

Scilab Textbook Companion for  
Power Plant Engineering  
by P. K. Nag<sup>1</sup>

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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	4
1 Introduction Economics of Power Generation	5
2 Analysis of Steam Cycles	22
3 Combined Cycle Power Generation	35
4 Fuels and combustion	47
5 Combustion Mechanism Combustion equipment and Firing Methods	67
6 Steam generators	73
7 Steam Turbines	85
8 Condenser Feedwater and Circulating water systems	117
9 Nuclear Power Plants	125
10 Hydroelectric power plant	134
11 Diesel engine and Gas Turbine Power Plants	151



# List of Scilab Codes

Exa 1.1	Load factor . . . . .	5
Exa 1.2	Average load . . . . .	6
Exa 1.3	Annual Revenue . . . . .	7
Exa 1.4	Annual energy . . . . .	8
Exa 1.5	Overall cost . . . . .	9
Exa 1.6	Cost of power generation . . . . .	10
Exa 1.7	Economic loading . . . . .	11
Exa 1.8	Cost of power generation . . . . .	12
Exa 1.9	Load factor and capacity factor . . . . .	13
Exa 1.10	Load factor and capacity factor . . . . .	14
Exa 1.11	Overall cost . . . . .	16
Exa 1.12	Amount of money saved . . . . .	17
Exa 1.13	Present worth of the payments . . . . .	18
Exa 1.14	Incremental heat rate . . . . .	18
Exa 1.15	Cost of electrical energy . . . . .	19
Exa 2.1	Power output and efficiency . . . . .	22
Exa 2.2	Mass flow rate . . . . .	23
Exa 2.3	Optimum pressures and temperatures . . . . .	25
Exa 2.4	Percentage of total electricity . . . . .	26
Exa 2.5	Percentage of total heat absorption . . . . .	27
Exa 2.6	Cycle efficiency . . . . .	28
Exa 2.7	Steam condition . . . . .	31
Exa 2.8	Steam generation capacity . . . . .	32
Exa 2.9	Power developed . . . . .	33
Exa 3.1	Efficiency of combined cycle . . . . .	35
Exa 3.2	Rate of heat transfer . . . . .	36
Exa 3.3	Mass flow rate . . . . .	38
Exa 3.4	Power output and efficiency . . . . .	39

Exa 3.5	Overall efficiency . . . . .	42
Exa 3.6	Overall efficiency . . . . .	43
Exa 3.7	Power output and efficiency . . . . .	43
Exa 3.8	Thermal efficiency . . . . .	44
Exa 4.1	Mass flow rate . . . . .	47
Exa 4.2	Percentage of excess air . . . . .	48
Exa 4.3	Air fuel ratio . . . . .	49
Exa 4.4	Power output and efficiency . . . . .	50
Exa 4.5	Total volume of combustion . . . . .	53
Exa 4.6	Flue gas analysis . . . . .	55
Exa 4.7	Air leakage . . . . .	57
Exa 4.8	Height of stack and diameter of base . . . . .	58
Exa 4.9	Motor capacity . . . . .	59
Exa 4.10	Motor capacity . . . . .	60
Exa 4.11	Volumetric composition . . . . .	61
Exa 4.12	Height of gas plume . . . . .	63
Exa 4.13	Thermal efficiency . . . . .	64
Exa 5.1	Total surface area . . . . .	67
Exa 5.2	Voidage of the bed . . . . .	68
Exa 5.3	Sphericity of particles . . . . .	68
Exa 5.4	Flow rate of limestone . . . . .	69
Exa 5.5	Rate of heat removed . . . . .	70
Exa 5.6	Platform area . . . . .	71
Exa 6.1	Pressure head . . . . .	73
Exa 6.2	Amount of water required . . . . .	74
Exa 6.3	Pressure head . . . . .	75
Exa 6.4	Steam generation rate . . . . .	76
Exa 6.5	Blowdown . . . . .	79
Exa 6.6	Number of coils needed . . . . .	80
Exa 6.7	Number of tubes and the length . . . . .	81
Exa 6.8	Number of coils needed . . . . .	83
Exa 7.1	Maximum area . . . . .	85
Exa 7.2	Minimum area . . . . .	86
Exa 7.3	Throat and exit area . . . . .	87
Exa 7.4	Throat and exit area . . . . .	88
Exa 7.5	Throat and exit area . . . . .	89
Exa 7.6	Mass flow rate . . . . .	90
Exa 7.7	Exit area . . . . .	91

Exa 7.8	Exit area . . . . .	93
Exa 7.9	Force Thrust and efficiency . . . . .	94
Exa 7.10	Workdone and efficiency . . . . .	95
Exa 7.11	Power developed . . . . .	96
Exa 7.12	Thrust Power and efficiency . . . . .	97
Exa 7.13	Thrust Power and efficiency . . . . .	98
Exa 7.14	Workdone and efficiency . . . . .	99
Exa 7.15	Power output and efficiency . . . . .	100
Exa 7.16	Power developed . . . . .	102
Exa 7.17	Power developed . . . . .	103
Exa 7.18	Diagram power . . . . .	103
Exa 7.19	Number of impulse stages . . . . .	104
Exa 7.20	Height of blades . . . . .	106
Exa 7.21	Mean diamter of wheel . . . . .	106
Exa 7.22	Number of stages . . . . .	108
Exa 7.23	Interstage pressures . . . . .	109
Exa 7.25	Mean blade diameter . . . . .	110
Exa 7.26	Height of blades . . . . .	111
Exa 7.27	Intercasting steam condition . . . . .	112
Exa 7.28	Efficiency . . . . .	114
Exa 8.1	Rate of flow . . . . .	117
Exa 8.2	Rate of flow . . . . .	119
Exa 8.3	Temperature of water . . . . .	121
Exa 8.4	Temperature of water . . . . .	122
Exa 9.1	Mass defect and binding energy . . . . .	125
Exa 9.2	Decay constant . . . . .	126
Exa 9.3	Fuel consumption . . . . .	126
Exa 9.4	Area required . . . . .	127
Exa 9.5	Microscopic absorption . . . . .	128
Exa 9.6	Microscopic absorption . . . . .	128
Exa 9.7	Thermal neutron flux . . . . .	129
Exa 9.8	Number of collisions . . . . .	130
Exa 9.9	Rating of reactor . . . . .	131
Exa 9.10	Specific energy release rate . . . . .	132
Exa 9.11	Reactor power level . . . . .	132
Exa 10.1	Efficiency of the runner . . . . .	134
Exa 10.2	Number of jets . . . . .	135
Exa 10.3	Diameter of jet . . . . .	136

Exa 10.4	Specific speed . . . . .	136
Exa 10.5	Velocity of jet . . . . .	137
Exa 10.6	Head on the wheel . . . . .	138
Exa 10.7	Outlet and inlet blade angles . . . . .	139
Exa 10.8	The guide vane angle . . . . .	140
Exa 10.9	Discharge of turbine . . . . .	141
Exa 10.10	Blade angles . . . . .	142
Exa 10.11	Speed and diameter . . . . .	143
Exa 10.12	Specific speed . . . . .	144
Exa 10.13	Number of turbines . . . . .	145
Exa 10.14	Speed power and scale ratio . . . . .	145
Exa 10.15	Speed and power . . . . .	146
Exa 10.16	Efficiency . . . . .	147
Exa 10.17	Least number of turbines . . . . .	147
Exa 10.18	Power developed . . . . .	148
Exa 10.19	Power developed . . . . .	149
Exa 11.1	Net increase in brake power . . . . .	151
Exa 11.2	Temperature of air . . . . .	152
Exa 11.3	Energy balance sheet . . . . .	153
Exa 11.4	Energy balance sheet . . . . .	155
Exa 11.5	Blade angles . . . . .	157
Exa 11.6	Impeller tip diameter . . . . .	158
Exa 11.7	Workdone factor . . . . .	159
Exa 11.8	Airfuel ratio . . . . .	160
Exa 12.1	Compressed air temperature . . . . .	163
Exa 12.2	Storage time . . . . .	164

# Chapter 1

## Introduction Economics of Power Generation

Scilab code Exa 1.1 Load factor

```
1
2 clf()
3 clc
4 clear
5 //Input data
6 C=30//Capacity in MW
7 M=70//Loads are taken above 70 MW
8 t1=[0,6]//Time range in hours
9 t2=[6,10]//Time range in hours
10 t3=[10,12]//Time range in hours
11 t4=[12,16]//Time range in hours
12 t5=[16,20]//Time range in hours
13 t6=[20,22]//Time range in hours
14 t7=[22,24]//Time range in hours
15 L=[30,70,90,60,100,80,60]//Load in MW
16
17 //Calculations
18 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
19 AL=(E/24)//Average load in MW
20 PL=max(L(1),L(2),L(3),L(4),L(5),L(6),L(7))//Peak
    load in MW
21 LF=(AL/PL)//Load factor of the plant
22 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
23 T=(t3(2)-t3(1))+(t5(2)-t5(1))+(t6(2)-t6(1))//Time
    during which the standby unit remains in
    operation in h
24 AL1=(E1/T)//Average load in MW
25 LF1=(AL1/C)//Load factor
26 U=(E1/(C*T))//Use factor
27
28 //Output
29 t=[0,0,6,6,10,10,12,12,16,16,20,20,22,22,24,24]//
    Time for plotting load curve in hours
30 l=[0,30,30,70,70,90,90,60,60,100,100,80,80,60,60,0]
    //Load for plotting load curve in MW
31 plot(t,l)//Load curve taking Time in hours on X-axis
    and Load in MW on Y-axis
32 xtitle('Load Curve','Time hours','Load MW');
33
34
35 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

```

1
2 clc
3 clear
4 //Input data
5 P=60//Peak load on power plant in MW
6 L=[30,20,10,14]//Loads having maximum demands in MW
7 C=80//Capacity of the power plant in MW
8 A=0.5//Annual load factor
9 Y=8760//Number of hours in a year of 365 days
10
11 //Calculations
12 AL=(P*A)//Average load in MW
13 E=(AL*1000*Y)/10^6//Energy supplied per year in kWh
    *10^6
14 DF=(P/(L(1)+L(2)+L(3)+L(4)))//Demand factor
15 DIF=((L(1)+L(2)+L(3)+L(4))/P)//Diversity factor
16
17 //Output
18 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

```

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

```

```

11
12 // Calculations
13 AL=(L*P) //Average load in MW
14 E=(AL*Y) //Energy generated per year in MWh
15 CL=(E*1000) //Coal required per year in kg
16 CY=(E*Rs) //Cost of coal per year
17 CE=CL //Cost of energy sold in Rs
18 RY=(CE-CY)/10^7 //Revenue earned by the power plant
    per year in Rs crore
19 CF=(AL/C) //Capacity factor
20
21 //Output
22 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

```

1
2 clc
3 clear
4 //Input data
5 L=0.75 //Load factor
6 C=0.60 //Capacity factor
7 U=0.65 //Use factor
8 M=60 //Maximum power demand in MW
9 Y=8760 //Number of hours in a year of 365 days
10
11 // Calculations
12 A=(L*M) //Average load in MW
13 P=((A*1000)*Y)/10^6 //Annual energy production in kWh
    *10^6
14 PC=(A/C) //Plant capacity in MW
15 R=(PC-M) //Reserve capacity in MW
16 HIO=(P*1000/(U*PC)) //Hours in operation in hrs

```

```

17 NH=(Y-HI0)//Hours not in service in a year in hrs
18
19 //Output
20 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

```

1
2 clc
3 clear
4 //Input data
5 D=500//Maximum demand in MW
6 L=0.7//Load factor
7 //1)Steam power plant 2)Hydroelectric power plant 3)
    Nuclear power plant
8 CC=[3,4,5]//Capital cost per MW installed in Rs.
    crore
9 I=[6,5,5]//Interest in percent
10 D=[6,4,5]//Depreciation in percent
11 OP=[30,5,15]//Operating cost (including fuel) per
    kWh
12 TD=[2,3,2]//Transmission and distribution cost per
    kWh
13 Y=8760//Number of hours in a year of 365 days
14
15 //Calculations
16 //1)Steam power plant
17 CCX=(CC(1)*D*10^7)//Capital cost in Rs
18 IX=((I(1)/100)*CCX)//Interest in Rs
19 DX=((D(1)/100)*CCX)//Depreciation in Rs
20 AFCX=IX+DX//Annual fixed cost in Rs

```

```

21 EX=(L*D*1000*Y)//Energy generated per year in kWh
22 RX=(OP(1)+TD(1))//Running cost/kWh in paise
23 OX=((AFCX/EX)+(RX/100))*100//Overall cost/kWh in
    paise
24
25 //2)Hydroelectric Power plant
26 CCY=(CC(2)*D*10^7)//Capital cost in Rs
27 IY=((I(2)/100)*CCY)//Interest in Rs
28 DY=((D(2)/100)*CCY)//Depreciation in Rs
29 AFCY=IY+DY//Annual fixed cost in Rs
30 EY=(L*D*1000*Y)//Energy generated per year in kWh
31 RY=(OP(2)+TD(2))//Running cost/kWh in paise
32 OY=((AFCY/EY)+(RY/100))*100//Overall cost/kWh in
    paise
33
34 //3)Nuclear power plant
35 CCZ=(CC(3)*D*10^7)//Capital cost in Rs
36 IZ=((I(3)/100)*CCZ)//Interest in Rs
37 DZ=((D(3)/100)*CCZ)//Depreciation in Rs
38 AFCZ=IZ+DZ//Annual fixed cost in Rs
39 EZ=(L*D*1000*Y)//Energy generated per year in kWh
40 RZ=(OP(3)+TD(3))//Running cost/kWh in paise
41 OZ=((AFCZ/EZ)+(RZ/100))*100//Overall cost/kWh in
    paise
42
43 //Output
44 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

```

2  clc
3  clear
4  //Input data
5  C=210//Capacity in MW
6  ID=12//Interest and depreciation in percent
7  CC=18000//Capital cost/kW installed in Rs
8  L=0.6//Annual load factor
9  AC=0.54//Annual capacity factor
10 RC=(200*10^6)//Annual running charges in Rs
11 E=6//Energy consumed by power plant auxiliaries in
    percent
12 Y=8760//Number of hours in a year of 365 days
13
14 //Calculations
15 MD=(C/L)*AC//Maximum demand in MW
16 RSC=(C-MD)//Reserve Capacity in MW
17 AL=(L*MD)//Average load in MW
18 EP=(AL*1000*Y)//Energy produced per year in kWh
19 NE=((100-E)/100)*EP//Net energy delivered in kWh
20 AID=((ID/100)*CC*C*1000)//Annual interest and
    depreciation in Rs
21 T=(AID+RC)//Total annual cost in Rs
22 CP=(T/NE)*100//Cost of power generation in paise
23
24 //Output
25 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

```

1
2  clc
3  clear
4  //Input data

```

```

5 L=200 //The total load supplied by the plants in MW
6 //The incremental fuel costs for generating units a
  and b of power plant are given by
7 //dFa/dPa=0.065Pa+25
8 //dFb/dPb=0.08Pa+20
9
10 // Calculations
11 //Solving two equations
12 //Pa+Pb=200
13 //0.065Pa+25=0.08Pb+20
14 A=[1 1
15     0.065 -0.08] // Coefficient matrix
16 B=[L
17     (20-25)] // Constant matrix
18 X=inv(A)*B // Variable matrix
19 P=100 //If load is shared equally then Pa=Pb=100MW
20 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
21 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
22 x=a+b //Net increase in fuel cost due to departure
  from economic distribution of load in Rs. per
  hour
23
24 //Output
25 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

```

1
2 clc
3 clear
4 //Input data
5 C=200//Installed capacity of the plant in MW
6 CC=400//Capital cost in Rs crores
7 ID=12//Rate of interest and depreciation in percent
8 AC=5//Annual cost of fuel, salaries and taxation in
   Rs. crores
9 L=0.5//Load factor
10 AL2=0.6//Raised Annual load
11 Y=8760//Number of hours in a year of 365 days
12
13 //Calculations
14 AvL=(C*L)//Average Load in MW
15 E=(AvL*1000*Y)//Energy generated per year in kWh
16 IDC=((ID/100)*CC*10^7)//Interest and depreciation (
   fixed cost) in Rs
17 T=(IDC+(AC*10^7))//Total annual cost in Rs
18 CP1=(T/E)*100//Cost per kWh in paise
19 AvL2=(C*AL2)//Average Load in MW
20 E2=(AvL2*1000*Y)//Energy generated per year in kWh
21 CP2=(T/E2)*100//Cost per kWh in paise
22 S=((CP1)-(CP2))//Saving in cost per kWh in paise
23 S1=ceil(S)//Rounding off to next higher integer
24
25 //Output
26 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

```

1
2 clc

```

```

3 clear
4 //Input data
5 C=300//Capacity of power plant in MW
6 MXD=240//Maximum demand in MW in a year
7 MND=180//Minimum demand in MW in a year
8 //Assuming the load duration curve shown in Figure
   E1.9 on page no 30 to be straight line
9 Y=8760//Number of hours in a year of 365 days
10
11 //Calculations
12 E=((MND*Y)+0.5*(MXD-MND)*Y)*1000//Energy supplied
   per year in kWh
13 AL=(E/Y)//Average load in kW
14 L=((AL/1000)/MXD)//Load factor
15 CF=((AL/1000)*Y)/(C*Y)//Capacity factor
16
17 //Output
18 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

```

1
2 clf()
3 clc
4 clear
5 //Input data
6 t1x=[0,6]//Time range in hours
7 t2x=[6,12]//Time range in hours
8 t3=[12,14]//Time range in hours
9 t4=[14,18]//Time range in hours
10 t5=[18,24]//Time range in hours
11 L=[30,90,60,100,50]//Load in MW
12
13 //Calculations

```

```

14 t1=[0,6,6,12,12,14,14,18,18,24,24] //Time in hours
    for Load curve
15 L1=[30,30,90,90,60,60,100,100,50,50,0] //Load in MW
    for Load curve
16 t2=[0,4,4,10,10,12,12,18,18,24,24] //Time in hours
    for Load duration curve
17 L2=[100,100,90,90,60,60,50,50,30,30,24] //Load in MW
    for Load duration curve
18 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
19 AL=E/24 //Average load in MW
20 MD=max(L(1),L(2),L(3),L(4),L(5)) //Maximum demand in
    MW
21 LF=(AL/MD) //Load factor
22 Lx=[30,10] //Loads for selecting suitable generating
    units in MW
23 tx=[24,18,10,4] //Time for selecting suitable
    generating units in hrs
24 PC=(Lx(1)*tx(4)+Lx(2)*1) //Plant capacity in MW
25 CF=(E/(PC*24)) //Capacity factor
26
27 //Output
28 subplot(221)
29 plot(t1,L1) //Load curve taking Time in hrs on X-
    axis and Load in MW on Y- axis
30 xtitle('Load curve','Time hrs','Load MW')
31 subplot(222)
32 plot(t2,L2) //Load duration curve taking Time in hrs
    on X- axis and Load in MW on Y- axis
33 xtitle('Load duration curve','Time hrs','Load MW')
34 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

```
1
2  clc
3  clear
4  //Input data
5  C=10//Capacity of generating unit in MW
6  MD=[6,3.6,0.4]//Maximum demand for domestic
   consumers, industrial consumers and street-
   lighting load respectively in MW
7  L=[0.2,0.5,0.3]//Load factor for domestic consumers,
   industrial consumers and street-lighting load
   respectively
8  CC=10000//Capital cost of the plant per kW in Rs
9  RC=3600000//Total running cost per year in Rs
10 AID=10//Annual interest and depreciation on capital
   cost in percent
11 Y=8760//Number of hours in a year of 365 days
12
13 //Calculations
14 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
15 OC=(RC/E)//Operating charges per kWh in Rs
16 CCP=(C*1000*CC)//capital cost of the plant in Rs
17 FCY=((AID/100)*CCP)//Fixed charges per year in Rs
18 FCkW=(FCY/CC)//Fixed charges per kW in Rs
19 //a) For domestic consumers
20 TC1=((FCkW*MD(1)*1000)+(OC*MD(1)*L(1)*Y*1000))//
   Total chrges in Rs
21 OC1=(TC1/(MD(1)*L(1)*Y*1000))*100//Overall cost per
   kWh in paise
```

```

22 //b)For industrial consumers
23 TC2=((FCkW*MD(2)*1000)+(OC*MD(2))*L(2)*Y*1000)//
    Total chrges in Rs
24 OC2=(TC2/(MD(2)*L(2)*Y*1000))*100//Overall cost per
    kWh in paise
25 //c) For street-lighting load
26 TC3=((FCkW*MD(3)*1000)+(OC*MD(3))*L(3)*Y*1000)//
    Total chrges in Rs
27 OC3=(TC3/(MD(3)*L(3)*Y*1000))*100//Overall cost per
    kWh in paise
28
29 //Output
30 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

