# Scilab Textbook Companion for Thermal Engineering by K. K. Ramalingam[1]

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# Book Description

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

**Exa** Example (Solved example)

**Eqn** Equation (Particular equation of the above book)

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

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

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# Chapter 1

# Gas power cycles

**Scilab code Exa 1.1** The pressures

```
clc
clear
//Input data
V1=0.5;//Initial Volume before the commencement of
   compression in m^3
P1=1;//Initial pressure before the commencement of
   compression in bar
T1=300;//Initial temperature in K
P2=12;//Final pressure at the end of compression
   stroke in bar
Q=220;//Heat added during the constant volume
   process in kJ
r=1.4;//Isentropic constant for air
R=0.287;//Characteristic Gas constant in kJ/kg K
Cv=0.718;//Specific heat of mixture in kJ/kg K

//Calculations
r1=(P2/P1)^(1/r);//Compression ratio
T2=T1*(r1)^(r-1);//Final temperature after the end
   of compression stroke in K
V2=(P1*T2*V1)/(P2*T1);//Final volume after the end
```

```
of compression stroke in m^3
m=(P1*10^5*V1)/(R*T1*1000);//Mass of air flowing in kg
T3=(Q/(m*Cv))+T2;//Temperature after constant volume heat addition in K
P3=(P2*T3)/T2;//Pressure after constant volume heat addition in K
V3=V2;//Volume at 3
P4=P3*(1/r1)^(r);//Pressure after isentropic expansion in bar
V4=V1;//Volume after isentropic expansion in m^3
T4=T3*(1/r1)^(r-1);//Temperature at the end of isentropic expansion in K

//Output
printf('(a)The pressures at 1 is %3.0fbar\n (b)Pressure at 2 is %3.0fbar\n (c)Pressure at 3 is %3.2fbar\n (d)Pressure at 4 is %3.2fbar\n (e)Temperature at 1 is %3.1fK\n (f)Temperature at 2 is %3.1fK\n (g)Temperature at 3 is %3.0fK\n (h)Temperature at 4 is %3.0fK\n (i)Volume at 1 is %3.0fm^3\n (j)Volume at 2 is %3.5fm^3\n (k)Volume at 3 is %3.5fm^3\n (l)Volume at 4 is %3.0fm^3',P1,P2,P3,P4,T1,T2,T3,T4,V1,V2,V3,V4)
```

---

**Scilab code Exa 1.2** Compression ratio

```
clc
clear
//Input data
r1=6;//Initial compression ratio
r2=7;//Final compression ratio
r=1.4;//Isentropic coefficient of air

//Calculations
```

```
nr1=(1-(1/r1)^(r-1))*100;//Otto cycle efficiency when compression ratio is 6 in percentage
nr2=(1-(1/r2)^(r-1))*100;//Otto cycle efficiency when compression ratio is 7 in percentage
n=nr2-nr1;//Increase in efficiency in percentage

//Output
printf('The increase in efficiency due to change in compression ratio from 6 to 7 is %3.1fpercent',n)
```

---

**Scilab code Exa 1.3** Air standard efficiency

```
clc
clear
//Input data
T1=315;//Temperature at the beginning of isentropic compression in K
T2=600;//Temperature at the end of isentropic compression in K
r=1.4;//Isentropic constant of air

//Calculations
r1=(T2/T1)^(1/(r-1));//Compression ratio
n=(1-(1/r1^(r-1)))*100;//Efficiency of Otto cycle in percent

//Output
printf('(a)The compression ratio is %3.2f\n (b)Efficiency of the Otto cycle is %3.1f percent',r1,n)
```

---

**Scilab code Exa 1.4** Air standard efficiency

```
clc
clear
//Input data
D=0.1;//Diameter of the cylinder in m
L=0.15;//Stroke length in m
Vc=0.295*10^-3;//Clearance volume in m^3
r=1.4;//Isentropic constant of air

//Calculations
Vs=(3.14/4)*(D^2*L);//Swept volume in m^3
r1=(Vc+Vs)/Vc;//Compression ratio
n=(1-(1/r1)^(r-1))*100;//Otto cycle efficiency in
    percentage

//Output
printf('The air standard efficiency of air is %3.2f
    percent',n)
```

---

**Scilab code Exa 1.5** Mean effective pressure

```
clc
clear
//Input data
P1=1;//Initial pressure of air in bar
T1=300;//Initial temperature in K
P2=17;//Pressure at the end of isentropic
    compression in bar
P3=40;//Pressure at the end of constant volume heat
    addition in bar
Cv=0.717;//Specific heat of mixture in kJ/kg K
M=28.97;//Molecular weight in kg
Ru=8.314;//Universial gas constant in kJ/kg mole K
m=1;//Mass from which heat is extracted in kg
W=363;//Work done in kN m

```

```
//Calculations
Rc=Ru/M;//Characteristic gas constant in kJ/kg K
Cp=Rc+Cv;//Specific heat at constant pressure in kJ/kg K
r=Cp/Cv;//Isentropic gas constant
r1=(P2/P1)^(1/r);//Compression ratio
na=(1-(1/r1)^(r-1))*100;//Air standard efficiency in percentage
T2=T1*(P2/P1)^((r-1)/r);//Temperature at the end of isentropic compression process in K
T3=(P3/P2)*T2;//Temperature at the end of constant volume heat addition in K
Q=m*Cv*(T3-T2);//Heat supplied in kJ/kg
V1=(m*Rc*T1*1000)/(P1*10^5);//Initial volume before compression in m^3
V2=V1/r1;//Volume at the end of compression stroke in m^3
Vs=V1-V2;//Stroke volume in m^3
MEP=(W/Vs)/100;//Mean effective pressure in bar

//Output
printf('(a)Compression ratio is %3.2f\n (b)The air standard efficiency is %3.1f percent\n (c)Mean effective pressure is %3.2f bar',r1,na,MEP)
```

---

**Scilab code Exa 1.6** Compression ratio

```
clc
clear
//Input data
V1=0.6;//Initial volume of an engine working on otto cycle in m^3
P1=1;//Initial pressure in bar
T1=308;//Initial temperature in K
P2=10;//Pressure at the end of compression stroke in
```

```
bar
Q=210;//Heat added during constant heat process in kJ
r=1.4;//Isentropic constant of air

//Calculations
r1=(P2/P1)^(1/r);//Compression ratio
V2=V1/r1;//Clearance volume in m^3
C=(V2/(V1-V2))*100;//Percentage clearance in percent
na=(1-(1/r1)^(r-1))*100;//Air standard efficiency in percent
W=Q*(na/100);//Work done per cycle in kJ

//Output
printf('(a)Clearance volume as percentage of stroke volume is %3.2f percent\n (b)Compression ratio is %3.2f\n (c)Air standard efficiency is %3.1f percent\n (d)Work done per cycle is %3.2f kJ',C,r1,na,W)
```

---

**Scilab code Exa 1.7** Ideal power

```
clc
clear
//Input data
r=5.5;//Compression ratio of an engine working on the otto cycle
Q=250;//Heat supplied during constant volume in kJ
N=500;//Engine operating speed in rpm
r1=1.4;//Isentropic ratio

//Calculations
n=(1-(1/r)^(r1-1))*100;//Otto cycle efficiency in percent
W=Q*(n/100);//Work done per cycle in kJ
```

```
P=W*(N/60);//Work done per second i.e., Power developed in kJ/s or kW

//Output data
printf('Ideal power developed by the engine is %3.0f kW',P)
```

---

**Scilab code Exa 1.8** Mean effective pressure

```
clc
clear
//Input data
V1=0.53;//Volume of cylinder of an engine working on Otto cycle in m^3
V2=0.1;//Clearance volume in m^3
Q=210;//Heat supplied during constant volume in kJ
r=1.4;//Isentropic ratio

//Calculations
r1=V1/V2;//Compression ratio
n=(1-(1/r1)^(r-1))*100;//Otto cycle efficiency in percentage
W=Q*(n/100);//Work done per cycle in kJ
P=W/((V1-V2)*100);//Mean effective pressure in bar

//Output data
printf('Mean effective pressure is %3.3f bar',P)
```

---

**Scilab code Exa 1.10** Maximum theoretical power

```
clc
clear
//Input data
```

```
T3=1500;//Upper temperature limit of a otto cycle in K
T1=300;//Lower temperature limit in K
a=0.4;//Rate of flow of air through the cycle in kg/min
Cv=0.718;//

//Calculations
T2=(T1*T3)^(1/2);//Temperature at point 2 in K
T4=T2;//Temperature at point 4 in K
W=Cv*((T3-T2)-(T4-T1));//Work done per cycle in kJ/kg
P=W*(a/60);//Maximum power developed by the engine in kW

//Output
printf('Maximum power developed by the engine is %3.3f kW',P)
```

---

**Scilab code Exa 1.11** Efficiencies for cut off ratio

```
clc
clear
//Input data
r=1.4;//Air standard ratio
p1=1.25;//Cut off ratio 1
p2=1.50;//Cut off ratio 2
p3=2.00;//Cut off ratio 3
rc=16;//Compression ratio

//Calculations
n1=(1-((1/rc^(r-1)*(p1^r-1)/(r*(p1-1)))))*100;//Thermal efficiency of the diesel cycle for cut off ratio 1.25
n2=(1-((1/rc^(r-1)*(p2^r-1)/(r*(p2-1)))))*100;//
```

```
Thermal efficiency of the diesel cycle for cut off ratio 1.50
n3=(1-((1/rc^(r-1)*(p3^r-1)/(r*(p3-1)))))*100;//Thermal efficiency of the diesel cycle for cut off ratio 2.00

//Output
printf('(a)Thermal efficiency when cut off ratio is 1.25 is %3.2f percent\n (b)Thermal efficiency when cut off ratio is 1.50 is %3.0f percent\n (c)Thermal efficiency when cut off ratio is 2.00 is %3.1f percent\n',n1,n2,n3)
```

---

**Scilab code Exa 1.12** Air standard efficiency

```
clc
clear
r=15;//Compression ratio of a diesel engine
Q=5;//Heat supplied upto 5 percent of the stroke
r1=1.4;//Isentropic ratio

//Calculations
p=1+(Q/100)*(r-1);//Cut off ratio
n=(1-((1/r^(r1-1)*(p^r1-1)/(r1*(p-1)))))*100;//Efficiency of diesel cycle in percent

//Output
printf('Air standard efficiency of the diesel cycle is %3.2f percent',n)
```

---

**Scilab code Exa 1.13** Efficiency

```
clc
```

```
clear
//Input data
r=17;//Compression ratio of a diesel engine
e=13.5;//Expansion ratio
r1=1.4;//Isentropic ratio

//Calculations
p=r/e;//Cut off ratio
n=(1-((1/r^(r1-1)*(p^r1-1)/(r1*(p-1)))))*100;//Air
   standard efficiency in percent

//Output
printf('Air standard efficiency is %3.1f percent',n)
```

---

**Scilab code Exa 1.14** Compression ratio

```
clc
clear
//Input data
T1=300;//Temperature at the beggining of compression
    stroke in K
T2=873;//Temperature at the end of compression
   stroke in K
T3=2173;//Temperature at the beggining of expansion
   stroke in K
T4=1123;//Temperature at the end of expansion stroke
    in K
r1=1.4;//Isentropic ratio

//Calculations
r=(T2/T1)^(1/(r1-1));//Compression ratio
rho=T3/T2;//Cut off ratio
n=(1-((1/r1)*((T4-T1)/(T3-T2))))*100;//Efficiency of
    diesel cycle in percent

```

```
//Output data
printf('(a)Compression ratio is %3.2f \n (b)Cut off ratio is %3.2f \n (c)Ideal efficiency of the diesel cycle is %3.2f percent',r,rho,n)
```

---

**Scilab code Exa 1.15** Pressure

```
clc
clear
//Input data
r=18;//Compression ratio of diesel cycle
Q=2000;//Heat added in kJ/kg
T1=300;//Lowest temperature in the cycle in K
p1=1;//Lowest pressure in the cycle in bar
Cp=1;//Specific heat of air at constant pressure in kJ/kg K
Cv=0.714;//Specific heat of air at constant volume in kJ/kg K

//Calculations
r1=Cp/Cv;//Isentropic ratio
v1=((1-Cv)*T1)/(p1*10^5);//Initial volume at point 1 in the graph in m^3/kg
v2=v1/r;//Volume at point 2 in m^3/kg
p2=p1*(v1/v2)^(r1);//Pressure at point 2 in bar
T2=T1*(v1/v2)^(r1-1);//Temperature at point 2 in K
T3=(Q/Cp)+T2;//Temperature at point 3 in K
v3=v2*(T3/T2);//Volume at point 3 in K
v4=v1;//Since Constant volume heat rejection in m^3/kg
T4=T3/(v4/v3)^(r1-1);//Temperature at point 4 in K for isentropic expansion
p4=p1*(T4/T1);//Pressure at point 4 in bar

//Output
```

```
printf('(a)Pressure at point 1 in the cycle is %3.0f bar\n (b)Pressure at point 2 & 3 is %3.1f bar\n (c)Pressure at point 4 is %3.2f bar\n (d)Temperature at point 1 is %3.0f K\n (e)Temperature at point 2 is %3.0f K\n (f)Temperature at point 3 is %3.0f K\n (g)Temperature at point 4 is %3.0f K',p1,p2,p4,T1,T2,T3,T4)
```

**Scilab code Exa 1.16** Thermal efficiency

```
clc
clear
//Input data
r=16;//Compression ratio for the air standard diesel cycle
Q1=2200;//Heat added in kJ/kg
T4=1500;//Temperature at the end of isentropic expansion in K
T1=310;//Lowest temperature in the cycle in K
m=0.3;//Air flow rate in kg/sec
Cv=0.714;//Specific heat at constant volume in kJ/kg K

//Calculations
Q2=Cv*(T4-T1);//Heat rejected in kJ/kg
n=((Q1-Q2)/Q1)*100;//Efficiency in percent
P=m*(Q1-Q2);//Power developed in kW

//Output
printf('(a)Thermal efficiency is %3.2f percent\n (b)Power developed is %3.0f kW',n,P)
```

**Scilab code Exa 1.17** Air standard efficiency

```
clc
clear
//Input data
T1=303;//Temperature at the beginning of compression
    in K
T2=823;//Temperature at the end of compression in K
T3=3123;//Temperature at the end of heat addition in
    K
T4=1723;//Temperature at the end of isentropic
    expansion in K
r=1.4;//Isentropic ratio

//Calculations
n=(1-((T4-T1)/(r*(T3-T2))))*100;//Efficiency of the
    cycle in percent

//Output
printf('Air standard efficiency of the cycle is %3.1
    f percent',n)
```

