1*v1^2;
p2=0.6*10^5; //Pa
v2=sqrt(C/p2);
W=integrate('C/v^2', 'v', v1,v2);
disp("Work done=")
disp(W)
disp("Nm/kg")
```

Scilab code Exa 2.22 22

```
clc
m=1; //kg
p1=20*10^5; //Pa
V1=0.05; //m^3
V2=2*V1;
p2=p1*(V1/V2)^2;
C=p1*V1^2;
V3=V1;
W_12=integrate('C/V^2', 'V', V1,V2);

W_23=p2*(V2-V3);

W_net=W_12-W_23;
disp("Net work done = ")
disp(W_net)
disp("Nm")
```

Chapter 3

Properties Of Pure Substances

Scilab code Exa 3.1 1

```
clc
m_s=50; //kg
m_w=1.5; //kg
x=m_s/(m_s+m_w);
disp("dryness fraction=")
disp(x)
```

Scilab code Exa 3.2 2

```
clc
V=0.6; //m^3
m=3.0; //kg
p=5; //bar
v=V/m;
// At 5 bar: From steam tables
v_g=0.375; //m^3/kg
v_f=0.00109; //m^3/kg
v_fg=v_g - v_f;
```

```
x=1-((v_g - v)/v_fg);

disp("(i) Mass and volume of liquid")
m_liq=m*(1-x);
disp("mass of liquid=")
disp(m_liq)
disp("kg")
V_liq=m_liq*v_f;
disp("volume of liquid=")
disp(V_liq)
disp("m^3")

disp("(ii) Mass and volume of vapour")
m_vap=m*x;
disp("mass of vapour=")
disp(m_vap)
disp("kg")
V_vap=m_vap*v_g;
disp("volume of vapour=")
disp(V_vap)
disp("m^3")
```

Scilab code Exa 3.3 3

```
clc
V=0.05; //m^3
m_f=10; //kg
// From steam tables corresponding to 245 0C
p_sat=36.5; //bar
v_f=0.001239; //m^3/kg
v_g=0.0546; //m^3/kg
h_f=1061.4; //kJ/kg
h_fg=1740.2; //kJ/kg
s_f=2.7474; //kJ/kg.K
s_fg=3.3585; //kJ/kg.K
```

```
disp("(i) The pressure=")
disp(p_sat)
disp("bar")

disp("(ii) The mass")
V_f=m_f*v_f;
V_g=V - V_f;
m_g=V_g/v_g;
m=m_f+m_g;
disp("The total mass of mixture=")
disp(m)
disp("kg")

disp("(iii) The specific volume")
v_fg=v_g-v_f;
x= m_g/(m_g+ m_f);
v=v_f+x*v_fg;
disp("specific volume=")
disp(v)
disp("m^3/kg")

disp("(iv)The specific enthalpy")
h=h_f+x*h_fg;
disp("specific enthalpy=")
disp(h)
disp("kJ/kg")

disp("(v)The specific entropy")
s=s_f+x*s_fg;
disp("specific entropy =")
disp(s)
disp("kJ/kg.K")

disp("(vi)The specific internal enegy")
u=h-(p_sat*v*10^2); //kJ/kg
disp("specific internal energy=")
disp(u)
```

```
disp("kJ/kg")
```

Scilab code Exa 3.4 4

```
clc
m_w=2; //kg
t_w=25; //0C
p=5; //bar
x=0.9;
c_pw=4.18;
// at 5 bar; from steam tables
h_f=640.1; //kJ/kg
h_fg=2107.4; //kJ/kg
h=h_f+x*h_fg;
disp("Sensible heat associated with 1kg of water, Qw
    =")
Qw=c_pw*(t_w-0);
disp(Qw)
disp("kJ")
disp("Net quantity of heat to be supplies per kg of
    water, Q=")
Q=h-Qw;
disp(Q)
disp("kJ")

disp("Total amount of heat supplied, Q_total=")
Q_total=m_w*Q;
disp(Q_total)
disp("kJ")
```

Scilab code Exa 3.5 5

```
clc
```

```
m=4.4; //kg
p=6; //bar
t_sup=250; //0C
t_w= 30; //0C
c_ps=2.2; //kJ/kg
c_pw=4.18;
// At 6 bar, 250 0C; From steam tables
t_s=158.8; //0C
h_f=670.4; //kJ/kg
h_fg=2085; //kJ/kg
h_sup=h_f+h_fg+ c_ps*(t_sup-t_s);

disp("Amount of heat added per kg of water, Qw=")
Qw=c_pw*(t_w-0);
disp(Qw)

disp("Net amount of heat required to be supplied per
    kg, Q=")
Q=h_sup-Qw;
disp(Q)

disp("Total amount of heat required, Q_total=")
Q_total=m*Q;
disp(Q_total)
disp("kJ")
```

Scilab code Exa 3.6 6

```
clc
v=0.15; //m^3
p=4; //bar
x=0.8;
// At 4 bar: From steam tables
v_g=0.462; //m^3/kg
h_f= 604.7; //kJ/kg
```

```
h_fg=2133; //kJ/kg
density=1/x/v_g;
disp("mass of 0.15 m^3 steam, m=")
m=v*density;
disp(m)
disp("kg")

disp("Total heat of 1 m3 of steam which has a mass
    of 2.7056 kg, Q=")
Q=density*(h_f+x*h_fg);
disp(Q)
disp("kJ")
```

Scilab code Exa 3.7 7

```
clc
m=1000; //kJ/kg.K
p=16; //bar
x=0.9;
T_sup=653; //K
T_w=30; //0C
c_ps=2.2; //kJ/kg
c_pw=4.18;
// At 16 bar:From steam tables
T_s=474.4; //K
h_f=858.6; //kJ/kg
h_fg=1933.2; //kJ/kg

disp("(i) Heat supplied to feed water per hour to
    produce wet steam is given by")
H=m*[(h_f+x*h_fg)-c_pw*(T_w-0)];
disp(H)
disp("kJ")

disp("(ii) Heat absorbed by superheater per hour, Q=
```

```
    ")
Q=m*[(1-x)*h_fg+c_ps*(T_sup-T_s)];
disp(Q)
disp("kJ")
```

Scilab code Exa 3.8 8

```
clc

disp("(i) at 0.75 bar, between 100 C  and 150 C ")
// At 100  C
T1=100; // C
h_sup1=2679.4; //kJ/kg
// At 150  C
T2=150; // C
h_sup2=2778.2; //kJ/kg

c_ps=(h_sup2-h_sup1)/(T2-T1);
disp("mean specific heat=")
disp(c_ps)

disp("(ii) at 0.5 bar, between 300 C  and 400 C ")
T1=300; // C
h_sup1=3075.5; //kJ/kg
T2=400; // C
h_sup2=3278.9; //kJ/kg

c_ps=(h_sup2-h_sup1)/(T2-T1);
disp("mean specific heat c_ps=")
disp(c_ps)
```

Scilab code Exa 3.9 9

```
clc
m=1.5; //kg
p=5; //bar
x1=1;
x2=0.6;
p1=5*10^5; //N/m
// At 5 bar: From steam tables
t_s=151.8; //0C
h_f=640.1; //kJ/kg
h_fg=2107.4; //kJ/kg
v_g=0.375; //m^3/kg
v_g1=0.375*10^(-3);
h1=h_f+h_fg;
V=m*v_g;
u1=h1-p1*v_g1;
v_g2=V/m/x2; //m^3/kg

// From steam table corresponding to 0.625 m^3/kg
p2=2.9; //bar
disp("Pressure at new state =")
disp(p2)
disp("bar")

t_s=132.4; //0C
disp("Temperature at new state =")
disp(t_s)
disp(" C ")
h_f2=556.5; //kJ/kg
h_fg2=2166.6; //kJ/kg
u2=(h_f2+x2*h_fg2)-p2*x2*v_g2*10^2;

Q=u2-u1; //heat transferred at constant volume per
    kg

disp("Total heat transfered ,Q_total=")
Q_total=m*Q;
disp(Q_total)
disp("kJ")
```

Scilab code Exa 3.10 10

```
clc
V=0.9; //m^3
p1=8; //bar
x1=0.9;
p2=4; //bar
p3=3; //bar
v_g1=0.24; //m^3/kg

disp("(i) The mass of steam blown off :")
m1=V/x1/v_g1;
h_f1=720.9; //kJ/kg
h_fg1=2046.5; //kJ/kg
h_f2=604.7; //kJ/kg
h_fg2=2133; //kJ/kg
v_g2=0.462; //m^3/kg

h1=h_f1+x1*h_fg1; //The enthalpy of steam before
    blowing off

h2=h1;
x2=(h1-h_f2)/h_fg2;
m2=x1/(x2*v_g2);

disp("Mass of steam blown off =")
m=m1-m2;
disp(m)
disp("kg")

disp("(ii) Dryness fraction of steam in the vessel
    after cooling")
v_g3=0.606; //m^3/kg
x3=x2*v_g2/v_g3;
```

```
disp("dryness fraction =")
disp(x3)


disp("(iii) Heat lost during cooling")
h_f3=561.4; //kJ/kg
h_fg3=2163.2; //kJ/kg
h3=h_f3+x3*h_fg3;
u2=h2-p2*x2*v_g2*10^2; //kJ/kg
u3=h3-p3*x3*v_g3*10^2; //kJ/kg
Q=m*(u3-u2);
disp("Heat lost during cooling=")
disp(-Q)
disp("kJ")
```

Scilab code Exa 3.11 11

```
clc
p=8*10^5; //Pa
x=0.8;

v_g=0.240; //m^3/kg
h_fg=2046.5; //kJ/kg

disp("(i) External work done during evaporation")
W=p*x*v_g/10^3; //kJ
disp("W=")
disp(W)
disp("kJ")

disp("(ii) Internal latent heat")
Q=x*h_fg-W;
disp("Q=")
disp(Q)
disp("kJ")
```

Scilab code Exa 3.12 12

```
clc
p1=10; //bar
p2=10; //bar
x1=0.85;
V1=0.15; //m^3
t_sup2=300; //0C
t_sup1=179.9; //0C
c_ps=2.2; //kJ/kg.K
v_g1=0.194; //m^3/kg
m=V1/(x1*v_g1);
h_fg1=2013.6; //kJ/kg
Q=(1-x1)*h_fg1+c_ps*(t_sup2-t_sup1);
Q_total=m*Q;

disp("Total heat supplied=")
disp(Q_total)
disp("kJ")

v_sup2=v_g1*(t_sup2+273)/(t_sup1+273)
W=p1*(v_sup2 - (x1*v_g1))*10^2;
Percentage=W/Q*100;

disp("Percentage of total heat supplied=")
disp(Percentage)
disp("%")
```

Scilab code Exa 3.13 13

```
clc
```

```
p=18; //bar
x=0.85;
h_f=884.6; //kJ/kg
h_fg=1910.3; //kJ/kg
v_g=0.110; //m^3/kg
u_f=883; //kJ/kg
u_g=2598; //kJ/kg
v=x*v_g;
disp("Specific volume of wet steam=")
disp(v)
disp("m^3/kg")

h=h_f+x*h_fg;
disp("Specific enthalpy of wet steam=")
disp(h)
disp("kJ/kg")
u=(1-x)*u_f+ x*u_g;
disp("Specific internal energy of wet steam =")
disp(u)
disp("kJ/kg")
```

Scilab code Exa 3.14 14

```
clc
p=7; //bar
h=2550; //kJ/kg
h_f=697.1; //kJ/kg
h_fg=2064.9; //kJ/kg
v_g=0.273; //m^3/kg
u_f=696; //kJ/kg
u_g=2573; //kJ/kg
x=(h-h_f)/h_fg;
disp("(i) Dryness fraction=")
disp(x)

```

```
v=x*v_g;
disp("(ii) Specific volume of wet steam =")
disp(v)
disp("m^3/kg")

u=(1-x)*u_f+ x*u_g;
disp("(iii) Specific internal energy of wet steam=")
disp(u)
disp("kJ/kg")
```

Scilab code Exa 3.15 15

```
clc
p=120; //bar
v=0.01721; //m^3/kg

T=350; // C
disp("Temperature=")
disp(T)
disp(" C ")

h=2847.7; //kJ/kg
disp("specific enthalpy=")
disp(h)
disp("kJ/kg")

u=h-p*v*10^2; //kJ/kg
disp("Internal energy=")
disp(u)
disp("kJ/kg")
```

Scilab code Exa 3.16 16

```
clc
p=140; //bar
h=3001.9; //kJ/kg

T=400; //0C
disp("Temperature=")
disp(T)
disp(" C ")

v=0.01722; //m^3/kg
disp("The specific volume")
disp(v)
disp("m^3/kg")

u=h-p*v*10^2;
disp("specific internal energy=")
disp(u)
disp("kJ/kg")
```

Scilab code Exa 3.17 17

```
clc
// At 10 bar: From steam table for superheated steam
h_sup=3051.2; //kJ/kg
T_sup=573; //K
T_s=452.9; //K
v_g=0.194; //m^3/kg
v_sup=v_g*T_sup/T_s;
p=10; //bar

u1=h_sup-p*v_sup*10^2; //kJ/kg
disp("Internal energy of superheated steam at 10 bar
    = ")
disp(u1)
disp("kJ/kg")
```

```
// At 1.4 bar: From steam tables
p=1.4; //bar
h_f=458.4; //kJ/kg
h_fg=2231.9; //kJ/kg
v_g=1.236; //m^3/kg
x=0.8;
h=h_f+x*h_fg;
u2=h-p*x*v_g*10^2; //kJ
du=u2-u1;
disp("Change in internal energy=")
disp(du)
disp("kJ")
```

Scilab code Exa 3.18 18

```
clc
m=1; //kg
p=20; //bar
T_sup=400; //0C
x=0.9;
c_ps=2.3; //kJ/kg.K

disp("(i) Internal energy of 1 kg of superheated
   steam")
// At 20 bar: From steam tables
T_s=212.4; //0C
h_f=908.6; //kJ/kg
h_fg=1888.6; //kJ/kg
v_g=0.0995; //m^3/kg
h_sup = h_f+h_fg+c_ps*(T_sup-T_s);
v_sup=v_g*(T_sup+273)/(T_s+273);
u=h_sup-p*v_sup*10^2;
disp("Internal energy=")
disp(u)
```

```
disp("kJ/kg")

disp("(ii) Internal energy of 1 kg of wet steam")
h=h_f+x*h_fg;
u=h-p*x*v_g*10^2;
disp("Internal energy=")
disp(u)
disp("kJ/kg")
```

Scilab code Exa 3.19 19

```
clc
h_g1=2797.2; //kJ/kg
c_ps= 2.25;
T_sup=350; //0C
T_s=212.4; //0C
h1=h_g1+c_ps*(T_sup-T_s);
h_f2=908.6; //kJ/kg
h_fg2=1888.6; //kJ/kg

// Main:20 bar, 250 0C
T_sup=250; //0C
Q=2*[h_g1+c_ps*(T_sup-T_s)];
x2=(Q-h1-h_f2)/h_fg2;
disp("Quality of steam")
disp(x2)
```

Scilab code Exa 3.20 20

```
clc
m=1; //kg
p=6; //bar
x=0.8;
```

```
T_s=473; //K
h_fg=2085; //kJ/kg
c_pw=4.18;
s_wet=c_pw*log(T_s/273)+x*h_fg/T_s;
disp("Entropy of wet steam=")
disp(s_wet)
disp("kJ/kg.K")
```

Scilab code Exa 3.21 21

```
clc
p1=10; //bar
t_sup=400; //0C
p2=0.2; //bar
x2=0.9;
h_sup=3263.9; //kJ/kg
s_sup=7.465;  //kJ/kg
h1=3263.9; //kJ/kg
s1=s_sup;
h_f2=251.5; //kJ/kg
h_fg2=2358.4; //kJ/kg
s_f2=0.8321; //kJ/kg.K
s_g2=7.9094; //kJ/kg.K
s_fg2=s_g2-s_f2;
h2=h_f2+x2*h_fg2;
s2=s_f2+x2*s_fg2;

disp("(i) Drop in enthalpy")
dh=h1-h2;
disp("Drop in enthalpy = ")
disp(dh)
disp("kJ/kg")


disp("(ii) Change in entropy")
```

```
ds=s1-s2;
disp("Change in entropy = ")
disp(ds)
disp("kJ/kg.K")
```

Scilab code Exa 3.22 22

```
clc
m=1; //kg
p=12; //bar
T_sup=523; //K
c_ps=2.1; //kJ/kg.K
T_s=461; //K
h_fg=1984.3; //kJ/kg
c_pw=4.18;
s_sup=c_pw*log(T_s/273)+h_fg/T_s+c_ps*log(T_sup/T_s)
    ;
disp("Entropy =")
disp(s_sup)
disp("kJ/kg.K")
```

Scilab code Exa 3.23 23

```
clc
m=3; //kg
v1=0.75; //m^3/kg
v2=1.2363; //m^3/kg
x=v1/v2;
h_f=458.4; //kJ/kg
h_fg=2231.9; //kJ/kg
h_s=m*[h_f+x*h_fg]; //kJ
v_sup=1.55; //m^3/kg
p=2; //bar
```

```
t_s=120.2; //0C
t_sup=400; //0C
h=3276.6; //kJ/kg
U=1708; //kJ/kg
Degree=t_sup-t_s;
h_sup=m*h;

Q_added=h_sup - h_s;
disp("Heat added =")
disp(Q_added)
disp("kJ")

U_s=m*U;
U_sup=m*(h-p*v_sup*10^2);
dU= U_sup - U_s;
W=Q_added - dU;
disp("work done = ")
disp(W)
disp("kJ")
```

Scilab code Exa 3.24 24

```
clc
p=5; //bar
m=50; //kg
T1=20; //0C
m_s=3; //kg
T2=40; //0C
m_eq=1.5; //kg
h_f=640.1; //kJ/kg
h_fg=2107.4; //kJ/kg
c_pw=4.18;
m_w=m+m_eq;
x=[(m_w*c_pw*(T2-T1))/m_s + c_pw*T2 - h_f]/h_fg;
disp("Dryness fraction of steam")
```

```
disp(x)
```

Scilab code Exa 3.25 25

```
clc
p=1.1; //bar
x=0.95;
c_pw=4.18;
m1=90; //kg
m2=5.25; //kg
T1=25; //0C
T2=40; //0C
m=m1+m2;
h_f=428.8; //kJ/kg
h_fg= 2250.8; //kJ/kg
m_s= [m*c_pw*(T2-T1)]/[(h_f + x*h_fg) - c_pw*T2];
disp("Mass of steam condensed=")
disp(m_s)
disp("kg")
```

Scilab code Exa 3.26 26

```
clc
p1=8; //bar
p2=1; //bar
T_sup2=115; //0C
T_s2=99.6; //0C
h_f1=720.9; //kJ/kg
h_fg1=2046.5; //kJ/kg
h_f2=417.5; //kJ/kg
h_fg2=2257.9; //kJ/kg
c_ps=2.1;
x1=[h_f2+h_fg2+c_ps*(T_sup2-T_s2)-h_f1]/h_fg1;
```

```
disp("Dryness fraction of the steam in the main = ")
disp(x1)
```

Scilab code Exa 3.27 27

```
clc
m_w=2; //kg
m_s=20.5; //kg
t_sup=110; //0C
p1=12; //bar
p3=1; //bar
p2=p1;
h_f2=798.4; //kJ/kg
h_fg2=1984.3; //kJ/kg
T_s=99.6; //0C
h_f3=417.5; //kJ/kg
h_fg3=2257.9; //kJ/kg
T_sup=110; //0C
c_ps=2; //kJ/kg.K
x2=[h_f3+h_fg3 + c_ps*(T_sup-T_s) - h_f2]/h_fg2;
x1=x2*m_s/(m_w+m_s);
disp("Quality of steam supplied = ")
disp(x1)
```

Scilab code Exa 3.28 28

```
clc
p1=15; //bar
p2=p1;
p3=1; //bar
t_sup3=150; //0C
m_w=0.5; //kg/min
m_s=10; //kg/min
```

```
h_f2=844.7; //kJ/kg
h_fg2=1945.2; //kJ/kg
h_sup3=2776.4; //kJ/kg
x2=(h_sup3 - h_f2)/h_fg2;
x1=x2*m_s/(m_s + m_w);
disp("Quality of steam supplied = ")
disp(x1)
```

Chapter 4

First Law of Thermodynamics

Scilab code Exa 4.1 1

```
clc
Q=-50; //kJ/kg
W=-100; //kJ/kg
dU=Q-W;
disp("gain in internal energy = ")
disp(dU)
disp("kJ/kg")
```

Scilab code Exa 4.2 2

```
clc
u1=450; //kJ/kg
u2=220; //kJ/kg
W=120; //kJ/kg
Q=(u2-u1) + W;
disp("Heat rejected by air =")
disp(-Q)
disp("kJ/kg")
```

Scilab code Exa 4.3 3

```
clc
m=0.3; //kg
cv=0.75; //kJ/kg.K
T1=313; //K
T2=433; //K
W=-30; //kJ
dU=m*cv*(T2-T1);
Q=dU + W;
disp("Heat rejected during the process=")
disp(-Q)
disp("kJ")
```

Scilab code Exa 4.4 4

```
clc
p1=105; //kPa
V1=0.4;  //m^3
p2=p1;
V2=0.20; //m^3
Q=-42.5; //kJ
W=p1*(V2-V1);
dU=Q-W;
disp("change in internal energy = ")
disp(dU)
disp("kJ")
```

Scilab code Exa 4.6 6

```
clc
p=1.1; //bar
x=0.95;
c_pw=4.18;
m1=90; //kg
m2=5.25; //kg
T1=25; //0C
T2=40; //0C
m=m1+m2;
h_f=428.8; //kJ/kg
h_fg= 2250.8; //kJ/kg
m_s= [m*c_pw*(T2-T1)]/[(h_f + x*h_fg) - c_pw*T2];
disp("Mass of steam condensed=")
disp(m_s)
disp("kg")
```

Scilab code Exa 4.7 7

```
clc
W_12=-82; //kJ
Q_12=-45; //kJ
dU_12=Q_12 - W_12;
W_21=100; //kJ
dU_21=-dU_12;
Q_21=dU_21 + W_21;
disp("Heat added to the system = ")
disp(Q_21)
disp("kJ")
```

Scilab code Exa 4.8 8

```
clc
Q2=9000; //kJ
```

```
Q1=3000; //kJ
Q=Q1-Q2;
W=0;
dU=W-Q;
disp("Work done = ")
disp(W)

disp("Change in internal energy = ")
disp(dU)
disp("kJ")
```

Scilab code Exa 4.9 9

```
m=20; //kg
g=9.81; //m/s^2
z2=0;
z1=15;

disp("(i) When the stone is about to enter the water
   ")
Q=0
W=0
dU=0
PE=m*g*(z2-z1)
KE=-PE

disp("(ii) When the stone dips into the tank and
   comes to rest")
Q=0
W=0
KE=0
PE=m*g*(z2-z1)
dU=-PE

disp("(iii) When the water and stone come to their
```

```
    initial temperature")
W=0
KE=0
Q=-dU
```

Scilab code Exa 4.10 10

```
clc
Q_lqm=168; //kJ
W_lqm=64; //kJ
dU_lm=Q_lqm - W_lqm;
W_lnm=21; //kJ
W_ml=-42; //kJ

Q_lnm=dU_lm + W_lnm;
disp("(i)Q_lnm=")
disp(Q_lnm)
disp("kJ")


Q_ml=W_ml - dU_lm;
disp("(ii)Q_ml = ")
disp(Q_ml)
disp("kJ")


W_ln=21; //kJ
dU_ln=84; //kJ
Q_ln=dU_ln + W_ln;
Q_nm=Q_lnm-Q_ln;
disp("Q_nm = ")
disp(Q_nm)
disp("kJ")
```

Scilab code Exa 4.11 11

```
clc
T1=55; //0C
T2=95; //0C
W=integrate('200', 'T', T1, T2);
Q=integrate('160', 'T', T1, T2);
dU=Q-W;
disp("change in internal energy=")
disp(dU/10^3)
disp("kJ")
```

Scilab code Exa 4.12 12

```
clc
Q=-340; //kJ
n=200; //cycles/min

//For Process 1-2

W_12=4340; //kJ/min
Q_12=0;

dE_12=Q_12-W_12;
disp("dE_12 =")
disp(dE_12)
disp("kJ/min")

//For process 2-3

Q_23=42000; //kJ/min
W_23=0;
```

```
dE_23=Q_23-W_23;
disp("dE_23 =")
disp(dE_23)
disp("kJ/min")

//For process 3-4

Q_34=-4200; //kJ/min
dE_34=-73200; //kJ/min

W_34=Q_34-dE_34;
disp("W_34 =")
disp(W_34)
disp("kJ/min")

//For process 4-1
Q_41=Q*n-Q_12-Q_23-Q_34;
disp("Q_41 =")
disp(Q_41)
disp("kJ/min")

dE_41=0-dE_12-dE_23-dE_34;
disp("dE_41 =")
disp(dE_41)
disp("kJ/min")

W_41=Q_41-dE_41;
disp("W_41 =")
disp(W_41)
disp("kJ/min")
```

Scilab code Exa 4.13 13

```
clc
```

```
P=1200; //kW
Qin=3360; //kJ/kg
Qout=2520; //kJ/kg
F=6; //kW
dQ=Qin - Qout;
dW=P-F; //kJ/s
m = dW/dQ;
disp("Steam flow round the cycle")
disp(m)
disp("kg/s")
```

Scilab code Exa 4.14 14

```
clc
dT=25; //0C
Q=30; //kJ
cv=1.2; //kJ/kg.0C
m=2.5; //kg
dU=m*cv*dT;


disp("change in internal energy = ")
disp(dU)
disp("kJ")

W=Q - dU;
disp("Work done = ")
disp(W)
disp("kJ")
```

Scilab code Exa 4.15 15

```
clc
```

```
Q=50; //kJ
dV=0.14; //m^3
p=1.2*10^5; //N/m^2
m=90; //kg
d=5.5; //m
g=9.8; //m/s^2
W_adb = -110; //kJ
Wnet=m*g*d/1000; //kJ


disp("(i)Change in internal energy")
W=p*dV/1000 + Wnet; //kJ
dE=Q-W;
disp("dE=")
disp(dE)
disp("kJ")

disp("(ii) Adiabatic process")
Q=0;
dE=-W_adb;
disp("dE=")
disp(dE)
disp("kJ")

disp("(iii)Change in internal energy")
Q=50; //kJ
dE=Q - [W_adb+W];
disp("dE=")
disp(dE)
disp("kJ")
```

Scilab code Exa 4.16 16

```
clc
V1=0.15; //m^3
```

```
V2=0.05; //m^3
Q=-45; //kJ
p1=(5/V1+1.5)*10^5; //N/m^2
p2=(5/V2+1.5)*10^5; //N/m^2
W=integrate('(5/V+1.5)*10^2', 'V', V1, V2);


disp("(i)Change in internal energy = ")
dU=Q-W;
disp("dU=")
disp(dU)
disp("kJ")


disp("(ii) Change in enthalpy")
dH=(dU*10^3+(p2*V2-p1*V1))/10^3;
disp("dH=")
disp(dH)
disp("kJ")
```

Scilab code Exa 4.17 17

```
clc
V1=0.25; //m^3
p1=500; //kPa
p2=100; //kPa
V2=V1*(p1/p2)^(1/1.25)
n=1.25
dU=3.64*(p2*V2 - p1*V1)


disp("(i) If the expansion is quasi-static")
W=(p1*V1-p2*V2)/(n-1);
Q=dU+W
disp("Heat transfered=")
```

```
disp(Q)
disp("kJ")


disp("(ii) In another process")
Q=32; //kJ
W=Q-dU;
disp("Work done=")
disp(W)
disp("kJ")


disp("(iii)The difference")
disp("(iii) The work in (ii) is not equal to      p
   dV since the process is not quasi-static.")
```

Scilab code Exa 4.18 18

```
clc
v1=0.3; //m^3/kg
T1=20; //0C
v2=0.55; //m^3/kg
T2=260; //0C
p=1.6*10^5; //Pa

disp("(i)Heat added per kg = ")
Q=integrate('1.5 + 75/(T+45)', 'T', T1,T2);
disp("Q=")
disp(Q)
disp("kJ/kg")


disp("(ii)The work done per kg of fluid")
W=p*(v2-v1)/1000; //kJ/kg
disp("W=")
```

```
disp(W)
disp("kJ/kg")


disp("(iii)Change in internal energy")
dU=Q-W;
disp("dU=")
disp(dU)
disp("kJ/kg")


disp("(iv)Change in enthalpy")
dH=Q;
disp("dH=")
disp(dH)
disp("kJ/kg")
```

Scilab code Exa 4.19 19

```
clc
m=1; //kg
du=-42000; //J
cp=840; //J/kg.0C
cv=600; //J/kg.0C
dT=du/m/cv;
Q=m*cp*dT;
W=(Q-du)/10^3;
disp("Work done=")
disp(W)
disp("kJ")
```

Scilab code Exa 4.20 20

```
clc
p1=190; //kPa
V1=0.035; //m^3
p2=420; //kPa
V2=0.07; //m^3
dU=3.6*(p2*V2-p1*V1);
// p=a+b*v
// a+0.035*b=190
// a+0.07*b=420
// solving the two equations
p=[1,0.035;1,0.07];
q=[190;420];
X=inv(p)*q;
a=X(1,1);
b=X(2,1);
W=integrate('a+b*V', 'V', V1, V2);
disp("Work done by the system = ")
disp(W)
disp("kJ")


Q=dU+W;
disp("Heat transfer into the system = ")
disp(Q)
disp("kJ")
```

Scilab code Exa 4.21 21

```
clc
Qv=90; //kJ
Qp=-95; //kJ
W=-18; //kJ
U_l=105; //kJ
W_lm=0;
Q_lm=90;
```

```
U_m=U_l+90;
dU_mn=Qp-W;
U_n=U_m+dU_mn;
dQ=Qv+Qp;
dW=dQ;
W_nl=dW-W;
disp("W_nl(in kJ)=")
disp(W_nl)
disp("U_l in kJ =")
disp(U_l)
disp("U_m in kJ =")
disp(U_m)
disp("U_n in kJ")
disp(U_n)
```

Scilab code Exa 4.23 23

```
clc
V1=0.2; //m^3
p1=4*10^5; //N/m^2
T1=403; //K
p2=1.02*10^5; //N/m^2
dH=72.5; //kJ
Q_23=dH;
cp=1; //kJ/kg
cv=0.714; //kJ/kg
y=1.4;
V2=V1*(p1/p2)^(1/y);
T2=T1*((p2/p1)^((y-1)/y));
R=(cp-cv)*1000; //J/kg.K
m=p1*V1/R/T1;
T3=Q_23/(m*cp) +T2;
V3=V2*T3/T2;
W_12=(p1*V1 - p2*V2)/(y-1);
W_23=p2*(V3-V2);
```

```
W_123=W_12+W_23;
disp("Total work done = ")
disp(W_123)
disp("J")


disp("(ii) Index of expansion, n")
p3=p2;
n=(p1*V1-p3*V3)/W_123 + 1;
disp("value of index = ")
disp(n)
```

Scilab code Exa 4.25 25

```
clc
d=0.15; //m
T=303; //K
p=3*10^5; //N/m^2
l=0.085; //m
Q=-4000; //J

disp("(i) Workdone by the system")
dv=%pi/4*d^2*l;
W=p*dv;
disp("W=")
disp(W/10^3)
disp("kJ")


disp("(ii) Decrease in internal energy of the system
   ")
dU=(Q-W)/10^3;
disp("Decrease in internal energy = ")
disp(-dU)
disp("kJ")
```

Scilab code Exa 4.27 27

```
clc
y=1.4
R=294.2; //J/kg.0C
p1=1*10^5; //N/m^2
T1=353; //K
V1=0.45; //m^3
V2=0.13; //m^3
p2=5*10^5; //N/m^2
cv=R/(y-1);

disp("(i) The mass of gas")
m=p1*V1/R/T1;
disp("m=")
disp(m)
disp("kg")


disp("(ii) The value of index    n    for
    compression")
n=log(p2/p1)/log(V1/V2);
disp("n=")
disp(n)


disp("(iii) The increase in internal energy of the
    gas")
T2=T1*(V1/V2)^(n-1);
dU=m*cv*(T2-T1)/10^3;
disp("dU=")
disp(dU)
disp("kJ")

```

```
disp("(iv) The heat received or rejected by the gas
    during compression.")
W=m*R*(T1-T2)/(n-1)/10^3;
Q=dU+W;
disp("Q=")
disp(Q)
disp("kJ")
```

Scilab code Exa 4.28 28

```
clc
p1=1.02*10^5; //Pa
T1=295; //K
V1=0.015; //m^3
p2=6.8*10^5; //Pa
y=1.4;


disp("(i) Final temperature")
T2=T1*(p2/p1)^((y-1)/y);
t2=T2-273;
disp("t2=")
disp(t2)
disp(" C ")


disp("(ii) Final volume :")
V2=V1*(p1/p2)^(1/y);
disp("V2=")
disp(V2)
disp("m^3")


disp("(iii)Work done")
```

```
R=287;
m=p1*V1/R/T1;
W=m*R*(T1-T2)/(y-1)/10^3;
disp("W=")
disp(W)
disp("kJ")
```

Scilab code Exa 4.29 29

```
clc
m=0.44; //kg
T1=453; //K
ratio=3; //ratio=V2/V1
T2=288; //K
W_12=52.5; //kJ
y=log(T2/T1)/ log(1/ratio) + 1;
R=W_12*(y-1)/m/(T1-T2);
// We have got two equations
// cp-cv=R
// cp-y*cv=0
M=[1,-1;1,-y];
N=[R;0];
X=inv(M)*N;
cp=X(1,1);
cv=X(2,1);
disp("cp=")
disp(cp)
disp("kJ/kg.K")


disp("cv=")
disp(cv)
disp("kJ/kg.K")
```

Scilab code Exa 4.30 30

```
clc
n=1.3;
m=1; //kg
p1=1.1; //bar
T1=300; //K
p2=6.6; //bar
R0=8314;
M=30;
cp=1.75; //kJ/kg.K
R=R0/M/1000; //kJ/kg.K
cv=cp - R;
y=cp/cv;
T2=T1 *(p2/p1)^((n-1)/n);
W=R*(T1-T2)/(n-1);
Q=((y-n)/(y-1))*W;
disp("Heat supplied = ")
disp(Q)
disp("kJ/kg")
```

Scilab code Exa 4.31 31

```
clc
cp=14.3; //kJ/kg.K
cv=10.2; //kJ/kg.K
V1=0.1; //m^3
T1=300; //K
p1=1; //bar
p2=8; //bar
y=cp/cv;
R=cp-cv;
```

```
V2=V1*(p1/p2)^(1/y);
V3=V2;
T2=T1*(p2/p1)^((y-1)/y);
p3=p1*V1/V3;
T3=300; //K


disp("(i) Pressure at the end of constant volume
    cooling = ")
disp(p3)
disp("bar")


disp("(ii) Change in internal energy during constant
     volume process")
m=p1*V1/R/T1*10^2; //kg

dU_23=m*cv*(T3-T2);
disp("dU_23 = ")
disp(dU_23)
disp("kJ")


disp("(iii) Net work done and heat transferred
    during the cycle")
W_12=m*R*(T1-T2)/(y-1);
W_23=0;
W_31=p3*V3*log(V1/V3)*10^2; //kJ
disp("Net work done=")
Wnet=W_12+W_23+W_31;
disp(Wnet)
disp("kJ")
Qnet=Wnet;
disp("Heat transferred during the complete cycle = "
    )
disp(Qnet)
disp("kJ")
```

Scilab code Exa 4.32 32

```
clc
V1=0.15; //m^3
p1=15; //bar
T1=550; //K
T2=T1;
r=4; //r=V2/V1
V2=r*V1;
T3=290; //K
p2=p1*V1/V2;
W_12=p1*V1*log(V2/V1)*10^2; //kJ
V3=V2;
p3=p2*T3/T2;
W_23=0;
n=log(p1/p3)/log(V3/V1);
W_31=(p3*V3-p1*V1)/(n-1)*10^2; //kJ

disp("net work done = ")
Wnet=W_12+W_23+W_31
disp("kJ")

Qnet=Wnet;
disp("Heat transferred during the cycle = ")
disp(Qnet)
disp("kJ")
```

Scilab code Exa 4.33 33

```
clc
m=1; //kg
p1=5; //bar
```

```
V1=0.02; //m^3
V2=0.08; //m^3
p2=1.5; //bar

function p=f(V)
    p=a+b*V;
endfunction

// 5=a+0.02*b
// 1.5=a+0.08*b
// Solving above two equations

A=[1,0.02;1,0.08];
B=[5;1.5];
X=inv(A)*B;
a=X(1,1);
b=X(2,1);

disp("(i) p-V diagram")

V=0.02:0.001:0.08;
p=a+b*V;
plot(V,p,'b')

V=[0.0667 0.08];
p=[1.5 1.5];
plot(V,p,'g')

V=0.02:0.001:0.0667;
function p=fa(V)
    p=0.1/V;
endfunction

plot(V,fa,'r')

V=[0.0667 0.0667];
p=[1.5 0];
plot(V,p,'--')
```

```
xtitle("p-V diagram", "V(m^3)", "p(bar)");
legend("p=a+b*V","p=constant","pv=constant")


disp("(ii) Work done and heat transfer")

W_12=integrate('(a+b*V)*10^2','V',V1,V2);
disp("Work done by the system =")
disp(W_12)
disp("kJ")

p3=p2;
V3=p1*V1/p3;
W_23=p2*(V3-V2)*10^2; //kJ

W_31=p3*V3*log(V1/V3)*10^2; //kJ
disp("Work done on the system =")
disp(W_31)
disp("kJ")

W_net=W_12+W_23+W_31;
disp("Net work done =")
disp(W_net)
disp("kJ")

Q_net=W_net;
disp("Heat transferred during the complete cycle =")
disp(Q_net)
disp("kJ")
```

Scilab code Exa 4.34 34

```
clc
cv=0.71; //kJ/kg.K
```

```
R=0.287; //kJ/kg.K
d=8; //cm
l=3.5; //cm
S=150; //N/cm
p1=30; //N/cm
V1=45; //cm^3
T1=293; //K
cv=0.71; //kJ/kg.K
R=0.287; //kJ/kg.K
A=%pi/4*d^2;
C=p1-S/A^2*V1;
dV=l*A;
V2=V1+dV;
p2=S/A^2*V2 + C;
W=integrate('A^2/S*p/100', 'p', p1, p2);
T2=p2*V2*T1/p1/V1;
m=p1*V1/R/T1/10^5; //kg
dU=m*cv*(T2-T1);
Q_12=dU + W*10^(-3);
disp("Amount of heat added to the system = ")
disp(Q_12)
disp("kJ")
```

Scilab code Exa 4.35 35

```
clc
r=10; //kg/min
p1=1.5*10^5; //N/m^2
rho1=26; //kg/m^3
C1=110; //m/s
u1=910; //kJ/kg
p2=5.5*10^5; //N/m^2
rho2=5.5; //kg/m^3
C2=190; //m/s
u2=710; //kJ/kg
```

```
Q=55; //kJ/s
h=55; //m
g=9.81; //m/s^2
v2=1/rho2;
v1=1/rho1;

disp("(i) Change in enthalpy")
dh=u2-u1+ (p2*v2-p1*v1)/10^3;
disp(dh)
disp("kJ/kg")

disp("(ii) Work done during the process (W).")

