Scilab Textbook Companion for Power Plant Engineering by P. K. Nag[1]

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Book Description

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

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

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

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

Contents

List of Scilab Codes

Chapter 1

Introduction Economics of Power Generation

Scilab code Exa 1.1 Load factor

```

clf()
clc
clear
//Input data
C=30//Capacity in MW
M=70//Loads are taken above 70 MW
t1=[0,6] //Time range in hours
t2=[6,10] //Time range in hours
t3=[10,12] //Time range in hours
t4=[12,16] //Time range in hours
t5=[16,20] //Time range in hours
t6=[20,22] //Time range in hours
t7=[22,24] //Time range in hours
L=[30,70,90,60,100,80,60] //Load in MW

//Calculations
E=((L(1)*(t1(2)-t1(1)))+(L(2)*(t2(2)-t2(1)))+(L(3)*(
    t3(2)-t3(1)))+(L(4)*(t4(2)-t4(1)))+(L(5)*(t5(2)-
```

```
t5(1)))+(L(6)*(t6(2)-t6(1)))+(L(7)*(t7(2)-t7(1))))//Energy generated in MWh
AL=(E/24)//Average load in MW
PL=max(L(1),L(2),L(3),L(4),L(5),L(6),L(7))//Peak load in MW
LF=(AL/PL)//Load factor of the plant
E1=((L(3)-M)*(t3(2)-t3(1)))+((L(5)-M)*(t5(2)-t5(1)))+((L(6)-M)*(t6(2)-t6(1)))//Energy generated if the load above 70 MW is supplied by a standby unit of 30 MW capacity in MWh
T=(t3(2)-t3(1))+(t5(2)-t5(1))+(t6(2)-t6(1))//Time during which the standby unit remains in operation in h
AL1=(E1/T)//Average load in MW
LF1=(AL1/C)//Load factor
U=(E1/(C*T))//Use factor

//Output
t=[0,0,6,6,10,10,12,12,16,16,20,20,22,22,24,24]//Time for plotting load curve in hours
l=[0,30,30,70,70,90,90,60,60,100,100,80,80,60,60,0]//Load for plotting load curve in MW
plot(t,l)//Load curve taking Time in hours on X-axis and Load in MW on Y- axis
xtitle('Load Curve','Time hours','Load MW');


printf('(a)Load factor of the plant is %3.2f\n(b)Load factor of a standby equipment of %3.0f capacity if it takes up all the loads above %3.0f MW is %3.2f\n(c)Use factor is %3.2f',LF,C,M,LF1,U)
```

Scilab code Exa 1.2 Average load

```

clc
clear
//Input data
P=60//Peak load on power plant in MW
L=[30,20,10,14]//Loads having maximum demands in MW
C=80//Capacity of the power plant in MW
A=0.5//Annual load factor
Y=8760//Number of hours in a year of 365 days

//Calculations
AL=(P*A)//Average load in MW
E=(AL*1000*Y)/10^6//Energy supplied per year in kWh
   *10^6
DF=(P/(L(1)+L(2)+L(3)+L(4)))//Demand factor
DIF=((L(1)+L(2)+L(3)+L(4))/P)//Diversity factor

//Output
printf('(a) The average load on the power plant is
   %3.0f MW \n(b) The energy supplied per year is %3
   .1f *10^6 kWh \n(c) Demand factor is %3.3f \n(d)
   Diversity factor is %3.3f',AL,E,DF,DIF)
```

Scilab code Exa 1.3 Annual Revenue

```

clc
clear
//Input data
C=210//Capacity of thermal power plant in MW
P=160//Maximum load in MW
L=0.6//Annual load factor
m=1//Coal consumption per kWh of energy generated
Rs=450//Cost of coal in Rs per tonne
Y=8760//Number of hours in a year of 365 days
```

```

//Calculations
AL=(L*P)//Average load in MW
E=(AL*Y)//Energy generated per year in MWh
CL=(E*1000)//Coal required per year in kg
CY=(E*Rs)//Cost of coal per year
CE=CL//Cost of energy sold in Rs
RY=(CE-CY)/10^7//Revenue earned by the power plant
   per year in Rs crore
CF=(AL/C)//Capacity factor

//Output
printf('(a) The annual revenue earned by the power
   plant is Rs %3.2f crore \n(b) Capacity factor is
   %3.3f',RY,CF)
```

Scilab code Exa 1.4 Annual energy

```

clc
clear
//Input data
L=0.75//Load factor
C=0.60//Capacity factor
U=0.65//Use factor
M=60//Maximum power demand in MW
Y=8760//Number of hours in a year of 365 days

//Calculations
A=(L*M)//Average load in MW
P=((A*1000)*Y)/10^6//Annual energy production in kWh
    *10^6
PC=(A/C)//Plant capacity in MW
R=(PC-M)//Reserve capacity in MW
HIO=(P*1000/(U*PC))//Hours in operation in hrs
```

```
NH=(Y-HIO)//Hours not in service in a year in hrs

//Output
printf('(a) Annual energy production is %3.1f * 10^6 kWh \n(b) Reserve capacity over and above the peak load is %3.0f MW \n(c) The hours during which the plant is not in service per year is %3.0f hrs',P,R,NH)
```

Scilab code Exa 1.5 Overall cost

```

clc
clear
//Input data
D=500//Maximum demand in MW
L=0.7//Load factor
//1)Steam power plant 2)Hydroelectric power plant 3)Nuclear power plant
CC=[3,4,5]//Capital cost per MW installed in Rs. crore
I=[6,5,5]//Interest in percent
D=[6,4,5]//Depreciation in percent
OP=[30,5,15]//Operating cost (including fuel) per kWh
TD=[2,3,2]//Transmission and distribution cost per kWh
Y=8760//Number of hours in a year of 365 days

//Calculations
//1)Steam power plant
CCX=(CC(1)*D*10^7)//Capital cost in Rs
IX=((I(1)/100)*CCX)//Interest in Rs
DX=((D(1)/100)*CCX)//Depreciation in Rs
AFCX=IX+DX//Annual fixed cost in Rs
```

```
EX=(L*D*1000*Y)//Energy generated per year in kWh
RX=(OP(1)+TD(1))//Running cost/kWh in paise
OX=((AFCX/EX)+(RX/100))*100//Overall cost/kWh in paise

//2)Hydroelectric Power plant
CCY=(CC(2)*D*10^7)//Capital cost in Rs
IY=((I(2)/100)*CCY)//Interest in Rs
DY=((D(2)/100)*CCY)//Depreciation in Rs
AFCY=IY+DY//Annual fixed cost in Rs
EY=(L*D*1000*Y)//Energy generated per year in kWh
RY=(OP(2)+TD(2))//Running cost/kWh in paise
OY=((AFCY/EY)+(RY/100))*100//Overall cost/kWh in paise

//3)Nuclear power plant
CCZ=(CC(3)*D*10^7)//Capital cost in Rs
IZ=((I(3)/100)*CCZ)//Interest in Rs
DZ=((D(3)/100)*CCZ)//Depreciation in Rs
AFCZ=IZ+DZ//Annual fixed cost in Rs
EZ=(L*D*1000*Y)//Energy generated per year in kWh
RZ=(OP(3)+TD(3))//Running cost/kWh in paise
OZ=((AFCZ/EZ)+(RZ/100))*100//Overall cost/kWh in paise

//Output
printf('(i)Overall cost per kWh in Steam power plant is %3.0f paise \n(ii)Overall cost per kWh in Hydroelectric power plant is %3.0f paise \n(iii)Overall cost per kWh in Nuclear power plant is %3.0f paise',OX,OY,OZ)
```

Scilab code Exa 1.6 Cost of power generation

```

```

```
clc
clear
//Input data
C=210//Capacity in MW
ID=12//Interest and depreciation in percent
CC=18000//Capital cost/kW installed in Rs
L=0.6//Annual load factor
AC=0.54//Annual capacity factor
RC=(200*10^6)//Annual running charges in Rs
E=6//Energy consumed by power plant auxiliaries in percent
Y=8760//Number of hours in a year of 365 days

//Calculations
MD=(C/L)*AC//Maximum demand in MW
RSC=(C-MD)//Reserve Capacity in MW
AL=(L*MD)//Average load in MW
EP=(AL*1000*Y)//Energy produced per year in kWh
NE=((100-E)/100)*EP//Net energy delivered in kWh
AID=((ID/100)*CC*C*1000)//Annual interest and depreciation in Rs
T=(AID+RC)//Total annual cost in Rs
CP=(T/NE)*100//Cost of power generation in paise

//Output
printf('(a) The cost of power generation per kWh is %3.0f paise \n(b) The reserve capacity is %3.0f MW',CP,RSC)
```

Scilab code Exa 1.7 Economic loading

```

clc
clear
//Input data
```

```
L=200//The total load supplied by the plants in MW
//The incremental fuel costs for generating units a and b of power plant are given by
//dFa/dPa=0.065Pa+25
//dFb/dPb=0.08Pa+20

//Calculations
//Solving two equations
//Pa+Pb=200
//0.065Pa+25=0.08Pb+20
A=[1 1
   0.065 -0.08]//Coefficient matrix
B=[L
   (20-25)]//Constant matrix
X=inv(A)*B//Variable matrix
P=100//If load is shared equally then Pa=Pb=100MW
a=(((0.065*P^2)/2)+(25*P))-(((0.065*X(1)^2)/2)+(25*X(1)))//increase in fuel cost for unit a in Rs. per hour
b=(((0.08*P^2)/2)+(20*P))-(((0.08*X(2)^2)/2)+(20*X(2)))//increase in fuel cost for unit a in Rs. per hour
x=a+b//Net increase in fuel cost due to departure from economic distribution of load in Rs. per hour

//Output
printf('(a)The economic loading of two units when the total load supplied by the power plants is 200 MW are %3.2f MW and %3.2f MW\n(b)The loss in fuel cost per hour if the load is equally shared by both units is Rs.%3.2f per hour',X(1),X(2),x)
```

Scilab code Exa 1.8 Cost of power generation

```

clc
clear
//Input data
C=200//Installed capacity of the plant in MW
CC=400//Capital cost in Rs crores
ID=12//Rate of interest and depreciation in percent
AC=5//Annual cost of fuel, salaries and taxation in
    Rs. crores
L=0.5//Load factor
AL2=0.6//Raised Annual load
Y=8760//Number of hours in a year of 365 days

//Calculations
AvL=(C*L)//Average Load in MW
E=(AvL*1000*Y)//Energy generated per year in kWh
IDC=((ID/100)*CC*10^7)//Interest and depreciation (
    fixed cost) in Rs
T=(IDC+(AC*10^7))//Total annual cost in Rs
CP1=(T/E)*100//Cost per kWh in paise
AvL2=(C*AL2)//Average Load in MW
E2=(AvL2*1000*Y)//Energy generated per year in kWh
CP2=(T/E2)*100//Cost per kWh in paise
S=((CP1)-(CP2))//Saving in cost per kWh in paise
S1=ceil(S)//Rounding off to next higher integer

//Output
printf('Cost of generation per kWh is %3.0f paise \n
     Saving in cost per kWh if the annual load factor
     is raised to 60 percent is %3.0f paise',CP1,S1)
```

Scilab code Exa 1.9 Load factor and capacity factor

```

clc
```

```
clear
//Input data
C=300//Capacity of power plant in MW
MXD=240//Maximum demand in MW in a year
MND=180//Minimum demand in MW in a year
//Assuming the load duration curve shown in Figure
   E1.9 on page no 30 to be straight line
Y=8760//Number of hours in a year of 365 days

//Calculations
E=((MND*Y)+0.5*(MXD-MND)*Y)*1000//Energy supplied
   per year in kWh
AL=(E/Y)//Average load in kW
L=((AL/1000)/MXD)//Load factor
CF=((AL/1000)*Y)/(C*Y)//Capacity factor

//Output
printf('(a) Load factor is %3.3f \n(b) Capacity
   factor is %3.2f',L,CF)
```

Scilab code Exa 1.10 Load factor and capacity factor

```

clf()
clc
clear
//Input data
t1x=[0,6]//Time range in hours
t2x=[6,12]//Time range in hours
t3=[12,14]//Time range in hours
t4=[14,18]//Time range in hours
t5=[18,24]//Time range in hours
L=[30,90,60,100,50]//Load in MW

//Calculations
```

```
t1=[0,6,6,12,12,14,14,18,18,24,24]//Time in hours for Load curve
L1=[30,30,90,90,60,60,100,100,50,50,0]//Load in MW for Load curve
t2=[0,4,4,10,10,12,12,18,18,24,24]//Time in hours for Load duration curve
L2=[100,100,90,90,60,60,50,50,30,30,24]//Load in MW for Load duration curve
E=((L(1)*(t1x(2)-t1x(1)))+(L(2)*(t2x(2)-t2x(1)))+(L(3)*(t3(2)-t3(1)))+(L(4)*(t4(2)-t4(1)))+(L(5)*(t5(2)-t5(1))))//Energy generated in MWh
AL=E/24//Average load in MW
MD=max(L(1),L(2),L(3),L(4),L(5))//Maximum demand in MW
LF=(AL/MD)//Load factor
Lx=[30,10]//Loads for selecting suitable generating units in MW
tx=[24,18,10,4]//Time for selecting suitable generating units in hrs
PC=(Lx(1)*tx(4)+Lx(2)*1)//Plant capacity in MW
CF=(E/(PC*24))//Capacity factor

//Output
subplot(221)
plot(t1,L1)//Load curve taking Time in hrs on X- axis and Load in MW on Y- axis
xtitle('Load curve','Time hrs','Load MW')
subplot(222)
plot(t2,L2)//Load duration curve taking Time in hrs on X- axis and Load in MW on Y- axis
xtitle('Load duration curve','Time hrs','Load MW')
printf('(c)Suitable generating units to supply the load are\ni)One unit of %3.0f MW will run for %3.0f hours\nii)One unit of %3.0f MW will run for %3.0f hours\niii)One unit of %3.0f MW will run for %3.0f hours\niv)One unit of %3.0f MW will run for %3.0f hours\n\n(d)Load factor is %3.2f\n\n(e)Capacity of the plant is %3.0f MW and Capacity
```

```
factor is %3.3f',Lx(1),tx(1),Lx(1),tx(2),Lx(1),tx(3),Lx(2),tx(4),LF,PC,CF)
```

Scilab code Exa 1.11 Overall cost

```

clc
clear
//Input data
C=10//Capacity of generating unit in MW
MD=[6,3.6,0.4]//Maximum demand for domestic consumers, industrial consumers and street-lighting load respectively in MW
L=[0.2,0.5,0.3]//Load factor for domestic consumers, industrial consumers and street-lighting load respectively
CC=10000//Capital cost of the plant per kW in Rs
RC=3600000//Total rumming cost per year in Rs
AID=10//Annual interest and depreciation on capital cost in percent
Y=8760//Number of hours in a year of 365 days

//Calculations
E=((MD(1)*L(1))+(MD(2)*L(2))+(MD(3)*L(3)))*Y*1000//Energy supplied per year to all three consumers in kWh
OC=(RC/E)//Operating charges per kWh in Rs
CCP=(C*1000*CC)//capital cost of the plant in Rs
FCY=((AID/100)*CCP)//Fixed charges per year in Rs
FCkW=(FCY/CC)//Fixed charges per kW in Rs
//a) For domestic consumers
TC1=((FCkW*MD(1)*1000)+(OC*MD(1)*L(1)*Y*1000))//Total chrges in Rs
OC1=(TC1/(MD(1)*L(1)*Y*1000))*100//Overall cost per kWh in paise
```

```
//b)For industrial consumers
TC2=((FCkW*MD(2)*1000)+(OC*MD(2))*L(2)*Y*1000)//Total chrges in Rs
OC2=(TC2/(MD(2)*L(2)*Y*1000))*100//Overall cost per kWh in paise
//c) For street-lighting load
TC3=((FCkW*MD(3)*1000)+(OC*MD(3))*L(3)*Y*1000)//Total chrges in Rs
OC3=(TC3/(MD(3)*L(3)*Y*1000))*100//Overall cost per kWh in paise

//Output
printf('Overall cost of energy per kWh for:\n(a)Domestic consumers is %3.0f paise\n(b)Industrial consumers is %3.0f paise\n(c)Street-lighting load is %3.0f paise',OC1,OC2,OC3)
```

Scilab code Exa 1.12 Amount of money saved

```

clc
clear
//Input data
CC=(80*10^6)//Capital cost in Rs
L=30//Useful life in years
S=5//Salvage value of the capital cost in percent
i=0.06//Yearly rate of compound interest

//Calculations
A=((100-S)/100)*CC//Difference of capital cost and salvage value in Rs
P=((A*i)/((1+i)^L-1))//The amount of money to be saved annually in Rs

//Output
```

```
printf('The amount of money to be saved annually is Rs.%3.0f/-',P)
```

Scilab code Exa 1.13 Present worth of the payments

```

clc
clear
//Input data
i=4000//Initial investment in Rs crore
Y=4//Period in years
A=1200//Amount added in Rs crore
B=400//Amount paid from 5th year onwards to the 12th year in Rs crore
a=5//5th year
b=12//12th year
y=30//Period in years
C=600//Salvage value in Rs crore
I=0.1//Interest rate

//Calculations
X=(1/(1+I))//X value for calculations
PW=(i+(A*X^Y)+((B/I)*X^b*((I+1)^b-1))-((B/I)*X^a*((I+1)^a-1))-(C*X^y))//Present worth of the payments at the time of commissioning in Rs. crores

//Output
printf('Present worth of the payments at the time of commissioning is Rs.%3.2f crores',PW)
```

Scilab code Exa 1.14 Increamental heat rate

```

```

```
clc
clear
//Input data
O=1000//Combined output of two units in MW
//Two coal generating units P and Q have the
   incremental heat rate defined by
//(IR)P=0.4818*10^-7.LP^4 - 0.9089*10^-4.LP^3 +
   0.6842*10^-1.LP^2 - 0.2106*10.LP + 9860
//(IR)R=0.9592*10^-7.LQ^4 - 0.7811*10^-4.LQ^3 +
   0.2625*10^-1.LQ^2 - 0.2189*10.LQ + 9003

//Calculations
//LP+LQ=1000
//By making (IR)P=(IR)Q and solving the above three
   equations by a numerical methos such as Newton-
   Raphson algorithm , we get
LP=732.5//Heat rate in MW
LQ=(O-LP)//Heat rate in MW
IR=0.4818*10^-7*LP^4 - 0.9089*10^-4*LP^3 +
   0.6842*10^-1*LP^2 - 0.2106*100*LP + 9860
IR1=0.9592*10^-7*LQ^4 - 0.7811*10^-4*LQ^3 +
   0.2625*10^-1*LQ^2 - 0.2189*10*LQ + 9003

//Output
printf('Incremental heat transfer rate at which the
   combined output of the two units is %3.0f MW is
   IR = (IR)P = (IR)Q = %i kJ/kWh',O,IR)
```

Scilab code Exa 1.15 Cost of electrical energy

```

clc
clear
//Input data
F=2700//Fixed cost of the thermal station per kW of
```

```
   installed capacity per year in Rs,
FO=40//Fuel and operating costs per kWh generated in paise
L=[100,75,50,25]//Load factors
Y=8760//Number of hours in a year of 365 days

//Calculations
FC=(F/Y)*100//Fixed costs per kW per hour in paise
E1=(L(1)/100)//Energy produced in 1 hr with 1 kW plant in kWh
FOC1=(E1*FO)//Fuel and operating cost in paise
TC1=(FC+FOC1)//Total cost per hr in paise
C1=(TC1/E1)//Cost per kWh in paise
E2=(L(2)/100)//Energy produced in 1 hr with 1 kW plant in kWh
FOC2=(E2*FO)//Fuel and operating cost in paise
TC2=(FC+FOC2)//Total cost per hr in paise
C2=(TC2/E2)//Cost per kWh in paise
E3=(L(3)/100)//Energy produced in 1 hr with 1 kW plant in kWh
FOC3=(E3*FO)//Fuel and operating cost in paise
TC3=(FC+FOC3)//Total cost per hr in paise
C3=(TC3/E3)//Cost per kWh in paise
E4=(L(4)/100)//Energy produced in 1 hr with 1 kW plant in kWh
FOC4=(E4*FO)//Fuel and operating cost in paise
TC4=(FC+FOC4)//Total cost per hr in paise
C4=(TC4/E4)//Cost per kWh in paise

//Output
printf('
   ==========================================================================
   nLoad       Energy produced      Fixed cost    Fuel
   and          Total cost      Cost per\nfactor     in 1
   hr with           per hr        operating cost     per
   hr          kWh\n(percent) 1kW plant(kWh)     (paise
   )          (paise)          (paise)          (paise)\n
   ==========================================================================
```

```
n%3.0f          %3.0f                   %3.0f
           %3.0f              %3.0f              %3.0f\
n%3.0f          %3.2f                  %3.0f
           %3.0f              %3.0f              %3.0f\
n%3.0f          %3.2f                  %3.0f
           %3.0f              %3.0f              %3.0f\
n%3.0f          %3.2f                  %3.0f
           %3.0f              %3.0f              %3.0f\
n
```

```
',L(1),E1,FC,FOC1,TC1,C1,L(2),E2,FC,FOC2,TC2,C2,L
(3),E3,FC,FOC3,TC3,C3,L(4),E4,FC,FOC4,TC4,C4)
```

Chapter 2

Analysis of Steam Cycles

Scilab code Exa 2.1 Power output and efficiency

```

clc
clear
//Input data
p1=40//Initial pressure of steam in bar
T1=500//Initial temperature of steam in degree C
m1=5500//Rate of steam in kg/h
p2=2//Pressure of steam after expansion in bar
n1=0.83//Isentropic efficiency
q=0.87//Quality
m2=2700//Mass flow rate in kg/h
p3=0.1//Pressure of steam after expansion in l.p
   turbine in bar
n2=0.78//Isentropic efficiency

//Calculations
h1=3445.3//Enthalpy in kJ/kg
s1=7.0901//Entropy in kJ/kg.K which is 1.5301+x2s
   *5.5970
x2s=(5.5600/5.5970)//dryness fraction
h2s=(504.7+(x2s*2201.9))//Enthalpy in kJ/kg
```

```
h2=h1-(n1*(h1-h2s))//Enthalpy in kJ/kg
h3=(504.7+(q*2201.9))//Enthalpy in kJ/kg
h4=((m2*h3+m1*h2)/(m1+m2))//Enthalpy in kJ/kg
x4=(2183.78/2201.9)//dryness fraction
s4=(1.5301+x4*5.5970)//Entropy in kJ/kg.K
x5s=0.8574//dryness fraction
h5s=(191.84+x5s*2392.5)//Enthalpy in kJ/kg
dh4h5=(n2*(h4-h5s))//Difference in enthalpy (h4-h5)
    in kJ/kg
h6=191.83//Enthalpy in kJ/kg
W1=((m1*(h1-h2))+((m1+m2)*dh4h5))/3600//Power output
     of the plant in kW
Q1=(m1*(h1-h6))/3600//Heat input in kW
n1=(W1/Q1)*100//Efficiency in percent
WT=(m1*(h1-h2))/3600//Power output without the
    geothermal heat supply in kW
Q2=(m1*(h1-h6))/3600//Heat input without the
    geothermal heat supply in kW
n2=(WT/Q2)*100//Efficiency of the cycle without the
    geothermal heat supply in percent

//Output
printf('(a)Power output of the cycle is %3.1f kW \n
    Efficiency of the cycle is %3.1f percent \n\n (b)
    Without geothermal heat supply \n Power output of
     the cycle is %3.2f kW \n Efficiency of the cycle
     is %3.2f percent',W1,n1,WT,n2)
```

Scilab code Exa 2.2 Mass flow rate

```

clc
clear
//Input data
p1=90//Initial pressure of steam in bar
```

```
T1=500//Initial temperature of steam in degree C
O=(500*1000)//Output in kW
T2=40//Condensation temperature in degree C
nhp=0.92//Efficiency of h.p turbine
nlp=0.9//Efficiency of l.p turbine
np=0.75//Isentropic efficiency of the pump
TTD=-1.6//Temperature in degree C

//Calculations
p2=(0.2*p1)//Optimum reheat pressure in bar
h1=3386.1//Enthalpy in kJ/kg
s1=6.6576//Entropy in kJ/kg.K
s2s=s1//Entropy in kJ/kg.K
h2s=2915//Enthalpy in kJ/kg
h3=3469.8//Enthalpy in kJ/kg
s3=7.4825//Entropy in kJ/kg.K
x4s=(s3-0.5725)/7.6845//Dryness fraction
h4s=(167.57+x4s*2406.7)//Enthalpy in kJ/kg
h5=167.57//Enthalpy in kJ/kg
h7=883.42//Enthalpy in kJ/kg
Wps=(0.001008*p1*10)//Workdone by the pump in kJ/kg
h6s=176.64//Enthalpy in kJ/kg
dh1h2=(nhp*(h1-h2s))//Difference in enthalpy (h1-h2) in kJ/kg
h2=h1-dh1h2//Enthalpy in kJ/kg
dh3h4=(nlp*(h3-h4s))//Difference in enthalpy (h3-h4) in kJ/kg
h4=h3-dh3h4//Enthalpy in kJ/kg
Wp=(Wps/np)//Workdone by the pump in kJ/kg
h6=(Wp+h5)//Enthalpy in kJ/kg
tsat=207.15//Saturation temperature at 18 bar in degree C
t9=(tsat-TTD)//Temperature in degree C
h9=875//Enthalpy in kJ/kg
m=((h9-h6)/(h2-h7))//Mass of steam in kg
WT=(dh1h2+(1-m)*dh3h4)//Workdone by the turbine in kJ/kg
Wnet=(WT-Wp)//Net workdone in kJ/kg
```

```
ws=(O/Wnet)//Mass flow rate of steam at turbine inlet in kg/s
Q1=((h1-h9)+(1-m)*(h3-h2))//Heat input in kJ/kg
n=(Wnet/Q1)*100//Efficiency of the cycle in percent
Wr=(Wnet/WT)//Work ratio

//Output
printf('(a)Mass flow rate of steam at turbine inlet is %3.0f kg/s \n (b)The cycle efficiency is %3.2f percent \n (c)Work ratio is %3.3f',ws,n,Wr)
```