```

1
2 clc
3 clear
4 //Input data
5 CC=(80*10^6)//Capital cost in Rs
6 L=30//Useful life in years
7 S=5//Salvage value of the capital cost in percent
8 i=0.06//Yearly rate of compound interest
9
10 //Calculations
11 A=((100-S)/100)*CC//Difference of capital cost and
    salvage value in Rs
12 P=((A*i)/((1+i)^L-1))//The amount of money to be
    saved annually in Rs
13
14 //Output

```

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

---

### Scilab code Exa 1.13 Present worth of the payments

```
1
2 clc
3 clear
4 //Input data
5 i=4000//Initial investment in Rs crore
6 Y=4//Period in years
7 A=1200//Amount added in Rs crore
8 B=400//Amount paid from 5th year onwards to the 12th
    year in Rs crore
9 a=5//5th year
10 b=12//12th year
11 y=30//Period in years
12 C=600//Salvage value in Rs crore
13 I=0.1//Interest rate
14
15 //Calculations
16 X=(1/(1+I))//X value for calculations
17 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
18
19 //Output
20 printf('Present worth of the payments at the time of
    commissioning is Rs. %3.2 f crores ', PW)
```

---

### Scilab code Exa 1.14 Incremental heat rate

```
1
```

```

2  clc
3  clear
4  //Input data
5  O=1000//Combined output of two units in MW
6  //Two coal generating units P and Q have the
   incremental heat rate defined by
7  //(IR)P=0.4818*10-7.LP4 - 0.9089*10-4.LP3 +
   0.6842*10-1.LP2 - 0.2106*10.LP + 9860
8  //(IR)R=0.9592*10-7.LQ4 - 0.7811*10-4.LQ3 +
   0.2625*10-1.LQ2 - 0.2189*10.LQ + 9003
9
10 // Calculations
11 //LP+LQ=1000
12 //By making (IR)P=(IR)Q and solving the above three
   equations by a numerical method such as Newton-
   Raphson algorithm , we get
13 LP=732.5//Heat rate in MW
14 LQ=(O-LP)//Heat rate in MW
15 IR=0.4818*10-7*LP4 - 0.9089*10-4*LP3 +
   0.6842*10-1*LP2 - 0.2106*100*LP + 9860
16 IR1=0.9592*10-7*LQ4 - 0.7811*10-4*LQ3 +
   0.2625*10-1*LQ2 - 0.2189*10*LQ + 9003
17
18 //Output
19 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

```

1
2  clc
3  clear
4  //Input data
5  F=2700//Fixed cost of the thermal station per kW of

```

```

        installed capacity per year in Rs,
6  F0=40//Fuel and operating costs per kWh generated in
    paise
7  L=[100,75,50,25]//Load factors
8  Y=8760//Number of hours in a year of 365 days
9
10 //Calculations
11 FC=(F/Y)*100//Fixed costs per kW per hour in paise
12 E1=(L(1)/100)//Energy produced in 1 hr with 1 kW
    plant in kWh
13 FOC1=(E1*F0)//Fuel and operating cost in paise
14 TC1=(FC+FOC1)//Total cost per hr in paise
15 C1=(TC1/E1)//Cost per kWh in paise
16 E2=(L(2)/100)//Energy produced in 1 hr with 1 kW
    plant in kWh
17 FOC2=(E2*F0)//Fuel and operating cost in paise
18 TC2=(FC+FOC2)//Total cost per hr in paise
19 C2=(TC2/E2)//Cost per kWh in paise
20 E3=(L(3)/100)//Energy produced in 1 hr with 1 kW
    plant in kWh
21 FOC3=(E3*F0)//Fuel and operating cost in paise
22 TC3=(FC+FOC3)//Total cost per hr in paise
23 C3=(TC3/E3)//Cost per kWh in paise
24 E4=(L(4)/100)//Energy produced in 1 hr with 1 kW
    plant in kWh
25 FOC4=(E4*F0)//Fuel and operating cost in paise
26 TC4=(FC+FOC4)//Total cost per hr in paise
27 C4=(TC4/E4)//Cost per kWh in paise
28
29 //Output
30 printf('

```

---

nLoad and hr with hr )	Energy produced Total cost per hr kWh\n(percent) (paise)	Fixed cost Cost per\nfactor operating cost 1kW plant(kWh) (paise)	Fuel in 1 per (paise)\n
------------------------------------	--	---	----------------------------------

---

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

```
1
2 clc
3 clear
4 //Input data
5 p1=40//Initial pressure of steam in bar
6 T1=500//Initial temperature of steam in degree C
7 m1=5500//Rate of steam in kg/h
8 p2=2//Pressure of steam after expansion in bar
9 n1=0.83//Isentropic efficiency
10 q=0.87//Quality
11 m2=2700//Mass flow rate in kg/h
12 p3=0.1//Pressure of steam after expansion in l.p
    turbine in bar
13 n2=0.78//Isentropic efficiency
14
15 //Calculations
16 h1=3445.3//Enthalpy in kJ/kg
17 s1=7.0901//Entropy in kJ/kg.K which is 1.5301+x2s
    *5.5970
18 x2s=(5.5600/5.5970)//dryness fraction
19 h2s=(504.7+(x2s*2201.9))//Enthalpy in kJ/kg
```

```

20 h2=h1-(n1*(h1-h2s))//Enthalpy in kJ/kg
21 h3=(504.7+(q*2201.9))//Enthalpy in kJ/kg
22 h4=((m2*h3+m1*h2)/(m1+m2))//Enthalpy in kJ/kg
23 x4=(2183.78/2201.9)//dryness fraction
24 s4=(1.5301+x4*5.5970)//Entropy in kJ/kg.K
25 x5s=0.8574//dryness fraction
26 h5s=(191.84+x5s*2392.5)//Enthalpy in kJ/kg
27 dh4h5=(n2*(h4-h5s))//Difference in enthalpy (h4-h5)
    in kJ/kg
28 h6=191.83//Enthalpy in kJ/kg
29 W1=((m1*(h1-h2))+((m1+m2)*dh4h5))/3600//Power output
    of the plant in kW
30 Q1=(m1*(h1-h6))/3600//Heat input in kW
31 n1=(W1/Q1)*100//Efficiency in percent
32 WT=(m1*(h1-h2))/3600//Power output without the
    geothermal heat supply in kW
33 Q2=(m1*(h1-h6))/3600//Heat input without the
    geothermal heat supply in kW
34 n2=(WT/Q2)*100//Efficiency of the cycle without the
    geothermal heat supply in percent
35
36 //Output
37 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

```

1
2 clc
3 clear
4 //Input data
5 p1=90//Initial pressure of steam in bar

```

```

6 T1=500//Initial temperature of steam in degree C
7 Q=(500*1000)//Output in kW
8 T2=40//Condensation temperature in degree C
9 nhp=0.92//Efficiency of h.p turbine
10 nlp=0.9//Efficiency of l.p turbine
11 np=0.75//Isentropic efficiency of the pump
12 TTD=-1.6//Temperature in degree C
13
14 //Calculations
15 p2=(0.2*p1)//Optimum reheat pressure in bar
16 h1=3386.1//Enthalpy in kJ/kg
17 s1=6.6576//Entropy in kJ/kg.K
18 s2s=s1//Entropy in kJ/kg.K
19 h2s=2915//Enthalpy in kJ/kg
20 h3=3469.8//Enthalpy in kJ/kg
21 s3=7.4825//Entropy in kJ/kg.K
22 x4s=(s3-0.5725)/7.6845//Dryness fraction
23 h4s=(167.57+x4s*2406.7)//Enthalpy in kJ/kg
24 h5=167.57//Enthalpy in kJ/kg
25 h7=883.42//Enthalpy in kJ/kg
26 Wps=(0.001008*p1*10)//Workdone by the pump in kJ/kg
27 h6s=176.64//Enthalpy in kJ/kg
28 dh1h2=(nhp*(h1-h2s))//Difference in enthalpy (h1-h2)
    in kJ/kg
29 h2=h1-dh1h2//Enthalpy in kJ/kg
30 dh3h4=(nlp*(h3-h4s))//Difference in enthalpy (h3-h4)
    in kJ/kg
31 h4=h3-dh3h4//Enthalpy in kJ/kg
32 Wp=(Wps/np)//Workdone by the pump in kJ/kg
33 h6=(Wp+h5)//Enthalpy in kJ/kg
34 tsat=207.15//Saturation temperature at 18 bar in
    degree C
35 t9=(tsat-TTD)//Temperature in degree C
36 h9=875//Enthalpy in kJ/kg
37 m=((h9-h6)/(h2-h7))//Mass of steam in kg
38 WT=(dh1h2+(1-m)*dh3h4)//Workdone by the turbine in
    kJ/kg
39 Wnet=(WT-Wp)//Net workdone in kJ/kg

```

```

40 ws=(0/Wnet)//Mass flow rate of steam at turbine
    inlet in kg/s
41 Q1=((h1-h9)+(1-m)*(h3-h2))//Heat input in kJ/kg
42 n=(Wnet/Q1)*100//Efficiency of the cycle in percent
43 Wr=(Wnet/WT)//Work ratio
44
45 //Output
46 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

```

1
2 clc
3 clear
4 //Input data
5 p1=70//Pressure at which an ideal seam power plant
    operates in bar
6 T1=550//Temperature at which an ideal seam power
    plant operates in degrees C
7 p2=0.075//Pressure at which an ideal seam power
    plant operates in bar
8
9 //Calculations
10 TB=285.9//Saturation temperature at 70 bar in degree
    C
11 TC=40.3//Saturation temperature at 0.075 bar in
    degree C
12 Tr=(TB-TC)/(7+1)//Temperature rise per heater for
    maximum cycle efficiency in degree C
13 t1=(TB-Tr)//Temperature at heater 1 in degree C
14 P1=4.33//Pressure at heater 1 in MPa
15 t2=(t1-Tr)//Temperature at heater 2 in degree C
16 P2=2.5318//Pressure at heater 2 in MPa

```

```

17 t3=(t2-Tr)//Temperature at heater 3 in degree C
18 P3=1.367//Pressure at heater 3 in MPa
19 t4=(t3-Tr)//Temperature at heater 4 in degree C
20 P4=0.6714//Pressure at heater 4 in MPa
21 t5=(t4-Tr)//Temperature at heater 5 in degree C
22 P5=0.2906//Pressure at heater 5 in MPa
23 t6=(t5-Tr)//Temperature at heater 6 in degree C
24 P6=0.108//Pressure at heater 6 in MPa
25 t7=(t6-Tr)//Temperature at heater 7 in degree C
26 P7=32.65//Pressure at heater 7 in kPa
27
28 //Output
29 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

```

1
2 clc
3 clear
4 //Input data
5 ng=0.97//Efficiency of electric generator
6 nt=0.95//Efficiency of turbine
7 nb=0.92//Efficiency of boiler
8 nc=0.42//Efficiency of cycle
9 no=0.33//Efficiency of overall plant
10

```

```

11 //Calculations
12 na=(no/(ng*nt*nb*nc))//Efficiency of auxiliaries
13 n=(1-na)*100//Percentage of total electricity
    generated which is consumed in running the
    auxiliaries
14
15 //Output
16 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

```

1
2 clc
3 clear
4 //Input data
5 T1=140//Temperature with which feed water enters
    into economiser in degree C
6 T2=[25,250]//Temperature from air is preheated to in
    degree C
7 P1=60//Pressure with which steam leaves the drum in
    bar
8 x1=0.98//Dryness fraction
9 T3=450//Temperature with which steam leaves the
    superheater in degree C
10 cc=25.2//Calorific value of coal in MJ/kg
11 r=8.5//Rate of evaporation of steam per kg coal
12 wf=1//Mass of coal in kg
13 R=15//Air fuel ratio by mass
14 Cpa=1.005//Specific heat of air at constant pressure
    in kJ/kg.K
15 Cpw=4.2//Specific heat of water at constant pressure
    in kJ/kg.K
16

```

```

17 //Calculations
18 h1=(T1*Cpw)//Enthalpy in kJ/kg
19 hf=1213.35//Enthalpy in kJ/kg
20 h2=hf//Enthalpy in kJ/kg
21 hfg=1571//Enthalpy in kJ/kg
22 h4=3301.8//Enthalpy in kJ/kg
23 h3=(hf+x1*hfg)//Enthalpy in kJ/kg
24 n=((r*(h4-h1))/(wf*cc*1000))*100//Efficiency
25 he=(r*(h2-h1))/wf*10^-3//Heat transfer in the
    economiser in MJ/kg
26 hb=(r*(h3-h2))/wf*10^-3//Heat transfer in the boiler
    in MJ/kg
27 hs=(r*(h4-h3))/wf*10^-3//Heat transfer in the
    superheater in MJ/kg
28 ha=(R*Cpa*(T2(2)-T2(1)))/wf*10^-3//Heat transfer in
    the air preheater in MJ/kg
29 pe=((h2-h1)/(h4-h1))*100//Percentage of total heat
    absorbed in the economiser in percent
30 pb=((h3-h2)/(h4-h1))*100//Percentage of total heat
    absorbed in the boiler in percent
31 ps=((h4-h3)/(h4-h1))*100//Percentage of total heat
    absorbed in the superheater in percent
32
33 //Output
34 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

```

1
2 clc
3 clear
4 //Input data
5 p1=150//Pressure of inlet steam in bar
6 T1=550//Temperature of steam in degree C
7 p2=20//Pressure after expansion in bar
8 T2=500//Reheat temperature in degree C
9 pc=0.075//Condenser pressure in bar
10 php=50//Pressure of steam in h.p turbine in bar
11 pip=[10,5,3]//Pressure of steam in i.p turbines in
    bar
12 plp=1.5//Pressure of steam in l.p turbine in bar
13 m=300*1000//Steam flow rate in kg/h
14
15 //Calculations
16 h1=3448.6//Enthalpy in kJ/kg
17 h4=3467.6//Enthalpy in kJ/kg
18 s1=6.5119//Entropy in kJ/kg.K
19 s2=s1//Entropy in kJ/kg.K
20 s3=s1//Entropy in kJ/kg.K
21 s4=7.4317//Entropy in kJ/kg.K
22 s5=s4//Entropy in kJ/kg.K
23 s6=s5//Entropy in kJ/kg.K
24 s7=s6//Entropy in kJ/kg.K
25 s8=s7//Entropy in kJ/kg.K
26 s9=s8//Entropy in kJ/kg.K
27 t2=370//Temperature in degree C
28 t3=245//Temperature in degree C
29 t5=400//Temperature in degree C
30 t6=300//Temperature in degree C
31 t7=225//Temperature in degree C
32 t8=160//Temperature in degree C
33 h2=3112//Enthalpy in kJ/kg
34 h3=2890//Enthalpy in kJ/kg
35 h5=3250//Enthalpy in kJ/kg
36 h6=3050//Enthalpy in kJ/kg
37 h7=2930//Enthalpy in kJ/kg

```

```

38 h8=2790//Enthalpy in kJ/kg
39 x9=(s9-0.5764)/7.6751//Dryness fraction
40 h9=168.79+x9*2406////Enthalpy in kJ/kg
41 h10=168.79//Enthalpy in kJ/kg
42 h11=h10+0.001*pip(2)*100//Enthalpy in kJ/kg
43 h12=467.11//Enthalpy in kJ/kg
44 t14=111.37//Temperature in degree C
45 h14=467//Enthalpy in kJ/kg
46 h13=h12//Enthalpy in kJ/kg
47 h14=h13//Enthalpy in kJ/kg
48 h15=h14//Enthalpy in kJ/kg
49 h16=561.47//Enthalpy in kJ/kg
50 h17=h16//Enthalpy in kJ/kg
51 h18=640.23//Enthalpy in kJ/kg
52 h19=h18+0.001*(p1-pip(2))*100//Enthalpy in kJ/kg
53 h20=762.8//Enthalpy in kJ/kg
54 h21=h20//Enthalpy in kJ/kg
55 h22=1154.23//Enthalpy in kJ/kg
56 h23=h22//Enthalpy in kJ/kg
57 m1=((h23-h21)/(h2-h22))//Mass in kg
58 m2=((h21-h19)-(m1*(h22-h20)))/(h5-h20)//Mass in kg
59 m3=((((1-m1-m2)*(h18-h17))-((m1+m2)*(h20-h18)))/(h6-
    h18+h18-h17)//Mass in kg
60 m4=((1-m1-m2-m3)*(h17-h15))/(h7-h16)//Mass in kg
61 m5((((1-m1-m2-m3-m4)*(h14-h11))-(m4*(h16-h12)))/(h8-
    h12+h14-h11)//Mass in kg
62 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
63 Wp=(0.5+14.5+0.15)//Workdone in kJ/kg
64 Wnet=(WT-Wp)//Net workdone in kJ/kg
65 Q1=(h1-h23)+(1-m1)*(h4-h3)//Heat supplied in kJ/kg
66 ncy=(Wnet/Q1)*100//Cycle efficiency in percent
67 t23=264//Temperature in degree C
68 sr=(3600/Wnet)//Steam rate in kJ/kWh
69 hr=((Q1/Wnet)*3600)//Heat rate in kJ/kWh
70 P=((Wnet*m)/3600)/10^3//Power output in MW

```

```

71
72 //Output
73 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

```

1
2 clc
3 clear
4 //Input data
5 m=10000//Mass flow rate of steam in kg/h
6 p=3//Pressure of steam in bar
7 P=1000//Power in kW
8 n=0.7//Internal efficiency of turbine
9
10 //Calculations
11 dh=(P*3600)/m//Change in enthalpy in kJ/kg
12 h2=2725.3//Enthalpy in kJ/kg from Fig. E2.7
13 h1=dh+h2//Enthalpy in kJ/kg
14 dh1h2s=dh/n//Change in enthalpy in kJ/kg
15 h2s=h1-dh1h2s//Enthalpy in kJ/kg
16 x2s=(h2s-561.47)/2163.8//Dryness fraction
17 s2s=1.6718+x2s*(6.999-1.6718)//Entropy in kJ/kg.K
18 s1=s2s//Entropy in kJ/kg.K
19 p1=37.3//Pressure in bar from Mollier diagram
20 t1=344//Temperature in degree C
21
22 //Output
23 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

```
1
2 clc
3 clear
4 //Input data
5 P1=5.6//Power load in MW
6 H1=1.163//Heat load in MW
7 p1=40//Pressure in bar
8 T1=500+273//Temperature in K
9 p2=0.06//Pressure in bar
10 p3=2//Pressure in bar
11 CV=25//Calorific value in MJ/kg
12 n=88//Boiler efficiency in percent
13 T=6//Temperature rise in degree C
14
15 //Calculations
16 h1=3445.3//Enthalpy in kJ/kg
17 s1=7.0901//Entropy in kJ/kg.K
18 s2=s1//Entropy in kJ/kg.K
19 s3=s1//Entropy in kJ/kg.K
20 x2=(s2-1.5301)/5.5970//Dryness fraction
21 h2=2706.7//Enthalpy in kJ/kg
22 h26=2201.9//Difference in enthalpy in kJ/kg
23 w=(H1*10^3)/h26//Rate of steam extraction in kg/h
24 x3=(s1-0.52)/7.815//Dryness fraction
25 h3=(149.79+x3*2416)//Enthalpy in kJ/kg
26 h4=149.79//Enthalpy in kJ/kg
27 ws=((P1*10^3+(w*(h2-h3)))/((h1-h2)+(h2-h3)))//Steam
    generation capacity in kg/s
28 ws1=(ws*3600)/1000//Steam generation capacity in t/h
29 h7=(504.7+(1.061*10^-3*(p1-p3)*100))//Enthalpy in kJ
```

```

    /kg
30 h5=(149.79+(1.006*100*p1*10^-3))//Enthalpy in kJ/kg
31 Q1=((ws-w)*(h1-h5)+(w*(h1-h7))//Heat input in kW
32 wf=((Q1/1000)/((n/100)*CV))*(3600/1000)//Fuel
    burning rate in t/h
33 Q2=((ws-w)*(h3-h4))//Heat rejected to the condensor
    in kW
34 wc=(Q2/(4.187*T))/1000//Rate of flow of cooling
    water in m^3/s
35
36 //Output
37 printf('(a) the steam generation capacity of the
    boiler 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 boiler 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

```

1
2 clc
3 clear
4 //Input data
5 m=21000//Steam rate in kg/h
6 p1=17//Pressure in bar
7 T1=230+273//Temperature in K
8 P=132.56//Power in kW
9 x2=0.957//Dryness fraction
10 p2=3.5//Pressure in bar
11 P1=1337.5//Power in l.p turbine in kW
12 p3=0.3//Pressure in bar
13 x3=0.912//Dryness fraction
14

```

```

15 //Calculations
16 h1=2869.7//Enthalpy in kJ/kg
17 s1=6.5408//Entropy in kJ/kg.K
18 h2=(870.44+x2*1924.7)//Enthalpy in kJ/kg
19 h3=h2//Enthalpy in kJ/kg
20 h56=(P1*3600)/m//Difference in Enthalpy in kJ/kg
21 h6=(289.23+x3*2336.1)//Enthalpy in kJ/kg
22 h5=2649.04//Enthalpy in kJ/kg
23 s4s=s1//Entropy in kJ/kg.K
24 x4s=(s4s-1.7275)/5.2130//Dryness fraction
25 h4s=584.33+x4s*2148.1//Enthalpy in kJ/kg
26 w=(P/(h1-h2))//Flow rate in kg/s
27 ws=(m/3600)//Steam flow rate in kg/s
28 h4=((ws*h5)-(w*h3))/(ws-w)//Enthalpy in kJ/kg
29 x4=(h4-584.33)/2148.1//Dryness fraction
30 W=(ws-w)*(h1-h4)//Power developed by h.p turbine in
    kW
31 n=((h1-h4)/(h1-h4s))*100//Isentropic efficiency in
    percent
32
33 //Output
34 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