---

**Scilab code Exa 1.18** Mean effective pressure

```
clc
clear
//Input data
r=15;//Compression Ratio of a diesel engine
P1=1;//Operating Pressure of a diesel engine in bar
r1=1.4;//Isentropic constant
V1=15;//Volume at the start of compression stroke in
    m^3
V3=1.8;//Volume at the end of constant Pressure heat
    addition in m^3
V4=V1;//Volume at the end of Isentropic expansion
```

```
stroke in m^3
V2=1;//Volume at the end of isentropic compression stroke in m^3
Vs=V1-V2;//Swept volume in m^3

//Calculations
P2=P1*(r)^r1;//Pressure at the end of Isentropic compression of air
P3=P2;//Pressure at the end of constant pressure heat addition in bar
P4=P3*(V3/V4)^r1;//Pressure at the end of Isentropic expansion stroke in bar
Pm=(V2/Vs)*(P2*((V3/V2)-1)+(P3*(V3/V2)-P4*(V4/V2))/(r1-1)-(P2-P1*(V1/V2))/(r1-1));//Mean effective pressure in bar

//Output
printf('Mean effective pressure of the cycle is %3.2f bar',Pm)
```

---

**Scilab code Exa 1.19** Compression ratio

```
clc
clear
//Input data
P1=1.5;//Pressure at the 7/8th stroke of compression in bar
P2=16;//Pressure at the 1/8th stroke of compression in bar
n=1.4;//Polytropic index
c=8;//Cutoff occurs at 8% of the stroke in percentage

//Calculations
R1=(P2/P1)^(1/n);//Ratio of volumes
```

```
R2=(R1-1)/((7/8)-(R1/8));//Ratio of stroke volume to the clearance volume
r=1+R2;//Compression ratio
rho=1+((c/100)*r);//Cut off ratio
na=(1-((1/r^(n-1))*(((rho^n)-1)/(n*(rho-1)))))*100;//Air standard efficiency in percentage

//Output
printf('(a)Compression ratio of the engine is %3.3f\n (b)Air standard efficiency is %3.2f percent',r,na)
```

**Scilab code Exa 1.20** Loss in efficiency

```
clc
clear
//Input data
r=16;//Compression ratio of diesel engine
r1=1.4;//Isentropic ratio

//Calculations
rho1=1+(r-1)*(6/100);//Cutoff ratio at 6% of stroke
rho2=1+(r-1)*(9/100);//Cutoff ratio at 9% of stroke
n1=(1-(1/r^(r1-1))*(1/r1)*(rho1^r1-1)/(rho1-1))*100;//Efficiency of the cycle at 6% of the stroke in percent
n2=(1-(1/r^(r1-1))*(1/r1)*(rho2^r1-1)/(rho2-1))*100;//Efficiency of the cycle at 9% of the stroke in percent
L=n1-n2;//The loss in efficiency in percent

//Output
printf('The loss in efficiency is %3.2f percent',L)
```

**Scilab code Exa 1.21** Compression ratio

```
clc
clear
//Input data
P1=1.03;//Pressure at the beginning of compression
   stroke in bar
T1=303;//Initial temperature in K
P2=40;//Maximum pressure in the cycle in bar
Q=550;//The heat supplied during the cycle in kJ/kg
r=1.4;//Isentropic compression ratio
Cp=1.004;//Specific heat at constant pressure in kJ/
   kg K

//Calculations
r1=(P2/P1)^(1/r);//Compression ratio
T2=(P2/P1)^((r-1)/r)*T1;//Temperature at the end of
   compression stroke in K
T3=(Q/Cp)+T2;//Temperature at the end of heat
   addition in K
rho=T3/T2;//Cut off ratio
n=(1-(1/r1^(r-1))*(1/r)*(rho^r-1)/(rho-1))*100;//Air
    standard efficiency in percentage

//Output\n
printf('(a)Compression ratio is %3.2f \n (b)
   Temperature at the end of compression is %3.1f K\
   n (c)Temperature at the end of comstant pressure
   heat addition is %3.0f K \n (d)Air standard
   efficiency is %3.2f percent',r1,T2,T3,n)
```

---

**Scilab code Exa 1.22** Air standard efficiency

```
clc
clear
//Input data
r=12;//Compression ratio of an oil engine, working
   on the combustion cycle
r1=1.4;//Isentropic ratio
P1=1;//Pressure at the
P3=35;//Pressure at the end of constant volume heat
   addition in bar

//Calculations
rho=1+(1/10)*(r-1);//Cut off ratio at 1/10th of the
   stroke
P2=P1*(r)^r1;//Pressure at the end of isentropic
   compression in bar
a=P3/P2;//Pressure ratio
n=(1-(1/r^(r1-1))*(a*rho^r1-1)/((a-1)+(r1*a*(rho-1))
   ))*100;//Air standard efficiency in percent

//Output
printf('The air standard efficiency of an oil engine
    working on the combustion cycle is %3.2f percent
   ',n)
```

---

**Scilab code Exa 1.23** Cut off ratio

```
clc
clear
//Input data
P1=1;//Pressure at the beginning of compression
   stroke of an oil engine working on a air standard
    dual cycle in bar
T1=303;//Temperature at the beginning of compression
    stroke in K
P3=40;//The maximum pressure reached in bar
```

```
T4=1673;//Maximum temperature reached in K
P4=P3;//Pressure at the start of constant pressure heat addition in bar
Cp=1.004;//Specific heat at constant pressure in kJ/kg K
Cv=0.717;//Specific heat at constant volume in kJ/kg K
r1=10;//Compression ratio

//Calculations
r=Cp/Cv;//Isentropic ratio
T2=T1*r1^(r-1);//Temperature at the end of compression stroke in K
P2=P1*r1^r;//Pressure at the end of compression stroke in bar
T3=T2*(P3/P2);//Temperature at the end of constant volume heat addition in K
rho=T4/T3;//Cut off ratio

//Output
printf('(a)Temperature at the end of constant volume heat addition is %3.1f K\n (b)Cut off ratio is %3.3f',T3,rho)
```

---

**Scilab code Exa 1.24** Work done

```
clc
clear
//Input data
P1=1;//pressure at the beginning of compression stroke in bar
T1=298;//Temperature at the beginning of compression stroke in K
P3=38;//Pressure at the end of constant volume heat addition in bar
```

```
T4=1573;//Temperature at the end of constant volume
    heat addition in K
r=9.5;//Compression ratio
Cp=1.004;//Specific heat of air at constant pressure
Cv=0.717;//Specific heat of air at constant volume

//Calculations
r1=Cp/Cv;//Isentropic ratio
T2=T1*r^(r1-1);//Temperature at the end of
    compression stroke in K
P2=P1*r^r1;//Pressure at the end of compression
    stroke in bar
T3=T2*(P3/P2);//Temperature at the end of constant
    volume heat addition in K
rho=T4/T3;//Cut off ratio
T5=T4*(rho/r)^(r1-1);//Temperature at the end of
    expansion stroke in K
Qs=Cv*(T3-T2)+Cp*(T4-T3);//Heat supplied per kg in
    kJ
Qr=Cv*(T5-T1);//Heat rejected per kg in kJ
W=Qs-Qr;//Work done per kg of air in kJ
n=(W/Qs)*100;//Efficiency of the air standard dual
    cycle in percent

//Output
printf('(a)The work done per kg of air is %3.1f kJ\n
    (b)Cycle efficiency is %3.2f percent',W,n)
```

**Scilab code Exa 1.25** Cycle efficiency

```
clc
clear
//Input data
r=10.5;//Compression ratio
P3=65;//Maximum pressure in bar
```

```
P4=P3;//Pressure at the end of constant volume heat addition in bar
qs=1650;//Heat supplied in kJ/kg
P1=1;//Pressure at the beginning of compression stroke in bar
T1=368;//Temperature at the beginning of compression stroke in K
Cp=1.004;//Specific heat of air at constant pressure in kJ/kg K
Cv=0.717;//Specific heat of air at constant volume in kJ/kg K

//Calculations
r1=Cp/Cv;//Compression ratio
P2=P1*r^r1;//Pressure at the end of compression stroke in bar
T2=T1*r^(r1-1);//Temperature at the end of compression stroke in K
T3=T2*(P3/P2);//Temperature at the end of constant volume heat addition in K
qv=Cv*(T3-T2);//Heat supplied at constant volume in kJ/kg
qp=qs-qv;//Heat supplied at constant pressure in kJ/kg
T4=(qp/Cp)+T3;//Temperature at the end of constant volume heat addition in K
rho=T4/T3;//Cut off ratio
T5=T4*(rho/r)^(r1-1);//Temperature at the end of expansion stroke in K
P5=P4*(rho/r)^r1;//Pressure at the end of expansion stroke in K
q=Cv*(T5-T1);//Heat rejected in kJ/kg
n=((qs-q)/qs)*100;//Efficiency of the cycle in percent

//Output
printf('(a)Pressure at the end of compression stroke is %3.1f bar\n (b)Temperature at the end of
```

```
compression stroke is %3.1f K\n (c)Temperature at the end of constant volume heat addition is %3.1f K\n (d)Temperature at the end of constant pressure heat addition is %3.2f K\n (e)Temperature at the end of expansion stroke is %3.2f K\n (e)Pressure at the end of expansion stroke is %3.2f bar\n (f)Efficiency of the cycle is %3.2f percent',P2,T2,T3,T4,T5,P5,n)
```

---

**Scilab code Exa 1.26** Air standard efficiency

```
clc
clear
//Input data
r=8.5;//Compression ratio
e=5.5;//Expansion ratio
P1=1;//Pressure at the beginning of compression stroke in bar
T1=313;//Temperature at the beginning of compression stroke in K
n=1.3;//polytropic constant
Cp=1.004;//Specific heat of air at constant pressure in kJ/kg K
Cv=0.717;//Specific heat of air at constant volume in kJ/kg K

//Calculations
rho=r/e;//Cut off ratio
T2=T1*r^(n-1);//Temperature at the end of compression stroke in K
T3=(2*Cv*T2)/(2*Cv-Cp*rho+1);//Temperature at the end of constant volume heat addition in K
T4=rho*T3;//Temperature at the end of constant pressure heat addition in K
a=T3/T2;//Pressure ratio i.e.,P3/P2
```

```
n1=(1-(1/r^(n-1))*(a*rho^n-1)/((a-1)+(n*a*(rho-1))))
    *100;//Air standard efficiency in percent

//Output
printf('The air standard efficiency is %3.2f percent
    ',n1)
```

---

**Scilab code Exa 1.27** Ideal thermal efficiency

```
clc
clear
//Input data
P1=1;//Initial pressure in a compression engine
    working on a dual combustion engine in bar
T1=300;//Initial Temperature in K
P2=25;//Pressure at the end of compression stroke in
     bar
Q=400;//Heat supplied per kg of air during constant
    volume heating in kJ/kg
P5=2.6;//Pressure at the end of isentropic expansion
     in bar
Cp=1.005;//Specific heat of air at constant pressure
     in kJ/kg K
Cv=0.715;//Specific heat of air at constant volume
    in kJ/kg K

//Calculations
r=Cp/Cv;//Isentropic index
r1=(P2/P1)^(1/r);//Compression ratio
T2=T1*(r1)^(r-1);//Temperature at the end of
    compression stroke in K
T3=(Q/Cv)+T2;//Temperature at the end of constant
    volume heat addition in K
a=T3/T2;//Pressure ratio
P3=a*P2;//Pressure ratio at the end of constant
```

```
volume heat addition in bar
P4=P3;//Pressure at the end of constant pressure heat addition in bar
x=(P5/P4)^(1/r);//Ratio of volume at the end of constant pressure heat addition to the volume at the end of isentropic expansion
rho=x*(r1);//Cut off ratio
n=(1-(1/r1^(r-1))*(a*rho^r-1)/((a-1)+(r*a*(rho-1))))*100;//Air standard efficiency in percent of a dual combustion engine

//Output
printf('The ideal thermal efficiency is %3.1f percent',n)
```

---

**Scilab code Exa 1.28** Temperature

```
clc
clear
//Input data
P1=1;//Initial pressure of an enfine working on a dual combustion cycle in bar
T1=318;//Initial temperature before compression in K
r1=14;//Compression ratio
r=1.4;//Isentropic index
a=2;//Pressure ratio in the compression process
rho=2;//Cut off ratio

//Calculations
T2=T1*r1^(r-1);//Temperature at the end of compression stroke in K
T3=T2*a;//Temperature at the end of constant volume heat addition in K
T4=rho*T3;//Temperature at the end of constant pressure heat addition in K
```

```
T5=T4*(rho/r1)^(r-1);//Temperature at the end of isentropic compression in K
n=(1-((T5-T1)/(r*(T4-T3)+(T3-T2))))*100;//Efficiency of an engine working on a dual combustion cycle in percent

//Output
printf('(a)Temperature at the end of compression stroke is %3.0f K\n (b)Temperature at the end of constant volume heat addition is %3.0f K\n (c)Temperature at the end of constant pressure heat addition is %3.0f K\n (d)Temperature at the end of isentropic expansion process is %3.0f K\n (e)Efficiency of the cycle is %3.2f percent',T2,T3,T4,T5,n)
```

---

**Scilab code Exa 1.29** Pressure ratio

```
clc
clear
//Input data
r=15;//Compression ratio
Vs=0.01;//Stroke volume in m^3
P1=1;//Initial pressure in bar
T1=310;//Initial temperature in K
P3=65;//Pressure in constant pressure heat addition stroke in bar
Cp=1;//Specific heat of air at constant pressure in kJ/kg K
Cv=0.714;//Specific heat of air at constant volume in kJ/kg K
R=287;//Molar gas constant

//Calculations
r1=Cp/Cv;//Isentropic index
```

```
P2=P1*(r)^r1;//Pressure at the end of compression stroke in bar
a=P3/P2;//Pressure ratio
rho=1+((5/100)*(r-1))
V2=Vs/(r-1);//Volume at the end of compression stroke in m^3
V1=Vs+V2;//Initial volume in m^3
m=P1*10^5*V1/(R*T1);//Mass of air contained in the cylinder in kg
T2=T1*r^(r1-1);//Temperature at the end of compression stroke in K
a=P3/P2;//Pressure ratio
T3=T2*a;//Temperature at the end of constant volume heat addition in K
T4=T3*rho;//Temperature at the end of constant pressure heat addition in K
T5=T4/(r/rho)^(r1-1);//Temperature at the end of isentropic expansion in K
Qs=(Cv*(T3-T2)+Cp*(T4-T3))*m;//Heat supplied in kJ
Qr=m*Cv*(T5-T1);//Heat rejected in kJ
W=Qs-Qr;//Work done per cycle in kJ
n=(W/Qs)*100;//Efficiency of the cycle in percent
Mep=(W/Vs)/100;//Mean effective pressure in bar

//Output
printf('(1)Pressure ratio is %3.3f\n (2)Cut off ratio is %3.2f\n (3)Heat supplied per cycle is %3.0f kJ\n (4)Heat rejected per cycle is %3.2f kJ\n (5)Work done per cycle is %3.2f kJ\n (6)Thermal efficiency of the cycle is %3.0f percent\n (7)Mass of air contained in the cylinder is %3.4f kg\n (8)Mean effective pressure is %3.2f bar',a,rho,Qs,Qr,W,n,m,Mep)
```