Scilab code Exa 2.3 Optimum pressures and temperatures

```

clc
clear
//Input data
p1=70//Pressure at which an ideal seam power plant operates in bar
T1=550//Temperature at which an ideal seam power plant operates in degrees C
p2=0.075//Pressure at which an ideal seam power plant operates in bar

//Calculations
TB=285.9//Saturation temperature at 70 bar in degree C
TC=40.3//Saturation temperature at 0.075 bar in degree C
Tr=(TB-TC)/(7+1)//Temperature rise per heater for maximum cycle efficiency in degree C
t1=(TB-Tr)//Temperature at heater 1 in degree C
P1=4.33//Pressure at heater 1 in MPa
t2=(t1-Tr)//Temperature at heater 2 in degree C
P2=2.5318//Pressure at heater 2 in MPa
```

```
t3=(t2-Tr)//Temperature at heater 3 in degree C
P3=1.367//Pressure at heater 3 in MPa
t4=(t3-Tr)//Temperature at heater 4 in degree C
P4=0.6714//Pressure at heater 4 in MPa
t5=(t4-Tr)//Temperature at heater 5 in degree C
P5=0.2906//Pressure at heater 5 in MPa
t6=(t5-Tr)//Temperature at heater 6 in degree C
P6=0.108//Pressure at heater 6 in MPa
t7=(t6-Tr)//Temperature at heater 7 in degree C
P7=32.65//Pressure at heater 7 in kPa

//Output
printf('The optimum pressure and temperature at
   different heaters are: \n Heater 1: t1 = %3.1f
   degree C and p1 = %3.2f MPa\n Heater 2: t2 = %3.1
   f degree C and p2 = %3.4f MPa\n Heater 3: t3 = %3
   .1f degree C and p3 = %3.3f MPa\n Heater 4: t4 =
   %3.1f degree C and p4 = %3.4f MPa\n Heater 5: t5
   = %3.1f degree C and p5 = %3.4f MPa\n Heater 6:
   t6 = %3.1f degree C and p6 = %3.3f MPa\n Heater
   7: t7 = %3.1f  degree C and p7 = %3.2f kPa',t1,P1
   ,t2,P2,t3,P3,t4,P4,t5,P5,t6,P6,t7,P7)
```

Scilab code Exa 2.4 Percentage of total electricity

```

clc
clear
//Input data
ng=0.97//Efficiency of electric generator
nt=0.95//Efficiency of turbine
nb=0.92//Efficiency of boiler
nc=0.42//Efficiency of cycle
no=0.33//Efficiency of overall plant

```

```
//Calculations
na=(no/(ng*nt*nb*nc))//Efficiency of auxiliaries
n=(1-na)*100//Percentage of total electricity generated which is consumed in running the auxiliaries

//Output
printf('Percentage of total electricity generated which is consumed in running the auxiliaries is %3.2f percent',n)
```

Scilab code Exa 2.5 Percentage of total heat absorption

```

clc
clear
//Input data
T1=140//Temperature with which feed water enters into economiser in degree C
T2=[25,250]//Temperature from air is preheated to in degree C
P1=60//Pressure with which steam leaves the drum in bar
x1=0.98//Dryness fraction
T3=450//Temperature with which steam leaves the superheater in degree C
cc=25.2//Calorific value of coal in MJ/kg
r=8.5//Rate of evaporation of steam per kg coal
wf=1//Mass of coal in kg
R=15//Air fuel ratio by mass
Cpa=1.005//Specific heat of air at constant pressure in kJ/kg.K
Cpw=4.2//Specific heat of water at constant pressure in kJ/kg.K

```

```
//Calculations
h1=(T1*Cpw)//Enthalpy in kJ/kg
hf=1213.35//Enthalpy in kJ/kg
h2=hf//Enthalpy in kJ/kg
hfg=1571//Enthalpy in kJ/kg
h4=3301.8//Enthalpy in kJ/kg
h3=(hf+x1*hfg)//Enthalpy in kJ/kg
n=((r*(h4-h1))/(wf*cc*1000))*100//Efficiency
he=(r*(h2-h1))/wf*10^-3//Heat transfer in the
    economiser in MJ/kg
hb=(r*(h3-h2))/wf*10^-3//Heat transfer in the boiler
    in MJ/kg
hs=(r*(h4-h3))/wf*10^-3//Heat transfer in the
    superheater in MJ/kg
ha=(R*Cpa*(T2(2)-T2(1)))/wf*10^-3//Heat transfer in
    the air preheater in MJ/kg
pe=((h2-h1)/(h4-h1))*100//Percentage of total heat
    absorbed in the economiser in percent
pb=((h3-h2)/(h4-h1))*100//Percentage of total heat
    absorbed in the boiler in percent
ps=((h4-h3)/(h4-h1))*100//Percentage of total heat
    absorbed in the superheater in percent

//Output
printf('Efficiency of steam generator is %3.2f
    percent \n\n Heat transfer per kg fuel in \n (i)
    economiser is %3.4f MJ/kg \n (ii)boiler is %3.3f
    MJ/kg \n (iii)superheater is %3.3f MJ/kg \n (iv)
    air pre-heater is %3.3f MJ/kg \n\n Percentage of
    total heat absorption taking place in \n (i)
    economiser is %3.2f percent \n (ii)boiler is %3.2
    f percent \n (iii)superheater is %3.2f percent',n
    ,he,hb,hs,ha,pe,pb,ps)
```

Scilab code Exa 2.6 Cycle efficiency

```

clc
clear
//Input data
p1=150//Pressure of inlet steam in bar
T1=550//Temperature of steam in degree C
p2=20//Pressure after expansion in bar
T2=500//Reheat temperature in degree C
pc=0.075//Condenser pressure in bar
php=50//Pressure of steam in h.p turbine in bar
pip=[10,5,3]//Pressure of steam in i.p turbines in
    bar
plp=1.5//Pressure of steam in l.p turbine in bar
m=300*1000//Steam flow rate in kg/h

//Calculations
h1=3448.6//Enthalpy in kJ/kg
h4=3467.6//Enthalpy in kJ/kg
s1=6.5119//Entropy in kJ/kg.K
s2=s1//Entropy in kJ/kg.K
s3=s1//Entropy in kJ/kg.K
s4=7.4317//Entropy in kJ/kg.K
s5=s4//Entropy in kJ/kg.K
s6=s5//Entropy in kJ/kg.K
s7=s6//Entropy in kJ/kg.K
s8=s7//Entropy in kJ/kg.K
s9=s8//Entropy in kJ/kg.K
t2=370//Temperature in degree C
t3=245//Temperature in degree C
t5=400//Temperature in degree C
t6=300//Temperature in degree C
t7=225//Temperature in degree C
t8=160//Temperature in degree C
h2=3112//Enthalpy in kJ/kg
h3=2890//Enthalpy in kJ/kg
h5=3250//Enthalpy in kJ/kg
h6=3050//Enthalpy in kJ/kg
h7=2930//Enthalpy in kJ/kg
```

```
h8=2790//Enthalpy in kJ/kg
x9=(s9-0.5764)/7.6751//Dryness fraction
h9=168.79+x9*2406////Enthalpy in kJ/kg
h10=168.79//Enthalpy in kJ/kg
h11=h10+0.001*pip(2)*100//Enthalpy in kJ/kg
h12=467.11//Enthalpy in kJ/kg
t14=111.37//Temperature in degree C
h14=467//Enthalpy in kJ/kg
h13=h12//Enthalpy in kJ/kg
h14=h13//Enthalpy in kJ/kg
h15=h14//Enthalpy in kJ/kg
h16=561.47//Enthalpy in kJ/kg
h17=h16//Enthalpy in kJ/kg
h18=640.23//Enthalpy in kJ/kg
h19=h18+0.001*(p1-pip(2))*100//Enthalpy in kJ/kg
h20=762.8//Enthalpy in kJ/kg
h21=h20//Enthalpy in kJ/kg
h22=1154.23//Enthalpy in kJ/kg
h23=h22//Enthalpy in kJ/kg
m1=((h23-h21)/(h2-h22))//Mass in kg
m2=((h21-h19)-(m1*(h22-h20)))/(h5-h20)//Mass in kg
m3=(((1-m1-m2)*(h18-h17))-((m1+m2)*(h20-h18)))/(h6-
    h18+h18-h17)//Mass in kg
m4=((1-m1-m2-m3)*(h17-h15))/(h7-h16)//Mass in kg
m5=(((1-m1-m2-m3-m4)*(h14-h11))-(m4*(h16-h12)))/(h8-
    h12+h14-h11)//Mass in kg
WT=(h1-h2)+(1-m1)*(h2-h3)+(1-m1)*(h4-h5)+(1-m1-m2)*(
    h5-h6)+(1-m1-m2-m3)*(h6-h7)+(1-m1-m2-m3-m4)*(h7-
    h8)+(1-m1-m2-m3-m4-m5)*(h8-h9)//Workdone by
    turbine in kJ/kg
Wp=(0.5+14.5+0.15)//Workdone in kJ/kg
Wnet=(WT-Wp)//Net workdone in kJ/kg
Q1=(h1-h23)+(1-m1)*(h4-h3)//Heat supplied in kJ/kg
ncy=(Wnet/Q1)*100//Cycle efficiency in percent
t23=264//Temperature in degree C
sr=(3600/Wnet)//Steam rate in kJ/kWh
hr=((Q1/Wnet)*3600)//Heat rate in kJ/kWh
P=((Wnet*m)/3600)/10^3//Power output in MW
```

```

//Output
printf('(a) The cycle efficiency is %3.2f percent \n (b) The feedwater temperature is %i degree C \n (c) The steam rate is %3.2f kJ/kWh \n (d) The heat rate is %3.0f kJ/kWh \n (e) The quality of steam at turbine exhaust is %3.4f \n (f) The power output is %3.2f MW',ncy,t23,sr,hr,x9,P)
```

Scilab code Exa 2.7 Steam condition

```

clc
clear
//Input data
m=10000//Mass flow rate of steam in kg/h
p=3//Pressure of steam in bar
P=1000//Power in kW
n=0.7//Internal efficiency of turbine

//Calculations
dh=(P*3600)/m//Change in enthalpy in kJ/kg
h2=2725.3//Enthalpy in kJ/kg from Fig. E2.7
h1=dh+h2//Enthalpy in kJ/kg
dh1h2s=dh/n//Change in enthalpy in kJ/kg
h2s=h1-dh1h2s//Enthalpy in kJ/kg
x2s=(h2s-561.47)/2163.8//Dryness fraction
s2s=1.6718+x2s*(6.999-1.6718)//Entropy in kJ/kg.K
s1=s2s//Entropy in kJ/kg.K
p1=37.3//Pressure in bar from Mollier diagram
t1=344//Temperature in degree C

//Output
printf('The steam condition required at inlet of the turbine: \n Enthalpy is %3.1f kJ/kg \n Entropy
```

```
is %3.4f kJ/kg.K \n Pressure is %3.1f bar \n Temperature is %i degree C',h1,s1,p1,t1)
```

Scilab code Exa 2.8 Steam generation capacity

```

clc
clear
//Input data
Pl=5.6//Power load in MW
Hl=1.163//Heat load in MW
p1=40//Pressure in bar
T1=500+273//Temperature in K
p2=0.06//Pressure in bar
p3=2//Pressure in bar
CV=25//Calorific value in MJ/kg
n=88//Boiler efficiency in percent
T=6//Temperature rise in degree C

//Calculations
h1=3445.3//Enthalpy in kJ/kg
s1=7.0901//Entropy in kJ/kg.K
s2=s1//Entropy in kJ/kg.K
s3=s1//Entropy in kJ/kg.K
x2=(s2-1.5301)/5.5970//Dryness fraction
h2=2706.7//Enthalpy in kJ/kg
h26=2201.9//Difference in enthalpy in kJ/kg
w=(Hl*10^3)/h26//Rate of steam extraction in kg/h
x3=(s1-0.52)/7.815//Dryness fraction
h3=(149.79+x3*2416)//Enthalpy in kJ/kg
h4=149.79//Enthalpy in kJ/kg
ws=((Pl*10^3+(w*(h2-h3)))/((h1-h2)+(h2-h3)))//Steam generation capacity in kg/s
ws1=(ws*3600)/1000//Steam generation capacity in t/h
h7=(504.7+(1.061*10^-3*(p1-p3)*100))//Enthalpy in kJ
```

```
   /kg
h5=(149.79+(1.006*100*p1*10^-3))//Enthalpy in kJ/kg
Q1=(((ws-w)*(h1-h5))+(w*(h1-h7)))//Heat input in kW
wf=((Q1/1000)/((n/100)*CV))*(3600/1000)//Fuel
   burning rate in t/h
Q2=((ws-w)*(h3-h4))//Heat rejected to the condensor
   in kW
wc=(Q2/(4.187*T))/1000//Rate of flow of cooling
   water in m^3/s

//Output
printf('(a) the steam generation capacity of the
   bolier is %3.2f t/h \n (b) the heat input to the
   boiler is %3.1f kW \n (c) the fuel burning rate
   of the bolier is %3.3f t/h \n (d) the heat
   rejected to the condensor is %3.0f kW \n (e) the
   rate of flow of cooling water in the condensor is
    %3.3f m^3/s',ws1,Q1,wf,Q2,wc)
```

Scilab code Exa 2.9 Power developed

```

clc
clear
//Input data
m=21000//Steam rate in kg/h
p1=17//Pressure in bar
T1=230+273//Temperature in K
P=132.56//Power in kW
x2=0.957//Dryness fraction
p2=3.5//Pressure in bar
Pl=1337.5//Power in l.p turbine in kW
p3=0.3//Pressure in bar
x3=0.912//Dryness fraction

```

```
//Calculations
h1=2869.7//Enthalpy in kJ/kg
s1=6.5408//Entropy in kJ/kg.K
h2=(870.44+x2*1924.7)//Enthalpy in kJ/kg
h3=h2//Enthalpy in kJ/kg
h56=(P1*3600)/m//Difference in Enthalpy in kJ/kg
h6=(289.23+x3*2336.1)//Enthalpy in kJ/kg
h5=2649.04//Enthalpy in kJ/kg
s4s=s1//Entropy in kJ/kg.K
x4s=(s4s-1.7275)/5.2130//Dryness fraction
h4s=584.33+x4s*2148.1//Enthalpy in kJ/kg
w=(P/(h1-h2))//Flow rate in kg/s
ws=(m/3600)//Steam flow rate in kg/s
h4=((ws*h5)-(w*h3))/(ws-w)//Enthalpy in kJ/kg
x4=(h4-584.33)/2148.1//Dryness fraction
W=(ws-w)*(h1-h4)//Power developed by h.p turbine in kW
n=((h1-h4)/(h1-h4s))*100//Isentropic efficiency in percent

//Output
printf('(a) the steam quality at the exhaust of the h.p turbine is %3.3f \n (b) the power developed by the h.p turbine is %3.2f kW \n (c) the isentropic efficiency of the h.p turbine is %3.2f percent',x4,W,n)
```

Chapter 3

Combined Cycle Power Generation

Scilab code Exa 3.1 Efficiency of combined cycle

```

clc
clear
//Input data
p=40//Pressure in bar
T1=400+273//Temperature in K
T2=40+273//Temperature in K
x
   =[10,515.5,72.23,363.0,0.1478,0.5167,80.9*10^-6,0.0333]
   //Property values from table p(bar),t(degree C),
   hf,hg(kJ/kg),sf,sg(kJ/kg.K),vf,vg(m^3/kg)
y
   =[0.2,277.3,38.35,336.55,0.0967,0.6385,77.4*10^-6,1.163]
   //Property values from table p(bar),t(degree C),
   hf,hg(kJ/kg),sf,sg(kJ/kg.K),vf,vg(m^3/kg)

//Calculations
h1=3216//Enthalpy in kJ/kg
s1=6.7690//Entropy in kJ/kg.K
```

```
s2=s1//Entropy in kJ/kg.K
x2=(s2-0.5725)/(8.2570-0.5725)//Dryness fraction
h2=167.57+x2*2406.7//Enthalpy in kJ/kg
h3=167.57//Enthalpy in kJ/kg
h4=(167.57+p*100*1.008*10^-3)//Enthalpy in kJ/kg
h5=1087.31//Enthalpy in kJ/kg
h6=2801.4//Enthalpy in kJ/kg
ha=x(4)//Enthalpy in kJ/kg
sa=x(6)//Entropy in kJ/kg.K
sb=sa//Entropy in kJ/kg.K
xb=(sb-y(5))/(y(6)-y(5))//Dryness fraction
hb=(y(3)+xb*(y(4)-y(3)))//Enthalpy in kJ/kg
hc=y(3)//Enthalpy in kJ/kg
hd=hc//Enthalpy in kJ/kg
m=(h6-h5)/(hb-hc)//Mass of mercury circulated per kg of steam
Q1=m*(ha-hd)+(h1-h6)+(h5-h4)//Heat supplied in kJ/kg
Q2=(h2-h3)//Heat rejected in kJ/kg
nc=(1-(Q2/Q1))*100//Efficiency in percent

//Output
printf('(a) The amount of mercury circulated per kg of water is %3.4f kg \n (b) The efficiency of the combined cycle is %3.1f percent',m,nc)
```

Scilab code Exa 3.2 Rate of heat transfer

```

clc
clear
//Input data
m=5//Mass flow rate in kg/s
p1=40//Pressure in bar
T1=440+273//Temperature in K
p2=1.5//Pressure in bar
```

```
p3=1//Pressure in bar
T3=60+273//Temperature in K
p4=16//Pressure in bar
T4=100+273//Temperature in K
p5=9//Pressure in bar

//Calculations
h1=3307.1//Enthalpy in kJ/kg
s1=6.9041//Entropy in kJ/kg.K
s2=s1//Entropy in kJ/kg.K
h2=2570.8//Enthalpy in kJ/kg
h3=417.46//Enthalpy in kJ/kg
h6=(251.13+(1.0172*10^-3)*(p3-0.1994)*100)//Enthalpy in kJ/kg
m3=(m/2)//Mass flow rate in kg/s
m6=m3//Mass flow rate in kg/s
h4=(m3*h3+m6*h6)/m//Enthalpy in kJ/kg
h5=(h4+(1.0291*10^-3)*(p1-p3)*100)//Enthalpy in kJ/kg
ha=241.58//Enthalpy in kJ/kg
sa=0.7656//Entropy in kJ/kg.K
sb=sa//Entropy in kJ/kg.K
hb=229.43//Enthalpy in kJ/kg
hc=71.93//Enthalpy in kJ/kg
hd=hc+(0.7914*10^-3*(p4-p5)*100)//Enthalpy in kJ/kg
Q1=(m*(h1-h5))/1000//Heat supplied in kW
Wnets=(m*((h1-h2)-(h5-h4)))//Net workdone by steam in kW
mR12=(m3*(h2-h3))/(ha-hd)//Mass of R12 in kg/s
WnetR=(mR12*((ha-hb)-(hd-hc)))//Net workdone by R12 in kW
T=Wnets+WnetR//Total output in kW
Qh=(m6*(h2-h6))//Heat rejected in kW

//Output
printf('(a) Rate of heat transfer in the steam generator is %3.3f kW \n (b) The net power output of the binary cycle is %i kW \n (c) The rate of
```

```
   heat transfer to the industrial process is %3.0f
  kW',Q1,T,Qh)
```

Scilab code Exa 3.3 Mass flow rate

```

clc
clear
//Input data
rp=7.5//Pressure ratio
T1=15+273//Inlet air temperature in K
T3=750+273//Maximum temperature in K
T6=100+273//Temperature in K
p1=50//Pressure in bar
T7=600+273//Temperature in K
p2=0.1//Pressure in bar
P=200//Total power in MW
CV=43.3//calorific value in MJ/kg
cpg=1.11//Specific heat for gas in kJ/kg.K
g=1.33//Ratio of specific heats for gas
cpa=1.005//Specific heat for air in kJ/kg.K
g1=1.4//Ratio of specific heats for air

//Calculations
T2=(T1*rp^((g1-1)/g1))//Temperature in K
T4=(T3/rp^((g-1)/g))//Temperature in K
ha=3670//Enthalpy in kJ/kg
hb=2305//Enthalpy in kJ/kg
hc=192//Enthalpy in kJ/kg
hd=hc//Enthalpy in kJ/kg
//ma*cpg*(T3-T6)=ms*(ha-hd)
//ma*cpg*(T3-T4)-ma*cpa*(T2-T1)+ms*(ha-hb)=P*1000
//Solving these two equations
A=[cpg*(T3-T6) (hd-ha)
   cpg*(T3-T4)-cpa*(T2-T1) (ha-hb)]//Coefficient
```

```
matrix
B=[0
   (P*10^3)]//Constant matrix
X=inv(A)*B//Variable matrix
Wgt=(cpg*(T3-T4)-cpa*(T2-T1))*X(1)*10^-3//Net workdone by Gas turbine in MW
Wst=(P-Wgt)//Net workdone by steam turbine in MW
Q1=(X(1)*cpg*(T3-T2+T3-T4))//Heat supplied in MW
nth=(P/(Q1*10^-3))*100//Thermal efficiency in percent
af=(CV*10^3)/(cpg*(T3-T2+T3-T4))//Air fuel ratio

//Output
printf('(a) The flow rate of air is %3.2f kg/s and steam is %3.2f kg/s \n (b) The power outputs of the gas turbine is %3.2f MW and steam turbine is %3.2f MW \n (c) The thermal efficiency of the combined plant is %3.0f percent \n (d) The air fuel ratio is %3.1f',X(1),X(2),Wgt,Wst,nth,af)
```

Scilab code Exa 3.4 Power output and efficiency

```

clc
clear
//Input data
p1=1//Pressure in bar
T1=25+273//Temperature in K
rp=8//Pressure ratio of compressor
Tm=900+273//Maximum temperature in K
pd=3//pressure drop in combustion chamber in percent
nc=0.88//Efficiency of compressor
nt=0.88//Efficiency of turbine
CV=44.43//Calorific value of fuel in MJ/kg
cpa=1.006//Specific heat of air in kJ/kg.K
```

```
cpg=1.148//Specific heat of gas in kJ/kg.K
g1=1.333//Specific heat ratio of gas
g=1.4//Specific heat ratio of air
T3=425+273//Temperature in K
p2=40//Pressure in bar
p3=0.04//Condensor pressure in bar
Th=170.4+273//Temperature of feed water to the HRSG in K
nst=0.82//Efficiency of steam turbine
pdh=5//Pressure drop in HRSG in kPa
m=29.235//Steam flow rate in kg/s
A=1.0401//si=1.0401+0.1728*(h/c)
B=0.1728//si=1.0401+0.1728*(h/c)

//Calculations
//Gas turbine plant
T2=(rp^((g-1)/(g*nt)))*T1//Temperature in K
//Combustor
pc=((pd/100)*rp)//Pressure loss in bar
pcx=(rp-pc)//Pressure in bar
f=((cpg*(Tm-T1))-(cpa*(T2-T1)))/((CV*10^3)-(cpa*(T2-T1)))//Fuel flow rate in kg/s
af=(1-f)/f//Air fuel ratio
//C8H18+12.5O2->8CO2+9H2O
afc=(12.5*32)/(0.232*114)//Air fuel ratio for stoichiometric combustion
ea=((af-afc)/afc)*100//Excess air in percent
//Gas turbine
p4=p1+0.05//Pressure in bar
T4=(Tm/(pcx/p4)^(((g1-1)*nt)/g1))//Temperature in K
//HRSG
T5=250+30//Temeprature in K
ha=3272//Enthalpy in kJ/kg
hf=1087.31//Enthalpy in kJ/kg
ws=(cpg*((T4-273)-T5))/(ha-hf)//Flow rate in kg/s
he=721.1//Enthalpy in kJ/kg
T6=(T4-273)-((ws*(ha-he))/cpg)//Temperature in degree C
```

```
//Power output
sa=6.853//Entropy in kJ/kg.K
sbs=sa//Entropy in kJ/kg.K
xbs=(sbs-0.4266)/8.052//Dryness fraction
hbs=(121.46+xbs*2432.9)//ENthalpy in kJ/kg
Wst=(m*(ha-hbs)*nst)//Workdone in kW
wg=(m/ws)//gas flow rate in kg/s
wa=(1-f)*wg//Air flow rate entering the compressor in kg/s
Wgt=(wg*cpg*(Tm-T4))-(wa*cpa*(T2-T1))//Power output of gas turbine in kW
TO=Wst+Wgt//Total power output in kW
wf1=(f*wa)//Fuel mass flow rate in kg/s
wf=4.466//Rounding off of wf1 for exact answers
no=(TO/(wf*(CV*10^3)))*100//Overall efficiency of the combined plant in percent
ns=((ha-hbs)/(ha-he))*nst//Efficiency of steam plant
ngtp=(Wgt/(wf*(CV*10^3)))//Efficiency of the GT plant
xL=((wg*cpg*(T6-(T1-273)))/(wf*(CV*10^3)))//Lost heat coefficient
nov=(ns+ngtp-ns*ngtp-ngtp*xL)//The overall efficiency
//Energy fluxes and irreversibilities
si=(A+B*((18*1)/(8*12)))//si for octane C8H18
dHo=(wf*CV*10^3)//Power in kW
dGo=(si*dHo)//Power in kW
TS=(dGo-dHo)//Power in kW
//Compressor
dS=(cpa*log(T2/T1))-(((cpa*(g-1))/g)*log(rp))//change in entropy in kJ/kg.K
Ic=(wa*T1*dS)//power in kW
Icx=((wg*T1*((cpg*log(Tm/T1))-(((cpg*(g1-1))/g1)*log(pcx))))-(wa*T1*((cpa*log(T2/T1))-(((cpa*(g-1))/g)*log(rp))))+TS)//Compressor in kW
Icg=(-cpg*log(Tm/T4))-(((cpg*(g1-1))/g1)*log(p4/pcx))//Difference in entropy in kJ/kg.K
IGT=(Icg*T1*wg)//Gas turbine in kW
```

```
se=2.046//Enntropy in kJ/kg.K
sae=(sa-se)//Difference in entropy in kJ/kg.K
s64=(cpg*log((T6+273)/T4))-(((cpg*(g1-1))/g1)*log(p4
   /p1))//Difference in entropy in kJ/kg.K
Ih=(T1*m*sae)+(wg*T1*s64)//For HRSG in kW
hb=(ha-(nst*(ha-hbs)))//Enthalpy in kJ/kg
xb=(hb-121.46)/2432.9//Dryness Fraction
sb=(0.4226+xb*8.052)//Entropy in kJ/kg.K
Ist=(m*(sb-sa)*T1)//For steam turbine in kW
Iexh=(wg*cpg*((T6-(T1-273))-(T1*log((T6+273)/T1))))
   //For exhaust in kW
Tl=Icx+Icg+IGT+Ih+Ist+Iexh//Exergy losses in kW
T=Tl+Wgt+Wst//Total exergy output and exergy
   destruction in kW
ee=((Wst+Wgt)/T)*100//Exergy efficiency in percent

//Output
printf('(a) Total power output is %3.2f kW and
   overall efficiency is %3.2f percent lost heat
   coefficient is %3.3f\n Exergy efficiency is %3.0f
    percent \n\n Input is %3.0f kW \n Total Output
   is %3.0f kW \n Total losses is %3.0f kW \n Exergy
    outut + exergy destruction = %3.0f kW which is
   1.3 percent gretter than the exergy input',TO,no,
   xL,ee,dGo,(Wgt+Wst),Tl,T)
```