```
1
2  clc
3  clear
4  //Input data
5  p=40//Pressure in bar
6  T1=400+273//Temperature in K
7  T2=40+273//Temperature in K
8  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)
9  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)
10
11 //Calculations
12 h1=3216//Enthalpy in kJ/kg
13 s1=6.7690//Entropy in kJ/kg.K
```

```

14 s2=s1//Entropy in kJ/kg.K
15 x2=(s2-0.5725)/(8.2570-0.5725)//Dryness fraction
16 h2=167.57+x2*2406.7//Enthalpy in kJ/kg
17 h3=167.57//Enthalpy in kJ/kg
18 h4=(167.57+p*100*1.008*10^-3)//Enthalpy in kJ/kg
19 h5=1087.31//Enthalpy in kJ/kg
20 h6=2801.4//Enthalpy in kJ/kg
21 ha=x(4)//Enthalpy in kJ/kg
22 sa=x(6)//Entropy in kJ/kg.K
23 sb=sa//Entropy in kJ/kg.K
24 xb=(sb-y(5))/(y(6)-y(5))//Dryness fraction
25 hb=(y(3)+xb*(y(4)-y(3)))//Enthalpy in kJ/kg
26 hc=y(3)//Enthalpy in kJ/kg
27 hd=hc//Enthalpy in kJ/kg
28 m=(h6-h5)/(hb-hc)//Mass of mercury circulated per kg
    of steam
29 Q1=m*(ha-hd)+(h1-h6)+(h5-h4)//Heat supplied in kJ/kg
30 Q2=(h2-h3)//Heat rejected in kJ/kg
31 nc=(1-(Q2/Q1))*100//Efficiency in percent
32
33 //Output
34 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

```

1
2 clc
3 clear
4 //Input data
5 m=5//Mass flow rate in kg/s
6 p1=40//Pressure in bar
7 T1=440+273//Temperature in K
8 p2=1.5//Pressure in bar

```

```

9 p3=1//Pressure in bar
10 T3=60+273//Temperature in K
11 p4=16//Pressure in bar
12 T4=100+273//Temperature in K
13 p5=9//Pressure in bar
14
15 //Calculations
16 h1=3307.1//Enthalpy in kJ/kg
17 s1=6.9041//Entropy in kJ/kg.K
18 s2=s1//Entropy in kJ/kg.K
19 h2=2570.8//Enthalpy in kJ/kg
20 h3=417.46//Enthalpy in kJ/kg
21 h6=(251.13+(1.0172*10^-3)*(p3-0.1994)*100)//Enthalpy
    in kJ/kg
22 m3=(m/2)//Mass flow rate in kg/s
23 m6=m3//Mass flow rate in kg/s
24 h4=(m3*h3+m6*h6)/m//Enthalpy in kJ/kg
25 h5=(h4+(1.0291*10^-3)*(p1-p3)*100)//Enthalpy in kJ/
    kg
26 ha=241.58//Enthalpy in kJ/kg
27 sa=0.7656//Entropy in kJ/kg.K
28 sb=sa//Entropy in kJ/kg.K
29 hb=229.43//Enthalpy in kJ/kg
30 hc=71.93//Enthalpy in kJ/kg
31 hd=hc+(0.7914*10^-3*(p4-p5)*100)//Enthalpy in kJ/kg
32 Q1=(m*(h1-h5))/1000//Heat supplied in kW
33 Wnets=(m*((h1-h2)-(h5-h4)))/1000//Net workdone by steam
    in kW
34 mR12=(m3*(h2-h3))/(ha-hd)//Mass of R12 in kg/s
35 WnetR=(mR12*((ha-hb)-(hd-hc)))/1000//Net workdone by R12
    in kW
36 T=Wnets+WnetR//Total output in kW
37 Qh=(m6*(h2-h6))/1000//Heat rejected in kW
38
39 //Output
40 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 %3.0 f  
kW', Q1, T, Qh)

---

### Scilab code Exa 3.3 Mass flow rate

```
1
2 clc
3 clear
4 //Input data
5 rp=7.5//Pressure ratio
6 T1=15+273//Inlet air temperature in K
7 T3=750+273//Maximum temperature in K
8 T6=100+273//Temperature in K
9 p1=50//Pressure in bar
10 T7=600+273//Temperature in K
11 p2=0.1//Pressure in bar
12 P=200//Total power in MW
13 CV=43.3//calorific value in MJ/kg
14 cpg=1.11//Specific heat for gas in kJ/kg.K
15 g=1.33//Ratio of specific heats for gas
16 cpa=1.005//Specific heat for air in kJ/kg.K
17 g1=1.4//Ratio of specific heats for air
18
19 //Calculations
20 T2=(T1*rp^((g1-1)/g1))//Temperature in K
21 T4=(T3/rp^((g-1)/g))//Temperature in K
22 ha=3670//Enthalpy in kJ/kg
23 hb=2305//Enthalpy in kJ/kg
24 hc=192//Enthalpy in kJ/kg
25 hd=hc//Enthalpy in kJ/kg
26 //ma*cpg*(T3-T6)=ms*(ha-hd)
27 //ma*cpg*(T3-T4)-ma*cpa*(T2-T1)+ms*(ha-hb)=P*1000
28 //Solving these two equations
29 A=[cpg*(T3-T6) (hd-ha)
30     cpg*(T3-T4)-cpa*(T2-T1) (ha-hb)]// Coefficient
```

```

matrix
31 B=[0
32     (P*10^3)]//Constant matrix
33 X=inv(A)*B//Variable matrix
34 Wgt=(cpg*(T3-T4)-cpa*(T2-T1))*X(1)*10^-3//Net
workdone by Gas turbine in MW
35 Wst=(P-Wgt)//Net workdone by steam turbine in MW
36 Q1=(X(1)*cpg*(T3-T2+T3-T4))//Heat supplied in MW
37 nth=(P/(Q1*10^-3))*100//Thermal efficiency in
percent
38 af=(CV*10^3)/(cpg*(T3-T2+T3-T4))//Air fuel ratio
39
40 //Output
41 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

```

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

```

```

14 cpg=1.148 // Specific heat of gas in kJ/kg.K
15 g1=1.333 // Specific heat ratio of gas
16 g=1.4 // Specific heat ratio of air
17 T3=425+273 // Temperature in K
18 p2=40 // Pressure in bar
19 p3=0.04 // Condensor pressure in bar
20 Th=170.4+273 // Temperature of feed water to the HRSG
    in K
21 nst=0.82 // Efficiency of steam turbine
22 pdh=5 // Pressure drop in HRSG in kPa
23 m=29.235 // Steam flow rate in kg/s
24 A=1.0401 // si=1.0401+0.1728*(h/c)
25 B=0.1728 // si=1.0401+0.1728*(h/c)
26
27 // Calculations
28 // Gas turbine plant
29 T2=(rp((g-1)/(g*nt))) * T1 // Temperature in K
30 // Combustor
31 pc=(pd/100) * rp // Pressure loss in bar
32 pcx=(rp-pc) // Pressure in bar
33 f=((cpg*(Tm-T1))-(cpa*(T2-T1)))/((CV*103)-(cpa*(T2-
    T1))) // Fuel flow rate in kg/s
34 af=(1-f)/f // Air fuel ratio
35 // C8H18+12.5O2->8CO2+9H2O
36 afc=(12.5*32)/(0.232*114) // Air fuel ratio for
    stoichiometric combustion
37 ea=((af-afc)/afc)*100 // Excess air in percent
38 // Gas turbine
39 p4=p1+0.05 // Pressure in bar
40 T4=(Tm/(pcx/p4)((g1-1)*nt)/g1) // Temperature in K
41 // HRSG
42 T5=250+30 // Temperature in K
43 ha=3272 // Enthalpy in kJ/kg
44 hf=1087.31 // Enthalpy in kJ/kg
45 ws=(cpg*((T4-273)-T5)))/(ha-hf) // Flow rate in kg/s
46 he=721.1 // Enthalpy in kJ/kg
47 T6=(T4-273)-((ws*(ha-he))/cpg) // Temperature in
    degree C

```

```

48 //Power output
49 sa=6.853//Entropy in kJ/kg.K
50 sbs=sa//Entropy in kJ/kg.K
51 xbs=(sbs-0.4266)/8.052//Dryness fraction
52 hbs=(121.46+xbs*2432.9)//ENthalpy in kJ/kg
53 Wst=(m*(ha-hbs)*nst)//Workdone in kW
54 wg=(m/ws)//gas flow rate in kg/s
55 wa=(1-f)*wg//Air flow rate entering the compressor
    in kg/s
56 Wgt=(wg*cpg*(Tm-T4))-(wa*cpa*(T2-T1))//Power output
    of gas turbine in kW
57 T0=Wst+Wgt//Total power output in kW
58 wf1=(f*wa)//Fuel mass flow rate in kg/s
59 wf=4.466//Rounding off of wf1 for exact answers
60 no=(T0/(wf*(CV*10^3)))*100//Overall efficiency of
    the combined plant in percent
61 ns=((ha-hbs)/(ha-he))*nst//Efficiency of steam plant
62 ngtp=(Wgt/(wf*(CV*10^3))//Efficiency of the GT
    plant
63 xL=((wg*cpg*(T6-(T1-273)))/(wf*(CV*10^3))//Lost
    heat coefficient
64 nov=(ns+ngtp-ns*ngtp-ngtp*xL)//The overall
    efficiency
65 //Energy fluxes and irreversibilities
66 si=(A+B*((18*1)/(8*12))//si for octane C8H18
67 dHo=(wf*CV*10^3)//Power in kW
68 dGo=(si*dHo)//Power in kW
69 TS=(dGo-dHo)//Power in kW
70 //Compressor
71 dS=(cpa*log(T2/T1))-(((cpa*(g-1))/g)*log(rp))//
    change in entropy in kJ/kg.K
72 Ic=(wa*T1*dS)//power in kW
73 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
74 Icg=(-cpg*log(Tm/T4))-(((cpg*(g1-1))/g1)*log(p4/pcx)
    )//Difference in entropy in kJ/kg.K
75 IGT=(Icg*T1*wg)//Gas turbine in kW

```

```

76 se=2.046//Enentropy in kJ/kg.K
77 sae=(sa-se)//Difference in entropy in kJ/kg.K
78 s64=(cpg*log((T6+273)/T4))-(((cpg*(g1-1))/g1)*log(p4
    /p1))//Difference in entropy in kJ/kg.K
79 Ih=(T1*m*sae)+(wg*T1*s64)//For HRSG in kW
80 hb=(ha-(nst*(ha-hbs)))//Enthalpy in kJ/kg
81 xb=(hb-121.46)/2432.9//Dryness Fraction
82 sb=(0.4226+xb*8.052)//Entropy in kJ/kg.K
83 Ist=(m*(sb-sa)*T1)//For steam turbine in kW
84 Iexh=(wg*cpg*((T6-(T1-273))-(T1*log((T6+273)/T1))))
    //For exhaust in kW
85 Tl=Icx+Icg+IGT+Ih+Ist+Iexh//Exergy losses in kW
86 T=Tl+Wgt+Wst//Total exergy output and exergy
    destruction in kW
87 ee=((Wst+Wgt)/T)*100//Exergy efficiency in percent
88
89 //Output
90 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',T0,no,
    xL,ee,dGo,(Wgt+Wst),Tl,T)

```

---

### Scilab code Exa 3.5 Overall efficiency

```

1
2 clc
3 clear
4 //Input data
5 n1=0.5//Efficiency of mercury
6 n2=0.4//Efficiency of steam
7 n3=0.25//Efficiency of composite cycle

```

```

8
9 // Calculations
10 n=(1-(1-n1)*(1-n2)*(1-n3))*100//Overall efficiency
    of the combined cycle in percent
11
12 //Output
13 printf('The overall efficiency of the combined cycle
    is %3.1f percent ',n)

```

---

#### Scilab code Exa 3.6 Overall efficiency

```

1
2 clc
3 clear
4 //Input data
5 z=30//Percentage of total energy of fuel
6 n=40//Cycle efficiency in percent
7
8 // Calculations
9 on=((z/100)+(1-(z/100))*(n/100))*100//Overall
    efficiency in percent
10
11 //Output
12 printf('The overall efficiency of the combined plant
    is %3.0f percent ',on)

```

---

#### Scilab code Exa 3.7 Power output and efficiency

```

1
2 clc
3 clear
4 //Input data
5 Tc=1250+273//Cathode temperature in K

```

```

6 Ta=500+273//Anode temperature in K
7 e=1.602*10^-19//Charge in coulomb
8 K=1.38*10^-23//Boltzmann constant in J/molecule.K
9 b=18//Constant
10
11 //Calculations
12 Va=((b*K*Ta)/e)//Voltage of anode in V
13 Vc=((b*K*Tc)/e)//Voltage of cathode in V
14 Vo=Vc-Va//Output voltage in V
15 Ja=(120*Ta^2*exp(-b))//Current density in Cathode in
    A/cm^2
16 Jc=(120*Tc^2*exp(-b))//Current density in Anode in A
    /cm^2
17 P=Vo*(Jc-Ja)//Power output per unit area in /cm^2
18 nth=((((Tc-Ta)/Tc)*(b/(b+2))))*100//Thermal efficiency
    in percent
19
20 //Output
21 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

```

1
2 clc
3 clear
4 //Input data
5 P=100//Power in kW
6 V=115//Voltage in V
7 To=1500//Outer temperature in K
8 Te=1000//Exit temperature in K
9 Ta=350//Ambient temperature in K

```

```

10 nth=30//Thermal efficiency in percent
11 nge=92//Generator efficiency in percent
12 //Properties of thermoelectrons
13 a=0.0012//At 1250K in V/K
14 kp=0.02//In W/cm.K
15 kn=0.03//In W/cm.K
16 dp=0.01//In ohm.cm
17 dn=0.012//In ohm.cm
18 J=20//Current density in A/cm^2
19
20 //Calculations
21 zmax=(a^2/(sqrt(dp*kp)+sqrt(dn*kn))^2)//Maximum
    value of figure of merit in K^-1
22 mo=sqrt(1+(zmax*((To+Te)/2)))//Optimum value of the
    resistance ratio
23 nmax=((((To-Te)/To)*((mo-1)/(mo+(Te/To)))))*100//
    Maximum thermal efficiency in percent
24 V1=(a*(To-Te)*(mo/(mo+1)))//Voltage per couple in V
25 nc=(V/V1)//Number of couples in series
26 L=((a*(To-Te))/((1+mo)*(dp+dn)))/J//Length in cm
27 A=((P*Te)/V)/J//Area in cm^2
28 I=(J*A)//Current in A
29 Vo=(a*(To-Te))//Voltage in V
30 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
31 Q2=((a*I*Te)+((A/L)*(kp+kn)*(To-Te))+P)/1000//Heat
    rejected at full load in kW
32 Q1n=((A/L)*(kp+kn)*(To-Te))/1000//At no load heat
    input in kW
33 Q2n=Q1n//At no load heat rejected in kW
34 no=((nmax/100)+(1-(nmax/100))*(nth/100)*(nge/100))
    *100//Overall efficiency in percent
35
36 //Output
37 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<sup>2</sup> \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

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

```

21
22 // Calculations
23 b=C/C1;//Equating coefficients of the carbon from
    equation
24 g=H/H1;//Equating coefficients of the hydrogen from
    equation
25 d=S/S1;//Equating coefficients of the sulphur from
    the equation
26 e=(b+d)/(X/Og);//By volumetric analysis
27 x=b+d+e+(g/2)-(O/O1);//Moles of oxygen are supplied
    for combustion
28 f=3.76*x;//Equating coefficients of the nitrogen
    from equation
29 Mo=x*O1;//Mass of oxygen supplied in kg
30 Ma=Mo/0.232;//Mass of air supplied for 100 kg of
    fuel in kg
31 Wa=Ma/100;//Mass of air supplied for 1 kg fuel in kg
32 Wrh={(11.5*C)+(34.5*[(H)-(O/8)])+(4.3*S)}/100;//
    Theoretical air required per kg of fuel in kg
33 E=[(Wa-Wrh)/Wrh]*100;//Percentage of excess air in %
34 D=(b*Co2)+(d*So2)+(e*O1)+(f*N1);//Mass of dry flue
    gas formed for 100 kg fuel in kg
35 dfg=D/100;//Mass of dry flue gas formed per kg of
    fuel in kg
36 Mw=(g*H2O)/100;//Mass of water vapour formed per kg
    of fuel
37
38 //Output
39 printf('(a) Mass of air supplied WA = %3.2 f kg \n (b
    )Percentage excess air supplied = %3.2 f
    percentage \n (c)mass of dry flue gas formed = %3
    .2 f kg \n (d) Mass of water vapour formed = %3.2 f
    kg ',Wa,E,dfg,Mw)

```

---

Scilab code Exa 4.2 Percentage of excess air

```

1
2 clc
3 clear
4 //Input data
5 C02=11.5; //Percentage of carbondioxide present in
   combustion in %
6 O2=2.7; //Percentage of oxygen present in the
   combustion in %
7 C0=0.7; //Percentage of carbonmonoxide present in the
   combuston in %
8
9 //Calculations
10 a=85.1/3.76; //Equating moles for nitrogen from the
   equation
11 x=(C02+C0)/3; //Equating moles for carbon from the
   equation
12 b=[a-C02-(C0/2)-O2]*2; //Equating moles for oxygen
   from the equation
13 y=a/x; //Moles of oxygen supplied for one mole of
   propane gas
14 z=5; //Theoretically 5 moles of oxygen are required
   for reacting
15 E=[(y-z)/z]*100; //The excess of air supplied in %
16
17 //Output
18 printf('The percentage excess air used is = %3.1f
   percentage ',E)

```

---

#### Scilab code Exa 4.3 Air fuel ratio

```

1
2 clc
3 clear
4 //Input data
5 C02=12.1; //The amount of carbondioxide released from

```

```

    the combustion in %
6 O2=3.8; //The amount of oxygen released from the
    combustion in %
7 CO=0.9; //The amount of carbonmonoxide released from
    the combustion in %
8 MO=32; //Molecular weight of Oxygen
9
10 //Calculations
11 a=83.2/3.76; //Equating moles for nitrogen from the
    equation
12 b=(2*a) - (2*CO2) - (2*O2) - CO; //Equating moles for
    oxygen from the equation
13 x=CO2+CO; //Equating moles for carbon from the
    equation
14 y=2*b; //Equating moles for hydrogen from the
    equation
15 z=18.75; //Moles of Oxygen from the stoichiometric
    equation
16 z1=a; //Moles of Oxygen from the combustion equation
17 E=[(z1-z)/z]*100; //Percentage of excess air in%
18 A=(a*MO)/0.232; //Actual air supplied per mole of
    C13H23
19 Mc=179; //Molecular weight of C13H23
20 Af=A/Mc; //Air fuel ratio during the test
21
22 //Output
23 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

```

1
2 clc
3 clear

```

```

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

```

```

25 cp=1.05; //Heat capacity of dry flue gas (dfg) in kJ/
    kgK
26 Ta=30; //The ambient temperature of air in degree
    centigrade
27 Mc=44; //Molecular weight of Carbondioxide
28 Mco=28; //Molecular weight of carbonmonoxide
29 Mo=32; //Molecular weight of oxygen
30 Mn=28; //Molecular weight of nitrogen
31 Mx=12; //Molecular weight of carbon
32 h1=3373.7; //Enthalpy at 100 bar and 500 degree
    centigrade in kJ/kg
33 hf=675.55; //Enthalpy at 160 degree centigrade in kJ/
    kg
34 hg=2724.7; //Enthalpy at 100 bar in kJ/kg
35
36 //Calculations
37 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
38 Ed=Mdfg*cp*(Te-Ta); //Energy loss due to dry exhaust
    gas in kJ/kg fuel
39 //Since Mdfg is 11.73kg through sciab calculation ,
    there is a variation in Ed value and Ei value
40 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
41 E1=L*HHV; //Energy loss other than dry exhaust loss
    and incomplete combustion loss in MJ/kg fuel
42 TE1=(Ed/1000)+(Ei/1000)+E1; //Total energy loss in MJ
    /kg fuel
43 Be=[(HHV-TE1)/(HHV)]*100; //Boiler efficiency in %
44 Wf=([(R*1000)*(h1-hf)]/((Be/100)*HHV*1000))/3600; //
    The fuel burning rate in kg/s
45 Wth=(11.5*(C/100))+(34.5*[(H/100)-(O/800)])+(4.3*(S
    /100)); //Theoretical air required per kg of fuel
    in kg
46 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
47 per=[(WA-Wth)/Wth]*100;//Percentage excess air used
    in %
48 pea=[(h1-hg)/(h1-hf)]*100;//Percentage of energy
    absorbed in the superheater
49
50 //Output
51 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

```

1
2 clc
3 clear
4 //Input data
5 C=83.7;//The amount of carbon present in the fuel
    oil according to ultimate analysis of a fuel oil
    in %
6 H=12.7;//The amount of hydrogen present in the fuel
    oil according to ultimate analysis of a fuel oil
    in %
7 O=1.2;//The amount of oxygen present in the fuel oil
    according to ultimate analysis of a fuel oil in
    %
8 N=1.7;//The amount of nitrogen present in the fuel
    oil according to ultimate analysis of a fuel oil