---

**Scilab code Exa 1.30** Thermal efficiency

```
clc
clear
//Input data
P1=1;//Initial pressure of air received by gas
   turbine plant in bar
T1=310;//Initial tamperature in K
P2=5.5;//Pressure at the end of compression in bar
r=1.4;//isentropic index

//Calculations
rp=P2/P1;//pressure ratio
n=(1-(1/rp)^((r-1)/r))*100;//Thermal efficiency of
   the turbine in percent

//Output data
printf('Thermal efficiency of the turbine unit is %3
   .2f percent',n)
```

**Scilab code Exa 1.31** Power developed

```
clc
clear
//Input data
P1=1;//Initial pressure of a simple closed cycle gas
    turbine plant in bar
T1=298;//Initial temperature in K
P2=5.1;//Pressure of gas after compression in bar
T3=1123;//Temperature at the end of compression in K
P3=P2;//Pressure at the end of constant pressure
   stroke
P4=1;//Pressure of hot air after expansion in the
   turbine in bar
r=1.4;//Isentropic constant
Cp=1.005;//Specific heat of air in kJ/kg K

```

```
//Calculations
T2=T1*(P2/P1)^((r-1)/r);//Temperature at the end of
   process 1-2 in K
T4=T3*(P4/P3)^((r-1)/r);//Temperature at the end of
   process 3-4 in K
Wt=Cp*(T3-T4);//Work done by the turbine in kJ/kg
Wc=Cp*(T2-T1);//Work required by the compressor in
   kJ/kg
W=Wt-Wc;//Net work done by the turbine in kJ/kg
P=1*W;//Power developed by the turbine assembly per
   kg per second in kW

//Output
printf('Power developed by the turbine assembly per
   kg of air supplied per second is %3.2f kW',P)
```

**Scilab code Exa 1.32** Maximum temperature

```
clc
clear
//Input data
P1=1;//The pressure of air entering the compressor
   of a gas turbine plant operating on Brayton cycle
    in bar
T1=293;//Initial temperature in K
r=6.5;//Pressure ratio of the cycle
r1=1.4;//Isentropic ratio

//Calculations
T2=T1*(r)^((r1-1)/r1);//Temperature at the end of
   compression in K
T4=2.3*(T2-T1)/0.708;//Temperature at point 4 in K
T3=T4*(r)^((r1-1)/r1);//Maximum temperature in K
n=(1-((T4-T1)/(T3-T2)))*100;//Turbine plant
   efficiency in percent
```

```

//Output
printf('(a)The maximum temperature of the cycle is %3.1f K\n (b)Cycle efficiency is %3.2f percent',T3,n)
```

---

**Scilab code Exa 1.33** Air fuel ratio

```
clc
clear
//Input data
P1=1;//Pressure in an oil gas turbine installation in bar
T1=298;//Initial Temperature in K
P2=4;//Pressure after compression in bar
CV=42100;//Calorific value of oil in kJ/kg
T3=813;//The temperature reached after compression in K
m=1.2;//Air flow rate in kg/s
Cp=1.05;//Specific heat of air at constant pressure in kJ/kg K
r=1.4;//Isentropic ratio

//Calculations
r1=P2/P1;//Pressure ratio
T2=(r1)^((r-1)/r)*T1;//Temperature at the end of compression stroke in K
T4=T3/(r1)^((r-1)/r);//Temperature at the end of isentropic expansion in K
Wt=m*Cp*(T3-T4);//Work done by the turbine in kJ/s or kW
Wc=m*Cp*(T2-T1);//Work to be supplied to the compressor in kJ/s or kW
Wn=Wt-Wc;//Net work done by the turbine unit in kW
qs=m*Cp*(T3-T2);//Heat supplied by the oil in kJ/s
```

```
M=qs/CV;//Mass of fuel burnt per second in kg/s
a=m/M;//Air fuel ratio

//Output
printf('(a)The net power output of the installation is %3.2f kW\n (b)Air fuel ratio is %3.1f',Wn,a)
```

---

**Scilab code Exa 1.34** Net power

```
clc
clear
//Input data
T1=300;//Minimum temperature of the plant containing a two stage compressor with perfect intercooling and a single stage turbine in K
T5=1100;//Maximum temperature of the plant in K
P1=1;//Initial Pressure in bar
P5=15;//Final pressure in bar
Cp=1.05;//Specific heat of air in kJ/kg K
r=1.4;//Isentropic ratio
P6=P1;//Pressure at 6 in bar

//Calculations
P3=(P1*P5)^(1/2);//The intermediate pressure for cooling in bar
P2=P3;//Pressure at point 2 in bar
T2=T1*(P2/P1)^((r-1)/r);//Temperature at the end of process 1-2
T3=T1;//Intermediate temperature in K
T4=1.473*T3;//Temperature at point 4 in K
T6=T5/(P5/P6)^((r-1)/r);//Temperature at point 6 in k
Wt=Cp*(T5-T6);//Work done by the turbine per kg of air in kJ/s
Wc=Cp*(T4-T3)+Cp*(T2-T1);//Work done by the
```

```
compressor per kg of air in kJ/s
Wn=Wt-Wc;//Net work done in kJ/s
Pn=Wn;//Net power developed in kW

//Output
printf('The net power of the plant per kg of air/s is %3.2f kW',Pn)
```

---

**Scilab code Exa 1.35** Maximum power

```
clc
clear
//Input data
P1=1;//Initial Pressure of a gas turbine power plant in bar
P2=8;//Final pressure in bar
T1=300;//Initial temperature in K
T5=850;//Temperature of air expanded in the turbine in K
m=1.8;//Mass of air circulated per second in kg
Cp=1.05;//Specific heat of air at constant pressure in kJ/kg K
r=1.4;//Ratio of specific heat

//Calculations
P4=(P1*P2)^(0.5);//Pressure for maximum power output in bar
P3=P2;//Pressure after the constant pressure process in bar
T3=T5;//For reheating condition Temperature in K
T2=T1*(P2/P1)^((r-1)/r);//Temperature at the end of constant entropy process in K
T4=T3/((P3/P4)^((r-1)/r));//Temperature after the process 3-4 in K
T6=T4;//Temperature at the end of process 5-6 in K
```

```
Wt=m*Cp*((T3-T4)+(T5-T6));//Work done by the turbine in kJ/s
Wc=m*Cp*(T2-T1);//Work absorbed by the compressor in kJ/s
P=Wt-Wc;//Power that can be obtained from gas turbine installation in kW

//Output
printf('The maximum power that can be obtained from turbine installation is %3.0f kW',P)
```

---

**Scilab code Exa 1.36** Mass of fluid

```
clc
clear
//Input data
P1=1.5;//Pressure at the inlet of the low pressure compressor in bar
T1=300;//Temperature at the inlet of the low pressure compressor in K
P5=9;//Maximum pressure in bar
T5=1000;//Maximum temperature in K
P=400;//Net power developed by the turbine in kW
Cp=1.0;//Specific heat of air at constant pressure in kJ/kg K
r=1.4;//Ratio of specific heat

//Calculations
P8=P1;//For perfect intercooling and perfect reheating in bar
P4=P5;//For perfect intercooling and perfect reheating in bar
P2=(P1*P4)^0.5;//Pressure at the end of Isentropic compression in LP compressor in bar
P6=P2;//Pressure at the end of process 5-6 in bar
```

```
T2=T1*(P2/P1)^((r-1)/r);//Temperature at the end of
    isentropic compression in K
T3=T1;//For perfect intercooling in K
T4=T2;//For perfect intercooling in K
T6=T5/(P5/P6)^((r-1)/r);//Temperature at the end of
    process 5-6 in K
T7=T5;//Temperature in K
T8=T6;//Temperature in K
Wt=Cp*((T5-T6)+(T7-T8));//Work done by the turbine
    in kg/s
Wc=Cp*((T2-T1)+(T4-T3));//Work absorbed by the
    compressor in kJ/s
Wn=Wt-Wc;//Net work output in kJ/s
m=P/Wn;//Mass of fluid flow per second in kg/s
qs=m*Cp*((T5-T4)+(T7-T6));//Heat supplied from the
    external source in kJ/s

//Output
printf('(a)Mass of fluid to be circulated in the
    turbine is %3.3f kg/s\n (b)The amount of heat
    supplied per second from the external source is
    %3.1f kJ/s',m,qs)
```

---

**Scilab code Exa 1.37** Mass of air

```
clc
clear
//Input data
T1=293;//Temperature of a constant pressure open
    cycle gas turbine plant in K
T3=1043;//The maximum temperature in K
a=6.5;//The pressure ratio
P=1000;//Power developed by the installation in kW
Cp=1.05;//Specific heat at constant pressure in kJ/
    kg K
```

```
r=1.4;//Isentropic ratio

//Calculations
T2=T1*a^((r-1)/r);//Temperature after the isentropic
    compression stroke in K
T4=T3/a^((r-1)/r);//Temperature after the isentropic
    expansion process in K
Wt=Cp*(T3-T4);//Work done by the turbine per kg of
   air per second in kJ
Wc=Cp*(T2-T1);//Work absorbed by the compressor per
   kg of air per second in kJ
Wn=Wt-Wc;//Net work output in kJ/s
m=P/Wn;//Mass of fluid circulated per second in kg/s
Q=m*Cp*(T3-T2);//Heat supplied by the heating
   chamber in kJ/s

//Output
printf('(a)Mass of air circulating in the
   installation is %3.2f kg/s\n (b)Heat supplied by
   the heating chamber is %3.1f kJ/s',m,Q)
```

---

**Scilab code Exa 1.38** Overall efficiency

```
clc
clear
//Input data
a=6;//Pressure ratio of a gas turbine plant
T1=293;//Inlet temperature of air in K
T3=923;//Maximum temperature of the cycle in K
P=2000;//Power developed in the cycle in kW
nc=85;//Efficiency of the compressor in percentage
nt=85;//Efficiency of the turbine in percentage
Cp=1;//Specific heat of gas at constant pressure in
   kJ/kg K
Cv=0.714;//Specific heat of gas at constant volume
```

```
   in kJ/kg K

//Calculations
r=Cp/Cv;//Ratio of specific heats
T2a=a^((r-1)/r)*T1;//Temperature at 2' in K
T2=((T2a-T1)/(nc/100))+T1;//Temperature at point 2
   in K
T4a=T3/a^((r-1)/r);//Temperature at the point 4' in
   K
T4=T3-((T3-T4a)*(nt/100));//Temperature at the point
    4 in K
Wt=Cp*(T3-T4);//Work done by the turbine per kg of
   air in kJ
Wc=Cp*(T2-T1);//Work done by the compressor per kg
   of air in kJ
Wn=Wt-Wc;//Net work output of the turbine per kg of
   air in kJ
qA=Cp*(T3-T2);//Heat supplied per kg of air in kJ
n=(Wn/qA)*100;//Overall efficiency of the turbine
   plant in percentage
m=P/Wn;//Mass of air circulated per second in kg

//Output
printf('(1)Overall efficiency of the turbine is %3.0
   f percentage\n (2)Mass of air circulated by the
   turbine is %3.2f kg',n,m)
```

**Scilab code Exa 1.39** Isentropic efficiency

```
clc
clear
//Input data
T1=293;//Initial temperature of a gas turbine plant
   in K
P1=1;//Initial pressure in bar
```

```
P2=4.5;//Pressure after the compression in bar
nc=80;//Isentropic efficiency of a compressor in percentage
T3=923;//Temperature of the gas whose properties may be assumed to resemble with those of air in the combustion chamber in K
deltaP=0.1;//Pressure drop in a combustion chamber in bar
nt=20;//Thermal efficiency of the plant in percentage
r=1.4;//Isentropic index
P4=1;//Pressure at point 4 in bar

//Calculations
P3=P2-deltaP;//Pressure at point 3 in bar
T21=T1*(P2/P1)^((r-1)/r);//Temperature after the compression process in K
T2=(T21-T1)/(nc/100)+T1;//Temperature at the point 2 in K
T41=T3/(P3/P4)^((r-1)/r);//Temperature at the end of expansion process in K
Ac=T2-T1;//Work done by the compressor per kg of air per specific heat at constant pressure Ac=Wc/Cp
At=T3;//Work done by the turbine per kg of air per specific heat at constant pressure At=Wt/Cp
An=At-Ac;//Net work done per kg of air
Bs=T3-T2;//Heat supplied per kg of air per specific heat at constant pressure Bs=qs/Cp;qs=heat supplied
T4=An-((nt/100)*Bs);//Temperature at point 4 in K
nT=((T3-T4)/(T3-T41))*100;//Isentropic efficiency of the turbine in percentage

//Output
printf('The isentropic efficiency of the turbine is %3.2f percent',nT)
```

**Scilab code Exa 1.40** Overall efficiency

```
clc
clear
//Input data
P1=1;//Pressure of air received by the gas turbine plant in bar
T1=300;//Initial Temperature in K
P2=5;//Pressure of air after compression in bar
T3=850;//Temperature of air after the compression in K
nc=80;//Efficiency of the compressor in percent
nt=85;//Efficiency of the turbine in percent
r=1.4;//Isentropic index of gas
P3=P2;//Since 2−3 is constant pressure process in bar
P41=1;//Pressure at the point 41 in bar
Cp=1.05;//Specific heat of the gas at constant pressure in kJ/kg K

//Calculations
T21=T1*(P2/P1)^((r-1)/r);//Temperature at the point 21 on the curve in K
T2=(T21-T1)/(nc/100)+T1;//Temperature at the point 2 in K
T41=T3/(P3/P41)^((r-1)/r);//Temperature at the point 41 in K
T4=T3-((nt/100)*(T3-T41));//Temperature of gas at the point 4 in K
Wt=Cp*(T3-T4);//work done by the turbine in kJ/kg of air
Wc=Cp*(T2-T1);//Work done by the compressor in kJ/kg of air
Wn=Wt-Wc;//Net work done by the plant in kJ
```

```
nt=(Wn/(Cp*(T3-T2)))*100;//Thermal efficiency of the plant in percentage

//Output
printf('Overall efficiency of the plant is %3.2f percent',nt)
```