Q=330; //kJ/kg
KE=(C2^2-C1^2)/2/10^3; //kJ
PE=g*h/10^3; //kJ
W=-Q-KE-PE-dh;
disp("Work done = ")
disp(W)
disp("kJ")


disp("Work done per second = ")
P=W*10/60;
disp(P)
disp("kW")
```

Scilab code Exa 4.36 36

```
clc
m=15; //kg/s
v=0.45; //m^3/kg
P=12000; //kW
W=P/m; //kJ/kg
h1=1260; //kJ/kg
```

```
h2=400; //kJ/kg
C1=50; //m/s
C2=110; //m/s

disp("(i) Heat rejected = ")
Q=h2-h1+(C2^2-C1^2)/2/10^3 +W;
Qnet=m*Q;
disp("Qnet=")
disp(-Qnet)
disp("kW")

disp("(ii) Inlet area")
A=v*m/C1;
disp("A=")
disp(A)
disp("m^2")
```

Scilab code Exa 4.37 37

```
clc
m=0.5; //kg/s
C1=6; //m/s
C2=5; //m/s
p1=1; //bar
p2=7; //bar
v1=0.85; //m^3/kg
v2=0.16; //m^3/kg
du=90; //kJ/kg
Q=-120; //kJ/kg


disp("(i) Power required to drive the compressor")
W=-du+(C1^2-C2^2)/2/1000 + (p1*v1 - p2*v2)*10^2 + Q;
Power=m*W;
disp("Power=")
```

```
disp(-Power)
disp("kW")


disp("(ii) Inlet and outlet pipe cross-sectional
    areas")
A1=m*v1/C1;
A2=m*v2/C2;
disp("Inlet crosssectional area = ")
disp(A1)
disp("m^2")

disp("Outlet crossectional area=")
disp(A2)
disp("m^2")
```

Scilab code Exa 4.38 38

```
clc
h1=800; //kJ/kg
C1=5; //m/s
h2=2520; //kJ/kg
C2=50; //m/s
dZ=4; //m
g=9.81; //m/s^2
Q=2180; //kJ/kg
W=h1-h2+(C1^2 - C2^2)/2/1000 +dZ*g/1000+Q;
disp("Power developed = ")
disp(W)
disp("kW")
```

Scilab code Exa 4.39 39

```
clc
g=9.8; //m/s^2
m=4500/3600; //kg/s
C1=2800/60; //m/s
Z1=5.5; //m
h1=2800; //kJ/g
C2=5600/60; //m/s
Z2=1.5; //m
h2=2300; //kJ/kg
Q=-16000/3600; //kJ/s
W=Q-m*[(h1-h2) + (C2^2 - C1^2)/2/1000 + (Z2-Z1)*g
    /1000];
disp("Power output of the turbine = ")
disp(-W)
disp("kW")
```

Scilab code Exa 4.40 40

```
clc
p1=6.87; //bar
C1=50; //m/s
p2=1.37; //bar
C2=500; //m/s
disp("From steam table corresponding to p1")
h1=2850; //kJ/kg
h2=h1 - (C2^2-C1^2)/2/1000;
disp("Final enthalpy of steam = ")
disp(h2)
disp("kJ")
```

Scilab code Exa 4.41 41

```
clc
```

```
m=220/60; //kg/s
C1=320; //m/s
p1=6*10^5; //N/m^2
u1=2000*10^3; //J/kg
v1=0.36; //m^3/kg
C2=140; //m/s
p2=1.2*10^5; //N/m^2
u2=1400*10^3; //J/kg
v2=1.3; //m^3/kg
Q=100*10^3; //J/s
W=(m*[(u1-u2)+ (p1*v1 - p2*v2) + (C1^2-C2^2)/2] -Q)
    /10^6;
disp("power capacity of the system = ")
disp(W)
disp("MW")
```

Scilab code Exa 4.42 42

```
clc
p1=7.5*10^5; //N/m^2
C1=140; //m/s
h1=950*10^3; //J/kg
p2=2*10^5; //N/m^2
C2=280; //m/s
h2=650*10^3; //J/kg
m=5; //kg/s
W=(h1-h2)+(C1^2-C2^2)/2
Power=m*W/1000;
disp("Power capacity of turbine = ")
disp(Power)
disp("kW")
```

Scilab code Exa 4.43 43

```
clc
C1=12; //m/s
p1=1*10^5; //N/m^2
v1=0.5; //m^3/kg
C2=90; //m/s
p2=8*10^5; //N/m^2
v2=0.14; //m^3/kg
dh=150; //kJ/kg
Q=-11.67; //kJ/s
m=0.2; //kg/s

disp("(i) Motor power required to drive the
    compressor")
W=m*[-dh + (C1^2-C2^2)/2/1000] +Q;
disp("Power=")
disp(-W)
disp("kW")


disp("(ii)Ratio of inlet to outlet pipi diameter")
ratio=sqrt(C2/C1*v1/v2);
disp("ratio=")
disp(ratio)
```

Scilab code Exa 4.44 44

```
clc
W=-175; //kJ/kg
dh=70; //kJ/kg
Q_water=-92; //kJ/kg
Q=dh+W;
Q_atm=Q-Q_water;
disp("Heat transferred to the atmosphere = ")
disp(-Q_atm)
disp("kJ/kg")
```

Scilab code Exa 4.45 45

```
clc
h1=2800*10^3; //J/kg
C1=50; //m/s
A1=900*10^(-4); //m^2
v1=0.187; //m^3/kg
h2=2600*10^3; //J/kg
v2=0.498; //m^3/kJ
disp("(i) Velocity at exit of the nozzle")
C2=sqrt(2*[(h1-h2) + C1^2/2]);

disp("C2=")
disp(C2)
disp("m/s")


disp("(ii) Mass flow rate")
m=A1*C1/v1;
disp("m=")
disp(m)
disp("kg/s")


disp("(iii) Area at the exit")
A2=m*v2/C2*10^4;
disp("A2=")
disp(A2)
disp("cm^2")
```

Scilab code Exa 4.46 46

```
clc
h1=240; //kJ/kg
h2=192; //kJ/kg
dZ=20; //m
g=9.81; //m/s^2
Q=(h2-h1)+dZ*g/1000;

disp("heat transfer = ")
disp(-Q)
disp("kJ/kg")
```

Scilab code Exa 4.47 47

```
clc
p1=2; //bar
C1=300; //m/s
Q=0;
h1=915*10^3; //J/kg
h2=800*10^3; //J/kg
C2=sqrt(2*[h1-h2 + C1^2/2]);
disp("Relative velocity of gas leaving the pipe=")
disp(C2)
disp("m/s")
```

Scilab code Exa 4.48 48

```
clc
mw=50; //kg/s
p1=10^5; //N/m^2
p2=4.2*10^5; //N/m^2
h=10.7; //m
d1=0.2; //m
d2=0.1; //m
```

```
v1=1/1000;
v2=1/1000;
g=9.81; //m/s^2

C1=mw*4/%pi/d1^2*v1;
C2=mw*4/%pi/d2^2*v2;
W=mw*[(p1*v1-p2*v2) + (g*(0-h))+(C1^2-C2^2)/2]/10^3;
disp("Capacity of electric motor")
disp(-W)
disp("kW")
```

Scilab code Exa 4.49 49

```
clc
Ca=250; //m/s
t=-14; //0C
ha=250; //kJ/kg
hg=900; //kJ/kg
ratio=0.0180;
Ef=45*10^3; //kJ/kg
Q=-21; //kJ/kg
ma=1; //kg
mg=1.018; //kg
mf=0.018; //kg
Eg=0.06*mf/mg*Ef;
Cg=sqrt(2000*([ma*(ha+Ca^2/2/1000) + mf*Ef + Q]/mg -
    hg-Eg));
disp("velocity of exhaust gas jet = ")
disp(Cg)
disp("m/s")
```

Scilab code Exa 4.50 50

```
clc
t1=20; //0C
C1=40; //m/s
t2=820; //0C
C2=40; //m/s
t3=620; //0C
C3=55; //m/s
t4=510; //0C
m=2.5; //kg/s
cp=1.005; //kJ/kg.0C


disp("(i) Heat exchanger")
Q_12=m*cp*(t2-t1);
disp("rate of heat transfer=")
disp(Q_12)
disp("kJ/s")


disp("(ii) Turbine")
W_23=m*[(cp*(t2-t3))+(C2^2-C3^2)/2/1000];
disp("Power output of turbine=")
disp(W_23)
disp("kW")


disp("(iii) Nozzle")
C4=sqrt(2*1000*(cp*(t3-t4)+C3^2/2/1000));
disp("Velocity at exit from the nozzle= ")
disp(C4)
disp("m/s")
```

Scilab code Exa 4.51 51

```
clc
```

```
V=0.028; //m^3
p1=80; //bar
t=350; //0C
p2=50; //bar
v1=0.02995; //m^3/kg
h1=2987.3; //kJ/kg
v2=0.02995; //m^3/kg
vg2=0.0394; //m^3/kg
uf2=1149; //kJ/kg
ug2=2597; //kJ/kg

m=V/v1;
u1=h1 - (p1*v1*10^2); //kJ/kg


disp("(i) State of steam after cooling")
x2=v2/vg2;
disp("dryness fraction = ")
disp(x2)


disp("(ii) Heat rejected by the steam")
u2=(1-x2)*uf2 + x2*ug2;
Q=m*(u2-u1);
disp("Heat rejected = ")
disp(-Q)
disp("kJ")
```

Scilab code Exa 4.52 52

```
clc
m=0.08; //kg
p=2*10^5; //Pa
V=0.10528; //m^3
h1=2706.3; //kJ/kg
```

```
h2=3071.8; //kJ/kg
v1=0.885; //m^3/kg
v2=V/m; //m^3/kg


disp("(i) Heat supplied")
Q=m*(h2-h1);
disp("Q=")
disp(Q)
disp("kJ")

disp("(ii) Work done")
W=p*(v2-v1);
W_total=m*W/10^3;
disp("Total work done = ")
disp(W_total)
disp("kJ")
```

Scilab code Exa 4.53 53

```
clc
m=1; //kg
p=8; //bar
s1=6.55; //kJ/kg.K
T=200; //0C
s_f1=2.0457; //kJ/kg.K
s_fg1=4.6139; //kJ/kg.K
h_f1=720.9; //kJ/kg
h_fg1=2046.5; //kJ/kg
h2=2839.3; //kJ/kg

x1=(s1-s_f1)/s_fg1;
h1=h_f1+x1*h_fg1;
Q=h2-h1;
disp("Heat supplied=")
```

```
disp(Q)
disp("kJ/kg")

// For T-s diagram

s=0:0.01:10;
T=(-(s-5)^2+298);
plot(s,T)

T=[295.44 295.44];
s=[6.6 3.45];
plot(s,T,'g')

s=[6.6 7];
T=[295.44 300];
plot(s,T,'g')

s=[6.55 6.55];
T=[270 295.44];
plot(s,T,'r')

s=[6.6 6.6];
T=[270 295.44];
plot(s,T,'--r')

s=[6.66 6.66];
T=[270 295.44];
plot(s,T,'r')

xtitle("T-s diagram", "s(kJ/kg K)", "T(K)")
//The area in red represents the heat flow and it
    goes upto x-axis
```

Scilab code Exa 4.54 54

```
clc
p1=7*10^5; //Pa
p2=1.5*10^5; //Pa
Q=420; //kJ/kg
uf=696; //kJ/kg
x=0.95;
ug=2573; //kJ/kg
u_f2=2580; //kJ/kg
u_g2=2856; //kJ/kg
x2=15/50;
h_f1=697.1; //kJ/kg
h_fg1=2064.9; //kJ.kg
h_f2=2772.6; //kJ/kg
h_g2=2872.9; //kJ/kg


disp("(i) Change of internal energy")
u1=(1-x)*uf + x*ug;
u2=2602.8; //kJ/kg
du=u2-u1;
disp("du=")
disp(du)
disp("kJ/kg")


disp("(ii) Change in enthalpy")
h1=h_f1+x*h_fg1;
h2=h_f2+x2*(h_g2-h_f2);
dh=h2-h1;
disp("dh=")
disp(dh)
disp("kJ/kg")


disp("(iii) Work done = ")
W=Q-du;
disp("W=")
disp(W)
```

```
disp("kJ/kg")
```

Scilab code Exa 4.55 55

```
clc
p1=5.5*10^5; //Pa
x1=1;
p2=0.75*10^5; //Pa
v1=0.3427; //m^3/kg
v2=p1*v1/p2;
// Since v2 > vg (at 0.75 bar), therefore, the steam
    is superheated at state 2.
u2=2567.25; //kJ/kg
u1=2565; //kJ/kg
du=u2-u1; //kJ/kg
C=p1*v1;

disp("Work done = ")
W=integrate('C/v', 'v', v1,v2)
disp("N-m/kg")


disp("Heat supplied = ")
Q=du+W/10^3;
disp(Q)
disp("kJ/kg")
```

Scilab code Exa 4.56 56

```
p1=100; //bar
p2=10; //bar
s1=5.619; //kJ/kg.K
T=584; //K
```

```
s2=7.163; //kJ/kg.K
u1=2545; //kJ/kg
u2=2811.8; //kJ/kg


disp("(i)Heat supplied ")
Q=T*(s2-s1);
disp("Q=")
disp(Q)
disp("kJ/kg")


disp("(ii) Work done")
W=Q-(u2-u1);
disp("W=")
disp(W)
disp("kJ/kg")
```

Scilab code Exa 4.57 57

```
clc
m=1; //kg
p1=120*10^5; //N/m^2
t1=400; //0C
p2=38; //bar
h1=3051.3; //kJ/kg
v1=0.02108; //m^3/kg
u1=h1-p1*v1/10^3; //kJ/kg
u2=2602; //kJ/kg
disp("WOrk done = ")
W=u1-u2;
disp(W)
disp("kJ/kg")
```

Scilab code Exa 4.58 58

```
clc
p1=7*10^5; //N/m^2
x1=0.98;
p2=0.34*10^5; //N/m^2
vg=0.273; //m^3/kg
n=1.1;
v_g2=4.65; //m^3/kg
u_f1=696; //kJ/kg
u_g1=2573; //kJ/kg
u_f2=302; //kJ/kg
u_g2=2472; //kJ/kg


v1=x1*vg;
v2=v1*(p1/p2)^(1/n);
x2=v2/v_g2;


disp("(i) Work done by the steam during the process"
    )
W=(p1*v1-p2*v2)/(n-1)/10^3; //kJ/kg
disp("W=")
disp(W)
disp("kJ/kg")


disp("(ii) Heat transferred")
u1=(1-x1)*u_f1+x1*u_g1;
u2=(1-x2)*u_f2+x2*u_g2;
Q=u2-u1 + W;
disp("Q=")
disp(Q)
```

```
disp("kJ/kg")
```

Scilab code Exa 4.59 59

```
clc
p1=15; //bar
t1=350; //0C
C1=60; //m/s
p2=1.2; //bar
C2=180; //m/s
s1=7.102; //kJ/kg
s_f2=1.3609; //kJ/kg
s_g2=7.2884; //kJ/kg
h_f2=439.4; //kJ/kg
h_fg2=2241.1; //kJ/kg
h1=3147.5; //kJ/kg


x2=(s1 - s_f2)/(s_g2-s_f2);
h2=h_f2+x2*h_fg2;

W=(h1-h2) + (C1^2 - C2^2)/2/1000;
disp("Work done = ")
disp(W)
disp("kJ/kg")
```

Scilab code Exa 4.60 60

```
clc
p1=10; //bar
t1=200; //0C
C1=60; //m/s^2
c2=650; //m/s
```

```
p2=1.5; //bar
h1=2827.9; //kJ/kg
h_f2=467.1; //kJ/kg
h2=2618.45; //kJ/kg
h_g2=2693.4; //kJ/kg
x2=(h2-h_f2)/(h_g2-h_f2);
disp("quality of steam leaving the nozzle=")
disp(x2)
```

Scilab code Exa 4.61 61

```
clc
h1=2776.4; //kJ/kg
h2=h1;
h_f1=884.6; //kJ/kg
h_fg1=1910.3; //kJ/kg
x1=(h1-h_f1)/h_fg1;
disp("Initial dryness fraction = ")
disp(x1)
```

Scilab code Exa 4.62 62

```
p1=10; //bar
x1=0.9; //bar
p2=2; //bar


// Using Mollier chart, we get
x2=0.94;
disp("x2 =")
disp(x2)
```

Scilab code Exa 4.63 63

```
clc

disp("(a)From steam tables")

p1=15*10^5; //Pa
p2=7.5*10^5; //Pa
h_f1=844.7; //kJ/kg
ts1=198.3; //0C
s_f1=2.3145; //kJ/kg.K
s_g1=6.4406; //kJ/kg.K
v_g1=0.132; //m^3/kg
h_fg1=1945.2; //kJ/kg
x1=0.95;
h_f2=709.3; //kJ/kg
h_fg2=2055.55; //kJ/kg
s_f2=2.0195; //kJ/kg
s_g2=6.6816; //kJ/kg.K
v_g2=0.255; //m^3/kg
x2=0.9;
x3=1;
s_f3=0.521; //kJ/kg K
s_g3=8.330; //kJ/kg K

h2=h_f2+x2*h_fg2;
h1=h_f1 + x1*h_fg1;
s1=s_f1 + x1*(s_g1-s_f1);
s2=s1;
ds_12=s2-s1;

s3=s_f3+x3*(s_g3-s_f3);
ds_23=s3-s2;

```

```
ds=ds_12+ds_23;
disp("(i) Change in entropy =")
disp(ds)
disp("kJ/kg K")

h3=h2;

disp("(ii) Change in enthalpy")
dh=h2-h1;
disp(dh)
disp("kJ/kg")


disp("(iii) Change in internal energy")
u1=h1-p1*x1*v_g1/10^3;
u2=h2-p2*x2*v_g2/10^3;
du=u2-u1;
disp("du=")
disp(du)
disp("kJ/kg")


// Only the expansion of steam from point 1 to 2 (i.e., isentropic expansion) is reversible because of unresisted flow whereas the expansion from point 2 to point 3 (i.e., throttling expansion) is irreversible because of frictional resistance to flow. Increase of entropy also shows that expansion from point 2 to point 3 is irreversible.


disp("(b) Using Mollier chart")
h1=2692; //kJ/kg
h2=2560; //kJ/kg
s1=6.23; //kJ/kg K
s2=s1;
s3=8.3; //kJ/kg K
```

```
disp("(i) Change in entropy =")
ds=s3-s1;
disp(ds)
disp("kJ/kg K")


disp("(ii) Change in enthalpy =")
dh=h2-h1;
disp(dh)
disp("kJ/kg")
```

Scilab code Exa 4.64 64

```
clc
V1=5.5; //m^3
p1=16*10^5; //Pa
T1=315; //K
V2=V1;
p2=12*10^5; //Pa
R=0.287*10^3;
y=1.4;

m1=p1*V1/R/T1;
T2=T1*(p2/p1)^((y-1)/y);

m2=p2*V2/R/T2;
disp("Mass of air which left the receiver=")
m=m1-m2;
disp(m)
disp("kg")
```

Scilab code Exa 4.65 65

```
clc
cp=1; //kJ/kg.K
cv=0.711; //kJ/kg.K
V1=1.6; //m^3
V2=V1;
p1=5*10^5; //Pa
T1=373; //K
p2=1*10^5; //Pa
R=287;
y=1.4;

m1=p1*V1/R/T1;
T2=T1*(p2/p1)^((y-1)/y);
m2=p2*V2/R/T2;
KE=(m1*cv*T1)-(m2*cv*T2)-(m1-m2)*cp*T2;
disp("Kinetic energy of discharge air =")
disp(KE)
disp("kJ")

disp("This is the exact answer when using proper
    value of cv")
```

Scilab code Exa 4.66 66

```
clc
//For oxygen
cpa=0.88; //kJ/kg K
Ra=0.24; //kJ/kg K
V1a=0.035; //m^3
p1a=4.5; //bar
T1a=333; //K
V2a=0.07; //m^3

//For methane
V1b=0.07; //m^3
```

```
V2b=0.035; //m^3
p1b=4.5; //bar
T1b=261; //K
cpb=1.92; //kJ/kg K
Rb=0.496; //kJ/kg K

yb=cpb/(cpb-Rb); //for methane
cva=cpa-Ra; //for oxygen

disp("(i) Final state condition")

p2b=p1b*(V1b/V2b)^yb;
disp("p2 for methane =")
disp(p2b)
disp("bar")

T2b=p2b*V2b*T1b/p1b/V1b;
disp("T2 for methane =")
disp(T2b)
disp("K")

p2a=p2b;

T2a=p2a*V2a/p1a/V1a*T1a;
disp("T2 for oxygen =")
disp(T2a)
disp("K")

Wb=(p1b*V1b - p2b*V2b)/(yb-1)*100; //kJ

disp("(ii) Work done by the piston ")
disp("The piston will be in virtual equilibrium and
   hence zero work is effected by the piston.")

Wa=-Wb;

ma=p1a*V1a/Ra/T1a*10^2;

```

```
Q=ma*cva*(T2a-T1a) + Wa;
disp("(iii) Heat transferred to oxygen =")
disp(Q)
disp("kJ")
```

Chapter 5

Second Law of Thermodynamics and Entropy

Scilab code Exa 5.1 1

```
clc
Q1=1500/60; //kJ/s
W=8.2; //kW

disp("(i) Thermal efficiency")
n=W/Q1;
disp("n=")
disp(n)


disp("(ii) Rate of heat rejection")
Q2=Q1-W;
disp("Q2=")
disp(Q2)
disp("kW")
```

Scilab code Exa 5.2 2

```
clc
Q_12=30; //kJ
W_12=60; //kJ
dU_12=Q_12-W_12;
Q_21=0;
W_21=Q_21+dU_12;
disp("W_21 =")
disp(W_21)
disp("Thus 30 kJ work has to be done on the system
    to restore it to original state, by adiabatic
    process.")
```

Scilab code Exa 5.3 3

```
clc
Q2=12000; //kJ/h
W=0.75*60*60; //kJ/h
COP=Q2/W;
disp("Coefficient of performance")
disp(COP)

Q1=Q2+W;
disp("heat transfer rate=")
disp(Q1)
disp("kJ/h")
```

Scilab code Exa 5.4 4

```
clc
T2=261; //K
T1=308; //K
```

```
Q2=2; //kJ/s
Q1=Q2*(T1/T2);
W=Q1-Q2;

disp("Least power required to pump the heat
    continuosly")
disp(W)
disp("kW")
```

Scilab code Exa 5.5 5

```
clc

disp("(i) Heat abstracted from outside=")
Q1=2*10^5; //kJ/h
W=3*10^4; //kJ/h
Q2=Q1-W;
disp("Heat abstracted from outside=")
disp(Q2)
disp("kJ/h")


disp("(ii) Co-efficient of performance")
COP_hp=Q1/(Q1-Q2);
disp("Co-efficient of performance=")
disp(COP_hp)
```

Scilab code Exa 5.6 6

```
clc
T1=2373; //K
T2=288; //K
n_max=1-T2/T1;
```

```
disp("Highest possible theoritical efficiency=")
disp(n_max*100)
disp("%")
```

Scilab code Exa 5.7 7

```
clc
T1=523; //K
T2=258; //K
Q1=90; //kJ

n=1-T2/T1;
disp("(i) Efficiency of the system")
disp(n*100)
disp("%")


disp("(ii) The net work transfer")
W=n*Q1;
disp("W=")
disp(W)
disp("kJ")


disp("(iii) Heat rejected to the sink")
Q2=Q1-W;
disp("Q2=")
disp(Q2)
disp("kJ")
```

Scilab code Exa 5.8 8

```
clc
```

```
T1=1023; //K
T2=298; //K
n_carnot=1-T2/T1;
W=75*1000*60*60;
Q=3.9*74500*1000;
n_thermal=W/Q;
disp("n_carnot =")
disp(n_carnot)

disp("n_thermal =")
disp(n_thermal)

disp("Since thermal > carnot , therefore claim of
    the inventor is not valid (or possible")
```

Scilab code Exa 5.9 9

```
clc
T1=1273; //K
T2=313; //K
n_max=1-T2/T1;
Wnet=1;
Q1=Wnet/n_max;
Q2=Q1-Wnet;
disp("the least rate of heat rejection = ")
disp(Q2)
disp("kW")
```

Scilab code Exa 5.10 10

```
clc
one_ton_of_refrigeration=210; //kJ/min
```

```
Cooling_required=40*(one_ton_of_refrigeration); //kJ
    /min
T1=303; //K
T2=238; //K
COP_refrigerator=T2/(T1-T2);
COP_actual=0.20*COP_refrigerator;
W=Cooling_required/COP_actual/60;
disp("power required = ")
disp(W)
disp("kW")
```

Scilab code Exa 5.11 11

```
clc
E=12000; //kJ/min

T2=308; //K

// Source 1
T1=593; //K
n1=1-T2/T1;

// Source 2
T1=343; //K
n2=1-T2/T1;

W1=E*n1;
disp("W1 =")
disp(W1)

W2=E*n2;
disp("W2 =")
disp(W2)

disp("Thus, choose source 2.")
```

```
disp("The source 2 is selected even though
    efficiency in this case is lower, because the
    criterion for selection is the larger output.")
```

Scilab code Exa 5.12 12

```
clc
T1=973; //K
T2=323; //K
T3=248; //K

Q1=2500; //kJ
W=400; //kJ

disp("(i)Heat rejection to the 50 C  reservoir")
n_max=1-T2/T1;
W1=n_max*Q1;
COP_max=T3/(T2-T3);
W2=W1-W;
Q4=COP_max*W2;
COP1=Q4/W2;
Q3=Q4+W2;
Q2=Q1-W1;
disp("Heat rejection to the 50 C  reservoir=")
disp(Q2+Q3)
disp("kJ")


disp("(ii)Heat rejected to 50 C  reservoir ")
n=0.45*n_max;
W1=n*Q1;
W2=W1-W;
COP2=0.45*COP1;
Q4=W2*COP2;
Q3=Q4+W2;
```

```
Q2=Q1-W1;

disp("Heat rejected to 50 C  reservoir=")
disp(Q2+Q3)
disp("kJ")
```

Scilab code Exa 5.13 13

```
clc
T1=298; //K
T2=273; //K
Q1=24; //kJ/s
T3=653; //K
COP=T1/(T1-T2);
disp("(i) determine COP and work input required")

disp("Coefficient of performance = ")
disp(COP)

COP_ref=T2/(T1-T2);
W=Q1/COP_ref;
disp("Work input required = ")
disp(W)
disp("kW")


disp("(ii)Determine overall COP of the system ")
Q4=T1*W/(T3-T1);
Q3=Q4+W;
Q2=Q1+W;
COP=Q1/Q3;
disp("COP=")
disp(COP)

COP_overall=(Q2+Q4)/Q3;
```

```
disp("Overall COP=")
disp(COP_overall)
```

Scilab code Exa 5.14 14

```
clc
T_e1=493; //K
T_e2=298; //K
T_p1=298; //K
T_p2=273; //K
Amt=15; //tonnes produced per day
h=334.5; //kJ/kg
Q_abs=44500; //kJ/kg
Q_p2=Amt*10^3*h/24/60;
COP_hp=T_p2/(T_p1-T_p2);
W=Q_p2/COP_hp/60;
disp("(i)Power developed by the engine = ")
disp(W)
disp("kW")


disp("(ii) Fuel consumed per hour")
n_carnot=1-(T_e2/T_e1);
Q_e1=W/n_carnot*3600; //kJ/h
fuel_consumed=Q_e1/Q_abs;
disp("Quantity of fuel consumed/hour = ")
disp(fuel_consumed)
disp("kg/h")
```

Scilab code Exa 5.15 15

```
clc
T1=550; //K
```

```
T3=350; //K
// W=Q2*((T1-T2)/T2)
// W=Q2((T2-T3)/T2)
// From this we get following expression
T2=(T1+T3)/2;
disp("Intermediate temperature =")
disp(T2)
disp("K")
```

Scilab code Exa 5.16 16

```
clc
T1=600; //K
T2=300; //K


disp("(i) When Q1=Q2")
T3=2*T1/(T1/T2+1);
disp("T3=")
disp(T3)
disp("K")


disp("(ii) Efficiency of Carnot engine and COP of
    carnot refrigerator")
n=(T1-T3)/T1; //carnot engine
COP=T2/(T3-T2); //refrigerator

disp("Efficiency of carnot engine = ")
disp(n)

disp("COP of carnot refrigerator = ")
disp(COP)
```

Scilab code Exa 5.17 17

```
clc
T3=278; //K
T2=350; //K
T4=T2;
T1=1350; //K

Q1=100/[((T4/T1)*(T1-T2)/(T4-T3))+T2/T1]; //Q4+Q2=100; Q4=Q1*((T4/T1)*(T1-T2)/(T4-T3)); Q2=T2/T1*Q1;

disp("Q1=")
disp(Q1)
disp("kJ")
```

Scilab code Exa 5.18 18

```
clc
Q1=300; //kJ/s
T1=290; //0C
T2=8.5; //0C
disp("let  dQ /T = A")

disp("(i) 215 kJ/s are rejected")
Q2=215; //kJ/s
A= Q1/(T1+273) - Q2/(T2+273)
disp("Since, A<0, Cycle is irreversible.")


disp("(ii) 150 kJ/s are rejected")
Q2=150; //kJ/s
```

```
A= Q1/(T1+273) - Q2/(T2+273)
disp("Since A=0, cycle is reversible")


disp("(iii) 75 kJ/s are rejected.")
Q2=75; //kJ/s
A= Q1/(T1+273) - Q2/(T2+273)
disp("Since A>0, cycle is impossible")
```

Scilab code Exa 5.19 19

```
clc
P1=0.124*10^5; //N/m^2
T1=433; //K
T2=323; //K
h_f1=687; //kJ/kg
h2=2760; //kJ/kg
h3=2160; //kJ/kg
h_f4=209; //kJ/kg
Q1=h2-h_f1;
Q2=h_f4-h3;
disp("Let A= dQ /T")
A=Q1/T1+Q2/T2;
disp(A)
disp("A<0. Hence classius inequality is verified")
```

Scilab code Exa 5.20 20

```
clc
T1=437; //K
T2=324; //K
h2=2760; //kJ/kg
h1=690; //kJ/kg
```

```
h3=2360; //kJ/kg
h4=450; //kJkg

Q1=h2-h1;
Q2=h4-h3;

disp("Let A= dQ /T")
A=Q1/T1 + Q2/T2;
disp(A)
disp("Since A<0, Classius inequality is verified")
```

Scilab code Exa 5.21 21

```
clc
T0=273; //K
T1=673; //K
T2=298; //K
m_w=10; //kg
T3=323; //K
c_pw=4186; //kJ/kg.K
disp("Let C=mi*cpi")
C=m_w*c_pw*(T3-T2)/(T1-T3);

S_iT1=C*log(T1/T0); // Entropy of iron at 673 K
S_wT2=m_w*c_pw*log(T2/T0); //Entropy of water at 298
    K
S_iT3=C*log(T3/T0); //Entropy of iron at 323 K
S_wT3=m_w*c_pw*log(T3/T0); //Entropy of water at 323
    K

dS_i=S_iT3 - S_iT1;
dS_w=S_wT3 - S_wT2;
dS_net=dS_i + dS_w

disp("Since dS>0, process is irreversible")
```

Scilab code Exa 5.23 23

```
clc
T1=293; //K
V1=0.025; //m^3
V3=V1;
p1=1.05*10^5; //N/m^2
p2=4.5*10^5; //N/m^2
R=0.287*10^3;
cv=0.718;
cp=1.005;
T3=293; //K

disp("(i)Net heat flow")
m=p1*V1/R/T1;
T2=p2/p1*T1;
Q_12=m*cv*(T2-T1);
Q_23=m*cp*(T3-T2)

disp("Net heat flow = ")
Q_net=Q_12+Q_23;
disp(Q_net)
disp("kJ")


disp("(ii) Net entropy change")
dS_32=m*cp*log(T2/T1);
dS_12=m*cv*log(T2/T1);
dS_31=dS_32 - dS_12;
disp("Decrease in entropy = ")
disp(dS_31)
disp("kJ/K")
```

Scilab code Exa 5.24 24

```
clc
p1=1.05*10^5; //N/m^2
V1=0.04; //m^3
T1=288; //K
p2=4.8*10^5;
T2=T1;
R0=8314;
M=28;


disp("(i) The change of entropy =")
R=R0/M;
m=p1*V1/R/T1;
dS=m*R*log(p1/p2)
disp("Decrease in entropy =")
disp(-dS)
disp("J/K")


disp("(ii)Heat rejected = ")
Q=T1*(-dS);
disp("Q=")
disp(Q)
disp("J")


W=Q;
disp("Work done = ")
disp(W)
disp("J")

V2=p1*V1/p2;
```

```
v1=V1/m; //specific volume
v2=V2/m; //specific volume

v=v2:0.01:v1;
function p=f(v)
    p=p1*v1/v
endfunction

plot(v,f)

p=p1
plot(v,p,'--')

p=[0 p2]
v=[v2 v2]
plot(v,p,'--')

p=[0 p1]
v=[v1 v1]
plot(v,p,'--')

xtitle("p-v diagram", "v(m^3/kg)", "p(N/m^2)")

xset('window', 1)

T=[288 288]
s=[10 (10-dS)]
plot(s,T)

s=[10 10]
T=[0 288]
plot(s,T,'--')

s=[(10-dS) (10-dS)]
T=[0 288]
plot(s,T,'--')

xtitle("T-s diagram", "s(kJ/kg K)", "T(K)")
```

Scilab code Exa 5.25 25

```
clc
R=287; //kJ/kg.K
dU=0;
W=0;
Q=dU+W;

dS=R*log(2); //v2/v1=2

disp("Change in entropy = ")
disp(dS)
disp("kJ/kg.K")
```

Scilab code Exa 5.26 26

```
clc
m=0.04; //kg
p1=1*10^5; //N/m^2
T1=293; //K
p2=9*10^5; //N/m^2
V2=0.003; //m^3
cp=0.88; //kJ/kg.K
R0=8314;
M=44;

R=R0/M;
T2=p2*V2/m/R;
ds_2A=R/10^3*log(p2/p1);
ds_1A=cp*log(T2/T1);
ds_21=ds_2A - ds_1A;
```

```
dS_21=m*ds_21;
disp("Decrease in entropy=")
disp(dS_21)
disp("kJ/K")
```

Scilab code Exa 5.27 27

```
clc
p1=7*10^5; //N/m^2
T1=873; //K
p2=1.05*10^5; //N/M62
n=1.25;
m=1; //kg
R=0.287;
cp=1.005;
T2=T1*(p2/p1)^((n-1)/n);

// At constant temperature from 1 to A
ds_1A=R*log(p1/p2);

// At constant pressure from A to 2
ds_2A=cp*log(T1/T2);


ds_12=ds_1A - ds_2A;
disp("Increase in entropy = ")
disp(ds_12)
disp("kJ/kg.K")
```

Scilab code Exa 5.28 28

```
clc
p1=7*10^5; //Pa
```

```
T1=733; //K
p2=1.012*10^5; //Pa
T2a=433; //K
y=1.4;
cp=1.005;

disp("(i) To prove that the process is irreversible"
   )
T2=T1*(p2/p1)^((y-1)/y);
disp("T2 =")
disp(T2)
disp("But the actual temperature is 433K at th
   epressure of 1.012 bar, Hence the process is
   irreversible. Proved.")


disp("(ii) Change of entropy per kg of air")
ds=cp*log(T2a/T2);
disp("Increase of entropy=")
disp(ds)
disp("kJ/kg.K")
```

Scilab code Exa 5.29 29

```
clc
V1=0.3; //m^3
p1=4*10^5; //N/m^2
V2=0.08; //m^3
n=1.25;
p2=p1*(V1/V2)^n;

disp("(i) Change in enthalpy")
dH=n*(p2*V2-p1*V1)/(n-1)/10^3;
disp("dH=")
disp(dH)
```

```
disp("kJ")


disp("(ii) Change in internal energy")
dU=dH-(p2*V2 - p1*V1)/10^3;
disp("dU=")
disp(dU)
disp("kJ")


disp("(iii) Change in entropy")
dS=0;
disp("dS")
disp(dS)


disp("(iv)Heat transfer")
Q=0;
disp("Q=")
disp(Q)


disp("(v) Work transfer")
W=Q-dU;
disp("W=")
disp(W)
disp("kJ")
```

Scilab code Exa 5.30 30

```
clc
m=20; //kg
p1=4*10^5; //Pa
p2=8*10^5; //Pa
V1=4; //m^3
```

```
V2=V1;
cp=1.04; //kJ/kg.K
cv=0.7432; //kJ/kg.K
R=cp-cv;
T1=p1*V1/R/1000; //kg.K;    T=mass*temperature
T2=p2*V2/R/1000; //kg.K


disp("(i) Change in internal energy")
dU=cv*(T2-T1);
disp("dU=")
disp(dU)
disp("kJ")


disp("(ii) Work done")
Q=0;
W=Q-dU;
disp("W")
disp(W)
disp("kJ")


disp("(iii) Heat transferred = ")
disp(Q)


disp("(iv) Change in entropy =")
dS=m*cv*log(T2/T1);
disp(dS)
disp("kJ/K")
```

Scilab code Exa 5.31 31

```
clc
```

```
V1=5; //m^3
p1=2*10^5; //Pa
T1=300; //K
p2=6*10^5; //Pa
p3=2*10^5; //Pa
R=287;
n=1.3;
y=1.4;

m=p1*V1/R/T1;
T2=T1*(p2/p1)^((n-1)/n);
T3=T2*(p3/p2)^((y-1)/y);
W_12=m*R*(T1-T2)/(n-1)/1000; //polytropic compression
W_23=m*R*(T2-T3)/(y-1)/1000; //Adiabatic expansion

W_net=W_12+W_23;
disp("Net work done on the air = ")
disp(-W_net)

T=[T1 310 320 330 340 350 360 370 380 T2];
function s=f(T)
    s=(y-n)/(y-1)/(1-n)*R/10^3*log(T);
endfunction
s=[f(T1) f(310) f(320) f(330) f(340) f(350) f(360) f(370) f(380) f(T2)]
plot(s,T)

T=[T2 T3];
s=[f(T2) f(T2)];
plot(s,T,'r')

xtitle("T-s diagram", "s(kJ/kg K)", "T(K)")
legend("p*v^1.3=constant", "p*v^y=constant")
```

Scilab code Exa 5.32 32

```
clc
V1=0.004; //m^3
p1=1*10^5; //Pa
T1=300; //K
T2=400; //K
y=1.4;
M=28;
R0=8.314;
R=R0/M;


disp("(i) The heat supplied")
m=p1*V1/R/1000/T1; //kg
cv=R/(y-1);
Q=m*cv*(T2-T1);
disp("Q")
disp(Q)
disp("kJ")


disp("(ii) The entropy change")
dS=m*cv*log(T2/T1);
disp("dS=")
disp(dS)
disp("kJ/kg.K")
```

Scilab code Exa 5.33 33

```
clc
V1=0.05; //m^3
p1=1*10^5; //Pa
T1=280; //K
p2=5*10^5; //Pa
```

```
disp("(i) Change in entropy")
R0=8.314;
M=28;
R=R0/M;
m=p1*V1/R/T1/1000;


dS=m*R*log(p1/p2);
disp("dS=")
disp(dS)
disp("kJ/K")

disp("(ii)Work done")
Q=T1*dS;
disp("Q=")
disp(Q)
disp("kJ")
```

Scilab code Exa 5.34 34

```
clc
R=0.287; //kJ/kg.K
m=1; //kg
p1=8*10^5; //Pa
p2=1.6*10^5; //Pa
T1=380; //K
n=1.2;
y=1.4;


disp("(i) Final specific volume and temperature")
v1=R*T1/p1*10^3; //m^3/kg
v2=v1*(p1/p2)^(1/n);
T2=T1*(p2/p1)^((n-1)/n);
```

```
disp("v2=")
disp(v2)
disp("m^3/kg")
disp("T2=")
disp(T2)


disp("(ii) Change of internal energy, work done and
    heat interaction")
dU=R/(y-1)*(T2-T1);
disp("dU=")
disp(dU)
disp("kJ/kg")

W=R*(T1-T2)/(n-1);
disp("W=")
disp(W)
disp("kJ/kg")

Q=dU + W;
disp("Q=")
disp(Q)
disp("kJ/kg")


disp("(iii) Change in entropy")
dS=R/(y-1)*log(T2/T1) + R*log(v2/v1)
disp("dS=")
disp(dS)
disp("kJ/kg.K")
```

Scilab code Exa 5.35 35

```
clc
y=1.4;
```

```
cv=0.718; //kJ/kg.K
m=1; //kg
T1=290; //K
n=1.3;
r=16;
y=1.4;

T2=T1*(r)^(n-1);

disp("(a)")

T=[T1 300 310 320 330 340 350 360 370 380 390 400
   410 420 430 440 450 460 470 480 490 500 510 520
   530 540 550 560 570 580 590 600 610 620 630 640
   650 660 T2];
function s=f(T)
    s=(y-n)*cv/(1-n)/10^3*log(T);
endfunction
s=[f(T1) f(300) f(310) f(320) f(330) f(340) f(350) f
   (360) f(370) f(380) f(390) f(400) f(410) f(420) f
   (430) f(440) f(450) f(460) f(470) f(480) f(490) f
   (500) f(510) f(520) f(530) f(540) f(550) f(560) f
   (570) f(580) f(590) f(600) f(610) f(620) f(630) f
   (640) f(650) f(660) f(T2)];
plot(s,T)

T=[0 T2];
s=[f(T2) f(T2)];
plot(s,T,'r--')

T=[0 T1];
s=[f(T1) f(T1)];
plot(s,T,'r--')

T=[T1 T2];
s=[f(T1) f(T2)];
plot(s,T,'r--')

```

```
xtitle("T-s diagram", "s", "T")
legend("p*v^n=c")

//Heat transferred = Area of trapezium = Base*mean ordinate

//Heat transferred=dS*(T1+T2)/2
//Hence we get
disp("Entropy change=Heat transferred/Mean absolute temperature")

disp("(b)Entropy change")
dS=cv*((n-y)/(n-1))*log(T2/T1);
disp("dS=")
disp(dS)
disp("kJ/kg.K")
disp("There is decrease in entropy")

Q=cv*((y-n)/(n-1))*(T1-T2);
Tmean = (T1+T2)/2;
dS_app=Q/Tmean;

%error=((-dS) - (-dS_app))/(-dS) * 100;
disp("%age error =")
disp(%error)
disp("%")
```

Scilab code Exa 5.36 36

```
clc
cp=1.005; //kJ/kg.K
R=0.287; //kJ/kg.K
V1=1.2; //m^3
p1=1*10^5; //Pa
p2=p1;
```

```
T1=300; //K
T2=600; //K
T3=T1;
p1=1*10^5; //Pa
cv=cp-R;

disp("(i) The net heat flow")
m=p1*V1/R/1000/T1; //kg
Q=m*R*(T2-T1);
disp("Q=")
disp(Q)
disp("kJ")


disp("(ii) The overall change in entropy")
dS_12=m*cp*log(T2/T1);
dS_23=m*(cp-R)*log(T3/T2); //cv=cp-R
dS_overall=dS_12+dS_23;
disp("Overall change in entropy=")
disp(dS_overall)
disp("kJ/K")


s=sqrt(300):0.1:sqrt(600);
T=s^2;
plot(s,T)

s=22.18:0.1:sqrt(600);
T=10*(s-16.725)^2;
plot(s,T,'r')

s=[17 25];
T=[600 600];
plot(s,T,'--')

s=[17 25];
T=[300 300];
plot(s,T,'--')
```

```
xtitle("T-s diagram", "S", "T")
legend("p=C", "V=C")
```

Scilab code Exa 5.37 37

```
clc
cv=0.718; //kJ/kg.K
R=0.287; //kJ/kg.K
p1=1*10^5; //Pa
T1=300; //K
V1=0.018; //m^3
p2=5*10^5; //Pa
T3=T1;
cp=cv+R;
p3=p2;

m=p1*V1/R/T1/1000; //kg
T2=T1*p2/p1;

disp("(i) constant volume process")
disp("dS=")
dS_12=m*cv*log(T2/T1);
disp(dS_12)
disp("kJ/K")

disp("(ii) Constant prssure process ")
disp("dS=")
dS_23=m*cp*log(T3/T2);
disp(dS_23)
disp("kJ/K")

disp("(iii) Isothermal process")
disp("dS=")
dS_31=m*R*log(p3/p1);
```

```
disp(dS_31)
disp("kJ/K")

disp("T-s diagram")
s=sqrt(300):0.1:sqrt(600);
T=s^2;
plot(s,T)

s=22.18:0.1:sqrt(600);
T=10*(s-16.725)^2;
plot(s,T,'r')

s=[sqrt(300) 22.18];
T=[300 300];
plot(s,T,'g')

xtitle("T-s diagram", "S", "T")
legend("p=C", "V=C", "T=C")

disp("p-V diagram")
xset('window',1)

V=[0.018 0.018];
p=[1 5];
plot(V,p)

p=[5 5];
V=[0.0036 0.018];
plot(V,p,'r')

V=0.0036:0.0001:0.018;
function p=f(V)
    p=1*0.018/V;
endfunction

plot(V,f,'g')

xtitle("p-V diagram", "V", "p")
```

```
legend("V=C","p=C","T=C")
```

Scilab code Exa 5.39 39

```
clc
m=4; //kg
T1=400; //K
T2=500; //K

dS=integrate('m*(0.48+0.0096*T)/T', 'T', T1,T2);
disp("dS=")
disp(dS)
disp("kJ")
```

Scilab code Exa 5.40 40

```
clc
p1=1*10^5; //Pa
T1=273;  //K
p2=25*10^5; //Pa
T2=750; //K
R=0.29; //kJ/kg.K ; cp=0.85+0.00025*T; cv
    =0.56+0.00025*T; R=cp-cv;
v2=R*T2/p2;
v1=R*T1/p1;
ds=integrate('(0.56+0.00025*T)/T', 'T', T1, T2) +
    integrate('R/v', 'v', v1, v2);

disp("ds=")
disp(ds)
disp("kJ/kg K")
```

Scilab code Exa 5.41 41

```
clc
cv=0.715; //kJ/kg K
R=0.287; //kJ/kg K
V_A=0.25; //m^3
p_Ai=1.4; //bar
T_Ai=290; //K
V_B=0.25; //m^3
p_Bi=4.2; //bar
T_Bi=440; //K

disp("(i) Final equilibrium temperature")
m_A=p_Ai * 10^5 * V_A / R / 1000/ T_Ai; //kg
m_B=p_Bi * 10^5 * V_B / R / 1000/ T_Bi; //kg

T_f=(m_B * T_Bi + m_A * T_Ai)/(m_A + m_B);
disp("T_f = ")
disp(T_f)
disp("K")


disp("(ii) Final pressure on each side of the
    diaphragm")
p_Af=p_Ai*T_f/T_Ai;
disp("p_Af=")
disp(p_Af)
disp("bar")

p_Bf=p_Bi*T_f/T_Bi;
disp("p_Bf=")
disp(p_Bf)
disp("bar")

```

```
disp("(iii) Entropy change of the system")
dS_A=m_A*cv*log(T_f/T_Ai);
dS_B=m_B*cv*log(T_f/T_Bi);
dS_net=dS_A+dS_B;
disp("Net change of entropy=")
disp(dS_net)
disp("kJ/K")
```

Scilab code Exa 5.42 42

```
clc
cv=1.25; //kJ/kg.K
T1=530; //K
v1=0.0624; //m^3/kg
v2=0.186; //m^3/kg
dT_31=25; //K
T3=T1-dT_31; //K
dT_21=165; //K
T2=T1-dT_21; //K
// Path 1-2 : Reversible adiabatic process
ds_12=0;

// To calculate ( s 3 s1 ) a reversible path has to be selected joining 3 and 1.This is achieved by selecting the reversible adiabatic path 1-2 and the reversible constant volume process 2-3.