```

```

    in %
9  S=0.7; //The amount of sulphur present in the fuel
    oil according to ultimate analysis of a fuel oil
    in %
10 td=27; //The dry bulb temperature of combustion air
    in degree centigrade
11 tw=21; //The wet bulb temperature of combustion air
    in degree centigrade
12 E=0.3; //Excess air and assuming complete combustion
    in %
13 t=200; //Temperature to find total volume of
    combustion products in degree centigrade
14 p=1.013; //Pressure to find total volume of
    combustion products in bar
15
16 //Calculations
17 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
18 WA=(1+E)*Wth; //Actual air required per kg of fuel in
    kg/kg fuel
19 sh=0.0132; //Specific humidity at DBT and WBT in kg
    moisture/kg dry air
20 W=WA*sh; //Water vapour entering with air per kg fuel
    in kg vap/kg fuel
21 Tw=(9*(H/100))+WA; //Total water vapour formed per kg
    fuel in kg
22 CO2=(44/12)*(C/100); //mass of carbondioxide gas per
    kg of fuel
23 O2=0.232*E*Wth; //Mass of oxygen gas per kg of fuel
24 N2=0.768*(1+E)*Wth+(N/100); //Mass of nitrogen gas
    per kg of fuel
25 SO2=(64/32)*(S/100); //Mass of nitrogen gas per kg of
    fuel
26 H2O=1.383; //Mass of water per kg of fuel
27 M=(CO2/44)+(O2/32)+(N2/28)+(SO2/64)+(H2O/18); //Moles
    of combustion gases formed per kg fuel
28 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
29 C021=((C02/44)/[(C02/44)+(O2/32)+(N2/28)])*100; //
    Composition of dry flue gas CO2 by volume
30 O21=((O2/32)/[(C02/44)+(O2/32)+(N2/28)])*100; //
    Composition of dry flue gas O2 by volume
31 N21=((N2/28)/[(C02/44)+(O2/32)+(N2/28)])*100; //
    Composition of dry flue gas N2 by volume
32
33 //Output
34 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,C021,O21,
    N21)

```

---

#### Scilab code Exa 4.6 Flue gas analysis

```

1
2 clc
3 clear
4 //Input data
5 C2H6=22.6; //The amount of gas present in the fuel
    gas according to volumetric analysis of fuel gas
    by volume in %
6 CH4=73.6; //The amount of gas present in the fuel gas
    according to volumetric analysis of fuel gas by
    volume in %
7 CO2=2.4; //The amount of gas present in the fuel gas
    according to volumetric analysis of fuel gas by
    volume in %
8 N2=1.4; //The amount of gas present in the fuel gas
    according to volumetric analysis of fuel gas by

```

```

    volume in %
9  E=0.25; //Assuming combustion air to be dry and in
    excess
10 t=260; //The temperature for the total gas volume for
    complete combustion in degree centigrade
11 p=1.013; //The pressure for the total gas volume for
    complete combustion in bar
12 Mch=30; //Molecular weight of C2H6
13 Mc=16; //Molecular weight of CH4
14 Mco=44; //Molecular weight of CO2
15 Mn=28; //Molecular weight of N2
16 Mo=32; //Molecular weight of O2
17 Mh=18; //Molecular weight of H2O
18
19 //Calculations
20 x=100; //Assuming 100 moles of fuel gas
21 Mf=[(C2H6/100)*Mch]+[(CH4/100)*Mc]+[(N2/100)*Mn]+[(
    CO2/100)*Mco]; //Molecular weight of fuel gas
22 Ma=[(226.3*(Mo+(3.76*Mn))*(1+E))]/28.96; //Moles of
    air supplied
23 Mc=1440; //Moles of combustion gas from the equation
24 Mr=x+Ma+Mc; //Total reaction molecules
25 Mwc=[(121.2*Mco)+(215*Mh)+(56.6*Mo)+(1065.4*Mn)]/Mc;
    //Molecular weight of combustion gas in kg/kgmol
26 Mt=Mc/(x*20); //Total number of moles of combustion
    gas per kg fuel gas
27 VG=Mt*22.4*[(273+t)/273]; //Volume of combustion
    products per kg fuel gas
28 CO21=(121.2/(121.2+56.6+1065.4))*100; //Gas analysis
    of CO2 by volume
29 O21=(56.6/1243.2)*100; //Gas analysis of O2 by volume
30 N2=(1065.4/1243.2)*100; //Gas analysis of N2 by
    volume
31
32 //Output
33 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<sup>3</sup>/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,C021,O21,N2)

---

#### Scilab code Exa 4.7 Air leakage

```
1
2 clc
3 clear
4 //Input data
5 C021=9.7;//Carbondioxide gas analysis before the air
   preheater
6 C022=9.2;//Carbondioxide gas analysis after the air
   preheater
7 O21=4.0;//Oxygen gas analysis before the air
   preheater
8 O22=4.9;//Oxygen gas analysis after the air
   preheater
9 N21=86.3;//Nitrogen gas analysis before the air
   preheater
10 N22=85.9;//Nitrogen gas analysis after the air
   preheater
11 C=72;//The coal used shows the carbon percentage by
   mass in %
12
13 //Calculations
14 W1=[(3.04)*(N21/100)*(C/100)]/[(C021/100)];//Before
   air preheater in kg air/kg fuel
15 W2=[(3.04)*(N22/100)*(C/100)]/[(C022/100)];//After
   air preheater in kg air/kg fuel
16 A=W2-W1;//Air leakage in kg air/kg fuel
17
18 //Output
19 printf('The air leakage into the air preheater per
```

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

---

**Scilab code Exa 4.8** Height of stack and diameter of base

```
1
2 clc
3 clear
4 //Input data
5 n=6; //Total lancashire boilers in a textile factory
6 Ws=6; //Each boiler supplying steam in t/h
7 p=16; //Pressure at which steam is supplied in bar
8 t=250; //Temperature at which steam is supplied in
    degree centigrade
9 CV=43960; //Calorific value of the fuel oil in kJ/kg
10 no=75; //Overall efficiency of the boiler in %
11 a=16; //The amount of air required for efficient
    burning of the fuel in kg
12 H=20; //Drought of water gauge required at the base
    of chimney in mm
13 tf=320; //The flue gases leave the boiler in degree
    centigrade
14 ts=300; //The average temperature of the gases in the
    stack in degree centigrade
15 ta=30; //The atmospheric temperature in degree
    centigrade
16 R=0.287; //Real Gas constant in kJ/kgK
17 h1=2919.2; //enthalpy at the entrance of the boiler
    in kJ/kgK
18 hf=125.8; //Enthalpy at the feed in kJ/kgK
19 pi=3.1412; //Mathematical constant
20 g=9.81; //gravitational fore constant in m/s^2
21 P=1.013; //Atmospheric pressure in bar
22
23 //Calculations
24 H1=[(H*R*(273+ta)*(273+ts))]/[P*100*[(273+ts)-(273+
```

```

    ta)]]; //The draught produced in m
25 Wf=[[(Ws*1000)*6*(h1-hf)]/((no/100)*CV)]/3600; //Air
    fuel ratio in kg/s
26 Wa=a*Wf; //Actual air fuel ratio in kg/s
27 Wfg=17*Wf; //Air fuel ratio in kg/s
28 D=[[(Wfg*R*(273+ts)*(4/pi))]/[(101.3)*(2*g*H1)^(1/2)
    ]]^(1/2); //Diameter at its base in m
29
30 //Output
31 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

```

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

```

```

16 R=0.287; //Real gas constant
17 P=101.325; //Atmospheric pressure in kPa
18 g=9.812; //gravitational force constant m/s^2
19
20 //Calculations
21 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
22 WA=Wth*(1+0.3); //Actual air required per kg fuel in
    kg air/kg fuel
23 Va=(R*(273+ta))/P; //Volume flow rate of air in m^3/
    kg
24 FD=((WA*Wf*1000*Va*p*g)/(3600*nm))/1000; //FD fan
    motor capacity in kW
25
26 //Output
27 printf('The required motor capacity needed for the
    FD fan is %3.2f kW ',FD)

```

---

#### Scilab code Exa 4.10 Motor capacity

```

1
2 clc
3 clear
4 //Input data
5 tg=180; //The gas temperature in degree centigrade
6 p=250; //The draught produced by the ID fan in mm
7 nf=0.52; //The efficiency of the fan
8 Va=0.858; //Volume flow rate of air in m^3/kg
9 g=9.812; //gravitational force constant in m/s^2
10 Wf=10; //Coal rate in t/h
11 Wa=12.9; //Actual air required per kg fuel in kg air/
    kg fuel
12 ta=30; //Room temperature in degree centigrade
13

```

```

14 // Calculations
15 Wfg=[(Wf+(Wa*10))*1000]/3600; //Fuel gas required in
    kg/s
16 Vfg=[Va*(tg+273)]/(ta+273); //Volume flow rate of
    fuel gas in m^3/kg
17 ID=((Wfg*Vfg*p*g)/(nf))/1000; //ID fan motor capacity
    in kW
18
19 //Output
20 printf('The motor capacity of the ID fan is %3.2f kW
    ',ID)

```

---

#### Scilab code Exa 4.11 Volumetric composition

```

1
2 clc
3 clear
4 //Input data
5 CO2=13.2; //The volume of carbondioxide present in
    the partial analysis of dry flue gas in %
6 O2=3.2; //The volume of oxygen present in the partial
    analysis of dry flue gas in %
7 C=88; //The mass of carbon present in the coal
    according to coal analysis on mass basis in %
8 H=4.4; //The mass of hydrogen present in the coal
    according to coal analysis on mass basis in %
9 A=7.6; //The mass of ash present in the coal
    according to coal analysis on mass basis in %
10 M=0; //Moisture present in the fuel was nil
11 Mc=12; //Molecular weight of the carbon
12 Hh=2; //Molecular weight of the hydrogen
13 Mo=32; //Molecular weight of the oxygen
14 Mho=18; //Molecular weight of water
15 p=101.325; //Atmospheric pressure in kPa
16

```

```

17 // Calculations
18 c=C/Mc;//Equating coefficients of the carbon from
    the equation
19 g=H/Mh;//Equating coefficients of the hydrogen from
    the equation
20 x=(CO2/100)/(O2/100);//From dry fuel gas analysis (
    dfg)
21 d=[[(CO2/100)*(47.5)]-7.333]/[[[(CO2/100)*(3.032)
    ]-1]);//Coefficient of the carbonmonoxide in the
    equations product side
22 b=c-d;//Coefficient of the carbondioxide in the
    equation product side
23 a=10.21-(0.742*d);//Coefficient of the oxygen in the
    reactant side of the equation
24 e=b/x;//Coefficient of the oxygen in the product
    side of the equation
25 f=3.76*a;//Equating coefficients of the nitrogen
    from the equation
26 ma=(a*Mo)/0.232;//Mass of air supplied for 100 kg
    coal in kg
27 ma1=ma/100;//Mass of air supplied per kg coal in kg
28 T=b+d+e+f;//Total number of moles of dry flue gas (
    dfg)
29 CO21=(b/T)*100;//Carbondioxide by volume in
    percentage
30 O21=(e/T)*100;//Oxygen by volume in percentage
31 CO1=(d/T)*100;//Carbonmonoxide by volume in
    percentage
32 N21=(f/T)*100;//Nitrogen by volume in percentage
33 Mwv=(g*Mho)/100;//Mass of watervapour formed per kg
    coal in kg
34 Mf=(g)/(b+d+e+f+g);//Mole fraction of water vapour
    in flue gas
35 P=Mf*p;//Partial pressure of water vapour in kPa
36 D=32.9;//Dew point temperature from steam tables in
    degree centigrade
37
38 //Output

```

```

39 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 ',C021,021,C01,N21,ma1,Mwv,D)

```

---

#### Scilab code Exa 4.12 Height of gas plume

```

1
2 clc
3 clear
4 //Input data
5 H=200;//Height of the stack in m
6 D=4;//Diameter of the stack in m
7 m=1000;//Mass flow rate of gas in kg/s
8 Ts=100;//Stack exit gas temperature in degree
centigrade
9 Ta=5;//Ambient air temperature in degree centigrade
10 Vw=50;//Wind velocity in Km/h
11 Cp=1.005;//Specific heat of the gas in kJ/kgK
12 pi=3.142;//Mathematical constant the value of pi
13
14 //Calculations
15 Vw1=(50*1000)/(60*60);//Wind velocity in m/s
16 Qe=m*Cp*(Ts-Ta);//Heat emission from plume in kW
17 Qe1=Qe/1000;//Heat emission from the plume in MW
18 p=(101.325)/(0.287*373);//Density of the gas in kg/m
^3
19 A=(pi*D^2)/4;//Area of the stack in m^2
20 Vs=m/(p*A);//Stack gas exict velocity in m/s

```

```

21 H1=[(2.62*(Qe1^(1/2))*1000)/Vw1]-[(0.029*Vs*D)/Vw1];
    //The height of the gas plume in m
22
23 //Output
24 printf('The height of the gas plume is H = %3.1f m ',
    ,H1)

```

---

### Scilab code Exa 4.13 Thermal efficiency

```

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

```

```

kgK
18 i1=1.33; //Isentropic index for the combustion
    products
19 Mc=12; //Molecular weight of the carbon
20 Mh=2; //Molecular weight of the hydrogen
21 Mo=32; //Molecular weight of the oxygen
22 Mho=18; //Molecular weight of water
23 T0=288; //Datum temperature in K (Assumed)
24
25 //Calculations
26 h=(C/100)/(Mc); //Equating coefficients of the carbon
    from the equation
27 e=(H/100)/Mh; //Equating coefficients of the hydrogen
    from the equation
28 y=(CO/100)/(CO2/100); //From dry exhaust gas analysis
    for solving
29 a=h/(1+y); //The coefficient of the carbondioxide in
    the product side of the equation
30 b=h-a; //The coefficient of the carbonmonoxide in the
    product side of the equation
31 z=b/(CO/100); //The sum of coefficients of the
    product side of the equation
32 x=z-(b/2)+(e/2); //Mol of air supplied in kmol
33 wa=x*28.96; //Air supplied in kg/kg fuel
34 wf=1; //Assuming 1 kg of fuel supplied
35 T2=(t1+273)*(p2/p1)^((i1-1)/i); //Temperature at the
    outlet of the compressor in K
36 T3=[[(wa*Cp*(T2-T0))+(wf*CV*1000)]/[(wa+wf)*(Cp1)]]+
    T0; //Maximum temperature of the cycle in K
37 T4=T3/[(4)^((i1-1)/i1)]; //Temperature at point of
    the cycle in K
38 T5=[(Re/100)*(T4-T2)]+T2; //Temperature at point of
    the cycle in K
39 Wc=wa*Cp*(T2-(t1+273)); //Work done by the compressor
    in kW
40 Wt=23.54*Cp1*(T3-T4); //Work done by the turbine in
    kW
41 Q1=23.54*Cp1*(T3-T5); //Total work done by the system

```

```

    in kW
42 nc=(Wt-Wc)/Q1; //Efficiency of the cycle
43 nc1=nc*100; //Efficiency of the cycle in %
44 spc=3600/(Wt-Wc); //Specific fuel consumption in kg/
    kWh
45
46 //Output
47 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

```
1
2 clc
3 clear
4 //Input data
5 Vs=2500; //The mass of a bed of solid particles in kg
6 p=2650; //The density of the solid in kg/m3
7 d=800*10-6; //The mean particle size in m
8 s=0.84; //The sphericity of the particle
9
10 //Calculations
11 As=(6*Vs)/(p*d*s); //The total surface area of the
    particles in the bed
12
13 //Output
14 printf(' The total surface area of the particles in
    the bed As = %3.0f m2 ',As)
```

---

### Scilab code Exa 5.2 Voidage of the bed

```
1
2 clc
3 clear
4 //Input data
5 d=427*10^-6; //The mean particle size in m
6 pg=1.21; //The density of air in kg/m^3
7 v=1.82*10^-5; //The viscosity of air in kg/ms
8 pl=1620; //The density of the loosely packed bed in
   kg/m^3
9 ps=2780; //The density of the solids in kg/m^3
10 c1=27.2; //(Grace,1982) constant value.
11 c2=0.0408; //(Grace,1982) constant value
12 g=9.812; //Gravitational force constant in m/s^2
13
14 //Calculations
15 E=1-(pl/ps); //The voidage of the bed
16 Ar=[(pg)*(ps-pg)*g*(d^3)]/v^2; //Archimedes number
17 Re=[c1^2+(c2*Ar)]^(0.5)-c1; //Reynolds number
18 Umf=Re*v/(pg*d); //Minimum superficial velocity in m/
   s
19
20 //Output
21 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

```
1
2 clc
```

```

3 clear
4 //Input data
5 d=427*10^-6; //The mean particle size in m
6 pg=1.21; //The density of air in kg/m^3
7 v=1.82*10^-5; //The viscosity of air in kg/ms
8 Umf=0.14; //Minimum superficial velocity in m/s
9 Ar=7753; //Archimedes number from previous example
    problem
10
11 //Calculations
12 Re=(Umf*pg*d)/v; //Reynolds number
13 function[f] = F(x); //function definition
14     f = 7753*x^2 - 381.1*x - 4793;
15 endfunction
16 x = 100; //Initial guss
17 function[z] = D(x) //Derivative
18     z = 3*x^2 - 3;
19 endfunction
20 y = fsolve(x,F, D);
21
22 //Output
23 printf('The sphericity of particles is = %3.3f ',y)

```

---

#### Scilab code Exa 5.4 Flow rate of limestone

```

1
2 clc
3 clear
4 //Input data
5 O=35; //The output of the fluidized bed combustion
    system in MW
6 n=0.80; //Efficiency of the fluidized bed combustion
    system
7 H=26; //The heating value of coal in MJ/kg
8 S=3.6; //Sulphur content in the coal in %

```

```

9 C=3; //The calcium sulphur ratio
10 Ca=85; //The amount of calcium carbonate in the
    limestone in %
11 CaCO3=100; //The molecular weight of CaCO3
12
13 //Calculations
14 Cb=0/(n*H); //Coal burning rate in kg/s
15 Cb1=Cb*3600; //Coal burning rate in kg/h
16 Sf=(Cb1*(S/100))/32; //Flow rate of sulphur in Kmol/h
17 Cf=Sf*C; //The flow rate of calcium in Kmol/h
18 Caf=Cf*CaCO3; //Mass flow rate of CaCO3 in kg/h
19 L=Caf/(Ca/100); //Mass flow rate of limestone in kg/h
20
21 //Output
22 printf('The required flow rate of limestone is %3.1f
    kg/h ',L)

```

---

#### Scilab code Exa 5.5 Rate of heat removed

```

1
2 clc
3 clear
4 //Input data
5 CV=24; //The calorific value of the fuel in MJ/kg
6 C=0.65; //The amount of calorific value released in
    the bed in %
7 to=850; //Temperature at which products leave in
    degree centigrade
8 ti=30; //The inlet temperature in degree centigrade
9 tb=850; //The bed temperature in degree centigrade
10 A=14.5; //The air fuel ratio by mass
11 Cp=1.035; //The specific heat of the products leaving
    the bed surface in kJ/kgK
12 B=7000; //The burning rate of coal in kg/h
13

```

```

14 // Calculations
15 H=(C*CV*1000)-(A*Cp*(to-ti)); //Heat removal from the
    bed per kg fuel in kJ/kg fuel
16 Hr=(H*B)/3600; //Rate of heat removal from the bed in
    kW
17 Hb=(B/3600)*(1-C)*CV*1000; //The rate of heat removal
    from the above bed zone in kW
18
19 //Output
20 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

```

1
2 clc
3 clear
4 //Input data
5 tb=850; //The bed temperature in degree centigrade
6 CV=25; //The calorific value of the fuel in MJ/kg
7 A=9.5; //The stoichiometric air fuel ratio by mass
8 E=20; //The amount of excess air used in %
9 F=4.8; //The total fueling rate in MW
10 p=0.3145; //The density of air at bed temperature in
    kg/m^3
11 f=2; //The firing rate in MW/m^2
12 v=2.7; //The fluidizing velocity in m/s
13
14 // Calculations
15 P=F/f; //Planform area in m^2
16 m=(F*1000)/(CV*1000); //Fuel burning rate in kg/s
17 ma=A*(1+(E/100))*m; //Mass flow rate of air in kg/s
18 Pa=ma/(p*v); //Planform area in m^2
19

```