Scilab code Exa 3.5 Overall efficiency

```

clc
clear
//Input data
n1=0.5//Efficiency of mercury
n2=0.4//Efficiency of steam
n3=0.25//Efficiency of composite cycle
```

```

//Calculations
n=(1-(1-n1)*(1-n2)*(1-n3))*100//Overall efficiency of the combined cycle in percent

//Output
printf('The overall efficiency of the combined cycle is %3.1f percent',n)
```

Scilab code Exa 3.6 Overall efficiency

```

clc
clear
//Input data
z=30//Percentage of total energy of fuel
n=40//Cycle efficiency in percent

//Calculations
on=((z/100)+(1-(z/100))*(n/100))*100//Overall efficiency in percent

//Output
printf('The overall efficiency of the combined plant is %3.0f percent',on)
```

Scilab code Exa 3.7 Power output and efficiency

```

clc
clear
//Input data
Tc=1250+273//Cathode temperature in K
```

```
Ta=500+273//Anode temperature in K
e=1.602*10^-19//Charge in coloumb
K=1.38*10^-23//Boltzmann constant in J/molecule.K
b=18//Constant

//Calculations
Va=((b*K*Ta)/e)//Voltage of anode in V
Vc=((b*K*Tc)/e)//Voltage of cathode in V
Vo=Vc-Va//Output voltage in V
Ja=(120*Ta^2*exp(-b))//Current density in Cathode in A/cm^2
Jc=(120*Tc^2*exp(-b))//Current density in Anode in A/cm^2
P=Vo*(Jc-Ja)//Power output per unit area in /cm^2
nth=(((Tc-Ta)/Tc)*(b/(b+2)))*100//Thermal efficiency in percent

//Output
printf('(a) The output voltage is %3.4f V \n (b) The current density in the cathode is %3.3f A/cm^2 and anode is %3.3f A/cm^2 \n (c) Power output per unit area is %3.2f W/cm^2 \n (d) Thermal efficiency is %3.1f percent',Vo,Jc,Ja,P,nth)
```

Scilab code Exa 3.8 Thermal efficiency

```

clc
clear
//Input data
P=100//Power in kW
V=115//Voltage in V
To=1500//Outer temperature in K
Te=1000//Exit temperature in K
Ta=350//Ambient temperature in K
```

```
nth=30//Thermal efficiency in percent
nge=92//Generator efficiency in percent
//Properties of thermoelectrons
a=0.0012//At 1250K in V/K
kp=0.02//In W/cm.K
kn=0.03//In W/cm.K
dp=0.01//In ohm.cm
dn=0.012//In ohm.cm
J=20//Current density in A/cm^2

//Calculations
zmax=(a^2/(sqrt(dp*kp)+sqrt(dn*kn))^2)//Maximum value of figure of merit in K^-1
mo=sqrt(1+(zmax*((To+Te)/2)))//Optimum value of the resistance ratio
nmax=(((To-Te)/To)*((mo-1)/(mo+(Te/To))))*100//Maximum thermal efficiency in percent
Vl=(a*(To-Te)*(mo/(mo+1)))//Voltage per couple in V
nc=(V/Vl)//Number of couples in series
L=((a*(To-Te))/((1+mo)*(dp+dn)))/J//Length in cm
A=((P*Te)/V)/J//Area in cm^2
I=(J*A)//Current in A
Vo=(a*(To-Te))//Voltage in V
Q1=((a*I*To)-((1/2)*(L/A)*I^2*(dp+dn))+((A/L)*(kp+kn)*(To-Te)))/1000//Heat input to the thermoelectric generator in kW
Q2=((a*I*Te)+((A/L)*(kp+kn)*(To-Te))+P)/1000//Heat rejected at full load in kW
Q1n=(((A/L)*(kp+kn)*(To-Te)))/1000//At no load heat input in kW
Q2n=Q1n//At no load heat rejected in kW
no=((nmax/100)+(1-(nmax/100))*(nth/100)*(nge/100))*100//Overall efficiency in percent

//Output
printf('(a) The thermal efficiency of thermocouple generator is %3.1f percent \n (b) The number of thermo couples in series is %i \n (c) The lenght
```

```
of the thermal elements is %3.3f cm and area is
%3.2f cm^2 \n (d) The output open-circuit voltage
 is %3.1f V \n (e) At full load: \n The heat
input is %3.3f kW \n The heat rejected is %3.3f
kW \n At no load: \n The heat input is %3.3f kW \
n The heat rejected is %3.3f kW \n (f) The
overall efficiency of the combined thermo-
electric steam power plant is %3.2f percent',nmax
,nc,L,A,Vo,Q1,Q2,Q1n,Q2n,no)
```

Chapter 4

Fuels and combustion

Scilab code Exa 4.1 Mass flow rate

```

clc
clear
//Input data
C=84;//The mass of carbon present in the fuel in %
H=10;//The mass of hydrogen present in the fuel in %
S=3.2;//The mass of sulphur present in the fuel in %
O=1.6;//The mass of oxygen present in the fuel in %
I=1.2;//The mass of incombustible in the fuel in %
X=15.72;//The flue gas of combined CO2 and SO2 by
    volume in %
Og=1;//The flue gas of O2 by volume in %
Y=100;//Let us consider the fuel oil in kg
C1=12;//Molecular weight of Carbon
H1=2;//Molecular weight of hydrogen
S1=32;//Molecular weight of sulphur
O1=32;//Molecular weight of oxygen
Co2=44;//Molecular weight of carbondioxide
So2=64;//Molecular weight of sulphurdioxide
N1=28;//Molecular weight of nitrogen
H2O=18;//Molecular weight of water
```

```

//Calculations
b=C/C1;//Equating coefficients of the carbon from equation
g=H/H1;//Equating coefficients of the hydrogen from equation
d=S/S1;//Equating coefficients of the sulphur from the equation
e=(b+d)/(X/Og);//By volumetric analysis
x=b+d+e+(g/2)-(O/O1);//Moles of oxygen are supplied for combustion
f=3.76*x;//Equating coefficients of the nitrogen from equation
Mo=x*O1;//Mass of oxygen supplied in kg
Ma=Mo/0.232;//Mass of air supplied for 100 kg of fuel in kg
Wa=Ma/100;//Mass of air supplied for 1 kg fuel in kg
Wrh={(11.5*C)+(34.5*[(H)-(O/8)])+(4.3*S)}/100;//Theoretical air required per kg of fuel in kg
E=[(Wa-Wrh)/Wrh]*100;//Percentage of excess air in %
D=(b*Co2)+(d*So2)+(e*O1)+(f*N1);//Mass of dry flue gas formed for 100 kg fuel in kg
dfg=D/100;//Mass of dry flue gas formed per kg of fuel in kg
Mw=(g*H2O)/100;//Mass of water vapour formed per kg of fuel

//Output
printf('(a) Mass of air supplied WA = %3.2f kg \n (b)Percentage excess air supplied = %3.2f percentage \n (c)mass of dry flue gas formed = %3.2f kg \n (d) Mass of water vapour formed = %3.2f kg',Wa,E,dfg,Mw)
```

Scilab code Exa 4.2 Percentage of excess air

```

clc
clear
//Input data
CO2=11.5;//Percentage of carbondioxide present in
    combustion in %
O2=2.7;//Percentage of oxygen present in the
    combustion in %
CO=0.7;//Percentage of carbonmonoxide present in the
     combuston in %

//Calculations
a=85.1/3.76;//Equating moles for nitrogen from the
    equation
x=(CO2+CO)/3;//Equating moles for carbon from the
    equation
b=[a-CO2-(CO/2)-O2]*2;//Equating moles for oxygen
    from the equation
y=a/x;//Moles of oxygen supplied for one mole of
    propane gas
z=5;//Theoretically 5 moles of oxygen are required
    for reacting
E=[(y-z)/z]*100;//The excess of air supplied in %

//Output
printf('The percentage excess air used is = %3.1f
    percentage',E)
```

Scilab code Exa 4.3 Air fuel ratio

```

clc
clear
//Input data
CO2=12.1;//The amount of carbondioxide released from
```

```
the combustion in %
O2=3.8;//The amount of oxygen released from the combustion in %
CO=0.9;//The amount of carbonmonoxide released from the combustion in %
MO=32;//Molecular weight of Oxygen

//Calculations
a=83.2/3.76;//Equating moles for nitrogen from the equation
b=(2*a)-(2*CO2)-(2*O2)-CO;//Equating moles for oxygen from the equation
x=CO2+CO;//Equating moles for carbon from the equation
y=2*b;//Equating moles for hydrogen from the equation
z=18.75;//Moles of Oxygen from the stoichiometric equation
z1=a;//Moles of Oxygen from the combustion equation
E=[(z1-z)/z]*100;//Percentage of excess air in%
A=(a*MO)/0.232;//Actual air supplied per mole of C13H23
Mc=179;//Molecular weight of C13H23
Af=A/Mc;//Air fuel ratio during the test

//Output
printf('(a) The air fuel ratio during the test = %3.2f \n (b) The excess or deficiency of air used = %3.0f Percentage of excess air used',Af,E)
```

Scilab code Exa 4.4 Power output and efficiency

```

clc
clear
```

```
//Input data
C=61;//The mass of carbon present in the coal according to coal analysis on mass basis in %
H=4;//The mass of hydrogen present in the coal according to coal analysis on mass basis in %
O=3;//The mass of oxygen present in the coal according to coal analysis on mass basis in %
N=2;//The mass of nitrogen present in the coal according to coal analysis on mass basis in %
S=1;//The mass of sulphur present in the coal according to coal analysis on mass basis in %
M=4;//The mass of moisture present in the coal according to coal analysis on mass basis in %
A=25;//The mass of ash present in the coal according to coal analysis on mass basis in %
HHV=24.3;//The high heating value of the coal i.e energy released by complete combustion of 1 kg fuel in MJ/kg
CO2=12;//The amount of carbondioxide by volume according to dry flue gas analysis in %
CO=1.5;//The amount of carbonmonoxide by volume according to dry flue gas analysis in %
O2=7;//The amount of oxygen by volume according to dry flue gas analysis in %
N2=79.5;//The amount of nitrogen by volume according to dry flue gas analysis in %
Te=170;//Exhaust gas temperature in degree centigrade
L=0.03;//Energy loss other than dry exhaust loss and incomplete combustion is 3% of HHV
R=150;//Steam generation rate in t/h
Po=100;//Steam condition at boiler outlet in bar
To=500;//Steam condition at boiler outlet in degree centigrade
Ti=160;//Feed water inlet temperature in degree centigrade
HCO2=33083;//Heat of reaction in kJ/kg carbon
HCO=9500;//Heat of reaction in kJ/kg carbon
```

```
cp=1.05;//Heat capacity of dry flue gas (dfg) in kJ/kgK
Ta=30;//The ambient temperature of air in degree centigrade
Mc=44;//Molecular weight of Carbondioxide
Mco=28;//Molecular weight of carbonmonoxide
Mo=32;//Molecular weight of oxygen
Mn=28;//Molecular weight of nitrogen
Mx=12;//Molecular weight of carbon
h1=3373.7;//Enthalpy at 100 bar and 500 degree centigrade in kJ/kg
hf=675.55;//Enthalpy at 160 degree centigrade in kJ/kg
hg=2724.7;//Enthalpy at 100 bar in kJ/kg

//Calculations
Mdfg=([(C/100)*[(Mc*(CO2/100))+(Mco*(CO/100))+(Mo*(N2/100))]]/[Mx*[(CO2/100)+(CO/100)]]);//Mass of dry flue gas produced per kg of fuel in kg
Ed=Mdfg*cp*(Te-Ta);//Energy loss due to dry exhaust gas in kJ/kg fuel
//Since Mdfg is 11.73kg through sciab calculation , there is a variation in Ed value and Ei value
Ei=[(Mdfg)*(HCO2-HCO)*(Mx/Mco)]*[(Mco*(CO/100))/[(Mc*(CO2/100))+(Mco*(CO/100))+(Mo*(O2/100))+(Mco*(N2/100))]];//Energy loss due to incomplete combustion in kJ/kg fuel
El=L*HHV;//Energy loss other than dry exhaust loss and incomplete combustion loss in MJ/kg fuel
TEl=(Ed/1000)+(Ei/1000)+El;//Total energy loss in MJ/kg fuel
Be=[(HHV-TEl)/(HHV)]*100;//Boiler efficiency in %
Wf=([(R*1000)*(h1-hf)]/((Be/100)*HHV*1000))/3600;//The fuel burning rate in kg/s
Wth=(11.5*(C/100))+(34.5*[(H/100)-(O/800)])+(4.3*(S/100));//Thearetical air required per kg of fuel in kg
WA=[[(3.04*(N2/100)*(C/100))]/[(CO2/100)+(CO/100)
```

```
]]-[(N/100)*(1/0.768)];//Actual air supplied per kg of fuel in kg
per=[(WA-Wth)/Wth]*100;//Percentage excess air used in %
pea=[(h1-hg)/(h1-hf)]*100;//Percentage of energy absorbed in the superheater

//Output
printf('(a)The amount of dry flue gas produced per kg fuel = %3.2f kg \n (b)The dry exhaust loss = %3.1f kJ/kg fuel and incomplete combustion loss per kg fuel = %3.2f kJ/kg fuel \n (c)The boiler efficiency = %3.2f percentage \n (d) THe fuel burning rate = %3.3f kg/s \n (e)The percentage of excess air used = %3.2f percentage \n (f) The percentage of energy absorbed in the superheater = %3.2f percentage',Mdfg,Ed,Ei,Be,Wf,per,pea)
```

Scilab code Exa 4.5 Total volume of combustion

```

clc
clear
//Input data
C=83.7;//The amount of carbon present in the fuel oil according to ultimate analysis of a fuel oil in %
H=12.7;//The amount of hydrogen present in the fuel oil according to ultimate analysis of a fuel oil in %
O=1.2;//The amount of oxygen present in the fuel oil according to ultimate analysis of a fuel oil in %
N=1.7;//The amount of nitrogen present in the fuel oil according to ultimate analysis of a fuel oil
```

```
in %
S=0.7;//The amount of sulphur present in the fuel oil according to ultimate analysis of a fuel oil in %
td=27;//The dry bulb temperature of combustion air in degree centigrade
tw=21;//The wet bulb temperature of combustion air in degree centigrade
E=0.3;//Excess air and assuming complete combustion in %
t=200;//Temperature to find total volume of combustion products in degree centigrade
p=1.013;//Pressure to find total volume of combustion procucts in bar

//Calculations
Wth=(11.5*(C/100))+[34.5*((H/100)-(O/100)*(1/8))]+(4.3*(S/100));//Theoretical air required per kg of fuel in kg
WA=(1+E)*Wth;//Actual air required per kg of fuel in kg/kg fuel
sh=0.0132;//Specific humidity at DBT and WBT in kg moisture/kg dry air
W=WA*sh;//Water vapour entering with air per kg fuel in kg vap/kg fuel
Tw=(9*(H/100))+WA;//Total water vapour formed per kg fuel in kg
CO2=(44/12)*(C/100);//mass of carbondioxide gas per kg of fuel
O2=0.232*E*Wth;//Mass of oxygen gas per kg of fuel
N2=0.768*(1+E)*Wth+(N/100);//Mass of nitrogen gas per kg of fuel
SO2=(64/32)*(S/100);//Mass of nitrogen gas per kg of fuel
H2O=1.383;//Mass of water per kg of fuel
M=(CO2/44)+(O2/32)+(N2/28)+(SO2/64)+(H2O/18);//Moles of combustion gases formed per kg fuel
VG=M*22.4*[(273+t)/273]*(1.013/1.013);//Volume of
```

```
flue gases at 200 degree centigrade and 1.013 bar per kg fuel
CO21=((CO2/44)/[(CO2/44)+(O2/32)+(N2/28)])*100;//Composition of dry flue gas CO2 by volume
O21=((O2/32)/[(CO2/44)+(O2/32)+(N2/28)])*100;//Composition of dry flue gas O2 by volume
N21=((N2/28)/[(CO2/44)+(O2/32)+(N2/28)])*100;//Composition of dry flue gas N2 by volume

//Output
printf('(a)The total volume of combustion products at 200 degee centigrade and 1.013 bar = %3.2f m^3 \n (b)The dry flue gas analysis based on carbondioxide,oxygen and nitrogen is \n Carbondioxide = %3.2f percent \n Oxygen = %3.2f percent \n Nitrogen = %3.2f percent',VG,CO21,O21,N21)
```

Scilab code Exa 4.6 Flue gas analysis

```

clc
clear
//Input data
C2H6=22.6;//The amount of gas present in the fuel gas according to volumetric analysis of fuel gas by volume in %
CH4=73.6;//The amount of gas present in the fuel gas according to volumetric analysis of fuel gas by volume in %
CO2=2.4;//The amount of gas present in the fuel gas according to volumetric analysis of fuel gas by volume in %
N2=1.4;//The amount of gas present in the fuel gas according to volumetric analysis of fuel gas by
```

```
volume in %
E=0.25;//Assuming combustion air to be dry and in excess
t=260;//The temperature for the total gas volume for complete combustion in degree centigrade
p=1.013;//The pressure for the total gas volume for complete combustion in bar
Mch=30;//Molecular weight of C2H6
Mc=16;//Molecular weight of CH4
Mco=44;//Molecular weight of CO2
Mn=28;//Molecular weight of N2
Mo=32;//Molecular weight of O2
Mh=18;//Molecular weight of H2O

//Calculations
x=100;//Assuming 100 moles of fuel gas
Mf=[(C2H6/100)*Mch]+[(CH4/100)*Mc]+[(N2/100)*Mn]+[(CO2/100)*Mco];//Molecular weight of fuel gas
Ma=[(226.3*(Mo+(3.76*Mn))*(1+E))]/28.96;//Moles of air supplied
Mc=1440;//Moles of combustion gas from the equation
Mr=x+Ma+Mc;//Total reaction molecules
Mwc=[(121.2*Mco)+(215*Mh)+(56.6*Mo)+(1065.4*Mn)]/Mc;//Molecular weight of combustion gas in kg/kgmol
Mt=Mc/(x*20);//Total number of moles of combustion gas per kg fuel gas
VG=Mt*22.4*[(273+t)/273];//Volume of combustion products per kg fuel gas
CO21=(121.2/(121.2+56.6+1065.4))*100;//Gas analysis of CO2 by volume
O21=(56.6/1243.2)*100;//Gas analysis of O2 by volume
N2=(1065.4/1243.2)*100;//Gas analysis of N2 by volume

//Output
printf('(a)The molecular weight of the combustion products M = %3.2f kg/kg mol \n (b) The total gas volume for complete combustion at 260 degree
```

```
centigrade and 1.013 bar is %3.2f m^3/kg fuel \n (c)The dry flue gas analysis on \n carbondioxide = %3.1f percent \n oxygen = %3.1f percent \n nitrogen = %3.1f percent ',Mwc,VG,CO21,O21,N2)
```

Scilab code Exa 4.7 Air leakage

```

clc
clear
//Input data
CO21=9.7;//Carbondioxide gas analysis before the air preheater
CO22=9.2;//Carbondioxide gas analysis after the air preheater
O21=4.0;//Oxygen gas analysis before the air preheater
O22=4.9;//Oxygen gas analysis after the air preheater
N21=86.3;//Nitrogen gas analysis before the air preheater
N22=85.9;//Nitrogen gas analysis after the air preheater
C=72;//The coal used shows the carbon percentage by mass in %

//Calculations
W1=[(3.04)*(N21/100)*(C/100)]/[(CO21/100)];//Before air preheater in kg air/kg fuel
W2=[(3.04)*(N22/100)*(C/100)]/[(CO22/100)];//After air preheater in kg air/kg fuel
A=W2-W1;//Air leakage in kg air/kg fuel

//Output
printf('The air leakage into the air preheater per
```

```
   kg of coal fired is %3.0f kg air/kg fuel',A)
```

Scilab code Exa 4.8 Height of stack and diameter of base

```

clc
clear
//Input data
n=6;//Total lancashire boilers in a textile factory
Ws=6;//Each boiler supplying steam in t/h
p=16;//Pressure at which steam is supplied in bar
t=250;//Temperature at which steam is supplied in
   degree centigrade
CV=43960;//Calorific value of the fuel oil in kJ/kg
no=75;//Overall efficiency of the boiler in %
a=16;//The amount of air required for efficient
   burning of the fuel inkg
H=20;//Drought of water gauge required at the base
   of chimney in mm
tf=320;//The flue gases leave the boiler in degree
   centigrade
ts=300;//The average temperature of the gases in the
    stack in degree centigrade
ta=30;//The atmospheric temperature in degree
   centigrade
R=0.287;//Real Gas constant in kJ/kgK
h1=2919.2;//enthalpy at the entrance of the boiler
   in kJ/kgK
hf=125.8;//Enthalpy at the feed in kJ/kgK
pi=3.1412;//Mathematical constant
g=9.81;//gravitational fore constant in m/s^2
P=1.013;//Atmospheric pressure in bar

//Calculations
H1=[(H*R*(273+ta)*(273+ts))]/[P*100*[(273+ts)-(273+
```

```
ta)]];//The draught produced in m
Wf=[[(Ws*1000)*6*(h1-hf)]/((no/100)*CV)]/3600;//Air fuel ratio in kg/s
Wa=a*Wf;//Actual air fuel ratio in kg/s
Wfg=17*Wf;//Air fuel ratio in kg/s
D=[[(Wfg*R*(273+ts)*(4/pi))]/[(101.3)*(2*g*H1)^(1/2)]]^(1/2);//Diameter at its base in m

//Output
printf('(a)The height of the stack H = %3.2f m \n (b)The diameter at its base D = %3.2f m ',H1,D)
```

Scilab code Exa 4.9 Motor capacity

```

clc
clear
//Input data
Wf=10;//Coal rate in t/h
C=78;//The mass of carbon present in the coal according to coal analysis on mass basis in %
H=3;//The mass of hydrogen present in the coal according to coal analysis on mass basis in %
O=3;//The mass of oxygen present in the coal according to coal analysis on mass basis in %
S=1;//The mass of sulphur present in the coal according to coal analysis on mass basis in %
M=7;//The mass of moisture present in the coal according to coal analysis on mass basis in %
A=8;//The mass of ash present in the coal according to coal analysis on mass basis in %
E=0.3;//Excess air in percentage
p=180;//Plenum chamber pressure in mm water gauge
nm=0.6;//Mechanical efficiency of the fan
ta=30;//Room temperature in degree centigrade
```

```
R=0.287;//Real gas constant
P=101.325;//Atmospheric pressure in kPa
g=9.812;//gravitational force constant m/s^2

//Calculations
Wth=(11.5*(C/100))+(34.5*[(H/100)-(O/(8*100))])+(4.3*(S/100));//Theoretical air required per kg fuel in kg air/kg fuel
WA=Wth*(1+0.3);//Actual air required per kg fuel in kg air/kg fuel
Va=(R*(273+ta))/P;//Volume flow rate of air in m^3/kg
FD=((WA*Wf*1000*Va*p*g)/(3600*nm))/1000;//FD fan motor capacity in kW

//Output
printf('The required motor capacity needed for the FD fan is %3.2f kW ',FD)
```

Scilab code Exa 4.10 Motor capacity

```

clc
clear
//Input data
tg=180;//The gas temperature in degree centigrade
p=250;//The draught produced by the ID fan in mm
nf=0.52;//The efficiency of the fan
Va=0.858;//Volume flow rate of air in m^3/kg
g=9.812;//gravitational force constant in m/s^2
Wf=10;//Coal rate in t/h
Wa=12.9;//Actual air required per kg fuel in kg air/kg fuel
ta=30;//Room temperature in degree centigrade