---

**Scilab code Exa 1.41** Overall efficiency

```
clc
clear
//Input data
P1=1;//Initial pressure of a gas turbine plant in bar
T1=310;//Initial temperature in K
P2=4;//Pressure of air after compressing in a rotary compressor in bar
P3=P2;//Constant pressure process
P41=P1;//Since 1−41 is a constant pressure process in bar
T3=900;//Temperature of air at the point 3 in constant process in K
nc=80;//Efficiency of the compressor in percentage
nt=85;//Efficiency of the turbine in percentage
E=70;//Effectiveness of the plant in percentage
r=1.4;//Isentropic index
Cp=1;//Specific heat of air at constant pressure in kJ/kg K

//Calculations
T21=T1*(P2/P1)^((r-1)/r);//Temperature at the point 21 in the temperature versus entropy graph in K
T2=T1+((T21-T1)/(nc/100));//Temperature of air after the compression process in K
T41=T3/((P3/P41)^((r-1)/r));//Temperature at the
```

```
point 41 after the isentropic expansion process in K
T4=T3-((T3-T41)*(nt/100));//Temperature at the point 4 in K
Wt=Cp*(T3-T4);//Work done by the turbine in kJ
Wc=Cp*(T2-T1);//Work done by the compressor in kJ
Wn=Wt-Wc;//Net work done in kJ
qs=Cp*(T3-T2);//Heat supplied in kJ
qa=Cp*(T4-T2);//Heat available in the exhaust gases in kJ
H=qa*(E/100);//Actual heat recovered from the exhaust gases in the heat exchanger in kJ
Hs=qs-(H);//Heat supplied by the combustion chamber in kJ
nt=(Wn/Hs)*100;//Thermal efficiency of the gas turbine plant with heat exchanger in percent

//Output
printf('The overall efficiency of the plant is %3.1f percent',nt)
```

# Chapter 7

# Performance of IC engines

**Scilab code Exa 7.1** Brake torque

```
clc
clear
//Input data
N=1500;//Engine speed in rpm
p=110;//Load on brakes in kg
L=900;//Length of brake arm in mm
g=9.81;//Gravitational force in N/m^2
pi=3.14;//Mathematical constant

//Calculations
T=((p*g)*(L/1000));//Braking torque in Nm
P=((T/1000)*((2*3.14*N)/60));//Power available at
    the brakes of the engine in kW

//Output
printf('(a) Brake torque is %3.1f Nm \n (b)Power
    available at the brakes of the engine is %3.2f kW
    ',T,P)
```

**Scilab code Exa 7.2** Power available at brakes

```
clc
clear
//Input data
N=700;//Engine speed in rpm
D=0.6;//Diameter of brake drum in m
d=0.05;//Diameter of rope in m
W=35;//Dead load on the brake drum in kg
S=4.5;//Spring balance reading in kg
g=9.81;//Gravitational constant in N/m^2
pi=3.14;//Mathematical constant

//Calculations
P=(((W-S)*g*pi*(D+d))/1000)*(N/60);//Power in kW

//Output
printf('The power available at the brakes is %3.3f
   kW',P)
```

---

**Scilab code Exa 7.3** Brake thermal efficiency

```
clc
clear
//Input data
W=950;//Load on hydraulic dynamometer in N
C=7500;//Dynamometer constant
f=10.5;//Fuel used per hour in kg
h=50000;//Calorific value of fuel in kJ/kg
N=400;//Engine speed in rpm

//Calculations
P=(W*N)/C;//Power available at the brakes in kW
H=P*60;//Heat equivalent of power at brakes in kJ/
    min
```

```
Hf=(f*h)/60;//Heat supplied by fuel per minute in kJ/min
n=(H/Hf)*100;//Brake thermal efficiency in percentage

//Output
printf(' Brake thermal efficiency of the engine is %3.2f percent',n)
```

---

**Scilab code Exa 7.4** Specific fuel consumption

```
clc
clear
//Input data
n1=50.5;//Air standard efficiency in percentage
n2=50;//Brake thermal efficiency in percentage
N=3000;//Engine speed in rpm
H=10500;//Heating value of fuel in kcal/kg
T=7.2;//Torque developed in kgf*m
B=6.3;//Bore diameter in cm
S=0.095;//stroke in m

//Calculations
nbt=(n1/100)*(n2/100);//Brake thermal efficiency in percentage
B1=(2*(22/7)*N*T)/4500;//Brake horse power in kW
B2=B1/4;//Brake horse power per cylinder in kW
Bsf=(4500*60)/(H*427*nbt);//Brake specific fuel consumption in kg/BHP hr
bmep=(B2*4500)/(S*(3.14*B^2/4)*(N/2));//Brake mean effective pressure in kgf/cm^2

//Output
printf('(a)Specific fuel consumption is %3.3f kg/BHP hr\n (b)Brake mean effective pressure is %3.3f
```

```
   kgf/cm^2',Bsf,bmep)
```

**Scilab code Exa 7.5** Mechanical efficiency

```
clc
clear
//Input data
W=30;//The net dynamometer load in kg
R=0.5;//Radius in m
N=2400;//Speed in rpm
FHP=6.5;//Engine power in hp

//Calculations
BHP=(2*3.14*R*N*W)/4500;//Brake horse power in kW
IHP=BHP+FHP;//Indicated horse power in kW
nm=(BHP/IHP)*100;//Mechanical efficiency in
   percentage

//Output
printf('Mechanical efficiency of the engine is %3.2f
    percent',nm)
```

**Scilab code Exa 7.6** IHP

```
clc
clear
//Input data
d=25;//Diameter of cylinder in cm
l=0.4;//Stroke of piston in m
N=200;//Speed in rpm
m=10;//Misfires per minute
M=6.2;//Mean effective pressure in kgf/cm^2
nm=0.8;//Mechanical efficiency in percent
```

```

//Calculations
np=(N/2)-m;//Number of power strokes per minute
A=(3.14*d^2)/4;//Area of the cylinder
I=(M*l*A*np)/4500;//Indicated horse power in kW
B=I*nm;//Brake horse power in kW
F=I-B;//Friction horse power in kW

//Output
printf('(a)The indicated horse power is %3.2f kW \n
   (b)The brake horse power is %3.2f kW \n (c)
   Friction horse power is %3.2f kW',I,B,F)
```

---

**Scilab code Exa 7.7** Average piston speed

```
clc
clear
//Input data
I=5;//Indicated power developed by single cylinder
   of 2 stroke petrol engine
M=6.5;//Mean effective pressure in bar
d=0.1;//Diameter of piston in m

//Calculations
A=(3.14*d^2)/4;//Area of the cylinder
LN=(I*1000*60)/(M*10^5*A);//Product of length of
   stroke and engine speed
S=2*LN;//Average piston speed in m/s

//Output
printf('The average piston speed is %3.2f m/s',S)
```

---

**Scilab code Exa 7.8** Dimensions of cylinder

```
clc
clear
//Input data
P=60;//Power developed by oil engine in kW
M=6.5;//Mean effective pressure in kgf/cm^2
N=85;//Number of explosions per minute
r=1.75;//Ratio of stroke to bore diameter
nm=0.8;//Mechanical efficiency

//Calculations
I=P/nm;//Indicated horse power
d=((I*100*4*4500)/(M*r*3.14*N))^(1/3);//Bore diameter in cm
l=r*d;//Stroke length in cm

//Output
printf('(a)Diameter of the bore is %3.2f cm \n (b) Stroke length of the piston is %3.2f cm',d,l)
```

---

**Scilab code Exa 7.9** Bore and stroke of piston

```
clc
clear
//Input data
I=45;//Power developed by two cylinder internal combustion engine operating on two stroke principle
N=1100;//Speed in rpm
M=6;//Mean effective pressure in kgf/cm^2
r=1.3;//Ratio of stroke to the bore
nc=2;//Number of cylinders

//Calculations
d=((I*4500*4)/(M*(r/100)*3.14*N*nc))^(1/3);//Diameter of the bore in cm
```

```
l=1.3*d;//Stroke length in cm

//Output
printf('(a)The bore diameter of the cylinder is %3.2f cm\n (b)Stroke length of the piston is %3.2f cm',d,l)
```

---

**Scilab code Exa 7.10** Volumetric efficiency

```
clc
clear
//Input data
d=6;//Diameter of the bore in cm
l=9;//Length of the stroke in cm
m=0.00025;//Mass of charge admitted in each suction stroke
R=29.27;//Gas constant Kgfm/kg K
p=1;//Normal pressure in kgf/cm^2
T=273;//Temperature in K

//Calculations
V=(m*R*T)*10^6/(p*10^4);//Volume of charge admitted in each cycle in m^3
Vs=(3.14*d^2*l)/4;//Swept volume of the cylinder
nv=(V/Vs)*100;//Volumetric efficiency in percentage

//Output
printf('The volumetric efficiency is %3.1f percent',nv)
```

---

**Scilab code Exa 7.11** Volumetric efficiency

```
clc
```

```
clear
//Input data
d=0.12;//Diameter of the bore in m
l=0.13;//Length of stroke in m
N=2500;//Speed of the engine in rpm
d1=0.06;//Diameter of the orifice in m
Cd=0.70;//Discharge coefficient of orifice
hw=33;//Heat causing air flow through orifice in cm
    of water
p=760;//Barometric reading in mm of Hg
T1=298;//Ambient temperature in degree K
p1=1.013;//Pressure of air at the end of suction in
    bar
T2=22;//Temperature of air at the end of suction in
    degree C
R=0.287;//Universal gas constant
n=6;//Number of cylinders in the engine
n1=1250;//Number of strokes per minute for a four
    stroke engine operating at 2500 rpm

//Calculations
V=(3.14*d^2*l)/4;//Swept volume of piston in m^3
Ao=(3.14*d1^2)/4;//Area of the orifice in m^2
rho=p1*10^5/((R*T1)*1000);//Density of air at 1.013
    bar and 22 degrees C
Va=840*Cd*Ao*(hw/rho)^(1/2);//Volume of air passing
    through the orifice in m^3/min
V1=8.734/n;//Actual volume of air per cylinder in m
    ^3/min
As=V1/n1;//Air supplied per cycle per cylinder in m
    ^3
nv=(As/V)*100;//Volumetric efficiency of the engine
    in percentage

//Output
printf('The volumetric efficiency of the engine is
    %3.2f percent',nv)
```

**Scilab code Exa 7.12** Air standard efficiency

```
clc
clear
//Input data
d=0.15;//Diameter of the piston in m
l=0.19;//Length of the stroke in m
V=0.00091;//Clearance volume in m^3
N=250;//Speed of the engine in rpm
M=6.5;//Indicated mean effective pressure in bar
c=6.3;//Gas consumption in m^3/hr
H=16000;//Calorific value of the has in kJ/m^3
r1=1.4;//Polytropic index

//Calculations
Vs=(3.14*d^2*l)/4;//Swept volume in m^3
Vt=Vs+V;//Total cylinder volume in m^3
r=Vt/V;//Compression ratio
na=(1-(1/r^(r1-1)))*100;//Air standard efficiency in
    percent
A=(3.14*d^2)/4;//Area of the bore in m
I=(M*10^5*l*A*N)/(1000*60);//Indicated power in kW
Hs=(c*H)/(60*60);//Heat supplied per second
nt=(I/Hs)*100;//Indicated thermal efficiency in
   percent

//Output
printf('(a)The air standard efficiency is %3.1f
   percent\n (b)Indicated power is %3.3f kW\n (c)
   Indicated thermal efficiency is %3.1f percent',na
   ,I,nt)
```

**Scilab code Exa 7.13** Diameter of venturi

```
clc
clear
//Input data
ma=6;//Air supplied per minute by a single jet
   carburetor in kg/min
mf=0.44;//Mass flow rate of petrol in kg/min
s=0.74;//Specific gravity of petrol in kg/m^3
p1=1;//Initial pressure of air in bar
T1=300;//Initial temperature of air in K
Ci=1.35;//Isentropic coefficient of air
V=90;//Speed of air in the venturi in m/s
Vc=0.85;//Velocity coefficient of the venturi in m/s
Cf=0.66;//Coefficient of discharge for the jet
Cp=1005;//Coefficient of pressure in J/kg K
n=1.35;//Isentropic coefficient of air
R=0.281;//Real gas constant in Nm/kg K
rhof=740;//Density of fuel in mm of Hg

//Calculations
p2=(1-((V/Vc)^(2)/(2*T1*Cp)))^((n)/(n-1));//Pressure
    at the venturi in bar
V1=((R*T1)/(p1*10^5))*1000;//Initial volume in m^3/
   kg
V2=V1*((p1/p2)^(0.741));//Final volume in m^3/kg
A2=((ma*V2)/(V*60))*10^4;//Throat area of venturi in
    cm^2
d=((A2*4)/3.14)^(0.5);//Diameter of venturi in cm
deltaPa=1-p2;//Pressure drop causing air flow in bar
deltaPf=0.8*deltaPa;//Pressure drop causing fuel
   flow in bar
Af=(mf/60)*(10^4)/((Cf)*(2*rhof*deltaPf*10^5)^(1/2))
   ;//Area through which fuel flows in cm^2
df=((Af*(4/3.14))^(1/2))*10;//Diameter of fuel jet
   in mm

printf('(a)The diameter of the venturi of the
```

```
   venturi if the air speed is 90 m/s is %3.2f cm\n
   (b)The diameter of the jet if the pressure drop
   at the jet is 0.8 times the pressure drop at the
   venturi is %3.4f mm',d,df)
```

**Scilab code Exa 7.14** Fuel supplied

```
clc
clear
//Input data
r=14;//The compression ratio of a diesel engine
Vc=1;//Clearance volume in m^3
c=0.08;//Fuel supply cut off point
nr=0.55;//Relative efficiency
H=10000;//Calorific value of fuel in kcal/kg
r1=1.4;//Ratio of specific heat of air
Vs=13;//Stroke volume in m^3

//Calculations
rho=Vc+(c*Vs);//Cut off ratio
na=1-(1*(rho^r1-1)/((r^(r1-1)*r1)*(rho-1)));//Air
   standard efficiency of diesel cycle in percent
In=(na*nr);//Indicated thermal efficiency in percent
H1=(4500*60)/(In*427);//Heat in fuel supplied/1HP hr
W=H1/10^4;//Weight of fuel required/1HP hr

//Output
printf('The weight of fuel required per 1HP hr is %3
   .4f kg',W)
```

**Scilab code Exa 7.15** Fuel to be injected

```
clc
```

```
clear
//Input data
P=120;//Power developed by a six cykinder four
    stroke diesel engine
N=2400;//Speed in rpm
f=0.2;//Brake specific fuel consumption in kg/kWh
s=0.85;//Specific gravity of fuel

//Calculations
F=f*P;//Fuel consumed per hour in kg
F1=F/6;//Fuel consumed per cylinder in kg/h
n=(N*60)/2;//Number of cycles per hour
F2=(F1/n)*10^3;//Fuel consumption per cycle in gm
V=F2/s;//Volume of fuel to be injected per cycle in
    cc

//Output
printf('The quantity kof fuel to be injected per
    cycle per cylinder is %3.4f cc',V)
```

---

**Scilab code Exa 7.16** Diameter of orifice

```
clc
clear
//Input data
P=20;//Power developed by a four stroke diesel
    engine per cylinder in kW
N=2000;//Operating speed of the diesel engine in rpm
s=0.25;//Specific fuel consumption in kh/kW
p1=180;//Pressure of fuel injected in bar
d=25;//Distance travelled by crank in degrees
p2=38;//Pressure in the combustion chamber in bar
Cd=0.85;//Coefficient of velocity
A=30;//API in degrees