```
20 //Output
21 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

```
1
2 clc
3 clear
4 //Input data
5 H=18;//The length of furnace wall riser in m
6 O=76.2;//The outer diameter of the furnace wall
   riser in mm
7 T=6.1;//The thickness of the furnace wall riser in
   mm
8 P=80;//Pressure at which saturated water is recieved
   in bar
9 V=1.5;//The velocity of the saturated water in m/s
10 CR=12.5;//Assuming circulation ratio
11 S=1.2;//Assuming slip ratio
12 g=9.81;//Gravitational force constant in m/s^2
13 pi=3.142;//Mathematical constant
14
15 //Calculations
16 xt=1/CR;//The quality of steam at the top of the
   riser
17 vf=0.001384;//Specific volume of saturated liquid at
```

```

    80 bar in m3/kg
18 vfg=0.02214; // Specific volume of Evaporation gas at
    80 bar in m3/kg
19 vg=0.02352; // Specific volume of saturated gas at 80
    bar in m3/kg
20 pf=1/vf; // Density of the saturated liquid at 80 bar
    in kg/m3
21 vt=vf+(xt*vfg); // Specific volume of the steam at the
    top of the riser in m3/kg
22 pt=1/vt; // Density of steam at the top of the riser
    in kg/m3
23 pm=(pt+pf)/2; // Mean density in kg/m3
24 Ph=[H*g*(pf-pm)]/1000; // The pressure head developed
    in kPa
25 C=(vf/vg)*S; // The part of calculation for the void
    fraction
26 VF=1/[1+((1-xt)*C)/xt]; // The void fraction at riser
    exit
27 hfg=1441.3; // Enthalpy of the evaporation in kJ/kg
28 di=0-12.2; // Inner diameter of the furnace wall riser
    in mm
29 A=(pi*di2)/4; // Inner area in m2
30 w=pf*A*V; // Mass flow rate of saturated water
    entering the riser in kg/s
31 ws=xt*w; // The rate of steam formation in the riser
    tube in kg/s
32 h=[(ws*hfg)/(O*H)]/1000; // Heat transfer rate per
    unit projected area in kW/m2
33
34 //output
35 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/m2 ', Ph, VF, h)

```

---

### Scilab code Exa 6.2 Amount of water required

```
1
2 clc
3 clear
4 //Input data
5 t=60; //The temperature of water while supplying it
      to desuperheater in degree centigrade
6 ws=200; //The amount of steam carrying in a steam
      line in t/h
7 p=35; //The pressure of steam in bar
8 ts=400; //The temperature to be maintained by the
      steam in degree centigrade
9 to=450; //The outlet temperature of the steam from
      boiler in degree centigrade
10 h1=3337.2; //The enthalpy of steam at 450 degree C in
      kJ/kg
11 h2=252; //The enthalpy of water at 60 degree C in kJ/
      kg
12 h3=3222.3; //The enthalpy of steam at 400 degree C in
      kJ/kg
13
14 // Calculations
15 w=(ws*(h1-h3))/(h3-h2); //Mass flow rate of water in
      t/h
16 w1=w*(1000/3600); //Mass flow rate of water in kg/s
17
18 //Output
19 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

```
1
2 clc
```

```

3 clear
4 //Input data
5 H=15;//The high of downcomer riser circuit in m
6 P=160;//The pressure at which downcomer riser
   circuit operates in bar
7 xe=0.5;//The exit quality of the steam
8 S=1.2;//Slip factor
9 vf=0.001711;//Specific volume of saturated liquid in
   m^3/kg
10 vg=0.009306;//Specific volume of saturated gas in m
   ^3/kg
11 g=9.806;//Gravitational force constant in m/s^2
12
13 //Calculations
14 C=S*(vf/vg);//The part of calculation for the void
   fraction
15 VF=1/[1+((1-xe)*C)/xe];//The void fraction at riser
   exit
16 pf=1/vf;//Density of the saturated liquid in kg/m^3
17 pg=1/vg;//Density of the saturated gas in kg/m^3
18 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
19 P1=g*(pf-pm)*H;//Pressure head developed due to
   natural circulation in N/m^2
20 P2=P1/1000;//ressure head developed due to natural
   circulation in kPa
21
22 //Output
23 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

1

```

2  clc
3  clear
4  //Input data
5  W=120; //The amount of electricity produced in the
        power plant in MW
6  po=100; //The pressure of the steam at the outlet of
        boiler in bar
7  to=500; //The temperature of steam at the outlet of
        boiler in degree centigrade
8  p=0.1; //The condenser pressure in bar
9  nb=0.9; //The efficiency of the boiler
10 CV=25.7; //The calorific value of the coal in MJ/kg
11 ti=160; //The feed water temperature at boiler inlet
        in degree centigrade
12 H=40; //The high of the risers in the furnace wall in
        m
13 xt=0.08; //The quality of the steam at the top of the
        riser
14 v=2; //The exit velocity of the riser and entering
        the drum in m/s
15 Do=60; //The outer diameter of the risers in mm
16 T=3; //The thickness of the wall in mm
17 pi=3.142; //Mathematical constant
18 g=9.806; //Gravitational force constant in m/s^2
19
20 // Calculations
21 h1=3374.8; //Enthalpy at point 1 in kJ/kg
22 s1=6.6011; //Entropy at point 1 in kJ/kgK
23 sf=0.6479; //Entropy of the saturated liquid at point
        1 in kJ/kgK
24 sg=7.5055; //Entropy of the Saturated vapour at point
        1 in kJ/kgK
25 x2=(s1-sf)/sg; //The quality of the steam
26 h2=191.46+(x2*2393.29); //Enthalpy at point 2 in kJ/
        kg
27 h3=191.46; //Enthalpy at point 3 in kJ/kg
28 h5=675.5; //Enthalpy at point 5 in kJ/kg
29 ws=(W*1000)/(h1-h2); //Mass flow rate of steam in kg/

```

```

s
30 wf=(ws*(h1-h5))/(nb*CV*1000); //Mass flow rate of
    fuel in kg/s
31 E=ws/wf; //Evaporation factor
32 vf=0.0014523; //The specific volume of saturated
    liquid in m^3/kg
33 vg=0.0165884; //The specific volume of saturated
    vapour in m^3/kg
34 vt=vf+(xt*vg); //Specific volume at the top in m^3/kg
35 pt=1/vt; //Density of the steam at the top in kg/m^3
36 pf=1/vf; //The density of the steam in kg/m^3
37 pm=(pf+pt)/2; //The average mixture density in kg/m^3
38 H1=[g*H*(pf-pm)]/10^5; //Pressure head available for
    natural circulation in bar
39 CR=1/xt; //Circulation ratio
40 di=(Do-(2*T))/1000; //The inner diameter of the riser
    in m
41 A=(pi*di^2)/4; //Area for the inner diameter in m^2
42 w=(A*pt*v*xt); //The rate of steam formation in the
    riser in kg/s
43 Nr=ceil(ws)/w; //The number of risers
44 hfg=1319.8; //Enthalpy of the evaporation in kJ/kg
45 Ha=(w*hfg)/((Do/1000)*H); //Heat absorption rate per
    unit projected area of the riser in kW/m^2
46
47 //Output
48 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
    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

```
1
2 clc
3 clear
4 //Input data
5 ws=64; //The steam flow rate in kg/s
6 p=60; //The pressure at which steam leaves the boiler
   in bar
7 m=0.02; //Moisture content in the steam
8 wf=62; //The feedwater flow rate in kg/s
9 Pf=3; //concentration of feedwater in ppm
10 wm=2; //The flow rate of makeup water
11 Pm=50; //concentration of makeup water in ppm
12 Ps=5; //Leaving the drum water in ppm
13 Pw=1000; //The concentration in the drum water in ppm
14 mf=7; //The fuel burning rate in kg/m
15 CV=23; //The heating value in MJ/kg
16 ta=30; //The room temperature in degree centigrade
17 hf=1213.35; //Enthalpy of saturated liquid at 60 bar
   in kJ/kg
18 ha=125.79; //Enthalpy at ambient temperature in kJ/kg
19
20 //Calculations
21 BD=[(wf*Pf)+(wm*Pm)-(m*ws*Ps)]/1000; //The rate of
   blowdown in kg/s
22 E=[(BD*(hf-ha))/(mf*CV*1000)]*100; //The energy loss
   in blowdown in percentage
23 S=m*ws*Ps*10^-6*3600*24; //Scale deposition in
   superheater tubes
24
25 //Output
26 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

```
1
2 clc
3 clear
4 //Input data
5 ws=600; //Mass flow rate of feedwater in kg/s
6 p=140; //The inlet pressure of the feedwater in bar
7 t=170; //The inlet temperature of the feedwater in
  degree centigrade
8 wg=1250; //The mass flow rate of flue gases in kg/s
9 tg2=450; //The temperature at which flue gases leave
  the economisers coils in degree centigrade
10 Vf=12; //The velocity of the flue gas in m/s
11 Vw=1.2; //The velocity of the water leaving the coil
  in m/s
12 Do=0.07; //The outer diameter of the tube in m
13 Di=0.06; //The inner diameter of the tube in m
14 U=70; //The overall heat transfer coefficient in W/m
  ^2K
15 Cp=1.12; //The specific heat capacity of the flue
  gases in kJ/kgK
16 V=0.08; //The vertical pitch of the coil in m
17 B=4.8; //The width of the duct in m
18 C=0.005; //The clearance on the both sides of the
  duct in m
19 pi=3.142; //Mathematical constant
20
21 //Calculations
22 hf=1571.1; //The enthalpy of the saturated liquid at
  140 bar in kJ/Kg
```

```

23 ts=336.75; //The saturated temperature at 140 bar in
    degree centigrade
24 vf=0.001611; //The specific volume of the saturated
    liquid at 140 bar in m^3/kg
25 hf1=719.21; //The enthalpy of the saturated liquid at
    170 degree C in kJ/kg
26 vf1=0.001114; //The specific volume of the saturated
    liquid at 170 degree C in m^3/kg
27 tg1=[(ws*(hf-hf1))/(wg*Cp)]+tg2; //The temperature at
    which flue gases enters the economisers coils in
    degree centigrade
28 t1m=(478.25-280)/(log(478.25/280)); //The mean
    temperature for inlet and exit temperature in
    degree centigrade
29 Q=ws*(hf-hf1); //The rate of heat transfer in the
    economiser in kW
30 Ao=[Q/(U*t1m)]*10^3; //The outer area in m^2
31 n=[(ws*(vf/Vw)*(4/pi)*(1/Di^2))]; //The number of
    coils needed in the economiser
32 l=Ao/(n*pi*Do); //The length of one coil in m
33 nt=1/(B-(2*C)); //The number of turns in on ecoil
34 VH=nt*V; //The vertical height of the duct occupied
    by the economiser coils
35
36 //Output
37 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

```

1
2 clc

```

```

3 clear
4 //Input data
5 tg2=160; //The temperature to which the flue gases
   are cooled in degree centigrade
6 ta1=35; //The ambient temperature of the air in
   degree centigrade
7 wa=1167; //The mass flow rate of air in kg/s
8 Vg=13; //The inlet velocity of the flue gases in m/s
9 U=30; //The overall heat transfer coefficient in W/m
   ^2K
10 Cpg=1.10; //The specific heat of the flue gas in kJ/
   kgK
11 Cpa=1.005; //The specific heat of the air in kJ/kgK
12 R=0.287; //Real gas constant in kJ/kgK
13 wg=1250; //The mass flow rate of gas in kg/s
14 tg1=450; //The temperature at the inlet of flue gas
   in degree centigrade
15 P=101.325; //Atmospheric temperature in kPa
16 pi=3.1414; //Mathematical constant
17 Di=0.06; //The inner diameter of the tube in m
18 Do=0.065; //The outer diameter of the tube in m
19
20 //Calculations
21 vg1=(R*(273+tg1))/P; //Specific volume of the gas in
   m^3/kg
22 ta2=[(wg*Cpg*(tg1-tg2))/(wa*Cpa)]+ta1; //The
   temperature of the heated air in degree
   centigrade
23 t1m=(75-125)/log(75/125); //The mean temperature of
   the inlet and exit temperature in degree
   centigrade
24 Q=wg*Cpg*(tg1-tg2); //The rate of heat transfer in
   the economiser in kW
25 Ao=[Q/(U*t1m)]*10^3; //The outer area in m^2
26 n=[(wg*(vg1/Vg)*(4/pi)*(1/Di^2))]; //The number of
   coils needed in the economiser
27 l=Ao/(n*pi*Do); //The length of one coil in m
28

```

```

29 //Output
30 printf('(a)The length of the tubes = %3.2f m\n (b)
    The number of tubes = %3.0f ',1,n)

```

---

### Scilab code Exa 6.8 Number of coils needed

```

1
2 clc
3 clear
4 //Input data
5 di=0.05;//The inner diameter of the superheater coil
    in m
6 T=0.005;//The thickness of the coil in m
7 p=60;//The pressure of the steam at the exit in bar
8 t=500;//The temperature of the steam at the exit in
    degree centigrade
9 V2=10;//The velocity of the steam at the exit in m/s
10 ws=80;//The mass flow rate of steam in kg/s
11 H=140;//The heat flux in the super heated coils in
    kW/m^2
12 pi=3.142;//Mathematical constant
13 Do=0.06;//The outer diameter of the tube in m
14
15 //Calculations
16 h1=2784.3;//The enthalpy of the saturated gas at 60
    bar in kJ/kg
17 h2=3422.2;//The enthalpy of the saturated gas at 500
    degreeC in kJ/kg
18 v2=0.05665;//The specific volume of gas at 500
    degreeC in m^3/kg
19 Q=ws*(h2-h1);//Heat absorption rate in superheater
    coil in kW
20 Ao=Q/H;//Surface area required in m^2
21 n=[(ws*(v2/V2)*(4/pi)*(1/di^2))];//The number of
    coils needed in the economiser

```

```
22 l=Ao/(n*pi*Do); //The length of one coil in m
23
24 //Output
25 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

```
1
2 clc
3 clear
4 //Input data
5 p1=10//Initial pressure in bar
6 T1=300+273//Initial temperature in K
7 p2=2//Final pressure in bar
8 m=1//Mass flow rate of steam in kg/s
9
10 //Calculations
11 px=(0.546*p1)//Critical pressure in bar
12 ho=3052.2//Enthalpy in kJ/kg
13 so=7.1229//Entropy in kJ/kg.K
14 sx=so//Entropy in kJ/kg.K
15 hx=2905.9//Enthalpy in kJ/kg
16 vx=0.4125//Specific volume in m3/kg
17 Vx=(44.72*sqrt(ho-hx))//Critical velocity in m/s
18 Ax=(vx/Vx)*104//Minimum area of the nozzle in sq.cm
19
20 //Output
21 printf('Minimum area of the nozzles is %3.3f sq.cm',
```

Ax)

---

### Scilab code Exa 7.2 Minimum area

```
1
2 clc
3 clear
4 //Input data
5 p1=10//Initial pressure in bar
6 T1=300+273//Initial temperature in K
7 p2=1//Final pressure in bar
8 x=0.15//Friction loss of the isentropic enthalpy
   drop
9 ms=1//Steam flow rate in kg/s
10 d=25//Exit diameter of the nozzles in mm
11
12 //Calculations
13 px=(0.546*p1)//Critical pressure in bar
14 h1=3052.2//Enthalpy in kJ/kg
15 s1=7.1276//Entropy in kJ/kg
16 s2s=s1//Entropy in kJ/kg
17 h2s=2916.2//Enthalpy in kJ/kg
18 Vx=(44.72*sqrt(h1-h2s))//Critical velocity in m/s
19 h3s=2605//Enthalpy in kJ/kg
20 V1=(44.72*sqrt((h1-h2s)+(0.85*(h2s-h3s))))//Velocity
   in m/s
21 s3s=s1//Entropy in kJ/kg
22 x3s=(s3s-1.3025)/6.0579//Dryness fraction
23 h3s=(417.46+(x3s*2258.01))//Enthalpy in kJ/kg
24 h2s3=((1-x)*(h2s-h3s))//Enthalpy in kJ/kg
25 h3=h2s-h2s3//Enthalpy in kJ/kg
26 x3=(h3-417.46)/2258.01//Dryness fraction
27 v3=(0.001043+(x3*1.694))//Specific volume in m^3/kg
28 v2s=0.416//Specific volume in m^3/kg
29 vx=v2s//Specific volume in m^3/kg
```

```

30 Ax=(ms/Vx)*vx*10^4//Minimum area in cm^2
31 A1=(ms*v3)/V1*10^4//Area in cm^2
32 n=(A1*4)/(3.14*(d/10)^2)//Number of nozzles
33
34 //Output
35 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

```

1
2 clc
3 clear
4 //Input data
5 p1=7.8//Pressure in bar
6 t1=180+273//Temperature in K
7 p2=1.03//pressure in bar
8 m=3.6//flow rate of air in kg/s
9 g=1.4//Ratio of specific heats
10 R=287//Characteristic gas constant in J/kg.K
11 cp=1.005//Specific heat in kJ/kg.K
12
13 //Calculations
14 pxpo=(2/(g+1))^(g/(g-1))//Ratio of pressure
15 px=pxpo*p1//Critical pressure in bar
16 txto=(2/(g+1))//Ratio of temperatures
17 tx=t1*txto//Critical temperature in K
18 vx=(R*tx)/(px*10^5)//Critical specific volume in m
    ^3/kg
19 Vx=sqrt(g*R*tx)//Critical velocity in m/s
20 Ax=((m*vx)/Vx)*10^6//Critical area in mm^2
21 tot1=(p1/p2)^((g-1)/g)//Ratio of temperatures
22 t1i=t1/tot1//Temperature in K
23 v1=(R*t1i)/(p2*10^5)//Specific volume in m^3/kg
24 V1=44.72*sqrt(cp*(t1-t1i))//Velocity in m/s

```

```

25 A1=((m*v1)/V1)*10^6//Area in mm^2
26
27 //Output
28 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

```

1
2 clc
3 clear
4 //Input data
5 p1=3.8//pressure in bar
6 T1=450+273//Temperature in K
7 p2=1//pressure in bar
8 m=16//Flow rate in kg/s
9 Cd=0.98//coefficient of discharge
10 nv=0.93//nozzile effeciency
11 cp=1.11//Specific heat in kJ/kg.K
12 g=1.333//Ratio of specific heats
13
14 //Calculations
15 pxpo=(2/(g+1))^(g/(g-1))//Pressure ratio
16 px=pxpo*p1//Critical pressure in bar
17 TxTo=2/(g+1)//Temperature ratio
18 Tx=T1*TxTo//Critical temperature in K
19 Vx=44.72*sqrt(cp*(T1-Tx))//critical velocity in m/s
20 R=(cp*(g-1)*1000)/g//Characteristic gas constant in
    J/kg.K
21 vx=(R*Tx)/(px*10^5)//Critical specific volume in m
    ^3/kg
22 ws=(m/Cd)//Mass flow rate in kg/s
23 Ax=(ws*vx)/Vx//Critical area in m^2
24 T1sTo=(p2/p1)^((g-1)/g)//Temperature ratio
25 T1s=T1*T1sTo//Temperature in K

```

```

26 T1i=(T1-(nv*(T1-T1s)))/R//Temperature in K
27 v1=(R*T1i)/(p2*10^5)//Specific volume in m^3/kg
28 V1=44.72*sqrt(cp*(T1-T1i))//Velocity in m/s
29 A1=(ws*v1)/V1//Area in m^2
30
31 //Output
32 printf('Throat area is %3.4f m^2 \n Exit area is %3
    .4f m^2 ',Ax,A1)

```

---

#### Scilab code Exa 7.5 Throat and exit area

```

1
2 clc
3 clear
4 //Input data
5 p1=20//pressure in bar
6 T1=300+273//Temperature in K
7 p2=3//pressure in bar
8 m=0.3//Flow rate in kg/s
9 n=1.3//Adiabatic constant
10 Cd=0.98//Coefficient of discharge
11 Cv=0.92//Coefficient of velocity
12
13 //Calculations
14 vo=0.1255//Specific volume in m^3/kg
15 px=(0.546*p1)//Critical pressure in bar
16 vx=(p1/px)^(1/n)*vo//Critical specific volume in m
    ^3/kg
17 Vx=sqrt(n*px*10^5*vx)//Critical velocity in m/s
18 Ax=((m*vx)/Vx)*10^6//Critical area in m^2
19 v1vo=(p1/p2)^(1/n)//Ratio of specific volumes
20 v1=(vo*v1vo)//Specific volume in m^3/kg
21 V1=sqrt(2*((n/(n-1))*10^5*((p1*vo)-(p2*v1))))//
    Velocity in m/s
22 A1=((m*v1)/V1)*10^6//Area in mm^2

```

```

23 ho=3050//Enthalpy in kJ/kg
24 hx=2920//Enthalpy in kJ/kg
25 h1s=2650//Enthalpy in kJ/kg
26 ws=(m/Cd)//Flow rate in kg/s
27 Vsx=44.72*sqrt(ho-hx)//Velocity in m/s
28 V1s=44.72*sqrt(ho-h1s)//Velocity in m/s
29 Vo1=(V1s*Cv)//Velocity in m/s
30 hoh1=(V1/44.72)^2//Change in enthalpy in kJ/kg
31 h1=ho-hoh1//Enthalpy in kJ/kg
32 x1=(h1-561.47)/2163.8//Dryness fraction
33 vo1=(0.001073+(x1*0.6047))//Specific volume in m^3/
    kg
34 Ao1=((ws*vo1)/Vo1)*10^6//Exit nozzle area in mm^2
35 Vox=(Vsx*Cv)//Velocity in m/s
36 hohx=(Vox/44.72)^2//Change in enthalpy in kJ/kg
37 hox=(ho-hohx)//Enthalpy in kJ/kg
38 vox=0.22//Specific volume in m^3/kg
39 Aox=((ws*vox)/Vox)*10^6//Critical area in m^2
40
41 //Output
42 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)
43 //In textbook , Ao1 is given wrong.