```

```
//Calculations
Wfg=[(Wf+(Wa*10))*1000]/3600;//Fuel gas required in kg/s
Vfg=[Va*(tg+273)]/(ta+273);//Volume flow rate of fuel gas in m^3/kg
ID=((Wfg*Vfg*p*g)/(nf))/1000;//ID fan motor capacity in kW

//Output
printf('The motor capacity of the ID fan is %3.2f kW',ID)
```

Scilab code Exa 4.11 Volumetric composition

```

clc
clear
//Input data
CO2=13.2;//The volume of carbondioxide present in the partial analysis of dry flue gas in %
O2=3.2;//The volume of oxygen present in the partial analysis of dry flue gas in %
C=88;//The mass of carbon present in the coal according to coal analysis on mass basis in %
H=4.4;//The mass of hydrogen present in the coal according to coal analysis on mass basis in %
A=7.6;//The mass of ash present in the coal according to coal analysis on mass basis in %
M=0;//Moisture present in the fuel was nil
Mc=12;//Molecular weight of the carbon
Mh=2;//Molecular weight of the hydrogen
Mo=32;//Molecular weight of the oxygen
Mho=18;//Molecular weight of water
p=101.325;//Atmospheric pressure in kPa

```

```
//Calculations
c=C/Mc;//Equating coefficients of the carbon from the equation
g=H/Mh;//Equating coefficients of the hydrogen from the equation
x=(CO2/100)/(O2/100);//From dry fuel gas analysis (dfg)
d=[[(CO2/100)*(47.5)]-7.333]/[[(CO2/100)*(3.032)]-1];//Coefficient of the carbonmonoxide in the equations product side
b=c-d;//Coefficient of the carbondioxide in the equation product side
a=10.21-(0.742*d);//Coefficient of the oxygen in the reactant side of the equation
e=b/x;//Coefficient of the oxygen in the product side of the equation
f=3.76*a;//Equating coefficients of the nitrogen from the equation
ma=(a*Mo)/0.232;//Mass of air supplied for 100 kg coal in kg
ma1=ma/100;//Mass of air supplied per kg coal in kg
T=b+d+e+f;//Total number of moles of dry flue gas (dfg)
CO21=(b/T)*100;//Carbondioxide by volume in percentage
O21=(e/T)*100;//Oxygen by volume in percentage
CO1=(d/T)*100;//Carbonmonoxide by volume in percentage
N21=(f/T)*100;//Nitrogen by volume in percentage
Mwv=(g*Mho)/100;//Mass of watervapour formed per kg coal in kg
Mf=(g)/(b+d+e+f+g);//Mole fraction of water vapour in flue gas
P=Mf*p;//Partial pressure of water vapour in kPa
D=32.9;//Dew point temperature from steam tables in degree centigrade

//Output
```

```
printf('(a)The complete volumetric composition of
   the dry flue gas is \n Carbondioxide by volume =
   %3.2f percentage \n Oxygen by volume = %3.2f
   percentage \n Carbonmonoxide by volume = %3.2f
   percentage \n Nitrogen by volume = %3.2f
   percentage \n (b) The actual amount of air
   supplied per kg coal = %3.2f kg \n (c) Mass of
   water vapour formed per kg coal = %3.2f kg \n (d)
    The dew point temperature of the flue gas = %3.2
   f degree centigrade ',CO21,O21,CO1,N21,ma1,Mwv,D)
```

Scilab code Exa 4.12 Height of gas plume

```

clc
clear
//Input data
H=200;//Height of the stack in m
D=4;//Diameter of the stack in m
m=1000;//Mass flow rate of gas in kg/s
Ts=100;//Stack exit gas temperature in degree
   centigrade
Ta=5;//Ambient air temperature in degree centigrade
Vw=50;//Wind velocity in Km/h
Cp=1.005;//Specific heat of the gas in kJ/kgK
pi=3.142;//Mathematical constant the value of pi

//Calculations
Vw1=(50*1000)/(60*60);//Wind velocity in m/s
Qe=m*Cp*(Ts-Ta);//Heat emission from plume in kW
Qe1=Qe/1000;//Heat emission from the plume in MW
p=(101.325)/(0.287*373);//Density of the gas in kg/m
   ^3
A=(pi*D^2)/4;//Area of the stack in m^2
Vs=m/(p*A);//Stack gas exict velocity in m/s
```

```
H1=[(2.62*(Qe1^(1/2))*1000)/Vw1]-[(0.029*Vs*D)/Vw1];
    //The height of the gas plume in m

//Output
printf('The height of the gas plume is H = %3.1f m '
    ,H1)
```

Scilab code Exa 4.13 Thermal efficiency

```

clc
clear
//Input data
CV=20;//Calorific value of the fuel in MJ/kg
C=65;//The amount of carbon present in the fuel
    according to gravimetric analysis in %
H=25;//The amount of hydrogen present in the fuel
    according to gravimetric analysis in %
O=10;//The amount of oxygen present in the fuel
    according to gravimetric analysis in %
p1=1;//Pressure at the inlet of the compressor in
    bar
t1=27;//Temperature at the inlet of the compressor
    in degree centigrade
p2=4;//The pressure which compressor compresses it
    isentropically in bar
Re=78;//The regenerator effectiveness in %
CO2=6;//The amount of carbondioxide according to the
     analysis of dry exhaust gas in %
CO=1.5;//The amount of carbonmonoxide according to
    the analysis of dry exhaust gas in %
Cp=1.005;//Specific heat capacity of the air in kJ/
    kgK
i=1.44;//Isentropic index for the air
Cp1=1.15;//Specific heat capacity of the air in kJ/
```

```
kgK
i1=1.33;//Isentropic index for the combustion products
Mc=12;//Molecular weight of the carbon
Mh=2;//Molecular weight of the hydrogen
Mo=32;//Molecular weight of the oxygen
Mho=18;//Molecular weight of water
T0=288;//Datum temperature in K (Assumed)

//Calculations
h=(C/100)/(Mc);//Equating coefficients of the carbon from the equation
e=(H/100)/Mh;//Equating coefficients of the hydrogen from the equation
y=(CO/100)/(CO2/100);//From dry exhaust gas analysis for solving
a=h/(1+y);//The coefficient of the carbondioxide in the product side of the equation
b=h-a;//The coefficient of the carbonmonoxide in the product side of the equation
z=b/(CO/100);//The sum of coefficients of the product side of the equation
x=z-(b/2)+(e/2);//Mol of air supplied in kmol
wa=x*28.96;//Air supplied in kg/kg fuel
wf=1;//Assuming 1 kg of fuel supplied
T2=(t1+273)*(p2/p1)^((i-1)/i);//Temperature at the outlet of the compressor in K
T3=[[(wa*Cp*(T2-T0))+(wf*CV*1000)]/[(wa+wf)*(Cp1)]]+T0;//Maximum temperature of the cycle in K
T4=T3/[(4)^((i1-1)/i1)];//Temperature at point of the cycle in K
T5=[(Re/100)*(T4-T2)]+T2;//Temperature at point of the cycle in K
Wc=wa*Cp*(T2-(t1+273));//Work done by the compressor in kW
Wt=23.54*Cp1*(T3-T4);//Work done by the turbine in kW
Q1=23.54*Cp1*(T3-T5);//Total work done by the system
```

```
in kW
nc=(Wt-Wc)/Q1;//Efficiency of the cycle
nc1=nc*100;//Efficiency of the cycle in %
spc=3600/(Wt-Wc);//Specific fuel consumption in kg/kWh

//Output
printf('(a) The maximum temperature of the cycle T3 = %3.0f K \n (b)Thermal efficiency of the plant = %3.3f or %3.2f percentage\n (c) Specific fuel consumption = %3.3f kg/kWh ',T3,nc,nc1,spc)
```

Chapter 5

Combustion Mechanism Combustion equipment and Firing Methods

Scilab code Exa 5.1 Total surface area

```

clc
clear
//Input data
Vs=2500;//The mass of a bed of solid particles in kg
p=2650;//The density of the solid in kg/m^3
d=800*10^-6;//The mean particle size in m
s=0.84;//The sphericity of the particle

//Calculations
As=(6*Vs)/(p*d*s);//The total surface area of the particles in the bed

//Output
printf(' The total surface area of the particles in the bed As = %3.0f m^2 ',As)
```

Scilab code Exa 5.2 Voidage of the bed

```

clc
clear
//Input data
d=427*10^-6;//The mean particle size in m
pg=1.21;//The density of air in kg/m^3
v=1.82*10^-5;//The viscosity of air in kg/ms
pl=1620;//The density of the loosely packed bed in
    kg/m^3
ps=2780;//The density of the solids in kg/m^3
c1=27.2;//(Grace,1982)constant value.
c2=0.0408;//(Grace,1982)constant value
g=9.812;//Gravitational forc constant in m/s^2

//Calculations
E=1-(pl/ps);//The voidage of the bed
Ar=[(pg)*(ps-pg)*g*(d^3)]/v^2;//Archimedes number
Re=[c1^2+(c2*Ar)]^(0.5)-c1;//Reynolds number
Umf=Re*v/(pg*d);//Minimum superficial velocity in m/
    s

//Output
printf('(a) The voidage of the bed = %3.3f \n (b)
    The minimum fluidization velocity Umf = %3.3f m/s
     ',E,Umf)
```

Scilab code Exa 5.3 Sphericity of particles

```

clc
```

```
clear
//Input data
d=427*10^-6;//The mean particle size in m
pg=1.21;//The density of air in kg/m^3
v=1.82*10^-5;//The viscosity of air in kg/ms
Umf=0.14;//Minimum superficial velocity in m/s
Ar=7753;//Archimedes number from previous example problem

//Calculations
Re=(Umf*pg*d)/v;//Reynolds number
function[f] = F(x);//function definition
    f = 7753*x^2- 381.1*x -4793;
endfunction
x = 100;//Initial guss
function[z] = D(x)//Derivative
    z= 3*x^2 - 3;
endfunction
y = fsolve(x,F, D);

//Output
printf('The sphericity of particles is = %3.3f ',y)
```

Scilab code Exa 5.4 Flow rate of limestone

```

clc
clear
//Input data
O=35;//The output of the fluidized bed combustion system in MW
n=0.80;//Efficiency of the fluidized bed combustion system
H=26;//The heating value of coal in MJ/kg
S=3.6;//Sulphur content in the coal in %
```

```
C=3;//The calcium sulphur ratio
Ca=85;//The amount of calcium carbonate in the
   limestone in %
CaCO3=100;//The molecular weight of CaCO3

//Calculations
Cb=O/(n*H);//Coal burning rate in kg/s
Cb1=Cb*3600;//Coal burning rate in kg/h
Sf=(Cb1*(S/100))/32;//Flow rate of sulphur in Kmol/h
Cf=Sf*C;//The flow rate of calcium in Kmol/h
Caf=Cf*CaCO3;//Mass flow rate of CaCO3 in kg/h
L=Caf/(Ca/100);//Mass flow rate of limestone in kg/h

//Output
printf('The required flow rate of limestone is %3.1f
    kg/h ',L)
```

Scilab code Exa 5.5 Rate of heat removed

```

clc
clear
//Input data
CV=24;//The calorific value of the fuel in MJ/kg
C=0.65;//The amount of calorific value released in
   the bed in %
to=850;//Temperature at which products leave in
   degree centigrade
ti=30;//The inlet temperature in degree centigrade
tb=850;//The bed temperature in degree centigrade
A=14.5;//The air fuel ratio by mass
Cp=1.035;//The specific heat of the products leaving
    the bed surface in kJ/kgK
B=7000;//The burning rate of coal in kg/h

```

```
//Calculations
H=(C*CV*1000)-(A*Cp*(to-ti));//Heat removal from the bed per kg fuel in kJ/kg fuel
Hr=(H*B)/3600;//Rate of heat removal from the bed in kW
Hb=(B/3600)*(1-C)*CV*1000;//The rate of heat removal from the above bed zone in kW

//Output
printf('(a) The rate of heat removal from the bed = %3.0f kW \n (b) The rate of heat removal from the above bed zone = %3.0f kW ',Hr,Hb)
```

Scilab code Exa 5.6 Platform area

```

clc
clear
//Input data
tb=850;//The bed temperature in degree centigrade
CV=25;//The calorific value of the fuel in MJ/kg
A=9.5;//The stoichiometric air fuel ratio by mass
E=20;//The amount of excess air used in %
F=4.8;//The total fueling rate in MW
p=0.3145;//The density of air at bed temperature in kg/m^3
f=2;//The firing rate in MW/m^2
v=2.7;//The fluidizing velocity in m/s

//Calculations
P=F/f;//Planform area in m^2
m=(F*1000)/(CV*1000);//Fuel burning rate in kg/s
ma=A*(1+(E/100))*m;//Mass flow rate of air in kg/s
Pa=ma/(p*v);//Planform area in m^2

```

```
//Output
printf('(a) The planform area = %3.1f m^2 \n (b) Fuel burning rate = %3.3f kg/s \n     Air flow rate = %3.4f kg/s \n     Planform area = %3.2f m^2 ',P,m,ma,Pa)
```

Chapter 6

Steam generators

Scilab code Exa 6.1 Pressure head

```

clc
clear
//Input data
H=18;//The length of furnace wall riser in m
O=76.2;//The outer diameter of the furnace wall riser in mm
T=6.1;//The thickness of the furnace wall riser in mm
P=80;//Pressure at which saturated water is recieved in bar
V=1.5;//The velocity of the saturated water in m/s
CR=12.5;//Assuming circulation ratio
S=1.2;//Assuming slip ratio
g=9.81;//Gravitational force constant in m/s^2
pi=3.142;//Mathematical constant

//Calculations
xt=1/CR;//The quality of steam at the top of the riser
vf=0.001384;//Specific volume of saturated liquid at
```

```
    80 bar in m^3/kg
vfg=0.02214;//Specific volume of Evaporation gas at
   80 bar in m^3/kg
vg=0.02352;//Specific volume of saturated gas at 80
   bar in m^3/kg
pf=1/vf;//Density of the saturated liquid at 80 bar
   in kg/m^3
vt=vf+(xt*vfg);//Specific volume of the steam at the
    top of the riser in m^3/kg
pt=1/vt;//Density of steam at the top of the riser
   in kg/m^3
pm=(pt+pf)/2;//Mean density in kg/m^3
Ph=[H*g*(pf-pm)]/1000;//The pressure head developed
   in kPa
C=(vf/vg)*S;//The part of calculation for the void
   fraction
VF=1/[1+((1-xt)*C)/xt];//The void fraction at riser
   exit
hfg=1441.3;//Enthalpy of the evaporation in kJ/kg
di=O-12.2;//Inner diameter of the furnace wall riser
    in mm
A=(pi*di^2)/4;//Inner area in m^2
w=pf*A*V;//Mass flow rate of saturated water
   entering the riser in kg/s
ws=xt*w;//The rate of steam formation in the riser
   tube in kg/s
h=[(ws*hfg)/(O*H)]/1000;//Heat transfer rate per
   unit projected area in kW/m^2

//output
printf('(a) The pressure head developed = %3.1f kPa
   \n (b)The void fraction at riser exit = %3.4f \n
   (c) The heat transfer rate per unit projected
   area = %3.1f kW/m^2 ',Ph,VF,h)
```

Scilab code Exa 6.2 Amount of water required

```

clc
clear
//Input data
t=60;//The temperature of water while supplying it
   to desuperheater in degree centigrade
ws=200;//The amount of steam carrying in a steam
   line in t/h
p=35;//The pressure of steam in bar
ts=400;//The temperature to be maintained by the
   steam in degree centigrade
to=450;//The outlet temperature of the steam from
   boiler in degree centigrade
h1=3337.2;//The enthalpy of steam at 450 degree C in
    kJ/kg
h2=252;//The enthalpy of water at 60 degree C in kJ/
   kg
h3=3222.3;//The enthalpy of steam at 400 degree C in
    kJ/kg

//Calculations
w=(ws*(h1-h3))/(h3-h2);//Mass flow rate of water in
   t/h
w1=w*(1000/3600);//Mass flow rate of water in kg/s

//Output
printf('The amount of water that must be sprayed is
   %3.3f t/h  or  %3.3f kg/s ',w,w1)
```

Scilab code Exa 6.3 Pressure head

```

clc
```

```
clear
//Input data
H=15;//The high of downcomer riser circuit in m
P=160;//The pressure at which downcomer riser circuit operates in bar
xe=0.5;//The exit quality of the steam
S=1.2;//Slip factor
vf=0.001711;//Specific volume of saturated liquid in m^3/kg
vg=0.009306;//Specific volume of saturated gas in m^3/kg
g=9.806;//Gravitational force constant in m/s^2

//Calculations
C=S*(vf/vg);//The part of calculation for the void fraction
VF=1/[1+((1-xe)*C)/xe];//The void fraction at riser exit
pf=1/vf;//Density of the saturated liquid in kg/m^3
pg=1/vg;//Density of the saturated gas in kg/m^3
pm=pf-[[(pf-pg)/(1-C)]*[1-{(1/((VF)*(1-C)))-1}*log(1/(1-(VF*(1-C))))]];//The average mixture density in the riser in kg/m^3
P1=g*(pf-pm)*H;//Pressure head developed due to natural circulation in N/m^2
P2=P1/1000;//ressure head developed due to natural circulation in kPa

//Output
printf('The pressure head developed due to natural circulation is %3.0f N/m^2  or  %3.3f kPa',P1,P2)
```

Scilab code Exa 6.4 Steam generation rate

```
clc
clear
//Input data
W=120;//The amount of electricity produced in the
    power plant in MW
po=100;//The pressure of the steam at the outlet of
    boiler in bar
to=500;//The temperature of steam at the outlet of
    boiler in degree centigrade
p=0.1;//The condenser pressure in bar
nb=0.9;//The efficiency of the boiler
CV=25.7;//The calorific value of the coal in MJ/kg
ti=160;//The feed water temperature at boiler inlet
    in degree centigrade
H=40;//The high of the risers in the furnace wall in
     m
xt=0.08;//The quality of the steam at the top of the
     riser
v=2;//The exit velocity of the riser and entering
    the drum in m/s
Do=60;//The outer diameter of the risers in mm
T=3;//The thickness of the wall in mm
pi=3.142;//Mathematical constant
g=9.806;//Gravitational force constant in m/s^2

//Calculations
h1=3374.8;//Enthalpy at point 1 in kJ/kg
s1=6.6011;//Entropy at point 1 in kJ/kgK
sf=0.6479;//Entropy of the saturated liquid at point
     1 in kJ/kgK
sg=7.5055;//Entropy of the Saturated vapour at point
     1 in kJ/kgK
x2=(s1-sf)/sg;//The quality of the steam
h2=191.46+(x2*2393.29);//Enthalpy at point 2 in kJ/
    kg
h3=191.46;//Enthalpy at point 3 in kJ/kg
h5=675.5;//Enthalpy at point 5 in kJ/kg
ws=(W*1000)/(h1-h2);//Mass flow rate of steam in kg/
```

```
s
wf=(ws*(h1-h5))/(nb*CV*1000);//Mass flow rate of fuel in kg/s
E=ws/wf;//Evaporation factor
vf=0.0014523;//The specific volume of saturated liquid in m^3/kg
vg=0.0165884;//The specific volume of saturated vapour in m^3/kg
vt=vf+(xt*vg);//Specific volume at the top in m^3/kg
pt=1/vt;//Density of the steam at the top in kg/m^3
pf=1/vf;//The density of the steam in kg/m^3
pm=(pf+pt)/2;//The average mixture density in kg/m^3
H1=[g*H*(pf-pm)]/10^5;//Pressure head available for natural circulation in bar
CR=1/xt;//Circulation ratio
di=(Do-(2*T))/1000;//The inner diameter of the riser in m
A=(pi*di^2)/4;//Area for the inner diameter in m^2
w=(A*pt*v*xt);//The rate of steam formation in the riser in kg/s
Nr=ceil(ws)/w;//The number of risers
hfg=1319.8;//Enthalpy of the evaporation in kJ/kg
Ha=(w*hfg)/((Do/1000)*H);//Heat absorption rate per unit projected area of the riser in kW/m^2

//Output
printf('(a)The steam generation rate = %3.3f kg/s \n (b) The fuel burning rate = %3.3f kg/s \n (c) The evaporation factor = %3.2f \n (d) The pressure head available for natural circulation = %3.4f bar \n (e) The circulation ratio = %3.1f \n (f)The number of risers required = %3.0f \n (g) The heat absorbtion rate per unit projected area of the riser = %3.2f kW/m^2',ws,wf,E,H1,CR,Nr,Ha)
```

Scilab code Exa 6.5 Blowdown

```

clc
clear
//Input data
ws=64;//The steam flow rate in kg/s
p=60;//The pressure at which steam leaves the boiler
    in bar
m=0.02;//Moisture contant in the steam
wf=62;//The feedwater flow rate in kg/s
Pf=3;//concentration of feedwater in ppm
wm=2;//The flow rate of makeup water
Pm=50;//concentration of makeup water in ppm
Ps=5;//Leaving the drum water in ppm
Pw=1000;//The concentration in the drum water in ppm
mf=7;//The fuel burning rate in kg/m
CV=23;//The heating value in MJ/kg
ta=30;//The room temperature in degree centigrade
hf=1213.35;//Enthalpy of saturated liquid at 60 bar
   in kJ/kg
ha=125.79;//Enthalpy at ambient temperature in kJ/kg

//Calculations
BD=[(wf*Pf)+(wm*Pm)-(m*ws*Ps)]/1000;//The rate of
   blowdown in kg/s
E=[(BD*(hf-ha))/(mf*CV*1000)]*100;//The energy loss
   in blowdown in percentage
S=m*ws*Ps*10^-6*3600*24;//Scale deposition in
   superheater tubes

//Output
printf('(a)The blowdown required = %3.4f kg/s \n (b)
    Heat loss in blowdown as a percentage of total
```

```
heat released in the furnace = %3.2f percentage \
n (c) The deposition of scale in superheater tube
 = %3.3f kg/day ',BD,E,S)
```

Scilab code Exa 6.6 Number of coils needed

```

clc
clear
//Input data
ws=600;//Mass flow rate of feedwater in kg/s
p=140;//The inlet pressure of the feedwater in bar
t=170;//The inlet temperature of the feedwater in degree centigrade
wg=1250;//The mass flow rate of flue gases in kg/s
tg2=450;//The temperature at which flue gases leave the economisers coils in degree centigrade
Vf=12;//The velocity of the flue gas in m/s
Vw=1.2;//The velocity of the water leaving the coil in m/s
Do=0.07;//The outer diameter of the tube in m
Di=0.06;//The inner diameter of the tube in m
U=70;//The overall heat transfer coefficient in W/m^2K
Cp=1.12;//The specific heat capacity of the flue gases in kJ/kgK
V=0.08;//The vertical pitch of the coil in m
B=4.8;//The width of the duct in m
C=0.005;//The clearence on the both sides of the duct in m
pi=3.142;//Mathematical constant

//Calculations
hf=1571.1;//The enthalpy of the saturated liquid at 140 bar in kJ/Kg
```

```
ts=336.75;//The saturated temperature at 140 bar in degree centigrade
vf=0.001611;//The specific volume of the saturated liquid at 140 bar in m^3/kg
hf1=719.21;//The enthalpy of the saturated liquid at 170 degree C in kJ/kg
vf1=0.001114;//The specific volume of the saturated liquid at 170 degree C in m^3/kg
tg1=[(ws*(hf-hf1))/(wg*Cp)]+tg2;//The temperature at which flue gases enters the economisers coils in degree centigrade
t1m=(478.25-280)/(log(478.25/280));//The mean temperature for inlet and exit temperature in degree centigrade
Q=ws*(hf-hf1);//The rate of heat transfer in the economiser in kW
Ao=[Q/(U*t1m)]*10^3;//The outer area in m^2
n=[(ws*(vf/Vw)*(4/pi)*(1/Di^2))];//The number of coils needed in the economiser
l=Ao/(n*pi*Do);//The length of one coil in m
nt=l/(B-(2*C));//The number of turns in on ecoil
VH=nt*V;//The vertical height of the duct occupied by the economiser coils

//Output
printf('(a) The number of coils needed in the economiser = %3.0f \n (b) The length of one coil = %3.1f m \n (c) The verticle height of the duct occupied by the economiser coils = %3.2f m ',n,l,VH)
```

Scilab code Exa 6.7 Number of tubes and the length

```

clc
```

```
clear
//Input data
tg2=160;//The temperature to which the flue gases are cooled in degree centigrade
ta1=35;//The ambient temperature of the air in degree centigrade
wa=1167;//The mass flow rate of air in kg/s
Vg=13;//The inlet velocity of the flue gases in m/s
U=30;//The overall heat transfer coefficient in W/m^2K
Cpg=1.10;//The specific heat of the flue gas in kJ/kgK
Cpa=1.005;//The specific heat of the air in kJ/kgK
R=0.287;//Real gas constant in kJ/kgK
wg=1250;//The mass flow rate of gas in kg/s
tg1=450;//The temperature at the inlet of flue gas in degree centigrade
P=101.325;//Atmospheric temperature in kPa
pi=3.1414;//Mathematical constant
Di=0.06;//The inner diameter of the tube in m
Do=0.065;//The outer diameter of the tube in m

//Calculations
vg1=(R*(273+tg1))/P;//Specific volume of the gas in m^3/kg
ta2=[(wg*Cpg*(tg1-tg2))/(wa*Cpa)]+ta1;//The temperature of the heated air in degree centigrade
t1m=(75-125)/log(75/125);//The mean temperature of the inlet and exit temperature in degree centigrade
Q=wg*Cpg*(tg1-tg2);//The rate of heat transfer in the economiser in kW
Ao=[Q/(U*t1m)]*10^3;//The outer area in m^2
n=[(wg*(vg1/Vg)*(4/pi)*(1/Di^2))];//The number of coils needed in the economiser
l=Ao/(n*pi*Do);//The length of one coil in m

```

```
//Output
printf('(a)The length of the tubes = %3.2f m\n (b)
   The number of tubes = %3.0f  ',l,n)
```