// Path 1-3 : Adiabatic process
v3=0.186; //m^3/kg
v3=v2;
ds_13=cv*log(T3/T2);
disp("Chang in entropy = ")
disp(ds_13)
disp("kJ/kgK")
```

Scilab code Exa 5.44 44

```
clc
T1=500; //K
T2=400; //K
T3=300; //K
Q1=1500; //kJ/min
W=200; //kJ/min

//Q1/T1 + Q2/T2 + Q3/T3=0
//Q1+Q2+Q3=W
//For solving the above two equations we use
    following method
//Q2-Q3=-1300
//Q2/400 - Q3/300 =-1500/500=-3

A=[1,-1;(1/400),(-1/300)];
B=[(-1300);(-3)];
X=inv(A)*B;
Q2=X(1,1);
disp("Q2 =")
disp(Q2)
disp("kJ/min")

Q3=X(2,1);
disp("Q3 =")
disp(Q3)
disp("kJ/min")

disp("(ii) Entropy change ")
dS1=(-Q1)/T1;
disp("Entropy change of source 1 =")
disp(dS1)
disp("kJ/K")
```

```
dS2=(-Q2)/T2;
disp("Entropy change of sink 2 =")
disp(dS2)
disp("kJ/K")

dS3=Q3/T3;
disp("Entropy change of source 3 =")
disp(dS3)
disp("kJ/K")


disp("(iii) Net change of the entropy")
dSnet = dS1 + dS2 + dS3;
disp("dSnet=")
disp(dSnet)
```

Scilab code Exa 5.45 45

```
clc
T1=250; //K
T2=125; //K
//cv=0.0045*T^2
Q1=integrate('0.045*T^2', 'T', T1, T2);
dS_system=integrate('0.045*T', 'T', T1, T2);

//dS_reservoir=(Q1-W)/T_resservoir

//dS_universe >= 0
//But for maximum work done dS_universe=0
dS_universe=0;

W_max=((-Q1) -T2*(dS_universe-dS_system))/1000;
disp("W_max=")
disp(W_max)
```

```
disp("kJ")
```

Scilab code Exa 5.46 46

```
clc
cp=1.005; //kJ/kg K
T_A=333; //K
T_B=288; //K
p_A=140; //kPa
p_B=110; //kPa
//h=cp*T
//v/T=0.287/p
ds_system=integrate('cp/T', 'T', T_A, T_B) +
    integrate('0.287/p', 'p', p_A, p_B);
ds_surr=0;
ds_universe=ds_system+ds_surr;
disp("change in entropy of universe = ")
disp(ds_universe)
disp("kJ/kgK")
disp("Since change in entropy of universe from A to
    B is -ve")
disp("The flow is from B to A")
```

Scilab code Exa 5.47 47

```
clc
m1=3; //kg
m2=4; //kg
T0=273; //K
T1=80+273; //K
T2=15+273; //K
c_pw=4.187; //kJ/kgK
tm=(m1*T1 + m2*T2)/(m1+m2);
```

```
Si=m1*c_pw*log(T1/T0) + m2*c_pw*log(T2/T0);
Sf=(m1+m2)*c_pw*log(tm/T0);
dS=Sf-Si;
disp("Net change in entropy =")
disp(dS)
disp("kJ/K")
```

Scilab code Exa 5.49 49

```
clc
m=1; //kg
T1=273; //K
T2=363; //K
c=4.187;

disp("(a)")
disp("(i) Entropy of water=")
ds_water=m*c*log(T2/T1);
disp(ds_water)
disp("kJ/kgK")


disp("(ii) Entropy change of the reservoir ")
Q=m*c*(T2-T1);
ds_reservoir=-Q/T2;
disp("ds_reservoir=")
disp(ds_reservoir)
disp("kJ/K")


disp("(iii) Entropy change of universe =")
ds_universe=ds_water+ds_reservoir;
disp(ds_universe)
disp("kJ/K")

```

```
disp("(b)")
T3=313; //K
ds_water=m*c*(log(T3/T1) + log(T2/T3));
ds_res1=-m*c*(T3-T1)/T3;
ds_res2=-m*c*(T2-T3)/T2;

ds_universe=ds_water+ds_res1+ds_res2;
disp("(iii) Entropy change of universe =")
disp(ds_universe)
disp("kJ/K")

disp("(c) The entropy change of universe would be
    less and less, if the water is heated in more and
     more stages, by bringing the water in contact
    successively with more and more heat reservoirs,
    each succeeding reservoir being at a higher
    temperature than the preceding one.")
disp("When water is heated in infinite steps, by
    bringing in contact with an infinite number of
    reservoirs in succession, so that at any instant
    the temperature difference between the water and
    the reservoir in contact is infinitesimally small
    , then the entropy change of the universe would
    be zero and the water would be reversibly heated.
    ")
```

Scilab code Exa 5.50 50

```
clc
cp=2.093; //kJ/kg0C
c=4.187;
Lf=333.33; //kJ/kg
m=1; //kg
T0=273; //K
```

```
T1=268; //K
T2=298; //K
Q_s=m*cp*(T0-T1);
Q_f=m*Lf;
Q_l=m*c*(T2-T0);
Q=Q_s+Q_f+Q_l;

disp("(i) Entropy increase of the universe")
ds_atm=-Q/T2;
ds_sys1=m*cp*log(T0/T1);
ds_sys2=Lf/T0;
ds_sys3=m*c*log(T2/T0);
ds_total=ds_sys1+ds_sys2+ds_sys3;
ds_universe=ds_total+ds_atm;

disp("Entropy increase of universe=")
disp(ds_universe)
disp("kJ/K")


disp("(ii) Minimum amount of work necessary to
    convert the water back into ice at     5 C , Wmin
    .")
dS_refrigerator=0;

// dS_atm=(Q+W)/T;
// dS_universe >= 0
// dS_system=(s1-s4)
//dS_universe=dS_system+dS_refrigerator+dS_atm

dS_system=-1.6263; //kJ/kg K
T=298; //K

//For minimum work
W_min=T*(-dS_system)-Q;
disp("Minimum work done =")
disp(W_min)
disp("kJ")
```

Chapter 6

Availability and Irreversibility

Scilab code Exa 6.1 1

```
clc
T0=293; //K
T1=300; //K
T2=370; //K
cv=0.716;
cp=1.005;
R=0.287;
p1=1; //bar
p2=6.8; //bar
m=1; //kg
Wmax=-[cv*(T2-T1) - T0*[cp*log(T2/T1)-R*log(p2/p1)
   ]];
n=1/(1-(log(T2/T1)/log(p2/p1)));
Wact=m*R*(T1-T2)/(n-1);

I=Wmax - Wact;
disp("Irreversibility = ")
disp(I)
disp("kJ/kg")
```

Scilab code Exa 6.2 2

```
clc
T1=1000; //K
T2=500; //K
T0=300; //K
Q=7200; //kJ/min

disp("(i) Net change of entropy :")
dS_source=-Q/T1;
dS_system=Q/T2;
dS_net=dS_source+dS_system;
disp("dS_net=")
disp(dS_net)
disp("kJ/min.K")


disp("(ii) Decrease in available energy :")
AE_source=(T1-T0)*(-dS_source); //Available energy
    with the source
AE_system=(T2-T0)*dS_system; //Available energy with
     the system
dAE=AE_source - AE_system; //Decrease in available
    energy
disp("dAE=")
disp(dAE)
disp("kJ")
```

Scilab code Exa 6.3 3

```
clc
m=8; //kg
```

```
T1=650; //K
p1=5.5*10^5; //Pa
p0=1*10^5; //Pa
T0=300; //K
cp=1.005; //kJ/kg.K
cv=0.718;
R=0.287;
//p1*v1/T1=p0*v0/T0
//Let r=v1/v0=1/2.54
r=1/2.54;


disp("(i) Change in available energy(for bringing
   the system to dead state)=")
ds=cv*log(T1/T0) + R*log(r);
dAE=m*[cv*(T1-T0) - T0*[ds]];
//dAE is the change in available energy in kJ

V1=m*R*10^3*T1/p1;
V0=V1/r;
disp("Loss of availability , L=")
L=p0*(V0 - V1)/10^3;
disp(L)
disp("kJ")


disp("(ii) Available Energy and Effectiveness")
Q=m*cp*(T1-T0);
ds=m*cp*log(T1/T0);
Unavailable_energy=T0*ds;
Available_energy = Q - Unavailable_energy;
disp("Available energy = ")
disp(Available_energy)
disp("kJ")

Effectiveness=Available_energy/dAE;
disp("Effectiveness = ")
disp(Effectiveness)
```

Scilab code Exa 6.4 4

```
clc
c_pg=1; //kJ/kgK
h_fg=1940.7; //kJ/kg
Ts=473; //K ; Temperature of saturation of steam
T1=1273; //K ; Initial temperature of gases
T2=773; //K ; Final temperature of gases
T0=293; //K ; atmospheric temperature

//Heat lost by gases=Heat gained by 1 kg saturated
   water when it is converted to steam at 200 0C

m_g=h_fg/c_pg/(T1-T2);
dS_g=m_g*c_pg*log(T2/T1);
dS_w=h_fg/Ts;

dS_net=dS_g + dS_w;
disp("Net change in entropy = ")
disp(dS_net)
disp("kJ/K")

E=T0*dS_net; //Increase in unavailable energy due to
    hea transfer
disp("Increase in unavailable energy =")
disp(E)
disp("kJ")
```

Scilab code Exa 6.5 5

```
clc
```

```
m_g=3; //kg
p1=2.5; //bar
T1=1200; //K; Temperature of infinite source
T1a=400; //K; Initial temperature
Q=600; //kJ
cv=0.81; //kJ/kg.K
T0=290; //K; Surrounding Temperature
//final temperature = T2a

T2a=Q/m_g/cv + T1a;
AE=(T1-T0)*Q/T1; //Available energy with the source
dS=m_g*cv*log(T2a/T1a); //Change in entropy of the gas

UAE=T0*dS; //Unavailability of the gas
A=Q-UAE; //Available energy with the gas

loss=AE-A;
disp("Loss in available energy due to heat transfer =")
disp(loss)
disp("kJ")
```

Scilab code Exa 6.6 6

```
clc
m=60; //kg
T1=333; //K
T0=279; //K
p=1; //atm
cp=4.187;

//dW=-m*cp*(1-T0/T)dT
//Wmax=Available energy
Wmax=integrate('m*cp*(1-T0/T)', 'T', T0, T1);
```

```
Q1=m*cp*(T1-T0);

//Let unavailable energy=E
E=Q1-Wmax;
disp("unavailable energy = ")
disp(E)
disp("kJ")
```

Scilab code Exa 6.7 7

```
clc
m=15; //kg
T1=340; //K
T0=300; //K
cp=4.187; //kJ/kgK
//Work added during churning = Increase in enthalpy
    of water
W=m*cp*(T1-T0);
ds=cp*log(T1/T0);
AE=m*[cp*(T1-T0)-T0*ds];
AE_loss=W-AE; //Loss in availability
disp("Loss in availability")
disp(AE_loss)
disp("kJ")
```

Scilab code Exa 6.8 8

```
clc
m=5; //kg
T1=550; //K
p1=4*10^5; //Pa
T2=290; //K
T0=T2;
```

```
p2=1*10^5; //Pa
p0=p2;
cp=1.005; //kJ/kg K
cv=0.718; //kJ/kg K
R=0.287; //kJ/kg K

disp("(i) Availability of the system :")
ds=cp*log(T1/T0) - R*log(p1/p0);
Availability=m*[cv*(T1-T0) - T0*ds];
disp("Availability of the system =")
disp(Availability)
disp("kJ")


disp("(ii) Available energy and Effectiveness")
Q=m*cp*(T1-T0);
dS=m*cp*log(T1/T0);
E=T0*dS; //Unavailable energy
AE=Q-E;
disp("Available Energy = ")
disp(AE)
disp("kJ")

disp("Effectiveness=")
Effectiveness=AE/Availability;
disp(Effectiveness)
```

Scilab code Exa 6.9 9

```
clc
R=0.287; //kJ/kgK
cp=1.005; //kJ/kgK
m=25/60; //kg/s
p1=1; //bar
p2=2; //bar
```

```
T1=288; //K
T0=T1;
T2=373; //K

W_act=cp*(T2-T1); //W_actual
W_total= m*W_act;

disp("Total actual power required =")
disp(W_total)
disp("kW")

ds=cp*log(T2/T1) - R*log(p2/p1);
Wmin=cp*(T2-T1) - T0*(ds);

disp("Minimuumm work required = ")
W=m*Wmin;
disp(W)
disp("kW")
```

Scilab code Exa 6.10 10

```
clc
m_O2=1; //kg
m_H2=1; //kg
p=1*10^5; //Pa
T_O2=450; //K
T_H2=450; //K
T0=290; //K
R0=8.314;
M_O2=32;
M_H2=2;

R_O2=R0/M_O2;
v_O2=m_O2*R_O2*T_O2/p;

```

```
R_H2=R0/M_H2;
v_H2=m_H2*R_H2*T_H2/p;

v_f=v_O2 + v_H2; //total volume after mixing

dS_O2=R_O2*log(v_f/v_O2);
dS_H2=R_H2*log(v_f/v_H2);

dS_net=dS_O2 + dS_H2;

//Let E be the loss in availability
E=T0*dS_net;
disp("Loss in availability=")
disp(E)
disp("kJ")
```

Scilab code Exa 6.11 11

```
clc
T0=283; //K
cp=4.18; //kJ/kgK
m1=20; //kg
T1=363; //K
m2=30; //kg
T2=303; //K
T3=327; //K

AE1=integrate('m1*cp*(1-T0/T)', 'T', T0, T1);
AE2=integrate('m2*cp*(1-T0/T)', 'T', T0, T2);

AE_total=AE1 + AE2; //before mixing

//If T K is the final temperature after mixing
T=(m1*T1+m2*T2)/(m1+m2);
m_total=m1+m2;
```

```

//Available energy of 50kg of water at 54 0C
AE3=m_total*cp*[(T3-T0) - T0*log(T3/T0)];

//Decrease in available energy due to mixing dAE
dAE=AE_total - AE3;
disp("dAE=")
disp(dAE)
disp("kJ")
```

Scilab code Exa 6.12 12

```
clc
T_w1=323; //K
T_w2=343; //K
T_o1=513; //K
T_o2=363; //K
SG_oil=0.82;
c_po=2.6; //kJ/kg K
c_pw=4.18; //kJ/kg K
T0=300; //K
m_o=1; //kg

//Heat lost by oil=Heat gained by water
m_w=(m_o*c_po*(T_o1-T_o2))/(c_pw*(T_w2-T_w1));

dS_w=m_w*c_pw*log(T_w2/T_w1);
dS_o=m_o*c_po*log(T_o2/T_o1);

dAE_w=m_w*[c_pw*(T_w2-T_w1)]-T0*dS_w;
dAE_o=m_o*[c_po*(T_o2-T_o1)]-T0*dS_o;

// Loss in availability E=
E=dAE_w+dAE_o;
disp("Loss in availability =")
```

```
disp(E)
disp("kJ")
```

Scilab code Exa 6.13 13

```
clc
m_i=1; //kg
T_i=273; //K
m_w=12; //kg
T_w=300; //K
T0=288; //K
c_pw=4.18; //kJ/kg K
c_pi=2.1; //kJ/kg K
L_i=333.5; //kJ/kg

Tc=(m_w*c_pw*T_w + m_i*c_pw*T_i - L_i)/(m_w*c_pw +
    m_i*c_pw);

dS_w=m_w*c_pw*log(Tc/T_w);
dS_i=m_i*c_pw*log(Tc/T_i) + L_i/T_i;

dS_net=dS_w+dS_i;
disp("Increase in entropy =")
disp(dS_net)
disp("kJ/K")

dAE=T0*dS_net;
disp("Increase in unavailable energy = ")
disp(dAE)
disp("kJ")
```

Scilab code Exa 6.14 14

```
clc
T1=673; //K
T2=473; //K
T0=303; //K
T1a=T2;

//dSa/dS=T1/T1a

// W=(T1-T0)*dS; Work done by the power cycle when
   there was no temperature difference between the
   vapour condensing and vapour evaporating
// Wa=(T1-T0)*dSa; Work done by the power cycle when
    the vapour condenses at 400 C  and vapour
   evaporates at 200 C

//Fraction of energy that becomes unavailable is
   given by (W-Wa)/W

UAE=T0*(T1-T1a)/T1a/(T1-T0);
disp("the fraction of energy that becomes
   unavailable =")
disp(UAE)
```

Scilab code Exa 6.15 15

```
clc
T1=293; //K
T2=353; //K
Tf=1773; //K
T0=288; //K
c_pl=6.3; //kJ/kg K

dAE=c_pl*(T2-T1) - T0*c_pl*log(T2/T1);

n=(1-T0/Tf); //efficiency
```

```
//W=heat supplied*efficiency
//The possible work from a heat engine is a measure
    of the loss of availability , E
E=c_pl*(T2-T1)*n;

Effectiveness=dAE/E;
disp("Effectiveness of the heating process =")
disp(Effectiveness)
```

Scilab code Exa 6.16 16

```
clc
T0=293; //K
T1=293; //K
T2=373; //K
T3=323; //K
cp=1.005;

disp("(i) The ratio of mass flow")
//cp=Specific heat of air constant pressure
//cp*T1 + x*cp*T2 = (1+x)*cp*T3
x=(T3-T1)/(T2-T3);
disp("x=")
disp(x)


disp("(ii) The effectiveness of heating process")
ds_13=cp*log(T3/T1);
ds_32=cp*log(T2/T3);
A=cp*(T3-T1) - T1*ds_13; //Increase of availability
    of system
B=x*[cp*(T2-T3)-T0*(ds_32)];// Loss of availability
    of surroundings

```

```
Effectiveness=A/B;
disp("Effectiveness of heating process=")
disp(Effectiveness)
```

Scilab code Exa 6.17 17

```
clc
m=2.5; //kg
p1=6*10^5; //Pa
r=2; //r=V2/V1
cv=0.718; //kJ/kg K
R=0.287; //kJ/kg K
T1=363; //K
p2=1*10^5; //Pa
T2=278; //K
V1=m*R*T1/p1;
V2=2*V1;
T0=278; //K
p0=1*10^5; //Pa
Q=0; //adiabatic process

disp("(i)The maximum work")
dS=m*cv*log(T2/T1) + m*R*log(V2/V1);
Wmax=m*[cv*(T1-T2)] + T0*(cv*log(T2/T1) + R*log(V2/
   V1));
disp("Wmax=")
disp(Wmax)
disp("kJ")


disp("(ii)The change in availability")
dA=Wmax+p0*(V1-V2);
disp("Change in availability =")
disp(dA)
disp("kJ")
```

```
disp("(iii) The irreversibility")

I=T0*m*(cv*log(T2/T1)+R*log(V2/V1));

disp("Irreversibility =")
disp(I)
disp("kJ")
```

Scilab code Exa 6.18 18

```
clc
m=1; //kg
p1=7*10^5; //Pa
T1=873; //K
p2=1*10^5; //Pa
T2=523; //K
T0=288; //K
Q=-9; //kJ/kg
cp=1.005; //kJ/kg K
R=0.287; //kJ/kg K
disp("(i) The decrease in availability ")
dA=cp*(T1-T2) - T0*(R*log(p2/p1) - cp*log(T2/T1));
disp("dA=")
disp(dA)
disp("kJ/kg")


disp("(ii) The maximum work")
Wmax=dA; //change in availability
disp("Wmax")
disp(Wmax)
disp("kJ/kg")

```

```

disp("The irreversibility")
W=cp*(T1-T2) + Q;
I=Wmax - W;
disp("Irreversibility =")
disp(I)
disp("kJ/kg")
```

Scilab code Exa 6.19 19

```
clc
cp=1.005; //kJ/kg K
cv=0.718; //kJ/kg K
R=0.287; //kJ/kg K
m=1; //kg
T1=290; //K
T0=290; //K
T2=400; //K
p1=1; //bar
p0=1; //bar
p2=6; //bar


//Wrev=change in internal energy - T0*change in entropy
disp("(i) The irreversibility")
Wrev=-[cv*(T2-T1) - T0*[cp*log(T2/T1) - R*log(p2/p1)]];
n=[1/(1-log(T2/T1)/log(p2/p1))];
Wact=m*R*(T1-T2)/(n-1);

I=Wrev-Wact;
disp("Irreversibility=")
disp(I)
disp("kJ")
```

```
disp("(ii)The effectiveness = ")
effectiveness=Wrev/Wact*100;
disp(effectiveness)
disp("%")
```

Scilab code Exa 6.20 20

```
clc
I=0.62; //kg/m^2
N1=2500; //rpm
w1=2*%pi*N1/60; //rad/s
m=1.9; //kg;  Water equivalent of shaft bearings
cp=4.18;
T0=293; //K
t0=20; //0C

disp("(i)Rise in temperature of bearings")
KE=1/2*I*w1^2/1000; //kJ
dT=KE/(m*cp); //rise in temperature of bearings
disp("dT=")
disp(dT)
disp("0C")

t2=t0+dT;
disp("Final temperature of the bearings =")
disp(t2)
disp("0C")

T2=t2+273;

disp("(ii)Final r.p.m. of the flywheel")
AE=integrate('m*cp*(1-T0/T)', 'T', T0, T2);
UE=KE - AE;
```

```
disp("Available energy =")
disp(AE)
disp("kJ")

UAE=KE-AE;
disp("Unavailable energy =")
disp(UAE)
disp("kJ")

w2=sqrt(AE*10^3*2/I);
N2=w2*60/2/%pi;
disp("Final rpm of the flywheel =")
disp(N2)
disp("rpm")
```

Scilab code Exa 6.21 21

```
clc
p1=8; //bar
T1=453; //K
p2=1.4; //bar
T2=293; //K
T0=T2;
p0=1; //bar
m=1; //kg
C1=80; //m/s
C2=40; //m/s
cp=1.005; //kJ/kg K
R=0.287; //kJ/kg K
disp("(i) Reversible work and actual work ")
A1=cp*(T1-T0)-T0*(cp*log(T1/T0)-R*log(p1/p0))+C1
    ^2/2/10^3; //Availability at the inlet
A2=cp*(T2-T0)-T0*(cp*log(T2/T0)-R*log(p2/p0))+C2
    ^2/2/10^3; //Availability at the exit
```

```
W_rev=A1-A2;
disp("W_rev =")
disp(W_rev)
disp("kJ/kg")

W_act=cp*(T1-T2) + (C1^2-C2^2)/2/10^3;
disp("W_act =")
disp(W_act)
disp("kJ/kg")

disp("(ii) Irreversibilty and effectiveness =")

I=W_rev-W_act;
disp("Irreversibilty =")
disp(I)
disp("kJ/kg")

Effectiveness=W_act/W_rev*100;
disp("Effectiveness =")
disp(Effectiveness)
disp("%")
```

Scilab code Exa 6.22 22

```
clc
p1=20; //bar
t1=400; //0C
p2=4; //bar
t2=250; //0C
t0=20; //0C
T0=t0+273;
h1=3247.6; //kJ/kg
s1=7.127; //kJ/kg K

```

```
//let h2'=h2a and s2'=s2a
h2a=2964.3; //kJ/kg
s2a=7.379; //kJ/kg K

s2=s1;
s1a=s1;

//By interpolation , we get
h2=2840.8; //kJ/kg


disp("(i) Isentropic efficiency")
n_isen=(h1-h2a)/(h1-h2);
disp(" Isentropic efficiency =")
disp(n_isen)


disp("(ii) Loss of availability")
A=h1-h2a + T0*(s2a-s1a);
disp(" Loss of availability=")
disp(A)
disp("kJ/kg")


disp("(iii)Effectiveness")
Effectiveness=(h1-h2a)/A;
disp("Effectiveness =")
disp(Effectiveness)
```

Chapter 7

Thermodynamic Relations

Scilab code Exa 7.17 17

```
clc
B=5*10^(-5); // /K
K=8.6*10^(-12); // m^2/N
v=0.114*10^(-3); //m^3/kg
p2=800*10^5; //Pa
p1=20*10^5; //Pa
T=288; //K
disp("(i) Work done on the copper = ")
W=-v*K/2*(p2^2-p1^2);
disp(W)
disp("J/kg")

disp("(ii) Change in entropy =")
ds=-v*B*(p2-p1);
disp(ds)
disp("J/kg K")

disp("(iii) The heat transfer =")
Q=T*ds;
disp(Q)
disp("J/kg")
```

```
disp("(iv) Change in internal energy =")
du=Q-W;
disp(du)
disp("J/kg")

disp("(v) cp      cv =")
R=B^2*T*v/K;
disp(R)
disp("J/kg K")
```

Scilab code Exa 7.18 18

```
clc
vg=0.1274; //m^3/kg
vf=0.001157; //m^3/kg
// dp/dT=32; //kPa/K
T3=473; //K

h_fg=32*10^3*T3*(vg-vf)/10^3;
disp("h_fg=")
disp(h_fg)
disp("kJ/kg")
```

Scilab code Exa 7.19 19

```
clc
h_fg=334; //kJ/kg
v_liq=1; //m^3/kg
v_ice=1.01; //m^3/kg
T1=273; //K
T2=263; //K
p1=1.013*10^5; //Pa
```

```
p2=(p1+h_fg*10^3/(v_ice-v_liq)*log(T1/T2))/10^5;
disp("p2=")
disp(p2)
disp("bar")
```

Scilab code Exa 7.20 20

```
clc
h_fg=294.54; //kJ/kg

// log(p)=7.0323 - 3276.6/T - 0.652*log(T)
// Differentiating both sides , we get
// 1/2.302/p*dp/dT=3276.6/T^2-0.652/2.302/T

//Putting p=0.1 bar , we get
p=0.1; //bar
T=523; //K

vg=h_fg*10^3/T/(2.302*3276.6*p*10^5/T^2 - 0.652*p
    *10^5/T);
disp("vg=")
disp(vg)
disp("m^3/kg")
```

Chapter 8

Ideal and Real Gases

Scilab code Exa 8.1 1

```
clc
R=287; //J/kg K
V1=40; //m^3
V2=40; //m^3
p1=1*10^5; //Pa
p2=0.4*10^5; //Pa
T1=298; //K
T2=278; //K

m1=p1*V1/R/T1;
m2=p2*V2/R/T2;

//Let mass of air removed be m
m=m1-m2;
disp("Mass of air removed =")
disp(m)
disp("kg")

V=m*R*T1/p1;
disp("Volume of gas removed =")
disp(V)
```

```
disp("m^3")
```

Scilab code Exa 8.2 2

```
clc
V=0.04; //m^3
p=120*10^5; //Pa
T=293; //K
R0=8314;

disp("(i) kg of nitrogen the flask can hold")
M=28; //molecular weight of Nitrogen
R=R0/M;

m=p*V/R/T;
disp("kg of nitrogen=")
disp(m)
disp("kg")


disp("(ii) Temperature at which fusible plug should
    melt")
p=150*10^5; //Pa

T=p*V/R/m; //K
t=T-273; //0C
disp("Temperature =")
disp(t)
disp(" C ")
```

Scilab code Exa 8.3 3

```
clc
```

```
p1=1*10^5; //Pa
T1=293; //K
d=6; //m; diameter of the spherical balloon
p2=0.94*p1;
T2=T1;
cv=10400; //J/kg K
R=8314/2;
r=3; //m

disp("(i) Mass of original gas escaped")

//dm=m1-m2
//dm=(p1-p2)*V1/R/T1
//m1=p1*V1/R/T1

%mass_escaped=(p1-p2)/p1*100;
disp("%mass_escaped =")
disp(%mass_escaped)
disp("%")

disp("(ii)Amount of heat to be removed ")
T2=0.94*T1;
m=p1*4/3*%pi*r^3/R/T1;

Q=m*cv*(T1-T2)/10^6;
disp("Q =")
disp(Q)
disp("MJ")
```

Scilab code Exa 8.4 4

```
clc
m=28; //kg
V1=3; //m^3
T1=363; //K
```

```
R0=8314;
M=28; //Molecular mass of N2
R=R0/m;
V2=V1;
T2=293; //K

disp("(i) Pressure (p1) and specific volume (v1) of
    the gas")

p1=m*R*T1/V1/10^5; //bar
disp("Pressure =")
disp(p1)
disp("bar")

v1=V1/m;
disp("specific volume=")
disp(v1)
disp("m^3/kg")


disp("(ii) cp = ?, cv = ?")
//cp-cv=R/1000;
//cp-1.4cv=0;
//solving the above two eqns
A=[1,-1;1,-1.4];
B=[R/1000;0];
X=inv(A)*B;

cp=X(1,1);
disp("cp=")
disp(cp)
disp("kJ/kg K")

cv=X(2,1);
disp("cv=")
disp(cv)
disp("kJ/kg K")

```

```
disp("(iii) Final pressure of the gas after cooling
   to 20 C ")
p2=p1*T2/T1;
disp("p2=")
disp(p2)
disp("bar")


disp("(iv) du, dh, s, Q")

du=cv*(T2-T1);
disp("Increase in specific internal energy=")
disp(du)
disp("kJ/kg")

dh=cp*(T2-T1);
disp("Increase in specific Enthalpy =")
disp(dh)
disp("kJ/kg")

v2=v1;
ds=cv*log(T2/T1) + R*log(v2/v1);
disp("Increase in specific entropy =")
disp(ds)
disp("kJ/kg K")

W=0; //constant volume process
Q=m*du+W;
disp("Heat transfer =")
disp(Q)
disp("kJ")
```

Scilab code Exa 8.5 5

```
clc

disp("Part (a)")

R=0.287; //kJ/kg K
y=1.4;
m1=1; //kg
p1=8*10^5; //Pa
T1=373; //K
p2=1.8*10^5; //Pa
cv=0.717; //kJ/kg K
n=1.2;
//pv^1.2 = constant

disp("(i) The final specific volume, temperature and
    increase in entropy")

v1=R*10^3*T1/p1;
v2=v1*(p1/p2)^(1/n);
disp("v2=")
disp(v2)
disp("m^3/kg")

T2=p2*v2/R/10^3; //K
t2=T2-273; //0C
disp("Final temperature =")
disp(t2)
disp("0C")

ds=cv*log(T2/T1) + R*log(v2/v1);
disp("ds=")
disp(ds)
disp("kJ/kg K")


disp("(ii) Work done and heat transfer")

W=R*(T1-T2)/(n-1);
```

```
disp("Work done=")
disp(W)
disp("kJ/kg")

Q=cv*(T2-T1) + W;
disp("Heat transfer=")
disp(Q)
disp("kJ/kg")


disp("Part (b)")

disp("(i) Though the process is assumed now to be irreversible and adiabatic , the end states are given to be the same as in (a). Therefore , all the properties at the end of the process are the same as in (a).")


disp("(ii) Adiabatic process")
Q=0;
disp("Heat transfer=")
disp(Q)
disp("kJ/kg")

W=-cv*(T2-T1);
disp("Work done=")
disp(W)
disp("kJ/kg")
```

Scilab code Exa 8.6 6

```
clc
d=2.5; //m; diameter
V1=4/3*%pi*(d/2)^3; //volume of each sphere
```

```
T1=298; //K
T2=298; //K
m1=16; //kg
m2=8; //kg
V=2*V1; //total volume
m=m1+m2;
R=287; //kJ/kg K

p=m*R*T1/V/10^5; //bar
disp("pressure in the spheres when the system
    attains equilibrium=")
disp(p)
disp("bar")
```

Scilab code Exa 8.7 7

```
clc
m=6.5/60; //kg/s
cv=0.837; //kJ/kg K
p1=10*10^5; //Pa
p2=1.05*10^5; //Pa
T1=453; //K
R0=8.314;
M=44; //Molecular mass of CO2

R=R0/M;
cp=cv+R;
y=cp/cv;

T2=T1*(p2/p1)^((y-1)/y);
t2=T2-273;
disp("Final temperature=")
disp(t2)
disp("0C")

```

```
v2=R*10^3*T2/p2; //m^3/kg
disp("final specific volume =")
disp(v2)
disp("m^3/kg")

ds=0; //Reversible and adiabatic process
disp("Increase in entropy=")
disp(ds)

Q=0; //Adiabatic process
disp("Heat transfer rate from turbine=")
disp(Q)

W=m*cp*(T1-T2);
disp("Power delivered by the turbine=")
disp(W)
disp("kW")
```

Scilab code Exa 8.8 8

```
clc
p1=8*10^5; //Pa
V1=0.035; //m^3
T1=553; //K
p2=8*10^5; //Pa
V2=0.1; //m^3
n=1.4;
R=287; //J/kg K
T3=553; //K
cv=0.71; //kJ/kg K

m=p1*V1/R/T1;
T2=p2*V2/m/R;
p3=p2/((T2/T3)^(n/(n-1)));
V3=m*R*T3/p3;
```

```
disp("(i) The heat received in the cycle")

//constant pressure process 1-2
W_12=p1*(V2-V1)/10^3; //kJ
Q_12=m*cv*(T2-T1) + W_12; //kJ

//polytropic process 2-3
W_23=m*R/10^3*(T2-T3)/(n-1);
Q_23=m*cv*(T3-T2) + W_23;

Q_received=Q_12 + Q_23;
disp("Total heat received in the cycle=")
disp(Q_received)
disp("kJ")


disp("(ii) The heat rejected in the cycle")

//Isothermal process 3-1
W_31=p3*V3*log(V1/V3)/10^3; //kJ
Q_31=m*cv*(T3-T1) + W_31;
disp("Heat rejected in the cycle =")
disp(-Q_31)
disp("kJ")


disp("(ii) Efficiency of the cycle")
n=(Q_received - (-Q_31))/Q_received*100;
disp("Efficiency of the cycle =")
disp(n)
disp("%")
```

Scilab code Exa 8.9 9

```
clc
v=44; //m^3/kg-mol
T=373; //K

disp("(i) Using Van der Waals equation")

a=362850; //N*m^4/(kg-mol)^2
b=0.0423; //M^3/kg-mol
R0=8314; //J/kg K

p=((R0*T/(v-b)) - a/v^2);
disp("Pressure using Van der Waals equation=")
disp(p)
disp("N/m^2")


disp("(ii) Using perfect gas equation")

p=R0*T/v;
disp("Pressure using perfect gas equation=")
disp(p)
disp("N/m^2")
```

Scilab code Exa 8.10 10

```
clc
V=3; //m^3
m=10; //kg
T=300; //K

disp("(i) Using perfect gas equation")
R0=8314;
M=44;
R=R0/M;
p=m*R*T/V;
```

```
disp("Pressure Using perfect gas equation =")
disp(p)
disp("N/m^2")


disp("(ii) Using Van der Waals equation")
a=362850; //Nm^4/(kg-mol)^2
b=0.0423; //m^3/(kg-mol)
v=13.2; //m^3/kg-mol

p=R0*T/(v-b) - a/v^2;
disp("Pressure Using Van der Waals equation=")
disp(p)
disp("N/m^2")


disp("(iii) Using Beattie Bridgeman equation")

A0=507.2836;
a=0.07132;
B0=0.10476;
b=0.07235;
C=66*10^4;
A=A0*(1-a/v);
B=B0*(1-b/v);
e=C/v/T^3;

p=R0*T*(1-e)/v^2*(v+B) - A/v^2;
disp("Pressure Using Beattie Bridgeman equation = ")
disp(p)
disp("N/m^2")
```

Scilab code Exa 8.11 11

```
clc
```

```
a=139250; //Nm^4/(kg-mol)^2
b=0.0314; //m^3/kg-mol
R0=8314; //Nm/kg-mol K
v1=0.2*32; //m^3/kg-mol
v2=0.08*32; //m^3/kg-mol
T=333; //K
disp("(i) Work done during the process")
W=integrate('R0*T/(v-b) - a/v^2', 'v', v1, v2);
disp("W=")
disp(W)
disp("Nm/kg-mol")


disp("(ii) The final pressure")
p2=R0*T/(v2-b) - a/v2^2;
disp("p2=")
disp(p2)
disp("N/m^2")
```

Scilab code Exa 8.12 12

```
clc
pr=20;
Z=1.25;
Tr=8.0;
Tc=282.4; //K

T=Tc*Tr;
disp("Temperature =")
disp(T)
disp("K")
```

Scilab code Exa 8.13 13

```
clc
p=260*10^5; //Pa
T=288; //K
pc=33.94*10^5; //Pa
Tc=126.2; //K
R=8314/28;

pr=p/pc;
Tr=T/Tc;
Z=1.08;

rho=p/Z/R/T;
disp("Density of N2=")
disp(rho)
disp("kg/m^3")
```

Scilab code Exa 8.14 14

```
clc
p=200*10^5; //Pa
pc=73.86*10^5; //Pa
Tc=304.2; //K
pr=p/pc;
Z=1;
Tr=2.48;

T=Tr*Tc;
disp("Temperature =")
disp(T)
disp("K")
```

Scilab code Exa 8.15 15

```
clc
d=12; //m; diameter of spherical balloon
V=4/3*%pi*(d/2)^3;
T=303; //K
p=1.21*10^5; //Pa
pc=12.97*10^5; //Pa
Tc=33.3; //K
R=8314/2;

pr=p/pc;
Tr=T/Tc;
Z=1;

m=p*V/Z/R/T;
disp("Mass of H2 in the balloon =")
disp(m)
disp("kg")
```

Scilab code Exa 8.16 16

```
clc

// dp_c/dv=0
// d^2 p/dv^2=0

// p_cp=R0*T_cp/(v_cp-b) - a/v_cp^2

// As T_cp is constant
// dp_cp/dv_cp=(-R0*T_cp)/(v_cp-b)^2 + 2*a/v_cp^3 =
   0

// d^2 p_cp/dv_cp=2*R0*T_cp/(v_cp-b)^3 - 6*a/v_cp^4
   = 0

// Solving these we get v_cp=3*b;
```

```
//  2*a/v_cp^3 - R0*T_cp/[v_cp-1/3*v_cp]^2

//a=9/8*R0*T_cp*v_cp

//Z_cp=p_cp*v_cp/R0/T_cp

Z_cp=3/2-9/8;

disp("Z_cp=")
disp(Z_cp)
```

Chapter 9

Gases and Vapour Mixtures

Scilab code Exa 9.1 1

```
clc
V=0.35; //m^3
m_CO=0.4; //kg
m_air=1; //kg
m_O2=0.233; //kg
m_N2=0.767; //kg
T=293; //K
R0=8.314; //kJ/kg K
M_O2=32; //Molecular mass of O2
M_N2=28; //Molecular mass of N2
M_CO=28; //Molecular mass of CO

disp("Partial Pressures=")

p_O2=m_O2*R0*10^3*T/M_O2/V/10^5; //bar
disp("partial pressure for p_O2")
disp(p_O2)
disp("bar")

p_N2=m_N2*R0*10^3*T/M_N2/V/10^5; //bar
disp("partial pressure for p_N2")
```

```
disp(p_N2)
disp("bar")

p_CO=m_CO*R0*10^3*T/M_CO/V/10^5; //bar
disp("partial pressure for p_CO")
disp(p_CO)
disp("bar")


disp("(ii) Total pressure in the vessel")
p=p_O2+p_N2+p_CO;
disp("p=")
disp(p)
disp("bar")
```

Scilab code Exa 9.2 2

```
clc
R0=8.314;

M_O2=32;
M_N2=28;
M_Ar=40;
M_CO2=44;

R_O2=R0/M_O2; //kJ/kg K
R_N2=R0/M_N2; //kJ/kg K
R_Ar=R0/M_Ar; //kJ/kg K
R_CO2=R0/M_CO2; //kJ/kg K

%O2=0.2314;
%N2=0.7553;
%Ar=0.0128;
%CO2=0.0005;

```

```
disp("(i) Gas constant for air")
R=%O2*R_O2 + %N2*R_N2 + %Ar*R_Ar + %CO2*R_CO2;
disp("R=")
disp(R)
disp("kJ/kg K")

disp("(ii) Apparent molecular weight.")
M=R0/R;
disp("M=")
disp(M)
```

Scilab code Exa 9.3 3

```
clc
p=1; //bar

//For oxygen
m_O2=0.2314;
M_O2=32;
n_O2=m_O2/M_O2;

//For Nitrogen
m_N2=0.7553;
M_N2=28;
n_N2=m_N2/M_N2;

//For Argon
m_Ar=0.0128;
M_Ar=40;
n_Ar=m_Ar/M_Ar;

//For CO2
m_CO2=0.0005;
M_CO2=44;
n_CO2=m_CO2/M_CO2;
```

```
n=n_O2 + n_N2 + n_Ar + n_CO2;

//Let Vi/V be A

A_O2=n_O2/n * 100;
disp("Vi/V of O2=")
disp(A_O2)
disp("%")

A_N2=n_N2/n * 100;
disp("Vi/V of N2=")
disp(A_N2)
disp("%")

A_Ar=n_Ar/n *100;
disp("Vi/V of Ar")
disp(A_Ar)
disp("%")

A_CO2=n_CO2/n * 100;
disp("Vi/V of CO2=")
disp(A_CO2)
disp("%")


P_O2=n_O2/n*p;
disp("Partial pressure of O2=")
disp(P_O2)
disp("bar")