```

---

#### Scilab code Exa 7.6 Mass flow rate

```

1
2 clc
3 clear
4 //Input data
5 p1=5//Pressure of steam in bar
6 V=100//Velocity in m/s
7 p2=1.5//Exit pressure in bar

```

```

8 At=1280//Throat area in mm^2
9 Ae=1600//Exit area in mm^2
10 rp=0.58//Critical pressure ratio
11
12 //Calculations
13 ho=2749//Enthalpy in kJ/kg
14 so=6.822//Entropy in kJ/kg.K
15 px=(rp*p1)//Critical pressure in bar
16 sx=so//Entropy in kJ/kg.K
17 xx=(sx-1.660)/5.344//Dryness fraction
18 hx=(556+(xx*2168))//Enthalpy in kJ/kg
19 Vx=sqrt(((ho+((V^2*10^-3))/2)-hx)*(2/10^-3))//
    Velocity in m/s
20 vx=(xx*0.6253)//Specific volume in m^3/kg
21 w=(At*10^-6*Vx)/vx//Mass flow rate in kg/s
22 s1s=sx//Entropy in kJ/kg.K
23 x1s=(so-1.434)/5.789//Dryness fraction
24 h1s=(467+x1s*2226)//ENthalpy in kJ/kg
25 z=((Vx^2*10^-3)/2)-hx//z value
26 //By iteratio scheme
27 x1=0.932//Dryness fraction
28 v1=1.080//Specific volume in m^3/kg
29 h1=2542//Enthalpy in kJ/kg
30 V1=652.2//Velocity in m/s
31 nn=((hx-h1)/(hx-h1s))//Nozzle efficiency
32
33 //Output
34 printf('Mass flow rate is %3.3f kg/s \n Nozzle
    efficiency is %3.3f',w,nn)

```

---

#### Scilab code Exa 7.7 Exit area

```

1
2 clc
3 clear

```

```

4 //Input data
5 p1=5//Pressure in bar
6 T1=200+273//Temperature in K
7 p2=2//Pressure in bar
8 m=0.3//Mass flow rate in kg/s
9 n=1.3//Adiabatic index
10
11 //Calculations
12 vo=0.4249//Specific volume in m^3/kg
13 ho=2855.4//Enthalpy in kJ/kg
14 so=7.0592//Entropy in kJ/kg.K
15 x1=0.972//Dryness fraction
16 h1=(504.7+x1*2201.9)//Enthalpy in kJ/kg
17 v1=x1*0.8857//Specific volume in m^3/kg
18 V1=44.72*sqrt(ho-h1)//Velocity in m/s
19 A1=((m*v1)/V1)*10^6//Area in mm^2
20 rp=(p1/p2)^(1/n)//Specific volume ratio
21 vR=(vo*rp)//Specific volume in m^3/kg
22 VR=sqrt(2*((n/(n-1))*(p1*vo-p2*vR)*10^5))//Velocity
    in m/s
23 AR=((m*vR)/VR)*10^6//Area in mm^2
24 TR=T1/(p1/p2)^((n-1)/n)//Temperature in K
25 tR=(TR-273)//Temperature in degree C
26 ts=120.23//Saturation temperature at pressure p1 in
    degree C
27 ds=ts-tR//Degree of subcooling in degree C
28 ps=1.4327//Saturation pressure at tR in bar
29 dsu=(p2/ps)//Degree of supersaturation
30
31 //Output
32 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

```
1
2 clc
3 clear
4 //Input data
5 p1=5//Pressure in bar
6 T1=200//Temperature in degree C
7 p2=2//Pressure in bar
8 m=0.3//Mass flow rate in kg/s
9 n=1.3//Adiabatic index
10 nn=0.92//Nozzle efficiency
11 cp=1.925//mean specific heat in kJ/kg.K
12 x=[2.308,1943]//pv*10^3 = 2.308(h-1943)
13
14 //Calculations
15 vo=0.4249//Specific volume in m^3/kg
16 ho=2855.4//Enthalpy in kJ/kg
17 so=7.0592//Entropy in kJ/kg.K
18 x1=0.972//Dryness fraction
19 h1=(504.7+x1*2201.9)//Enthalpy in kJ/kg
20 v1=x1*0.8857//Specific volume in m^3/kg
21 V1=44.72*sqrt(ho-h1)//Velocity in m/s
22 h=ho-h1//Change in enthalpy in kJ/kg
23 hoq=nn*h//Change in enthalpy in kJ/kg
24 VQ=44.72*sqrt(hoq)//Velocity in m/s
25 toq=(hoq/cp)//Temperature difference in degree C
26 tQ=(T1-toq)//Temperature in degree C
27 TQ=tQ+273//Temperature in K
28 vQ=((p1*100*vo)/(T1+273))*(TQ/T1)//Specific volume
    in m^3/kg
29 A1=((m*vQ)/VQ)*10^6//Area in mm^2
30 vQ=(x(1)*(ho-hoq-x(2)))/(10^3*p2)//Specific volume
    in m^3/kg
```

```

31 A11=((m*vQ)/VQ)*10^6//Area in mm^2
32
33 //Output
34 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

```

1
2 clc
3 clear
4 //Input data
5 V1=1000//Speed in m/s
6 Vb=400//Peripheral velocity in m/s
7 a=20//Nozzle angle in degree
8 m=0.75//Mass flow in kg/s
9 f=80//Percentage reduction of relative velocity
10
11 //Calculations
12 b1=atand((V1*sind(a))/((V1*cosd(a))-Vb))//Blade
    angle in degree
13 V=342//Velocity from E7.9 in m/s
14 Vr1=V/sind(b1)//Velocity in m/s
15 dVw=(2*Vr1*cosd(b1))//Velocity in m/s
16 Pt=(m*dVw)//Tangential thrust in N
17 WD=(Pt*Vb)/1000//Diagram power in kW
18 nD=(WD/(0.5*m*V1^2*10^-3))*100//Diagram efficiency
    in percent
19 Pa=0//Axial thrust in N
20 Vr2=(f/100)*Vr1//Velocity in m/s
21 Pa2=m*sind(b1)*(Vr1-Vr2)//Axial thrust in N
22 WD2=(m*(Vr1+Vr2)*cosd(b1)*Vb)/1000//Diagram power in
    kW
23 nD2=(WD2/(0.5*m*V1^2*10^-3))*100//Diagram efficiency
    in percent

```

```

24
25 //Output
26 printf('Blade Angle is %3.2f degrees \n\n Neglecting
    the friction effects \n Tangential force is %3.2
    f 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

```

1
2 clc
3 clear
4 //Input data
5 a=20//Nozzle angle in degrees
6 b2=30//Blade exit angle in degrees
7 Vb=130//Mean blade speed in m/s
8 V1=330//Velocity of steam in m/s
9 f=0.8//Friction factor
10 nn=0.85//Nozzle efficiency
11 p1=20//Pressure in bar
12 T1=250+273//Temperature in K
13 p2=0.07//Pressure in bar
14 rf=1.06//Reheat factor
15
16 //Calculations
17 b1=atand((V1*sind(a))/((V1*cosd(a))-Vb))//Blade
    angle in degrees
18 Vr1=((V1*sind(a))/sind(b1))//Velocity in m/s
19 Vr2=(f*Vr1)//Velocity in m/s
20 dVw=(Vr1*cosd(b1))+(Vr2*cosd(b2))//Vecoity in m/s
21 WD=(dVw*Vb)/1000//Workdone in kJ/kg
22 nb1=((2*dVw*Vb)/V1^2)*100//Efficiency in percent

```

```

23 nst=(nn*nb1)//Efficiency in percent
24 nin=(nst*rf)*100//Efficiency in percent
25 h1=2902.3//Enthalpy in kJ/kg
26 s1=6.5466//Entropy in kJ/kg.K
27 x2s=(s1-0.5582)/7.7198//Dryness fraction
28 h2s=(163.16+x2s*2409.54)//Enthalpy in kJ/kg
29 h12=(0.7041*(h1-h2s))//Change in enthalpy in kJ/kg
30 n=ceil(h12/WD)//Number of stages
31
32 //Output
33 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

```

1
2 clc
3 clear
4 //Input data
5 d=800//Diameter in mm
6 N=3000//Speed in rpm
7 V1=300//Velocity in m/s
8 a=20//Nozzle angle in degrees
9 f=0.86//Frictional factor
10 T=140//Axial thrust in N
11
12 //Calculations
13 Vb=((3.14*(d/1000)*N)/60)//Velocity in m/s
14 b1=atand((V1*sind(a))/((V1*cosd(a))-Vb))//Blade
    angle in degrees
15 b2=b1//Blade angle in degrees
16 Vr1=(V1*sind(a))/sind(b1)//Velocity in m/s
17 Vr2=f*Vr1//Velocity in m/s

```

```

18 w=(T/((Vr1*sind(b1))-(Vr2*sind(b2))))//Mass flow
    rate in kg/s
19 dVw=(Vr2*cosd(b2))+(Vr1*cosd(b1))//Velocity in m/s
20 P=(w*dVw*Vb*10^-3)//Power developed in kW
21
22 //Output
23 printf('Power deveped in the blading is %3.2f kW',P
    )

```

---

### Scilab code Exa 7.12 Thrust Power and efficiency

```

1
2 clc
3 clear
4 //Input data
5 p1=15//Pressure in bar
6 T1=300+273//Temperature in K
7 p2=10//Pressure in bar
8 nn=95//Nozzle efficiency in percent
9 a=20//Nozzle angle in degrees
10 x=5//The blade exit angle is 5 degrees less than the
    inlet angle
11 f=0.9//Friction factor
12 m=1350//Steam flow rate in kg/h
13
14 //Calculations
15 h1=3038.9//Enthalpy in kJ/kg
16 s1=6.9224//Entropy in kJ/kg.K
17 s2=s1//Entropy in kJ/kg.K
18 t2s=250//Temperature in degree C
19 h2s=2943.1//Enthalpy in kJ/kg
20 V1=44.72*sqrt((nn/100)*(h1-h2s))//Velocity in m/s
21 Vb=V1*(cosd(a)/2)//Velocity in m/s
22 b1=atand((V1*sind(a))/((V1*cosd(a))-Vb))//Blade
    angle in degrees

```

```

23 b2=b1-x//Blade angle in degrees
24 Vr1=((V1*sind(a))/sind(b1))//Velocity in m/s
25 Vr2=(f*Vr1)//Velocity in m/s
26 dVw=(Vr1*cosd(b1))+(Vr2*cosd(b2))//Velocity in m/s
27 dVa=(Vr1*sind(b1))-(Vr2*sind(b2))//Velocity in m/s
28 Pa=(m/3600)*dVa//Axial thrust in N
29 Pt=(m/3600)*dVw//Tangential thrust in N
30 WD=(Pt*Vb*10^-3)//Diagram Power in kW
31 dn=((WD*1000)/((1/2)*(m/3600)*V1^2))*100//Diagram
    efficiency in percent
32
33 //Output
34 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

```

1
2 clc
3 clear
4 //Input data
5 V1=600//Velocity in m/s
6 a=16//Nozzle angle in degrees
7 Vb=120//Mean blade angle in degrees
8 b2=18//Exit angle in degrees
9 aa1=22//Exit angle in degrees
10 b4=36//Exit angle in degrees
11 m=5//Steam flow rate in kg/s
12 f=0.85//Friction coefficient
13
14 //Calculations
15 b1=atand((V1*sind(a))/((V1*cosd(a))-Vb))//Exit angle
    in degrees

```

```

16 Vr1=((V1*sind(a))/sind(b1))//Velocity in m/s
17 Vr2=(f*Vr1)//Velocity in m/s
18 a1=atand((Vr2*sind(b2))/((Vr2*cosd(b2))-Vb))//Angle
    in degrees
19 V2=((Vr2*sind(b2))/sind(a1))//Velocity in m/s
20 V3=(f*V2)//Velocity in m/s
21 dVw1=(Vr1*cosd(b1))+(Vr2*cosd(b2))//Velocity in m/s
22 dVa1=(V1*sind(a))-(V2*sind(a1))//Velocity in m/s
23 b3=atand((V3*sind(aa1))/((V3*cosd(aa1))-Vb))//Angle
    in degrees
24 Vr3=((V3*sind(aa1))/sind(b3))//Velocity in m/s
25 Vr4=(f*Vr3)//velocity in m/s
26 dVw2=(Vr3*cosd(b3))+(Vr4*cosd(b4))//Velocity in m/s
27 dVa2=(V3*sind(aa1))-(Vr4*sind(b4))//Velocity in m/s
28 udVw=(dVw1+dVw2)//Total velocity in m/s
29 udVa=(dVa1+dVa2)//Total velocity in m/s
30 Pt=(m*udVw*10^-3)//tangential thrust in kN
31 Pa=(m*udVa*10^-3)//Axial thrust in kN
32 WD=(Pt*Vb)//Power developed in kW
33 nd=((2*udVw*Vb)/V1^2)*100//Diagram efficiency in
    percent
34
35 //Output
36 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

```

1
2 clc
3 clear
4 //Input data
5 a=17//Nozzle angle in degrees

```

```

6 Vb=125//Blade velocity in m/s
7 b2=22//Blade angle n degrees
8 a1=26//Blade angle n degrees
9 b4=30//Blade angle n degrees
10 f=0.9//Friction factor
11 a2=90//Axial angle in degrees
12
13 //Calculations
14 dVw=1040//Velocity in m/s from Velocity triangles
    Fig. E.7.14
15 V1=575//Velocity in m/s from Velocity triangles Fig.
    E.7.14
16 V4=75//Velocity of steam exiting stage in m/s from
    Velocity triangles Fig. E.7.14
17 WD=(dVw*Vb)/1000//Diagram work in kJ/kg
18 nd=((WD*1000)/((1/2)*V1^2))*100//Diagram efficiency
    in percent
19
20 //Output
21 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

```

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

```

```

10 nn=88//Nozzle efficiency in percent
11 y=0.2//Velocity ratio
12 b2=30//Exit blade angle in degrees
13 b4=30//Exit blade angle in degrees
14 f=0.9//Friction coefficient
15 in=75//Internal efficiency of the turbine in percent
16
17 //Calculations
18 h1=3106.4//Enthalpy in kJ/kg
19 s1=6.6643//Entropy in kJ/kg.K
20 x2s=(s1-0.5582)/7.7198//dryness fraction
21 h2s=(163.16+x2s*2409.54)//Enthalpy in kJ/kg
22 dh=(h1-h2s)//Change in enthalpy in kJ/kg
23 h13s=x*dh//Change in enthalpy in kJ/kg
24 h13=(nn/100)*h13s//Change in enthalpy in kJ/kg
25 V1=(44.72*sqrt(h13))//Velocity in m/s
26 Vb=(y*V1)//Velocity in m/s
27 b1=atand((V1*sind(a))/((V1*cosd(a))-Vb))//Angle in
    degrees
28 Vr1=((V1*sind(a))/sind(b1))//Velocity in m/s
29 Vr2=(f*Vr1)//Velocity in m/s
30 dVw1=(Vr1*cosd(b1))+(Vr2*cosd(b2))//Velocity in m/s
31 V2=sqrt((Vr2*sind(b2))^2+((Vr2*cosd(b2))-Vb)^2)//
    Velocity in m/s
32 V3=f*V2//Velocity in m/s
33 b3=atand((V3*sind(b2))/((V3*cosd(b2))-Vb))//Angle in
    degrees
34 Vr3=((V3*sind(b2))/sind(b3))//Velocity in m/s
35 Vr4=f*Vr3//Velocity in m/s
36 dVw2=(Vr3*cosd(b3))+(Vr4*cosd(b4))//Velocity in m/s
37 dVw=(dVw1+dVw2)//Velocity in m/s
38 nb1=((2*dVw*Vb)/V1^2)*100//Efficiency in percent
39 ns=(nn*nb1)/100//Efficiency in percent
40 ht=(in/100)*dh//Total change in enthalpy in kJ/kg
41 hc=(ns/100)*h13s//Total change in enthalpy in kJ/kg
42 pp=(hc/ht)*100//Percentage of enthalpy
43
44 //Output

```

```

45 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

```

1
2 clc
3 clear
4 //Input data
5 R=50//Percentage of reaction
6 b1=35//Angle in degrees
7 q=b1//Angle in degrees
8 b2=20//Angle in degrees
9 a=b2//Angle in degrees
10 N=1500//Speed in rpm
11 d=0.67//Mean diameter in m
12 p=1.5//Pressure in bar
13 x=0.96//Dryness fraction
14 w=3.6//Flow rate in kg/s
15
16 //Calculations
17 Vb=(3.14*d*N)/60//Velocity in m/s
18 V1=(Vb*(sind(180-b1)/sind(b1-b2)))//Velocity in m/s
19 Vr1=(Vb*(sind(b2)/sind(b1-b2)))//Velocity in m/s
20 dVw=(V1*cosd(a))+(Vr1*cosd(q))//Velocity in m/s
21 v1=(0.001052+x*1.15937)//Specific volume in m^3/kg
22 hb=((w*v1)/(3.14*d*V1*sind(a)))*1000//Required
    height in mm
23 P=(w*dVw*Vb)/1000//Power developed in kW
24
25 //Output
26 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

```
1
2 clc
3 clear
4 //Input data
5 N=400//Speed in rpm
6 P=5//Power in MW
7 m=6//Flow rate in kg/kWh
8 b2=20//Blade angle in degrees
9 a=b2//Angle in degrees
10 x=1.35//Velocity ratio
11 p=1.2//Pressure in bar
12 x1=0.95//Steam quality
13 Dh=12//Ratio of Dm and hb
14
15 //Calculations
16 w=(m*P*1000)/3600//Mass flow rate in kg/s
17 v1=(0.0010468+x1*1.454)//Specific volume in m^3/kg
18 hb=((w*v1)/(Dh*3.14*x*((Dh*N)/60)*3.14*sind(a)))
    ^(1/3)*1000//Blade height in mm
19 Vb=((3.14*Dh*(hb/1000)*N)/60)//velocity in m/s
20 V1=(x*Vb)//Velocity in m/s
21 dVw=((2*V1*cosd(a))-Vb)//velocity in m/s
22 WD=(w*dVw*Vb*10^-3)//Diagram power in kW
23
24 //Output
25 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

```

1
2 clc
3 clear
4 //Input data
5 N=3000//Speed in rpm
6 Vb=100//Mean blade speed in m/s
7 x=0.56//Velocity ratio
8 a=20//Blade angle in degrees
9 b2=a//Blade angle in degrees
10 v=0.65//Specific volume in m3/kg
11 h=25//Mean height in mm
12 n=5//Number of pairs of blades
13
14 //Calculations
15 V1=(Vb/x)//Velocity in m/s
16 Vr2=V1//Velocity in m/s
17 Dm=(Vb*60)/(3.14*N)//Diameter in m
18 w=((3.14*Dm*h*V1*sind(a))/v)/1000//Mass flow rate in
    kg/s
19 ws=(w*3600)//Mass flow rate in kg/hr
20 b1=atand((V1*sind(a))/((V1*cosd(a))-Vb))//Blade
    angle in degrees
21 Vr1=((V1*sind(a))/sind(b1))//Velocity in m/s
22 dhmb=(1/2)*(Vr22-Vr12)/1000//Change in enthalpy in
    kJ/kg
23 dsta=(2*dhmb)//Change in enthalpy of stage in kJ/kg
24 dsta5=(n*dsta)//Total Change in enthalpy of stage in
    kJ/kg
25 Dp=(w*dsta5)//Diagram power in kW
26
27 //Output
28 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