Scilab code Exa 6.8 Number of coils needed

```

clc
clear
//Input data
di=0.05;//The inner diameter of the superheater coil
    in m
T=0.005;//The thickness of the coil in m
p=60;//The pressure of the steam at the exit in bar
t=500;//The temperature of the steam at the exit in
   degree centigrade
V2=10;//The velocity of the steam at the exit in m/s
ws=80;//The mass flow rate of steam in kg/s
H=140;//The heat flux in the super heated coils in
   kW/m^2
pi=3.142;//Mathematical constant
Do=0.06;//The outer diameter of the tube in m

//Calculations
h1=2784.3;//The enthalpy of the saturated gas at 60
   bar in kJ/kg
h2=3422.2;//The enthalpy of the saturated gas at 500
    degreeC in kJ/kg
v2=0.05665;//The specific volume of gas at 500
   degreeC in m^3/kg
Q=ws*(h2-h1);//Heat absorption rate in superheater
   coil in kW
Ao=Q/H;//Surface area required in m^2
n=[(ws*(v2/V2)*(4/pi)*(1/di^2))];//The number of
   coils needed in the economiser
```

```
l=Ao/(n*pi*Do);//The length of one coil in m

//Output
printf('(a)The length of the one coil = %3.2f m\n (b
   ) The number of coils = %3.0f  ',l,n)
```

Chapter 7

Steam Turbines

Scilab code Exa 7.1 Maximum area

```

clc
clear
//Input data
p1=10//Initial pressure in bar
T1=300+273//Initial temperature in K
p2=2//Final pressure in bar
m=1//Mass flow rate of steam in kg/s

//Calculations
px=(0.546*p1)//Critical pressure in bar
ho=3052.2//Enthalpy in kJ/kg
so=7.1229//Entropy in kJ/kg.K
sx=so//Entropy in kJ/kg.K
hx=2905.9//Enthalpy in kJ/kg
vx=0.4125//Specific volume in m^3/kg
Vx=(44.72*sqrt(ho-hx))//Critical velocity in m/s
Ax=(vx/Vx)*10^4//Minimum area of the nozzle in sq.cm

//Output
printf('Minimum area of the nozzles is %3.3f sq.cm',
```

```
   Ax)
```

Scilab code Exa 7.2 Minimum area

```

clc
clear
//Input data
p1=10//Initial pressure in bar
T1=300+273//Initial temperature in K
p2=1//Final pressure in bar
x=0.15//Friction loss of the isentropic enthalpy
   drop
ms=1//Steam flow rate in kg/s
d=25//Exit diameter of the nozzles in mm

//Calculations
px=(0.546*p1)//Critical pressure in bar
h1=3052.2//Enthalpy in kJ/kg
s1=7.1276//Entropy in kJ/kg
s2s=s1//Entropy in kJ/kg
h2s=2916.2//Enthalpy in kJ/kg
Vx=(44.72*sqrt(h1-h2s))//Critical velocity in m/s
h3s=2605//Enthalpy in kJ/kg
V1=(44.72*sqrt((h1-h2s)+(0.85*(h2s-h3s))))//Velocity
    in m/s
s3s=s1//Entropy in kJ/kg
x3s=(s3s-1.3025)/6.0579//Dryness fraction
h3s=(417.46+(x3s*2258.01))//Enthalpy in kJ/kg
h2s3=((1-x)*(h2s-h3s))//Enthalpy in kJ/kg
h3=h2s-h2s3//Enthalpy in kJ/kg
x3=(h3-417.46)/2258.01//Dryness fraction
v3=(0.001043+(x3*1.694))//Specific volume in m^3/kg
v2s=0.416//Specific volume in m^3/kg
vx=v2s//Specific volume in m^3/kg
```

```
Ax=(ms/Vx)*vx*10^4//Minimum area in cm^2
A1=(ms*v3)/V1*10^4//Area in cm^2
n=(A1*4)/(3.14*(d/10)^2)//Number of nozzles

//Output
printf('Minimum area of the nozzles is %3.2f cm^2 \n the number of nozzles are %3.0f',Ax,n)
```

Scilab code Exa 7.3 Throat and exit area

```

clc
clear
//Input data
p1=7.8//Pressure in bar
t1=180+273//Temperature in K
p2=1.03//pressure in bar
m=3.6//flow rate of air in kg/s
g=1.4//Ratio of specific heats
R=287//Characteristic gas constant in J/kg.K
cp=1.005//Specific heat in kJ/kg.K

//Calculations
pxpo=(2/(g+1))^(g/(g-1))//Ratio of pressure
px=pxpo*p1//Critical pressure in bar
txto=(2/(g+1))//Ratio of temperatures
tx=t1*txto//Critical temperature in K
vx=(R*tx)/(px*10^5)//Critical specific volume in m^3/kg
Vx=sqrt(g*R*tx)//Critical velocity in m/s
Ax=((m*vx)/Vx)*10^6//Critical area in mm^2
tot1=(p1/p2)^((g-1)/g)//Ratio of temperatures
t1i=t1/tot1//Temperature in K
v1=(R*t1i)/(p2*10^5)//Specific volume in m^3/kg
V1=44.72*sqrt(cp*(t1-t1i))//Velocity in m/s
```

```
A1=((m*v1)/V1)*10^6//Area in mm^2

//Output
printf('Area of throat is %3.0f mm^2 \n Exit area is
    %i mm^2',Ax,A1)
```

Scilab code Exa 7.4 Throat and exit area

```

clc
clear
//Input data
p1=3.8//pressure in bar
T1=450+273//Tempereture in K
p2=1//pressure in bar
m=16//Flow rate in kg/s
Cd=0.98//coefficient of discharge
nv=0.93//nozzile effeciency
cp=1.11//Specific heat in kJ/kg.K
g=1.333//Ratio of specific heats

//Calculations
pxpo=(2/(g+1))^(g/(g-1))//Pressure ratio
px=pxpo*p1//Critical pressure in bar
TxTo=2/(g+1)//Temperature ratio
Tx=T1*TxTo//Critical temperature in K
Vx=44.72*sqrt(cp*(T1-Tx))//critical velocity in m/s
R=(cp*(g-1)*1000)/g//Characteristic gas constant in
   J/kg.K
vx=(R*Tx)/(px*10^5)//Critical specific volume in m
   ^3/kg
ws=(m/Cd)//Mass flow rate in kg/s
Ax=(ws*vx)/Vx//Critical area in m^2
T1sTo=(p2/p1)^((g-1)/g)//Temperature ratio
T1s=T1*T1sTo//Temperature in K
```

```
T1i=(T1-(nv*(T1-T1s)))//Temperature in K
v1=(R*T1i)/(p2*10^5)//Specific volume in m^3/kg
V1=44.72*sqrt(cp*(T1-T1i))//Velocity in m/s
A1=(ws*v1)/V1//Area in m^2

//Output
printf('Throat raea is %3.4f m^2 \n Exit arae is %3
    .4f m^2',Ax,A1)
```

Scilab code Exa 7.5 Throat and exit area

```

clc
clear
//Input data
p1=20//pressure in bar
T1=300+273//Tempereture in K
p2=3//pressure in bar
m=0.3//Flow rate in kg/s
n=1.3//Adiabatic constant
Cd=0.98//Coefficient of discharge
Cv=0.92//Coefficient of velocity

//Calculations
vo=0.1255//Specific volume in m^3/kg
px=(0.546*p1)//Critical pressure in bar
vx=(p1/px)^(1/n)*vo//Critical specific volume in m
    ^3/kg
Vx=sqrt(n*px*10^5*vx)//Critical velocity in m/s
Ax=((m*vx)/Vx)*10^6//Critical area in m^2
v1vo=(p1/p2)^(1/n)//Ratio of specific volumes
v1=(vo*v1vo)//Specific volume in m^3/kg
V1=sqrt(2*((n/(n-1))*10^5*((p1*vo)-(p2*v1))))//
    Velocity in m/s
A1=((m*v1)/V1)*10^6//Area in mm^2
```

```
ho=3050//Enthalpy in kJ/kg
hx=2920//Enthalpy in kJ/kg
h1s=2650//Enthalpy in kJ/kg
ws=(m/Cd)//Flow rate in kg/s
Vsx=44.72*sqrt(ho-hx)//Velocity in m/s
V1s=44.72*sqrt(ho-h1s)//Velocity in m/s
Vo1=(V1s*Cv)//Velocity in m/s
hoh1=(V1/44.72)^2//Change in enthalpy in kJ/kg
h1=ho-hoh1//Enthalpy in kJ/kg
x1=(h1-561.47)/2163.8//Dryness fraction
vo1=(0.001073+(x1*0.6047))//Specific volume in m^3/kg
Ao1=((ws*vo1)/Vo1)*10^6//Exit nozzle area in mm^2
Vox=(Vsx*Cv)//Velocity in m/s
hohx=(Vox/44.72)^2//Change in enthalpy in kJ/kg
hox=(ho-hohx)//Enthalpy in kJ/kg
vox=0.22//Specific volume in m^3/kg
Aox=((ws*vox)/Vox)*10^6//Critical area in m^2

//Output
printf('(a) Area of throat is %3.1f mm^2 \n Exit area is %3.1f mm^2 \n\n (b) Area of throat is %3.1f mm^2 \n Exit area is %3.1f mm^2',Ax,A1,Aox,Ao1)
//In textbook, Ao1 is given wrong.
```

Scilab code Exa 7.6 Mass flow rate

```

clc
clear
//Input data
p1=5//Pressure of steam in bar
V=100//Velocity in m/s
p2=1.5//Exit pressure in bar
```

```
At=1280//Throat area in mm^2
Ae=1600//Exit area in mm^2
rp=0.58//Critical pressure ratio

//Calculations
ho=2749//Enthalpy in kJ/kg
so=6.822//Entropy in kJ/kg.K
px=(rp*p1)//Critical pressure in bar
sx=so//Entropy in kJ/kg.K
xx=(sx-1.660)/5.344//Dryness fraction
hx=(556+(xx*2168))//Enthalpy in kJ/kg
Vx=sqrt(((ho+((V^2*10^-3))/2)-hx)*(2/10^-3))//
   Velocity in m/s
vx=(xx*0.6253)//Specific volume in m^3/kg
w=(At*10^-6*Vx)/vx//Mass flow rate in kg/s
s1s=sx//Entropy in kJ/kg.K
x1s=(so-1.434)/5.789//Dryness fraction
h1s=(467+x1s*2226)//ENthalpy in kJ/kg
z=((Vx^2*10^-3)/2)-hx//z value
//By iteratio scheme
x1=0.932//Dryness fraction
v1=1.080//Specific volume in m^3/kg
h1=2542//Enthalpy in kJ/kg
V1=652.2//Velocity in m/s
nn=((hx-h1)/(hx-h1s))//Nozzle efficiency

//Output
printf('Mass flow rate is %3.3f kg/s \n Nozzle
   efficiency is %3.3f',w,nn)
```

Scilab code Exa 7.7 Exit area

```

clc
clear
```

```
//Input data
p1=5//Pressure in bar
T1=200+273//Temperature in K
p2=2//Pressure in bar
m=0.3//Mass flow rate in kg/s
n=1.3//Adiabatic index

//Calculations
vo=0.4249//Specific volume in m^3/kg
ho=2855.4//Enthalpy in kJ/kg
so=7.0592//Entropy in kJ/kg.K
x1=0.972//Dryness fraction
h1=(504.7+x1*2201.9)//Enthalpy in kJ/kg
v1=x1*0.8857//Specific volume in m^3/kg
V1=44.72*sqrt(ho-h1)//Velocity in m/s
A1=((m*v1)/V1)*10^6//Area in mm^2
rp=(p1/p2)^(1/n)//Specific volume ratio
vR=(vo*rp)//Specific volume in m^3/kg
VR=sqrt(2*((n/(n-1))*(p1*vo-p2*vR)*10^5))//Velocity in m/s
AR=((m*vR)/VR)*10^6//Area in mm^2
TR=T1/(p1/p2)^((n-1)/n)//Temperature in K
tR=(TR-273)//Temperature in degree C
ts=120.23//Saturation temperature at pressure p1 in degree C
ds=ts-tR//Degree of subcooling in degree C
ps=1.4327//Saturation pressure at tR in bar
dsu=(p2/ps)//Degree of supersaturation

//Output
printf('(a) Exit area when the flow is in equilibrium throughout is %3.0f mm^2 \n (b) Exit area when the flow is supersaturated is %3.1f mm^2 \n (i) The degree of supercooling is %3.2f degree C \n (ii) The degree of supersaturation is %3.3f',A1,AR,ds,dsu)
```

Scilab code Exa 7.8 Exit area

```

clc
clear
//Input data
p1=5//Pressure in bar
T1=200//Temperature in degree C
p2=2//Pressure in bar
m=0.3//Mass flow rate in kg/s
n=1.3//Adiabatic index
nn=0.92//Nozzle efficiency
cp=1.925//mean specific heat in kJ/kg.K
x=[2.308,1943]//pv*10^3 = 2.308(h-1943)

//Calculations
vo=0.4249//Specific volume in m^3/kg
ho=2855.4//Enthalpy in kJ/kg
so=7.0592//Entropy in kJ/kg.K
x1=0.972//Dryness fraction
h1=(504.7+x1*2201.9)//Enthalpy in kJ/kg
v1=x1*0.8857//Specific volume in m^3/kg
V1=44.72*sqrt(ho-h1)//Velocity in m/s
h=ho-h1//Change in enthalpy in kJ/kg
hoq=nn*h//Change in enthalpy in kJ/kg
VQ=44.72*sqrt(hoq)//Velocity in m/s
toq=(hoq/cp)//Temperature difference in degree C
tQ=(T1-toq)//Temperature in degree C
TQ=tQ+273//Temperature in K
vQ=((p1*100*vo)/(T1+273))*(TQ/T1)//Specific volume
   in m^3/kg
A1=((m*vQ)/VQ)*10^6//Area in mm^2
vQ=(x(1)*(ho-hoq-x(2)))/(10^3*p2)//Specific volume
   in m^3/kg
```

```
A11=((m*vQ)/VQ)*10^6//Area in mm^2

//Output
printf('Exit area is %3.1f mm^2 which upon checking
   is %3.0f mm^2',A1,A11)
```

Scilab code Exa 7.9 Force Thrust and efficiency

```

clc
clear
//Input data
V1=1000//Speed in m/s
Vb=400//Peripheral velocity in m/s
a=20//Nozzle angle in degree
m=0.75//Mass flow in kg/s
f=80//Percentage reduction of relative velocity

//Calculations
b1=atand((V1*sind(a))/((V1*cosd(a))-Vb))//Blade
   angle in degree
V=342//Velocity from E7.9 in m/s
Vr1=V/sind(b1)//Velocity in m/s
dVw=(2*Vr1*cosd(b1))//Velocity in m/s
Pt=(m*dVw)//Tangential thrust in N
WD=(Pt*Vb)/1000//Diagram power in kW
nD=(WD/(0.5*m*V1^2*10^-3))*100//Diagram efficiency
   in percent
Pa=0//Axial thrust in N
Vr2=(f/100)*Vr1//Velocity in m/s
Pa2=m*sind(b1)*(Vr1-Vr2)//Axial thrust in N
WD2=(m*(Vr1+Vr2)*cosd(b1)*Vb)/1000//Diagram power in
    kW
nD2=(WD2/(0.5*m*V1^2*10^-3))*100//Diagram efficiency
    in percent
```

```

//Output
printf('Blade Angle is %3.2f degrees \n\n Neglecting the friction effects \n Tangential force is %3.2f N \n Axial thrust is %i N \n Diagram efficiency is %3.1f percent \n\n Considering the friction effects \n Axial thrust is %3.1f N \n Diagram Power is %3.2f kW \n Diagram efficiency is %3.2f percent',b1,Pt,Pa,nD,Pa2,WD2,nD2)
```

Scilab code Exa 7.10 Workdone and efficiency

```

clc
clear
//Input data
a=20//Nozzle angle in degrees
b2=30//Blade exit angle in degrees
Vb=130//Mean blade speed in m/s
V1=330//Velocity of steam in m/s
f=0.8//Friction factor
nn=0.85//Nozzle efficiency
p1=20//Pressure in bar
T1=250+273//Temperature in K
p2=0.07//Pressure in bar
rf=1.06//Reheat factor

//Calculations
b1=atand((V1*sind(a))/((V1*cosd(a))-Vb))//Blade angle in degrees
Vr1=((V1*sind(a))/sind(b1))//Velocity in m/s
Vr2=(f*Vr1)//Velocity in m/s
dVw=(Vr1*cosd(b1))+(Vr2*cosd(b2))//Vecoity in m/s
WD=(dVw*Vb)/1000//Workdone in kJ/kg
nb1=((2*dVw*Vb)/V1^2)*100//Efficiency in percent
```

```
nst=(nn*nb1)//Efficiency in percent
nin=(nst*rf)*100//Efficiency in percent
h1=2902.3//Enthalpy in kJ/kg
s1=6.5466//Entropy in kJ/kg.K
x2s=(s1-0.5582)/7.7198//Dryness fraction
h2s=(163.16+x2s*2409.54)//Enthalpy in kJ/kg
h12=(0.7041*(h1-h2s))//Change in enthalpy in kJ/kg
n=ceil(h12/WD)//Number of stages

//Output
printf('(a) Work done in the stage per kg of steam is %3.2f kJ/kg \n Stage efficiency is %3.1f percent \n\n (b) Number of stages are %3.0f',WD,nst,n)
```

Scilab code Exa 7.11 Power developed

```

clc
clear
//Input data
d=800//Diameter in mm
N=3000//Speed in rpm
V1=300//Velocity in m/s
a=20//Nozzle angle in degrees
f=0.86//Frictional factor
T=140//Axial thrust in N

//Calculations
Vb=((3.14*(d/1000)*N)/60)//Velocity in m/s
b1=atand((V1*sind(a))/((V1*cosd(a))-Vb))//Blade angle in degrees
b2=b1//Blade angle in degrees
Vr1=(V1*sind(a))/sind(b1)//Velocity in m/s
Vr2=f*Vr1//Velocity in m/s
```

```
w=(T/((Vr1*sind(b1))-(Vr2*sind(b2))))//Mass flow rate in kg/s
dVw=(Vr2*cosd(b2))+(Vr1*cosd(b1))//Velocity in m/s
P=(w*dVw*Vb*10^-3)//Power developed in kW

//Output
printf('Power deveoped in the blading is %3.2f kW',P)
```

Scilab code Exa 7.12 Thrust Power and efficiency

```

clc
clear
//Input data
p1=15//Pressure in bar
T1=300+273//Temperature in K
p2=10//Pressure in bar
nn=95//Nozzle efficiency in percent
a=20//Nozzle angle in degrees
x=5//The blade exit angle is 5 degrees less than the inlet angle
f=0.9//Friction factor
m=1350//Steam flow rate in kg/h

//Calculations
h1=3038.9//Enthalpy in kJ/kg
s1=6.9224//Entropy in kJ/kg.K
s2=s1//Entropy in kJ/kg.K
t2s=250//Temperature in degree C
h2s=2943.1//Enthalpy in kJ/kg
V1=44.72*sqrt((nn/100)*(h1-h2s))//Velocity in m/s
Vb=V1*(cosd(a)/2)//Velocity in m/s
b1=atand((V1*sind(a))/((V1*cosd(a))-Vb))//Blade angle in degrees
```

```
b2=b1-x//Blade angle in degrees
Vr1=((V1*sind(a))/sind(b1))//Velocity in m/s
Vr2=(f*Vr1)//Velocity in m/s
dVw=(Vr1*cosd(b1))+(Vr2*cosd(b2))//Velocity in m/s
dVa=(Vr1*sind(b1))-(Vr2*sind(b2))//Velocity in m/s
Pa=(m/3600)*dVa//Axial thrust in N
Pt=(m/3600)*dVw//Tangential thrust in N
WD=(Pt*Vb*10^-3)//Diagram Power in kW
dn=((WD*1000)/((1/2)*(m/3600)*V1^2))*100//Diagram efficiency in percent

//Output
printf('(a) Axial thrust is %3.2f N \n  Tangential thrust is %3.2f N \n\n (b) Diagram Power is %3.3f kW \n\n (c) Diagram Efficiency is %3.1f percent',Pa,Pt,WD,dn)
```

Scilab code Exa 7.13 Thrust Power and efficiency

```

clc
clear
//Input data
V1=600//Velocity in m/s
a=16//Nozzle angle in degrees
Vb=120//Mean blade angle in degrees
b2=18//Exit angle in degrees
aa1=22//Exit angle in degrees
b4=36//Exit angle in degrees
m=5//Steam flow rate in kg/s
f=0.85//Friction coefficient

//Calculations
b1=atand((V1*sind(a))/((V1*cosd(a))-Vb))//Exit angle in degrees
```

```
Vr1=((V1*sind(a))/sind(b1))//Velocity in m/s
Vr2=(f*Vr1)//Velocity in m/s
a1=atand((Vr2*sind(b2))/((Vr2*cosd(b2))-Vb))//Angle
    in degrees
V2=((Vr2*sind(b2))/sind(a1))//Velocity in m/s
V3=(f*V2)//Velocity in m/s
dVw1=(Vr1*cosd(b1))+(Vr2*cosd(b2))//Velocity in m/s
dVa1=(V1*sind(a))-(V2*sind(a1))//Velocity in m/s
b3=atand((V3*sind(aa1))/((V3*cosd(aa1))-Vb))//Angle
    in degrees
Vr3=((V3*sind(aa1))/sind(b3))//Velocity in m/s
Vr4=(f*Vr3)//velocity in m/s
dVw2=(Vr3*cosd(b3))+(Vr4*cosd(b4))//Velocity in m/s
dVa2=(V3*sind(aa1))-(Vr4*sind(b4))//Velocity in m/s
udVw=(dVw1+dVw2)//Total velocity in m/s
udVa=(dVa1+dVa2)//Total velocity in m/s
Pt=(m*udVw*10^-3)//tangential thrust in kN
Pa=(m*udVa*10^-3)//Axial thrust in kN
WD=(Pt*Vb)//Power developed in kW
nd=((2*udVw*Vb)/V1^2)*100//Diagram efficiency in
    percent

//Output
printf('(a) the tangential thrust is %3.3f kW \n (b)
     Axial thrust is %3.2f kN \n (c) Power developed
    is %3.2f kW \n (d) Diagram efficiency is %3.2f
    percent',Pt,Pa,WD,nd)
```

Scilab code Exa 7.14 Workdone and efficiency

```

clc
clear
//Input data
a=17//Nozzle angle in degrees
```

```
Vb=125//Blade velocity in m/s
b2=22//Blade angle n degrees
a1=26//Blade angle n degrees
b4=30//Blade angle n degrees
f=0.9//Friction factor
a2=90//Axial angle in degrees

//Calculations
dVw=1040//Velocity in m/s from Velocity triangles
    Fig. E.7.14
V1=575//Velocity in m/s from Velocity triangles Fig.
     E.7.14
V4=75//Velocity of steam exiting stage in m/s from
    Velocity triangles Fig. E.7.14
WD=(dVw*Vb)/1000//Diagram work in kJ/kg
nd=((WD*1000)/((1/2)*V1^2))*100//Diagram efficiency
    in percent

//Output
printf('(a) Absolute velocity of steam leaving the
    stage is %3.0f m/s \n (b) the diagram work is %3
    .0f kJ/kg \n (c) the diagram efficiency is %3.2f
    percent',V4,WD,nd)
```

Scilab code Exa 7.15 Power output and efficiency

```

clc
clear
//Input data
p1=35//Pressure in bar
T1=350+273//Temperature in K
p2=0.07//Pressure in bar
x=1/4//Fraction of drop in isentropic enthalpy
a=20//Nozzle angle in degrees
```

```
nn=88//Nozzle efficiency in percent
y=0.2//Velocity ratio
b2=30//Exit blade angle in degrees
b4=30//Exit blade angle in degrees
f=0.9//Friction coefficienct
in=75//Internal efficiency of the turbine in percent

//Calculations
h1=3106.4//Enthalpy in kJ/kg
s1=6.6643//Entropy in kJ/kg.K
x2s=(s1-0.5582)/7.7198//dryness fraction
h2s=(163.16+x2s*2409.54)//Enthalpy in kJ/kg
dh=(h1-h2s)//Change in enthalpy in kJ/kg
h13s=x*dh//Change in enthalpy in kJ/kg
h13=(nn/100)*h13s//Change in enthalpy in kJ/kg
V1=(44.72*sqrt(h13))//Velocity in m/s
Vb=(y*V1)//Velocity in m/s
b1=atand((V1*sind(a))/((V1*cosd(a))-Vb))//Angle in degrees
Vr1=((V1*sind(a))/sind(b1))//Velocity in m/s
Vr2=(f*Vr1)//Velocity in m/s
dVw1=(Vr1*cosd(b1))+(Vr2*cosd(b2))//Velocity in m/s
V2=sqrt((Vr2*sind(b2))^2+((Vr2*cosd(b2))-Vb)^2)//Velocity in m/s
V3=f*V2//Velocity in m/s
b3=atand((V3*sind(b2))/((V3*cosd(b2))-Vb))//Angle in degrees
Vr3=((V3*sind(b2))/sind(b3))//Velocity in m/s
Vr4=f*Vr3//Velocity in m/s
dVw2=(Vr3*cosd(b3))+(Vr4*cosd(b4))//Velocity in m/s
dVw=(dVw1+dVw2)//Velocity in m/s
nb1=((2*dVw*Vb)/V1^2)*100//Efficiency in percent
ns=(nn*nb1)/100//Efficiency in percent
ht=(in/100)*dh//Total change in enthalpy in kJ/kg
hc=(ns/100)*h13s//Total change in enthalpy in kJ/kg
pp=(hc/ht)*100//Percentage of enthalpy

//Output
```

```
printf('Efficiency of first stage is %3.2f percent \
   n Percentage of the total power developed by the
   turbine is %3.2f percent',ns,pp)
```