```

```
//Calculations
T=d/(360*(N/60));//Duration of fuel injection in s
SG=(141.5/(131.5+A))*10^3;//Specific gravity of fuel
V=Cd*(2*(p1-p2)*10^5/SG)^(1/2);//Velocity of fuel
    injection in m/s
Vf=(s/60)*P/((N/2)*SG);//Volume of fuel injected per
     cycle in m^3/cycle
Na=Vf/(V*T);//Nozzle orifice area in m^2
d=(((4*Na)/3.14)^(1/2))*10^3;//Diameter of the
    orifice of the fuel injector in mm

//Output
printf('The diameter of the orifice is %3.4f mm',d)
```

---

**Scilab code Exa 7.17** Total orifice area

```
clc
clear
//Input data
P=200;//Power developed by a six cylinder diesel
    engine in kW
N=2000;//Operating speed of the engine in rpm
bs=0.2;//The brake specific fuel consumption in kg/
    kWh
p1=35;//The pressure of air in the cylinder at the
    beginning of injection in bar
p2=55;//Maximum cylinder pressure in bar
p3=180;//Initial injection pressure in bar
p4=520;//Maximum pressure at the injector in bar
Cd=0.75;//Coefficient of discharge
S=850;//Specific gravity of fuel
p5=1;//Atmospheric pressure in bar
a=16;//The crank angle over which injection takes
    place in degrees

```

```
//Calculations
Po=P/6;//Power output per cylinder in kW
F=(Po*bs)/60;//Fuel consumed per cylinder in kg/min
Fi=F/(N/2);//Fuel injected per cycle in kg
T=a/(360*(N/60));//Duration of injection in s
deltaP1=p3-p1;//Pressure difference at the beginning
     of injection in bar
deltaP2=p4-p2;//Pressure difference at the end of
    injection in bar
avP=(deltaP1+deltaP2)/2;//Average pressure
    difference in bar
V=Cd*(2*(avP*10^5)/S)^(1/2);//Velocity of injection
    of fuel jet in m/s
Vo=Fi/S;//Volume of fuel injected per cycle in m^3/
    cycle
A=(Vo/(V*T))*10^6;//Area of fuel orifices in mm^2

//Output
printf('The total orifice area required per injector
     if the injection takes place over 16 degree
    crank angle is %3.4f mm^2',A)
```

---

**Scilab code Exa 7.18** Indicated power

```
clc
clear
//Input data
A=450;//Area of indicator diagram in mm^2
l=60;//Length of indicator diagram in mm
s=1.1;//Spring number in bar/mm
d=0.1;//Diameter of piston in m
L=0.13;//Length of stroke in m
N=400;//Operating speed of the engine in rpm

//Calculations
```

```
Av=A/l;//Average height of indicator diagram in mm
pm=Av*s;//Mean effective pressure in bar
np=N/2;//Number of power strokes per minute for a four stroke diesel engine
Ar=(3.14*d^2)/4;//Area of the piston in m^2
I=(pm*10^5*L*Ar*np)/(1000*60);//Indicated power in kW

//Output
printf('(a)The indicated mean effective pressure is %3.2f bar\n (b)Indicated power is %3.2f kW',pm,I)
```

---

**Scilab code Exa 7.19** BHP

```
clc
clear
//Input data
d=25;//Diameter of the bore in cm
l=0.4;//Stroke length in m
N=300;//Operating speed of the engine in rpm
n=120;//Number of explosions per minute
pm=6.7;//Mean effective pressure in kgf/cm^2
Tnet=90;//Net brake load in kg
R=0.75;//Radius of brake drum in m
f=0.22;//Fuel supplied per minute in m^3
C=4500;//Calorific value of fuel in kcal/m^3

//Calculations
BHP=(2*3.14*R*N*Tnet)/4500;//Brake horse power in kW
A=(3.14*d^2)/4;//Area of the cylinder in cm^2
IHP=(pm*l*A*n)/4500;//Indicated horse power in kW
H=f*C;//Heat supplied by fuel per minute in kcal
nt1=((IHP*C)/(990*427))*100;//Thermal efficiency on IHP basis in percent
nt2=((BHP*C)/(990*427))*100;//Thermal efficiency on
```

```
BHP basis in percent

//Output
printf('(a)The brake horse power is %3.2f kW\n (b)Indicated horse power is %3.3f kW\n (c)Thermal efficiency on IHP basis is %3.2f percent\n (d)Thermal efficiency on BHP basis is %3.2f percent',BHP,IHP,nt1,nt2)
```

---

**Scilab code Exa 7.20** IHP

```
clc
clear
//Input data
D=0.6;//Brake wheel diameter of a constant speed compression ignition engine operating on four stroke cycle in m
t=0.01;//Thickness of brake band in m
N=500;//Operating speed of the engine in rpm
W=20;//Load on brake band in kgf
S=3;//Spring balance reading in kgf
l=6.25;//Length of indicator diagram in cm
A=4.35;//Area of indicator diagram in cm^2
Sn=11;//Spring number in kgf/cm^2/cm
d=10;//Diameter of the bore in cm
L=0.13;//Length of the stroke in m
F=0.23;//Specific fuel consumption in kg/BHP hr
CV=10000;//Heating value of fuel in kcal/kg

//Calculations
BHP=(3.14*(D+t)*N*(W-S))/4500;//Brake horse power in kW
MEP=(A*Sn)/l;//Mean effective pressure in kgf/cm^2
Ar=(3.14*d^2)/4;//Area of the cylinder in cm^2
np=N/2;//Number of explosions per minute
```

```
IHP=(MEP*L*Ar*np)/4500;//Indicated horse power in kW
nm=(BHP/IHP)*100;//Mechanical efficiency in percentage
Wf=F*BHP;//Fuel consumption per hr in kg/hr
nt=((IHP*4500*60)/(Wf*CV*427))*100;//Indicated thermal efficiency in percentage
nb=((BHP*4500*60)/(Wf*CV*427))*100;//Brake thermal efficiency in kW

//Output
printf('(a)The brake horse power is %3.2f kW\n (b)Indicated horse power is %3.3f kW\n (c)Mechanical efficiency is %3.1f percent\n (d)Indicated thermal efficiency is %3.0f percent\n (e)Brake thermal efficiency is %3.1f percent',BHP,IHP,nm,nt,nb)
```

---

**Scilab code Exa 7.21** Indicated thermal efficiency

```
clc
clear
//Input data
N=1200;//Operating speed of a four cylinder engine in rpm
BHP=25.3;//The brake horse power when all 4 cylinders are operating in kW
T=10.5;//The average torque when one cylinder was cut out in mkgf
CV=10000;//Calorific value of the fuel used in kcal/kg
f=0.25;//The amount of petrol used in engine per BHP hour
J=427;//

//Calculations
```

```
BHP1=(2*3.14*N*T)/4500;//BHP for 3 cylinders when 1
   cylinder is cut out in kW
IHP=BHP-BHP1;//IHP of one cylinder in kW
IHPt=IHP*4;//Total IHP of the engine with 4
   cylinders
Wf=(f*BHP)/60;//Fuel used per minute in kg
ni=((IHPt*4500)/(Wf*CV*J))*100;//Indicated thermal
   efficiency in percent
nm=(BHP/IHPt)*100;//Mechanical efficiency in percent
nb=(IHPt*nm)/100;//Brake thermal efficiency in
   percent

//Output
printf('The indicated thermal efficiency is %3.1f
   percent',ni)
```

**Scilab code Exa 7.22** IHP

```
clc
clear
//Input data
B=32;//Brake horse power in kW with all cylinders
   working
B1=21.6;//BHP with number 1 cylinder cut out in kW
B2=22.3;//BHP with number 2 cylinder cut out in kW
B3=22.5;//BHP with number 3 cylinder cut out in kW
B4=23;//BHP with number 4 cylinder cut out in kW

//Calculations
I1=B-B1;//Indicated horse power of number 1 cylinder
    in kW
I2=B-B2;//IHP of number 2 cylinder in kW
I3=B-B3;//IHP of number 3 cylinder in kW
I4=B-B4;//IHP of number 4 cylinder in kW
I=I1+I2+I3+I4;//Total IHP of the engine in kW
```

```
nm=(B/I)*100;//Mechanical efficiency in percent

//Output
printf('(a)The IHP of the engine is %3.1f kW\n (b) Mechanical efficiency is %3.1f percent',I,nm)
```

---

**Scilab code Exa 7.23** Compression ratio

```
clc
clear
//Input data
r=15;//The air fuel ratio by weight
CV=45000;//Calorific value of fuel in kJ/kg
nm=85;//Mechanical efficiency of 4 stroke 4 cylinder engine in percent
na=53;//Air standard efficiency of the engine in percent
nr=65;//Relative efficiency of the engine in percent
nv=80;//Volumetric efficiency of the engine in percent
r1=1.3;//Stroke to bore ratio
p1=1;//Suction pressure in bar
T=303;//Suction temperature in K
S=3000;//The operating speed of the engine in rpm
P=75;//Power at brakes in kW
r2=1.4;//Ratio of specific heats for air
R1=0.287;//Characteristic gas constant for air fuel mixture in kJ/kg K

//Calculations
R=(1/(1-(na/100)))^(1/(r2-1));//Compression ratio of the engine
nti=((na/100)*(nr/100))*100;//The indicated thermal efficiency in percent
Pi=P/(nm/100);//Indicated power in kW
```

```
F=Pi/((nti*CV)/100);//Fuel per second injected in kg/sec
B=F/P;//Brake specific fuel consumption in kg/kWsec
A=1+r;//Mass of fuel mixture entering the engine foe every one kg of fuel in kg
m=A*F;//Mass of air fuel mixture per second in kg
V=(m*R1*T)/(p1*10^5/1000);//Volume of air fuel mixture supplied to the engine per sec
Vs=V/(nv/100);//Swept volume per second in m^3/sec
d=((Vs*2*60*4)/(S*3.14*r1*4))^(1/3)*1000;//Diameter of the bore in mm
L=r1*d;//Stroke length in mm

//Output
printf('(a)Compression ratio is %3.1f \n (b)Indicated thermal efficiency is %3.1f percent\n (c)Brake specific fuel consumption is %3.7f kg/kWsec\n (d)Bore diameter of the engine is %3.1f mm\n (e)Stroke length of the engine is %3.1f mm',R,nti,B,d,L)
```

---

**Scilab code Exa 7.24** Heat balance

```
clc
clear
//Input data
d=0.3;//Diameter of the bore in m
L=0.45;//Stroke length in m
N=220;//Operating speed of the engine in rpm
T=3600;//Duration of trial in sec
F=7;//Fuel consumption in kg per minute
CV=45000;//Calorific value of fuel in kJ/kg
A=320;//Area of indicator diagram in mm^2
l=60;//Length of indicator diagram in mm
S=1.1;//Spring index in bar/mm
```

```
W=130;//Net load on brakes in kg
D=1.65;//Diameter of brake drum in m
W1=500;//Total weight of jacket cooling water in kg
t=40;//Temperature rise of jacket cooling water in
   degrees celsius
t1=300;//Temperature of exhaust gases in degrees
   celsius
ma=300;//Air consumption in kg
sg=1.004;//Specific heat of exhaust gas in kJ/kgK
sw=4.185;//Specific heat of water in kJ/kgK
t2=25;//Room temperature in degrees celsius
g=9.81;//gravity

//Calculations
P=(W*g*3.14*D*N)/(1000*60);//Power available at
   brakes in kW
pm=(A*S)/l;//Mean effective pressure in bar
I=(pm*10^5*L*((3.14*d^2)/4)*N)/(1000*2*60);//
   Indicated power developed in kW
nm=(P/I)*100;//Mechanical efficiency in percent
nt=(P/((F/T)*CV))*100;//Brake thermal efficiency in
   percent
ni=(I/((F/T)*CV))*100;//Indicated thermal efficiency
    in percent
Hs=F*CV;//Heat supplied on one hour basis
Hp=P*T;//Heat equivalent of brake power in kJ
Hf=I-P;//Heat lost in friction in kJ
Hc=W1*t*sw;//Heat carried away by cooling water in
   kJ
He=(ma+F)*(t1-t2)*sg;//Heat carried away by exhaust
   gas in kJ
Hu=Hs-(He+Hf+Hc+He);//Heat unaccounted in kJ
nb=(He/Hs)*100;//Heat equivalent of power at brakes
   in percent
nf=(Hf/Hs)*100;//Heat lost in friction in percent
nw=(Hc/Hs)*100;//Heat removed by jacket water in
   percent
ne=(He/Hs)*100;//Heat carried away by exhaust gases
```

```
in percent
nu=(Hu/Hs)*100;//Heat unaccounted in percent

//Output
printf('(a)Power available at brakes is %3.2f kW\n (b)Indicated power developed is %3.2f kW\n (c)Mechanical efficiency is %3.2f percent\n (d)Brake Thermal efficiency is %3.2f percent\n (e)Indicated thermal efficiency is %3.2f percent',P,I,nm,nt,ni)
```

---

**Scilab code Exa 7.25** BHP

```
clc
clear
//Input data
d=25;//The bore diameter of a single cylinder 4 stroke engine in cm
l=0.38;//Stroke length in m
t=3600;//Duration of test in sec
r=19710;//Total number of revolutions
F=6.25;//Fuel oil used in kg
A=5.7;//Area of indicator diagram in cm^2
L=7.6;//Length of indicator diagram in cm
S=8.35;//Spring number in kgf/cm^3
P=63.5;//Net load on brake drum in kg
R=1.2;//Radius of brake drum in m
Ww=5.7;//Rate of coolant flow in kg/min
deltaT=44;//Temperature rise of coolant in degrees celsius
T1=15.5;//Atmospheric temperature in degrees celsius
As=30;//Air supplied per kg of fuel
CV=10600;//Calorific value of fuel in kcal/kg
Te=390;//Exhaust gas temperature in degrees celsius
sm=0.25;//Mean specific heat of exhaust gas
```

```
//Calculations
Hs=(F*CV)/60;//Heat supplied by fuel per minute in kcal
pm=(A*S)/L;//Mean effective pressure in kgf/cm^2
I=(pm*l*(3.14*d^2)*r)/(4*60*2*4500);//Indicated horse power in kW
B=(P*R*2*3.14*r)/(4500*60);//Brake horse power in kW
Hei=(I*4500)/427;//Heat equivalent of IHP/min in kcal
Heb=(B*4500)/427;//Heat equivalent of BHP/min in kcal
Hf=Hei-Heb;//Heat in friction per minute in kcal
Hc=Ww*deltaT;//Heat carried away by coolant in kcal
We=(F+(As*F))/60;//Weight of exhaust gases per minute
He=We*(Te-T1)*sm;//Heat carried away by exhaust gases in kcal

//Output
printf('(a)Indicated horse power is %3.2f kcal\n (b) Brake horse power developed is %3.2f kcal\n (c) Heat equivalent of friction is %3.1f kcal',I,B,Hf)
```