P_N2=n_N2/n*p;
disp("Partial pressure of N2=")
disp(P_N2)
disp("bar")

P_Ar=n_Ar/n*p;
```

```
disp("Partial pressure of Ar=")
disp(P_Ar)
disp("bar")

P_CO2=n_CO2/n*p;
disp("Partial pressure of CO2=")
disp(P_CO2)
disp("bar")
```

Scilab code Exa 9.4 4

```
clc
p=1*10^5; //Pa
T=293; //K
n_CO2=1; //moles of CO2
n=4; //moles of air
M_CO2=44;
M_N2=28;
M_O2=32;

//Let A be the volumeetric analysis
A_O2=0.21;
A_N2=0.79;

n_O2=A_O2*n;
n_N2=A_N2*n;

disp("(i) The masses of CO2, O2 and N2, and the
    total mass")

m_CO2=n_CO2*M_CO2;
disp("Mass of CO2=")
disp(m_CO2)
disp("kg")

```

```
m_O2=n_O2*M_O2;
disp("Mass of O2=")
disp(m_O2)
disp("kg")

m_N2=n_N2*M_N2;
disp("Mass of N2=")
disp(m_N2)
disp("kg")

m=m_CO2 + m_O2 + m_N2;
disp("Total mass =")
disp(m)
disp("kg")


disp("(ii) The percentage carbon content by mass")
//Since the molecular weight of carbon is 12, therefore, there are 12 kg of carbon present for every mole of CO2
m_C=12; //kg

%C=m_C/m*100;
disp("Percentage carbon in mixture")
disp(%C)
disp("%")


disp("(iii) The apparent molecular weight and the gas constant for the mixture")
n=n_CO2 + n_O2 + n_N2;
M=n_CO2/n*M_CO2 + n_O2/n*M_O2 + n_N2/n*M_N2;
disp("Apparent Molecular weight")
disp(M)

R0=8.314;
R=R0/M;
disp("Gas constant for the mixture=")
```

```
disp(R)
disp("kJ/kg K")


disp("(iv) The specific volume of the mixture")
v=R*10^3*T/p;
disp("specific volume=")
disp(v)
disp("m^3/kg")
```

Scilab code Exa 9.5 5

```
clc
p=1*10^5; //Pa
T=298; //K
M_H2=2;
M_O2=32;
R0=8314;

// ratio = V_H2/V_O2=2;
ratio=2;

disp("(i) The mass of O2 required")
//Let the mass of O2 per kg of H2 = x kg
m_H2=1; //kg
n_H2=m_H2/M_H2;

// n_O2=x/M_O2
x=M_O2*n_H2/ratio;
disp("Mass of O2 per kg of H2=")
disp(x)
disp("kg")


disp("(ii) The volume of the container")
```

```
n_O2=x/M_O2;
n=n_H2 + n_O2;
V=n*R0*T/p;
disp("V=")
disp(V)
disp("m^3")
```

Scilab code Exa 9.6 6

```
clc

//Let composition of mixture by volume be denoted by
    c1
//Let Final composition desired be denoted by c2

c1_H2=0.78;
c1_CO=0.22;

c2_H2=0.52;
c2_CO=0.48;

M_H2=2;
M_CO=28;

M=c1_H2*M_H2 + c1_CO*M_CO;

// Let x kg of mixture be removed and y kg of CO be
   added.

x=(c1_H2 - c2_H2)/c1_H2*M;
disp("Mass of mixture removed =")
disp(x)
disp("kg")

y=M_CO/M*x;
```

```
disp("Mass of CO added=")
disp(y)
disp("kg")
```

Scilab code Exa 9.7 7

```
clc

ratio=1/8; //volume ratio; v1/v2
T1=1223; //K

cp_CO2=1.235; //kJ/kg K
cp_O2=1.088; //kJ/kg K
cp_N2=1.172; //kJ/kg K

n_CO2=0.13;
n_O2=0.125;
n_N2=0.745;

M_CO2=44;
M_O2=32;
M_N2=28;

m_CO2=M_CO2*n_CO2;
m_O2=M_O2*n_O2;
m_N2=M_N2*n_N2;

m=m_CO2 + m_O2 + m_N2;

// Let Fraction by mass be denoted by F
F_CO2=m_CO2/m;
F_O2=m_O2/m;
F_N2=m_N2/m;
```

```
cp=F_CO2*cp_CO2 + F_O2*cp_O2 + F_N2*cp_N2;

R0=8.314;
R=F_CO2*R0/M_CO2 + F_O2*R0/M_O2 + F_N2*R0/M_N2;

cv=cp - R;
n=1.2;

disp("(i) The workdone")
T2=T1*(ratio)^(n-1);
W=R*(T1-T2)/(n-1);
disp("W=")
disp(W)
disp("kJ/kg")


disp("(ii) The heat flow")
du=cv*(T2-T1);
Q=du + W;
disp("Q=")
disp(Q)
disp("kJ/kg")


disp("(iii) Change of entropy per kg of mixture")
ds_1A=R*log(1/ratio); //isothermal process
ds_2A=cv*log(T1/T2);

ds_12=ds_1A - ds_2A;
disp("change of entropy=")
disp(ds_12)
disp("kJ/kg K")
```

Scilab code Exa 9.8 8

```
clc

M_CO2=44;
M_H2=2;
M_N2=28;
M_CH4=16;
M_CO=28;

// Let volumetric analysis be denoted by V
V_CO=0.28;
V_H2=0.13;
V_CH4=0.04;
V_CO2=0.04;
V_N2=0.51;

Cp_CO=29.27; //kJ/mole K
Cp_H2=28.89; //kJ/mole K
Cp_CH4=35.8; //kJ/mole K
Cp_CO2=37.22; //kJ/mole K
Cp_N2=29.14; //kJ/mole K

R0=8.314;

Cp=V_CO*Cp_CO + V_H2*Cp_H2 + V_CO2*Cp_CO2 + V_CH4*
    Cp_CH4 + V_N2*Cp_N2;
disp("Cp=")
disp(Cp)
disp("kJ/mole K")

Cv=Cp-R0;
disp("Cv=")
disp(Cv)
disp("kJ/mole K")

M=V_CO*M_CO + V_H2*M_H2 + V_CO2*M_CO2 + V_CH4*M_CH4
    + V_N2*M_N2;

cp=Cp/M;
```

```
disp("cp=")
disp(cp)
disp("kJ/kg K")

cv=Cv/M;
disp("cv")
disp(cv)
disp("kJ/kg K")
```

Scilab code Exa 9.9 9

```
clc

p=1.3; //bar
R0=8.314;

M_CO2=44;
M_O2=32;
M_N2=28;
M_CO=28;

m_O2=0.1;
m_N2=0.7;
m_CO2=0.15;
m_CO=0.05;

//Considering 1 kg of mixture
m=1; //kg

//let moles be denoted by n
n_O2=m_O2/M_O2;
n_N2=m_N2/M_N2;
n_CO2=m_CO2/M_CO2;
n_CO=m_CO/M_CO;

```

```
M=1/(m_O2/M_O2 + m_N2/M_N2 + m_CO2/M_CO2 + m_CO/M_CO
    );

n=m/M;

x_O2=n_O2/n;
x_N2=n_N2/n;
x_CO2=n_CO2/n;
x_CO=n_CO/n;

disp("(i) Partial pressures of the constituents")
P_O2=x_O2*p;
disp("Partial pressure of O2=")
disp(P_O2)
disp("bar")

P_N2=x_N2*p;
disp("Partial pressure of N2=")
disp(P_N2)
disp("bar")

P_CO2=x_CO2*p;
disp("Partial pressure of CO2=")
disp(P_CO2)
disp("bar")

P_CO=x_CO*p;
disp("Partial pressure of CO=")
disp(P_CO)
disp("bar")

disp("Gas constant of mixture =")
R_mix=R0/M;
disp(R_mix)
disp("kJ/kg K")
```

Scilab code Exa 9.10 10

```
clc
p=4*10^5; //Pa
T=293; //K
R0=8.314;

m_N2=4; //kg
m_CO2=6; //kg

M_N2=28; //Molecular mass
M_CO2=44; //Molecular mass

n_N2=m_N2/M_N2; //moles of N2
n_CO2=m_CO2/M_CO2; //moles of CO2

x_N2=n_N2/(n_N2+n_CO2);
disp("x_N2=")
disp(x_N2)

x_CO2=n_CO2/(n_CO2+n_N2);
disp("x_CO2=")
disp(x_CO2)


disp("(ii) The equivalent molecular weight of the
    mixture")
M=x_N2*M_N2 + x_CO2*M_CO2;
disp("M=")
disp(M)
disp("kg/kg-mole")


disp("(iii) The equivalent gas constant of the
```

```
mixture")
m=m_N2+m_CO2;
Rmix=(m_N2*(R0/M_N2) + m_CO2*(R0/M_CO2))/m;
disp("Rmix=")
disp(Rmix)
disp("kJ/kg K")


disp("(iv) The partial pressures and partial volumes
    ")
P_N2=x_N2*p/10^5;
disp("P_N2=")
disp(P_N2)
disp("bar")

P_CO2=x_CO2*p/10^5;
disp("P_CO2=")
disp(P_CO2)
disp("bar")

V_N2=m_N2*R0/M_N2*T/p*10^3;
disp("V_N2")
disp(V_N2)
disp("m^3")

V_CO2=m_CO2*R0/M_CO2*T/p*10^3;
disp("V_CO2")
disp(V_CO2)
disp("m^3")

disp("(v) The volume and density of the mixture")

V=m*Rmix*10^3*T/p;
disp("V=")
disp(V)
disp("m^3")

rho_mix=m/V;
```

```
disp("Density of mixture=")
disp(rho_mix)
disp("kg/m^3")


disp("(vi) cp and cv of the mixture")

y_N2=1.4;
cv_N2=(R0/M_N2)/(y_N2 - 1);
cp_N2=cv_N2*y_N2;

y_CO2=1.286;
cv_CO2=(R0/M_CO2)/(y_CO2 - 1);
cp_CO2=cv_CO2*y_CO2;

cp=(m_N2*cp_N2 + m_CO2*cp_CO2)/(m_N2+m_CO2);
disp("cp=")
disp(cp)
disp("kJ/kg K")

cv=(m_N2*cv_N2 + m_CO2*cv_CO2)/(m_N2+m_CO2);
disp("cv=")
disp(cv)
disp("kJ/kg K")



T1=293; //K
T2=323; //K
dU=m*cv*(T2-T1);
disp("Change in internal energy =")
disp(dU)
disp("kJ")

dH=m*cp*(T2-T1);
disp("Change in enthalpy =")
disp(dH)
disp("kJ")
```

```
dS=m*cv*log(T2/T1); //Constant volume process
disp("Change in entropy=")
disp(dS)
disp("kJ/kg K")


disp("When the mixture is heated at constant
    pressure")

disp("If the mixture is heated at constant pressure
     U  and  H  will remain the same")

dS=m*cp*log(T2/T1);
disp("Change in entropy =")
disp(dS)
disp("kJ/kg K")
```

Scilab code Exa 9.11 11

```
clc

Cv_O2=21.07; //kJ/mole K
Cv_CO=20.86; //kJ/mole K

p_O2=8*10^5; //Pa
p_CO=1*10^5; //Pa

V_O2=1.8; //m^3
V_CO=3.6; //m^3

T_O2=323; //K
T_CO=293; //K

R0=8314;
```

```

n_O2=p_O2*V_O2/R0/T_O2;
n_CO=p_CO*V_CO/R0/T_CO;

n=(n_O2+n_CO);
V=(V_O2+V_CO);

disp("(i) Final temperature (T) and pressure (p) of
   the mixture")

//Before mixing
U1=n_O2*Cv_O2*T_O2 + n_CO*Cv_CO*T_CO;

//After mixing
//U2=T*(n_O2*Cv_O2 + n_CO*Cv_CO);
//U1=U2

T=U1/(n_O2*Cv_O2 + n_CO*Cv_CO);
t=T-273;
disp("Final temperature =")
disp(t)
disp(" C ")

p=n*R0*T/V/10^5;
disp("Final pressure =")
disp(p)
disp("bar")


disp("(ii) Change of entropy")
//For oxygen
dS_O1A=n_O2*R0*log(V/V_O2); //isothermal process
dS_O2A=n_O2*Cv_O2*log(T_O2/T); //constant volume
   process

dS_O12=dS_O1A - dS_O2A; // Change of entropy of O2

//For CO
```

```
dS_CO12=n_CO*R0*log(V/V_CO) + n_CO*Cv_CO*log(T/T_CO)
    ; //Change of entropy of CO


dS=(dS_O12 + dS_CO12)/10^3;
disp("Change of entropy of system =")
disp(dS)
disp("kJ/K")
```

Scilab code Exa 9.12 12

```
clc

p_A=16*10^5; //Pa
p_B=6.4*10^5; //Pa

T_A=328; //K
T_B=298; //K

n_A=0.6; //kg-mole
m_B=3; //kg

R0=8314;
M_A=28;
y=1.4;

V_A=n_A*R0*T_A/p_A;

m_A=n_A*M_A;
R=R0/M_A;

V_B=m_B*R*T_B/p_B;

V=V_A+V_B;
```

```
m=m_A+m_B;
T=303; //K


disp("(a) (i) Final equilibrium pressure, p")
p=m*R*T/V/10^5;
disp("p=")
disp(p)
disp("bar")

cv=R/10^3/(y-1);

disp("(ii) Amount of heat transferred, Q :")

U1=cv*(m_A*T_A + m_B*T_B);
U2=m*cv*T;

Q=U2-U1;
disp("Q=")
disp(Q)
disp("kJ")


disp("(b) If the vessel were insulated :")

disp("(i) Final temperature,")

T=cv*(m_A*T_A + m_B*T_B)/(m*cv);
t=T-273;
disp("T=")
disp(t)
disp(" C ")


disp("(ii) Final pressure")

p=m*R*T/V/10^5;
disp("p=")
```

```
disp(p)
disp("bar")
```

Scilab code Exa 9.13 13

```
clc

m_O2=3; //kg
M_O2=32;

m_N2=9; //kg
M_N2=28;

R0=8.314;

R_O2=R0/M_O2;
R_N2=R0/M_N2;

x_O2=(m_O2/M_O2)/((m_O2/M_O2) + (m_N2/M_N2));
x_N2=(m_N2/M_N2)/((m_O2/M_O2) + (m_N2/M_N2));

dS=-m_O2*R_O2*log(x_O2) -m_N2*R_N2*log(x_N2);
disp("Change in entropy =")
disp(dS)
disp("kJ/kg K")
```

Scilab code Exa 9.14 14

```
clc
m_N2=2.5; //kg
M_N2=28;

p_N2=15; //bar
```

```
p_total=20; //bar

n_N2=m_N2/M_N2;
p_O2=p_total-p_N2;

n_O2=p_O2/p_N2*n_N2;
M_O2=32;

m_O2=n_O2*M_O2;
disp("Mass of O2 added =")
disp(m_O2)
disp("kg")
```

Scilab code Exa 9.15 15

```
clc
n_O2=1;

//V_O2=0.21*V;
//V_N2=0.79*V;
M_N2=28;
M_O2=32;

disp("(i) Moles of N2 per mole of O2 :")
n_N2=n_O2*0.79/0.21;
disp("n_N2=")
disp(n_N2)
disp("moles")

n=n_O2+n_N2;
disp("(ii) p_O2 and p_N2 :")
p=1; //atm

p_O2=n_O2/n*p;
disp("p_O2=")
```

```
disp(p_O2)
disp("atm")

p_N2=n_N2/n*p;
disp("p_N2=")
disp(p_N2);
disp("atm")


disp("(iii) The kg of nitrogen per kg of mixture :")
x=n_N2*M_N2/(n_N2*M_N2+n_O2*M_O2);
disp(" The kg of nitrogen per kg of mixture =")
disp(x)
disp("kg N2/kg mix")
```

Scilab code Exa 9.16 16

```
clc
V=0.6; //m^3
p1=12*10^5; //Pa
p2=18*10^5; //Pa
T=298; //K
R0=8.314;
x_O2=0.23;
x_N2=0.77;

n=p1*V/R0/10^3/T;

//Considering 100 kg of air
m_O2=23; //kg
m_N2=77; //kg
M_O2=32;
M_N2=28;
m=100; //kg

```

```
R=(m_O2/M_O2 + m_N2/M_N2)*R0/m; //for air
M=R0/R; //for air

m=p1*V/R/T/10^3;

m_O2=x_O2*m;
disp("Mass of O2=")
disp(m_O2)
disp("kg")

m_N2=x_N2*m;
disp("Mass of N2=")
disp(m_N2)
disp("kg")


//After adding CO2 in the vessel
p2=18*10^5; //Pa;

// p_CO2+p_N2+p_O2=18*10^5
// p_N2 + p_O2=12*10^5

p_CO2=6*10^5; //Pa
M_CO2=44;
R_CO2=R0/M_CO2;

m_CO2=p_CO2*V/(R_CO2*10^3*T);
disp("Mass of CO2 = ")
disp(m_CO2)
disp("kg")
```

Scilab code Exa 9.17 17

```
clc
V=6; //m^3
```

```
%A=0.45;
%B=0.55;
R_A=0.288; //kJ/kg K
R_B=0.295; //kJ/kg K
m=2; //kg
T=303; //K

disp("(i) The partial pressures")
m_A=%A*m;
m_B=%B*m;

p_A=m_A*R_A*10^3*T/V/10^5; //bar
disp("p_A=")
disp(p_A)
disp("bar")

p_B=m_B*R_B*10^3*T/V/10^5; //bar
disp("p_B=")
disp(p_B)
disp("bar")


disp("(ii) The total pressure")
p=p_A+p_B;
disp("p=")
disp(p)
disp("bar")


disp("(iii) The mean value of R for the mixture")
Rm=(m_A*R_A + m_B*R_B)/(m_A + m_B);
disp("Rm=")
disp(Rm)
disp("kJ/kg K")
```

Scilab code Exa 9.18 18

```
clc
m_O2=4; //kg
m_N2=6; //kg
p=4*10^5; //Pa
T=300; //K
M_O2=32;
M_N2=28;
m=10; //kg

disp("(i) The mole fraction of each component")
n_O2=m_O2/M_O2;
n_N2=m_N2/M_N2;

x_O2=n_O2/(n_O2+n_N2);
disp("x_O2=")
disp(x_O2)

x_N2=n_N2/(n_N2+n_O2);
disp("x_N2=")
disp(x_N2)


disp("(ii) The average molecular weight")
M=(n_O2*M_O2 + n_N2*M_N2)/(n_O2 + n_N2);
disp("M=")
disp(M)


disp("(iii) The specific gas constant")
R0=8.314;
R=R0/M;
disp("R=")
disp(R)
disp("kJ/kg K")

disp("(iv) The volume and density")
```

```
V=m*R*T*10^3/p;
disp("V=")
disp(V)
disp("m^3")

rho=(m_O2/V) + (m_N2/V);
disp("density=")
disp(rho)
disp("kg/m^3")


disp("(v) The partial pressures and partial volumes"
    )

p_O2=n_O2*R0*10^3*T/V/10^5; //bar
disp("p_O2=")
disp(p_O2)
disp("bar")

p_N2=n_N2*R0*10^3*T/V/10^5; //bar
disp("p_N2=")
disp(p_N2)
disp("bar")

V_O2=x_O2*V;
disp("V_O2=")
disp(V_O2)
disp("m^3")

V_N2=x_N2*V;
disp("V_N2=")
disp(V_N2)
disp("m^3")
```

Scilab code Exa 9.19 19

```
clc
cp_CO2=0.85; //kJ/kg K
cp_N2=1.04; //kJ/kg K
m_CO2=4; //kg
T1_CO2=313; //K
m_N2=8; //kg
T1_N2=433; //K
p2=0.7; //bar
p1_CO2=1.4; //bar
p1_N2=1;
R=8.314;
M_CO2=44;
M_N2=28;
R_CO2=R/M_CO2;
R_N2=R/M_N2;

disp("(i) Final temperature, T2")
T2=(m_CO2*cp_CO2*T1_CO2 + m_N2*cp_N2*T1_N2)/(m_CO2*cp_CO2 + m_N2*cp_N2);
disp("T2=")
disp(T2)
disp("K")


disp("(ii) Change in entropy")
n_CO2=0.0909;
n_N2=0.2857;
n=n_CO2 + n_N2;

x_CO2=n_CO2/n;
x_N2=n_N2/n;

p2_CO2=x_CO2*p2;
p2_N2=x_N2*p2;
```

```
dS=m_CO2*cp_CO2*log(T2/T1_CO2) - m_CO2*R_CO2*log(
    p2_CO2/p1_CO2) + m_N2*cp_N2*log(T2/T1_N2) - m_N2*
    R_N2*log(p2_N2/p1_N2);
disp("dS=")
disp(dS)
disp("kJ/K")
```

Scilab code Exa 9.20 20

```
clc

cv_O2=0.39; //kJ/kg K
cv_N2=0.446; //kJ/kg K
n_O2=1;
n_N2=2;
M_O2=32;
M_N2=28;
m_O2=32; //kg
m_N2=2*28; //kg
T_O2=293; //K
T_N2=301; //K
R0=8.314;
p_O2=2.5*10^5; //Pa
p_N2=1.5*10^5; //Pa

T2=(m_O2*cv_O2*T_O2 + m_N2*cv_N2*T_N2)/(m_O2*cv_O2 +
    m_N2*cv_N2);

V_O2=n_O2*R0*10^5*T_O2/p_O2;
V_N2=n_N2*R0*10^5*T_N2/p_N2;
V=V_O2+V_N2;

dS=m_O2*[cv_O2*log(T2/T_O2) + R0/M_O2*log(V/V_O2)] +
    m_N2*[cv_N2*log(T2/T_N2) + R0/M_N2*log(V/V_N2)];
disp("dS=")
```

```
disp(dS)
disp("kJ")
```

Scilab code Exa 9.21 21

```
clc
cv_N2=0.744; //kJ/kg K
cv_H2=10.352; //kJ/kg K
cp_N2=1.041; //kJ/kg K
cp_H2=14.476; //kJ/kg K

V=0.45; //m^3
V_H2=0.3; //m^3
V_N2=0.15; //m^3

p_H2=3*10^5; //Pa
p_N2=6*10^5; //Pa

T_H2=403; //K
T_N2=303; //K

R_H2=8.314/2;
R_N2=8.314/28;

disp("(i) Temperature of equilibrium mixture")

m_H2=p_H2*V_H2/(R_H2*10^3)/T_H2;
m_N2=p_N2*V_N2/(R_N2*10^3)/T_N2;

T2=(m_H2*cv_H2*T_H2 + m_N2*cv_N2*T_N2)/(m_H2*cv_H2 +
    m_N2*cv_N2);
disp("T2=")
disp(T2)
disp("K")

```

```
disp("(ii) Pressure of the mixture")
p2_H2=m_H2*R_H2*10^3*T2/V;
p2_N2=m_N2*R_N2*10^3*T2/V;

p2=p2_H2+p2_N2;
disp("p2=")
disp(p2/10^5)
disp("bar")

disp("(iii) Change in entropy :")

dS_H2=m_H2*[cp_H2*log(T2/T_H2) - R_H2*log(p2_H2/p_H2
   )];
disp("Change in entropy of H2 =")
disp(dS_H2)
disp("kJ/K")

dS_N2=m_N2*[cp_N2*log(T2/T_N2) - R_N2*log(p2_N2/p_N2
   )];
disp("Change in entropy of N2 =")
disp(dS_N2)
disp("kJ/K")

dS=dS_H2+dS_N2;

disp("Total change in entropy =")
disp(dS)
disp("kJ/K")
```

Scilab code Exa 9.22 22

```
clc

cv_N2=0.745; //kJ/kg K
```

```
cv_CO2=0.653; //kJ/kg K

cp_N2=1.041; //kJ/kg K
cp_CO2=0.842; //kJ/kg K

m_N2=4; //kg
m_CO2=6; //kg
pmix=4; //bar
m=m_N2+m_CO2;

T1=298; //K
T2=323; //K

cv_mix=(m_N2*cv_N2 + m_CO2*cv_CO2)/(m_N2+m_CO2);
disp("cv_mix=")
disp(cv_mix)
disp("kJ/kg K")

cp_mix=(m_N2*cp_N2 + m_CO2*cp_CO2)/(m_N2+m_CO2);
disp("cp_mix=")
disp(cp_mix)
disp("kJ/kg K")

dU=m*cv_mix*(T2-T1);
disp("Change in internal energy=")
disp(dU)
disp("kJ")

dH=m*cp_mix*(T2-T1);
disp("Change in enthalpy=")
disp(dH)
disp("kJ")

dS=m_N2*cv_N2*log(T2/T1) + m_CO2*cv_CO2*log(T2/T1);
disp("Change in entropy=")
disp(dS)
disp("kJ/K")
```

Chapter 10

Psychrometrics

Scilab code Exa 10.1 1

```
clc
t_db=293; //K
W=0.0095; //kg/kg of dry air
p_t=1.0132;
disp("(i) Partial pressure of vapour")
p_v=p_t*W/(W+0.622);
disp("p_v=")
disp(p_v)
disp("bar")


disp("(ii) Relative humidity phi :")
p_vs=0.0234; //bar; From steam tables corresponding
    to 20 0C
phi=p_v/p_vs;
disp("relative hmidity =")
disp(phi)


disp("(iii) Dew point temperature")
t_dp=13 + (14-13)/(0.01598 - 0.0150)
```

```
*(0.01524-0.0150); //From stea table by
    interpolation
disp("t_dp=")
disp(t_dp)
disp("0C")
```

Scilab code Exa 10.2 2

```
clc
t_db=290; //K
phi=0.6; //relative humidity
p_t=1.01325; //bar
p_vs=0.0194; //bar

p_v=phi*p_vs;

W=0.622*p_v/(p_t - p_v);
disp("Specific Humidity=")
disp(W)
disp("kg/kg of dry air")


t_dp=9 + (10-9)*(0.01164-0.01150)/(0.01230 -
    0.01150); //By interpolation from steam tables
disp("dew point temperature =")
disp(t_dp)
 disp("0C")
```

Scilab code Exa 10.3 3

```
clc
phi=0.55;
p_vs=0.0425; //bar
```

```
p_t=1.0132; //bar

p_v=phi*p_vs;
W=0.622*p_v/(p_t-p_v);

//Specific humidity after removing o.oo4 kg of water
    vapour
Wnew=W-0.004;
p_v=p_t*Wnew/(Wnew+0.622);
p_vs=0.0234; //bar

disp("(i) Relative humidity")
phi=p_v/p_vs;
disp("phi=")
disp(phi)


disp("(ii) Dew point temperature")

disp("Corresponding to 0.0171 bar, from steam tables
   ")
t_dp=15; //0C
disp("t_dp=")
disp(t_dp)
disp("0C")
```

Scilab code Exa 10.4 4

```
clc
t_db=35; //0C
t_wb=25; //0C
p_t=1.0132; //bar

//Corresponding to 25 0C in steam tables
p_vs_wb=0.0317; //bar
```

```
p_v=p_vs_wb - (p_t - p_vs_wb)*(t_db - t_wb)/(1527.4
    - 1.3*t_wb);


disp("(i) Specific humidity")
W=0.622*p_v/(p_t-p_v);
disp("W=")
disp(W)
disp("kg/kg of dry air")

disp("(ii) Relative humidity")

//Corresponding to 35 0C, from steam tables
p_vs=0.0563;

phi=p_v/p_vs;
disp("phi")
disp(phi)


disp("(iii) Vapour density")
R_v=8314.3/18;
T_v=308; //K

rho_v=p_v*10^5/(R_v*T_v);
disp("rho_v=")
disp(rho_v)
disp("kg/m^3")


disp("(iv) Dew point temperature")
t_dp=21 + (22-21)*(0.0252-0.0249)/(0.0264-0.0249);
disp("t_dp")
disp(t_dp)
disp("0C")
```

```
disp("(v) Enthalpy of mixture per kg of dry air")
cp=1.005;
h_g=2565.3; //kJ/kg; corresponding to 35 0C
h_vapour=h_g + 1.88*(t_db - t_dp);

h=cp*t_db + W*h_vapour;
disp("h=")
disp(h)
disp("kJ/kg of dry air")
```

Scilab code Exa 10.5 5

```
clc

//For the air at 35 0C DBT and 60% R.H.
p_vs=0.0563; //bar; Corresponding to 35 0C from stem
    tables

phi=0.6;
p_t=1.0132; //bar
cp=1.005;
t_db=35; //0C
h_g=2565.5; //kJ/kg
m1=1; //kg
m2=2; //kg
m=m1+m2;

p_v=phi*p_vs;
W1=0.622*p_v/(p_t-p_v);

//Corresponding to 0.0388 bar, from steam tables
t_dp=26+(27-26)*(0.0338-0.0336)/(0.0356-0.0336);

h_vapour=h_g + 1.88*(t_db - t_dp);
h1=cp*t_db+W1*h_vapour;
```

```

//For the air at 20 C DBT and 13 C dew point temperature :
p_v=0.0150; //bar

W2=0.622*p_v/(p_t-p_v);
t_db=20; //0C
t_dp=13;
h_g=2538.1; //kJ/kg
h_vapour=h_g + 1.88*(t_db - t_dp);

h2=cp*t_db+W2*h_vapour;

//let enthalpy per kg of moist air be h
h=((m1*h1/(1+W1)) + (m2*h2/(1+W2)))/m;

//Let Mass of vapour/kg of moist air be M
M=(m1*W1/(1+W1) + m2*W2/(1+W2))/m;


//Let specific humidity be denoted by SH
SH=M/(1-M);
disp("Specific humidity =")
disp(SH)
disp("kg/kg of dry air")
```

Scilab code Exa 10.6 6

```
clc

//For air at 20 0C and 75% R.H
p_vs=0.0234; //bar
phi=0.75;
p_t=1.0132;
cp=1.005;
```

```
t_db=20; //0C


p_v=phi*p_vs;
t_dp=15 + (16-15)*(0.01755-0.017)/(0.0182-0.017);
W=0.622*p_v/(p_t-p_v);

h_g=2538.1; //kJ/kg
h_vapour=h_g + 1.88*(t_db - t_dp);
h1=cp*t_db + W*h_vapour;


disp("(i) Relative humidity of heated air :")

//For air at 30 C DBT
p_vs=0.0425; //bar; corresponding to 30 0C
phi=p_v/p_vs;
disp("Relative humidity=")
disp(phi*100)
disp("%")


disp("(ii) Heat added to air per minute")
h_g=2556.3; //kJkg
t_db=30;
h2=cp*t_db+W*h_vapour;
V=90; //m^3
R=287;
T=293; //K

m=(p_t-p_v)*V*10^5/R/T;

Amt=m*(h2-h1);
disp("Amount of heat added per minute=")
disp(Amt)
disp("kJ")
```

Scilab code Exa 10.7 7

```
clc

//For air at 35 0C DBT and 50% RH
p_vs=0.0563; //bar; At 35 0C, from steam tables
phi=0.5;
p_t=1.0132;
t_db1=35; //0C
t_dp1=23; //0C
cp=1.005;
R=287;
p_v=phi*p_vs;
W1=0.622*p_v/(p_t-p_v);
h_g1=2565.3; //kJ/kg

h_vapour=h_g1 + 1.88*(t_db1 - t_dp1);
h1=cp*t_db1+W1*h_vapour;


disp("(i) R.H. of cooled air")
p_vs=0.0317;
phi=p_v/p_vs;
disp("RH of cooled air=")
disp(phi*100)
disp("%")


disp("(ii) Heat removed from air")
h_g2=2547.2; //kJ/kg
t_db2=25; //0C
t_dp2=23; //0C
W2=W1;
T=308; //K
```

```
V=40; //m^3

h_vapour=h_g2 + 1.88*(t_db2 - t_dp2);
h2=cp*t_db2+W2*h_vapour;
m=(p_t-p_v)*10^5*V/R/T;

//Let Heat removed be denoted by H
H=m*(h1-h2);
disp("Heat removed =")
disp(H)
disp("kJ")
```

Scilab code Exa 10.8 8

```
clc

//For the air at 35 C DBT and 50% R.H.
p_vs=0.0563; //bar; At 35 0C, from steam tables
phi=0.5;
p_v=phi*p_vs;
p_t=1.0132; //bar

t_dp1=23; //0C
t_db1=35; //0C
W1=0.622*p_v/(p_t-p_v);
h_g1=2565.3; //kJ/kg
R=287;
cp=1.005;

h_vapour=h_g1 + 1.88*(t_db1 - t_dp1);
h1=cp*t_db1+W1*h_vapour;


disp("(i) Relative humidity of out coming air and
    its wet bulb temperature.")
```

```
disp("Relative humidity of exit air is 100 per cent.")

t_wb=20; //0C
disp("Wet bulb temperture=")
disp(t_wb)
disp("0C")

p_v=0.0234; //bar
p_vs=p_v;
t_db2=20; //0C
h_g2=2538.1; //kJ/kg
t_dp2=t_db2;

W2=0.622*p_v/(p_t-p_v);
h_vapour=h_g2 + 1.88*(t_db2 - t_dp2);
h2=cp*t_db2+W2*h_vapour;

T=308; //K
V=120; //m^3

W=W1-W2; //Weight of water vvapour removed per kg of dry air
h=h1-h2; //Heat removed per kg of dry air
m=(p_t-p_v)*10^5*V/R/T;


disp("(ii) Capacity of the cooling coil in tonnes of refrigeration")
C=m*(h1-h2)*60/14000;
disp("Capacity =")
disp(C)
disp("TR")


disp("(iii) Amount of water removed per hour")
Amt=m*(W1-W2)*60;
```

```
disp("Amount of water removed per hour=")
disp(Amt)
disp("kg/h")
```

Scilab code Exa 10.9 9

```
clc
p_vs=0.0563; //bar
phi=0.2;
p_v=phi*p_vs;
p_t=1.0132; //bar

W1=0.622*p_v/(p_t-p_v);

disp("(i) Dew point temperature")
//
t_dp=8+(9-8)*(0.01126-0.01072)/(0.01150-0.01072);
disp("dew point temperature=")
disp(t_dp)
disp("0C")


disp("(ii) Relative humidity of the exit air :")
p_vs_wb=0.0170; //bar
p_vs=0.0234; //bar
t_db=20; //0C
t_wb=15; //0C

p_v=p_vs_wb - (p_t-p_vs_wb)*(t_db-t_wb)/(1527.4-1.3*t_wb);
W2=0.622*p_v/(p_t-p_v);

RH=p_v/p_vs;
disp("Relative humidity=")
disp(RH)
```

```

p_v=0.01126; //bar
R=287;
T=308; //K
V=150;

m=(p_t-p_v)*V*10^5/R/T;


disp("(iii) Amount of water vapour added to the air per minute")
amt=m*(W2-W1);
disp("Amount =")
disp(amt)
disp("kg/min")
```

Scilab code Exa 10.10 10

```
clc
p_s=0.0206; //bar
p_t=1; //bar
p_s1=0.03782; //bar
W_2s=0.622*p_s/(p_t-p_s);

cp=1.005;
t_db2=18; //0C
t_db1=28; //0C

h_g2=2534.4; //kJ/kg
h_f2=75.6; //kJ/kg
h_g1=2552.6; //kJ/kg

W1=(cp*(t_db1-t_db2) + W_2s*(h_g2-h_f2))/(h_g1-h_f2);

```

```
p_v1=W1*p_t/(0.622+W1);

RH=p_v1/p_s1; //Relative humidity
disp("Relative humidity")
disp(RH)
```

Scilab code Exa 10.11 11

```
clc
t_db1=38; //0C
t_db2=18; //0C
phi_1=0.75;
phi_2=0.85;
p_t=1; //bar
cp=1.005;

//At 38 0C
p_vs=0.0663; //bar
h_g1=2570.7; //kJ/kg
p_v=phi_1*p_vs;
W1=0.622*p_v/(p_t-p_v);

//At 18 0C
p_vs=0.0206; //bar
h_g2=2534.4; //kJ/kg
h_f2=75.6; //kJ/kg
p_v=phi_2*p_vs;
W2=0.622*p_v/(p_t-p_v);

q=(W2*h_g2 - W1*h_g1) + cp*(t_db2-t_db1) + (W1-W2)*
   h_f2;
disp("Heat transfer rate=")
disp(q)
disp("kJ/kg of dry air")
```

Scilab code Exa 10.12 12

```
clc

//At 38 0C
p_vs=0.0663; //bar
h_g1=2570.7; //kJ/kg
phi=0.25;
p_t=1.0132;
p_v=phi*p_vs;
cp=1.005;

//At 18 0C
h_g2=2534.4; //kJ/kg
p_vs=0.0206; //bar
W1=0.622*p_v/(p_t-p_v);

t_db1=38; //0C
t_db2=18; //0C

W2=(cp*(t_db1-t_db2) + W1*h_g1)/h_g2;

//amount of water added =amt
amt=W2-W1;
disp("amt=")
disp(amt)
disp("kg/kg of dry air")

p_v2=amt*p_t/(0.622+amt);

RH=p_v2/p_vs;
disp("Final relative humidity")
disp(RH)
```

Scilab code Exa 10.13 13

```
clc

disp("(i) Mass of spray water required")

//At 22 0c
p_vs=0.0264; //bar
phi_3=0.55;
p_t=1.0132; //bar

p_v3=phi_3*p_vs;
W3=0.622*p_v3/(p_t-p_v3);

//At 3 0C
p_vs1=0.0076; //bar
p_v1=p_vs1;

W1=0.622*p_v1/(p_t-p_v1);

R=287;
T_3=295; //K

v=R*T_3/(p_t-p_v3)/10^5;

m=(W3-W1)/v;
disp(" Mass of spray water required=")
disp(m)
disp("kg moisture/m^3")


disp("(ii) Temperature to which the air must be
    heated")
t_dp=12.5; //0C
```

```
cp=1.005;
t_db3=22; //0C
h_g3=2524; //kJ/kg
h_vapour3=h_g3 + 1.88*(t_db3 - t_dp);
W2=0.0047;
h_g2=2524; //kJ/kg
h4=41.87;

t_db2=(cp*t_db3 + W3*h_vapour3 -W2*h_g2 + 1.88*W2*
    t_dp - (W3-W2)*h4)/(cp-W2*1.88);
disp("t_db2=")
disp(t_db2)
disp("0C")
```

Scilab code Exa 10.14 14

```
clc

disp("(i) Make-up water required")
p_vs=0.0206; //bar
phi=0.6;
p_t=1.013; //bar

p_v1=phi*p_vs;
p_a1=p_t-p_v1;
V=9; //m^3
R=287;
T=291; //K

m_a=p_a1*10^5*V/R/T;

m_v1=0.0828; //kg/s

//At exit at 26 0C
p_vs=0.0336; //bar
```

```
phi=1;
p_v=p_vs;
W2=0.622*p_v/(p_t-p_v);
m_v2=W2*m_a;

m=m_v2-m_v1;
disp("Make-up water required=")
disp(m)
disp("kg/s")


disp("(ii) Final temperature of the water")
m_w1=5.5; //kg/s
m_w2=m_w1-m;

Wi=4.75; //kJ/s

h_w1=184.3; //kJ/kg
h_a1=18.09; //kJ/kg
h_v1=2534.74; //kJ/kg

h_v2=2549; //kJ/kg
h_a2=26.13; //kJ/kg

h_w2=(Wi + m_w1*h_w1 + m_a*h_a1 + m_v1*h_v1 - m_a*
   h_a2 - m_v2*h_v2)/m_w2;

//By interpolation, h_w2 corresponds to t
t=26.7; //0C
disp("final temperature of water=")
disp(t)
disp("0C")
```

Scilab code Exa 10.15 15

```
clc

m_water=60000; //kg/s
c=4.186;
t1=30; //0C
t2=35; //0C
Q=m_water*c*(t2-t1);

h1=76.5; //kJ/kg
W1=0.016; //kg/kg of air
h2=92.5; //kJ/kg
W2=0.0246; //kg/kg of air

m_air=Q/(h2-h1);

A=m_air/10; //Quantity of air handled per fan
disp("Quantity of air handled per fan=")
disp(A)
disp("kg/h")


B=m_air*(W2-W1);
disp("Quantity of make up water=")
disp(B)
disp("kg/h")
```

Scilab code Exa 10.17 17

```
clc
h1=35.4; //kJ/kg
h2=45.2; //kJ/kg
v_s1=0.8267; //m^3/kg
m_a=241.9;

disp("(i) R.H. of heated air =")
```

```
RH=41; // From chart
disp(RH)
disp("%")

disp("(ii) WBT of heated air =")
WBT=16.1; //0C
disp(WBT)
disp(" C ")

disp("(iii) Heat added to air per minute =")
Q=m_a*(h2-h1);
disp(Q)
disp("kJ")
```

Scilab code Exa 10.18 18

```
clc
h1=29.3; //kJ/kg
h2=42.3; //kJ/kg
h3=h2;
t_db2=24.5; //0C
t_db1=12; //0C
v_s1=0.817; //m^3/kg
amt=0.30; //Amount of air circulation m^3/min/person
capacity=60; //Seating capacity of office
BF=0.4; //By-pass factor
W3=8.6;
W1=6.8;

m_a=amt*capacity/v_s1;

disp("(i) Heating capacity of the heating coil =")
Q=m_a*(h2-h1)/60;
disp(Q)
disp("kW")
```

```
t_db4=(t_db2-BF*t_db1)/(1-BF);
disp("Coil surface temperature =")
disp(t_db4)
disp(" C ")

disp("(ii) The capacity of the humidifier =")
c=m_a*(W3-W1)/1000*60;
disp(c)
disp("kg/h")
```

Scilab code Exa 10.19 19

```
clc
h1=82.5; //kJ/kg
h2=47.5; //kJ/kg
h3=55.7; //kJ/kg
h5=36.6; //kJ/kg
W1=19.6; //gm/kg
W3=11.8; //gm/kg
t_db2=17.6; //0C
t_db3=25; //0C
v_s1=0.892; //m^3/kg
amt=250; //m^3/min

m_a=amt/v_s1;
disp("(i) The capacity of the cooling coil =")
capacity=m_a*(h1-h2)*60/14000;
disp(capacity)
disp("TR")

BF=(h2-h5)/(h1-h5);
disp("by-pass factor of the cooling coil =")
disp(BF)

```

```
disp("(ii) The heating capacity of the heating coil
   =")
Q=m_a*(h3-h2)/60;
disp(Q)
disp("kW")

BF=0.3;
t_db6=(t_db3-BF*t_db2)/(1-BF);
disp("surface temperature of heating coil =")
disp(t_db6)
disp(" C ")

disp("(iii) The mass of water vapour removed per
   hour =")
m=m_a*(W1-W3)*60/1000;
disp(m)
disp("kg/h")
```

Chapter 11

Chemical Thermodynamics

Scilab code Exa 11.1 1