Scilab code Exa 7.16 Power developed

```

clc
clear
//Input data
R=50//Percentage of reaction
b1=35//Angle in degrees
q=b1//Angle in degrees
b2=20//Angle in degrees
a=b2//Angle in degrees
N=1500//Speed in rpm
d=0.67//Mean diameter in m
p=1.5//Pressure in bar
x=0.96//Dryness fraction
w=3.6//Flow rate in kg/s

//Calculations
Vb=(3.14*d*N)/60//Velocity in m/s
V1=(Vb*(sind(180-b1)/sind(b1-b2)))//Veocity in m/s
Vr1=(Vb*(sind(b2)/sind(b1-b2)))//Velocity in m/s
dVw=(V1*cosd(a))+(Vr1*cosd(q))//Velocity in m/s
v1=(0.001052+x*1.15937)//Specific volume in m^3/kg
hb=((w*v1)/(3.14*d*V1*sind(a)))*1000//Required
   height in mm
P=(w*dVw*Vb)/1000//Power developed in kW

//Output
printf('(a) the required height of blading is %3.1f
   mm \n (b) the power developed by the ring is %3.3
   f kW',hb,P)
```

Scilab code Exa 7.17 Power developed

```

clc
clear
//Input data
N=400//Speed in rpm
P=5//Power in MW
m=6//Flow rate in kg/kWh
b2=20//Blade angle in degrees
a=b2//Angle in degrees
x=1.35//Velocity ratio
p=1.2//Pressure in bar
x1=0.95//Steam quality
Dh=12//Ratio of Dm and hb

//Calculations
w=(m*P*1000)/3600//Mass flow rate in kg/s
v1=(0.0010468+x1*1.454)//Specific volume in m^3/kg
hb=((w*v1)/(Dh*3.14*x*((Dh*N)/60)*3.14*sind(a)))^(1/3)*1000//Blade height in mm
Vb=((3.14*Dh*(hb/1000)*N)/60)//velocity in m/s
V1=(x*Vb)//Velocity in m/s
dVw=((2*V1*cosd(a))-Vb)//velocity in m/s
WD=(w*dVw*Vb*10^-3)//Diagram power in kW

//Output
printf('(a)Blade height is %3.0f mm \n (b) the diagram power is %3.2f kW',hb,WD)
```

Scilab code Exa 7.18 Diagram power

```

clc
clear
//Input data
N=3000//Speed in rpm
Vb=100//Mean blade speed in m/s
x=0.56//Velocity ratio
a=20//Blade angle in degrees
b2=a//Blade angle in degrees
v=0.65//Specific volume in m^3/kg
h=25//Mean height in mm
n=5//Number of pairs of blades

//Calculations
V1=(Vb/x)//Velocity in m/s
Vr2=V1//Velocity in m/s
Dm=(Vb*60)/(3.14*N)//Diameter in m
w=((3.14*Dm*h*V1*sind(a))/v)/1000//Mass flow rate in kg/s
ws=(w*3600)//Mass flow rate in kg/hr
b1=atand((V1*sind(a))/((V1*cosd(a))-Vb))//Blade angle in degrees
Vr1=((V1*sind(a))/sind(b1))//Velocity in m/s
dhmb=(1/2)*(Vr2^2-Vr1^2)/1000//Change in enthalpy in kJ/kg
dsta=(2*dhmb)//Change in enthalpy of stage in kJ/kg
dsta5=(n*dsta)//Total Change in enthalpy of stage in kJ/kg
Dp=(w*dsta5)//Diagram power in kW

//Output
printf('Mass flow rate of steam is %3.3f kg/s \n Useful enthalpy drop is %3.2f kJ/kg \n The diagram power is %3.1f kW',w,dsta5,Dp)
```

Scilab code Exa 7.19 Number of impulse stages

```

clc
clear
//Input data
P=8//Power in MW
N=5000//Speed in rpm
p=40//pressure in bar
T=500//Temperature in degree C
p2=0.1//Pressure in bar
in=0.85//Internal efficiency of turbine
nm=0.96//Mechanical efficiency
nn=0.92//Nozzle efficiency
a=15//Nozzle angle in degrees
Vb=300//Blade velocity in m/s

//Calculations
V1=(2*Vb)/cosd(a)//Velocity in m/s
dh=((V1/44.72)^2/nn)//Change in enthalpy in kJ/kg
h1=3445.3//Enthalpy in kJ/kg
s1=7.0901//Entropy in kJ/kg.K
s2=s1//Entropy in kJ/kg.K
x2=(s2-0.6493)/7.5009//Dryness fraction
h2s=(191.83+x2*2392.8)//Enthalpy in kJ/kg
h12s=(h1-h2s)//Change in enthalpy in kJ/kg
n=(h12s/dh)//Number of stages
w=((P*1000)/(in*nm))/h12s//Mass flow rate in kg/s
h13=(nn*dh)//Change in enthalpy in kJ/kg
h3=h1-h13//Enthalpy in kJ/kg
v3=0.17//Specific volume in m^3/kg
A=(w*v3)/V1//Area in m^2
hm=(A/(((Vb*60)/N)*sind(a)))*1000//Height in mm

//Output
printf('(a) the number of impulse stages are%3.0f \n
    (b) the nozzle height is %3.1f mm',n,hm)
```

Scilab code Exa 7.20 Height of blades

```

clc
clear
//Input data
p=1.5//Pressure in bar
x1=0.9//Dryness fraction
m=7//Steam flow rate in kg/s
N=3000//Turbine speed in rpm
x=0.7//Velocity ratio
y=0.75//Velocity ratio
a=20//Exit angle in degrees
b2=a//Angle in degrees
hx=1/10//Fraction of height

//Calculations
v=0.001052+x1*1.15937//Specific volume in m^3/kg
Dm=((m*v*60)/(3.14*hx*y*3.14*N))^(1/3)//Diameter in
    m
hb=Dm*1000*hx//Height in mm
Vb=(3.14*Dm*N)/60//Velocity in m/s
dVw=((2*x*Vb*cosd(a)/sind(a))-Vb)//Velocity in m/s
P=(m*dVw*Vb)/1000//Power developed in kW

//Output
printf('Height of the moving blades at exit is %3.1f
    mm \n Power developed in the blade row is %3.2f
    kW',hb,P)
```

Scilab code Exa 7.21 Mean diamter of wheel

```

clc
clear
//Input data
p=40//Pressure in bar
T=500//Temperature in degree C
p1=0.1//Pressure in bar
a=16//Nozzle angle in degrees
N=3000//Speed in rpm

//Calculations
h1=3445.3//Enthalpy in kJ/kg
s1=7.0901//Entropy in kJ/kg.K
s2=s1//Entropy in kJ/kg.K
x2s=(s2-0.6493)/7.5009//Dryness fraction
h2s=(191.83+x2s*2392.8)//Enthalpy in kJ/kg
V1=44.72*sqrt(h1-h2s)//Velocity in m/s
Vb=V1*(cosd(a)/2)//Velocity in m/s
Dm=(Vb*60)/(3.14*N)//Diameter in m
V2=44.72*sqrt((h1-h2s)/2)//Velocity in m/s
Vb2=V2*cosd(a)//Velocity in m/s
Dm2=(Vb2*60)/(3.14*N)//Diameter in m
V3=44.72*sqrt((h1-h2s)/4)//Velocity in m/s
Vb3=V3*(cosd(a)/2)//Velocity in m/s
Dm3=(Vb3*60)/(3.14*N)//Diameter in m
V4=44.72*sqrt(h1-h2s)//Velocity in m/s
Vb4=V4*(cosd(a)/4)//Velocity in m/s
Dm4=(Vb4*60)/(3.14*N)//Diameter in m
V5=44.72*sqrt((h1-h2s)/(2*4))//Velocity in m/s
Vb5=V5*cosd(a)//Velocity in m/s
Dm5=(Vb5*60)/(3.14*N)//Diameter in m

//Output
printf('The mean diameter of the wheel if the turbine were of \n (a) single impulse stage is %3.2f m \n (b) single 50 percent reaction stage is %3.1f m \n (c) four pressure (or Rateau) stages is %3.2f m \n (d) one two-row Curtis stage is %3
```

```
.3f m \n (e) four stage 50 percent reaction stages is %3.2f m',Dm,Dm2,Dm3,Dm4,Dm5)
```

Scilab code Exa 7.22 Number of stages

```

clc
clear
//Input data
p=150//Pressure in bar
T=600//Temperature in degree C
Vb=300//Velocity in m/s
nn=95//Nozzle efficiency in percent
a=15//Nozzle angle in degrees
a1=25//Angle in degrees

//Calculations
h1=3582.3//Enthalpy in kJ/Kg
s1=6.6776//Entropy in kJ/kg.K
s2=s1//Entropy in kJ/kg.K
x2s=(s2-0.6493)/7.5009//Dryness fraction
h2s=(191.83+x2s*2392.8)//Enthalpy in kJ/kg
h12s=(h1-h2s)//Difference in enthalpy in kJ/kg
V1=(Vb*2)/cosd(a)//Velocity in m/s
dhs=(V1/44.72)^2/(nn/100)//Change in enthalpy in kJ/kg
n1=ceil(h12s/dhs)//Number of stages
V2=(Vb/cosd(a1))//Velocity in m/s
dhs2=(V2/44.72)^2/(nn/(2*100))//Change in enthalpy in kJ/kg
n2=h12s/dhs2//Number of stages
V3=(Vb*4)/cosd(a)//Velocity in m/s
dhs3=(V3/44.72)^2/(nn/100)//Change in enthalpy in kJ/kg
dhhs3=(h12s-dhs3)//Change in enthalpy in kJ/kg
```

```
n3=dhhs3/dhs//Number of stages
n4=dhhs3/dhs2//Number of stages

//Output
printf('Number of stages required in \n (a) all
   simple impulse stages are %3.0f \n (b) all 50
   percent reaction stages are %3.0f \n (c) a 2-row
   Cutris stage follwed by simple impulse stages are
    %3.0f \n (d) a 2-row Cutris stage followed by 50
    percent reaction stages are %3.0f',n1,n2,n3,n4)
```

Scilab code Exa 7.23 Interstage pressures

```

clc
clear
//Input data
p1=20//Pressure in bar
T=400//Temperature in degree C
p2=0.1//Pressure in bar
n=4//Number of stages
ns=75//Stage efficiency in percent

//Calculations
h16s=(3250-2282)//Change in enthalpy in kJ/kg
h12s=(h16s/n)//Change in enthalpy in kJ/kg
p=[8,2.6,0.6]//pressures in bar from Mollier chart
h12=(ns/100)*h12s//Change in enthalpy in kJ/kg
h23s=(3060-2800)//Change in enthalpy in kJ/kg
h23=(ns/100)*h23s//Change in enthalpy in kJ/kg
h34s=(2870-2605)//Change in enthalpy in kJ/kg
h34=(ns/100)*h34s//Change in enthalpy in kJ/kg
h45s=(2680-2410)//Change in enthalpy in kJ/kg
h45=(ns/100)*h45s//Change in enthalpy in kJ/kg
h5=2470//Enthalpy in kJ/kg
```

```
rf=(h12s+h23s+h34s+h45s)/h16s//Reheat factor
nth=((h12+h23+h34+h45)/h16s)*100//Internal
   efficiency in percent
nin=(ns*rf)//Internal efficiency in percent

//Output
printf('The interstage pressures are %i bar, %3.1f
   bar, %3.1f bar \n The reheat factor is %3.3f \n
   The turbine internal efficiency is %3.1f percent'
   ,p(1),p(2),p(3),rf,nin)
```

Scilab code Exa 7.25 Mean blade diameter

```

clc
clear
//Input data
n=20//Number of stages
P=12//Power in MW
p=15//Pressure in bar
T=350//Temperature in degree C
p1=0.14//Pressure in bar
ns=75//Stage efficiency in percent
rf=1.04//Reheat factor
p2=1//Pressure in bar
a=20//Angle in degrees
v=0.7//Velocity ratio
h=1/12//Blade height in terms of mean blade diameter

//Calculations
nint=(ns/100)*rf//Internal efficiency
dhs=855//Enthalpy in kJ/kg
dha=ceil(nint*dhs)//Actual enthalpy change in kJ/kg
w=(P*1000)/dha//Mass flow rate in kg/s
Vb=(sqrt((dha/n)/((((2/v)*cosd(a))-1)*10^-3)))//
```

```
Velocity in m/s//
vg=1.694//Specific volume in m^3/kg
Dm=sqrt((w*vg)/(3.14*h*(Vb/v)*sind(a)))//Diameter in m
N=((Vb*60)/(3.14*Dm))//Speed in rpm

//Output
printf('(a) the flow rate of steam required is %3.2f kg/s \n (b) the mean blade diameter is %3.3f m \n (c) the speed of the rotor is %3.0f rpm',w,Dm,N)
//In textbook, Vb is given wrong as 141.4 m/s instead of 140.6 m/s. Hence the answers are different.
```

Scilab code Exa 7.26 Height of blades

```


clc
clear
//Input data
V1=600//Velocity in m/s
Vb=120//Mean blade velocity in m/s
a=16//Nozzle angle in degrees
b=[18,21,35]//Exit angles in degrees
m=5//Steam flow rate in kg/s
h=25//Nozzle height in mm
v=0.375//Specific volume in m^3/kg
p=25//Pitch in mm
t=0.5//Thickness in mm
kb=0.9//Constant

//Calculations
l=((m*v)/(sind(a)*V1*(h/1000)*kb))//Length of the
```

```
nozzle arc in m //Length of the nozzle arc is calculated wrong as 0.454m instead of 0.5 m
b1= atand((V1*sind(a))/((V1*cosd(a))-Vb))//Angle in degrees
Vr1=((V1*sind(a))/sind(b1))//Velocity in m/s
Vr2=kb*Vr1//Velocity in m/s
V2=sqrt(Vr2^2+Vb^2-2*Vr2*Vb*cosd(b(1)))//Velocity in m/s
V3=291//Velocity in m/s
b3=atand((V3*sind(b(2)))/((V3*cosd(b(2)))-Vb))//Angle in degrees
Vr3=((V3*sind(b(2)))/sind(b3))//Velocity in m/s
Vr4=(Vr3*kb)//Velocity in m/s
hb1=((m*v*(h/1000))/(l*((p/1000)*sind(b(1))-(t/1000))*Vr2))*1000//Height in mm
hn=((m*v*(h/1000))/(l*((p/1000)*sind(b(2))-(t/1000))*V3))*1000//Height in mm
hb2=((m*v*(h/1000))/(l*((h/1000)*sind(b(3))-(t/1000))*Vr4))*1000//Height in mm

//Output
printf('Blade heights at the exit of each row: \n First row of moving blades is %3.1f mm \n Fixed row of guide blades is %3.1f mm \n Second row of moving blades is %3.1f mm',hb1,hn,hb2)
```

Scilab code Exa 7.27 Intercasting steam condition

```

clc
clear
//Input data
P=200//Power in MW
p=180//Pressure in bar
T=550//Temperature in degree C
```

```
P1=600//Power in MW
p1=300//Pressure in bar
T1=580//Temperature in degree C
nt=90//Turbine efficiency in percent

//Calculations
h1=3430//Enthalpy in kJ/kg
h2s=3040//Enthalpy in kJ/kg
h12s=(h1-h2s)//Enthalpy in kJ/kg
h12=(nt/100)*h12s//Enthalpy in kJ/kg
h2=3070//Enthalpy in kJ/kg
v2=0.06//Specific volume in m^3/kg
h4=3560//Enthalpy in kJ/kg
h3s=2000//Enthalpy in kJ/kg
h13s=(h1-h3s)//Enthalpy in kJ/kg
h13=(nt/100)*h13s//Enthalpy in kJ/kg
w=(P*10^3)/h13//Mass flow rate in kg/s
Vbm=350//Velocity in m/s
N=3000//Speed in rpm
a=25//Angle in degrees
Dm=(Vbm*60)/(3.14*N)//Diameter in m
hD=0.3//Assuming (hb/Dm)max
hb=(hD*Dm)//Height in m
Ab=(3.14*Dm*hb*0.9*sind(a))//Flow area in m^2
V1=(Vbm/cosd(a))//Velocity in m/s
Vo=(Ab*V1)//Volume flow rate in m^3/s
v=(Vo/w)//Specific volume in m^3/kg
h5s=2456//Enthalpy in kJ/kg
p5=0.36//Pressure in bar
h45s=(h4-h5s)//Enthalpy in kJ/kg
h45=(nt/100)*h45s//Enthalpy in kJ/kg
h5=h4-h45//Enthalpy in kJ/kg
x5=0.952//Dryness fraction
h56s=(h5-2340)//Enthalpy in kJ/kg
h56=(nt/100)*h56s//Enthalpy in kJ/kg
h6=h5-h56//Enthalpy in kJ/kg
v6=18//Specific volume in m^3/kg
mm=(Vo/v6)//Maximum mass flow that one stage can
```

```
accommodate in kg/s
np=(w/mm)//Number of parallel exhausts
rp=(p1/4)//Reheat pressure in bar
xh1=3410//Enthalpy in kJ/kg
xh2s=3015//Enthalpy in kJ/kg
xh12s=xh1-xh2s//Enthalpy in kJ/kg
xh12=(nt/100)*xh12s//Enthalpy in kJ/kg
xv2=0.035//Specific volume in m^3/kg
xh4=3060//Enthalpy in kJ/kg
xh3s=1960//Enthalpy in kJ/kg
xh13s=xh1-xh3s//Enthalpy in kJ/kg
xh3=(xh1-xh13s)//Enthalpy in kJ/kg
xw=(P1*10^3)/xh13s//Mass flow rate in kg/s
xvm=(Vo/xw)//Maximum specific volume in m^3/kg
Vf=(xw*xv2)//Volume flow rate in m^3/s
xh5s=2300//Enthalpy in kJ/kg
xh45s=xh4-xh5s//Enthalpy in kJ/kg
xh45=(nt/100)*xh45s//Enthalpy in kJ/kg
xh5=xh4-xh45s//Enthalpy in kJ/kg
xv5=1.25//Specific volume in m^3/kg
xx5=0.86//Dryness fraction
xh6s=2050//Enthalpy in kJ/kg
xh56s=xh5-xh6s//Enthalpy in kJ/kg
xh56=(nt/100)*xh56s//Enthalpy in kJ/kg
xh6=(xh5-xh56)//Enthalpy in kJ/kg
xv6=12//Specific volume in m^3/kg
xx6=0.792//Dryness fraction
xmm=(Vo/xv6)//Maximum mass flow in kJ/kg
xnp=ceil(xw/xmm)//Number of parallel exhausts

//Output
printf('Number of parallel exhausts in : \n (a) condition a are %i \n (b)condition b are %i',np,xnp)
```

Scilab code Exa 7.28 Efficiency

```

clc
clear
//Input data
P=100//Power in MW
T=550//temperature in degree C
p=0.1//Pressure in bar
m=500000//Mass flow rate in kg/h at rated load
mo=25000//Mass flow rate in kg/h at zero load
x=[1/4,1/2,3/4,1]//Fraction of load

//Calculations
b=(m-mo)/(P*10^3)//Steam rate in kg/kWh
y1=(x(1)*(P*10^3))//For one-fourth load
s1=(mo/y1)+b//Steam rate in kg/kWh
y2=(x(2)*(P*10^3))//For one-fourth load
s2=(mo/y2)+b//Steam rate in kg/kWh
y3=(x(3)*(P*10^3))//For one-fourth load
s3=(mo/y3)+b//Steam rate in kg/kWh
y4=(x(4)*(P*10^3))//For one-fourth load
s4=(mo/y4)+b//Steam rate in kg/kWh
h1=3511//Enthalpy in kJ/kg
xs1=6.8142//Entropy in kJ/kg.K
xs2=xs1//Entropy in kJ/kg.K
x2s=(xs2-0.6493)/7.5009//Dryness fraction
h2s=191.83+x2s*2392.8//Enthalpy in kJ/kg
nR=((h1-h2s)/(h1-191.83))*100//Rankine efficiency in percent
nac=((P*10^3*3600)/(m*(h1-191.83)))*100//Actual efficiency in percent
nTG=((P*10^3*3600)/(m*(h1-h2s)))*100//Turbogenerator efficiency in percent

//Output
printf('(a) Steam rate at: \n One-fourth load is %3.2f kg/kWh \n Half load is %3.2f kg/kWh \n Three-
```

```
fourth load is %3.2f kg/kWh \n Full load is %3.1f
 kg/kWh \n\n (b) Rankine cycle efficiency is %3.1
f percent \n (c) Actual efficiency at full load
is %3.1f percent \n (d) The turbogenerator
efficiency at full load is %3.1f percent',s1,s2,
s3,s4,nR,nac,nTG)
```

Chapter 8

Condenser Feedwater and Circulating water systems

Scilab code Exa 8.1 Rate of flow

```

clc
clear
//Input data
ws=250;//The amount of steam received by the surface
    condenser in t/h
tsat=40;//The saturated temperature in degree
   centigrade
m=12;//The amount of moisture present in the steam
   in percentage
tc1=32;//The inlet temperature of cooling water in
   degree centigrade
tc2=38;//The outlet temperature of cooling water in
   degree centigrade
p=0.078;//The pressure inside the condenser in bar
V=1.8;//velocity of circulating water in m/s
do=0.0254;//The outer diameter of the condenser
   tubes in m
T=0.00125;//The thickness of the condenser tubes in
```

```
m
pi=3.141;//Mathematical constant of pi
U=2.6;//The overall heat transfer coefficient in kW/m^2K
Cpc=4.187;//The specific heat of water in kJ/kgK
R=0.287;//Real gas constant in kJ/kgK
P=1000;//The density of water in kg/m^3

//Calculations
x2=0.88;//The quality of the steam
hfg=2407;//The enthalpy of evaporation at 40 degreeC in kJ/kg
h=x2*hfg;//The change in enthalpy in kJ/kg
di=do-(2*T);//The inner diameter of the condenser tubes in m
wc=[[(ws*1000)/3600]*h]/(Cpc*(tc2-tc1));//Mass flow rate of water in kg/s
psat=0.07375;//The saturated pressure at 40 degree centigrade in bar
pair=(p-psat)*100;//The pressure of air in kPa
vf=0.001008;//Specific volume of saturated liquid in m^3/kg
vfg=19.544;//Specific volume of vapour in m^3/kg
v2=vf+(x2*vfg);//Specific volume at 40 degree centigrade in m^3/kg
wair=[pair*[(ws*1000)/3600]*v2]/(R*(tsat+273));//Mass flow rate of air in kg/s
t1m=(8-2)/log(8/2);//The mean temperature in degree centigrade
Ao=[[(ws*1000)/3600]*h]/(U*t1m);//The area of the tubes in m^2
n=(wc*(4/pi)*(1/di^2)*(1/(P*V)));//The number of tubes
l=Ao/(pi*do*n);//Yhe length of tubes in m

//Output
printf('(a) The rate of flow of cooling water = %3.1f kg/s \n (b) The rate of air leakage into the
```

```
    condenser shell = %3.3f kg/s \n (c) The length of
     tubes = %3.2f m \n (d) The number of tubes = %3
    .0f ',wc,wair,l,n)
```

Scilab code Exa 8.2 Rate of flow

```

clc
clear
//Input data
ws=20;//The amount of dry saturated steam received
    by a surface condencer in t/h
tsh=40;//The temperature of dry saturated steam in
    degree centigrade
wa=(0.35/1000);//The mass flow rate of air per 1000
    kg of steam in kg
tc=38;//The temperature at which condensate leaves
    the temperature in degree centigrade
tm=10;//The temperature at which makeup water is
    supplied in degree centigrade
tc1=32;//The inlet temperature of cooling water in
    degree centigrade
tc2=38;//The outlet temperature of cooling water in
    degree centigrade
tas=27;//The temperature of air along with steam in
    degree centigrade
psat=0.07384;//The saturated pressure at 40 degree C
     in bar
vg=19.52;//The specific volume at 40 degree C in m
    ^3/kg
R=0.287;//Real gas constant in kJ/kgK
Cpc=4.187;//The specific heat of water in kJ/kgK
Cp=1.005;//The specific heat of air in kJ/kgK

//Calculations
```

```
pair=[(wa*R*(tsh+273)*1000)/vg]*10^-5;//The pressure of air in bar
psat1=0.06624;//The saturated pressure at 38 degree C in bar
vg1=21.63;//The specific volume at 38 degree C in m^3/kg
pair1=psat-psat1;//The pressure of air in bar
wa1=(ws*1000)*wa;//Mass of air removed per hour in kg/h
V1=((wa1*R*(273+tc2)*1000))/(pair1*10^5);//Volume of air remove per hour
ws1=V1/vg1;//The mass of steam accompanying air in kg/h
psat2=0.03564;//The saturated pressure at 27 degree C in bar
vg2=38.81;//The specific volume at 27 degree C in m^3/kg
pair2=psat-psat2;//The pressure of air in bar
V2=(wa1*R*1000*(tas+273))/(pair2*10^5);//Volume of air removed per hr in m^3/hr
ws2=V2/vg2;//The mass of steam accompanying air in kg/h
ws3=ws1-ws2;//Saving mass of steam by using seperate extraction in kg/hr
Q3=[ws3*Cpc*(tc-tm)]/3600;//Saving in heat supply in the boiler in kW
V=[(V1-V2)/V1]*100;//Percentage reduction in air ejector load in %
hc=159.3;//Enthalpy at 38 degree C in kJ/kg
hs1=2574.3;//Enthalpy at 40 degree C in kJ/kg
hs2=2550.3;//Enthalpy at 27 degree C in kJ/kg
Q2=[[(ws*1000)*(hs1-hc)]-[(wa1*(Cp*(tsh-tas)))]-(ws3*hs2)]/3600;//The amount of heat in kW
wc=Q2/(Cpc*(tc2-tc1));//The mass flow rate of water in kg/s

//Output
printf('(a) The rate of saving of condensate and the
```

```
    rate of saving in the heat supply in the boiler
    due to seperate air extraction pump = %3.3f kW \n
    (b) The percentage reduction in air ejector load
    due to this seperate air extraction method = %3
    .1f percent \n (c) The rate of cooling water flow
    = %3.0f kg/s ',Q3,V,wc)
```