---

**Scilab code Exa 7.26** Percentage of heat carried away by exhaust gas

```
clc
clear
//Input
F=10;//Quantity of fuel supplied during the trial of a diesel engine in kg/hr
CV=42500;//Calorific value of fuel in kJ/kg
r=20;//Air fuel ratio
T=20;//Ambient temperature in degrees celsius
```

```
mw=585;//Water circulated through the gas calorimeter in litres/hr
T1=35;//Temperature rise of water through the calorimeter in degrees celsius
T2=95;//Temperature of gases at exit from the calorimeter in degrees celsius
se=1.05;//Specific heat of exhaust gases in kJ/kgK
sw=4.186;//Specific heat of water in kJ/kgK

//Calculations
M=(F/60)*(r+1);//Mass of exhaust gases formed per minute
H=((mw/60)*sw*T1)+(M*se*(T2-T));//Heat carried away by the exhaust gases per minute in kJ/min
Hs=(F/60)*CV;//Heat supplied by fuel per minute in kJ/min
nh=(H/Hs)*100;//Percentage of heat carried away by the exhaust gas

//Output
printf('Percentage of heat carried away by exhaust gas is %3.2f percent',nh)
```

**Scilab code Exa 7.27** Percentage of heat carried away by exhaust gases

```
clc
clear
//Input data
F=11;//Fuel used per hour observed during the trial of a single cylinder four stroke diesel engine in kg
mc=85;//Carbon present in the fuel in percent
mh=14;//Hydrogen present in the fuel in percent
mn=1;//Non combustibles present in the fuel in percent
```

```
CV=50000;//Calorific value of fuel in kJ/kg
Vc=8.5;//Percentage of carbon dioxide present in exhaust gas by Volumetric analysis
Vo=10;//Oxygen present in exhaust gases in percent
Vn=81.5;//Nitrogen present in exhaust gases in percent
Te=400;//Temperature of exhaust gases in degrees celsius
se=1.05;//Specific heat of exhaust gas in kJ/kg
Pp=0.030;//Partial pressure of steam in the exhaust in bar
Ta=20;//Ambient temperature in degrees celsius
hs=2545.6;//Enthalpy of saturated steam in kJ/kg
Tsa=24.1;//Saturation temperature from graph in degrees celcius
Cp=2.1;//Specific heat in kJ/kg K
hst=3335;//Enthalpy of super heated steam in kJ/kg

//Calculations
Ma=(Vn*mc)/(33*Vc);//Mass of air supplied per kg of fuel in kg
Me=Ma+1;//Mass of exhaust gases formed per kg of fuel in kg
me=(Me*F)/60;//Mass of exhaust gases formed per minute in kg
ms=F*(mh/100);//Mass of steam formed per kg of fuel in kg
ms1=(ms*F)/60;//Mass of steam formed per minute in kg
mde=me-ms1;//Mass of dry exhaust gases formed per minute in kg
H=mde*se*(Te-Ta);//Heat carried away by the dry exhaust gases per minute in kJ/min
Es=hs+(Cp*(Te-Tsa));//Enthalpy of superheated steam in kJ/kg
He=ms1*hst;//Heat carried away by steam in the exhaust gases in kJ/min
Hl=H+He;//Total heat lost through dry exhaust gases
```

```
    and steam in kJ/min
Hf=(F/60)*CV;//Heat supplied by fuel per minute in
    kJ/min
nh=(Hl/Hf)*100;//Percentage of heat carried away by
    exhaust gases

//Output
printf('Percentage of heat carried away by exhaust
    gases is %3.1f percent',nh)
```

**Scilab code Exa 7.28** Increase in brake power of engine due to supercharging

```
clc
clear
//Input data
C=0.0033;//The capacity of a four stroke engine of
    compression ignition type
I=13;//Average indicated power developed in kW/m^3
N=3500;//Operating speed of the engine
nv=80;//Volumetric efficiency in percentage
p1=1.013;//Initial pressure in bar
T1=298;//Initial temperature in K
r=1.75;//Pressure ratio of the engine
ni=75;//The isentropic efficiency in percentage
nm=80;//mechanical efficiency in percentage
r1=1.4;//Polytropic index

//Calculations
Vs=(N/2)*C;//Swept volume in m^3/min
Vi=Vs*(nv/100);//Unsupercharged engine inducted
    volume in m^3/min
Pb=p1*r;//Blower delivery pressure in bar
T2s=((r)^((r1-1)/r1))*T1;//Final temperature in K
T2=((T2s-T1)/(ni/100))+T1;//Blower delivery
```

```
temperature in K
Ve=((Pb*Vs)*T1)/(T2*p1);//Equivalent volume at 1.013 bar and 298K in m^3/min
Vin=Ve-Vi;//Increase in inducted volume of air in m^3/min
Pin=Vin*I;//Increase in indicated power due to extra air inducted in kW
Pinp=((Pb-p1)*Vs*100)/60;//Increase in indicated power due to increase in induction pressure in kW
Pt=Pin+Pinp;//Total increase in indicated power in kW
nb=Pt*(nm/100);//Total increase in brake power efficiency in kW
ma=(Pb*Vs*100)/(60*0.287*T2);//Mass of air delivered by the blower in kg/s
Wb=ma*1.005*(T2-T1);//Work input to air by blower in kW
Pb1=Wb/(nv/100);//Power required to drive the blower in kW
Pb2=nb-Pb1;//Net increase in brake power in kW

//Output
printf('The net increase in brake power is %3.2f kW',Pb2)
```

# Chapter 8

# Steam Nozzles and Turbines

**Scilab code Exa 8.1** Final velocity of steam

```
clc
clear
//Input data
P1=12;//Pressure of Dry saturated steam entering a
   steam nozzle in bar
P2=1.5;//Discharge pressure of Dry saturated steam
   in bar
f=0.95;//Dryness fraction of the discharged steam
l=12;//Heat drop lost in friction in percentage
hg1=2784.8;//Specific enthalpy of steam at 12 bar
   from steam tables in kJ/kg
hg2=2582.3;//Specific enthalpy of 0.95 dry steam at
   1.5 bar from steam tables in kJ/kg

//Calculations
hd=hg1-hg2;//Heat drop in kJ/kg
V1=44.72*(hd)^(0.5);//Velocity of steam at discharge
    from the nozzle in m/s
n=1-(l/100);//Nozzle coefficient when 12 percent
   heat drop is lost in friction
V2=44.72*(n*hd)^(0.5);//Velocity of steam in m/s
```

```
percentV=((V1-V2)/V1)*100;//Percentage reduction in velocity

//Output
printf('(a)Final velocity of steam is %3.1f m/s\n (b)Percentage reduction in velocity is %3.2f percent',V1,percentV)
```

---

**Scilab code Exa 8.2** Mass of steam discharged

```
clc
clear
//Input data
P1=12;//Initial pressure of dry saturated steam expanded in a nozzle in bar
P2=0.95;//Final pressure of dry saturated steam expanded in a nozzle in bar
f=10;//Frictional loss in the nozzle of the total heat drop in percentage
d=12;//Exit diameter of the nozzle in mm
hd=437.1;//Heat drop in kJ/kg from steam tables
q=0.859;//Dryness fraction of steam at discharge pressure
vg=1.777;//Specific volume of dry saturated steam at 0.95 bar

//Calculations
n=1-(f/100);//Nozzle coefficient from moiller chart
V2=44.72*(n*hd)^(0.5);//Velocity of steam at nozzle exit in m/s
A=(3.14/4)*(0.012)^(2);//Area of the nozzle at the exit in mm^2
m=((A*V2)/(q*vg))*3600;//Mass of steam discharged through the nozzle per hour in kg/hour

```

```
//Output
printf('The mass of steam discharged,when the exit diameter of the nozzle is 12mm is %3.1f kg/hour',m)
```

---

**Scilab code Exa 8.3** Throat area

```
clc
clear
//Input data
P1=12;//Inlet pressure of steam nozzle in bar
T1=250;//Inlet temperature of steam nozzle in degrees celcius
P2=2;//Final pressure of the steam nozzle in bar
n=1.3;//Polytropic constant for superheated steam
St=6.831;//For isentropic expansion, entropy remains constant in kJ/kg
h1=2935.4//Enthalpy of steam at P1 from steam table in kJ/kg
ht=2860;//Enthalpy of steam at pt in kJ/kg
vt=0.325;//Specific volume of steam at the throat conditions in m^3/kg
m=0.2;//Mass of steam discharged through the nozzle in kg/hour
q=0.947;//The dryness fraction of steam at exit from steam tables
hg=2589.6;//Enthalpy of steam at exit in kJ/kg
vs=0.8854;//Specific volume of saturated steam in m^3/kg

//Calculations
pt=(P2/(n+1))^(n/(n-1))*P1;//Critical pressure ratio i.e.,Throat pressure in bar
Vt=(2*1000*(h1-ht))^(0.5);//Velocity of steam at throat in m/s
```

```
At=((m*vt)/Vt)*10^4;//Area of the throat in cm^2 from continuity equation
ve=q*vs;//Specific volume of steam at exit in m^3/kg
Ve=(2*1000*(h1-hg))^(0.5);//Velocity of steam at nozzle exit in m/s
Ae=((m*ve)/Ve)*10^4;//Exit area in cm^2

//Output
printf('(a)Throat area of steam nozzle is %3.3f cm^2\n (b)Exit area of steam nozzle is %3.3f cm^2\n (c)Exit velocity of the nozzle is %3.1f m/s',At,Ae,Ve)
```

---

**Scilab code Exa 8.4** Final exit velocity of steam

```
clc
clear
//Input data
P1=10;//Pressure of steam in bar
f=0.9;//Dryness fraction of steam
At=350;//Throat area in mm^2
Pb=1.4;//Back pressure in bar
h1=2574.8;//Enthalpy of steam at nozzle inlet from steam tables in kJ/kg
ft=0.87;//Dryness fraction of steam at throat pressure
fe=0.81;//Dryness fraction of steam at exit pressure
ht=2481;//Enthalpy of steam at throat pressure at ft in kJ/kg
vt=0.285;//Specific volume of steam at throat in m^3/kg
he=2266.2;//Enthalpy of steam at exit conditions in kJ/kg
ve=1.001;//Specific volume of steam at exit conditions in m^3/kg
```

```

//Calculations
Pt=0.582*P1;//Steam pressure at the throat in bar
hd=h1-ht;//Enthalpy drop upto the throat in kJ/kg
Vt=44.7*(hd)^(0.5);//Velocity of steam at the throat
     in m/s
hde=h1-he;//Enthalpy drop from nozzle entrance to
    exit in kJ/kg
Ve=44.7*(hde)^(0.5);//Velocity of steam at nozzle
    exit in m/s
Ae=(At*Vt*ve)/(Ve*vt);//Exit area of nozzle from the
     mass rate of flow equation in mm^2

//Output
printf('(a)Final exit velocity of steam is %3.1f m/s
    \n (b)Cross sectional area of the nozzle at exit
    for maximum discharge is %3.0f mm^2',Ve,Ae)
```

---

**Scilab code Exa 8.5** Velocity of steam at the throat

```
clc
clear
//Input data
P1=7;//Inlet pressure of a convergent divergent
    steam nozzle in bar
T1=275;//Inlet temperature of the nozzle in degrees
    celcius
P2=1;//Discharge pressure of steam in bar
l=60;//Length of diverging portion of the nozzle in
    mm
dt=6;//Diameter of the throat in mm
f1=10;//Percent of total available enthalpy drop
    lost in friction in the diverging portion in
    percentage
h1=3006.9;//Enthalpy of steam at 7bar pressure and
```

```
   275 degrees celcius in kJ/kg
ht=2865.9;//Enthalpy at the throat from Moiller
   chart in kJ/kg
he=2616.7;//Enthalpy at the exit from moiller chart
   in kJ/kg
vt=0.555;//Specific volume of steam at throat in m
   ^3/kg
Tt=202.8;//Temperature of steam at throat in degrees
    celcius from moiller chart
ve=1.65;//Volume of steam at exit in m^3/kg

//Calculations
Pt=0.546*P1;//The throat pressure for maximum
   discharge in bar
hd=h1-ht;//Enthalpy drop upto throat in kJ/kg
Vt=44.7*(hd)^(0.5);//Velocity of steam at throat in
   m/s
hid=h1-he;//Total isentropic drop from 7 bar,275
   degrees celcius to 1 bar in kJ/kg
hda=(1-(f1/100))*(hid);//Actual heat drop in kJ/kg
Ve=44.7*(hda)^(0.5);//Velocity at exit in m/s
At=(3.14/4)*(6/1000)^(2);//Throat area of the nozzle
    in m^2
m=(At*Vt)/vt;//Mass flow rate at nozzle throat in kg
   /s
Ae=((m*ve)/Ve)*10^4;//Exit area of the nozzle in cm
   ^2
de=(((Ae*4)/3.14)^(0.5))*10;//Diameter of the nozzle
    at exit in mm
alpha=atand((de-dt)/(2*60));//Half of the cone angle
    of the nozzle in degrees
alpha1=2*alpha;//Cone angle of the nozzle in degrees

//Output
printf('(a)Velocity of steam at throat is %3.0f m/s\
   n (b)Temperature of steam at the throat is %3.1f
   degrees celcius\n (c)Cone angle of the divergent
   portion is %3.3f degrees',Vt,Tt,alpha1)
```

# Chapter 9

# Air compressors

**Scilab code Exa 9.1** Isothermal compression

```
clc
clear
//Input data
m=1;//Mass of air that has to be compressed in kg
P1=1;//Initial pressure of a single stage reciprocating air compressor in bar
P2=6;//Final pressure in bar
T1=303;//Initial temperature of air in K
n=1.2;//Polytropic index of air
R=287;//Gas constant for air in J/kg K
r=1.4;//Isentropic index

//Calculations
W1=(m*R*T1*log(P2/P1))/1000;//Work required for compression in kJ/kg in Isothermal compression process
W2=((n/(n-1))*m*R*T1*((P2/P1)^((n-1)/n)-1))/1000;//Work required for compression in a polytropic compression process in kJ/kg
W3=((r/(r-1))*m*R*T1*((P2/P1)^((r-1)/r)-1))/1000;//Work required for compression in a Isentropic
```

```
compression process in kJ/kg

//Output
printf('(a)Work required in a isothermal compression is %3.3f kJ/kg \n(b)Work required in a polytropic compression is %3.3f kJ/kg \n(c)Work required in a isentropic compression is %3.3f kJ/kg',W1,W2,W3)
```