```
clc

%C=0.88; //Fraction of carbon in coal
%H=0.042; //Fraction of Hydrogen in coal
w_f=0.848; //gm
w_fw=0.027; //gm
w=1950; //gm
w_e=380; //gm
dt=3.06; //0C; Observed temperature rise
tc=0.017; //0C
dt1=dt+tc; //Corrected temperature rise
Cal=6700; //J/gm; Calorific value of fuse wire

Q_received=(w+w_e)*4.18*dt1; //Heat received by
   water

Q_rejected=w_fw*Cal; //Heat given out by fuse wire

Q_produced=Q_received - Q_rejected;

HCV=Q_produced/w_f;
```

```
disp("Higher calorific value=")
disp(HCV)
disp("kJ/kg")

LCV=HCV - 2465*9*%H;
disp("Lower Calorific value=")
disp(LCV)
disp("kJ/kg")
```

Scilab code Exa 11.2 2

```
clc
p1=75.882; //cm of Hg
T1=286; //K
V1=0.08; //m^3
p2=76; //cm of Hg
T2=288; //K

V2=p1*V1*T2/p2/T1;

m=28; //kg
c=4.18;
t2=23.5; //0C
t1=10; //0C

Q_received=m*c*(t2-t1);

HCV=Q_received/V2;
disp("Higher calorific value =")
disp(HCV)
disp("kJ/m^3")

amt=0.06/0.08; //Amount of vapour formed per m^3 of
    gas burnt
LCV=HCV-2465*amt;
```

```
disp("Lower calorific value =")
disp(LCV)
disp("kJ/kg")
```

Scilab code Exa 11.3 3

```
clc
C=0.85; //Weight of Carbon present
H2=0.06; //Weight of Hydrogen present
O2=0.06; //Weight of Oxygen present

w_required=C*8/3 + H2*8; //Weight of O2 required
w_needed=w_required-O2; //Weight of O2 to be
    supplied

w_air=w_needed*100/23;
disp("Weight of air needed=")
disp(w_air)
disp("kg")
```

Scilab code Exa 11.4 4

```
clc
C=0.848; //kg
H2=0.152; //kg
O2_used=C*8/3 + H2*8;


disp("(i) Minimum weight of air needed for
    combustion")
w_min=O2_used*100/23;
disp("Minimum weight of air needed for combustion=")
disp(w_min)
```

```
disp("kg")

w_excess=w_min*0.15; //Excess air supplied

w_O2=w_excess*23/100; //Weight of O2 in excess air

w_total=w_min + w_excess; //Total air supplied for
    combustion
w_N2=w_total*77/100; //Weight of N2 in flue gases


disp("(ii) the volumetric composition of the
    products of combustion")

//For CO2
x1=3.109;
y1=44;
z1=x1/y1;

//For O2
x2=w_O2;
y2=32;
z2=x2/y2;

//For N2
x3=w_N2;
y3=28;
z3=x3/y3;

z=z1+z2+z3;

//For CO2
%V1=z1/z*100;
disp("%volume of CO2 =")
disp(%V1)
disp("%")

//For O2
```

```
%V2=z2/z*100;
disp("%volume of O2 =")
disp(%V2)
disp("%")

//For CO2
%V3=z3/z*100;
disp("%volume of N2 =")
disp(%V3)
disp("%")
```

Scilab code Exa 11.5 5

```
clc
C=0.78;
H2=0.06;
O2=0.03;

w_O2=C*8/3 + H2*8;
w_min=(w_O2-O2)*100/23; //Minimum wt. of air needed
    for combustion

disp("(i) Weight of dry flue gases per kg of fuel")

//For CO2
x1=0.104;
y1=44;
z1=x1*y1;

//For CO
x2=0.002;
y2=28;
z2=x2*y2;

//For N2
```

```
x3=0.816;
y3=28;
z3=x3*y3;

//For O2
x4=0.078;
y4=32;
z4=x4*y4;

z=z1+z2+z3+z4;

W_CO2=z1/z; //Weight per kg of flue gas
W_CO=z2/z; //Weight per kg of flue gas
W_N2=z3/z; //Weight per kg of flue gas
W_O2=z4/z; //Weight per kg of flue gas

amt=3/11*W_CO2 + 3/7*W_CO;

W=C/amt; //Weight of dry flue gas per kg of fuel
disp("Weight of dry flue gas per kg of fuel = ")
disp(W)
disp("kg")

disp("(ii) Weight of excess air per kg of fuel")
m_O2=W_O2-4/7*W_CO; //Weight of excess oxygen per kg
    of flue gas
m_excess=W*m_O2; //Weight of excess O2 per kg of
   fuel

w_excess=m_excess*100/23; //Weight of excess air per
    kg of fuel
disp("Weight of excess air per kg of fuel=")
disp(w_excess)
disp("kg")
```

Scilab code Exa 11.6 6

```
clc
v_CO=0.05;
v_CO2=0.10;
v_H2=0.50;
v_CH4=0.25;
v_N2=0.10;

V_fuel=1;

V_O2=v_CO/2+v_H2/2+2*v_CH4; //Volume of O2 needed

V_air=V_O2*100/21; //Volume of air required

V_N2=V_air*79/100; //Volume of nitrogen in the air

V=v_CO + v_CO2 + v_CH4 + v_N2 + V_N2; //Dry
    combustion products

O2=6;
V_excess=O2*V/(21-O2);

V_total=V_air+V_excess;

ratio=V_total/V_fuel;
disp("Air fuel ratio=")
disp(ratio)
```

Scilab code Exa 11.7 7

```
clc

C=0.85;
H2=0.15;
```

```

//For CO2
x1=0.115;
y1=44;
z1=x1*y1;

//For CO
x2=0.012;
y2=28;
z2=x2*y2;

//For O2
x3=0.009;
y3=32;
z3=x3*y3;

//For N2
x4=0.86;
y4=28;
z4=x4*y4;

z=z1+z2+z3+z4;

W_CO2=z1/z; //Weight per kg of flue gas
W_CO=z2/z; //Weight per kg of flue gas
W_O2=z3/z; //Weight per kg of flue gas
W_N2=4/z; //Weight per kg of flue gas

W_C=3/11*W_CO2 + 3/7*W_CO; //Weight of carbon per kg
    of flue gas

W=C/W_C; //Weight of dry flue gas per kg of fuel

Vapour=1.35; //kg; Vapour of combustion

W_total=W+Vapour; //Total weight of gas

W_air=W_total-1; //Air supplied
```

```
ratio=W_air/1;
disp("Ratio of air to petrol =")
disp(ratio)

S_air=[C*8/3 + H2*8]*100/23; //Stoichiometric air

W_excess=W_air-S_air; //Excess air

%Excess=W_excess/S_air*100; //Percentage excess air
disp("Percentage excess air")
disp(%Excess)
disp("%")
```

Scilab code Exa 11.8 8

```
clc
C=0.86;
H2=0.08;
S=0.03;
O2=0.02;

W_O2=C*8/3 + H2*8 + S*1;

A=W_O2-O2; //Weight of oxygen to be supplied per kg
    of fuel

W_min=A*100/23;
r_correct=1/W_min/1; //    correct     fuel-air ratio
r_actual=1/12;


disp("(i) Mixture strength")
s=r_actual/r_correct*100; //Mixture strength

```

```
richness=s-100;
disp("richness=")
disp(richness)
disp("%")
disp("This show that mixture is 6.5% rich.")

D=1/r_correct-1/r_actual;

CO=0.313; //kg
CO2=2.662; //kg
N2=9.24; //kg
SO2=0.06; //kg

disp("(ii) The percentage composition of dry flue
    gases")

//For CO
x1=0.313; //kg
y1=28;
z1=x1/y1;

//For CO2
x2=2.662; //kg
y2=44;
z2=x2/y2;

//For N2
x3=9.24; //kg
y3=28;
z3=x3/y3;

//For SO2
x4=0.06; //kg
y4=64;
z4=x4/y4;

z=z1+z2+z3+z4;

```

```
//Let percentage volume be denoted by V

V_CO=z1/z*100;
disp("Percentage volume of CO=")
disp(V_CO)
disp("%")

V_CO2=z2/z*100;
disp("Percentage volume of CO2=")
disp(V_CO2)
disp("%")

V_N2=z3/z*100;
disp("Percentage volume of N2=")
disp(V_N2)
disp("%")


V_SO2=z4/z*100;
disp("Percentage volume of SO2=")
disp(V_SO2)
disp("%")
```

Scilab code Exa 11.9 9

```
clc

A=992/284*100/23; //Air required for complete
    combustion

B=13; //kg/kg of fuel; Air actually supplied

D=A-B; //Deficiency of air

W_CO2=0.466*11/3;
```

```
W_CO=0.379*7/3;
W_H2O=22/142*9;
W_N2=13*0.77;

//For CO2
x1=W_CO2
y1=44;
z1=x1/y1;

//For CO
x2=W_CO;
y2=28;
z2=x2/y2;

//For H2O
x3=W_H2O;
y3=18;
z3=x3/y3;

//For N2
x4=W_N2;
y4=28;
z4=x4/y4;

z=z1+z2+z3+z4;

%CO2=z1/z*100;
disp("Percentage of CO2=")
disp(%CO2)
disp("%")

%CO=z2/z*100;
disp("Percentage of CO=")
disp(%CO)
disp("%")

%H2O=z3/z*100;
disp("Percentage of H2O=")
```

```
disp(%H2O)
disp("%")

%N2=z4/z*100;
disp("Percentage of N2=")
disp(%N2)
disp("%")
```

Scilab code Exa 11.11 11

```
clc

C=80;

//Analysis of gas entering the economiser
CO2_1=8.3;
CO_1=0;
O2_1=11.4;
N2_1=80.3;

//Analysis of gas leaving the economiser
CO2_2=7.9;
CO_2=0;
O2_2=11.5;
N2_2=80.6;

A1=N2_1*C/33/(CO2_1 + CO_1); //Air supplied on the
    basis of conditions at entry to the economiser

A2=N2_2*C/33/(CO2_2 + CO_2); //Air applied on the
    basis of conditions at exit

leakage=A2-A1; //Air leakage
disp("Air leakege =")
disp(leakage)
```

```
disp("kg of air per kg of fuel")

W_fuel=0.85; //kg; Weight of fuel passing up the
    chimney

c=1.05;
T2=410;
T1=0;

W=A1+W_fuel; //Total weight of products
Q1=W*c*(T2-T1); //Heat in flue gases per kg of coal
Q2=leakage*1.005*(20-0); //Heat in leakage air

t=(Q1+Q2)/(1.005*leakage + W*1.05);

dT=T2-t;
disp("Fall in temperature as a result of the air
    leakage into the economiser")
disp(dT)
disp(" C ")
```

Scilab code Exa 11.12 12

```
clc

w_O2=3*32/46*100/23; //For complete combustion of 1
    kg of C2H6O, oxygen required

ratio=w_O2;
disp("A:F ratio=")
disp(ratio)

w1=88; //kg
w2=54; //kg

```

```
w=w1+w2; //kg
W=46; //kg

w_CO2=w1/W*100;
disp("CO2 produced by fuel")
disp(w_CO2)
disp("%")

w_H2O=w2/W*100;
disp("H2O produced by fuel")
disp(w_H2O)
disp("%")
```

Scilab code Exa 11.13 13

```
clc
// C2H2+xO2------>aCO2+bH2O
// 2C=aC; a=2
// 2H=2bH; b=1
// x=2.5

// C2H2+2.5O2+2.5*(79/21)N2 --> 2CO2+H2O+2.5*(79/21)N2

// 26 kg C2H2 + 80 kg O2 + 263.3 N2      88 kg CO2 + 18 kg H2O + 263.3 kg N2
// 1 kg C2H2 + 3.076 kg O2 + 10.12 kg N2        3.38 kg CO2 + 0.69 kg H2O + 10.12 kg N2

Amount= 3.076 + 10.12;
disp("Hence amount of theoretical air required for combustion of 1 kg acetylene =")
disp(Amount)
disp("kg")
```

Scilab code Exa 11.14 14

```
clc
// C2H2+2.5O2+2.5*(79/21)N2 --> 2CO2+H2O+2.5*(79/21)
   N2

//26 kg C2H2 + 160 kg O2 + 526.6 kg N2      88 kg CO2
    + 18 kg H2O + 526.6 kg N2 + 80 kg O2

//1 kg C2H2 + 6.15 kg O2 + 20.25 kg N2      3.38 kg
   CO2 + 0.69 kg H2O + 20.25 kg N2 + 3.07 kg O2

m_CO2=3.38; //kg
m_H2O=0.69; //kg
m_O2=3.07; //kg
m_N2=20.25; //kg
m_total=m_CO2+m_H2O+m_O2+m_N2;

CO2=m_CO2/m_total*100;
H2O=m_H2O/m_total*100;
O2=m_O2/m_total*100;
N2=m_N2/m_total*100;

disp("Hence the gravimetric analysis of the complete
    combustion is :")
disp("CO2=")
disp(CO2)
disp("%")

disp("H2O=")
disp(H2O)
disp("%")

disp("O2=")
```

```
disp(O2)
disp("%")

disp("N2=")
disp(N2)
disp("%")
```

Scilab code Exa 11.15 15

```
clc
AF_mole=(12.5+12.5*(79/21))/1;
AF_mass=AF_mole*28.97/(8*12+1*18);

disp("Air fuel ratio =")
disp(AF_mass)
disp("kg air/kg fuel")
```

Scilab code Exa 11.16 16

```
clc
// C8H18+12.5*O2+12.5*(79/21)N2 --> 8CO2+9H2O +12.5*(79/21)*N2

// C8H18 + (2) (12.5) O2 + (2) (12.5)*(79/21)N2-->8 CO2 + 9H2O + (1) (12.5) O2 + (2) (12.5)*(79/21)*N2

m_fuel=1*(8*12+1*18);
m_air=2*12.5*(1+79/21)*28.97;

disp("(i) Air-fuel ratio =")
AF=m_air/m_fuel;
disp(AF)
```

```
disp("(ii) Dew point of the products")
n=8+9+12.5+2*12.5*(79/21);

x=9/n;
p=100*x;

//Hence
t_dp=39.7; //0C

disp("t_dp=")
disp(t_dp)
disp(" C ")
```

Scilab code Exa 11.17 17

```
clc
// C2H6 + 3.5O2      2CO2 + 3H2O
// C2H6 + (0.9)*(3.5) O2 + (0.9)*(3.5)*(79/21) N2 a
    CO2 + b CO + 3H2O + (0.9)*(3.5)*(79/21)*N2

// a+b=2
// 2*a+b+3=0.9*3.5*2
// a=1.3
// b=0.7
// C2H6 + (0.9)*(3.5) O2 + (0.9)*(3.5)*(79/21)* N2
    1.3CO2 + 0.7CO + 3H2O + (0.9)*(3.5)*(79/21)N2

n=1.3+0.7+0.9*3.5*(79/21);

CO2=1.3/n*100;
CO=0.7/n*100;
N2=11.85/n*100;

disp("Volumetric analysis of dry products of
```

```
   combustion is as follows ")

disp("CO2 =")
disp(CO2)
disp("%")

disp("CO =")
disp(CO)
disp("%")

disp("N2 =")
disp(N2)
disp("%")
```

Scilab code Exa 11.18 18

```
clc
disp("(i) Combustion equation")

// x CH4 + y O2 + z N2          10.0 CO2 + 0.53 CO +
   2.37 O2 + a H2O + 87.1 N2

z=87.1;
y=z*(79/21);
x=10+0.53;
a=2*x;

//10.53 CH4 + 23.16 O2 + 87.1 N2       10.0 CO2 + 0.53
    CO + 2.37 O2 + 21.06 H2O + 87.1 N2

disp("CH4 + 2.2 O2 + 8.27 N2       0.95 CO2 + 0.05 CO
   + 2H2O + 0.225 O2 + 8.27 N2")

disp("(ii) Air-fuel ratio ")

```

```
AF_mole=2.2+8.27;
disp("air-fuel ratio on a mole basis =")
disp(AF_mole)
disp("moles air/mole fuel")

AF_mass=AF_mole*28.97/(12+1*4);
disp("air-fuel ratio on a mass basis =")
disp(AF_mass)
disp("air/kg fuel")

// CH4 + 2O2 + 2*(79/21)N2      CO2 + 2H2O + (2)*(79/21)N2
AF_theor=(2+2*(79/21))*28.97/(12+1*4);
disp("theoretical air-fuel ratio =")
disp(AF_theor)
disp("kg air/kg fuel")

disp("(iii) Percent theoretical air =")
%theo=AF_mass/AF_theor*100;
disp(%theo)
disp("%")
```

Scilab code Exa 11.19 19

```
clc
disp("(i) The stoichiometric A/F ratio")

// 1 kg of coal contains 0.82 kg C and 0.10 kg H2.
// Let the oxygen required for complete combustion = x moles
// the nitrogen supplied with the oxygen = x*79/21=3.76*x
// 0.82/12*C+0.10/2*H2 + x CO2 + 3.76x N2      a CO2 + b H2O + 3.76 x N2
a=0.82/12; // Carbon balance
```

```
b=0.10/2; //Hydrogen balance
x=(2*a+b)/2; // Oxygen balance

Stoichiometric_AF_ratio=2.976/0.233;
disp("Stoichiometric AF ratio =")
disp(Stoichiometric_AF_ratio)

n=a+b+3.76*x;

CO2=0.068/n*100;
H2=0.05/n*100;
N2=3.76*0.093/n*100;

disp("the analysis of the products is")
disp("CO2 =")
disp(CO2)
disp("%")

disp("H2 =")
disp(H2)
disp("%")

disp("N2 =")
disp(N2)
disp("%")
```

Scilab code Exa 11.20 20

```
clc

// C + O2       CO2
// 2H2 + O2       2H2O
// S + O2       SO2

O2_req=2.636; //kg
```

```

AF=O2_req/0.233;
disp("The stoichiometric A/F ratio =")
disp(AF)

disp("(i) Actual A/F ratio =")
AF_act=AF+0.3*AF;
disp(AF_act)

disp("(ii) Wet and dry analyses of products of
   combustion by volume")

// As per actual A/F ratio, N2 supplied = 0.767 *
   14.7 = 11.27 kg
// Also O2 supplied = 0.233 * 14.7 = 3.42 kg

// In the products then, we have
// N2 = 11.27 + 0.01 = 11.28 kg
// excess O2 = 3.42    2.636 = 0.78 kg

n_wet=0.5208;
n_dry=0.5008;

disp("Analysis of wet products is as follows :")

disp("CO2 =")
CO2=0.0734/n_wet*100;
disp(CO2)
disp("%")

disp("H2O =")
H2O=0.0200/n_wet*100;
disp(H2O)
disp("%")

disp("SO2 =")
SO2=0.0002/n_wet*100;
disp(SO2)
```

```
disp("%")

disp("O2 =")
O2=0.0244/n_wet*100;
disp(O2)
disp("%")

disp("N2 =")
N2=0.4028/n_wet*100;
disp(N2)
disp("%")

disp("Analysis of dry products is as follows :")

disp("CO2 =")
CO2=0.0734/n_dry*100;
disp(CO2)
disp("%")

disp("SO2 =")
SO2=0.0002/n_dry*100;
disp(SO2)
disp("%")

disp("O2 =")
O2=0.0244/n_dry*100;
disp(O2)
disp("%")

disp("N2 =")
N2=0.4028/n_dry*100;
disp(N2)
disp("%")
```

Scilab code Exa 11.21 21

```
clc

// 2H2 + O2    2H2O
// 2CO + O2    2CO2
// CH4 + 2O2    CO2 + 2H2O
// C4H8 + 6O2    4CO2 + 4H2O

n_O2=0.853; //total moles of O2

disp("(i) Stoichiometric A/F ratio =")
AF=n_O2/0.21;
disp(AF)

disp("(ii) Wet and dry analyses of the products of combustion if the actual mixture is 30% weak :")
AF_act=AF+0.3*AF;
n_N2=0.79*AF_act;
O2_excess=0.21*AF_act-n_O2;

n_wet=5.899;
n_dry=4.915;

disp("Analysis by volume of wet products is as follows :")

disp("CO2 =")
CO2=0.490/n_wet*100;
disp(CO2)
disp("%")

disp("H2O =")
H2O=0.984/n_wet*100;
disp(H2O)
disp("%")

disp("O2 =")
O2=O2_excess/n_wet*100;
disp(O2)
```

```
disp("%")

disp("N2 =")
N2=n_N2/n_wet*100;
disp(N2)
disp("%")

disp(" Analysis by volume of dry products is as
   follows :")

disp("CO2 =")
CO2=0.490/n_dry*100;
disp(CO2)
disp("%")

disp("O2 =")
O2=O2_excess/n_dry*100;
disp(O2)
disp("%")

disp("N2 =")
N2=n_N2/n_dry*100;
disp(N2)
disp("%")
```

Scilab code Exa 11.22 22

```
clc

// C2H6O + 3O2 + 3*79/21 N2      2CO2 + 3H2O +
   3*79/21 N2

O2_req=3*32/46;

AF=O2_req/0.233;
```

```
disp("Stoichiometric A/F ratio =")
disp(AF)

mix=0.8; //mixture strength

AF_actual=AF/mix;
disp("Actual A/F ratio =")
disp(AF_actual)

// C2H6O + 1.25*(3 O2 + 3*79/21 N2)      2CO2 + 3H2O
   + 0.25*3O2 + 1.25*3*79/21 N2

n=2+3+0.75+14.1;

disp("Hence wet analysis is")

disp("CO2 =")
CO2=2/n*100;
disp(CO2)
disp("%")

disp("H2O =")
H2O=3/n*100;
disp(H2O)
disp("%")

disp("O2 =")
O2=0.75/n*100;
disp(O2)
disp("%")

disp("N2 =")
N2=14.1/n*100;
disp(N2)
disp("%")

nd=2+0.75+14.1; //total dry moles

```

```
disp("Hence dry analysis is : ")

disp("CO2 =")
CO2=2/nd*100;
disp(CO2)
disp("%")

disp("O2 =")
O2=0.75/nd*100;
disp(O2)
disp("%")

disp("N2 =")
N2=14.1/nd*100;
disp(N2)
disp("%")

mix=1.3;
AF_act=AF/mix;
disp("Actual A/F ratio =")
disp(AF_act)
```

Scilab code Exa 11.23 23

```
clc
// C2H6O + 3O2 + 3*79/21 N2      2CO2 + 3H2O +
   3*79/21 N2
R0=8.314*10^3; //kJ/kg K
m=46; //kg

disp("(i) Volume of reactants per kg of fuel ")

n=1+3+3*79/21;
T=323; //K
p=1.013*10^5; //Pa
```

```

V=n*R0*T/p;

disp("Vr=")
Vr=V/m;
disp(Vr)
disp("m^3")

disp("(ii) Volume of products per kg of fuel")

n=2+3+3*79/21;
T=403; //K
p=1*10^5; //Pa

V=n*R0*T/p;

Vp=V/m;
disp("Vp=")
disp(Vp)
disp("m^3")
```

Scilab code Exa 11.24 24

```
clc

// 0.506H2 + 0.1CO + 0.26CH4 + 0.04C4H8 + 0.004O2 +
   0.03CO2 + 0.06N2 + 0.21   7O2 + 0.79   7N2
   a CO2 + b H2O + c O2 + d N2

a=0.1*0.26+4*0.04+0.03;
b=(2*0.506+4*0.26+8*0.04)/2;
c=(0.1+2*0.004+2*0.03+0.21*7*2-2*a-b)/2;
d=(2*0.06+2*0.79*7)/2;

n=0.55+0.411+5.59;
```

```

disp("analysis by volume is")
disp("CO2=")
CO2=0.55/n*100;
disp(CO2)
disp("%")

disp("O2=")
O2=0.411/n*100;
disp(O2)
disp("%")

disp("N2 =")
N2=5.59/n*100;
disp(N2)
disp("%")
```

Scilab code Exa 11.25 25

```
clc
// C_aH_bO_cN_dS_e

a=60/12;
b=20;
c=5/16;
d=10/14;
e=5/32;

// C_5 H_20 O_0.3125 N_0.7143 S_0.1562 + x O2 + x
    *(79/21)N2      p CO2 + q H2O + r SO2 + s N2
p=5;
q=20/2;
r=0.1562;
x=(2*p+q+2*r-0.3125)/2;
s=(0.7143+2*x*79/21)/2;
```

```
air=(9.92*32+x*79/21*28)/100;
disp("Stoichiometric air required =")
disp(air)
disp("kg/kg of fuel")
```

Scilab code Exa 11.26 26

```
clc

disp("(i) Stoichiometric air fuel ratio ")
// C_aH_bO_cN_d

a=84/12;
b=10;
c=3.5/16;
d=1.5/14;

// C7 H10 O0.218 N0.107 + x O2 + x*(79/21)N2        p
   CO2 + q H2O + r N2

p=7;
q=10/2;
x=(2*p+q-c)/2;
r=(d+2*x*(79/21))/2;

AF=(x*32+x*79/21*28)/100;
disp("Stoichiometric A/F ratio =")
disp(AF)

disp("(ii) Percentage composition of dry flue gases
   by volume with 20 per cent excess air :")

// C7H10O0.218N0.107 + (1.2)(9.39) O2 + (1.2)(9.39)
   *(79/21)N2       7CO2 + 5H2O + (0.2)(9.39) O2 +
```

```
   (1.2)(35.4) N2

n=7+0.2*9.39+1.2*35.4;

disp("Percentage composition of dry flue gases by
   volume is as follows :")
disp("CO2 =")
CO2=7/n*100;
disp(CO2)
disp("%")

disp("O2 =")
O2=1.878/n*100;
disp(O2)
disp("%")

disp("N2 =")
N2=42.48/n*100;
disp(N2)
disp("%")
```

Scilab code Exa 11.27 27

```
clc
// a C + b H + c O2 + (79/21)*c N2 = 8CO2 + 0.5CO +
   6.3O2 + x H2O + 85.2N2

a=8+0.5;
c=85.2/(79/21);
x=2*(c-8-0.5/2-6.3);
b=2*x;

disp("(i) Air-fuel ratio =")
AF=(c*32+(79/21)*c*28)/(a*12+b*1);
disp(AF)
```

```
disp("kg of air/kg of fuel")

disp("(ii) Per cent theoretical air required for combustion ")
mf_C=12*a/(12*a+b);
mf_H2=b*1/(12*a+b);
air=mf_C*8/3*100/23.3 + mf_H2*8*100/23.3; //air required for complete combustion
percent=AF/air*100;
disp("Per cent theoretical air required for combustion =")
disp(percent)
disp("%")
```

Scilab code Exa 11.28 28

```
clc
disp("(i) By a carbon balance")

// a C8H18 + 78.1N2 + 78.1*(21/79)O2      8.9CO2 + 8.2CO + 4.3H2 + 0.5CH4 + 78.1N2 + x H2O
a=(8.9+8.2+0.5)/8;

AF1=(78.1*28+78.1*21/79*32)/a/(8*12+1*18);
disp("Air fuel ratio =")
disp(AF1)


disp("(ii) By a hydrogen-oxygen balance ")

// a C8H18 + b O2 + b*(79/21)N2      8.9CO2 + 8.2CO + 4.3H2 + 0.5CH4 + b*(79/21)N2 + x*H2O

a=(8.9+8.2+0.5)/8;
x=(18*a-4.3*2-4*0.5)/2;
```

```
b=(8.9*2+8.2+x)/2;

AF2=(b*32+b*(79/21)*28)/a/(8*12+1*18);
disp("Air fuel ratio =")
disp(AF2)
```

Scilab code Exa 11.29 29

```
clc
// X(0.88/12 C + 0.12/2 H2) + Y O2 + 79/21*Y N2
   0.12CO2 + a O2 + (0.88       a) N2 + b H2O

X=0.12/(0.88/12);
b=0.06*X;
a=0.0513;
Y=0.2203;
Air_supplied=0.2203*32/0.233;

AF=Air_supplied/X;
disp("A/F ratio =")
disp(AF)
```

Scilab code Exa 11.30 30

```
clc
// X*(x/12 C + y/2 H2) + Y O2 + 79/21*Y/N2       0.15
   CO2 + 0.03CO + 0.03CH4 + 0.01H2 + 0.02O2 + a H2O
   + 0.76N2

Y=0.76/(79/21);
a=2*(Y-0.15-0.03/2-0.02);
Xx=12*(0.15+0.03+0.03);
Xy=2*(2*0.03+0.01+a);
```

```
ratio=Xx/Xy;

disp("Ratio of C to H2 in fuel =")
disp(ratio)
```

Scilab code Exa 11.31 31

```
clc
h_fg0=2441.8; //kJ/kg
m=3*18;
dH0_liq=-3301000; //kJ/mole

dH0_vap=dH0_liq+m*h_fg0;
disp("dH0_vapour =")
disp(dH0_vap)
disp("kJ/mole")
```

Scilab code Exa 11.32 32

```
clc

// C6H6 + 7.5O2        6CO2 + 3H2O (vapour)
dH0=-3169100; //kJ
n_R=1+7.5;
n_P=6+3;
R0=8.314;
T0=298; //K

dU0=(dH0-(n_P-n_R)*R0*T0)/(6*12+1*6);
disp("dU0 =")
disp(dU0)
disp("kJ/kg")
```

Scilab code Exa 11.33 33

```
clc
// CO+1/2 O2       CO2
H_R0=1*9705+1/2*9696; //kJ
H_RT=1*94080+1/2*99790; //kJ
H_P0=1*10760; //kJ
H_PT=1*149100; //kJ

dH_T=-(285200+(143975-14553)-(149100-10760));
disp("dH_T =")
disp(dH_T)
disp("kJ/mole")
```

Scilab code Exa 11.34 34

```
clc
disp("(i) Higher heating value at constant pressure"
  )
m=4*18;
h_fg=2443; //kJ/kg
LHVp=2044009; //kJ/kg
R0=8.3143; //kJ/kg K
T=298; //K

HHVp=LHVp+m*h_fg;
disp("HHVp =")
disp(HHVp)
disp("kJ/kg")

disp("(ii) Higher heating value at constant volume")
dn=3-(1+5);
```

```
HHVv=HHVp+dn*R0*T;
disp("HHVv =")
disp(HHVv)
disp("kJ/kg")
```

Scilab code Exa 11.35 35

```
clc
HHV=5494977; //kJ/kg
m=9*18;
u_fg=2305; //kJ/kg
LHVv=HHV-m*u_fg;
disp("LHVv =")
disp(LHVv)
disp("kJ/kg")
```

Scilab code Exa 11.36 36

```
clc
disp("(i) Air and benzene vapour ")

// C6H6(g) + 7.5O2(g) + 7.5*(79/21)N2(g) = 6CO2(g) +
    3H2O(g) + 7.5*(79/21)*N2(g)

LHVp=3169500; //kJ/mole

LHVv=LHVp/((12*6+6*1)+(7.5*32)+7.5*(79/21)*28)
disp("LHVv per kg of mixture =")
disp(LHVv)
disp("kJ/kg")

m=54; //kg/kg mole of fuel
```

```
h_fg=2442; //kJ/kg

HHVp=(LHVp+m*h_fg)/(78+240+790);
disp("HHVp per kg of mixture =")
disp(HHVp)
disp("kJ/kg")

disp("(ii) Air and octane vapour ")
LHVp=5116200; //kJ/mole of C8H18

// C8H18(g) + 12.5O2(g)         8CO2(g) + 9H2O(g) +
   12.5*(79/21)N2(g)

LHVp1=LHVp/((12*8+18*1)+12.5*32+12.5*79/21*28);
disp("LHVp per kg of mixture =")
disp(LHVp1)
disp("kJ/kg")

m=9*18;
HHVp=LHVp+m*h_fg;
HHVp1=HHVp/(114+400+1317);
disp("HHVp per kg of mixture =")
disp(HHVp1)
disp("kJ/kg")
```

Scilab code Exa 11.37 37

```
clc
m_CO2=44/12*0.88; //kg
m_H2O=18/2*0.12; //kg
u_fg=2304; //kJ/kg
h_fg=2442; //kJ/kg
HHVv=45670; //kJ/kg
R0=8.3143; //kJ/kg K
T=298; //K
```

```
disp("(i) (LHV)v =")
LHVv=HHVv-m_H2O*u_fg;
disp(LHVv)
disp("kJ/kg")

disp("(ii) (HHV)p, (LHV)p")

//1 mole fuel+x/32 O2-->3.23/44 CO2 + 1.08/18 H2O

x=32*(m_CO2/44+m_H2O/18/2);

// 1 kg fuel + 3.31 kg O2 = 3.23CO2 + 1.08H2O

dn=(m_CO2/44-x/32);

HHVp=HHVv-dn*R0*T;
disp("HHVp =")
disp(HHVp)
disp("kJ/kg")

LHVp=HHVp-m_H2O*h_fg;
disp("LHVp =")
disp(LHVp)
disp("kJ/kg")
```

Chapter 12

Vapour Power Cycles

Scilab code Exa 12.1 1

```
clc
p1=60; //bar; Inlet to turbine
p2=0.1; //bar; Exit from turbine
p3=0.09; //bar; Exit from condenser
p4=70; //bar ; Exit from pump
p5=65; //bar; Exit from boiler

t1=380; //0C
t5=400; //0C

x2=0.9; //Quality at exit from turbine

C=200; //m/s; Velocity at the exit from turbine

disp("(i) Power output of the turbine")

//At 60 bar 380 0C, From steam tables

h1=3123.5; //kJ/kg; By interpolation
h_f2=191.8; //kJ/kg
h_fg2=2392.8; //kJ/kg
```

```
x2=0.9;

h2=h_f2+x2*h_fg2;
m_s=10000/3600; //Rate of stem flow in kg/s

P=m_s*(h1-h2);
disp("Power output of the turbine =")
disp(P)
disp("kW")


disp("(ii) Heat transfer per hour in the boiler and
    condenser")

h_f4=1267.4; //kJ/kg
h_a=3167.6; //kJ/kg

Q1=10000*(h_a - h_f4);
disp("Heat transfer per hour in the boiler =")
disp(Q1)
disp("kJ/h")

h_f3=183.3; //kJ/kg
Q2=10000*(h2-h_f3);
disp("Heat transfer per hour in the condenser =")
disp(Q2)
disp("kJ/h")


disp("(iii) Mass of cooling water circulated per
    hour in the condenser")
c_pw=4.18;
t2=30;
t1=20;

m_w=Q2/c_pw/(t2-t1);
disp("m_w=")
disp(m_w)
```

```
disp("kg/h")
disp("This is the exact answer.")

disp("(iv) Diameter of the pipe connecting turbine
   with condenser")

v_g2=14.67; //m^3/kg

d=sqrt(m_s*x2*v_g2*4/%pi/C)*1000;
disp("Diameter =")
disp(d)
disp("mm")
```

Scilab code Exa 12.2 2

```
clc
p1=15; //bar
x1=1;
p2=0.4; //bar

//At 15 bar
t_s1=198.3; //0C
h_g1=2789.9; //kJ/kg
s_g1=6.4406; //kJ/kg K

//At 0..4 bar
t_s2=198.3; //0C
h_f2=317.7; //kJ/kg
h_fg2=2319.2; //kJ/kg
s_f2=1.0261; //kJ/kg K
s_fg2=6.6448; //kJ/kg K
T1=471.3; //K
T2=348.9; //K

n_carnot=(T1-T2)/T1;
```

```
disp("Carnot efficiency=")
disp(n_carnot)


x2=(s_g1 - s_f2)/s_fg2;
h2=h_f2+x2*h_fg2;

n_rankine=(h_g1-h2)/(h_g1-h_f2);
disp("Rankine efficiency=")
disp(n_rankine)
```

Scilab code Exa 12.3 3

```
clc
p1=20; //bar
p2=0.08; //bar

//At 20 bar, 360 0C

h1=3159.3; //kJ/kg
s1=6.9917; //kJ/kg K

//At 0.08 bar
h_f2=173.88; //kJ/kg
s_f2=0.5926; //kJ/kg K

h_fg2=2403.1; //kJ/kg
s_g=8.2287; //kJ/kg K
v_f=0.001008; //m^3/kg
s_fg=7.6361; //kJ/kg K

x2=(s1-s_f2)/s_fg;

h2=h_f2+x2*h_fg2;

```

```
W_pump=v_f*(p1-p2)*100; //kJ/kg
W_turbine=h1-h2;

W_net=h1-h2;
disp("Net work done=")
disp(W_net)
disp("kJ/kg")

h_f4=W_pump+h_f2;
Q1=h1-h_f4;

n_cycle=W_net/Q1;
disp("Cycle efficiency=")
disp(n_cycle)
```

Scilab code Exa 12.4 4

```
clc

n_turbine=0.9;
n_pump=0.8;
p1=80; //bar
p2=0.1; //bar
v_f=0.0010103; //m^3

//At 80 bar, 600 0C
h1=3642; //kJ/kg
s1=7.0206; //kJ/kg K
s_f2=0.6488; //kJ/kg K
s_fg2=7.5006; //kJ/kg K
h_f2=191.9; //kJ/kg
h_fg2=2392.3; //kJ/kg

x2=(s1-s_f2)/s_fg2;
h2=h_f2+x2*h_fg2;
```

```

W_turbine=n_turbine*(h1-h2);
W_pump=v_f*(p1-p2)*10^2;

W_actual=W_pump/n_pump; //Actual pump work

W_net=W_turbine - W_actual;
disp("Specific work =")
disp(W_net)
disp("kJ/kg")

h_f4=h_f2+W_actual;
Q1=h1-h_f4;

n_thermal=W_net/Q1; //Thermal efficiency
disp("Thermal efficiency =")
disp(n_thermal)
```

Scilab code Exa 12.5 5

```
clc
p1=28; //bar
p2=0.06; //bar

//At 28 bar
h1=2802; //kJ/kg
s1=6.2104; //kJ/kg K

//At 0.06 bar
h_f2=151.5; //kJ/kg
h_f3=h_f2;
h_fg2=2415.9; //kJ/kg
s_f2=0.521; //kJ/kg K
s_fg2=7.809; //kJ/kg K
v_f=0.001; //m^3/kg
```

```

x2=(s1-s_f2)/s_fg2;

h2=h_f2 + x2*h_fg2;

W_turbine=h1-h2;
W_pump=v_f*(p1-p2)*100; //kJ/kg

h_f4=h_f2+W_pump;
Q1=h1-h_f4;
W_net=W_turbine - W_pump;

n_cycle=W_net/Q1;
disp("cyclic efficiency =")
disp(n_cycle)

ratio=W_net/W_turbine; //Work ratio
disp("Work ratio =")
disp(ratio)

S=3600/W_net; //Specific steam combustion
disp("Specific steam combustion=")
disp(S)
disp("kg/kWh")
```

Scilab code Exa 12.6 6

```
clc
p1=35; //bar
x=1;
p2=0.2; //bar
m=9.5; //kg/s

//At 35 bar
h1=2802; //kJ/kg
```

```
h_g1=h1;
s_g1=6.1228; //kJ/kg K

//At0.26 bar
h_f=251.5; //kJ/kg
h_fg=2358.4; //kJ/kg
v_f=0.001017; //m^3/kg
s_f=0.8321; //kJ/kg
s_fg=7.0773; //kJ/kg K

disp("(i) The pump work")
W_pump=v_f*(p1-p2)*100; //kJ/kg
P=m*W_pump; //power required
disp("Power required to drive the pump")
disp(P)
disp("kW")


disp("(ii) The turbine work")

x2=(s_g1-s_f)/s_fg;
h2=h_f+x2*h_fg;

W_turbine=m*(h1-h2);
disp("Turbine work=")
disp(W_turbine)
disp("kW")


disp("(iii) The Rankine efficiency")
n_rankine=(h1-h2)/(h1-h_f);
disp("rankine efficiency=")
disp(n_rankine)


disp("(iv) The condenser heat flow :")
Q=m*(h2-h_f);
disp("The condenser heat flow=")
```

```
disp(Q)
disp("kW")


disp("(v) The dryness at the end of expansion=")
disp(x2)
```

Scilab code Exa 12.7 7

```
clc
dh=840; //kJ/kg; Adiabatic enthalpy drop
h1=2940; ///kJ/kg;
p2=0.1; //bar
h_f2=191.8; //kJ/kg

n_rankine=(dh)/(h1-h_f2)*100;
disp("rankine efficiency=")
disp(n_rankine)

S=3600/dh; //Specific steam combustion
disp("Specific steam combustion=")
disp(S)
disp("kg/kWh")
```

Scilab code Exa 12.8 8

```
clc
IP=35; // Power developed by the engine in kW
S=284; //Steam combustion in kg/h
p2=0.14; //Condenser pressure in bar
p1=15; //bar

h1=2923.3; //kJ/kg
```

```
s1=6.709; //kJ/kg K

h_f=220; //kJ/kg
h_fg=2376.6; //kJ/kg
s_f=0.737; //kJ/kg K
s_fg=7.296; //kJ/kg K

x2=(s1-s_f)/s_fg;
disp("(i) Final condition of steam =")
disp(x2)

h2=h_f+x2*h_fg;

disp("(ii) Rankine efficiency=")
n_rankine=(h1-h2)/(h1-h_f);
disp(n_rankine)

disp("(iii) Relative efficiency")
n_thermal=IP/(S/3600)/(h1-h_f);

n_relative=n_thermal/n_rankine;
disp("relative efficiency=")
disp(n_relative)
```

Scilab code Exa 12.9 9

```
clc
P=5000; //kW
C=40000; //kJ/kg
n_rankine=0.5;
n_turbine=0.9;
n_heat_transfer=0.85;
n_combustion=0.98;

m_f=P/n_turbine/(C*n_heat_transfer*n_combustion*
```

```
    n_rankine);
disp("Fuel oil combustion=")
disp(m_f)
disp("kg/s")
```

Scilab code Exa 12.10 10

```
clc
p2=2; //bar
p3=1.1; //bar
IP=1;
m=12.8/3600; //kg/kWs
n_mech=0.8; //Mechanical efficiency
h1=3037.6; //kJ/kg
v1=0.169; //m^3/kg
s1=6.918; //kJ/kg K
t_s2=120.2; //0C
h_f2=504.7; //kJ/kg
h_fg2=2201.6; //kJ/kg
s_f2=1.5301; //kJ/kg K
s_fg2=5.5967; //kJ/kg K
v_f2=0.00106; //m^3/kg
v_g2=0.885; //m^3/kg
t_s3=102.3; //0C
h_f3=428.8; //kJ/kg
h_fg3=2250.8; //kJ/kg
s_f3=1.333; //kJ/kg K
s_fg3=5.9947; //kJ/kg K
v_f3=0.001; //m^3/kg
v_g3=1.549; //m^3/kg

x2=(s1-s_f2)/s_fg2;
h2=h_f2+x2*h_fg2;
v2=x2*v_g2+(1-x2)*v_f2;

```

```
disp("(i)Ideal work=")
W=(h1-h2) + (p2-p3)*v2*100; //kJ/kg
disp(W)
disp("kJ/kg")


disp("(ii) Rankine engine efficiency=")
n_rankine=W/(h1-h_f3);
disp(n_rankine)


disp("(iii) Indicated and brake work per kg")
W_indicated=IP/m;
disp("Indicated worK =")
disp(W_indicated)
disp("kJ/kg")