Scilab code Exa 8.3 Temperature of water

```

clc
clear
//Input data
tw3=30;//The inlet temperature of water in degree
    centigrade
wc=1.15;//Mass flow rate of cooling water in kg per
    kg air
tdb1=20;//The dry bulb temperature of air in degree
    centigrade
R1=60;//Relative humidity of air while entering in
    percentage
tdb2=28;//The dry bulb temperature while leaving in
    degree centigrade
R2=90;//Relative humidity of air while leaving in
    percentage
tm=20;//The temperature of makeup water in degree
    centigrade
Cpc=4.187;//The specific heat of water in kJ/kgK
G=1;//Mass flow rate of dry air in kg/s

//Calculations
twb1=15.2;// from psychrometric chart The wet bulb
    temperature while entering in degree centigrade
twb2=26.7;// from psychrometric chart The wet bulb
    temperature while leaving in degree centigrade
```

```
h1=43;//The enthalpy from chart for dry air in kJ/kg dry air
h2=83.5;//The enthalpy from chart in kJ/kg dry air
W1=0.0088;//Humidity in kg water vapour/kg dry air
W2=0.0213;//Humidity in kg water vapour/kg dry air
hw3=125.8;//Enthalpy of water entering the tower in kJ/kg
hw=84;//Enthalpy of makeup water in kJ/kg
hwc=[(G/wc)*[(h2-h1)-(W2-W1)*hw]];//The change in enthalpy of water in kJ/kg
tw4=tw3-(hwc/Cpc);//The exit temperature of water in degree centigrade
ta=tw4-twb1;//The approach temperature in degree centigrade
tr=tw3-tw4;//The range temperature in degree centigrade
x=G*(W2-W1);//Fraction of water evaporated in kg/kg dry air

//Output
printf(' (a) The temperature of water leaving the tower = %3.1f degree centigrade \n (b) The fraction of water evaporated = %3.4f kg/kg dry air \n (c) The approach of the cooling tower = %3.1f degree centigrade \n  The Range of the cooling tower = %3.1f degree centigrade ',tw4,x,ta,tr)
```

Scilab code Exa 8.4 Temperature of water

```

clc
clear
//Input data
tw3=45;//The temperature of warm water in degree
```

```
centigrade
wc1=6;//The cooling water inflow in kg/s
V=10;//volume flow of ID fan in m^3/s
Ws=4.90;//Heat absorbed by air in kW
ti=20;//The temperature of air entering the tower in degree centigrade
R=60;//The relative humidity in percentage
to=26;//The temperature of air leaving the tower in degree centigrade
p=1.013;//The constant pressure throughout the tower in bar
r=0.287;//Real gas constant in kJ/kgK
Cpc=4.187;//The specific heat of water in kJ/kgK
Cp=1.005;//The specific heat of air in kJ/kgK

//Calculations
ps=0.0234;//The pressure at 20 degreec in bar
ps1=(R/100)*ps;//The pressure of water vapour in bar
pa1=p-ps1;//The pressure of air in bar
G1=(pa1)/(r*10^-3*(ti+273));//The mass flow rate of dry air in kg/s
w1=(ps1*10^5*V)/(0.4619*10^3*(ti+273));//Mass flow rate of vopour in kg/s
W1=w1/G1;//Moisture flow in kg vap/kg dry air
ps2=0.0336;//The pressure at 26 degree C at exit in bar
pw2=0.0336;//The pressure of water vapour at 26 degree C at exit in bar
W2=(0.622)*(pw2/(1-pw2));//oisture flow in kg vap/kg dry air
G2=G1;//The mass flow rate of dry air in kg/s
w2=W2*G2;//Moisture flow at exit in kg/s
wm=w2-w1;//Makeup water required in kg/s
wc2=wc1-wm;//The cooling water outflow in kg/s
hw3=Cpc*tw3;//The enthalpy of warm water in kJ/kg
hg=2538.1;//The enthalpy of gas at 20 degree C in kJ/kg
tsat=12;//The saturation temperature in degree
```

```
centigrade
pw1=0.01404;//The pressure at 12 degree C in bar
hw1=hg+(1.88*(ti-tsat));//The enthalpy of warm water in kJ/kg
hw2=2548.4;//The enthalpy of evaporation at 26 degree C in kJ/kg
hw4=[[G1*[(Cp*(to-ti))+W2*hw2-W1*hw1]-Ws]-(wc1*hw3)]/-wc2;//The enthapy of warm water at point 4 in kJ/kg
E=hw4/Cpc;//Exit water temperature in degree centigrade

//Output
printf('(a) The final temperature of the water = %3.2f degree centigrade \n (b)The amount of makeup water required per second = %3.4f kg/s ',E,wm)
```

Chapter 9

Nuclear Power Plants

Scilab code Exa 9.1 Mass defect and binding energy

```

clc
clear
//Input data
mp=1.007277;//Atomic Mass of proton in amu
mn=1.008665;//Atomic Mass of neutron in amu
me=0.00055;//Atomic Mass of electron in amu
mo=15.99491;//Atomic Mass of oxygen in amu
np=8;//Number of protons in oxygen
ne=8;//Number of electrons in oxygen
nn=8;//Number of neutrons in oxygen
a=931;//One amu in MeV
No=16;//Number of nucleons in oxygen

//Calculations
m=(np*mp)+(ne*me)+(nn*mn)-mo;//The mass defect in
   amu
B=m*a;//Binding energy in MeV
Bn=B/No;//Binding energy per nucleon

//Output
```

```
printf('The mass defect = %3.5f amu \n The binding energy per nucleon = %3.2f MeV ',m,Bn)
```

Scilab code Exa 9.2 Decay constant

```

clc
clear
//Input data
amr=226.095;//Atomic mass of radium in amu
AC=6.023*10^23;//Avogadro constant in molecules/g.mol
h=1620;//Half life of radium in years

//Calculations
D=(0.6931/(h*365*24*3600));//The decay constant in 1/s
Na=AC/amr;//Number of atoms per gram of radium
Ao=D*Na;//Initial activity in dis/s

//Output
disp(D,"The decay constant (in s^-1) = ");
disp(Ao,"The initial activity of 1 g of radium 226 in dis/s) = ");
```

Scilab code Exa 9.3 Fuel consumption

```

clc
clear
//Input data
F=190;//Each fission of U-235 yeilds in MeV
```

```
a=85;//Assuming the Neutrons absorbed by U-235 cause fission in percentage
b=15;//Non fission capture to produce an isotope U-236 in percentage
Q=3000;//The amount of thermal power produced in MW

//Calculations
E=F*1.60*10^-13;//Each fission yields a useful energy in J
N=1/E;//Number of fissions required
B=[(10^6)*(N*86400)]/(a/100);//One day operation of a reactor the number of U-235 nuclei burned is in absorptions per day
M=(B*235)/(6.023*10^23);//Mass of U-235 consumed to produce one MW power in g/day
M1=M*3;//Mass of U-235 consumed to produce 3000 MW power in g/day

//Output
printf('The fuel consumed of U-235 per day = %3.1f g/day ',M1)
```

Scilab code Exa 9.4 Area required

```

clc
clear
//Input data
sa1=10;//Cross section of nucleus in barns
N=2200;//Neutrons in m/s
En1=0.1;//Kinetic energy of neutrons increases in eV
En2=0.02525;//Kinetic energy of neutron in eV

//Calculations
sa2=sa1/[(En1/En2)^0.5];//The cross section of
```

```
neutrons in barns

//Output
printf('The cross section of neutrons = %3.2f barns ',sa2)
```

Scilab code Exa 9.5 Microscopic absorption

```

clc
clear
//Input data
U1=99.285;//Uranium consists of U-238 in percentage
U2=0.715;//Uranium consists of U-235 in Percentage
E=0.025;//The energy of neutrons in eV
sc=2.72;//Capture cross section for U-238 in barns
sf=0;//fission cross section for U-238 in barns
sc1=101;//Capture cross section for U-235 in barns
sf1=579;//fission cross section for U-235 in barns

//Calculations
sa=(U1/100)*(sc+sf)+(U2/100)*(sc1+sf1);//The microscopic absorption cross section of natural uranium in barns

//Output
printf("The microscopic absorption cross section of natural uranium = %3.1f barns ',sa)
```

Scilab code Exa 9.6 Microscopic absorption

```

clc
```

```
clear
//Input data
p=1;//The density of water in g/cm^3
sch=0.332;//The microscopic capture cross section of hydrogen in barn
sco=0.0002;//The microscopic capture cross section of oxygen in barn

//Calculations
N=(6.023*10^23)*p/18;//Number of molecules of water per cm^3
scw=(2*N*sch*10^-24)+(N*sco*10^-24);//The microscopic capture cross section of water in cm^-1

//output
printf('The microscopic capture cross section of water = %3.4f cm^-1 ',scw)
```

Scilab code Exa 9.7 Thermal neutron flux

```

clc
clear
//Input data
m=230;//The amount of boron piece in g
mw=10;//The molecular weight of boron
R=9.57*10^13;//Reaction rate in cm^-3s^-1
d=2.3;//Density of boron in g/cm^3
sa=755;//Absorbption cross section in barns
ss=4;//Elastic scattering cross section in barns

//Calculations
st=sa+ss;//The total cross section in barns
N=(d*6.023*10^23)/mw;//The number density of
```

```
neutrons in cm^-3
S=N*st*10^-24;//Number density of neutrons for total in cm^-1
F=R/S;//Neutron flux in cm^-2s^-1
L=1/S;//Average distance a neutron travels before it is absorbed in cm

//Output
disp(F,"The thermal neutron flux (in cm^-2s^-1) = ");
disp(L,"The average distance that a neutron travels before it is absorbed (in cm) = ");
```

Scilab code Exa 9.8 Number of collisions

```

clc
clear
//Input data
Eni=4.8;//The energy of the newly born electron in MeV
Enf=0.025;//The energy of the electron after slow down in eV
A=12;//The mass number of the graphite (carbon)

//Calculations
L=1-[[(A-1)^2/(2*A)]*log((A+1)/(A-1))];//The logarithmic energy decrement
n=(log(Eni*10^6/Enf))/L;//The number of collisions required to slowdown the neutron

//Output
printf('The logarithmic energy decrement representing the neutron energy loss per elastic collision = %3.3f \n The number of collisions
```

```
necessary = %3.0f ',L,n)
```

Scilab code Exa 9.9 Rating of reactor

```

clc
clear
//Input data
f=100;//The reactor is fuelled of natural uranium in
    tonnes
A=238.05;//The atomic mass of natural uranium
F=10^13;//The average thermal neutron flux in
   neutrons/cm^2s
A1=235.04;//The atomic mass of U-235
sf=579;//The fission cross section of U-235 in barns
sc=101;//The capture cross section of U-235 in barns
E=200;//The energy released per fission in MeV
P=0.715;//U-235 in natural uranium in percentage
N=2200;//The average thermal neutron in m/s

//Calculations
n=[(f*1000)*6.023*10^26*(P/100)]/A;//The number of U
   -235 atoms in the reactor in atoms
R=(sf*10^-24)*F*n;//The rate of fission in the
   reactor in fissions/s
T=R*E*1.602*10^-19;//Thermal power of the reactor in
    MW
Rr=T/f;//Rating the reactor MW/tonne
Rc=[[(R*A1*60*60*24)]/(6.023*10^26)];//The rate of
   consumption of U-235 by fission in kg/day
Rcc=Rc*1000;//The rate of consumption of U-235 by
   fission in g/day

//Output
printf('(a) The rating of the reactor = %3.2f MW/
```

```
tonne \n (b)The rate of consumption of U-235 per day = %3.3f kg/day (or) %3.0f g/day ',Rr,Rc,Rcc)
```

Scilab code Exa 9.10 Specific energy release rate

```

clc
clear
//Input data
f=3.5;//Mass fraction of U-235 in the fuel in percentage
G=180;//Energy per fission in Mev
F=10^13;//The neutron flux in neutrons/cm^2s
sf=577;//Fission cross section of U-235 in barns
M=1.602*10^-13;//One MeV in J

//Calculations
N=2.372*(f/100)*10^22;//The fuel density for a uranium oxide fuel in nuclei/cm^3
q=G*N*sf*10^-24*F;//The rate of energy release in MeV/cm^3s
qg=q*M;//The rate of energy release in W/cm^3

//Output
printf('The specific energy release rate for a light water uranium reactor = %3.2f W/cm^3',qg)
```

Scilab code Exa 9.11 Reactor power level

```

clc
clear
//Input data
```

```
P=1;//The operating power of a reactor in W
K=1.0015;//The effective multiplication factor of Reactor becomes suppercritical
t=0.0001;//The average neutron life in s
t1=1.0001;//Neutron life time in s

//Calculations
d=(K-1)/K;//The reactivity
Z=(d*P)/t;//The number of neutrons
n=exp(Z)/10^6;//Neutron density * 10^6

//Output
printf('The reactor power level at the end of 1s is %3.3f MW',n)
```

Chapter 10

Hydroelecric power plant

Scilab code Exa 10.1 Efficiency of the runner

```

clc
clear
//Input data
P=4000//Power in kW
N=400//Speed in r.p.m
h=200//Head in m
e=90//Efficiency in percent
d=1.5//Diameter in m
vd=10//Percentage decrease in velocity
a=165//Angle with which jet is deflected in degrees

//Calculations
V1=sqrt(2*9.81*h*(e/100))//Velocity in m/s
Vb=(3.14*d*N)/60//Velocity in m/s
nn=((2*(1-((e/100)*cosd(a)))*(V1-Vb)*Vb)/V1^2)*100//
    Efficiency in percent
p=(P/(nn/100))//Power developed in kW
pj=(p/2)//Power developed per jet in kW
dx=sqrt((pj*8)/(3.14*V1^3))//Diameter of each jet in
    m
```

```

//Output
printf('(a) the efficiency of the runner is %3.2f percent \n (b) the diameter of each jet is %3.4f m',nn,dx)
```

Scilab code Exa 10.2 Number of jets

```

clc
clear
//Input data
P=6000//Power in kW
h=300//Net head availabe in m
N=550//Speed in r.p.m
rd=(1/10)//Ratio of jet diameter to wheel diameter
nh=0.85//Hydraulic efficiency
Cv=0.98//Coefficient of velocity
f=0.46//Speed ratio
d=1000//Density in kg/m^3

//Calculations
V1=Cv*sqrt(2*9.81*h)//Velocity in m/s
Vb=f*sqrt(2*9.81*h)//Velocity in m/s
Q=((P*10^3)/(nh*d*9.81*h))//Discharge in m^3/s
D=((Vb*60)/(3.14*N))//Diameter in m
d=(D/10)//Diameter of jet in m
n=(Q/((V1*(3.14/4)*d^2)))//Number of jets

//Output
printf('(a) the number of jets are%3.0f \n (b) diameter of each jet is %3.3f m \n (c) diameter of the wheel is %3.2f m \n (d) the quantity of water required is %3.1f m^3/s',n,d,D,Q)
```

Scilab code Exa 10.3 Diameter of jet

```

clc
clear
//Input data
P=10//Capacity in MW
h=500//Head in m
Ns=10//Specific speed of the turbine
on=80//Overall efficiency in percent
Cv=0.98//Coefficient of velocity
x=0.46//Speed of the bucket wheel to the velocity of
    jet
da=1000//Density in kg/m^3

//Calculations
N=(Ns*h^(5/4))/sqrt(P*10^3)//Speed in r.p.m
V=(Cv*sqrt(2*9.81*h))//Velocity in m/s
Vb=(x*V)//Speed of bucket wheel in m/s
D=((60*Vb)/(3.14*N))//Diameter in m
d=sqrt((P*10^6)/((on/100)*(3.14/4)*da*V*9.81*h))//
   Diameter in m

//Output
printf('Diameter of jet is %3.3f m \n Diameter of
   bucket wheel is %3.2f m',d,D)
```

Scilab code Exa 10.4 Specific speed

```

clc
clear
```

```
//Input data
Cv=0.97//Coefficient of velocity
f=0.45//Friction coefficient
h=0.85//Head in m
d=1000//Density in kg/m^3
n=1//For a single jet turbine

//Calculations
Ns=((60/3.14)*(f*sqrt(2*9.8))*sqrt(n*(3.14/4)*Cv*
    sqrt(2*9.8)*9.8*h))//Specific speed in terms of d
    /D

//Output
printf('The specific speed of a single jet Pelton
    wheel is about %3.0f (d/D) where d and D
    represent the jet and bucket wheel diameters
    respectively',Ns)
```

Scilab code Exa 10.5 Velocity of jet

```

clc
clear
//Input data
n=4//Number of jets
d=60//Diameter of each jet in mm
a=165//Angle in degrees
v=45//Speed of the bucket wheel in m/s
de=1000//Density in kg/m^3

//Calculations
v1=(2*v)//Jet velocity in m/s
Q=(3.14/4)*(d/1000)^2*v1//Discharge in m^3/s
P=(1-cosd(a))*(v1^2/4)*Q*de*10^-3//Power developed
    in kW
```

```
P4=(P*4)//For four jets in kW
nd=((1-cosd(a))/2)*100//Maximum efficiency in
    percent

//Output
printf('Velocity of the jet for maximum efficiency
    is %3.0f m/s \n Power developed is %i kW \n
    Hydraulic efficiency is %3.1f percent',v1,P4,nd)
```

Scilab code Exa 10.6 Head on the wheel

```

clc
clear
//Input data
v=20//Peripheral velocity in m/s
vw=17//Velocity of whirl in m/s
vr=2//Radial velocity in m/s
Q=0.7//Flow in m^3/s
hn=80//Hydraulic efficiency in percent
d=1000//Density in kg/m^3

//Calculations
H=((vw*v)/(9.81*(hn/100)))//Head on the wheel in m
P=(d*Q*9.81*H*(hn/100)*10^-3)//Power generated in kW
al=180-atand(vr/vw)//Angle of guide vanes in degrees
bl=atand(vr/(v-vw))//Inlet blade angle in degrees

//Output
printf('Head on the wheel is %3.1f m \n The power
    generated by the turbine is %3.0f kW \n Eit angle
     of guide vanes is %3.2f degrees and Inlet blade
    angle is %3.1f degrees',H,P,al,bl)
```

Scilab code Exa 10.7 Outlet and inlet blade angles

```

clc
clear
//Input data
od=1.5//Outer diameter in m
id=0.75//Inner diameter in m
h=150//Head in m
P=14000//Power in kW
Ns=120//Specific speed
vw2=0//Velocity in m/s
a=(11+(20/60))//Angle in degrees
hn=92//Hydraulic efficiency in percent

//Calculations
N=(Ns*h^(5/4))/sqrt(P)//Speed in rpm
vb1=(3.14*od*N)/60//velocity in m/s
vw1=(((hn/100)*9.81*h)/vb1)//velocity in m/s
vf1=(tand(a)*vw1)//Velocity in m/s
vf2=vf1//Velocity in m/s
b1=atand(vf1/(vb1-vw1))//Angle in degrees
b1x=(b1-int(b1))*60//For output
vb2=(vb1/2)//Velocity in m/s
b2=atand(vf1/(vb2-vw2))//Angle in degrees
b2x=(b2-int(b2))*60//For output

//Output
printf('Inlet blade angle is %3.0f degrees %3.0f
   minutes \n Outlet blade angle is %3.0f degrees %3
   .0f minute',b1,b1x,b2,b2x)
```

Scilab code Exa 10.8 The guide vane angle

```

clc
clear
//Input data
h=70//net head in m
N=700//speed in rpm
o=85//over all efficiency in %
P=350//shaft power in kW
he=92//hydraulic efficiency in %
fr=.22//flow ratio
b=.1//breadth ratio
s=2//outer diameter in terms of inner diametre
//Calculations
vf1=fr*sqrt(2*9.81*h)//velocity in m/s
q=(P/(9.81*h*(o/100)))//discharge in m^3/s
d1=sqrt(q/(.94*b*vf1*3.14))//diameter in metre
b1=d1*b//breadth in metre
d2=d1/2//diametre in metre
vb1=(3.14*d1*N)/60//velocity in m/s
vw1=((he/100)*9.81*h)/vb1//velcity in m/s
a=atand(vf1/vw1)//angle in degrees
bet=atand(vf1/(vw1-vb1))//angle in degrees
vb2=(d2/d1)*vb1//velocity in m/s
bet2=atand(vf1/vb2)//angle in degrees

//Output
printf('(a)the guide vane angle is %3.1f degrees \n
   (b)the runner vane angle at inlet is %3.1f
   degrees and outlet is %3.2f degrees \n (c)the
   diametres of the runner at inlet is %3.1f metre
   and outlet is %3.2f metre\n (d)the width of the
   wheel at inlet is %3.2f metre',a,bet,bet2,d1,d2,
   b1)
```

Scilab code Exa 10.9 Discharge of turbine

```

clc
clear
//Input data
n=4//Number of units
P=70000//Power in kVA
f=50//Frequency in Hz
p=10//No.of pair of poles
h=505//Gross head in m
tn=94//Transmission efficiency in percent
po=260//Power in MW
e=91//Efficiency in percent
nn=0.98//Nozzle efficiency
Cv=0.98//Coefficient of velocity
x=0.48//Vb=0.48 V
dd=25//Nozzle diameter is 25% bigger than jet
   diameter
a=165//Angle of buckets in degrees
de=99.75//Discharge efficiency in percent

//Calculations
N=(120*f)/(p*2)//Synchronous speed in r.p.m
nh=((tn/100)*h)//Net head in m
pt=(po*10^3)/n//Power developed per turbine in kW
ip=(pt/(e/100))//Input water power in kW
Q=(ip/(9.81*nh))//Discharge in m^3/s
Qj=(Q/n)//Discharge per jet in m^3/s
V1=Cv*sqrt(2*9.81*nh)//Velocity in m/s
d=sqrt((4/3.14)*(Qj/V1))//Diameter of jet in m
nd=(1+(dd/100))*d//Nozzle tip diameter in m
Vb=(x*V1)//Velocity in m/s
D=((Vb*60)/(3.14*N))//Pitch circle diameter of the
```

```
    wheel in m
Ns=((N*sqrt(po*10^3))/nh^(5/4))//Specific speed
jr=(D/d)//Jet ratio
nob=(jr/2)+15//Number of buckets
nobb=ceil(nob)//Rounding off to next integer
W=((V1-Vb)*(1-(nn*cosd(a)))*Vb)/9.81//Workdone per
    kg in kg.m/kg
nth=((W/nh)*de)//Hydraulic efficiency in percent

//Output
printf('(a) the discharge of the turbine is %3.2f m
    ^3/s \n (b) the jet diameter is %3.3f m \n (c)
    the nozzle tip diameter is %3.3f m \n (d) the
    pitch circle diameter of the wheel is %3.2f m \n
    (e) the specific speed is %3.2f \n (f) the number
     of buckets on the wheel are %3.0f \n (g) the
    workdone per kg of water on the wheel is %3.2f kg
    .m/kg \n (h) the hydraulic efficiency is %3.0f
    percent',Q,d,nd,D,Ns,nobb,W,nth)
```

Scilab code Exa 10.10 Blade angles

```

clc
clear
//Input data
gh=35//Gross head in m
md=2//Mean diameter in m
N=145//Speed in rpm
a=30//Angle in degrees
oa=28//Outlet angle in degrees
x=7//Percentage of gross head lost
y=8//Reduction in relative velocity in percent

//Calculations
```

```
H=((100-x)/100)*gh//Net haed in m
V1=sqrt(2*9.81*H)//Velocity in m/s
Vb=(3.14*md*N)/60//Velocity in m/s
b1=atand((V1*sind(a))/((V1*cosd(a))-Vb))//Angle in degrees
Vr1=((V1*sind(a))/sind(b1))//Velocity in m/s
Vr2=((100-y)/100)*Vr1//Velocity in m/s
Vw1=(V1*cosd(a))//Velocity in m/s
Vw2=(Vb-(Vr2*cosd(oa)))//Velocity in m/s
E=((Vb*(Vw1-Vw2))/9.81)//Workdone in kg.m/kg
nb=(E/gh)*100//Hydraulic efficiency in percent

//Output
printf('Blade angle at inlet is %3.0f degrees \n Hydraulic efficiency is %3.0f percent',b1,nb)
```

Scilab code Exa 10.11 Speed and diameter

```

clc
clear
//Input data
P=10000//Power in kW
h=12//Head in m
Nr=2//Speed ratio
Fr=0.65//Flow ratio
x=0.3//Diameter of hub is 0.3 times the eternal diameter of the vane
on=94//Overall efficiency in percent

//Calculations
Q=(P/(9.81*h*(on/100)))//Discharge in m^3/s
Vr1=(Fr*sqrt(2*9.81*h))//Velocity in m/s
Ab=(Q/Vr1)//Area of flow in m^2
D=sqrt(((Ab*4)/3.14)/(1-x^2))//Diameter of runner in
```

```
m
Vb=(Nr*sqrt(2*9.81*h))//Velocity in m/s
N=((Vb*60)/(3.14*D))//Speed in rpm
f=50//Taking frequency as 50 Hz
p=(120*50)/N//Number of poles
N1=(120*f)/int(p)//Speed in rpm
Ns=(N1*sqrt(P))/h^(5/4)//Specific speed

//Output
printf('(a) the speed is %3.1f rpm \n (b) the diameter of the runner is %3.2f m \n (c) the specific speed is %3.0f',N1,D,Ns)
```