```
1
2 clc
3 clear
4 //Input data
5 P=8//Power in MW
6 N=5000//Speed in rpm
7 p=40//pressure in bar
8 T=500//Temperature in degree C
9 p2=0.1//Pressure in bar
10 in=0.85//Internal efficiency of turbine
11 nm=0.96//Mechanical efficiency
12 nn=0.92//Nozzle efficiency
13 a=15//Nozzle angle in degrees
14 Vb=300//Blade velocity in m/s
15
16 //Calculations
17 V1=(2*Vb)/cosd(a)//Velocity in m/s
18 dh=((V1/44.72)^2/nn)//Change in enthalpy in kJ/kg
19 h1=3445.3//Enthalpy in kJ/kg
20 s1=7.0901//Entropy in kJ/kg.K
21 s2=s1//Entropy in kJ/kg.K
22 x2=(s2-0.6493)/7.5009//Dryness fraction
23 h2s=(191.83+x2*2392.8)//Enthalpy in kJ/kg
24 h12s=(h1-h2s)//Change in enthalpy in kJ/kg
25 n=(h12s/dh)//Number of stages
26 w=((P*1000)/(in*nm))/h12s//Mass flow rate in kg/s
27 h13=(nn*dh)//Change in enthalpy in kJ/kg
28 h3=h1-h13//Enthalpy in kJ/kg
29 v3=0.17//Specific volume in m^3/kg
30 A=(w*v3)/V1//Area in m^2
31 hm=(A/(((Vb*60)/N)*sind(a)))*1000//Height in mm
32
33 //Output
34 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

```
1
2 clc
3 clear
4 //Input data
5 p=1.5//Pressure in bar
6 x1=0.9//Dryness fraction
7 m=7//Steam flow rate in kg/s
8 N=3000//Turbine speed in rpm
9 x=0.7//Velocity ratio
10 y=0.75//Velocity ratio
11 a=20//Exit angle in degrees
12 b2=a//Angle in degrees
13 hx=1/10//Fraction of height
14
15 //Calculations
16 v=0.001052+x1*1.15937//Specific volume in m3/kg
17 Dm=((m*v*60)/(3.14*hx*y*3.14*N))^(1/3)//Diameter in
    m
18 hb=Dm*1000*hx//Height in mm
19 Vb=(3.14*Dm*N)/60//Velocity in m/s
20 dVw=((2*x*Vb*cosd(a)/sind(a))-Vb)//Velocity in m/s
21 P=(m*dVw*Vb)/1000//Power developed in kW
22
23 //Output
24 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 diameter of wheel

```

1
2 clc
3 clear
4 //Input data
5 p=40//Pressure in bar
6 T=500//Temperature in degree C
7 p1=0.1//Pressure in bar
8 a=16//Nozzle angle in degrees
9 N=3000//Speed in rpm
10
11 //Calculations
12 h1=3445.3//Enthalpy in kJ/kg
13 s1=7.0901//Entropy in kJ/kg.K
14 s2=s1//Entropy in kJ/kg.K
15 x2s=(s2-0.6493)/7.5009//Dryness fraction
16 h2s=(191.83+x2s*2392.8)//Enthalpy in kJ/kg
17 V1=44.72*sqrt(h1-h2s)//Velocity in m/s
18 Vb=V1*(cosd(a)/2)//Velocity in m/s
19 Dm=(Vb*60)/(3.14*N)//Diameter in m
20 V2=44.72*sqrt((h1-h2s)/2)//Velocity in m/s
21 Vb2=V2*cosd(a)//Velocity in m/s
22 Dm2=(Vb2*60)/(3.14*N)//Diameter in m
23 V3=44.72*sqrt((h1-h2s)/4)//Velocity in m/s
24 Vb3=V3*(cosd(a)/2)//Velocity in m/s
25 Dm3=(Vb3*60)/(3.14*N)//Diameter in m
26 V4=44.72*sqrt(h1-h2s)//Velocity in m/s
27 Vb4=V4*(cosd(a)/4)//Velocity in m/s
28 Dm4=(Vb4*60)/(3.14*N)//Diameter in m
29 V5=44.72*sqrt((h1-h2s)/(2*4))//Velocity in m/s
30 Vb5=V5*cosd(a)//Velocity in m/s
31 Dm5=(Vb5*60)/(3.14*N)//Diameter in m
32
33 //Output
34 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

```

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

---

### Scilab code Exa 7.22 Number of stages

```

1
2 clc
3 clear
4 //Input data
5 p=150//Pressure in bar
6 T=600//Temperature in degree C
7 Vb=300//Velocity in m/s
8 nn=95//Nozzle efficiency in percent
9 a=15//Nozzle angle in degrees
10 a1=25//Angle in degrees
11
12 //Calculations
13 h1=3582.3//Enthalpy in kJ/Kg
14 s1=6.6776//Entropy in kJ/kg.K
15 s2=s1//Entropy in kJ/kg.K
16 x2s=(s2-0.6493)/7.5009//Dryness fraction
17 h2s=(191.83+x2s*2392.8)//Enthalpy in kJ/kg
18 h12s=(h1-h2s)//Difference in enthalpy in kJ/kg
19 V1=(Vb*2)/cosd(a)//Velocity in m/s
20 dhs=(V1/44.72)^2/(nn/100)//Change in enthalpy in kJ/
   kg
21 n1=ceil(h12s/dhs)//Number of stages
22 V2=(Vb/cosd(a1))//Velocity in m/s
23 dhs2=(V2/44.72)^2/(nn/(2*100))//Change in enthalpy
   in kJ/kg
24 n2=h12s/dhs2//Number of stages
25 V3=(Vb*4)/cosd(a)//Velocity in m/s
26 dhs3=(V3/44.72)^2/(nn/100)//Change in enthalpy in kJ
   /kg
27 dhhs3=(h12s-dhs3)//Change in enthalpy in kJ/kg

```

```

28 n3=dhhs3/dhs//Number of stages
29 n4=dhhs3/dhs2//Number of stages
30
31 //Output
32 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

```

1
2 clc
3 clear
4 //Input data
5 p1=20//Pressure in bar
6 T=400//Temperature in degree C
7 p2=0.1//Pressure in bar
8 n=4//Number of stages
9 ns=75//Stage efficiency in percent
10
11 //Calculations
12 h16s=(3250-2282)//Change in enthalpy in kJ/kg
13 h12s=(h16s/n)//Change in enthalpy in kJ/kg
14 p=[8,2.6,0.6]//pressures in bar from Mollier chart
15 h12=(ns/100)*h12s//Change in enthalpy in kJ/kg
16 h23s=(3060-2800)//Change in enthalpy in kJ/kg
17 h23=(ns/100)*h23s//Change in enthalpy in kJ/kg
18 h34s=(2870-2605)//Change in enthalpy in kJ/kg
19 h34=(ns/100)*h34s//Change in enthalpy in kJ/kg
20 h45s=(2680-2410)//Change in enthalpy in kJ/kg
21 h45=(ns/100)*h45s//Change in enthalpy in kJ/kg
22 h5=2470//Enthalpy in kJ/kg

```

```

23 rf=(h12s+h23s+h34s+h45s)/h16s//Reheat factor
24 nth=((h12+h23+h34+h45)/h16s)*100//Internal
    efficiency in percent
25 nin=(ns*rf)//Internal efficiency in percent
26
27 //Output
28 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

```

1
2 clc
3 clear
4 //Input data
5 n=20//Number of stages
6 P=12//Power in MW
7 p=15//Pressure in bar
8 T=350//Temperature in degree C
9 p1=0.14//Pressure in bar
10 ns=75//Stage efficiency in percent
11 rf=1.04//Reheat factor
12 p2=1//Pressure in bar
13 a=20//Angle in degrees
14 v=0.7//Velocity ratio
15 h=1/12//Blade height in terms of mean blade diameter
16
17 //Calculations
18 nint=(ns/100)*rf//Internal efficiency
19 dhs=855//Enthalpy in kJ/kg
20 dha=ceil(nint*dhs)//Actual enthalpy change in kJ/kg
21 w=(P*1000)/dha//Mass flow rate in kg/s
22 Vb=(sqrt(((dha/n)/(((2/v)*cosd(a))-1)*10^-3)))//

```

```

    Velocity in m/s//
23  vg=1.694//Specific volume in m^3/kg
24  Dm=sqrt((w*vg)/(3.14*h*(Vb/v)*sind(a)))//Diameter in
    m
25  N=((Vb*60)/(3.14*Dm))//Speed in rpm
26
27  //Output
28  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
    )
29  //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

```

1
2
3  clc
4  clear
5  //Input data
6  V1=600//Velocity in m/s
7  Vb=120//Mean blade velocity in m/s
8  a=16//Nozzle angle in degrees
9  b=[18,21,35]//Exit angles in degrees
10 m=5//Steam flow rate in kg/s
11 h=25//Nozzle height in mm
12 v=0.375//Specific volume in m^3/kg
13 p=25//Pitch in mm
14 t=0.5//Thickness in mm
15 kb=0.9//Constant
16
17 //Calculations
18 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
19 b1= atand((V1*sind(a))/((V1*cosd(a))-Vb))//Angle in
    degrees
20 Vr1=((V1*sind(a))/sind(b1))//Velocity in m/s
21 Vr2=kb*Vr1//Velocity in m/s
22 V2=sqrt(Vr2^2+Vb^2-2*Vr2*Vb*cosd(b(1)))//Velocity in
    m/s
23 V3=291//Velocity in m/s
24 b3=atand((V3*sind(b(2)))/((V3*cosd(b(2)))-Vb))//
    Angle in degrees
25 Vr3=((V3*sind(b(2)))/sind(b3))//Velocity in m/s
26 Vr4=(Vr3*kb)//Velocity in m/s
27 hb1=((m*v*(h/1000))/(1*((p/1000)*sind(b(1))-(t/1000)
    )*Vr2))*1000//Height in mm
28 hn=((m*v*(h/1000))/(1*((p/1000)*sind(b(2))-(t/1000)
    *V3))*1000//Height in mm
29 hb2=((m*v*(h/1000))/(1*((h/1000)*sind(b(3))-(t/1000)
    )*Vr4))*1000//Height in mm
30
31 //Output
32 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 Interacting steam condition

```

1
2 clc
3 clear
4 //Input data
5 P=200//Power in MW
6 p=180//Pressure in bar
7 T=550//Temperature in degree C

```

```

8 P1=600//Power in MW
9 p1=300//Pressure in bar
10 T1=580//Temperature in degree C
11 nt=90//Turbine efficiency in percent
12
13 //Calculations
14 h1=3430//Enthalpy in kJ/kg
15 h2s=3040//Enthalpy in kJ/kg
16 h12s=(h1-h2s)//Enthalpy in kJ/kg
17 h12=(nt/100)*h12s//Enthalpy in kJ/kg
18 h2=3070//Enthalpy in kJ/kg
19 v2=0.06//Specific volume in m^3/kg
20 h4=3560//Enthalpy in kJ/kg
21 h3s=2000//Enthalpy in kJ/kg
22 h13s=(h1-h3s)//Enthalpy in kJ/kg
23 h13=(nt/100)*h13s//Enthalpy in kJ/kg
24 w=(P*10^3)/h13//Mass flow rate in kg/s
25 Vbm=350//Velocity in m/s
26 N=3000//Speed in rpm
27 a=25//Angle in degrees
28 Dm=(Vbm*60)/(3.14*N)//Diameter in m
29 hD=0.3//Assuming (hb/Dm)max
30 hb=(hD*Dm)//Height in m
31 Ab=(3.14*Dm*hb*0.9*sind(a))//Flow area in m^2
32 V1=(Vbm/cosd(a))//Velocity in m/s
33 Vo=(Ab*V1)//Volume flow rate in m^3/s
34 v=(Vo/w)//Specific volume in m^3/kg
35 h5s=2456//Enthalpy in kJ/kg
36 p5=0.36//Pressure in bar
37 h45s=(h4-h5s)//Enthalpy in kJ/kg
38 h45=(nt/100)*h45s//Enthalpy in kJ/kg
39 h5=h4-h45//Enthalpy in kJ/kg
40 x5=0.952//Dryness fraction
41 h56s=(h5-2340)//Enthalpy in kJ/kg
42 h56=(nt/100)*h56s//Enthalpy in kJ/kg
43 h6=h5-h56//Enthalpy in kJ/kg
44 v6=18//Specific volume in m^3/kg
45 mm=(Vo/v6)//Maximum mass flow that one stage can

```

```

    accommodate in kg/s
46 np=(w/mm)//Number of parallel exhausts
47 rp=(p1/4)//Reheat pressure in bar
48 xh1=3410//Enthalpy in kJ/kg
49 xh2s=3015//Enthalpy in kJ/kg
50 xh12s=xh1-xh2s//Enthalpy in kJ/kg
51 xh12=(nt/100)*xh12s//Enthalpy in kJ/kg
52 xv2=0.035//Specific volume in m^3/kg
53 xh4=3060//Enthalpy in kJ/kg
54 xh3s=1960//Enthalpy in kJ/kg
55 xh13s=xh1-xh3s//Enthalpy in kJ/kg
56 xh3=(xh1-xh13s)//Enthalpy in kJ/kg
57 xw=(P1*10^3)/xh13s//Mass flow rate in kg/s
58 xvm=(Vo/xw)//Maximum specific volume in m^3/kg
59 Vf=(xw*xv2)//Volume flow rate in m^3/s
60 xh5s=2300//Enthalpy in kJ/kg
61 xh45s=xh4-xh5s//Enthalpy in kJ/kg
62 xh45=(nt/100)*xh45s//Enthalpy in kJ/kg
63 xh5=xh4-xh45s//Enthalpy in kJ/kg
64 xv5=1.25//Specific volume in m^3/kg
65 xx5=0.86//Dryness fraction
66 xh6s=2050//Enthalpy in kJ/kg
67 xh56s=xh5-xh6s//Enthalpy in kJ/kg
68 xh56=(nt/100)*xh56s//Enthalpy in kJ/kg
69 xh6=(xh5-xh56)//Enthalpy in kJ/kg
70 xv6=12//Specific volume in m^3/kg
71 xx6=0.792//Dryness fraction
72 xmm=(Vo/xv6)//Maximum mass flow in kJ/kg
73 xnp=ceil(xw/xmm)//Number of parallel exhausts
74
75 //Output
76 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

```
1
2 clc
3 clear
4 //Input data
5 P=100//Power in MW
6 T=550//temperature in degree C
7 p=0.1//Pressure in bar
8 m=500000//Mass flow rate in kg/h at rated load
9 mo=25000//Mass flow rate in kg/h at zero load
10 x=[1/4,1/2,3/4,1]//Fraction of load
11
12 //Calculations
13 b=(m-mo)/(P*10^3)//Steam rate in kg/kWh
14 y1=(x(1)*(P*10^3))//For one-fourth load
15 s1=(mo/y1)+b//Steam rate in kg/kWh
16 y2=(x(2)*(P*10^3))//For one-fourth load
17 s2=(mo/y2)+b//Steam rate in kg/kWh
18 y3=(x(3)*(P*10^3))//For one-fourth load
19 s3=(mo/y3)+b//Steam rate in kg/kWh
20 y4=(x(4)*(P*10^3))//For one-fourth load
21 s4=(mo/y4)+b//Steam rate in kg/kWh
22 h1=3511//Enthalpy in kJ/kg
23 xs1=6.8142//Entropy in kJ/kg.K
24 xs2=xs1//Entropy in kJ/kg.K
25 x2s=(xs2-0.6493)/7.5009//Dryness fraction
26 h2s=191.83+x2s*2392.8//Enthalpy in kJ/kg
27 nR=((h1-h2s)/(h1-191.83))*100//Rankine efficiency in
    percent
28 nac=((P*10^3*3600)/(m*(h1-191.83)))*100//Actual
    efficiency in percent
29 nTG=((P*10^3*3600)/(m*(h1-h2s)))*100//Turbogenerator
    efficiency in percent
30
31 //Output
32 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

```
1
2 clc
3 clear
4 //Input data
5 ws=250; //The amount of steam received by the surface
        condenser in t/h
6 tsat=40; //The saturated temperature in degree
        centigrade
7 m=12; //The amount of moisture present in the steam
        in percentage
8 tc1=32; //The inlet temperature of cooling water in
        degree centigrade
9 tc2=38; //The outlet temperature of cooling water in
        degree centigrade
10 p=0.078; //The pressure inside the condenser in bar
11 V=1.8; //velocity of circulating water in m/s
12 do=0.0254; //The outer diameter of the condenser
        tubes in m
13 T=0.00125; //The thickness of the condenser tubes in
```

```

    m
14 pi=3.141; //Mathematical constant of pi
15 U=2.6; //The overall heat transfer coefficient in kW/
    m^2K
16 Cpc=4.187; //The specific heat of water in kJ/kgK
17 R=0.287; //Real gas constant in kJ/kgK
18 P=1000; //The density of water in kg/m^3
19
20 // Calculations
21 x2=0.88; //The quality of the steam
22 hfg=2407; //The enthalpy of evaporation at 40 degreeC
    in kJ/kg
23 h=x2*hfg; //The change in enthalpy in kJ/kg
24 di=do-(2*T); //The inner diameter of the condenser
    tubes in m
25 wc=[(ws*1000)/3600]*h]/(Cpc*(tc2-tc1)); //Mass flow
    rate of water in kg/s
26 psat=0.07375; //The saturated pressure at 40 degree
    centigrade in bar
27 pair=(p-psat)*100; //The pressure of air in kPa
28 vf=0.001008; //Specific volume of saturated liquid in
    m^3/kg
29 vfg=19.544; //Specific volume of vapour in m^3/kg
30 v2=vf+(x2*vfg); //Specific volume at 40 degree
    centigrade in m^3/kg
31 wair=[pair*[(ws*1000)/3600]*v2]/(R*(tsat+273)); //
    Mass flow rate of air in kg/s
32 t1m=(8-2)/log(8/2); //The mean temperature in degree
    centigrade
33 Ao=[[(ws*1000)/3600]*h]/(U*t1m); //The area of the
    tubes in m^2
34 n=(wc*(4/pi)*(1/di^2)*(1/(P*V))); //The number of
    tubes
35 l=Ao/(pi*do*n); //The length of tubes in m
36
37 //Output
38 printf('(a) The rate of flow of cooling water = %3.1
    f 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

```
1
2 clc
3 clear
4 //Input data
5 ws=20;//The amount of dry saturated steam received
   by a surface condenser in t/h
6 tsh=40;//The temperature of dry saturated steam in
   degree centigrade
7 wa=(0.35/1000);//The mass flow rate of air per 1000
   kg of steam in kg
8 tc=38;//The temperature at which condensate leaves
   the temperature in degree centigrade
9 tm=10;//The temperature at which makeup water is
   supplied in degree centigrade
10 tc1=32;//The inlet temperature of cooling water in
   degree centigrade
11 tc2=38;//The outlet temperature of cooling water in
   degree centigrade
12 tas=27;//The temperature of air along with steam in
   degree centigrade
13 psat=0.07384;//The saturated pressure at 40 degree C
   in bar
14 vg=19.52;//The specific volume at 40 degree C in m
   ^3/kg
15 R=0.287;//Real gas constant in kJ/kgK
16 Cpc=4.187;//The specific heat of water in kJ/kgK
17 Cp=1.005;//The specific heat of air in kJ/kgK
18
19 //Calculations
```

```

20 pair=[(wa*R*(tsh+273)*1000)/vg]*10^-5; //The pressure
    of air in bar
21 psat1=0.06624; //The saturated pressure at 38 degree
    C in bar
22 vg1=21.63; //The specific volume at 38 degree C in m
    ^3/kg
23 pair1=psat-psat1; //The pressure of air in bar
24 wa1=(ws*1000)*wa; //Mass of air removed per hour in
    kg/h
25 V1=((wa1*R*(273+tc2)*1000))/(pair1*10^5); //Volume of
    air remove per hour
26 ws1=V1/vg1; //The mass of steam accompanying air in
    kg/h
27 psat2=0.03564; //The saturated pressure at 27 degree
    C in bar
28 vg2=38.81; //The specific volume at 27 degree C in m
    ^3/kg
29 pair2=psat-psat2; //The pressure of air in bar
30 V2=(wa1*R*1000*(tas+273))/(pair2*10^5); //Volume of
    air removed per hr in m^3/hr
31 ws2=V2/vg2; //The mass of steam accompanying air in
    kg/h
32 ws3=ws1-ws2; //Saving mass of steam by using seperate
    extraction in kg/hr
33 Q3=[ws3*Cpc*(tc-tm)]/3600; //Saving in heat supply in
    the boiler in kW
34 V=[(V1-V2)/V1]*100; //Percentage reduction in air
    ejector load in %
35 hc=159.3; //Enthalpy at 38 degree C in kJ/kg
36 hs1=2574.3; //Enthalpy at 40 degree C in kJ/kg
37 hs2=2550.3; //Enthalpy at 27 degree C in kJ/kg
38 Q2=[[(ws*1000)*(hs1-hc)]-[(wa1*(Cp*(tsh-tas)))]-(ws3
    *hs2)]/3600; //The amount of heat in kW
39 wc=Q2/(Cpc*(tc2-tc1)); //The mass flow rate of water
    in kg/s
40
41 //Output
42 printf('(a) The rate of saving of condensate and the