W_brake=n_mech*IP/m;
disp("Brake work =")
disp(W_brake)
disp("kJ/kg")

disp("(iv) Brake thermal efficiency=")
n_brake=W_brake/(h1-h_f3);
disp(n_brake)


disp("(v) Relative efficiency :")

n1=W_indicated/W; //on the basis of indicated work
disp("Relative efficiency on the basis of indicated
    work=")
disp(n1)

n2=W_brake/W; //on the basis of brake work
disp("Relative efficiency on the basis of brake work
    =")
disp(n2)
```

Scilab code Exa 12.11 11

```
clc
p2=0.75; //bar
p3=0.3; //bar
h1=3263.9; //kJ/kg
v1=0.307; //m^3/kg
s1=7.465; //kJ/kg K
T_s2=369.7; //K
h_g2=2670.9; //kJ/kg
s_g2=7.3954; //kJ/kg K
v_g2=1.869; //m^3/kg
h_f3=289.3; //kJ/kg
v_g3=5.229; //m^3/kg
cp=2.1;

disp("(i) Quality of steam at the end of expansion")
T_sup2=T_s2*(%e^((s1-s_g2)/cp));
t_sup2=T_sup2-273;
disp("t_sup2=")
disp(t_sup2)
disp(" C ")

h2=h_g2+cp*(T_sup2-366.5);

disp("(ii) Quality of steam at the end of constant
    volume operation, x3 :")
v2=v_g2/T_s2*T_sup2;
v3=v2;
x3=v3/v_g3;
disp("x3=")
disp(x3)


```

```
disp("(iii) Power developed")
P=(h1-h2) + (p2-p3)*v2*100;
disp("P=")
disp(P)
disp("kW")


disp("(iv) Specific steam consumption =")
ssc=3600/P;
disp(ssc)
disp("kg/kWh")


disp("(v) Modified Rankine cycle efficiency =")
n_mR=((h1-h2)+(p2-p3)*v2*100)/(h1-h_f3);
disp(n_mR)
```

Scilab code Exa 12.12 12

```
clc
h1=3100; //kJ/kg
h2=2100; //kJ/kg
h3=2500; //kJ/kg
h_f2=570.9; //kJ/kg
h_f5=125; //kJ/kg
h_f2=570.9; //kJ/kg
a=11200; //Quantity of bled steam in kg/h

m=(h_f2-h_f5)/(h2-h_f5);

S=a/m; //Steam supplied to the turbine per hour

W_net=(h1-h3) + (1-m)*(h3-h2);

P=W_net*S/3600; //Power developed by the turbine
```

```
disp("Power developed by the turbine=")
disp(P)
disp("kW")
```

Scilab code Exa 12.13 13

```
clc
//At 30bar, 400 0C

h1=3230.9; //kJ/kg
s1=6.921; //kJ/kg
s2=s1;
s3=s1;
//At 5 bar
s_f1=1.8604;
s_g1=6.8192; //kJ/kg K
h_f1=640.1; //kJ/kg

t2=172 //0C
h2=2796; //kJ/kg

//At 0.1 bar
s_f3=0.649; //kJ/kg K
s_fg3=7.501; //kJ/kg K
h_f3=191.8; //kJ/kg
h_fg3=2392.8; //kJ/kg

x3=(s2-s_f3)/s_fg3;
h3=h_f3+x3*h_fg3;

h_f4=191.8; //kJ/kg
h_f5=h_f4;

h_f6=640.1; //kJ/kg
h_f7=h_f6;
```

```
s7=1.8604; //kJ/kg K
s4=0.649; //kJ/kg K

m=(h_f6-h_f5)/(h2-h_f5);

W_T=(h1-h2) + (1-m)*(h2-h3);

Q1=h1-h_f6;

disp("(i) Efficiency of cycle =")
n_cycle=W_T/Q1;
disp(n_cycle)

SR=3600/W_T; //Steam rate
disp("Steam rate =")
disp(SR)
disp("kg/kWh")


T_m1=(h1-h_f7)/(s1-s7);

T_m1r=(h1-h_f4)/(s1-s4); //Without regeneration

dT_m1=T_m1-T_m1r;
disp("Increase in T_m1 due to regeneration=")
disp(dT_m1)
disp("0C")

W_Tr=h1-h3; //Without regeneration
SR1=3600/W_Tr; //Steam rate without regeneration
dSR=SR-SR1;
disp("Increase in steam rate due to regeneration=")
disp(dSR)
disp("kg/kWh")

n_cycle1=(h1-h3)/(h1-h_f4); //without regeneration
dn_cycle=n_cycle-n_cycle1;
disp("Increase in cycle efficiency due to
```

```
regeneration")
disp(dn_cycle*100)
disp("%")
```

Scilab code Exa 12.14 14

```
clc

//At 3 bar
t_s1=133.5; //0C
h_f1=561.4; //kJ/kg

//At 0.04 bar
t_s2=29; //0C
h_f2=121.5; //0C

h0=3231; //kJ/kg
h1=2700; //kJ/kg
h2=2085; //kJ/kg

t1=130; //0C
t2=27; //0C
c=4.186;

disp("(i) Mass of steam used")
m1=c*(t1-t2)/(h1-h_f2);
disp("m1=")
disp(m1)
disp("kg")


disp("(ii) Thermal efficiency of the cycle")
W=(h0-h1)+(1-m1)*(h1-h2);
Q=h0-c*t1;

```

```
n_thermal=W/Q;
disp("n_thermal=")
disp(n_thermal)
```

Scilab code Exa 12.15 15

```
clc

h0=3115.3; //kJ/kg
h1=2720; //kJ/kg
h2=2450; //kJ/kg
h3=2120; //kJ/kg

h_f1=640.1; //kJ/kg
h_f2=417.5; //kJ/kg
h_f3=173.9; //kJ/kg

m1=(h_f1-h_f2)/(h1-h_f1);
disp("m1=")
disp(m1)
disp("kJ/kg")

m2=((h_f2-h_f3)-m1*(h_f1-h_f3))/(h2-h_f3);
disp("m2=")
disp(m2)
disp("kJ/kg")

W=h0-h1 + (1-m1)*(h1-h2) + (1-m1-m2)*(h2-h3);
Q=h0-h_f1;

n=W/Q;
disp("Thermal Efficiency of the cycle=")
disp(n)
```

Scilab code Exa 12.16 16

```
clc
h0=2905; //kJ/kg
h1=2600; //kJ/kg
h2=2430; //kJ/kg
h3=2210; //kJ/kg
h4=2000; //kJ/kg

h_f1=640.1; //kJ/kg
h_f2=467.1; //kJ/kg
h_f3=289.3; //kJ/kg
h_f4=137.8; //kJ/kg

disp("(i) Mass of bled steam")

m1=(h_f1-h_f2)/(h1-h_f1);
disp("m1=")
disp(m1)
disp("kJ/kg")

m2=((h_f2-h_f3) - (m1*(h_f1-h_f2)))/(h2-h_f2);
disp("m2=")
disp(m2)
disp("kJ/kg")

m3=((h_f3-h_f4)-(m1+m2)*(h_f2-h_f4))/(h3-h_f4);
disp("m3=")
disp(m3)
disp("kJ/kg")

W=(h0-h1) + (1-m1)*(h1-h2)+(1-m1-m2)*(h2-h3) + (1-m1
    -m2-m3)*(h3-h4);

```

```
Q=h0-h_f1;

disp("(ii) Thermal efficiency of the cycle=")
n_thermal=W/Q;
disp(n_thermal)


disp("(iii) Thermal efficiency of Rankine cycle =")
n_rankine=(h0-h4)/(h0-h_f4);
disp(n_rankine)


disp("(iv) Theoretical gain due to regenerative feed
    heating =")
gain=(n_thermal-n_rankine)/(n_thermal);
disp(gain)

disp("(v) Steam consumption with regenerative feed
   heating =")
S1=3600/W;
disp(S1)
disp("kg/kWh")

disp("Steam consumption without regenerative feed
   heating =")
S2=3600/(h0-h4);
disp(S2)
disp("kg/kWh")

disp("(vi) Quantity of steam passing through the
   last stage of a 50000 kW turbine with
   regenerative feed-heating =")
quantity1=S1*(1-m1-m2-m3)*50000;
disp(quantity1)
disp("kg/h")

disp("quantity of steam without regeneration =")
quantity2=S2*50000;
```

```
disp(quantity2)
disp("kg/h")
```

Scilab code Exa 12.17 17

```
clc
h1=3460; //kJ/kg
h2=3460; //kJ/kg
h3=3111.5; //kJ/kg
h4=3585; //kJ/kg
h5=3207; //kJ/kg
h6=2466; //kJ/kg
h7=137.8; //kJ/kg
h8=962; //kJ/kg
h9=670.4; //kJ/kg
h10=962; //kJ/kg

p1=100; //bar
p2=95; //bar
p3=25; //bar
p4=22; //bar
p5=6; //bar
p6=0.05; //bar

n_mech=0.9;
n_gen=0.96;
n_boiler=0.9;

P=120*10^3; //kW

m1=(h10-h9)/(h3-h8);

m2=(h9-m1*h8-(1-m1)*h7)/(h5-h7);

W_IP=(1-m1-m2)*(p5-p6)*0.001*10^2;
```

```
W_HP=(p1-p5)*0.001*10^2;

W_total=(W_IP+W_HP)/n_mech;

W_indicated=(h2-h3) + (1-m1)*(h4-h5) + (1-m1-m2)*(h5-h6);

Output=(W_indicated - W_total)*n_mech*n_gen; //net electrical output

rate=P*3600/Output;

amt1=m1*rate; //Amounts of bled off, surface(high pressure) heater
disp("Amounts of bled off, surface(high pressure) heater =")
disp(amt1)
disp("kg/h")

amt2=m2*rate; //Amounts of bled off, surface(low pressure) heater
disp("Amounts of bled off, surface(low pressure) heater")
disp(amt2)
disp("kg/h")


disp("(iii) Overall thermal efficiency")
Q_boiler=(h1-h10)/n_boiler;
Q_reheater=(h4-h3)/n_boiler;

n_overall=Output/(Q_boiler+Q_reheater)*100;
disp("Overall thermal efficiency =")
disp(n_overall)
disp("%")


disp("(iv) Specific steam consumption =")
```

```
ssc=rate/P; //Specific steam consumption
disp(ssc)
disp("kg/kWh")
```

Scilab code Exa 12.18 18

```
clc
p1=15; //bar
p2=4; //bar
p4=0.1; //bar

h1=2920; //kJ/kg
h2=2660; //kJ/kg
h3=2960; //kJ/kg
h4=2335; //kJ/kg

W=h1-h2+h3-h4;
disp("work done per kg of steam")
disp(W)
disp("kJ/kg")

h_reheat=h3-h2;
disp("Amount of heat supplied during reheat =")
disp(h_reheat)
disp("kJ/kg")

h_4a=2125;  //kJ/kg

W1=h1-h_4a;
disp("Work output without reheat =")
disp(W1)
disp("kJ/kg")
```

Scilab code Exa 12.19 19

```
clc

h1=3450; //kJ/kg
h2=3050; //kJ/kg
h3=3560; //kJ/kg
h4=2300; //kJ/kg

h_f4=191.8; //kJ/kg

//From mollier diagram
x4=0.88;
disp("(i)Quality of steam at turbine exhaust =")
disp(x4)


n_cycle=((h1-h2) + (h3-h4))/((h1-h_f4) + (h3-h2));
disp("(ii) Cycle efficiency =")
disp(n_cycle)


SR=3600/((h1-h2) + (h3-h4));
disp("(iii) Steam rate in kg/kWh =")
disp(SR)
disp("kg/kWh")
```

Scilab code Exa 12.20 20

```
clc

h1=3250; //kJ/kg
h2=2170; //kJ/kg
h_f2=173.9; //kJ/kg

```

```
W=h1-h2;
Q=h1-h_f2;

n_thermal=W/Q;
disp("Thermal effifciency=")
disp(n_thermal);

x2=0.83; //From mollier chart
disp("x2=")
disp(x2)


disp("Second case")

h1=3250; //kJ/kg
h2=2807; //kJ/kg
h3=3263; //kJ/kg
h4=2426; //kJ/kg
h_f4=173.9; //kJ/kg
W=h1-h2+h3-h4;
Q=h1-h_f4+h3-h2;

n_thermal=W/Q;
disp("Thermal effifciency=")
disp(n_thermal);

x4=0.935; //From mollier chart
disp("x4=")
disp(x4)
```

Scilab code Exa 12.21 21

```
clc

disp("(a) The erosion of the moving blades is caused
```

```
   by the presence of water particles in (wet)
   steam in the L.P. stages. The water particles
   strike the leading surface of the blades. Such
   impact, if sufficiently heavy, produces severe
   local stresses in the blade material causing the
   surface metal to fail and flake off.")

disp(" The erosion, if any, is more likely to occur
   in the region where the steam is wettest, i.e.,
   in the last one or two stages of the turbine.
   Moreover, the water droplets are concentrated in
   the outer parts of the flow annuals where the
   velocity of impact is highest.")
disp("Erosion difficulties due to moisture in the
   steam may be avoided by reheating. The whole of
   steam is taken from the turbine at a suitable
   point 2, and a further supply of heat is given to
    it along 2-3 after which the steam is readmitted
    to the turbine and expanded along 3-4 to
   condenser pressure. Erosion may also be reduced
   by using steam traps in between the stages to
   separate moisture from the steam.")



disp("(b) TTD means    Terminal    temperature
    difference . It is the difference between
   temperatures of bled steam/condensate and the
   feed water at the two ends of the feed water
   heater")



disp("Part (c)")

h1=3580; //kJ/kg
h2=3140; //kJ/kg
h3=3675; //kJ/kg
```

```
h4=2335; //kJ/kg
h5=191.8; //kJ/kg

P=15*10^3; //kW
a=0.104; //moisture content in exit from LP turbine

p=40; //bar; From the mollier diagram
disp("(i)Reheat pressure=")
disp(p)
disp("bar")

disp("(ii) Thermal efficiency")
W=h1-h2+h3-h4;
Q=h1-h5+h3-h2;
n_th=W/Q*100;
disp("n_th=")
disp(n_th)
disp("%")

sc=P/W;//steam consumption
ssc=sc*3600/P; //specific steam consumption
disp("Specific steam consumption=")
disp(ssc)
disp("kg/kWh")

disp("(iv) Rate of pump work =")
rate=sc*0.15;
disp(rate)
```

Scilab code Exa 12.22 22

```
clc

h_l=355.988; //kJ/kg
s_l=0.5397; //kJ/kg K
```

```
s_f=0.0808; //kJ/kg K
s_g=0.6925; //kJ/kg K
h_f=29.98; //kJ/kg
h_g=329.85; //kJ/kg

p1=4; //bar
p2=0.04; //bar
v_f2=76.5*10^(-6); //m^3/kg

h1=2789.9; //kJ/kg
s1=6.4406; //kJ/kg
h_f=121.5; //kJ/kg
h_fg=2432.9; //kJ/kg
s_f=0.432; //kJ/kg K
s_fg2=8.052; //kJ/kg K

p4=15; //bar
p3=0.04; //bar

v_f=0.0001; //kJ/kg K

h_f4=123; //kJ/kg
h_m=254.88; //kJ/kg
h_fn=29.98; //kJ/kg
h_fk=29.988; //kJ/kg

disp("(i) Overall thermal efficiency ")
m=(h1-h_f4)/(h_m-h_fn); //The amount of mercury
    circulating for 1kg of steam in the bottom cycle
Q1=m*(h_l-h_fk); //total

x2=(s1-s_f)/(s_fg2);

h2=h_f+x2*h_fg;

W_T=m*(h_l-h_m)+(h1-h2); //total

n_overall=W_T/Q1; //W_P may be neglected
```

```
disp(" n_overall =")
disp(n_overall)


disp("(ii) Flow through mercury turbine=")
A=48000; //kg/h
m_Hg=m*A;
disp(m_Hg)
disp("kg/h")


disp("(iii) Useful work in binary vapour cycle=")
W_total=A*W_T/3600;
disp(W_total)
disp("kW")


disp("(iv) Overall efficiency under new conditions "
   )
n_Hg=0.84;
n_steam=0.88;

W_Hg=n_Hg*101.1;
h_m1=h_l-W_Hg;
m1=(h1-h_f4)/(h_m1-h_fn);

h_g=3037.6; //kJ/kg
s_g=6.918; //kJ/kg
s_f2=0.423; //kJ/kg K
s_fg2=8.052; //kJ/kg K

Q1=m1*(h_l - h_fk) + (h_g-h1);

x2=(s_g-s_f2)/s_fg2;
h2=h_f+x2*h_fg;

W_steam=n_steam*(h_g-h2);

```

```
W_total=m1*W_Hg + W_steam;

n_overall=W_total/Q1;
disp("n_overall")
disp(n_overall)
```

Scilab code Exa 12.23 23

```
clc
p1=60; //bar
t1=450; //0C
p2=3; //bar
p3=0.07; //bar; p3=(760-707.5)/760*1.013

n_turbine=0.87;
n_boiler=0.86;
n_alt=0.94;
n_mech=0.97;

P=22500; //kW

h1=3300; //kJ/kg
h2=2607; //kJ/kg

h2a=h1-n_turbine*(h1-h2);
h3=2165; //kJ/kg

h3a=h2a-n_turbine*(h2a-h3);

h_f4=163.4; //kJ/kg
h_f5=561.4; //kJ/kg

disp("(i) The steam bled per kg of steam supplied to
    the turbine")
m=(h_f5-h_f4)/(h2a-h_f4);
```

```
disp("m=")
disp(m)
disp("kJ/kg")


disp("(ii) Steam generated per hour")
W=(h1-h2a) + (1-m)*(h2a-h3a); //Work developed per
    kg of steam in the turbine
W_act=P/n_alt/n_mech; //actual work

steam=W_act/W*3600/1000; //tonnes/h
disp("Steam generated=")
disp(steam)
disp("tonnes/h")


disp("(iii) The overall efficiency of the plant")
P_avail=P*(1-0.09); //Net power available deducting
    pump power
Q=steam*1000*(h1-h_f5)/n_boiler/3600; //kW

n_overall=P_avail/Q
disp("n_overall=")
disp(n_overall)
```

Scilab code Exa 12.24 24

```
clc
t1=350; //0C
t_s=350; //0C

p2=7; //bar
p3=7; //bar
p4=0.4; //bar
t3=350; //0C
```

```
h1=2985; //kJ/kg
h2=2520; //kJ/kg
h3=3170; //kJ/kg
h4=2555; //kJ/kg

h_f2=697.1; //kJ/kg
h_f4=317.7; //kJ/kg

P=110*10^3; //kW

disp("(i) The ratio of steam bled to steam generated
   ")
m=(h_f2-h_f4)/(h2-h_f4);

ratio=1/m;
disp("ratio=")
disp(ratio)


disp("(ii) The boiler generating capacity =")
m_s=P/(h1-h2+(1-m)*(h3-h4))*3600/1000; //tonnes/hour
disp(m_s)
disp("tonnes/hour")


disp("(iii) Thermal efficiency of the cycle =")
n_thermal=((h1-h2) + (1-m)*(h3-h4))/((h1-h_f2)+(1-m)
   *(h3-h2));
disp(n_thermal)
```

Scilab code Exa 12.25 25

```
clc
h1=3315; //kJ/kg
```

```
h2=2716; //kJ/kg
h3=3165; //kJ/kg
h4=2236; //kJ/kg
h_f2=697.1;//kJ/kg
h_f6=h_f2;
h_f4=111.9; //kJ/kg
h_f5=h_f4;

disp("(i) Amount of steam bled off for feed heating
    =")
m=(h_f2-h_f4)/(h2-h_f4);
disp(m)
disp("steam bled off is 22.5% of steam generated by
    the boiler.")


disp("(ii) Amount of steam supplied to L.P. turbine
    =")
amt=100-m*100;
disp(amt)
disp("77.5% of the steam generated by the boiler.")


disp("(iii) Heat supplied in the boiler and reheater
    ")
Q_boiler=h1-h_f6;
disp("Q_boiler=")
disp(Q_boiler)
disp("kJ/kg")

Q_reheater=(1-m)*(h3-h2);
disp("Q_reheater=")
disp(Q_reheater)
disp("kJ/kg")

Qs=Q_boiler+Q_reheater;

disp("(iv) Cycle efficiency")
```

```
W=h1-h2 + (1-m)*(h3-h4);

n_cycle=W/Qs;
disp("n_cycle=")
disp(n_cycle)


disp("(v) Power developed by the system")
ms=50; //kg/s
Power=ms*W/1000; //MW
disp("Power=")
disp(Power)
disp("MW")
```

Scilab code Exa 12.26 26

```
clc

h1 = 3578; //kJ/kg
h2 = 3140; //kJ/kg
h3 = 3678; //kJ/kg
h4 = 3000; //kJ/kg
h5 = 2330; //kJ/kg
h_f1=1611; //kJ/kg
h_f2=1087.4; //kJ/kg
h_f4=640.1; //kJ/kg
h_f5=191.8; //kJ/kg
h_f6=h_f5;

disp("(i) Fraction of steam extracted from the
    turbines at each bled heater =")

disp("closed feed heater")
m1=(h_f2-h_f4)/(h2-h_f4);
disp(m1)
```

```
disp("kg/kg of steam supplied by the boiler")

disp("open feed heater")
m2=(1-m1)*(h_f4-h_f5)/(h4-h_f6);
disp(m2)
disp("kg/kg of steam supplied by the boiler")


disp("(ii) Thermal efficiency of the system")

W_total=(h1-h2) + (1-m1)*(h3-h4) + (1-m1-m2)*(h4-h5);
p1=150; //bar
p2=40; //bar
p4=5; //bar
p5=0.1; //bar

v_w1=1/1000; //m^3/kg
v_w2=v_w1;
v_w3=v_w1;

W_P1=v_w1*(1-m1-m2)*(p4-p5)*100; //kJ/kg
W_P2=v_w2*(1-m1)*(p1-p4)*100; //kJ/kg
W_P3=v_w3*m1*(p1-p2)*100; //kJ/kg

W_P=W_P1+W_P2+W_P3; //Total pump work
W_net=W_total-W_P;

Q=(1-m1)*h_f1 +m1*(h_f1); //Heat of feed water extering the boiler
Qs1=h1-Q;
Qs2=(1-m1)*(h3-h2);
Qst=Qs1+Qs2;

n_thermal=W_net/Qst*100;
disp("n_thermal=")
disp(n_thermal)
disp("%")
```

Scilab code Exa 12.27 27

```
clc

disp("(i) The minimum pressure at which bleeding is
   necessary=")

//It would be assumed that the feed water heater is
   an open heater. Feed water is heated to 180 C .
   So psat at 180 C ~= 10 bar is the pressure at
   which the heater operates. Thus, the pressure at
   which bleeding is necessary is 10 bar.
p_min=10; //bar
disp(p_min)
disp("bar")

h1=3285; //kJ/kg
h2=2980; //kJ/kg
h3=3280; //kJ/kg
h4a=3072.5; //kJ/kg
h5=2210; //kJ/kg
h5a=2356.6; //kJ/kg

h_f6=163.4; //kJ/kg
h_f8=762.6; //kJ/kg
h2a=3045.6; //kJ/kg


disp("(ii) The quantity of steam bled per kg of flow
    at the turbine inlet =")
m=(h_f8-h_f6)/(h4a-h_f6);
disp(m)
disp("kg of steam flow at turbine inlet.")

```

```
disp("(iii) Cycle efficiency =")
n_cycle=((h1-h2a)+(h3-h4a)+(1-m)*(h4a-h5a))/((h1-
    h_f8) + (h3 - h2a))*100;
disp(n_cycle)
disp("%")
```

Chapter 13

Gas Power Cycles

Scilab code Exa 13.1 1

```
clc
T1=671; //K
T2=T1;
T3=313; //K
T4=T3;
W=130; //kJ

disp("(i) Engine thermal efficiency =")
n_th=(T2-T3)/T2;
disp(n_th)


disp("(ii) Heat added =")
Q=W/n_th;
disp(Q)
disp("kJ")


disp("(iii) The entropy changes during heat
    rejection process")
Q_rejected=Q-W;
```

```
dS=Q_rejected/T3;
disp("dS=")
disp(dS)
disp("kJ/K")
```

Scilab code Exa 13.2 2

```
clc
cv=0.721; //kJ/kg K
cp=1.008; //kJ/kg K
m=0.5; //kg
n_th=0.5;
Q_isothermal=40; //kJ
p1=7*10^5; //Pa
V1=0.12; //m^3
R=287; //J/kg K

disp("(i) The maximum and minimum temperatures")
T1=p1*V1/m/R;
disp("Maximun temperature =")
disp(T1)
disp("K")

T2=(1-n_th)*T1;
disp("Minimum temperature =")
disp(T2)
disp("K")


disp("(ii) The volume at the end of isothermal
    expansion =")
V2=V1*%e^(Q_isothermal*10^3/m/R/T1);
disp(V2)
disp("m^3")

```

```
disp("(iii) The heat transfer for each of the four
    processes")

Q1=Q_isothermal;
disp("Isothermal expansion")
disp(Q1)
disp("kJ")

Q2=0;
disp("Adiabatic reversible expansion")
disp(Q2)

Q3=-Q_isothermal;
disp("Isothermal compression")
disp(Q3)

Q4=0;
disp("Adiabatic reversible compression")
disp(Q4)
```

Scilab code Exa 13.3 3

```
clc
p1=18*10^5; //Pa
T1=683; //K
T2=T1;
r1=6; //ratio V4/V1; Isentropic compression
r2=1.5; //ratio V2/V1; Isothermal expansion
y=1.4;
V1=0.18; //m^3

disp("(i) Temperatures and pressures at the main
    points in the cycle")

```

```
T4=T1/(r1)^(y-1);
disp("T4=")
disp(T4)
disp("K")

T3=T4;
disp("T3=")
disp(T3)
disp("K")

p2=p1/r2;
disp("p2=")
disp(p2/10^5)
disp("bar")

p3=p2/(r1)^y;
disp("p3=")
disp(p3/10^5)
disp("bar")

p4=p1/(r1)^y;
disp("p4=")
disp(p4/10^5)
disp("bar")


disp("(ii) Change in entropy =")
dS=p1*V1/T1/10^3*log(r2);
disp(dS)
disp("kJ/K")


disp("(iii) Mean thermal efficiency of the cycle")
Qs=T1*(dS);
Qr=T4*(dS);

n=1-Qr/Qs;
disp("n=")
```

```
disp(n)


disp("(iv) Mean effective pressure of the cycle =")
pm=(Qs-Qr)/8/V1/100; //bar
disp(pm)
disp("bar")


n=210; //cycles per minute
disp("(v) Power of the engine =")
P=(Qs-Qr)*n/60; //kW
disp(P)
disp("kW")
```

Scilab code Exa 13.4 4

```
clc

// First case
//(T1-T2)/T1=1/6
//T1=1.2*T2


// Second case
//(T1-(T2-(70+273)))/T3=1/3

T2=1029/0.6;
T1=1.2*T2;

disp("Temperature of the source =")
disp(T1)
disp("K")


```

```
disp("Temperature of the sink=")
disp(T2)
disp("K")
```

Scilab code Exa 13.5 5

```
clc

T1=1990; //K
T2=850; //K
Q=32.5/60; //kJ/s
P=0.4; //kW

n_carnot=(T1-T2)/T1;
disp("most efficient engine is one that works on
   Carnot cycle")
disp(n_carnot)

n_th=P/Q;
disp("n_thermal =")
disp(n_th)

disp("which is not feasible as no engine can be more
     efficient than that working on Carnot")
disp("Hence claims of the inventor is not true.")
```

Scilab code Exa 13.7 7

```
clc

n=0.6;
y=1.5;

```

```
r=(1/(1-n))^(1/(y-1));
disp("Compression ratio =")
disp(r)
```

Scilab code Exa 13.8 8

```
clc

D=0.25; //m
L=0.375; //m
Vc=0.00263; //m^3
p1=1; //bar
T1=323; //K
p3=25; //bar
Vs=%pi/4*D^2*L;
r=(Vs+Vc)/Vc;
y=1.4;

disp("(i) Air standard efficiency=")
n_otto=1-1/(r^(y-1));
disp(n_otto)


disp("(ii) Mean effective pressure ")
p2=p1*(r)^(y);
r_p=p3/p2;

p_m=p1*r*(r^(y-1) - 1)*(r_p - 1)/(y-1)/(r-1);
disp("Mean effective pressure =")
disp(p_m)
disp("bar")
```

Scilab code Exa 13.9 9

```
clc
cv=0.72; //kJ/kg K
y=1.4;
p1=1; //bar
T1=300; //K
Q=1500; //kJ/kg
r=8;
y=1.4;

disp("(i) Pressures and temperatures at all points")
T2=T1*(r)^(y-1);
disp("T2=")
disp(T2)
disp("K")

p2=p1*(r)^y;
disp("p2=")
disp(p2)
disp("bar")

T3=Q/cv + T2;
disp("T3=")
disp(T3)
disp("K")

p3=p2*T3/T2;
disp("p3=")
disp(p3)
disp("bar")

T4=T3/r^(y-1);
disp("T4=")
disp(T4)
disp("K")

p4=p3/r^(y);
disp("p4=")
disp(p4)
```

```
disp("bar")


disp("(ii) Specific work and thermal efficiency")
SW=cv*[(T3-T2) - (T4-T1)];
disp("Specific work =")
disp(SW)
disp("kJ/kg")

n_th=1-1/r^(y-1);
disp("Thermal efficiency =")
disp(n_th)
```

Scilab code Exa 13.10 10

```
clc
r=6; //v1/v2=v4/v3=r
p1=1; //bar
T1=300; //K
T3=1842; //K
y=1.4;

disp("(i) Temperature and pressure after the
    isentropic expansion")
p2=p1*(r)^y;
T2=T1*r^(y-1);
p3=p2*(T3/T2);

T4=T3/r^(y-1);
disp("T4=")
disp(T4)
disp("K")

p4=p3/(r)^(y);
disp("p4 =")
```

```
disp(p4)
disp("bar")

disp("(ii) Process required to complete the cycle")

disp("Process required to complete the cycle is the
    constant pressure scavenging. The cycle is called
     Atkinson cycle")

disp("(iii) Percentage improvement/increase in
    efficiency")
p5=1; //bar
T5=T3*(p5/p3)^((y-1)/y);

n_otto=(1-1/r^(y-1))*100;
disp("n_otto = ")
disp(n_otto)
disp("%")

n_atkinson=(1-y*(T5-T1)/(T3-T2))*100;
disp("n_atkinson=")
disp(n_atkinson)
disp("%")

dn=n_atkinson - n_otto; //Improvement in efficiency
disp("Improvement in efficiency =")
disp(dn)
disp("%")
```

Scilab code Exa 13.11 11

```
clc
p1=1; //bar
T1=343; //K
p2=7; //bar
```

```
Qs=465; //kJ/kg of air
cp=1; //kJ/kg K
cv=0.706; //kJ/kg K
y=1.41;

disp("(i) Compression ratio of engine =")
r=(p2/p1)^(1/y);
disp(r)


disp("(ii) Temperature at the end of compression =")
T2=T1*(r)^(y-1);
t2=T2-273;
disp(t2)
disp("0C")

disp("(iii) Temperature at the end of heat addition =")
T3=Qs/cv+T2;
t3=T3-273;
disp(t3)
disp("0C")
```

Scilab code Exa 13.12 12

```
clc

y=1.4;
R=0.287; //kJ/kg K
T1=311; //K
T3=2223; //K
//p2/p1=15

disp("(i) Compression ratio =")
r=15^(1/1.4);
```

```
disp(r)


disp("(ii) Thermal efficiency =")
n_th=1-1/r^(y-1);
disp(n_th)

disp("(iii) Work done")
T2=T1*(r)^(y-1);
T4=T3/r^(y-1);
cv=R/(y-1);

Q_supplied=cv*(T3-T2);
Q_rejected=cv*(T4-T1);

W=Q_supplied-Q_rejected;
disp("Work done=")
disp(W)
disp("kJ")
```

Scilab code Exa 13.13 13

```
clc
V1=0.45; //m^3
p1=1; //bar
T1=303; //K
p2=11; //bar
Qs=210; //kJ
n=210; //number of working cycles/min
R=287; //J/kg K
cv=0.71; //kJ/kg K
y=1.4;

disp("(i) Pressures, temperatures and volumes at
    salient points")
```

```
r=(p2/p1)^(1/y);

T2=T1*(r)^(y-1);
disp("T2=")
disp(T2)
disp("K")

V2=T2/T1*p1/p2*V1;
disp("V2=")
disp(V2)
disp("m^3")

m=p1*10^5*V1/R/T1;
T3=Qs/m/cv+T2;
disp("T3=")
disp(T3)
disp("K")

p3=T3/T2*p2;
disp("p3=")
disp(p3)
disp("bar")

V3=V2;
disp("V3=")
disp(V3)
disp("m^3")

p4=p3/r^y;
disp("p4=")
disp(p4)
disp("bar")

T4=T3/r^(y-1);
disp("T4=")
disp(T4)
disp("K")

```

```
V4=V1;
disp("V4=")
disp(V4)
disp("m^3")


disp("(ii) Percentage clearance =")
%clearance=V2/(V1-V2)*100;
disp(%clearance)
disp("%")


disp("(iii) Efficiency =")
Qr=m*cv*(T4-T1);
n_otto=(Qs-Qr)/Qs;
disp(n_otto)


disp("(iv) Mean effective pressure =")
p_m=(Qs-Qr)/(V1-V2)/100; //bar
disp(p_m)
disp("bar")


disp("(v) Power developed =")
P=(Qs-Qr)*n/60;
disp(P)
disp("kW")
```

Scilab code Exa 13.14 14

```
clc

// W=Qs-Qr=cv*(T3-T2) - cv*(T4-T1)
// T2=T1*(r^(y-1))
```

```
// T3=T4*(r^(y-1))
// W=cv*[T3-T1*r^(y-1) - T3/r^(y-1)+T1];
// dW/dr=-T1*(y-1)*r^(y-2) - T3*(1-y)*r^(-y)=0

//By solving this we get

disp("r=(T3/T1)^(1/2/(y-1))")

disp("(b)Change in efficiency")

T3=1220; //K
T1=310; //K

// For air
y=1.4;
r1=(T3/T1)^(1/2/(y-1));
n1=1-1/r1^(y-1); //air standard Efficiency
disp("Air standard Efficiency =")
disp(n1)

//For helium
cp=5.22; //kJ/kg K
cv=3.13; //kJ/kg K
y=cp/cv;
r2=(T3/T1)^(1/2/(y-1));

n2=1-1/r2^(y-1);
disp("Air standard efficiency for helium =")
disp(n2)

change=n1-n2;
disp("Change in efficiency=")
disp(change)

disp("Hence change in efficiency is nil")
```

Scilab code Exa 13.15 15

```
clc
// W=cv*[T3-T1*r^(y-1) - T3/r^(y-1)+T1]
//  r=(T3/T1)^(1/2/(y-1))
//  T2=T1*r^(y-1)
//  T4=T3/r^(y-1)

//  T2=T1*[(T3/T1)^(1/2/(y-1))]^(y-1)


//T2=sqrt(T1*T3)

//Similarly T4=T3/[(T3/T1)^(1/2/(y-1))]^(y-1)
//T4=sqrt(T1*T3)

disp("T2=T4=sqrt(T1*T3)")


disp("(b) Power developed ")
T1=310; //K
T3=1450; //K
m=0.38; //kg
cv=0.71; //kJ/kg K

T2=sqrt(T1*T3);
T4=T2;

W1=cv*[(T3-T2) - (T4-T1)]; //Work done
W=m/60*W1; //Work done per second

disp("Power =")
disp(W)
disp("kW")
```

Scilab code Exa 13.17 17

```
clc
r=15;
y=1.4;

//V3-V2=0.06*(V1-V2)
rho=1.84; //cut off ratio rho=V3/V2

n_diesel=1-1/y/r^(y-1)*((rho^y-1)/(rho-1));
disp("efficiency =")
disp(n_diesel)
```

Scilab code Exa 13.18 18

```
clc

L=0.25; //m
D=0.15; //m
V2=0.0004; //m^3
Vs=%pi/4*D^2*L;
V_total=Vs+V2;
y=1.4;
V3=V2+5/100*Vs;
rho=V3/V2;
r=(Vs+V2)/V2; //V1=Vs+V2

n_diesel=1-1/y/r^(y-1)*((rho^y-1)/(rho-1));
disp("efficiency =")
disp(n_diesel)
```

Scilab code Exa 13.19 19

```
clc
r=14; //let clearance volume be unity
y=1.4;

//When the fuel is cut-off at 5%
rho1=5/100*(r-1)+1;
n_diesel1=1-1/y/r^(y-1)*((rho1^y-1)/(rho1-1));

//When the fuel is cut-off at 8%
rho2=8/100*(r-1)+1;
n_diesel2=1-1/y/r^(y-1)*((rho2^y-1)/(rho2-1));

%loss=(n_diesel1-n_diesel2)*100;
disp("percentage loss in efficiency due to delay in
    fuel cut off =")
disp(%loss)
disp("%")
```

Scilab code Exa 13.20 20

```
clc

pm=7.5; //bar
r=12.5;
p1=1; //bar
y=1.4;

// pm = p1*r^y*[y*(rho-1) - r^(1-y)*(rho^y-1)]/(y-1)
    /(r-1)
//Solving above equation we get
```

```
rho=2.24;

%cutoff=(rho-1)/(r-1)*100;
disp("%cutoff=")
disp(%cutoff)
disp("%")
```

Scilab code Exa 13.21 21

```
clc
D=0.2; //m
L=0.3; //m
p1=1; //bar
T1=300; //K
R=287;
r=15;
y=1.4;

disp("(i) Pressures and temperatures at salient
   points")
Vs=%pi/4*D^2*L;

V1=r/(r-1)*Vs;
disp("V1=")
disp(V1)
disp("m^3")

m=p1*10^5*V1/R/T1;

p2=p1*r^y;
disp("p2=")
disp(p2)
disp("bar")

T2=T1*r^(y-1);
```

```
disp("T2=")
disp(T2)
disp("K")

V2=Vs/(r-1);
disp("V2=")
disp(V2)
disp("m^3")

rho=8/100*(r-1) + 1;
V3=rho*V2;
disp("V3=")
disp(V3)
disp("m^3")

T3=T2*V3/V2;
disp("T3=")
disp(T3)
disp("K")

p3=p2;
disp("p3=")
disp(p3)
disp("bar")

p4=p3*(rho/r)^y;
disp("p4=")
disp(p4)
disp("bar")

T4=T3*(rho/r)^(y-1);
disp("T4=")
disp(T4)
disp("K")

V4=V1;
disp("V4=")
disp(V4)
```

```
disp("m^3")

disp("(ii) Theoretical air standard efficiency =")
n_diesel=1-1/y/r^(y-1)*((rho^y-1)/(rho-1));
disp("efficiency =")
disp(n_diesel)


disp("(iii) Mean effective pressure =")
pm=(p1*r^y*(y*(rho-1) - r^(1-y)*(rho^y-1)))/(y-1)/(r
   -1);
disp(pm)
disp("bar")

disp("(iv) Power of the engine =")
n=380; //number of cycles per min
P=n/60*pm*Vs*100; //kW
disp(P)
disp("kW")
```

Scilab code Exa 13.22 22

```
clc
r1=15.3; //V1/V2
r2=7.5;  //V4/V3
p1=1; //bar
T1=300; //K
n_mech=0.8;
C=42000; //kJ/kg
y=1.4;
R=287;
cp=1.005;
cv=0.718;
V2=1; ////Assuming V2=1 m^3

```

```
T2=T1*r1^(y-1);
p2=p1*r1^y;
T3=r1/r2*T2;
m=p2*10^5*V2/R/T2;
T4=T3/r2^(y-1);

Q_added=m*cp*(T3-T2);
Q_rejected=m*cv*(T4-T1);
W=Q_added-Q_rejected;

pm=W/(r1-1)/V2/100;
disp("Mean effective pressure =")
disp(pm)
disp("bar")

ratio=p2/pm;
disp("Ratio of maximum pressure to mean effective
    pressure =")
disp(ratio)

n_cycle=W/Q_added;
disp("Cycle efficiency =")
disp(n_cycle)

n_thI=0.5;
n_cycle1=n_thI*n_cycle;

n_thB=n_mech*n_cycle1;

BP=1;
mf=BP/C/n_thB*3600;
disp("Fuel consumption per kWh =")
disp(mf)
disp("kg/kWh")
```

Scilab code Exa 13.23 23

```
clc
Vs=0.0053; //m^3
Vc=0.00035; //m^3
V3=Vc;
V2=V3;
p3=65; //bar
p4=65; //bar
T1=353; //K
p1=0.9; //bar
y=1.4;

r=(Vs+Vc)/Vc;
rho=(5/100*Vs+V3)/V3;
p2=p1*(r)^y;
B=p3/p2;

n_dual=1-1/r^(y-1)*[(B*rho^y-1)/((B-1)+B*y*(rho-1))
    ];
disp("Efficiency of the cycle =")
disp(n_dual)
```

Scilab code Exa 13.24 24

```
clc
r=14;
B=1.4;
rho=6/100*(r-1) + 1;
y=1.4;

n_dual=1-1/r^(y-1)*[(B*rho^y-1)/((B-1)+B*y*(rho-1))]
disp("Efficiency of the cycle =")
disp(n_dual)
```

Scilab code Exa 13.25 25

```
clc
D=0.25; //m
r=9;
L=0.3; //m
cv=0.71; //kJ/kg K
cp=1; //kJ/kg K
p1=1; //bar
T1=303; //K
p3=60; //bar
p4=p3;
n=3; //number of working cycles/ sec
y=1.4;
R=287;

disp("(i) Air standard efficiency")
Vs=%pi/4*D^2*L;

Vc=Vs/(r-1);
V1=Vs+Vc;
p2=p1*(r)^y;
T2=T1*r^(y-1);
T3=T2*p3/p2;
rho=4/100*(r-1)+1;
T4=T3*rho;

T5=T4*(rho/r)^(y-1);
p5=p4*(r/rho)^(y);

Qs=cv*(T3-T2)+cp*(T4-T3)

Qr=cv*(T5-T1);

```

```
n_airstandard=(Qs-Qr)/Qs;
disp("efficiency =")
disp(n_airstandard)


disp("(ii) Power developed by the engine")
m=p1*10^5*V1/R/T1;

W=m*(Qs-Qr);