---

**Scilab code Exa 9.2** Size of the cylinder

```
clc
clear
//Input data
Pi=60000;//Indicated power of a double acting air compressor in W
P1=1;//Initial pressure in bar
T1=293;//Initial temperature in K
n=1.2;//Polytropic index of the process
P2=8;//Final pressure in bar
N=120;//Speed at which the cylinder operates in rpm
S=150;//Average piston speed in m/min

//Calculations
L=S/(2*N);//Length of the stroke in m
X=(3.14*L)/4;//X=V/D^2 i.e.,Volume of air before compression/square of the diameter in m
Y=((n/(n-1))*P1*10^5*X*(((P2/P1)^((n-1)/n))-1));//Y=W/D^2 Work done by the compressor per cycle in N/m
Nw=2*N;//Number of working strokes per minute since it is a double acting cylinder
D=(((Pi*60)/(Y*Nw))^(0.5))*1000;//Diameter of the cylinder in mm

```

```
//Output
printf('(a)Length of the cylinder is %3.3f m \n (b) Diameter of the cylinder is %3.0f mm',L,D)
```

**Scilab code Exa 9.3** Indicated power

```
clc
clear
//Input data
D=0.15;//Diameter of a cylinder of a single acting reciprocating air compressor in m
L=0.2;//Length of the stroke in m
P1=1;//The pressure at which compressor sucks air in bar
P2=10;//Final pressure in bar
T1=298;//Initial Temperature in K
N=150;//Operating speed of the compressor in rpm
n=1.3;//Polytropic index of the process

//Calculations
V1=((3.14*D^2*L)/4);//Volume of air before compression in m^3
W=((n/(n-1))*P1*10^5*V1*((P2/P1)^((n-1)/n)-1));//Work done by the compressor for a polytropic compression of air in Nm
Pi=((W*N)/60)/1000;//Indicated power of the compressor in kW

//Output
printf('The indicated power of the compressor is %3.3f kW',Pi)
```

**Scilab code Exa 9.4** Mass of air delivered per minute

```
clc
clear
//Input data
D=0.25;//Diameter of the cylinder of a single acting air compressor in m
L=0.4;//Length of the stroke in m
P1=1;//Initial Pressure of the compressor in bar
T1=303;//Initial temperature of the compressor in K
P2=6;//Pressure during running in bar
N=250;//Operating speed of the compressor in rpm
R=287;//Gas constant in J/kg K

//Calculations
V1=(3.14*D^2*L)/4;//Volume of air before compression in m^3
m=(P1*10^5*V1)/(R*T1);//Mass of air delivered by the compressor per stroke in kg/stroke
Nw=N;//Since single acting cylinder number of working stroke is equal to Operating speed of the compressor in rpm
ma=m*Nw;//Mass of air delivered per minute in kg/min

//Output
printf('Mass of air delivered per minute is %3.2f kg/min',ma)
```

**Scilab code Exa 9.5** Temperature

```
clc
clear
//Input data
P1=1;//Initial pressure of a single acting compressor in bar
P2=12;//Final pressure in bar
N=500;//Operating speed of the compressor in rpm
```

```
T1=308;//Inlet air temperature in K
n=1.3;//Polytropic index

//Calculations
T2=T1*(P2/P1)^((n-1)/n);//Temperature of air delivered by the compressor in K

//Output
printf('Temperature of air delivered by the compressor is %3.2f K',T2)
```

---

**Scilab code Exa 9.6** Isentropic compression

```
clc
clear
//Input data
P1=1;//Pressure at which air is sucked by a compressor in bar
T1=293;//Initial temperature in K
P2=9;//Delivery pressure after compression in bar
r=1.41;//Isentropic index
n=1.3;//Polytropic index

//Calculations
T21=T1*((P2/P1)^((r-1)/r));//Temperature at the end of isentropic compression process in K
T22=T1*((P2/P1)^((n-1)/n));//Temperature at the end of isentropic compression process in K
T23=T1;//Temperature at the end of isotropic compression process in K (Temperature remains constant)

//Output
printf('(a)Temperature at the end of isentropic compression is %3.2f K\n (b)Temperature at the
```

```
end of polytropic compression is %3.2f K\n (c) Temperature at the end of isotropic compression is %3.0f K',T21,T22,T23)
```

---

**Scilab code Exa 9.7** Work done by air during suction

```
clc
clear
//Input data
V1=0.07;//Displacement of the piston of a single stage single cylinder air compressor in m^3
P1=1;//Initial pressure in bar
T1=308;//Initial temperature of air in K
P2=8.5;//Pressure after the compression process in bar
r=1.4;//Isentropic compression

//Calculations
V2=V1*((P1/P2)^(1/1.4));//Final volume of the cylinder in m^3
W1=P1*10^5*V1;//Work done by air during suction in Nm (or) J
W2=(P1*10^5*V1*(1-(P2/P1)^((r-1)/r)))/(r-1);//Work done by air during compression in Nm or J
Wa1=P2*10^5*V2;//Work done on air during delivery in Nm or J
Wa2=((-W2)+Wa1-W1)/1000;//Net work done on air during the cycle in kJ

//Output
printf('(a)Work done by air during suction is %3.0f J\n (b)Work done on air during compression is %3.0f J\n (c)Work done on air during delivery is %3.0f J\n (d)Net work done on air during the cycle is %3.3f kJ',W1,W2,Wa1,Wa2)
```

**Scilab code Exa 9.8** Work done on air during delivery

```
clc
clear
//Input data
V1=0.05;//displacement of a piston of a single
   cylinder single stage reciprocating compressor in
    m^3
P1=1;//pressure of air sucked in the compressor in
   bar
T1=300;//Initial Temperature of air in K
P2=7;//Pressure after the compression process in bar

//Calculations
V2=(P1*V1)/P2;//Volume after the compression in m^3
W1=P1*10^5*V1;//Work done by air during suction in
   Nm
W2=P1*10^5*V1*log(V2/V1);//Work done on sir during
   isothermal compression in Nm
H=-W2;//Heat transferred to the cylinder walls in Nm
    or J
W3=P1*10^5*V1;//Work done on air during delivery in
   Nm
Wn=W1+(-W2)-W3;//Net work done during the cycke in N
    m

//Output
printf('(a)Work done by air during suction is %3.0f
   Nm\n (b)Work done on air during Isothermal
   compression is %3.0f Nm\n (c)Heat transferred
   during this process is %3.0f J\n (d)Work done on
   air during delivery is %3.0f Nm\n (e)Net work
   done during the cycle is %3.0f Nm',W1,W2,H,W3,Wn)
```

**Scilab code Exa 9.9** Power required

```
clc
clear
//Input data
m=2;//Mass of air delivered per second in kg
P1=1;//Initial pressure of a single stage compressor in bar
T1=293;//Initial temperature in K
P2=7;//Final pressure in bar
n=1.4;//Polytropic index
R=287;//Gas constant in J/kg K

//Calculations
W=((n/(n-1))*m*R*T1*(((P2/P1)^((n-1)/n))-1))/(60*1000);//Work done by compressor in kW

//Output
printf('Power required to compress and deliver 2kg of air per minute is %3.3f kW',W)
```

---

**Scilab code Exa 9.10** Work done by compressor

```
clc
clear
//Input data
D=0.15;//Diameter of the bore of a single stage single acting reciprocating air compressor in m
L=0.225;//Stroke length in m
P1=1;//Pressure of air received in bar
T1=308;//Temperature of initial air in K
P2=6.5;//Delivery pressure in bar
```

```
n=1.3;//Polytropic index

//Calculations
Vs=(3.14*D^2*L)/4;//Stroke volume of the compressor in m^3
Vc=0.05*Vs;//Clearance volume in m^3
V1=Vs+Vc;//Initial volume of air in m^3
V4=Vc*(P2/P1)^(1/n);//The air in the clearance volume expands during suction stroke in m^3
V=V1-V4;//Effective swept volume in m^3
W=((n/(n-1))*P1*10^5*(V1-V4)*(((P2/P1)^((n-1)/n))-1));//Work done by the compressor per cycle in Nm

//Output
printf('Work done by the compressor per cycle is %3.1f Nm',W)
```

**Scilab code Exa 9.11** Volume of free air

```
clc
clear
//Input data
D=0.1;//Diameter of the bore of a single acting compressor in m
L=0.1;//Length of the stroke in m
N=400;//Operating speed of the compressor in in rpm
Vc=0.00008;//Clearance volume in m^3
n=1.2;//Polytropic index
T1=303;//Initial temperature in K
Tf=293;//Final temperature in K
P1=0.95;//Initial pressure in bar
P2=8;//Final pressure in bar
Pf=1.013;//Free air pressure in bar

//Calculations
```

```
Vs=(3.14*D^2*L)/4;//Stroke volume of the compressors
     in m^3
V1=Vc+Vs;//Initial volume of air is equal to
    cylinder volume in m^3
V4=Vc*(P2/P1)^(1/n);//Air in the clearance volume
    expands during suction stroke to V4
Ve=V1-V4;//Effective swept volume in m^3
Vf=(P1*(V1-V4)*Tf)/(T1*Pf);//Free air delivered per
    cycle can be obtained in m^3
A=Vf*N;//Free air delivered per minute in m^3/min

//Output
printf('(a)Free air delivered per cycle is %3.6f m
    ^3\n (b)Free air delivered per minute is %3.4f m
    ^3/min',Vf,A)
```

---

**Scilab code Exa 9.12** Power of the compressor

```
clc
clear
//Input data
P1=1;//Pressure of air drawn by a two stage single
    acting reciprocating air compressor in bar
T1=293;//Initial temperature in K
P3=60;//Final pressure after the compression in bar
P2=10;//Pressure after compression in the LP
    cylinder in bar
T2=303;//Temperature after cooling in K
D=0.16;//Diameter of a cylinder in m
L=0.2;//Stroke length of the cylinder in m
n=1.3;//Polytropic index
N=300;//Operating speed of the compressor in rpm
R=287;//Gas constant in J/kg K

//Calculations
```

```
V1=(3.14*D^2*L)/4;//Volume of the LP cylinder in m^3
V2=(P1*V1*T2)/(T1*P2);//Volume of the HP cylinder in m^3
W=(n/(n-1))*(P1*10^5*V1*(((P2/P1)^((n-1)/n))-1)+(P2*10^5*V2*(((P3/P2)^((n-1)/n))-1)));//Work done by the compressor per working cycle in N m
P=(W*N)/(60*1000);//Power of the compressor in kW

//Output
printf('Power of the compressor when it runs at 300 rpm is %3.3f kW',P)
```

---

**Scilab code Exa 9.13** Percentage saving in work

```
clc
clear
//Input data
P1=1;//Initial pressure in bar
P3=9;//Final pressure in bar
n=1.3;//Compression index

//Calculations
W1=(n/(n-1))*(P1*10^5*(((P3/P1)^((n-1)/n))-1));//Work done in compression in a single stage per unit volume per kg of air in N m
P2=(P1*P3)^(0.5);//Intercooler pressure for perfect intercooling in bar
W2=2*(n/(n-1))*(P1*10^5*(((P2/P1)^((n-1)/n))-1));//Work done in compression in a two stage compressor per unit volume per kg of air in N m
Wc=W1-W2;//Saving in work of compression in N m
nw=((W1-W2)/W1)*100;//Percentage saving in work of compression in percentage

//Output
```

```
printf('Percentage saving in the work of compression of air in two stages instead of single stage is %3.2f percent',nw)
```

---

**Scilab code Exa 9.14** Work required

```
clc
clear
//Input data
m=1;//Mass of air to be compressed in kg
P1=1;//Pressure of air before compression in bar
T1=303;//Initial temperature in K
P3=25;//Final pressure of air after compression in bar
n=1.3;//Polytropic index
R=287;//Gas constant in J/kg K

//Calculations
P2=(P1*P3)^(0.5);//Intermediate pressure in the case of perfect intercooling in bar
W=2*(n/(n-1))*(m*R*T1*(((P2/P1)^((n-1)/n))-1));//Work done in compression in a two stage compressor per unit volume per kg of air in N m

//Output data
printf('Minimum work required to compress 1kg of air for given conditions is %3.0f N m',W)
```

---

**Scilab code Exa 9.15** Power required to drive compressor

```
clc
clear
//Input data
```

```
V1=3;//Volume of air sucked in by a two stage
    compressor in m^3
P1=1.04;//Initial pressure in bar
T1=298;//Initial temperature in K
P2=9;//Delivery pressure in bar
n=1.25;//Polytropic index

//Calculations
P2=(P1*P2)^(0.5);//Intermediate pressure for perfect
     intercooling and for minimum work of compression
     in bar
W=2*(n/(n-1))*(P1*10^5*V1*(((P2/P1)^((n-1)/n))-1));
    //Work done in compression in a two stage
    compressor per unit volume per kg of air in Nm
P=W/(60*1000);//Power required to drive the
    compressor in kW

//Output
printf('The minimum power required to drive the
    compressor is %3.3f kW',P)
```

**Scilab code Exa 9.16** Mass of water

```
clc
clear
//Input data
P1=1;//Initial pressure of a two stage air
    compressor in bar
P3=36;//Final pressure in bar
T1=298;//Initial temperature in K
n=1.35;//Polytropic index
T3=298;//Temperature after intercooling in K
Tc=20;//Permissible temperature rise of the cooling
    water in K
R=287;//Gas constant in J/kg K
```

```
Cp=1;//Specific heat of air in kJ/kg K
Cw=4.2;//Specific heat of water in kJ/kg K
ma=1;//Mass of air in the compressor in kg

//Calculations
P2=(P1*P3)^(0.5);//Intercooler pressure for complete intercooling and for minimum work of compression in bar
T2=T1*(P2/P1)^((n-1)/n);//Temperature after the compression process in K
mw=(ma*Cp*(T2-T3))/(Cw*(Tc));//Mass of water to circulate in the intercooler per kg of air in kg

//Output
printf('Mass of water to circulate in the intercooler for abstracting heat is %3.3f kg',mw)
```

---

**Scilab code Exa 9.17** Volume ratio of LP to HP cylinders

```
clc
clear
//Input data
V1=0.2;//Volume of air flow per second in a two stage single acting reciprocating compressor in m^3
P1=0.1;//Intake pressure of air in MPa
T1=293;//Initial temperature in K
P3=0.8;//Final pressure after the air is compressed in MPa
N=600;//Operating speed of the compressor in rpm

//Calculations
P2=(P1*P3)^(0.5);//Intercooler pressure for perfect intercooling and for minimum work of compression in bar
```

```
Vl=(V1*60)/600;//Volume of the LP cylinder in m^3
Vh=(P1*Vl)/P2;//Volume of the high pressure cylinder
    in m^3
R=Vl/Vh;//Ratio of cylinder volumes

//Output
printf('The volume ratio of LP to HP cylinders is %3
   .2f',R)
```