Scilab code Exa 10.12 Specific speed

```

clc
clear
//Input data
P=10000//Power in kW
h=25//Head in m. In textbook it is given wrong as 2 m
N=135//Speed in rpm
h1=20//Head in m

//Calculations
Ns=((N*sqrt(P))/h^(5/4))//Specific speed
N1=sqrt(h1/h)*N//Speed in rpm
P2=P/(h/h1)^(3/2)//Power in kW

//Output
printf('Specific speed is %3.1f \n Normal speed is %3.1f rpm \n Output under a head of %i m is %3.0f kW',Ns,N1,h1,P2)
```

Scilab code Exa 10.13 Number of turbines

```

clc
clear
//Input data
Q=175//Discharge in m^3/s
h=18//Head in meter
N=150//Speed in rpm
oe=82//Overall efficiency in percent
Ns1=460//Maximum specific speed
Ns2=350//Maximum specific speed
d=1000//Density in kg/m^3

//Calculations
P=(d*Q*9.81*h*(oe/100)*10^-3)//power in kW
P1=((Ns1*h^(5/4))/N)^2//Power in kW
n1=P/P1//No.of turbains
P2=((Ns2*h^(5/4))/N)^2//Power in kW
n2=ceil(P/P2)//No.of turbains

//Output
printf('The number of turbines in \n (a) Francis
    turbine are%3.0f \n (b) Kaplan turbine are %i',n1
    ,n2)
```

Scilab code Exa 10.14 Speed power and scale ratio

```

clc
clear
//Input data
```

```
Ns=210//Specific speed
P=30//Power in MW
N=180//Speed in rpm
Q=0.6//Discharge in m^3/s
h=4.5//Head in m
e=88//Efficiency in percent
d=1000//Density in kg/m^3

//Calculations
Pm=(d*Q*9.81*h*(e/100)*10^-3)//Power in kW
Nm=(Ns*h^(5/4))/sqrt(Pm)//Speed in rpm
Hp=((N*sqrt(P*1000))/Ns)^(4/5)//Head in m
Dpm=(Nm/N)*sqrt(Hp/h)//Scale ratio
Qp=(P*10^6)/(d*9.81*Hp*(e/100))//Discharge in m^3/s

//Output
printf('Speed is %3.0f rpm \n Power is %3.3f kW \n Scale ratio is %3.3f \n Flow through the turbine is %3.1f m^3/s',Nm,Pm,Dpm,Qp)
```

Scilab code Exa 10.15 Speed and power

```

clc
clear
//Input data
x=1/5//Scale model
h=1.5//Head in m
P=5//Power in kW
N=450//Speed in rpm
h1=30//Head in m

//Calculations
N1=(x*N)/sqrt(h/h1)//Speed in rpm
Ns=(N*sqrt(P))/h^(5/4)//Specific speed
```

```
P1=((Ns*h1^(5/4))/N1)^2//Power in kW

//Output
printf('Speed is %3.0f rpm \n Power is %3.0f kW',N1,
   P1)
```

Scilab code Exa 10.16 Efficiency

```

clc
clear
//Input data
h=19//Head in m
Q=3//Flow rate in m^3/s
N=600//Speed in rpm
h1=5//Head in m

//Calculations
N1=N/sqrt(h/h1)//Speed in rpm
Q1=Q/sqrt(h/h1)//Discharge in m^3/s

//Output
printf('Speed of the turbine is %3.1f rpm \n Maximum
    flow rate is %3.1f m^3/s',N1,Q1)
```

Scilab code Exa 10.17 Least number of turbines

```

clc
clear
//Input data
Q=350//Discharge in m^3/s
h=30//Head in m
```

```
e=87//Turbine efficiency in percent
f=50//Frequency in Hz
p=24//Number of poles
Ns1=300//Specific speed
Ns2=820//Specific speed
d=1000//Dnsity of water in kg/m^3

//Calculations
N=(120*f)/p//Speed in rpm
P=d*Q*9.81*h*(e/100)*10^-3//Power in kW
P1=((Ns1*h^(5/4))/N)^2//Power in kW
n1=P/P1//No.of turbines
P2=((Ns2*h^(5/4))/N)^2//Power in kW
n2=ceil(P/P2)//No.of turbines

//Output
printf('Least number of machines required if using \
   n (a) Francis turbines are %3.0f \n (b) Kaplan
   turbines are %3.0f',n1,n2)
```

Scilab code Exa 10.18 Power developed

```

clc
clear
//Input data
h=27//Head in m
A=430//Area in sq.km
R=150//Rainfall in cm/year
pr=65//Percentage of rainfall utilised
pe=95//Penstock efficiency in percent
te=80//Turbine efficiency in percent
ge=86//Generator efficiency in percent
lf=0.45//Load factor
d=1000//Density of water in kg/m^3
```

```

//Calculations
Q=A*10^6*(R/100)*(pr/100)//Discharge in m^3 per year
Qs=(Q/(365*24*3600))//Quantity of water per second
   in m^3
P=(pe/100)*(te/100)*(ge/100)*d*Qs*9.81*h*10^-3//
   Power in kW
plc=(P/lf)//Peak load capacity in kW
C=(plc/(2*(ge/100)))//Capacity of each unit in kW

//Output
printf('(a) Power developed is %3.0f kW \n (b) As
   the available head is low, Kaplan turbines are
   suggested.\n Two turbines each of 3000kW capacity
    may be installed.',P)
```

Scilab code Exa 10.19 Power developed

```

clc
clear
//Input data
q=[30,25,20,0,010,50,80,100,110,65,45,30]//Mean
   discharge in millions of cu.m per month
   respectively
h=90//Head in m
n=86//Overall efficiency in percent

//Calculations
Qm=(q(1)+q(2)+q(3)+q(4)+q(5)+q(6)+q(7)+q(8)+q(9)+q
   (10)+q(11)+q(12))/12//Mean discharge in millions
   m^3/s
Q
   =[30,30,25,25,20,20,0,0,10,10,50,50,80,80,100,100,110,110,65,65,45
   //Discharge(million m^3/month) on y-axis
```

```
y=[0,1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,12,12]//Months on x-ais
D=[110,100,90,80,70,60,50,40,30,25,20,10,0]//Discharge per month in million m^3
pt=[8.3,16.7,25,25,25,33.3,41.7,50,66.7,75,83.3,91.7,100]//Percentage time
Po=((Qm*10^6*9.81*h*(n/100))/(30*24*3600*1000))//Power developed in MW

//Output
subplot(121)
plot(y,Q)//Graph Discharge(million m^3/month) vs Month
xtitle('Discharge(million m^3/month) vs Month','Months','Discharge(million m^3/month)')
subplot(122)
plot(pt,D)//Graph percentage time vs Discharge(million m^3/month)
xtitle('percentage time vs Discharge(million m^3/month)','percentage time','Discharge(million m^3/month)')
printf('Power developed is %3.2f MW',Po)
```

Chapter 11

Diesel engine and Gas Turbine Power Plants

Scilab code Exa 11.1 Net increase in brake power

```

clc
clear
//Input data
C=3.5//Capacity in litres
P=13.1//Indicated power in kW/m^3
N=3600//Speed in rpm
ve=82//Volumetric efficiency in percent
p1=1.013//Pressure in bar
T1=25+273//Temperature in K
rp=1.75//Pressure ratio
ie=70//Isentropic efficiency in percent
me=80//Mechanical efficiency in percent
g=1.4//Ratio of specific heats
R=0.287//Gas constant in kJ/kg.K
Cp=1.005//Specific heat in kJ/kg.K

//Calculations
EC=(C/1000)//Engine capacity in m^3
```

```
Vs=(N/2)*EC//Swept volume in m^3
Vui=(ve/100)*Vs//Unsupercharged induced volume in m^3/min
dp=(rp*p1)//Blower delivery pressure in bar
T2sT1=(rp)^((g-1)/g)//Ratio of temperatures
T2s=(T2sT1*T1)//Temperature in K
dT21=(T2s-T1)/(ie/100)//Difference in temperature in K
T2=dT21+T1//Temperature in K
EV=(Vs*dp*T1)/(p1*T2)//Equivalent volume in m^3/min
iiv=EV-Vui//Increase in induced volume in m^3/min
iip=(P*iiv)//Increase in indicated power in kW
iipi=((dp-p1)*100*Vs)/60//Increase in induced power due to increase in induction pressure in kW
tiip=iip+iipi//Total increase in indicated power in kW
tibp=tiip*(me/100)//Total increase in brake power in kW
ma=(dp*100*Vs)/(60*R*T2)//Mass of air in kg/s
WI=(ma*Cp*(T2-T1))//Work input to heater in kW
Pb=(WI/(me/100))//Power required in kW
NI=tibp-Pb//Net increase in brake power in kW

//Output
printf('Net increase in brake power is %3.2f kW',NI)
```

Scilab code Exa 11.2 Temperature of air

```

clc
clear
//Input data
p1=0.97//Pressure in bar
t1=30+273//Temperature in K
p2=2.1//Pressure in bar
```

```
af=18//Air fuel ratio
t3=580+273//Temperature in K
p3=1.9//Pressure in bar
p4=1.06//Pressure in bar
iec=0.75//Isentropic efficiency of compressor
iet=0.85//Isentropic efficiency of turbine
cpa=1.01//Specific heat for air in kJ/kg.K
ga=1.4//Ratio of specific heats
cpex=1.15//Specific heat in kJ/kg.K
gex=1.33//Ratio of specific heats

//Calculations
t2s=t1*(p2/p1)^((ga-1)/ga)//Tempeature in K
t21=(t2s-t1)/iec//Temperature in K
t2=t21+t1//Temperature in K
T2=t2-273//Temperature in degree C
t3t4s=(p3/p4)^((gex-1)/gex)//Ratio of temperatures
t4s=(t3/t3t4s)//Temperature in K
t4=t3-((t3-t4s)*iet)//Temperature in K
T4=t4-273//Temperature in degree C
mp=(((cpex*(1+(1/af))*(t3-t4))-(cpa*(t2-t1)))/(cpex*(1+(1/af))*(t3-t4)))*100//Percentage of mechanical power loss

//Output
printf('(a) the temperature of air leaving the compressor is %3.2f degree C \n (b) the temperature of gases leaving the turbine is %3.2f degree C \n (c) the mechanical power loss in the turbocharger as a percentage of the power generated in the turbine is %3.2f percent',T2,T4,mp)
```

Scilab code Exa 11.3 Energy balance sheet

```

clc
clear
//Input data
a=215//Current in A
v=210//Voltage in V
e=85//Efficiency in percent
q=11.8//Quantity of fuel supplied in kg/h
cv=43//Calorific value in MJ/kg
af=18//Air fuel ratio
w=560//Water in litres/h
tw=38//Temeparature in degree C
te=97//Temeparature in degree C
cp=1.04//Specific heat in kJ/kg.K
ta=30//Temeparature in degree C
l=32//Percentage lost
sw=4.187//Specific heat in kJ/kg.K

//Calculations
P=(a*v)/1000//Power in kW
BP=(P/(e/100))//Brake power in kW
E=(q/3600)*cv*1000//Energy supplied in kW
mg=(q/3600)*(1+af)//Rate of gases in kg/s
he=(mg*cp*(te-ta))+((w/3600)*sw*tw)//Heat carried away by exhaust gases in kW
hj=(l/100)*E//Heat lost to jacket cooling water in kW
pBP=(BP/E)*100//Percentage
pE=(E/E)*100//Percentage
phe=(he/E)*100//Percenatge
phj=(hj/E)*100//Percenatge

//Output
printf('                              ENERGY BALANCE SHEET \n                                                   (in kW)              (in percent)\n 1. Brake power                        %3.2f
```

```
%3.2f \n 2. Heat carried away by exhaust gases        %3.2f                 %3.2f \n 3. Heat lost to jacket cooling water         %3.2f              %3.2f \n 4. Heat loss unaccounted             %3.2f                %3.2f \n            Total                                  %3.2f              %3.2f',BP,pBP,he,phe,hj,phj,(E-(BP+he+hj)),(((E-(BP+he+hj))/E)*100),E,(pBP+phe+phj+(((E-(BP+he+hj))/E)*100)))
```

Scilab code Exa 11.4 Energy balance sheet

```

clc
clear
//Input data
t=20//Trial time in minutes
NL=680//Net brake load in N
mep=3//Mean effective pressure in bar
N=360//Speed in rpm
Fc=1.56//Fuel consumption in kg
cw=160//Cooling water in kg
Tw=32//Temperature of water at inlet in degree C
Wo=57//Water outlet temperature in degree C
a=30//Air in kg
Ta=27//Room temperature in degree C
Te=310//Exhaust gas temperature in degree C
d=210//Bore in mm
l=290//Stroke in mm
bd=1//Brake diameter in m
cv=44//Calorific value in MJ/kg
st=1.3//Steam formed in kg per kg fuel in the exhaust
cp=2.093//Specific heat of steam in exhaust in kJ/kg.K
```

```
cpx=1.01//Specific heat of dry exhaust gases in kJ/
   kg.K
cpw=4.187//Specific heat of water in kJ/kg.K

//Calculations
ip=(mep*100*(l/1000)*(3.14/4)*(d/1000)^2*N)/60//
   Indicated Power in kW
bp=((2*3.14*N*(NL*(1/2)))/60)/1000//Brake power in
   kW
nm=(bp/ip)*100//Mechanical efficiency in percent
qs=(Fc*cv*10^3)//Heat supplied in kJ
qip=(ip*t*60)//Heat equivalent of ip in kJ
qcw=(cw*cpw*(Wo-Tw))//Heat carried away by cooling
   water in kJ
tm=(Fc*a)//Toatl mass of exhaust gas in kg
ms=(st*Fc)//Mass of steam formed in kg
mde=(tm-ms)//Mass of dry exhaust gas in kg
Ed=(mde*cpx*(Te-Ta))//Energy carried away by dry
   exhaust gases in kJ
Es=(ms*((cpw*(100-Ta))+2257.9+(cp*(Te-100))))//
   Energy carried away by steam in kJ
TE=(Ed+Es)//Total energy carried away by exhaust
   gases in kJ
ue=(qs-(qip+qcw+TE))//Unaccounted energy in kJ
pqip=(qip/qs)*100//Percentage
pqcw=(qcw/qs)*100//Percentage
pTE=(TE/qs)*100//Percentage
pue=(ue/qs)*100//Percentage

//Output
printf('Indicated power is %3.2f kW \n Brake power
   is %3.3f kW \n\n
   ENERGY BALANCE SHEET \n
                                                    (
   in kJ)                (in percent)\n 1. Energy
   equivalent in ip                         %3.0f
                      %3.2f \n 2. Energy carried away
   by cooling water         %3.0f                     %3
```

```
.2f \n 3. Energy carried away by exhaust gases
      %3.0f                    %3.2f \n 4.
Unaccounted for energy loss                  %3.0f
          %3.2f \n               Total
                     %3.0f
          %3.2f',ip,bp,qip,pqip,qcw,pqcw,TE
,pTE,ue,pue,qs,(pqip+pqcw+pTE+pue))
```

Scilab code Exa 11.5 Blade angles

```

clc
clear
//Input data
Vbm=360//Blade velocity in m/s
b1=20//Blade angle at inlet in degrees
a2=b1//Angle in degrees
b2=52//Blade angle at exit in degrees
a1=b2//Angle in degrees
R=50//Degree of reaction in percent
dm=0.45//Mean diameter of the blade in m
bh=0.08//Mean blade height in m

//Calculations
Vf=(Vbm/(tand(b2)-tand(b1)))//Velocity in m/s
rt=(dm/2)+(bh/2)//Mean radius in m
Vbt=(Vbm*(rt/(dm/2)))//Velocity in m/s
Vw1m=Vf*tand(a1)//Velocity in m/s
Vw1t=(Vw1m*((dm/2)/rt))//Velocity in m/s
dVw1=(Vf*(tand(b1)+tand(b2))*Vbm)/Vbt//Velocity in m/s
rr=(dm/2)-(bh/2)//Radius in m
Vbr=(Vbm*(rr/(dm/2)))//Velocity in m/s
Vw1r=(Vw1m*((dm/2)/rr))//Velocity in m/s
Vr2=Vf/cosd(b2)//Velocity in m/s
```

```
dVwr=((Vw1m+((Vr2*sind(b2))-Vbm))*Vbm)/Vbr//Velocity in m/s
a1r=atand(Vw1r/Vf)//Angle in degrees
a2r=atand((dVwr-Vw1r)/Vf)//Angle in degrees
b1r=atand((Vw1r-Vbr)/Vf)//Angle in degrees
b2r=atand((Vbr+(Vf*tand(a2r)))/Vf)//Angle in degrees
a1t=atand(Vw1t/Vf)//Angle in degrees
a2t=atand((dVw1-Vw1t)/Vf)//Angle in degrees
b1t=atand((Vw1t-Vbt)/Vf)//Angle in degrees
b2t=atand((Vbt+(Vf*tand(a2t)))/Vf)//Angle in degrees
Rt=((Vf*(tand(b2t)-tand(b1t)))/(2*Vbt))*100//Degree of reaction at the tip in percent
Rr=((Vf*(tand(b2r)-tand(b1r)))/(2*Vbr))*100//Degree of reaction at the root in percent

//Output
printf('(a)The flow velocity is %3.0f m/s \n (b) The blade angles at the tip are : \n Fixed blades (root) are %3.2f degrees and %3.2f degrees \n Moving blades (root) are %3.2f degrees and %3.2f degrees \n Fixed blades (tip) are %3.2f degrees and %3.2f degrees \n Moving blades (tip) are %3.2f degrees and %3.2f degrees \n (c) The degree of reaction at : \n the tip is %3.0f percent \n the root is %3.0f percent',Vf,a1r,a2r,b1r,b2r,a1t,a2t,b1t,b2t,Rt,Rr)
```

Scilab code Exa 11.6 Impeller tip diameter

```

clc
clear
//Input data
N=16000//Speed in rpm
T1=17+273//Temperature in K
```

```
rp=4//Pressure ratio
in=82//Isentropic efficiency in percent
s=0.85//Slip factor
a=20//Angle in degrees
d=200//Diameter in mm
V=120//Velocity in m/s
cp=1.005//Specific heat in kJ/kg.K
g=1.4//Ratio of specific heats

//Calculations
T2sT1=(rp)^((g-1)/g)//Temperature ratio
T2s=T1*T2sT1//Temeprature in K
dTs=(T2s-T1)//Temperature difference in K
dT=dTs/(in/100)//Temperature difference in K
Wc=(cp*dT)//Power input in kJ/kg
Vb1=(3.14*(d/1000)*N)/60//Velocity in m/s
Vw1=(V*sind(a))//Pre-whirl velocity in m/s
Vb2=sqrt(((Wc*1000)+(Vb1*Vw1))/s)//Velocity in m/s
d2=((Vb2*60)/(3.14*N))*1000//Tip diameter in mm

//Output
printf('Impeller tip diameter is %3.0f mm',d2)
```

Scilab code Exa 11.7 Workdone factor

```

clc
clear
//Input data
T1=25+273//Temperature in K
rp=6//Pressure ratio
Vb=220//Mean velocity in m/s
b1=45//Angle in degrees
a2=b1//Angle in degrees
b2=15//Angle in degrees
```

```
a1=b2//Angle in degrees
R=50//Degree of reaction in percent
n=10//Number of stages
in=83//Isentropic efficiency in percent
cp=1.005//Specific heat in kJ/kg.K
g=1.4//Ratio of specific heats

//Calculations
V1=(Vb/(sind(b2)+(cosd(a1)*tand(a2))))//Velocity in
   m/s
V2=(V1*cosd(b2))/cosd(b1)//Velocity in m/s
dVw=(V2*sind(a2))-(V1*sind(a1))//Velocity in m/s.
    Textbook answer is wrong. Correct answer is 127 m
    /s
T2sT1=rp^((g-1)/g)//Temperature ratio
T2s=(T2sT1*T1)//Temperature in K
dTs=(T2s-T1)//Temperature difference in K
dT=(dTs/(in/100))//Temperature difference in K
W=(cp*dT)//Workdone in kJ/kg
w=(W*10^3)/(Vb*dVw*n)//Work done factor

//Output
printf('Workdone factor of the compressor is %3.2f',
    w)
```

Scilab code Exa 11.8 Airfuel ratio

```

clc
clear
//Input data
p1=1//Pressure in bar
T1=20+273//Temperature in K
Tm=900+273//Maximum temperature in K
rp=6//Pressure ratio
```

```
e=0.7//Effectiveness of regenerator
ma=210//Rate of air flow in kg/s
CV=40800//Calorific value in kJ/kg
ic=0.82//Isentropic efficiencies of both the compressors
it=0.92//Isentropic efficiencies of both the turbine
cn=0.95//Combustion efficiency
mn=0.96//Mechanical efficiency
gn=0.95//Generator efficiency
cp=1.005//Specific heat of air in kJ/kg.K
cpg=1.08//Specific heat of gas in kJ/kg.K
g1=1.4//Ratio of specific heats for air
g=1.33//Ratio of specific heats for gas

//Calculations
pi=sqrt(p1*rp)//Intermediate pressure in bar
T2sT1=(pi/p1)^((g1-1)/g1)//Temperature ratio
T2s=(T2sT1*T1)//temperature in K
T2=((T2s-T1)/ic)+T1//Temperature in K
T4s=(T1*(rp/pi)^((g1-1)/g1))//Temperature in K
T4=((T4s-T1)/ic)+T1//Temperature in K
T7s=(Tm/(rp/p1)^((g-1)/g))//Temperature in K
T7=Tm-(it*(Tm-T7s))//Temperature in K
T5=(e*(T7-T4))+T4//Temperature in K
mf=1/((cp*(Tm-T5))/((CV*cn)-(cp*(Tm-T5))))//Air fuel ratio
Wgt=((1+(1/mf))*cpg*(Tm-T7))//Workdone by turbine in kJ/kg of air
Wc=(cp*((T2-T1)+(T4-T1)))//Workdone by compressor in kJ/kg of air
Wnet=(Wgt-Wc)//Net workdone in kJ/kg of air
Q=(CV*cn)/mf//Heat supplied in kJ/kg of air
ncy=(Wnet/Q)*100//Cycle efficiency in percent
PO=(Wnet*ma*mn*gn)/10^3//Power output in MW
Fc=(ma*3600*(1/mf))//Fuel consumption per hour in kg
SFC=(Fc/(PO*10^3))//Specific fuel consumption in kg/kW.h
```

```
//Output
printf('(a) the air fuel ratio is %3.2f \n (b) the
   cycle efficiency is %3.1f percent \n (c) the
   power supplied by the plant is %3.0f MW \n (d)
   the specific fuel consumption of the plant is %3
   .3f kg/kW.h and the fuel consumption per hour is
   %3.2f kg',mf,ncy,PO,SFC,Fc)
```

Chapter 12

Flywheel Energy storage

Scilab code Exa 12.1 Compressed air temperature

```

clc
clear
//Input data
V=64000//Volume in m^3
Q=8300//Discharge in m^3/hr
p1=1//Pressure in bar
T1=20+273//Temperature in K
p2=100//Pressure in bar
pn=70//Polytropic efficiency in percent
pt=60//Peaking turbine efficiency in percent
g=1.4//Ratio of specific heats
cp=1.005//Specific heat in kJ/kg.K
R=0.287//Gas constant in kJ/kg.K

//Calculations
T2sT1=(p2/p1)^((g-1)/g)//Temperature ratio
T2s=(T1*T2sT1)//Temperature in K
T21=(T2s-T1)/(pn/100)//Difference in Temperatures in
    K
T2=(T21+T1)-273//Temperature in degree C
```

```
v=(R*T1)/(p2*100)//Specific volume in m^3/kg
mf=(Q/(v*3600))//Mass flow rate in kg/s
E=(mf*cp*T21)/1000//Rate of energy storage in MW
t=(V/Q)//Storage time in hour
tE=(E*t)//Total energy storage in MWh
Ed=(tE*(pt/100))//Total energy delivered by the peaking turbine in MWh

//Output
printf('(a) the compressed sir temperature is %3.0f degree C \n (b) the storage time is %3.2f hour \n (c) the total energy storage is %3.0f MWh \n (d) the total energy delivered by the peaking turbine is %3.0f MWh',T2,t,tE,Ed)
```

Scilab code Exa 12.2 Storage time

```

clc
clear
//Input data
V=175000//Volume in m^3
d=4//Diameter in m
U=1.5//Overall heat transfer coefficient in W/m^2.K
p2=2//Pressure in bar
p1=20//Pressure in bar
Ta=20//Ambient temperature in degree C
cp=4.35//Specific heta of water in kJ/kg.K
e=96//Efficiency in percent
ppe=25//Peaking plant efficiency in percent

//Calculations
//At 20 bar
T1=212.37//Saturation temperature in degree C
hf1=908.5//Enthalpy in kJ/kg
```

```
vf1=0.0011766//Specific volume in m^3/kg
//At 2 bar
T2=120.23//Saturation temperature in degree C
hf2=504.8//Enthalpy in kJ/kg
vf2=0.0010605//Specific volume in m^3/kg
ad=(1/2)*((1/vf1)+(1/vf2))//Average density of water in kg/m^3
tc=(d*ad*cp*1000)/(4*U*3600)//Time constant in h
ts=(log(1/(1-((1-((e/100)))/((T1-Ta)/(T1-T2))))))*tc//Storage time in h
m=(V/vf1)//Mass of water needed in kg
E=(m*(hf1-hf2))/(3600*10^3)//Total energy stored in MWh
Ed=(E*(e/100)*(ppe/100))//Energy delivered in MWh

//Output
printf('(a) the storage time is %3.3f h \n (b) the total energy stored in the accumulator is %3.1f MWh \n (c) the total energy that can be delivered by the peaking turbine is %3.2f MWh',ts,E,Ed)
```