P=W*n;
disp("P=")
disp(P)
disp("kW")
```

Scilab code Exa 13.26 26

```
clc
p1=1; //bar
T1=363; //K
r=9;
p3=68; //bar
p4=68; //bar
Q=1750; //kJ/kg
y=1.4;
cv=0.71;
cp=1.0;

disp("(i) Pressures and temperatures at salient
    points")
p2=p1*(r)^y;
disp("p2=")
disp(p2)
disp("bar")

```

```
T2=T1*r^(y-1);
disp("T2=")
disp(T2)
disp("K")

disp("p3=")
disp(p3)
disp("bar")

disp("p4=")
disp(p4)
disp("bar")

T3=T2*(p3/p2);
disp("T3=")
disp(T3)
disp("K")

Q1=cv*(T3-T2); //heat added at constant volume
Q2=Q-Q1; //heat added at constant pressure

T4=Q2/cp+T3;
disp("T4=")
disp(T4)
disp("K")

rho=T4/T3; //V4/V3=T4/T3

p5=p4*(rho/r)^y;
disp("p5=")
disp(p5)
disp("bar")

T5=T4*(rho/r)^(y-1);
disp("T5=")
disp(T5)
disp("K")

```

```
disp("(ii) Air standard efficiency =")
Qr=cv*(T5-T1);
n_airstandard=(Q-Qr)/Q;
disp(n_airstandard)


disp("(iii) Mean effective pressure =")
pm=1/(r-1)*(p3*(rho-1) + (p4*rho-p5*r)/(y-1) - (p2-
   p1*r)/(y-1));
disp(pm)
disp("bar")
```

Scilab code Exa 13.27 27

```
clc
T1=300; //K
r=15;
y=1.4;
//p3/p1=70

T2=T1*(r)^(y-1);

//p2/p1=r^y
//p2=44.3*p1

T3=1400; //K; T3=T2*p3/p2

T4=T3 + (T3-T2)/y;

//v1/v3=15
//v4=0.084*v1
//v5=v1
//T5=T4*(v5/v1)^(y-1)
T5=656.9; //K
```

```
n_airstandard=1-(T5-T1)/((T3-T2) + y*(T4-T3));
disp("Efficiency =")
disp(n_airstandard)

disp("Reasons for actual thermal efficiency being
    different from the theoretical value :")

disp("1. In theoretical cycle working substance is
    taken air whereas in actual cycle air with fuel
    acts as working substance")

disp("2. The fuel combustion phenomenon and
    associated problems like dissociation of gases,
    dilution of charge during suction stroke, etc.
    have not been taken into account")

disp("3. Effect of variable specific heat, heat loss
     through cylinder walls, inlet and exhaust
    velocities of air/gas etc. have not been taken
    into account.")
```

Scilab code Exa 13.28 28

```
clc
T1=373; //K
p1=1; //bar
p3=65; //bar
p4=p3;
Vs=0.0085; //m^3
ratio=21; //Air fuel ratio
r=15;
C=43890; //kJ/kg
cp=1;
cv=0.71;
```

```
V2=0.0006; //m^3
V1=0.009; //m^3
y=1.41;
V5=V1;
V3=V2;
R=287;

p2=p1*(r)^y;
T2=T1*r^(y-1);
T3=T2*p3/p2;
m=p1*10^5*V1/R/T1;

Q1=m*cv*(T3-T2); //Heat added during constant volume
     process 2-3
amt=Q1/C; //Amount of fuel added during the constant
     volume process 2-3
total=m/ratio; //Total amount of fuel added
quantity=total-amt; //Quantity of fuel added during
   the process 3-4

Q2=quantity*C; //Heat added during constant pressure
     process

T4=Q2/(m+total)/cp+T3;
V4=V3*T4/T3;
T5=T4*(V4/V5)^(y-1);

Q3=(m+total)*cv*(T5-T1); //Heat rejected during
   constant volume process 5-1

W=(Q1+Q2) - Q3;

n_th=W/(Q1+Q2);
disp("Thermal efficiency =")
disp(n_th)
```

Scilab code Exa 13.29 29

```
clc
T1=303; //K
p1=1; //bar
rc=9;
re=5;
n=1.25;
D=0.25; //m
L=0.4; //m
R=287;
cv=0.71;
cp=1;
num=8; //no. 0f cycles/sec

disp("(i) Pressure and temperatures at all salient points =")
p2=p1*(rc)^n;
disp("p2=")
disp(p2)
disp("bar")

T2=T1*(rc)^(n-1);
disp("T2=")
disp(T2)
disp("K")

//T4=1.8*T3
//Heat liberated at constant pressure= 2    heat liberated at constant volume
//cp*(T4-T3)=2*cv*(T3-T2)
//T4/T3=1.8

rho=rc/re;
```

```
T3=1201.9; //K
disp("T3=")
disp(T3)
disp("K")

p3=p2*T3/T2;
disp("p3=")
disp(p3)
disp("bar")

p4=p3;
disp("p4=")
disp(p4)
disp("bar")

T4=1.8*T3;
disp("T4=")
disp(T4)
disp("K")

p5=p4*(1/re)^(n);
disp("p5=")
disp(p5)
disp("bar")

T5=T4*(1/re)^(n-1)
disp("T5=")
disp(T5)
disp("K")


disp("(ii) Mean effective pressure = ")
pm=1/(rc-1)*[p3*(rho-1)+(p4*rho-p5*rc)/(n-1)-(p2-p1*
    rc)/(n-1)];
disp(pm)
disp("bar")

disp("(iii) Efficiency of the cycle")
```

```
Vs=%pi/4*D^2*L;
W=pm*10^5*Vs/1000;

V1=rc/(rc-1)*Vs
m=p1*10^5*V1/R/T1;
Q=m*(cv*(T3-T2) + cp*(T4-T3));

Efficiency=W/Q;
disp("Efficiency =")
disp(Efficiency)


disp("(iv) Power of the engine =")
P=W*num;
disp(P)
disp("kW")
```

Scilab code Exa 13.30 30

```
clc
v=10:1:100;
function p=f(v)
    p=1/v^1.4;
endfunction
plot(v,f)

v=[10 20]
p=[f(10) f(10)]
plot(v,p,'r')

v=20:1:100;
function p=fa(v)
    p=2.6515/v^1.4;
endfunction
plot(v,fa,'g')
```

```
v=[100 100]
p=[f(100) fa(100)]
plot(v,p,'--p')

v=[15 15]
p=[f(15) 0.040]
plot(v,p,'--')

v=[20 20]
p=[f(20) 0.040]
plot(v,p,'--r')

xtitle("p-v diagram", "v", "p")
legend("1-2b","2b-3", "3-4", "4-1", "2a-3a", "2-3")

//The air-standard Otto, Dual and Diesel cycles are
   drawn on common p-v and T-s diagrams for the same
    maximum pressure and maximum temperature, for
   the purpose of comparison.
// Otto 1-2-3-4-1
// Dual 1-2a-3a-3-4-1
// Diesel 1-2b-3-4-1


xset('window', 1)

s=10:1:50;
function T=fb(s)
    T=s^2
endfunction
plot(s,fb)

s=10:1:50;
function T=fc(s)
    T=(s+30)^2
endfunction
plot(s,fc,'r')
```

```

s=[12 12];
T=[fb(12) fc(12)];
plot(s,T,'--p')

s=[45 45];
T=[fb(45) fc(45)]
plot(s,T,'m')

s=10:1:27;
T=5*(s)^2;
plot(s,T,'g')

s=10:1:20;
T=7*s^2;
plot(s,T,'--r')

xtitle("T-s diagram", "s", "T")
legend("1-4", "2b-3", "1-2b", "3-4", "2-3", "2a-3a")

// The construction of cycles on T-s diagram proves
   that for the given conditions the heat rejected
   is same for all the three cycles (area under
   process line 4-1).
//   =1-(Heat rejected)/(Heat supplied)=1-constant/
   Qs

// The cycle with greater heat addition will be more
    efficient.
// From the T-s diagram

// Qs(diesel) = Area under 2b-3
// Qs(dual) = Area under 2a-3a-3
// Qs(otto) = Area under 2-3.

// Qs(diesel) > Qs(dual) > Qs(otto)

disp("Thus,   diesel   >   dual   >   otto   ")
```

Scilab code Exa 13.31 31

```
clc
cp=0.92;
cv=0.75;
y=1.22; //y=cp/cv
p1=1; //bar
p2=p1;
p3=4; //bar
p4=16; //bar
T2=300; //K

T3=T2*(p3/p2)^((y-1)/y);
T4=p4/p3*T3;
T1=T4/(p4/p1)^((y-1)/y);

disp("(i) Work done per kg of gas ")
Q_supplied=cv*(T4-T3);
Q_rejected=cp*(T1-T2);

W=Q_supplied-Q_rejected;
disp("W=")
disp(W)
disp("kJ/kg")


disp("(ii) Efficiency of the cycle =")
n=W/Q_supplied;
disp(n)
```

Scilab code Exa 13.32 32

```
clc
p1=101.325; //kPa
T1=300; //K
rp=6;
y=1.4;

T2=T1*rp^((y-1)/y);

//T3/T4=rp^((y-1)/y)
//T4=T3/1.668

//W_T=2.5*W_C

T3=2.5*(T2-T1)/(1-1/1.668);
disp("(i) Maximum temperature in the cycle =")
disp(T3)
disp("K")


disp("(ii) Cycle efficiency")
T4=T3/1.668;

n_cycle=((T3-T4) - (T2-T1))/(T3-T2);
disp(" Cycle efficiency =")
disp(n_cycle)
```

Scilab code Exa 13.33 33

```
clc
p1=1; //bar
p2=5; //bar
T3=1000; //K
cp=1.0425; //kJ/kg K
cv=0.7662; //kJ/kg K
y=cp/cv;
```

```
disp("(i)Temperature entropy diagram")

s=10:1:50;
function T=fb(s)
    T=s^2
endfunction
plot(s,fb,'--')

s=10:1:50;
function T=fc(s)
    T=(s+30)^2
endfunction
plot(s,fc,'r')

s=[12 12];
T=[fb(12) fc(12)];
plot(s,T,'m')

s=[45 45];
T=[fb(45) fc(45)]
plot(s,T,'g')


xtitle("T-s diagram", "s", "T")
legend("p1=1 bar", "p2=5 bar", "1-2", "3-4")

disp("(ii) Power required =")
T4=T3*(p1/p2)^((y-1)/y);
P=cp*(T3-T4);
disp("P=")
disp(P)
disp("kW")
```

Scilab code Exa 13.34 34

```
clc
m=0.1; //kg/s
p1=1; //bar
T4=285; //K
p2=4; //bar
cp=1; //kJ/kg K
y=1.4;

T3=T4*(p2/p1)^((y-1)/y);
disp("Temperature at turbine inlet =")
disp(T3)
disp("K")

P=m*cp*(T3-T4);
disp("Power developed =")
disp(P)
disp("kW")
```

Scilab code Exa 13.35 35

```
clc
y=1.4;
cp=1.005; //kJ/kg K
p1=1; //bar
T1=293; //K
p2=3.5; //bar
T3=873; //K
rp=p2/p1;

disp("(i) Efficiency of the cycle =")
n_cycle=1-1/rp^((y-1)/y);
disp(n_cycle)


disp("(ii) Heat supplied to air =")
```

```
T2=T1*(p2/p1)^((y-1)/y);
Q1=cp*(T3-T2);
disp(Q1)
disp("kJ/kg")

disp("(iii) Work available at the shaft =")
W=n_cycle*Q1;
disp(W)
disp("kJ/kg")

disp("(iv) Heat rejected in the cooler =")
Q2=Q1-W;
disp(Q2)
disp("kJ/kg")

disp("(v) Temperature of air leaving the turbine =")
T4=T3/rp^((y-1)/y);
disp(T4)
disp("K")
```

Scilab code Exa 13.36 36

```
clc
T1=303; //K
T3=1073; //K
C=45000; //kJ/kg
cp=1; //kJ/kg K
y=1.4;

T2=sqrt(T1*T3);
T4=T2;

//W_turbine-W_compressor=m_f*C*n=100;

m_f=100/C/(1-(T4-T1)/(T3-T2));
```

```
disp("m_f=")
disp(m_f)
disp("kg/s")

m_a=(100-m_f*(T3-T4))/(T3-T4-T2+T1);
disp("m_a=")
disp(m_a)
disp("kg/s")
```

Scilab code Exa 13.37 37

```
clc
T1=300; //K
p1=1; //bar
rp=6.25;
T3=1073; //K
n_comp=0.8;
n_turbine=0.8;
cp=1.005; //kJ/kg K
y=1.4;

T2=T1*(rp)^((y-1)/y);

//Let T2'=T2a
T2a=(T2-T1)/n_comp + T1;

W_comp=cp*(T2a-T1);
disp("Compressor work =")
disp(W_comp)
disp("kJ/kg")

T4=T3/rp^((y-1)/y);
T4a=T3-n_turbine*(T3-T4);

W_turbine=cp*(T3-T4a);
```

```
disp("Turbine work =")
disp(W_turbine)
disp("kJ/kg")

Q_s=cp*(T3-T2a);
disp("Heat supplied =")
disp(Q_s)
disp("kJ/kg")

W_net=W_turbine - W_comp;

n_cycle=W_net/Q_s*100;
disp("n_cycle")
disp(n_cycle)
disp("%")

t4a=T4a-273;
disp("Turbine exhaust temperature =")
disp(t4a)
disp("0C")
```

Scilab code Exa 13.38 38

```
clc
n_turbine=0.85;
n_compressor=0.80;
T3=1148; //K
T1=300; //K
cp=1; //kJ/kg K
y=1.4;
p1=1; //bar
p2=4; //bar
C=42000; //kJ/kg K
n_cc=0.90;

```

```
T2=T1*(p2/p1)^((y-1)/y);

T2a=(T2-T1)/n_compressor + T1;

ratio=0.9*C/cp/(T3-T2a) - 1; //ratio=ma/mf
disp("A/F ratio =")
disp(ratio)
```

Scilab code Exa 13.39 39

```
clc
cp=1.005; //kJ/kg K
y1=1.4;
y2=1.333;
p1=1; //bar
p4=p1;
T1=300; //K
p2=6.2; //bar
p3=p2;
n_compressor=0.88;
C=44186; //kJ/kg
ratio=0.017; //Fuel-air ratio; kJ/kg of air
n_turbine=0.9; //
cpg=1.147;

T2=T1*(p2/p1)^((y1-1)/y1);
T2a=(T2-T1)/n_compressor + T1; //T2'

T3=ratio*C/(1+ratio)/cp + T2a;
T4=T3*(p4/p3)^((y2-1)/y2);
T4a=T3-n_turbine*(T3-T4);
W_compressor=cp*(T2a-T1);
W_turbine=cpg*(T3-T4a);
W_net=W_turbine-W_compressor;
Qs=ratio*C;
```

```
n_th=W_net/Qs*100;
disp("Thermal efficiency =")
disp(n_th)
disp("%")
```

Scilab code Exa 13.40 40

```
clc
cp=1; //kJ/kg K
y=1.4;
C=41800; //kJ/kg
p1=1; //bar
T1=293; //K
p2=4; //bar
p4=p1;
p3=p2;
n_compressor=0.80;
n_turbine=0.85;
ratio=90; //Air-Fuel ratio
m_a=3; //kg/s

disp("(i)Power developed ")
T2=T1*(p2/p1)^((y-1)/y);
T2a=(T2-T1)/n_compressor + T1;
T3=C/(1+ratio)/cp + T2a;
T4=T3*(p4/p3)^((y-1)/y);
T4a=T3-n_turbine*(T3-T4);

W_turbine=(ratio+1)/ratio*cp*(T3-T4a);
W_compressor=cp*(T2a-T1);
W_net=W_turbine-W_compressor;
Qs=1/ratio*C;

P=m_a*W_net;
```

```
disp("Power=")
disp(P)
disp("kW/kg of air")


disp("(ii) Thermal efficiency of cycle =")
n_thermal=W_net/Qs;
disp(n_thermal)
disp("%")
```

Scilab code Exa 13.41 41

```
clc
T1=288; //K
T3=883; //K
rp=6; //rp=p2/p1
n_compressor=0.80;
n_turbine=0.82;
m_a=16; //kg/s
cp1=1.005; //kJ/kg K, For compression process
y1=1.4; // For compression process
cp2=1.11; //kJ/kg K
y2=1.333;

T2=T1*(rp)^((y1-1)/y1);
T2a=(T2-T1)/n_compressor + T1;
T4=T3/rp^((y2-1)/y2);
T4a=T3-n_turbine*(T3-T4);

W_compressor=cp1*(T2a-T1);
W_turbine=cp2*(T3-T4a);
W_net=W_turbine-W_compressor;

Power=m_a*W_net;
disp("Power =")
```

```
disp(Power)
disp("kW")
```

Scilab code Exa 13.42 42

```
clc
cp=1.11;
T3=883; //K
T2a=529; //K
W_turbine=290.4; //kJ/kg
W_net=48.2; //kJ/kg

Qs=cp*(T3-T2a);

n_thermal=W_net/Qs*100;
disp("Thermal efficiency =")
disp(n_thermal)
disp("%")

W_ratio=W_net/W_turbine; //Work ratio=net work
    output/Gross work output
disp("Work ratio =")
disp(W_ratio)
```

Scilab code Exa 13.43 43

```
clc
p1=1; //bar
p2=5; //bar
p3=4.9; //bar
p4=1; //bar
T1=293; //K
T3=953; //K
```

```
n_compressor=0.85;
n_turbine=0.80;
n_combustion=0.85;
y=1.4;
cp=1.024; //kJ/kg K
P=1065; //kW

disp("(i) The quantity of air circulation")
T2=T1*(p2/p1)^((y-1)/y);
T2a=(T2-T1)/n_compressor + T1;
T4=T3*(p4/p3)^((y-1)/y);
T4a=T3-n_turbine*(T3-T4);

W_compressor=cp*(T2a-T1);
W_turbine=cp*(T3-T4a);
W_net=W_turbine-W_compressor;

m_a=P/W_net;
disp("m_a =")
disp(m_a)
disp("kg")


disp("(ii) Heat supplied per kg of air circulation =
   ")
Qs=cp*(T3-T2a)/n_combustion;
disp(Qs)
disp("kJ/kg")


disp("(iii) Thermal efficiency of the cycle =")
n_thermal=W_net/Qs*100;
disp(n_thermal)
disp("%")
```

Scilab code Exa 13.44 44

```
clc
m_a=20; //kg/s
T1=300; //K
T3=1000; //K
rp=4; //rp=p2/p1
cp=1; //kJ/kg K
y=1.4;

T2=T1*(rp)^((y-1)/y);
T4=T3-T2+T1;

//p5/p4=(p5/p3)*(p3/p4)
//let p3/p4=r1
r1=(T3/T4)^(y/(y-1));

//r2=p5/p4;
r2=1/4*r1;
P_ratio=1/r2; //Pressure ratio of low pressure
    turbine
disp("Pressure ratio of low pressure turbine =")
disp(P_ratio)

T5=T4/(P_ratio)^((y-1)/y);
disp("Temperature of the exhaust from the unit =")
disp(T5)
disp("K")
```

Scilab code Exa 13.45 45

```
clc
T1=288; //K
p1=1.01; //bar
rp=7;
```

```
p2=rp*p1;
p3=p2;
p5=p1;
n_compressor=0.82;
n_turbine=0.85;
n_turbine=0.85;
T3=883; //K
cpa=1.005;
cpg=1.15;
y1=1.4;
y2=1.33;

disp("(i) Pressure and temperature of the gases
    entering the power turbine =")

T2=T1*rp^((y1-1)/y1);
T2a=(T2-T1)/n_compressor + T1;

W_compressor=cpa*(T2a-T1);

T4a=(cpg*T3-W_compressor)/cpg;
disp("Temperature of gases entering the power
    turbine =")
disp(T4a)
disp("K")

T4=T3-(T3-T4a)/n_turbine;

p4=p3/(T3/T4)^(y2/(y2-1));
disp("Pressure of gases entering the power turbine =
    ")
disp(p4)
disp("bar")


disp("(ii) Net power developed per kg/s mass flow")
T5=T4a/(p4/p5)^((y2-1)/y2);
T5a=T4a-n_turbine*(T4a-T5);
```

```

W_turbine=cpg*(T4a-T5a);
disp(" Net power developed per kg/s mass flow =")
disp(W_turbine)
disp("kW")


disp("(iii) Work ratio =")
W_ratio=W_turbine/(W_turbine+W_compressor);
disp(W_ratio)


disp("(iv) Thermal efficiency of the unit")
Qs=cpg*(T3-T2a);
n_thermal=W_turbine/Qs*100;
disp("n_thermal =")
disp(n_thermal)
disp("%")
```

Scilab code Exa 13.46 46

```
clc
T1=288; //K
rp=4; //rp=p2/p1=p3/p4
n_compressor=0.82;
e=0.78; //Effectiveness of the heat exchanger
n_turbine=0.70;
T3=873; //K
y=1.4;
R=0.287;

T2=T1*(rp)^((y-1)/y);
T2a=(T2-T1)/n_compressor + T1;
T4=T3/rp^((y-1)/y);
T4a=T3-n_turbine*(T3-T4);
```

```
cp=R*y/(y-1);
W_compressor=cp*(T2a-T1);
W_turbine=cp*(T3-T4a);
W_net=W_turbine-W_compressor;

T5=e*(T4a-T2a) + T2a;
Qs=cp*(T3-T5);

n_cycle=W_net/Qs*100;
disp("Efficiency =")
disp(n_cycle)
disp("%")
```

Scilab code Exa 13.47 47

```
clc

//Simple cycle
p2=4; //bar
p1=1; //bar
T1=293;
n_compressor=0.8;
n_turbine=0.85;
ratio=90; //Air Fuel ratio
C=41800; //kJ/kg
cp=1.024;
p4=1.01; //bar
p3=3.9; //bar
y=1.4;
e=0.72; //thermal ratio

T2=T1*(p2/p1)^((y-1)/y);
T2a=(T2-T1)/n_compressor + T1;
T3=C/cp/(ratio+1)+471;
```

```
T4=T3*(p4/p3)^((y-1)/y);

T4a=T3-n_turbine*(T3-T4);

n_thermal1=((T3-T4a)-(T2a-T1))/(T3-T2a)*100;
disp("Thermal efficiency of simple cycle=")
disp(n_thermal1)
disp("%")


//Heat exchanger cycle

T2a=471; // K (as for simple cycle)
T3=919.5; // K (as for simple cycle)
p3=4.04-0.14-0.05; //bar
p4=1.01+0.05; //bar

T4=T3*(p4/p3)^((y-1)/y);
T4a=T3-n_turbine*(T3-T4);

T5=e*(T4a-T2a) + T2a;

n_thermal2=((T3-T4a) - (T2a-T1))/(T3-T5)*100;
disp("Thermal efficiency of heat exchanger cycle =")
disp(n_thermal2)
disp("%")

dn=n_thermal2-n_thermal1;
disp("Increase in thermal efficiency =")
disp(dn)
disp("%")
```

Scilab code Exa 13.48 48

```
clc
```

```
T1=293; //K
T6=898; //K
T8=T6;
n_c=0.8; //Efficiency of each compressor stage
n_t=0.85; //Efficiency of each turbine stage
n_mech=0.95;
e=0.8;
cpa=1.005; //kJ/kg K
cpg=1.15; //kJ/kg K
y1=1.4;
y2=1.333;

disp("(i) Thermal efficiency")
T3=T1;

// p2/p1=sqrt(9)=3
T2=T1*(3)^((y1-1)/y1);
T2a=(T2-T1)/n_c + T1;
T4a=T2a;
W_c=cpa*(T2a-T1); //Work input per compressor stage
W_t=2*W_c/n_mech; //Work output of H.P. turbine
T7a=T6-W_t/cpg;
T7=T6-(T6-T7a)/n_t;

// (p6/p7)=(T6/T7)^(y2/(y2-1))=4.82;
// p8/p9=9/4.82=1.86
T9=T8/(1.86)^((y2-1)/y2);
T9a=T8-n_t*(T8-T9);

W=cpg*(T8-T9a)*n_mech; //Net work output
T5=e*(T9a-T4a)+T4a;

Q=cpg*(T6-T5)+cpg*(T8-T7a); //Heat supplied
n_thermal=W/Q*100;
disp("n_thermal =")
disp(n_thermal)
disp("%")

```

```
disp("(ii) Work ratio")
Gross_work=W_t+W/n_mech;
W_ratio=W/Gross_work;
disp("Work ratio=")
disp(W_ratio)


disp("(iii) Mass flow rate =")
m=4500/W;
disp(m)
disp("kg/s")
```

Scilab code Exa 13.49 49

```
clc
T1=293; //K
T5=1023; //K
T7=T5;
p1=1.5; //bar
p2=6; //bar
n_c=0.82;
n_t=0.82;
e=0.70;
P=350; //kW
cp=1.005; //kJ/kg K
y=1.4;

T3=T1;
px=sqrt(p1*p2);
T2=T1*(px/p1)^((y-1)/y);
T2a=T1+(T2-T1)/n_c;
T4a=T2a;
p5=p2;
T6=T5/(p5/px)^((y-1)/y);
T6a=T5-n_t*(T5-T6);
```

```
T8a=T6a;
Ta=T4a+e*(T8a-T4a);
W_net=2*cp*[(T5-T6a)-(T2a-T1)];

Q1=cp*(T5-T4a)+cp*(T7-T6a); //Without regenerator
Q2=cp*(T5-Ta)+cp*(T7-T6a);

disp("n_thermal without regenerator =")
n1=W_net/Q1*100;
disp(n1)
disp("%")

disp("n_thermal woth regenerator =")
n2=W_net/Q2*100;
disp(n2)
disp("%")

disp("(iii) Mass of fluid circulated =")
m=P/W_net;
disp(m)
disp("kg/s")
```

Chapter 14

Refrigeration Cycles

Scilab code Exa 14.1 1

```
clc
T2=235; //K
P=1.3; //kW

disp("(i) C.O.P. of Carnot refrigerator =")
COP=14000/P/60/60;
disp(COP)


disp("(ii) Higher temperature of the cycle =")
T1=T2/COP + T2;
t1=T1-273;
disp(t1)
disp("0C")


disp("(iii) Heat delivered as heat pump")
Qabs=14000/60; //Heat absorbed
W=P*60;
Q=Qabs+W;
disp("Q=")
```

```
disp(Q)
disp("kJ/min")

COP=Q/W;
disp("COP of heat pump =")
disp(COP)
```

Scilab code Exa 14.2 2

```
clc
T1=308; //K
T2=258; //K
capacity=12; //tonne

COP=T2/(T1-T2);
disp("(i) Co-efficient of performance =")
disp(COP)


disp("(ii) Heat rejected from the system per hour")
W=capacity*14000/5.16;
Q=capacity*14000+W;
disp("Q=")
disp(Q)
disp("kJ/h")


disp("(iii) Power required =")
P=W/60/60;
disp(P)
disp("kW")
```

Scilab code Exa 14.3 3

```
clc
T2=268; //K
T1=308; //K
Q=29; //Heat leakage from the surroundings into the
   cold storage in kW
COP_ideal=T2/(T1-T2);
COP_actual=1/3*COP_ideal;

W=Q/COP_actual;
disp("Power required =")
disp(W)
disp("kW")
```

Scilab code Exa 14.4 4

```
clc
T1=293; //K
T2=265; //K
T0=273; //K
L=335; //Latent heat of ice in kJ/kg
cpw=4.18;

COP=T2/(T1-T2);
Rn=cpw*(T1-T0)+L;
m_ice=COP*3600/Rn;
disp("ice formed per kWh =")
disp(m_ice)
disp("kg")
```

Scilab code Exa 14.5 5

```
clc
T1=291; //K
```

```
T2=265; //K
T0=273; //K
cpw=4.18; //kJ/kg
cpi=2.09; //kJ/kg
L=334; //kJ/kg
m=400; //kg

COP=T2/(T1-T2);
Rn=cpw*(T1-T0) + L + cpi*(T0-T2);

W=Rn*m/COP/3600; //kJ/s
disp("Least power =")
disp(W)
disp("kW")
```

Scilab code Exa 14.6 6

```
clc
cpw=4.18; //kJ/kg

disp("(i) Quantity of ice produced")
t=20; //0C
L=335; //kJ/kg
capacity=280; //tonnes

Q1=cpw*t + L; //Heat to be extracted per kg of water
    (to form ice at 0 C )
Rn=capacity*14000; //kJ/h

m_ice=Rn*24/Q1/1000;
disp("Quantity of ice produced in 24 hours =")
disp(m_ice)
disp("tonnes")


```

```
disp("(ii) Minimum power required =")
T1=298; //K
T2=263; //K

COP=T2/(T1-T2);
W=Rn/COP/3600; //kJ/s
disp("Power required =")
disp(W)
disp("kW")
```

Scilab code Exa 14.7 7

```
clc
cp1=1.25; //kJ/kg 0C
cp2=2.93; //kJ/kg 0C
L=232; //kJ/kg
T1=-3; //0C
T2=-8; //0C
T3=25; //0C

Q1=cp2*(T3-T1) + L + cp1*(T1-T2); //Heat removed in
    8 hours from each kg of fish

Q=Q1*20*1000/8; //Heat removed by the plant /min

disp("(i) Capacity of the refrigerating plant =")
capacity=Q/14000; //tonnes
disp(capacity)
disp("tonnes")

disp("(ii) Carnot cycle C.O.P. between this
    temperature range.")
T1=298; //K
T2=265; //K

```

```
COP=T2/(T1-T2);
disp("COP of reversed carnot cycle =")
disp(COP)


disp("(iii) Power required")
COP_actual=1/3*COP;

W=Q/COP_actual/3600; //kJ/s
disp("Power =")
disp(W)
disp("kW")
```

Scilab code Exa 14.8 8

```
clc
T1=1273; //K
T2=298; //K
T3=268; //K
T4=298; //K

//Let Q2/Q1=r1 , r2=Q3/Q4;
r1=298/1273; //Q2/Q1
r2=268/298; //Q3/Q4

//Let Q4/Q1=r
r=(1-r1)/(1-r2);
disp("The ratio in which the heat pump and heat
    engine share the heating load =")
disp(r)
```

Scilab code Exa 14.9 9

```
clc
y=1.4;
n=1.35;
cp=1.003; //kJ/kg K
p2=1; //bar
p1=8; //bar
T3=282; //K
T4=302; //K
T1=T4;
T4=T3*(p1/p2)^((n-1)/n);
T2=T1*(p2/p1)^((n-1)/n);

Q1=cp*(T3-T2); //Heat extracted from cold chamber
    per kg of air
Q2=cp*(T4-T1); //Heat rejected in the cooling
    chamber per kg of air
cv=cp/y;
R=cp-cv;
W=n/(n-1)*R*((T4-T3) - (T1-T2));

COP=Q1/W;
disp("COP=")
disp(COP)
```

Scilab code Exa 14.10 10

```
clc
p1=1000; //kPa
p2=100; //kPa
p4=p1;
p3=p2;
E=2000; // Refrigerating effect produced in kJ/min
T3=268; //K
T1=303; //K
y=1.4;
```

```
disp("(i) Mass of air circulated per minute")
T2=T1*(p2/p1)^((y-1)/y);
e=cp*(T3-T2); //Refrigerating effect per kg; kJ/kg

m=E/e;
disp("m=")
disp(m)
disp("kg/min")


disp("(ii) Compressor work (Wcomp.), expander work (Wexp.) and cycle work (Wcycle)")
T4=T3*(p4/p3)^((y-1)/y);

Wcomp=y/(y-1)*m*R*(T4-T3);
disp("Compressor work =")
disp(Wcomp)
disp("kJ/min")

Wexp=y/(y-1)*m*R*(T1-T2);
disp("Expander work =")
disp(Wexp)
disp("kJ/min")

W_cycle=Wcomp-Wexp;
disp("Wcycle=")
disp(W_cycle)
disp("kJ/min")


disp("(iii) C.O.P. and power required")
COP=E/W_cycle;
disp("COP =")
disp(COP)

P=W_cycle/60;
disp("Power required =")
```

```
disp(P)
disp("kW")
```

Scilab code Exa 14.11 11

```
clc
y=1.4;
cp=1.003; //kJ/kg K
T3=289; //K
T1=314; //K
p1=5.2; //bar
p2=1; //bar
capacity=6; //tonnes
R=287; //J/kg K
l=0.2; //m

T4=T3*(p1/p2)^((y-1)/y);
T2=T1*(p2/p1)^((y-1)/y);


disp("(i) C.O.P. =")
COP=T2/(T1-T2);
disp(COP)

disp("(ii) Mass of air in circulation")
e=cp*(T3-T2); //Refrigerating effect per kg of air
E=capacity*14000; //Refrigerating effect produced by the refrigerating machine in kJ/h

m=E/e/60;
disp("mass of air in circulation =")
disp(m)
disp("kg/min")
```

```
disp("Piston displacement of compressor")
V3=m*R*T3/p2/10^5;

V_swept=V3/2/240;

d_c=sqrt(V_swept/l/%pi*4);

disp("Diameter or bore of the compressor cylinder =")
disp(d_c*1000)
disp("mm")

disp("Piston displacement of expander")
V2=m*R*T2/p2/10^5;
V_swept=V2/2/240;

d_c=sqrt(V_swept/l/%pi*4);
disp("Diameter or bore of the expander cylinder =")
disp(d_c*1000)
disp("mm")


disp("(v) Power required to drive the unit")
W=capacity*14000/COP/3600;
disp("power =")
disp(W)
disp("kW")
```

Scilab code Exa 14.12 12

```
clc
m=6; //kg/min
n_relative=0.50;
cpw=4.187; //kJ/kg K
L=335; //kJ/kg
```

```
h_f2=31.4; //kJ/kg
h_fg2=154; //kJ/kg
h_f3=59.7; //kJ/kg
h_fg3=138; //kJ/kg
h_f4=59.7; //kJ/kg
x2=0.6;
s_f3=0.2232; //kJ/kg K
s_f2=0.1251; //kJ/kg K
T2=268; //K
T3=298; //K

h2=h_f2+x2*h_fg2;
x3=((s_f2-s_f3)+x2*(h_fg2/T2))*T3/h_fg3;
h3=h_f3+x3*h_fg3;
h1=h_f4;
COP_th=(h2-h1)/(h3-h2); //Theoritical COP
COP=n_relative*COP_th;

Q=cpw*(20-0) + L; //Heat extracted from 1 kg of
    water at 20 C for the formation of 1 kg of ice
    at 0 C

m_ice=COP*m*(h3-h2)/Q*60*24/1000; //in 24 hours
disp("m_ice=")
disp(m_ice)
disp("tonnes")
```

Scilab code Exa 14.13 13

```
clc
L=335; //kJ/kg
h3=1319.22; //kJ/kg
h1=100.04; //kJ/kg
h4=h1;
```

```
s_f2=-2.1338; //kJ/kg K
s_g2=5.0585; //kJ/kg K
s_g3=4.4852; //kJ/kg K
h_f2=-54.56; //kJ/kg
h_g2=1304.99; //kJ/kg

x2=(s_g3-s_f2)/(s_g2-s_f2);

h2=h_f2+x2*(h_g2-h_f2);
COP_theoritical=(h2-h1)/(h3-h2);
COP_actual=0.62*COP_theoritical;
RE=COP_actual*(h3-h2); //Actual refrigerating effect
    per kg
Q=28*1000*L/24/3600; //Heat to be extracted per
   second

m=Q/RE; //Mass of refrigerant circulated per second

W=m*(h3-h2);
disp("Power required =")
disp(W)
disp("kW")
```

Scilab code Exa 14.14 14

```
clc
h_f2=158.2; //kJ/kg
x2=0.62;
h_fg2=1280.8;
h1=298.9; //kJ/kg
h_f4=h1;
s_f2=0.630; //kJ/kg K
T2=268; //K
T3=298; //K
s_f3=1.124; //kJ/kg K
```

```
h_fg3=1167.1; //kJ/kg
m=6.4; //kg/min
cp=4.187;
L=335; //kJ/kg
h_f3=298.9; //kJ/kg

h2=h_f2+x2*h_fg2;
x3=((s_f2-s_f3)+x2*h_fg2/T2)/h_fg3*T3;
h3=h_f3+x3*h_fg3;

COP_theoritical=(h2-h1)/(h3-h2);
COP_actual=0.55*COP_theoritical;

W1=h3-h2; //Work done per kg of refrigerant
W=m*W1/60; //Work done per second kJ/s

Q=15*cp+L;
m_ice=W*3600*24/Q;
disp("Amount of ice formed in 24 hours =")
disp(m_ice)
disp("kg")
```

Scilab code Exa 14.15 15

```
clc
RE=5*14000/3600; //Total refrigeration produced in kg/s
h2=183.19; //kJ/kg
h3=209.41; //kJ/kg
h4=74.59; //kJ/kg
h1=h4;

disp("(i) The refrigerant flow rate")
RE_net=h2-h1; //Net refrigerating effect produced per kg
```

```
m=RE/RE_net;
disp("Refrigerant flow rate =")
disp(m)
disp("kg/s")


disp("(ii) The C.O.P. =")
COP=(h2-h1)/(h3-h2);
disp(COP)


disp("(iii) The power required to drive the
    compressor =")
P=m*(h3-h2);
disp(P)
disp("kW")


disp("(iv) The rate of heat rejection to the
    condenser =")
rate=m*(h3-h4);
disp(rate)
disp("kW")
```

Scilab code Exa 14.16 16

```
clc

disp("(i) If an expansion cylinder is used in a
    vapour compression system, the work recovered
    would be extremely small, in fact not even
    sufficient to overcome the mechanical friction.
    It will not be possible to gain any work. Further
    , the expansion cylinder is bulky. On the other
    hand the expansion valve is a very simple and
```

```
   handy device, much cheaper than the expansion
   cylinder. It does not need installation,
   lubrication or maintenance.")
disp("The expansion valve also controls the
   refrigerant flow rate according to the
   requirement, in addition to serving the function
   of reducting the pressure of the refrigerant.")


disp("(ii) The comparison between centrifugal and
   reciprocating compressors ")

disp("1.Suitability")

disp("Centrifugal compressor")
disp("Suitable for handling large volumes of air at
   low pressures")

disp("Reciprocating compressor")
disp("Suitable for low discharges of air at high
   pressure.")


disp("2.Operational speeds")

disp("Centrifugal compressor")
disp("Usually high")

disp("Reciprocating compressor")
disp("Low")


disp("3.Air supply")

disp("Centrifugal compressor")
disp("Continuous")

disp("Reciprocating compressor")
```

```
disp("Pulsating")


disp("4.Balancing")

disp("Centrifugal compressor")
disp("Less Vibrations")

disp("Reciprocating compressor")
disp("Cyclic vibrations occur")


disp("5.Lubrication system")

disp("Centrifugal compressor")
disp("Generally simple lubrication systems are
   required.")

disp("Reciprocating compressor")
disp("Generally complicated")


disp("6.Quality of air delivered")

disp("Centrifugal compressor")
disp("Air delivered is relatively more clean")

disp("Reciprocating compressor")
disp("Generally contaminated with oil.")


disp("7.Air compressor size")

disp("Centrifugal compressor")
disp("Small for given discharge")

disp("Reciprocating compressor")
disp("Large for same discharge")
```

```
disp("8.Free air handled")

disp("Centrifugal compressor")
disp("2000-3000 m3/min")

disp("Reciprocating compressor")
disp("250-300 m3/min")


disp("9.Delivery pressure")

disp("Centrifugal compressor")
disp("Normally below 10 bar")

disp("Reciprocating compressor")
disp("500 to 800 bar")


disp("10.Usual standard of compression")

disp("Centrifugal compressor")
disp("Isentropic compression")

disp("Reciprocating compressor")
disp("Isothermal compression")


disp("11.Action of compressor")

disp("Centrifugal compressor")
disp("Dynamic action")

disp("Reciprocating compressor")
disp("Positive displacement")
```

```
disp("(iii)")
h2=344.927; //kJ/kg
h4=228.538; //kJ/kg
h1=h4;
cpv=0.611; ///kJ/kg0C
// s2=s3
t3=39.995; //0C
h3=363.575+cpv*(t3-30);
Rn=h2-h1;
W=h3-h2;

COP=Rn/W;
disp("COP =")
disp(COP)

cp=2.0935; //kJ/kg 0C
Q=2400/24/3600*[4.187*(15-0)+335+cp*(0-(-5))];

W=Q/COP;
disp("Work required =")
disp(W)
disp("kW")
```

Scilab code Exa 14.17 17

```
clc
disp("(ii) Mass of refrigerant circulated per minute
   ")
h2=352; //kJ/kg
h3=374; //kJ/kg
h4=221; //kJ/kg
h1=h4;
v2=0.08; //m^3/kg
rpm=500;
D=0.2;
```

```
L=0.15;
n_vol=0.85;

RE=h2-h1;
V=%pi/4*D^2*L*rpm*2*n_vol;

m=V/v2;
disp("Mass of refrigerant circulated per minute = ")
disp(m)
disp("kg/min")

disp("(iii) Cooling capacity in tonnes of refrigeration =")
cc=50*(h2-h1)*60/14000;
disp(cc)
disp("TR")

disp("(iv)COP =")
COP=(h2-h1)/(h3-h2);
disp(COP)
```

Scilab code Exa 14.18 18

```
clc
te=-10; //0C
tc=40; //0C
h3=220; //kJ/kg
h2=183.1; //kJ/kg
h1=74.53; //kJ/kg
h_f4=26.85; //kJ/kg
m=1; //kg

disp("(i) The C.O.P. the cycle =")
COP=(h2-h1)/(h3-h2);
disp(COP)
```

```
disp("(ii) Refrigerating capacity =")
RC=m*(h2-h1);
disp(RC)
disp("kJ/min")

disp("Compressor power =")
CP=m*(h3-h2)/60;
disp(CP)
disp("kJ/s")
```

Scilab code Exa 14.19 19

```
clc
h2=178.61; //kJ/kg
h3a=203.05; //kJ/kg
h_f4=74.53; //kJ/kg
h1=h_f4;
s3a=0.682; //kJ/kg K
s2=0.7082; //kJ/kg K
cp=0.747; //kJ/kg K
T3a=313; //K
CE=20; //Cooling effect
C=0.03;
v_g=0.1088;
p_d=9.607;
p_s=1.509;
n=1.13;

m=CE/(h2-h1);
T3=T3a*%e^((s2-s3a)/cp)
h3=h3a+cp*(T3-T3a);

P=m*(h3-h2);
disp("Power required by the machine =")
```

```
disp(P)
disp("kW")

n_vol=1+C-C*(p_d/p_s)^(1/n); //Volumetric efficiency
V1=m*v_g; //volume of refrigerant at the intake conditions
V_swept=V1/n_vol;

V=V_swept*60/300;
disp("Piston displacement =")
disp(V)
disp("m^3")
```

Scilab code Exa 14.20 20