---

**Scilab code Exa 9.18** Ratio of cylinder diameters

```
clc
clear
//Input data
P1=1;//Initial pressure of air entering a two stage
   air compressor with complete intercooling in bar
P3=25;//Delivery pressure of air toe the mains in
   bar
T1=303;//Initial temperature in K
n=1.35;//Compression index

//Calculations
P2=(P1*P3)^(0.5);//Inter cooler pressure for perfect
    intercooling in bar
R=(P2/P1)^(0.5);//Ratio of cylindrical diameters

//Output
printf('The ratio of cylinder diameters for the
   efficiency of compression to be maximum is %3.3f'
   ,R)
```

---

**Scilab code Exa 9.19** Number of stages

```
clc
clear
//Input data
P1=1;//Initial pressure of a multistage compression in bar
Pn1=120;//Final pressure in bar
r=4;//Permissible pressure ratios per stage

//Calculations
n=log(Pn1/P1)/log(r)
n1=4;//As n=3.45 say 4 stages
P5=Pn1;//Since number of stages is 4
P4=P5/(Pn1/P1)^(1/n1);//Pressure after the stage 3 in bar
P3=P4/(Pn1/P1)^(1/n1);//Pressure after the stage 2 in bar
P2=P3/(Pn1/P1)^(1/n1);//Pressure after the stage 1 in bar

//Output
printf('(a)Number of stages are %3.0f\n (b) Intermediate pressures are, P2 = %3.2f bar, P3 = %3.2f bar, P4 = %3.2f bar',n1,P2,P3,P4)
```

---

**Scilab code Exa 9.20** Intermediate pressures

```
clc
clear
//Input data
P1=1;//Initial pressure of a 3 stage compressor in bar
P4=40;//Final pressure in bar
T1=293;//Initial temperature in K
n=1.3;//Polytropic index
V1=15;//Air delivered per minute in m^3/min
```

```

//Calculations
W=((3*n)/(n-1))*P1*10^5*V1*(((P4/P1)^((n-1)/(3*n)))
   -1);//Work done by the compressor in kJ/min
P=W/(60*1000);//Power required to deliver 15 m^3/min
    air in kW
P2=P1*(P4/P1)^(1/3);//Intermediate pressure after
   stage 1 in bar
P3=P2*(P4/P1)^(1/3);//Intermediate pressure after
   stage 2 in bar

//Output
printf('(a)Power required to deliver 15 m^3/min air
   at suction condition is %3.1f kW\n (b)
   Intermediate pressures are P2 = %3.3f bar P3 = %3
   .3f bar',P,P2,P3)
```

**Scilab code Exa 9.21** Heat rejected

```
clc
clear
//Input data
P1=1;//Atmospheric pressure in bar
P4=60;//Delivery pressure in bar
T1=303;//Initial temperature in K
n=1.3;//Index of compression
Cp=1.005;//Specific heat of air at constant pressure
    in kJ/kg K
S=3;//Number of stages

//Calculations
P2=P1*(P4/P1)^(1/3);//Intermediate pressure in bar
T2=T1*(P2/P1)^((n-1)/n);//Temperature of air
   entering the intercoolers in K
H=Cp*(T2-T1);//Heat rejected in each intercooler in
```

```
kJ

//Output
printf('Amount of heat rejected in each intercooler is %3.0f kJ',H)
```

---

**Scilab code Exa 9.22** Ratio of cylinder volumes

```
clc
clear
//Input data
P1=1;//Pressure at the end of suction stroke in LP cylinder of a 3 stage single acting reciprocating compressor in bar
T1=293;//Temperature at the end of suction stroke in LP cylinder in K
V=9;//Free air delivered by the compressor in m^3
P4=65;//Pressure delivered by the compressor in bar
n=1.25;//Polytropic index

//Calculations
P2=P1*(P4/P1)^(1/3);//Intermediate pressure after stage 1 in bar
P3=P2*(P4/P1)^(1/3);//Intermediate pressure after stage 2 in bar
V3=1;//The volume of cylinder for the third stage in m^3
V2=V3*(P3/P2);//Volume of the cylinder for second stage in m^3
V1=(P2/P1)*V2;//Volume of the cylinder for first stage in m^3
W=(((3*n)/(n-1))*P1*10^5*V*(((P4/P1)^((n-1)/(3*n)))-1))/1000;//Work done by the compressor in kJ/min
Pi=W/60;//Indicated power in kW

```

```
//Output
printf('(a)L.P. and I.P.compressor delivery pressure is P2 = %3.3f bar P3 = %3.2f bar\n (b)Ratio of cylinder volumes is V1:V2:V3 = %3.2f:%3.3f:%3.0f\n (c)Total indicated power is %3.2f kW',P2,P3,V1,V2,V3,Pi)
```

# Chapter 10

# Refrigeration and air conditioning

**Scilab code Exa 10.1** Power rating

```
clc
clear
//Input data
T1=273;//The temperature of ice in K
T2=298;//Temperature of water at room in K
COP=2.1;//Cop of the plant
ne=90;//Overall electrochemical efficiency in
   percentage
w=15;//Weight of ice produced per day in tonnes
cw=4.187;//Specific heat of water in kJ/kg degrees
   celcius
Li=335;//Latent heat of ice in kJ/kg
mi=1;//Mass of ice produced at 0 degrees celcius

//Calculations
m=(w*1000)/(24*60);//Mass of ice produced in kg/min
h=(mi*cw*(T2-T1))+Li;//Heat extracted from 1kg of
   water at 25 degrees celcius to produce 1kg of ice
    at 0 degrees celcius in kJ/kg
```

```
Q=m*h;//Total heat extracted in kJ
W=Q/COP;//Work done by the compressor in kJ/kg
P=W/(60*(ne/100));//Power of compressor in kW

//Output
printf('Power rating of the compressor-motor unit if the cop of the plant is 2.1 is %3.1f kW',P)
```

---

**Scilab code Exa 10.2** Refrigeration capacity

```
clc
clear
//Input data
m=400;//Mass of fruits supplied to a cold storage in kg
T1=293;//Temperature at which fruits are stored in K
T2=268;//Temperature of cold storage in K
t=8;//The time untill which fruits are cooled in hours
hfg=105;//Latent heat of freezing in kJ/kg
Cf=1.25;//Specific heat of fruit
TR=210;//One tonne refrigeration in kJ/min

//Calculations
Q1=m*Cf*(T1-T2);//Sensible heat in kJ
Q2=m*hfg;//Latent heat of freezing in kJ
Q=Q1+Q2;//Heat removed from fruits in 8 hrs
Th=(Q1+Q2)/(t*60);//Total heat removed in one minute in kJ/kg
Rc=Th/TR;//Refrigerating capacity of the plant in TR

//Output
printf('The refrigeration capacity of the plant is %3.3f TR',Rc)
```

---

**Scilab code Exa 10.3** COP of a heat pump

```
clc
clear
//Input data
T1=300;//The maximum temperature at which carnot
   cycle operates in K
T2=250;//The minimum temperature at which carnot
   cycle operates in K

//Calculations
COPr=T2/(T1-T2);//COP of the refrigerating machine
COPh=T1/(T1-T2)//COP of heat pump
n=((T1-T2)/T1)*100;//COP or efficiency of the heat
   engine in percentage

//Output data
printf('(a)COP of the machine when it is operated as
    a refrigerating machine is %3.2f\n (b)COP when
   it is operated as heat pump is %3.2f\n (c)COP or
   efficiency of the Heat engine is %3.2f percent',
   COPr,COPh,n)
```

---

**Scilab code Exa 10.4** Time taken to achieve cooling

```
clc
clear
//Input data
m=20000;//The storage capacity of fish in a storage
   plant in kg
T1=298;//Supplied temperature of fish in K
```

```
T2=263;//Temperature of cold storage in which fish
   are stored in K
T3=268;//Freezing point of fish in K
Caf=2.95;//Specific heat of fish above freezing
   point in kJ/kg K
Cbf=1.25;//Specific heat of below freezing point in
   kJ/kg K
W=75;//Work required by the plant in kW
TR=210;//One tonne refrigeration in kJ/min
hfg=230;//Latent heat of fish in kJ/kg

//Calculations
COPr=T2/(T1-T2);//COP of reversed carnot cycle
COPa=0.3*COPr;//Given that actual COP is 0.3 times
   of reversed COP
Hr=(COPa*W)*60;//Heat removed by the plant in kJ/min
C=Hr/TR;//Capacity of the plant in TR
Q1=m*Caf*(T1-T3);//Heat removed from the fish above
   freezing point in kJ
Q2=m*Cbf*(T3-T2);//Heat removed from fish below
   freezing point in kJ
Q3=m*hfg;//Total latent heat of the fish in kJ
Q=Q1+Q2+Q3;//Total heat removed by the plant in kJ
T=(Q/Hr)/60;//Time taken to achieve cooling in hrs

//Output data
printf('(a)Capacity of the plant is %3.2f TR\n (b)
   Time taken to achieve cooling is %3.2f hours',C,T
   )
```

**Scilab code Exa 10.5** Theoretical COP

```
clc
clear
//Input data
```

```
T2=298;//Maximum temperature at which CO2 machine works in K
T1=268;//Minimum temperature at which CO2 machine works in K
sf1=-0.042;//Liquid entropy at 268 K in kJ/kg K
hfg1=245.3;//Latent heat of gas at 268 K in kJ/kg
sf2=0.251;//Liquid entropy in kJ/kg K
hfg2=121.4;//Latent heat of gas at 298 K in kJ/kg
hf1=-7.54;//Liquid enthalpy at 268 K in kJ/kg
hf2=81.3;//Liquid enthalpy at 298 K in kJ/kg
hf3=81.3;//Enthalpy at point 3 in graph in kJ/kg

//Calculations
s2=sf2+(hfg2/T2);//Entropy at point 2 from the graph in kJ/kg K
x1=(s2-sf1)/(hfg1/T1);//Dryness fraction at point 1
h1=hf1+(x1*hfg1);//Enthalpy at point 1 in kJ/kg
h2=hf2+hfg2;//Enthalpy at point 2 in kJ/kg
COP=(h1-hf3)/(h2-h1);//Coefficient of performance for a CO2 machine working at given temperatures

//Output data
printf('Theoretical COP for a CO2 machine working at given temperatures is %3.2f',COP)
```

---

**Scilab code Exa 10.6** Capacity of refrigerator

```
clc
clear
//Input data
T2=298;//Maximum temperature at which ammonia refrigerating system works in K
T1=263;//Minimum temperature at which ammonia refrigerating system works in K
mf=5;//Fluid flow rate in kg/min
```

```
sf1=0.5443;//Liquid entropy at 298 K in kJ/kg K
sf2=1.1242;//Liquid entropy at 263 K in kJ/kg K
hfg1=1297.68;//Latent heat at 298 K in kJ/kg
hfg2=1166.94;//Latent heat at 263 K in kJ/kg
hf1=135.37;//Liquid enthalpy at point 1 in graph in kJ/kg
hf2=298.9;//Liquid enthalpy at point 2 in graph in kJ/kg
TR=210;//One tonne refrigeration in TR

//Calculations
s2=sf2+(hfg2/T2);//Entropy at point 2 in kJ/kg
x1=(s2-sf1)/(hfg1/T1);//Dryness fraction at point 1
h1=hf1+(x1*hfg1);//Enthalpy at point 1 in kJ/kg
h=h1-hf2;//Heat extracted of refrigerating effect produced per kg of refrigerant in kJ/kg
ht=mf*h;//Total heat extracted at a fluid flow rate of 5 kg/min in kJ/min
C=ht/TR;//Capacity of refrigerating in TR

//Output
printf('The capacity of refrigerator is %3.0f TR',C)
```

**Scilab code Exa 10.7** Theoretical COP

```
clc
clear
//Input data
T1=263;//Minimum temperature at which ammonia refrigerating machine works in K
T2=303;//Maximum temperature at which ammonia refrigerating machine works in K
x1=0.6;//Dryness fraction of ammonia during suction stroke
sf1=0.5443;//Liquid entropy at 263 K in kJ/kg K
```

```
hfg1=1297.68;//Latent heat at 263 K in kJ/kg
sf2=1.2037;//Liquid entropy at 303 K in kJ/kg K
hfg2=1145.8;//Latent heat at 303 K in kJ/kg
hf1=135.37;//Liquid enthalpy at 263 K in kJ/kg
hf2=323.08;//Liquid enthalpy at 303 K in kJ/kg

//Calculations
s1=sf1+((x1*hfg1)/T1);//Entropy at point 1 in kJ/kg
   K
x2=(s1-sf2)/(hfg2/T2);//Entropy at point 2 in kJ/kg
   K
h1=hf1+(x1*hfg1);//Enthalpy at point 1 in kJ/kg
h2=hf2+(x2*hfg2);//Enthalpy at point 2 in kJ/kg
COP=(h1-hf2)/(h2-h1);//Theoretical COP of ammonia
    refrigerating machine

//Output
printf('The theoretical COP of a ammonia
    refrigerating machine working between given
    temperatures is %3.2f',COP)
```

---

**Scilab code Exa 10.8** Ice produced

```
clc
clear
//Input data
T1=263;//Minimum temperature at which Vapour
    compression refrigerator using methyl chloride
    operates in K
T2=318;//Maximum temperature at which Vapour
    compression refrigerator using methyl chloride
    operates in K
sf1=0.183;//Entropy of the liquid in kJ/kg K
hfg1=460.7;//Enthalpy of the liquid in kJ/kg
sf2=0.485;//Entropy of the liquid in kJ/kg K
```

```
hfg2=483.6;//Enthalpy of the liquid in kJ/kg
x2=0.95;//Dryness fraction at point 2
hf3=133.0;//Enthalpy of the liquid in kJ/kg
W=3600;//Work to be spent corresponding to 1kW/hour
Cw=4.187;//Specific heat of water in kJ/kg degrees celcius
mi=1;//Mass of ice produced at 0 degrees celcius
Li=335;//Latent heat of ice in kJ/kg
hf1=45.4;//Enthalpy of liquid at 263 K in kJ/kg
hf2=133;//Enthalpy of liquid at 318 K in kJ/kg

//Calculations
s2=sf2+((x2*(hfg2-hf2))/T2);//Enthalpy at point 2 in kJ/kg
x1=(s2-sf1)/((hfg1-hf1)/T1);//Dryness fraction at point 1
h1=hf1+(x1*hfg1);//Enthalpy at point 1 in kJ/kg
h2=hf2+(x2*hfg2);//Enthalpy at point 2 in kJ/kg
COP=(h1-hf3)/(h2-h1);//Theoretical COP
COPa=0.6*COP;//Actual COP which is 60 percent of theoretical COP
H=W*COPa;//Heat extracted or refrigeration effect produced per kW hour in kJ
Hw=(mi*Cw*10)+Li;//Heat extracted from water at 10 degrees celcius for the formation of 1 kg of ice at 0 degrees celcius
I=H/Hw;//Amount of ice produced in kg/kW hr

//Output
printf('The amount of ice produced is %3.2f kg/kW hr',I)
```