```
clc
h2=1450.22; //kJ/kg
h3a=1488.57; //kJ/kg
h_f4=366.072; //kJ/kg
cpl2=4.556; //kJ/kg K
cpv1=2.492; //kJ/kg K
cpv2=2.903; //kJ/kg K
T1=303; //K
T2=308; //K
s3a=5.2086; //kJ/kg K
s2=5.755; //kJ/kg K
T3a=308; //K
N=1000;

h_f4a=h_f4-cpl2*(T2-T1);
h1=h_f4a;
T3=T3a*%e^((s2-s3a)/cpv2);
h3=h3a+cpv2*(T3-T3a);
m=50/(h2-h1);

```

```
disp("(i) Power required =")
P=m*(h3-h2);
disp(P)
disp("kW")


disp("(ii) Cylinder dimensions ")
D=(m*4*60/%pi/1.2/N/0.417477)^(1/3);
disp("Diameter of cylinder =")
disp(D)
disp("m")

L=1.2*D;
disp("Length of the cylinder=")
disp(L)
disp("m")
```

Scilab code Exa 14.21 21

```
clc
cooling_load=150; //W
n_vol=0.8;
N=720; //rpm
h2=183; //kJ/kg
h1=74.5; //kJ/kg
v2=0.08; //m^3/kg

m=cooling_load/(108.5*1000);
disp("Mass flow rate of the refrigerant =")
disp(m)
disp("kJ/s")

d=m*v2/n_vol;
disp("Displacement volume of the compressor =")
```

```
disp(d)
disp("m^3/s")
```

Scilab code Exa 14.22 22

```
clc
h2=183.2; //kJ/kg
h3=222.6; //kJ/kg
h4=84.9; //kJ/kg

v2=0.0767; //m^3/kg
v3=0.0164; //m^3/kg
v4=0.00083; //m^3/kg

V=1.5*1000*10^(-6); //Piston displacement volume m
    ^3/revolution
n_vol=0.80;

disp("(i) Power rating of the compressor (kW)")
discharge=V*1600*n_vol; //Compressor discharge
m=discharge/v2;

P=m/60*(h3-h2); //kW
disp("Power =")
disp(P)
disp("kW")


disp("(ii) Refrigerating effect =")
RE=m/60*(h2-h4);
disp(RE)
disp("kW")
```

Scilab code Exa 14.23 23

```
clc
COP=6.5;
W=50; //kW
h3a=201.45; //kJ/kg
h_f4=69.55; //kJ/kg
h1=h_f4;
h2=187.53; //kJ/kg
cp=0.6155; //kJ/kg
t3a=35; //0C

RC=W*COP; //Refrigerating capacity
Q1=h2-h_f4; //Heat extracted per kg of refrigerant
rate=RC/Q1; //Refrigerant flow rate
Q2=W/rate; //Heat input per kg
h=h2+Q2; //Enthalpy of vapour after compression
Q=h-h3a; //Superheat

t3=Q/cp+t3a;
disp("t3=")
disp(t3)
disp(" C ")
```

Scilab code Exa 14.24 24

```
clc
Q1=500; //total heating requirement of 500 kJ/min
n_compressor=0.8;
s1=0.7035; //kJ/kg K
s2=0.6799; //kJ/kg K
T2=322.31; //K
cp=0.7; //kJ/kg K
h_v2=206.24; //kJ/kg
h_l2=84.21; //kJ/kg
```

```
h_v1=182.07 //kJ/kg

Q2=Q1/n_compressor; //Heat rejected by the cycle

//Entropy of dry saturated vapour at 2 bar= Entropy of superheated vapour at 12 bar
T=T2*%e^((s1-s2)/cp);

H=h_v2+cp*(T-T2); //Enthalpy of superheated vapour at 12 bar
Q3=H-h_l2; //Heat rejected per cycle
m=Q2/Q3; //kg/min
W=m*(H-h_v1)/60; //kW
W_actual=W/n_compressor;
disp("Power =")
disp(W_actual)
disp("kW")
```

Scilab code Exa 14.25 25

```
clc
h2a=183.2; //kJ/kg K
cpv=0.733; //Vapour specific heat in kJ/kg K
cpl=1.235; //Liquid specific heat in kJ/kg K
s2a=0.7020; //Entropy of vapour in kJ/kg K
s3a=0.6854; //Entropy of vapour in kJ/kg K
T2=270; //K
T2a=263; //K
T3a=303; //K
h3a=199.6; //kJ/kg
h_f4=64.6; //kJ/kg
dT4=6; //dT4=T4-T4a
v2a=0.0767;
n=2; //number of cylinder

```

```
h2=h2a+cpv*(T2-T2a);
s2=s2a+cpv*log(T2/T2a);

T3=T3a*%e^((s2-s3a)/cpv);
h3=h3a+cpv*(T3-T3a);
h_f4a=h_f4-cpl*dT4;
h1=h_f4a;

v2=v2a/T2a*T2;

disp("(i) Refrigerating effect per kg =")
RE=h2-h1;
disp(RE)
disp("kJ/kg")

disp("(ii) Mass of refrigerant to be circulated per
    minute =")
m=2400/RE;
disp(m)
disp("kg/min")

disp("(iii) Theoretical piston displacement per
    minute =")
v=m*v2;
disp(v)
disp("m^3/min")

disp("(iv) Theoretical power required to run the
    compressor = ")
P=m/60*(h3-h2);
disp(P)
disp("kW")

disp("(v) Heat removed through the condenser per min
    =")
Q=m*(h3-h_f4a);
disp(Q)
disp("kJ/min")
```

```
disp("(vi) Theoretical bore (d) and stroke (l)")
d=(v/n/%pi*4/1.25/1000)^(1/3)*1000;
disp("Theroritical bore =")
disp(d)
disp("mm")

disp("stroke =")
l=1.25*d;
disp(l)
disp("mm")
```

Scilab code Exa 14.26 26

```
clc
h2=1597; //kJ/kg
h3=1790; //kJ/kg
h4=513; //kJ/kg
h1=h4;
t3=58; //0C
x1=0.13;
tc=27; //0C
capacity=10.5; //tonnes

disp("(i) Condition of the vapour at the outlet of
    the compressor =")
t=t3-tc;
disp(t)
disp(" C ")

disp("(ii) Condition of vapour at entrance to
    evaporator =")
disp(x1)

disp("COP =")
```

```
COP=(h2-h1)/(h3-h2);
disp(COP)

disp("(iv) Power required =")
P=capacity*14000/COP/3600;
disp(P)
disp("kW")
```

Scilab code Exa 14.27 27

```
clc
h2=615; //kJ/kg
h3=664; //kJ/kg
h4=446; //kJ/kg
h1=h4;
v2=0.14; //m^3/kg
capacity=20; //tonnes
n=6; //number of cylinder

disp("(i) Refrigerating effect per kg =")
RE=h2-h1;
disp(RE)
disp("kJ/kg")

disp("(ii) Mass of refrigerant to be circulated per
    minute =")
m=capacity*14000/RE/60;
disp(m)
disp("kg/min")

disp("(iii) Theoretical piston displacement =")
v=v2*m;
disp(v)
disp("m^3/min")

```

```
disp("(iv) Theoretical power =")
P=m/60*(h3-h2);
disp(P)
disp("kW")

disp("(v)COP =")
COP=(h2-h1)/(h3-h2);
disp(COP)

disp("(vi) Heat removed through the condenser =")
Q=m*(h3-h4);
disp(Q)
disp("kJ/min")

disp("(vii) Theoretical displacement per minute per
    cylinder")

d=(v/n*4/%pi/950)^(1/3)*1000;
disp("Diameter of cylinder =")
disp(d)
disp("mm")

l=d;
disp("Stroke length =")
disp(l)
disp("mm")
```

Chapter 15

Heat Transfer

Scilab code Exa 15.1 1

```
clc
t1=60; //0C
t2=35; //0C
L=0.22; //m
k=0.51; //W/m 0C

q=k*(t1-t2)/L;
disp("Rate of heat transfer per m^2 =")
disp(q)
disp("W/m^2")
```

Scilab code Exa 15.2 2

```
clc
t1=1325; //0C
t2=1200; //0C
t3=25; //0C
L=0.32; //m
```

```
k_A=0.84; //W/m 0C
k_B=0.16; //W/m 0C

//L_B=0.32-L_A
//(t1-t2)/(L_A/k_A)=(t1-t3)/((L_A/k_A + L_B/k_B)

L_A=(t1-t2)*k_A/k_B*L/((t1-t3)-(t1-t2)*k_A/k_A+(t1-t2)*k_A/k_B); //m
disp("L_A=")
disp(L_A*1000)
disp("mm")

L_B=0.32-L_A; //m
disp("L_B")
disp(L_B*1000)
disp("mm")


disp("(ii) Heat loss per unit area =")
q=(t1-t2)/L_A*k_A;
disp(q)
disp("W/m^2")


disp("If another layer of insulating material is added, the heat loss from the wall will reduce; consequently the temperature drop across the fire brick lining will drop and the interface temperature t2 will rise. As the interface temperature is already fixed. Therefore, a satisfactory solutionwill not be available by adding layer of insulation.")
```

Scilab code Exa 15.3 3

```
clc
L_A=0.1; //m
L_B=0.04; //m
k_A=0.7; //W/m 0C
k_B=0.48; //W/m 0C
k_C=0.065; //W/m 0C

//Q2=0.2*Q1
L_C=0.8*[(L_A/k_A) + (L_B/k_B)]*k_C/0.2;
disp("thickness of rock wool insulation =")
disp(L_C*1000)
disp("mm")
```

Scilab code Exa 15.4 4

```
clc
L_A=0.2; //m
L_C=0.006; //m
L_D=0.1; //m
t1=1150; //0C
t2=40; //0C
dt=t1-t2;
k_A=1.52; //W/m 0C
k_B=0.138; //W/m 0C
k_D=0.138; //W/m 0C
k_C=45; //W/m 0C
q=400; //W/m^2

disp("(i) The value of x = (L_C) ")
L_B=((t1-t2)/q - (L_A/k_A+L_C/k_C+L_D/k_D))*k_B
    *1000;
disp("L_B =")
disp(L_B)
disp("mm")

```

```

disp("(ii) Temperature of the outer surface of the
   steel plate t_so =")
t_so=q*L_D/k_D + t2;
disp(t_so)
disp("0C")
```

Scilab code Exa 15.5 5

```
clc
k_A=150; //W/m 0C
k_B=30; //W/m 0C
k_C=65; //W/m 0C
k_D=50; //W/m 0C

L_A=0.03; //m
L_B=0.08; //m
L_C=L_B;
L_D=0.05; //m

A_A=0.01; //m^2
A_B=0.003; //m^2
A_C=0.007; //m^2
A_D=0.01; //m^2

t1=400; //0C
t4=60; //0C

R_thA=L_A/k_A/A_A;
R_thB=L_B/k_B/A_B;
R_thC=L_C/k_C/A_C;
R_thD=L_D/k_D/A_D;

R_th_eq=R_thB*R_thC/(R_thB+R_thC);
R_th_total=R_thA+R_th_eq+R_thD;
```

```

Q=(t1-t4)/R_th_total;
disp("Q=")
disp(Q)
disp("W")
```

Scilab code Exa 15.6 6

```
clc
L=0.012; //m
t_hf=95; //0C
t_cf=15; //0C
k=50; //W/m 0C
h_hf=2850; //W/m^2 0C
h_cf=10; //W/m^2 0C

disp("(i) Rate of heat loss per m^2 of the tank
   surface area")
U=1/(1/h_hf + L/k + 1/h_cf);
A=1; //m^2
q=U*A*(t_hf-t_cf);
disp("q=")
disp(q)
disp("W/m^2")


disp("(ii) Temperature of the outside surface of the
    tank =")
t2=q/h_cf+t_cf;
disp(t2)
disp("0C")
```

Scilab code Exa 15.7 7

```
clc
L_A=0.003; //m
L_B=0.05; //m
L_C=L_A;

k_A=46.5; //W/m 0C
k_B=0.046; //W/m 0C
k_C=k_A;
h0=11.6; //W/m^2 0C
hi=14.5; //W/m^2 0C
t0=25; //0C
ti=6; //0C

A=0.5*0.5*2+0.5*1*4; //m^2

disp("(i) The rate of removal of heat =")
Q=A*(t0-ti)/(1/h0 + L_A/k_A + L_B/k_B + L_C/k_C + 1/
    hi);
disp(Q)
disp("W")


disp("(ii) The temperature at the outer surface of
    the metal sheet =")
t1=t0-Q/h0/A;
disp(t1)
disp("0C")
```

Scilab code Exa 15.8 8

```
clc
L_A=0.25; //m
L_B=0.1; //m
L_C=0.15; //m
k_A=1.65; //W/m  C
```

```
k_C=9.2; //W/m  C
t_hf=1250; // C
t1=1100; // C
t_cf=25; // C
h_hf=25; //W/m^2  C
h_cf=12; //W/m^2  C

disp("(i) Thermal conductivity =")
q=h_hf*(t_hf-t1);

k_B=L_B/((t_hf-t_cf)/q-1/h_hf-L_A/k_A-L_C/k_C-1/h_cf
   );
disp(" Thermal conductivity ,k=")
disp(k_B)
disp("W/m^2  C ")


disp("(ii) The overall transfer coefficient =")
R_th_total=1/h_hf+L_A/k_A+L_B/k_B+L_C/k_C+1/h_cf;
U=1/R_th_total;
disp(U)
disp("W/m^2  C ")


disp("(iii) All surface temperature ")

disp("t1=")
disp(t1)
disp(" C ")

t2=t1-q*L_A/k_A;
disp("t2=")
disp(t2)
disp(" C ")

t3=t2-q*L_B/k_B;
disp("t3=")
disp(t3)
```

```
disp(" C ")

t4=t3-q*L_C/k_C;
disp("t4=")
disp(t4)
disp(" C ")
```

Scilab code Exa 15.9 9

```
clc
r1=0.01; //m
r2=0.02; //m
r3=0.05; //m
t1=600; //0C
t3=1000; //0C
k_B=0.2; //W/m 0C

q=2*%pi*(t1-t3)/(log(r3/r2)/k_B);
disp("Heat transfer per metre of length =")
disp(q)
disp("W/m")
```

Scilab code Exa 15.10 10

```
clc
r1=0.06; //m
r2=0.12; //m
r3=0.16; //m
k_A=0.24; //W/m 0C
k_B=0.4; //W/m 0C
h_hf=60; //W/m^2 0C
h_cf=12; //W/m^2 0C
t_hf=65; //0C
```

```
t_cf=20; //0C
L=60; //m

Q=2*%pi*L*(t_hf-t_cf)/(1/h_hf/r1 + log(r2/r1)/k_A +
    log(r3/r2)/k_B + 1/h_cf/r3);
disp("Rate of heat loss =")
disp(Q)
disp("W")
```

Scilab code Exa 15.11 11

```
clc
r1=0.06; //m
r2=0.08; //m
k_A=42; //W/m 0C
k_B=0.8; //W/m 0C
t_hf=150; //0C
t_cf=20; //0C
h_hf=100; //W/m^2 0C
h_cf=30; //W/m^2 0C

//Q=2.1*2*%pi*r*L kW
//Q=0.989*L*10^3 W

//Q=2*%pi*L*(t_hf-t_cf)/(1/h_hf/r1 + log(r2/r1)/k_A
    + log(r3/r2)/k_B + 1/h_cf/r3)
//By solving above equation, using hit and trial
    method we get
r3=0.105; //m
thickness=(r3-r2)*1000; //mm
disp("Thickness of insulation =")
disp(thickness)
disp("mm")
```

Scilab code Exa 15.12 12

```
clc
r2=0.7; //m
r1=0.61; //m
dt=220; //dt=t1-t2; 0C
k=0.083; //W/m 0C

Q=dt/((r2-r1)/(4*%pi*k*r1*r2));
disp("Rate of heat leakage =")
disp(Q)
disp("W")
```

Scilab code Exa 15.13 13

```
clc
r1=0.001; //m
r2=0.0018; //m
k=0.12; //W/m 0C
h0=35; //W/m^2 0C

rc=k/h0;

thickness=(rc-r1)*10^3; //mm
disp("Critical thickness of insulation =")
disp(thickness)
disp("mm")

//Percentage change in heat transfer rate :
//Case I : The heat flow through an insulated wire

//Q1=2*%pi*L*(t1-tair)/(log(r2/r1)/k + 1/h0/r2)
```

```

//Case II : The heat flow through an insulated wire
    when critical thickness is used is given

//Q2=2*%pi*L*(t1-tair)/(log(rc/r1)/k + 1/h0/rc)

//%increase=(Q2-Q1)/Q1*100
%increase=(1/(log(rc/r1)/k + 1/h0/rc)-1/(log(r2/r1)/
    k + 1/h0/r2))/(1/(log(r2/r1)/k + 1/h0/r2))*100;
disp("Percentage change in heat transfer rate =")
disp(%increase)
disp("%")
```

Scilab code Exa 15.14 14

```
clc
A=1*1.5; //m^2
ts=300; //0C
tf=20; //0C
h=20; //W/m^2 0C
Q=h*A*(ts-tf)/10^3; //kW
disp("Rate of heat transfer =")
disp(Q)
disp("kW")
```

Scilab code Exa 15.15 15

```
clc
d=0.0015; //m
l=0.15; //m
A=%pi*d*l;
ts=120; //0C
tf=100; //0C
```

```
h=4500; //W/m^2 0C

Q=h*A*(ts-tf);
disp("Electric power to be supplied =")
disp(Q)
disp("W")
```

Scilab code Exa 15.16 16

```
clc
D=0.045; //m
l=3.2; //m
u=0.78; //m/s
k=0.66; //W/m K
v=0.478*10^(-6); //m^2/s
Pr=2.98;
tw=70; //0C
tf=50; //0C

A=%pi*D*l;
Re=D*u/v;

h=0.023*(Re)^0.8*(Pr)^0.4/D*k;
disp("Heat transfer co-efficient =")
disp(h)
disp("W/m^2 K")

Q=h*A*(tw-tf)/10^3;
disp("Rate of heat transfer =")
disp(Q)
disp("kW")
```

Scilab code Exa 15.17 17

```
clc
rho=983.2; //kg/m^2
cp=4.187; //kJ/kg K
k=0.659; //W/m 0C
v=0.478*10^(-6); //m^2/s
m=0.5/60; //kg/s
D=0.02; //m
ti=20; //0C
t0=50; //0C
ts=85; //surface temperature in 0C

tf=1/2*(ts+(ti+t0)/2);
A=%pi/4*D^2;
u=m/rho/A;
Re=D*u/v;
//Since Re < 2000, hence the flow is laminar.

Nu=3.65;
h=Nu*k/D;
tb=(t0+ti)/2;

L=m*cp*10^3*(t0-ti)/(ts-tb)/h/D/%pi;
disp("Length of the tube required for fully
    developed flow =")
disp(L)
disp("m")
```

Scilab code Exa 15.18 18

```
clc
m_h=0.2; //kg/s
m_c=0.5; //kg/s
t_h1=75; //0C
t_h2=45; //0C
t_c1=20; //0C
```

```
hi=650; //W/m^2 0C
h0=hi;
cph=4.187;
cpc=cph;

Q=m_h*cph*(t_h1-t_h2);
t_c2=m_h*cph/cpc*(t_h1-t_h2)/m_c+t_c1;

theta=((t_h1-t_c1)- (t_h2-t_c2))/log((t_h1-t_c1)/(
    t_h2-t_c2)); //Logarithmic mean temperature
    difference

U=hi*h0/(hi+h0);
A=Q*10^3/U/theta;
disp("The area of heat exchanger =")
disp(A)
disp("m^2")
```

Scilab code Exa 15.19 19

```
clc
t_c1=25; //0C
t_c2=65; //0C
cph=1.45; //kJ/kg K
m_h=0.9; //kg/s
t_h1=230; //0C
t_h2=160; //0C
U=420; //W/m^2 0C
cpc=4.187; //kJ/kg K

disp("(i) The rate of heat transfer =")
Q=m_h*cph*(t_h1-t_h2);
disp(Q)
disp("kJ/s")

```

```

disp("(ii) The mass flow rate of water =")
m_c=Q/cpc/(t_c2-t_c1);
disp(m_c)
disp("kg/s")


disp("(iii) The surface area of heat exchanger =")
LMTD=((t_h1-t_c2)- (t_h2-t_c1))/log((t_h1-t_c2)/(t_h2-t_c1)); //logarithmic mean temperature difference
A=Q*10^3/U/LMTD;
disp("A=")
disp(A)
disp("m^2")
```

Scilab code Exa 15.20 20

```
clc
m_s=800/60; //kg/s
m_c=m_s;
m_g=1350/60; //kg/s
m_h=m_g;
t_h1=650; //0C
t_c1=180; //0C
t_c2=350; //0C
d=0.03; //m
L=3; //m
cph=1; //kJ/kg K
cpc=2.71; //kJ/kg K
h_g=250;
h_s=600;

t_h2=t_h1-(m_c*cpc*(t_c2-t_c1)/cph/m_h);
U=h_g*h_s/(h_g+h_s);
```

```
Q=m_h*cph*10^3*(t_h1-t_h2);
theta=((t_h1-t_c2)- (t_h2-t_c1))/log((t_h1-t_c2)/(t_h2-t_c1)); //logarithmic mean temperature difference
//A=N*%pi*d*L

N=Q/U/theta/(%pi*d*L);
disp("number of tubes required =")
disp(N)
disp("tubes")
```

Scilab code Exa 15.21 21

```
clc
di=0.0296; //m
d0=0.0384; //m
U=4000; //W/m^2 0C
V=3; //m/s
t_c1=24; //0C
x=0.9;
ps=(760-660)/760*1.0133; //bar
t_h1=51; //0C
t_h2=51; //0C
h_fg=2592; //kJ/kg
t_c2=47; //0C
P=15; //MW
ssc=5; //specific steam consumption in kg/kWh
cpc=4.187; //kJ?kg K
rho=1000;

m_s=P*10^3*ssc/60; //kg/min

disp("(i) Mass of cooling water circulated per minute =")
m_w=m_s*x*h_fg/cpc/(t_c2-t_c1);
```

```
disp(m_w)
disp("kg/min")


disp("(ii) Condenser surface area")
Q=m_s*x*h_fg*10^3/60;

theta=((t_h1-t_c1)-(t_h2-t_c2))/log((t_h1-t_c1)/(t_h2-t_c2)); //Logarithmic mean temperature difference
A=Q/U/theta;
disp(A)
disp("m^2")


disp("(iii) Number of tubes required per pass =")
Np=m_w/60*4/%pi/di^2/V/rho;
disp(Np)


disp("(iv) Tube length =")
L=A/%pi/d0/(2*Np);
disp(L)
disp("m")
```

Scilab code Exa 15.22 22

```
clc
cp=4.187; //kJ/kg C
u=0.596*10^(-3); //Ns/m^2
k=0.635; //W/m C
Pr=3.93;
d=0.020; //m
l=2; //m
m_c=10; //kg/s
```

```
t_c1=17; /// C
t_h1=100; // C
t_h2=100; // C
rho=1000;
N=200;
Np=N/l;
h0=10*10^3;

V=m_c*4/%pi/d^2/rho/Np;
Re=rho*V*d/u;
hi=k/d*0.023*(Re)^0.8*(Pr)^0.33;
U=hi*h0/(hi+h0);

//theta1=t_h1-t_c1;
// theta2=t_h2-t_c2;
//AMTD=(theta1+theta2)/2
//AMTD=91.5 - 0.5*t_c2

t_c2=(U*%pi*d*l*N*91.5 + m_c*cp*10^3*t_c1)/(m_c*cp
    *10^3 + U*%pi*d*l*N*0.5);
disp("water exit temperature =")
disp(t_c2)
disp(" C ")
```

Scilab code Exa 15.23 23

```
clc
A=0.12; //m^2
T=800; //K
a=5.67*10^(-8);

disp("(i) The total rate of energy emission =")
Eb=a*A*T^4;
disp(Eb)
disp("W")
```

```
disp("(ii) The intensity of normal radiation =")
Ibn=a*T^4/%pi;
disp(Ibn)
disp("W/m^2.sr")


disp("(iii) The wavelength of maximum monochromatic
    emissive power =")
wavelength=2898/T;
disp(wavelength)
disp(" m ")
```

Scilab code Exa 15.24 24

```
clc
wavelength=0.49; // m
a=5.67*10^(-8);

disp("(i) The surface temperature of the sun")
T=2898/wavelength;
disp(T)
disp("K")


disp("(ii) The heat flux at the surface of the sun =
    ")
E_sun=a*T^4;
disp(E_sun)
disp("W/m^2")
```

Scilab code Exa 15.25 25

```
clc
T=2773; //K
lambda=1.2*10^(-6); //m
e=0.9;
a=5.67*10^(-8);

disp("(i) Monochromatic emissive power at 1.2  m length")
C1=0.3742*10^(-15); //W.m^4/m^2
C2=1.4388*10^(-4); //mK
E_lambda_b=C1*lambda^(-5)/(exp(C2/lambda/T)-1);
disp("E_lambda_b =")
disp(E_lambda_b)
disp("W/m^2")


disp("(ii) Wavelength at which the emission is maximum =")
lambda_max=2898/T;
disp(lambda_max)
disp(" m ")


disp("(iii) Maximum emissive power =")
E_lambda_b_max=1.285*10^(-5)*T^5;
disp(E_lambda_b_max)
disp("W/m^2 per metre length")


disp("(iv) Total emissive power =")
Eb=a*T^4;
disp(Eb)
disp("W/m^2")


disp("(v) Total emissive power =")
E=e*a*T^4;
disp(E)
```

```
disp("W/m^2")
```

Scilab code Exa 15.26 26

```
clc
T1=1273; //K
T2=773; //K
e1=0.42;
e2=0.72;
a=5.67*10^(-8);

disp("(i) When the body is grey with  1 = 0.42")
q=e1*a*(T1^4-T2^4)/10^3; //kW
disp("Heat loss per m2 by radiation =")
disp(q)
disp("kW")

disp("(ii) When the body is not grey")
E_emitted=e1*a*T1^4;
E_absorbed=e2*a*(T2)^4;

q=(E_emitted-E_absorbed)/10^3;
disp("Heat loss per m2 by radiation =")
disp(q)
disp("kW")
```

Scilab code Exa 15.27 27

```
clc
d=0.022; //m
di=0.18; //m
e1=0.62;
e2=0.82;
```

```
rho=7845; //kg/m^3
T1a=693; //K; For caseI
T1b=813; //K; For caseII
T2=1373; //K
l=1; //m
a=5.67*10^(-8);
cp=0.67; //kJ/kg K

A1=%pi*d*l;
A2=%pi*di*l;


Qi=A1*a*(T1a^4-T2^4)/(1/e1+A1/A2*(1/e2 - 1));

Qe=A1*a*(T1b^4-T2^4)/(1/e1+A1/A2*(1/e2 - 1));

Qav=-(Qi+Qe)/2;

t_h=%pi/4*d^2*rho*cp*(T1b-T1a)*10^3/Qav;
disp("Time required for the heating operation")
disp(t_h)
disp("s")
```

Scilab code Exa 15.28 28

```
clc
r1=0.05; //m
r2=0.1; //m
T1=400; //K
T2=300; //K
e1=0.5;
e2=0.5;
F_12=1;
a=5.67*10^(-8);
//A1/A2=r1/r2
```

```
Q=a*(T1^4-T2^4)/((1-e1)/e1+1/F_12+(1-e2)/e2*r1/r2);
disp("heat transfer rate per m2 area by radiation")
disp(Q)
disp("W/m^2")
```

Scilab code Exa 15.29 29

```
clc
r1=0.05; //m
r2=0.1; //m
r3=0.15; //m
T1=1000; //K
T3=500; //K
e1=0.05;
e2=e1;
e3=e1;
a=5.67*10^(-8);

F_12=1;
F_23=1;

// A1*a*(T1^4-T2^4)/(((1-e1)/e1) + 1/F_12 + ((1-e2)/e2)*A1/A2) = A2*a*(T2^4-T3^4)/(((1-e2)/e2) + 1/F_23 + ((1-e3)/e3)*A2/A3)

// A1/A2=r1/r2=5/10=0.5
// A2/A3=r2/r3=10/15=0.67

//Solving this we get
T2=770; //K

Q1=a*(T1^4-T2^4)/(((1-e1)/e1) + 1/F_12 + ((1-e2)/e2)*r1/r2);
disp("Heat flow per m2 area of cylinder 1 =")
```

```
disp(Q1)
disp("W")
```

Scilab code Exa 15.30 30

```
clc
r1=0.105; //m
r2=0.15; //m
T1=120; //K
T2=300; //K
e1=0.03;
e2=0.03;
h_fg=209.35; //kJ/kg
a=5.67*10^(-8);
F_12=1;

Q=4*%pi*r1^2*a*(T1^4-T2^4)/( ((1-e1)/e1) + 1/F_12 +
    ((1-e2)/e2)*r1^2/r2^2);

rate=-Q*3600/h_fg/1000;
disp("Rate of evaporation = ")
disp(rate)
disp("kg/h")
```

Scilab code Exa 15.31 31

```
clc
T1=91; //K
T2=303; //K
e1=0.03;
e2=0.03;
d1=0.3; //m
d2=0.45; //m
```

```
a=5.67*10^(-8);
F_12=1;

Q=4*%pi*(d1/2)^2*a*(T1^4-T2^4)/( ((1-e1)/e1) + 1/
    F_12 + ((1-e2)/e2)*d1^2/d2^2);
disp("Rate of heat flow =")
disp(Q)
disp("W")
```

Scilab code Exa 15.32 32

```
clc
e1=0.3;
e2=0.8;
e3=0.04;
A1=1; //m^2
A2=A1;
A3=A1;

// (E_b1 - E_b3)/[(1-e1)/e1+1+(1-e3)/e3]=(E_b3 -
    E_b2)/[(1-e3)/e3+1+(1-e2)/e2]

// a*(T1^4-T3^4)/(1/e1+1/e3-1)=a*(T3^4-T2^4)/(1/e3
    +1/e2-1)

// T3^4=0.48*(T1^4+1.08*T2^4)

// Q12=a*(T1^4-T2^4)/(1/e1+1/e2-1)
// Q13=a*(T1^4-T3^4)/(1/e1+1/e3-1)

// %reduction=(Q_12-Q13)/Q12;
%reduction=1-0.131*0.52;
disp("Percentage reduction in heat flow due to
    shield =")
disp(%reduction)
```

```
disp("%")
```

Chapter 16

Compressible Flow

Scilab code Exa 16.1 1

```
clc
V1=300; //m/s
p1=78; //kN/m^2
T1=313; //K
p2=117; //kN/m^2
R=287; //J/kg K
y=1.4;

//Let r1=p1/rho1
r1=R*T1;

V2=sqrt(2*(y/(y-1)*r1*(1-(p2/p1)^((y-1)/y)) + V1
    ^2/2));
disp("Velocity of gas at section 2 =")
disp(V2)
disp("m/s")
```

Scilab code Exa 16.2 2

```
clc
p1=35; //kN/m^2
V1=30; //m/s
T1=423; //K
V2=150; //m/s
R=290; //J/kg K
y=1.4;

//Let r1=p2/p1
r1=R*T1;

p2=p1*(1-((V2^2/2-V1^2/2)*(y-1)/y/r1))^(y/(y-1));
disp("p2=")
disp(p2)
disp("kN/m^2")

T2=T1*(p2/p1)^((y-1)/y);
t2=T2-273;
disp("t2 =")
disp(t2)
disp(" C ")
```

Scilab code Exa 16.3 3

```
clc
SG=0.8;
rho_oil=800; //kg/m^3
K_oil=1.5*10^9; //N/m^2; crude oil
K_Hg=27*10^9; //N/m^2; Mercury
rho_Hg=13600; //kg/m^3

C_oil=sqrt(K_oil/rho_oil);
disp("Sonic velocity of crude oil =")
disp(C_oil)
disp("m/s")
```

```

C_Hg=sqrt(K_Hg/rho_Hg)
disp("Sonic velocity of Mercury =")
disp(C_Hg)
disp("m/s")
```

Scilab code Exa 16.4 4

```
clc
T=228; //K
M=2;
R=287; //Jkg K
y=1.4;

C=sqrt(y*R*T);

V=M*C*3600/1000;
disp("Velocity of the plane =")
disp(V)
disp("km/h")
```

Scilab code Exa 16.5 5

```
clc
a=40*%pi/180; //Mach angle in radians
y=1.4;
R=287; //J/kg K
T=288; //K

C=sqrt(y*R*T);

V=C/sin(a);
disp("Velocity of bullet =")
```

```
disp(V)
disp("m/s")
```

Scilab code Exa 16.6 6

```
clc
p=88.3; //kN/m^2
T=271; //K
M=40*%pi/180;
y=1.4;
R=287; //J/kg K

C=sqrt(y*R*T);

V=C/sin(M);
disp("Velocity of the projectile =")
disp(V)
disp("m/s")
```

Scilab code Exa 16.7 7

```
clc
h=1800; //m
T=277; //K
t=4; //s
y=1.4;
R=287; //J/kg K

C=sqrt(y*R*T);

//tan(a)=h/t*V
//V=C/sin(a)
//From above two equations we get
```

```
a=(acos(C/h*t));

V=C/sin(a)*3600/1000;
disp("Speed of the aircraft =")
disp(V)
disp("km/h")
```

Scilab code Exa 16.8 8

```
clc
R=287; //J/kg K
y=1.4;
V0=1000*1000/3600; //m/s
p0=78.5; //kN/m^2
T0=265; //K

C0=sqrt(y*R*T0);
M0=V0/C0;

disp("(i) Stagnation pressure =")
ps=p0*(1+((y-1)/2*M0^2))^(y/(y-1));
disp(ps)
disp("kN/m^2")


disp("(ii) Stagnation temperature =")
Ts=T0*(1+((y-1)/2*M0^2));
disp(Ts)
disp("K")


disp("(iii) Stagnation density =")
rho_s=ps*10^3/R/Ts;
disp(rho_s)
```

```
disp("kg/m^3")
```

Scilab code Exa 16.9 9

```
clc
V0=1000*1000/3600; //m/s
T0=320; //K
p_atm=98.1; //kN/m^2
p=9.81; //kN/m^2
p0=98.1-p;
R=287; //J/kg K
y=1.4;

C0=sqrt(y*R*T0);
M0=V0/C0;

disp("Stagnation pressure =")
ps=p0*(1+((y-1)/2*M0^2))^(y/(y-1));
disp(ps)
disp("kN/m^2")


disp("Stagnation temperature =")
Ts=T0*(1+((y-1)/2*M0^2));
disp(Ts)
disp("K")


disp("Stagnation density =")
rho_s=ps*10^3/R/Ts;
disp(rho_s)
disp("kg/m^3")

M=0.8;

```

```
CF=1+M0^2/4+(2-y)/24*M0^4;
disp("Compressibility factor")
disp(CF)
```

Scilab code Exa 16.10 10

```
clc
R=287; //J/kg K
y=1.4;
p0=220*10^3; //N/m^2
T0=300; //K
V0=200; //m/s
C0=sqrt(y*R*T0);
rho_0=p0/R/T0;
disp("Stagnation pressure =")

disp("(i) Compressibility is neglected")
ps=(p0+rho_0*V0^2/2)/10^3;
disp("ps=")
disp(ps)
disp("kN/m^2")


disp("(ii) Compressibility is accounted for")
M0=V0/C0;

ps=(p0+rho_0*V0^2/2*(1+M0^2/4+(2-y)/24*M0^4))/10^3;
disp("ps=")
disp(ps)
disp("kN/m^2")
```

Scilab code Exa 16.11 11

```
clc
p0=35*10^3; //Pa
T0=235; //K
ps=65.4*10^3; //N/m^2
R0=8314; //Nm/mole K
M=28;

R=R0/M;
rho_0=p0/R/T0;

Va=sqrt(2*(ps-p0)/rho_0);
disp("Speed of the aircraft =")
disp(Va)
disp("m/s")
```

Scilab code Exa 16.12 12

```
clc
p0=30*10^3; //N/m^2
V0=152; //m/s
y=1.4;

rho_0=1.224; //kg/m^3
ps=p0+rho_0*V0^2/2;

rho_0=0.454; //kg/m^3
V0=sqrt(2*(ps-p0)/rho_0);
C0=sqrt(y*p0/rho_0);
M=V0/C0;

ccf=(1+M^2/4); //Compressibility correction factor

V=V0/sqrt(ccf); //True speed of aircraft
disp("True speed of aircraft =")
disp(V)
```

```
disp("m/s")
```

Scilab code Exa 16.13 13

```
clc
M=3; //Mach number
d=0.2; //m
p_nozzle=7.85; //kN/m^2
T_nozzle=200; //K
y=1.4;
A=%pi/4*d^2;

disp("Reservoir pressure =")
p_res=p_nozzle*(1+((y-1)/2*M^2))^(y/(y-1));
disp(p_res)
disp("kN/m^2")

disp("Reservoir temperature =")
T_res=T_nozzle*(1+((y-1)/2*M^2));
disp(T_res)
disp("K")

disp("Throat area (critical) =")
Ac=A*M/((2+(y-1)*M^2)/(y+1))^((y+1)/2/(y-1));
disp(Ac)
disp("m^2")
```

Scilab code Exa 16.14 14

```
clc
R=287; //J/kg K
y=1.4;
p_atm=100; //kN/m^2
```

```
p1=284+p_atm; //kN/m^2
T1=297; //K
D=0.02; //m

A2=%pi/4*D^2;
rho_1=p1*10^3/R/T1;

m_max=0.685*A2*sqrt(p1*10^3*rho_1);
disp("Maximum flow rate =")
disp(m_max)
disp("kg/s")
```

Scilab code Exa 16.15 15

```
clc
R=287; //J/kg K
y=1.4;
p1=2500*10^3; //N/m^2
T1=293; //K
p2=1750*10^3; //N/m^2

rho_1=p1/R/T1;

V2=sqrt(2*y/(y-1)*p1/rho_1*(1-(p2/p1)^((y-1)/y)));
disp("Velocity of air =")
disp(V2)
disp("m/s")
```

Scilab code Exa 16.16 16

```
clc
R=287; //J/kg K
y=1.4;
```

```
p_atm=10^5; //N/m^2
T1=293; //K
D2=0.025; //m
p1=140*10^3; //N/m^2

A2=%pi/4*D2^2;

disp("(i) Mass rate of flow of air when pressure in
    the tank is 140 kN/m2 (abs.)")
rho_1=p1/R/T1;
p2=10^5; //N/m^2

m=A2*sqrt(2*y/(y-1)*p1*rho_1*((p2/p1)^(2/y) - (p2/p1
    )^((y+1)/y)));
disp("m=")
disp(m)
disp("kg/s")


disp("(ii) Mass rate of flow of air when pressure in
    the tank is 300 kN/m2 (abs.)")
p1=300*10^3; //N/m^2
p2=10^5; //N/m^2
rho_1=p1/R/T1;

disp("The pressure ratio p2/p1 being less than the
    critical ratio 0.528, the flow in the nozzle will
    be sonic");

m_max=0.685*A2*sqrt(p1*rho_1);
disp("m_max=")
disp(m_max)
disp("kg/s")
```

Scilab code Exa 16.17 17

```
clc
p1=200; //kN/m^2
V1=170; //m/s
T1=473; //K
A1=0.001; //m^2
R=287; //J/kg K
cp=1000; //J/kg K
y=1.4;

disp("(i) Stagnation temperature (Ts) and stagnation
    pressure (ps)")

Ts=T1+V1^2/2/cp;
disp("Ts=")
disp(Ts)
disp("K")

ps=p1*(Ts/T1)^(y/(y-1));
disp("ps=")
disp(ps)
disp("kN/m^2")


disp("(ii) Sonic velocity and Mach number at this
    section")

C1=sqrt(y*R*T1);
disp("Sonic velocity =")
disp(C1)
disp("m/s")

M1=V1/C1;
disp("Mach number = ")
disp(M1)


disp("(iii) Velocity, Mach number and flow area at
    outlet section where pressure is 110 kN/m2")
```

```
p2=110; //kN/m^2
M2=sqrt(2/(y-1)*((ps/p2)^((y-1)/y) - 1));
disp("M2=")
disp(M2)

T2=Ts*(p2/ps)^((y-1)/y);
C2=sqrt(y*R*T2);
V2=M2*C2;
disp("V2=")
disp(V2)
disp("m/s")

A2=(p1*A1*V1*T2/T1/p2/V2)*10^6;
disp("A2=")
disp(A2)
disp("mm^2")


disp("(iv) Pressure (pt), temperature (Tt), velocity
    (Vt), and flow area (At) at throat of the nozzle
   ")
Mt=1;
Tt=Ts/(1+(y-1)/2*Mt^2);
disp("Tt =")
disp(Tt)
disp("K")

pt=ps*(Tt/Ts)^(y/(y-1));
disp("pt")
disp(pt)
disp("kN/m^2")

Ct=sqrt(y*R*Tt);
Vt=Mt*Ct;

At=(p1*A1*V1*Tt/T1/pt/Vt)*10^6;
disp("At=")
disp(At)
```

```
disp("mm^2")
```

Scilab code Exa 16.18 18

```
clc
y=1.4;
p1=26.5; //kN/m^2
rho_1=0.413; //kg/m^3
M1=2;
R=287;

M2=sqrt(((y-1)*M1^2 + 2)/(2*y*M1^2 - (y-1)));
disp("Mach number M2=")
disp(M2)

p2=p1*(2*y*M1^2 - (y-1))/(y+1);
disp("p2=")
disp(p2)
disp("kN/m^2")

rho_2=rho_1*((y+1)*M1^2)/((y-1)*M1^2 + 2);
disp("density, rho_2 =")
disp(rho_2)
disp("kg/m^3")

T1=p1*10^3/rho_1/R;
disp("T1=")
disp(T1)
disp("K")

T2=T1*((y-1)*M1^2 + 2)*(2*y*M1^2 - (y-1))/((y+1)^2*
    M1^2);
disp("T2=")
disp(T2)
disp("K")
```

```
C1=sqrt(y*R*T1);
V1=M1*C1;
disp("V1=")
disp(V1)
disp("m/s")

C2=sqrt(y*R*T2);
V2=M2*C2;
disp("V2 =")
disp(V2)
disp("m/s")
```

Scilab code Exa 16.19 19

```
clc
M1=1.5;
p1=170; //kN/m^2
T1=296; //K
y=1.4;

disp("(i) Pressure, temperature and Mach number downstream of the shock")

p2=p1*(2*y*M1^2 - (y-1))/(y+1);
disp("p2=")
disp(p2)
disp("kN/m^2")

T2=T1*((y-1)*M1^2 + 2)*(2*y*M1^2 - (y-1))/(y+1)^2/M1^2;
disp("T2=")
disp(T2)
disp("K")

```

```
M2=sqrt(((y-1)*M1^2 + 2)/(2*y*M1^2 - (y-1)));
disp("M2=")
disp(M2)

strength=p2/p1 - 1;
disp("Strength of stock =")
disp(strength)
```