```

rate of saving in the heat supply in the boiler  
 due to separate air extraction pump = %3.3f kW \n  
 (b) The percentage reduction in air ejector load  
 due to this separate 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

```

1
2 clc
3 clear
4 //Input data
5 tw3=30; //The inlet temperature of water in degree
   centigrade
6 wc=1.15; //Mass flow rate of cooling water in kg per
   kg air
7 tdb1=20; //The dry bulb temperature of air in degree
   centigrade
8 R1=60; //Relative humidity of air while entering in
   percentage
9 tdb2=28; //The dry bulb temperature while leaving in
   degree centigrade
10 R2=90; //Relative humidity of air while leaving in
   percentage
11 tm=20; //The temperature of makeup water in degree
   centigrade
12 Cpc=4.187; //The specific heat of water in kJ/kgK
13 G=1; //Mass flow rate of dry air in kg/s
14
15 //Calculations
16 twb1=15.2; // from psychrometric chart The wet bulb
   temperature while entering in degree centigrade
17 twb2=26.7; // from psychrometric chart The wet bulb
   temperature while leaving in degree centigrade

```

```

18 h1=43; //The enthalpy from chart for dry air in kJ/kg
    dry air
19 h2=83.5; //The enthalpy from chart in kJ/kg dry air
20 W1=0.0088; //Humidity in kg water vapour/kg dry air
21 W2=0.0213; //Humidity in kg water vapour/kg dry air
22 hw3=125.8; //Enthalpy of water entering the tower in
    kJ/kg
23 hw=84; //Enthalpy of makeup water in kJ/kg
24 hwc=[(G/wc)*[(h2-h1)-(W2-W1)*hw]]; //The change in
    enthalpy of water in kJ/kg
25 tw4=tw3-(hwc/Cpc); //The exit temperature of water in
    degree centigrade
26 ta=tw4-twb1; //The approach temperature in degree
    centigrade
27 tr=tw3-tw4; //The range temperature in degree
    centigrade
28 x=G*(W2-W1); //Fraction of water evaporated in kg/kg
    dry air
29
30 //Output
31 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

```

1
2 clc
3 clear
4 //Input data
5 tw3=45; //The temperature of warm water in degree

```

```

        centigrade
6  wc1=6; //The cooling water inflow in kg/s
7  V=10; //volume flow of ID fan in m^3/s
8  Ws=4.90; //Heat absorbed by air in kW
9  ti=20; //The temperature of air entering the tower in
        degree centigrade
10 R=60; //The relative humidity in percentage
11 to=26; //The temperature of air leaving the tower in
        degree centigrade
12 p=1.013; //The constant pressure throughout the tower
        in bar
13 r=0.287; //Real gas constant in kJ/kgK
14 Cpc=4.187; //The specific heat of water in kJ/kgK
15 Cp=1.005; //The specific heat of air in kJ/kgK
16
17 //Calculations
18 ps=0.0234; //The pressure at 20 degreec in bar
19 ps1=(R/100)*ps; //The pressure of water vapour in bar
20 pa1=p-ps1; //The pressure of air in bar
21 G1=(pa1)/(r*10^-3*(ti+273)); //The mass flow rate of
        dry air in kg/s
22 w1=(ps1*10^5*V)/(0.4619*10^3*(ti+273)); //Mass flow
        rate of vopour in kg/s
23 W1=w1/G1; //Moisture flow in kg vap/kg dry air
24 ps2=0.0336; //The pressure at 26 degree C at exit in
        bar
25 pw2=0.0336; //The pressure of water vapour at 26
        degree C at exit in bar
26 W2=(0.622)*(pw2/(1-pw2)); //oisture flow in kg vap/kg
        dry air
27 G2=G1; //The mass flow rate of dry air in kg/s
28 w2=W2*G2; //Moisture flow at exit in kg/s
29 wm=w2-w1; //Makeup water required in kg/s
30 wc2=wc1-wm; //The cooling water outflow in kg/s
31 hw3=Cpc*tw3; //The enthalpy of warm water in kJ/kg
32 hg=2538.1; //The enthalpy of gas at 20 degree C in kJ
        /kg
33 tsat=12; //The saturation temperature in degree

```

```

centigrade
34 pw1=0.01404; //The pressure at 12 degree C in bar
35 hw1=hg+(1.88*(ti-tsat)); //The enthalpy of warm water
    in kJ/kg
36 hw2=2548.4; //The enthalpy of evaporation at 26
    degree C in kJ/kg
37 hw4=[[G1*[(Cp*(to-ti))+W2*hw2-W1*hw1]-Ws]-(wc1*hw3)
    ]/-wc2; //The enthalpy of warm water at point 4 in
    kJ/kg
38 E=hw4/Cpc; //Exit water temperature in degree
    centigrade
39
40 //Output
41 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

```
1
2 clc
3 clear
4 //Input data
5 mp=1.007277; //Atomic Mass of proton in amu
6 mn=1.008665; //Atomic Mass of neutron in amu
7 me=0.00055; //Atomic Mass of electron in amu
8 mo=15.99491; //Atomic Mass of oxygen in amu
9 np=8; //Number of protons in oxygen
10 ne=8; //Number of electrons in oxygen
11 nn=8; //Number of neutrons in oxygen
12 a=931; //One amu in MeV
13 No=16; //Number of nucleons in oxygen
14
15 //Calculations
16 m=(np*mp)+(ne*me)+(nn*mn)-mo; //The mass defect in
    amu
17 B=m*a; //Binding energy in MeV
18 Bn=B/No; //Binding energy per nucleon
19
20 //Output
```

```
21 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

```
1
2 clc
3 clear
4 //Input data
5 amr=226.095; //Atomic mass of radium in amu
6 AC=6.023*10^23; //Avogadro constant in molecules/g.
    mol
7 h=1620; //Half life of radium in years
8
9 //Calculations
10 D=(0.6931/(h*365*24*3600)); //The decay constant in
    1/s
11 Na=AC/amr; //Number of atoms per gram of radium
12 Ao=D*Na; //Initial activity in dis/s
13
14 //Output
15 disp(D,"The decay constant (in s^-1) = ");
16 disp(Ao,"The initial activity of 1 g of radium 226
    in dis/s) = ");
```

---

### Scilab code Exa 9.3 Fuel consumption

```
1
2 clc
3 clear
4 //Input data
5 F=190; //Each fission of U-235 yeilds in MeV
```

```

6 a=85; //Assuming the Neutrons absorbed by U-235 cause
    fission in percentage
7 b=15; //Non fission capture to produce an isotope U
    -236 in percentage
8 Q=3000; //The amount of thermal power produced in MW
9
10 //Calculations
11 E=F*1.60*10^-13; //Each fission yields a useful
    energy in J
12 N=1/E; //Number of fissions required
13 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
14 M=(B*235)/(6.023*10^23); //Mass of U-235 consumed to
    produce one MW power in g/day
15 M1=M*3; //Mass of U-235 consumed to produce 3000 MW
    power in g/day
16
17 //Output
18 printf('The fuel consumed of U-235 per day = %3.1f g
    /day ',M1)

```

---

#### Scilab code Exa 9.4 Area required

```

1
2 clc
3 clear
4 //Input data
5 sa1=10; //Cross section of nucleus in barns
6 N=2200; //Neutrons in m/s
7 En1=0.1; //Kinetic energy of neutrons increases in eV
8 En2=0.02525; //Kinetic energy of neutron in eV
9
10 //Calculations
11 sa2=sa1/[(En1/En2)^0.5]; //The cross section of

```

```

        neutrons in barns
12
13 //Output
14 printf('The cross section of neutrons = %3.2f barns
        ',sa2)

```

---

### Scilab code Exa 9.5 Microscopic absorption

```

1
2 clc
3 clear
4 //Input data
5 U1=99.285;//Uranium consists of U-238 in percentage
6 U2=0.715;//Uranium consists of U-235 in Percentage
7 E=0.025;//The energy of neutrons in eV
8 sc=2.72;//Capture cross section for U-238 in barns
9 sf=0;//fission cross section for U-238 in barns
10 sc1=101;//Capture cross section for U-235 in barns
11 sf1=579;//fission cross section for U-235 in barns
12
13 //Calculations
14 sa=(U1/100)*(sc+sf)+(U2/100)*(sc1+sf1);//The
        microscopic absorption cross section of natural
        uranium in barns
15
16 //Output
17 printf("The microscopic absorption cross section of
        natural uranium = %3.1f barns ',sa)

```

---

### Scilab code Exa 9.6 Microscopic absorption

```

1
2 clc

```

```

3 clear
4 //Input data
5 p=1;//The density of water in g/cm^3
6 sch=0.332;//The microscopic capture cross section of
  hydrogen in barn
7 sco=0.0002;//The microscopic capture cross section
  of oxygen in barn
8
9 //Calculations
10 N=(6.023*10^23)*p/18;//Number of molecules of water
  per cm^3
11 scw=(2*N*sch*10^-24)+(N*sco*10^-24);//The
  microscopic capture cross section of water in cm
  ^-1
12
13 //output
14 printf('The microscopic capture cross section of
  water = %3.4f cm^-1 ',scw)

```

---

#### Scilab code Exa 9.7 Thermal neutron flux

```

1
2 clc
3 clear
4 //Input data
5 m=230;//The amount of boron piece in g
6 mw=10;//The molecular weight of boron
7 R=9.57*10^13;//Reaction rate in cm^-3s^-1
8 d=2.3;//Density of boron in g/cm^3
9 sa=755;//Absorbption cross section in barns
10 ss=4;//Elastic scattering cross section in barns
11
12 //Calculations
13 st=sa+ss;//The total cross section in barns
14 N=(d*6.023*10^23)/mw;//The number density of

```

```

    neutrons in cm-3
15 S=N*st*10-24; //Number density of neutrons for total
    in cm-1
16 F=R/S; //Neutron flux in cm-2s-1
17 L=1/S; //Average distance a neutron travels before it
    is absorbed in cm
18
19 //Output
20 disp(F,"The thermal neutron flux (in cm-2s-1) = ")
    ;
21 disp(L,"The average distance that a neutron travels
    before it is absorbed (in cm) = ");

```

---

#### Scilab code Exa 9.8 Number of collisions

```

1
2 clc
3 clear
4 //Input data
5 Eni=4.8; //The energy of the newly born electron in
    MeV
6 Enf=0.025; //The energy of the electron after slow
    down in eV
7 A=12; //The mass number of the graphite (carbon)
8
9 //Calculations
10 L=1-[[ (A-1)2/(2*A) ]*log((A+1)/(A-1))]; //The
    logarithmic energy decrement
11 n=(log(Eni*106/Enf))/L; //The number of collisions
    required to slowdown the neutron
12
13 //Output
14 printf('The logarithmic energy decrement
    representing the neutron energy loss per elastic
    collision = %3.3f \n The number of collisions

```

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

---

### Scilab code Exa 9.9 Rating of reactor

```
1
2 clc
3 clear
4 //Input data
5 f=100; //The reactor is fuelled of natural uranium in
   tonnes
6 A=238.05; //The atomic mass of natural uranium
7 F=10^13; //The average thermal neutron flux in
   neutrons/cm^2s
8 A1=235.04; //The atomic mass of U-235
9 sf=579; //The fission cross section of U-235 in barns
10 sc=101; //The capture cross section of U-235 in barns
11 E=200; //The energy released per fission in MeV
12 P=0.715; //U-235 in natural uranium in percentage
13 N=2200; //The average thermal neutron in m/s
14
15 //Calculations
16 n=[(f*1000)*6.023*10^26*(P/100)]/A; //The number of U
   -235 atoms in the reactor in atoms
17 R=(sf*10^-24)*F*n; //The rate of fission in the
   reactor in fissions/s
18 T=R*E*1.602*10^-19; //Thermal power of the reactor in
   MW
19 Rr=T/f; //Rating the reactor MW/tonne
20 Rc=[[(R*A1*60*60*24)]/(6.023*10^26)]; //The rate of
   consumption of U-235 by fission in kg/day
21 Rcc=Rc*1000; //The rate of consumption of U-235 by
   fission in g/day
22
23 //Output
24 printf('(a) The rating of the reactor = %3.2 f MW/
```

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

---

### Scilab code Exa 9.10 Specific energy release rate

```
1
2 clc
3 clear
4 //Input data
5 f=3.5; //Mass fraction of U-235 in the fuel in
   percentage
6 G=180; //Energy per fission in Mev
7 F=10^13; //The neutron flux in neutrons/cm^2s
8 sf=577; //Fission cross section of U-235 in barns
9 M=1.602*10^-13; //One MeV in J
10
11 //Calculations
12 N=2.372*(f/100)*10^22; //The fuel density for a
   uranium oxide fuel in nuclei/cm^3
13 q=G*N*sf*10^-24*F; //The rate of energy release in
   MeV/cm^3s
14 qg=q*M; //The rate of energy release in W/cm^3
15
16 //Output
17 printf('The specific energy release rate for a light
   water uranium reactor = %3.2 f W/cm^3 ',qg)
```

---

### Scilab code Exa 9.11 Reactor power level

```
1
2 clc
3 clear
4 //Input data
```

```
5 P=1; //The operating power of a reactor in W
6 K=1.0015; //The effective multiplication factor of
  Reactor becomes suppercritical
7 t=0.0001; //The average neutron life in s
8 t1=1.0001; //Neutron life time in s
9
10 // Calculations
11 d=(K-1)/K; //The reactivity
12 Z=(d*P)/t; //The number of neutrons
13 n=exp(Z)/10^6; //Neutron density * 10^6
14
15 //Output
16 printf('The reactor power level at the end of 1s is
  %3.3f MW',n)
```

---

# Chapter 10

## Hydroelectric power plant

Scilab code Exa 10.1 Efficiency of the runner

```
1
2 clc
3 clear
4 //Input data
5 P=4000//Power in kW
6 N=400//Speed in r.p.m
7 h=200//Head in m
8 e=90//Efficiency in percent
9 d=1.5//Diameter in m
10 vd=10//Percentage decrease in velocity
11 a=165//Angle with which jet is deflected in degrees
12
13 //Calculations
14 V1=sqrt(2*9.81*h*(e/100))//Velocity in m/s
15 Vb=(3.14*d*N)/60//Velocity in m/s
16 nn=((2*(1-((e/100)*cosd(a)))*(V1-Vb)*Vb)/V1^2)*100//
    Efficiency in percent
17 p=(P/(nn/100))//Power developed in kW
18 pj=(p/2)//Power developed per jet in kW
19 dx=sqrt((pj*8)/(3.14*V1^3))//Diameter of each jet in
    m
```

```

20
21 //Output
22 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

```

1
2 clc
3 clear
4 //Input data
5 P=6000//Power in kW
6 h=300//Net head availabe in m
7 N=550//Speed in r.p.m
8 rd=(1/10)//Ratio of jet diameter to wheel diameter
9 nh=0.85//Hydraulic efficiency
10 Cv=0.98//Coefficient of velocity
11 f=0.46//Speed ratio
12 d=1000//Density in kg/m^3
13
14 //Calculations
15 V1=Cv*sqrt(2*9.81*h)//Velocity in m/s
16 Vb=f*sqrt(2*9.81*h)//Velocity in m/s
17 Q=((P*10^3)/(nh*d*9.81*h))//Discharge in m^3/s
18 D=((Vb*60)/(3.14*N))//Diameter in m
19 d=(D/10)//Diameter of jet in m
20 n=(Q/((V1*(3.14/4)*d^2))//Number of jets
21
22 //Output
23 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

```
1
2 clc
3 clear
4 //Input data
5 P=10//Capacity in MW
6 h=500//Head in m
7 Ns=10//Specific speed of the turbine
8 on=80//Overall efficiency in percent
9 Cv=0.98//Coefficient of velocity
10 x=0.46//Speed of the bucket wheel to the velocity of
    jet
11 da=1000//Density in kg/m^3
12
13 //Calculations
14 N=(Ns*h^(5/4))/sqrt(P*10^3)//Speed in r.p.m
15 V=(Cv*sqrt(2*9.81*h))//Velocity in m/s
16 Vb=(x*V)//Speed of bucket wheel in m/s
17 D=((60*Vb)/(3.14*N))//Diameter in m
18 d=sqrt((P*10^6)/((on/100)*(3.14/4)*da*V*9.81*h))//
    Diameter in m
19
20 //Output
21 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

```
1
2 clc
3 clear
```

```

4 //Input data
5 Cv=0.97//Coefficient of velocity
6 f=0.45//Friction coefficient
7 h=0.85//Head in m
8 d=1000//Density in kg/m^3
9 n=1//For a single jet turbine
10
11 //Calculations
12 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
13
14 //Output
15 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

```

1
2 clc
3 clear
4 //Input data
5 n=4//Number of jets
6 d=60//Diameter of each jet in mm
7 a=165//Angle in degrees
8 v=45//Speed of the bucket wheel in m/s
9 de=1000//Density in kg/m^3
10
11 //Calculations
12 v1=(2*v)//Jet velocity in m/s
13 Q=(3.14/4)*(d/1000)^2*v1//Discharge in m^3/s
14 P=(1-cosd(a))*(v1^2/4)*Q*de*10^-3//Power developed
    in kW

```

```

15 P4=(P*4)//For four jets in kW
16 nd=((1-cosd(a))/2)*100//Maximum efficiency in
    percent
17
18 //Output
19 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

```

1
2 clc
3 clear
4 //Input data
5 v=20//Peripheral velocity in m/s
6 vw=17//Velocity of whirl in m/s
7 vr=2//Radial velocity in m/s
8 Q=0.7//Flow in m^3/s
9 hn=80//Hydraulic efficiency in percent
10 d=1000//Density in kg/m^3
11
12 //Calculations
13 H=((vw*v)/(9.81*(hn/100)))//Head on the wheel in m
14 P=(d*Q*9.81*H*(hn/100)*10^-3)//Power generated in kW
15 a1=180-atan(vr/vw)//Angle of guide vanes in degrees
16 b1=atan(vr/(v-vw))//Inlet blade angle in degrees
17
18 //Output
19 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,a1,b1)

```

---

Scilab code Exa 10.7 Outlet and inlet blade angles

```
1
2 clc
3 clear
4 //Input data
5 od=1.5//Outer diameter in m
6 id=0.75//Inner diameter in m
7 h=150//Head in m
8 P=14000//Power in kW
9 Ns=120//Specific speed
10 vw2=0//Velocity in m/s
11 a=(11+(20/60))//Angle in degrees
12 hn=92//Hydraulic efficiency in percent
13
14 //Calculations
15 N=(Ns*h^(5/4))/sqrt(P)//Speed in rpm
16 vb1=(3.14*od*N)/60//velocity in m/s
17 vw1=((hn/100)*9.81*h)/vb1//velocity in m/s
18 vf1=(tand(a)*vw1)//Velocity in m/s
19 vf2=vf1//Velocity in m/s
20 b1=atand(vf1/(vb1-vw1))//Angle in degrees
21 b1x=(b1-int(b1))*60//For output
22 vb2=(vb1/2)//Velocity in m/s
23 b2=atand(vf1/(vb2-vw2))//Angle in degrees
24 b2x=(b2-int(b2))*60//For output
25
26 //Output
27 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

```
1
2 clc
3 clear
4 //Input data
5 h=70//net head in m
6 N=700//speed in rpm
7 o=85//over all efficiency in %
8 P=350//shaft power in kW
9 he=92//hydraulic efficiency in %
10 fr=.22//flow ratio
11 b=.1//breadth ratio
12 s=2//outer diameter in terms of inner diameter
13 //Calculations
14 vf1=fr*sqrt(2*9.81*h)//velocity in m/s
15 q=(P/(9.81*h*(o/100)))//discharge in m3/s
16 d1=sqrt(q/(.94*b*vf1*3.14))//diameter in metre
17 b1=d1*b//breadth in metre
18 d2=d1/2//diameter in metre
19 vb1=(3.14*d1*N)/60//velocity in m/s
20 vw1=((he/100)*9.81*h)/vb1//velocity in m/s
21 a=atand(vf1/vw1)//angle in degrees
22 bet=atand(vf1/(vw1-vb1))//angle in degrees
23 vb2=(d2/d1)*vb1//velocity in m/s
24 bet2=atand(vf1/vb2)//angle in degrees
25
26 //Output
27 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
    diameters 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

```
1
2 clc
3 clear
4 //Input data
5 n=4//Number of units
6 P=70000//Power in kVA
7 f=50//Frequency in Hz
8 p=10//No.of pair of poles
9 h=505//Gross head in m
10 tn=94//Transmission efficiency in percent
11 po=260//Power in MW
12 e=91//Efficiency in percent
13 nn=0.98//Nozzle efficiency
14 Cv=0.98//Coefficient of velocity
15 x=0.48//Vb=0.48 V
16 dd=25//Nozzle diameter is 25% bigger than jet
    diameter
17 a=165//Angle of buckets in degrees
18 de=99.75//Discharge efficiency in percent
19
20 //Calculations
21 N=(120*f)/(p*2)//Synchronous speed in r.p.m
22 nh=((tn/100)*h)//Net head in m
23 pt=(po*10^3)/n//Power developed per turbine in kW
24 ip=(pt/(e/100))//Input water power in kW
25 Q=(ip/(9.81*nh))//Discharge in m^3/s
26 Qj=(Q/n)//Discharge per jet in m^3/s
27 V1=Cv*sqrt(2*9.81*nh)//Velocity in m/s
28 d=sqrt((4/3.14)*(Qj/V1))//Diameter of jet in m
29 nd=(1+(dd/100))*d//Nozzle tip diameter in m
30 Vb=(x*V1)//Velocity in m/s
31 D=((Vb*60)/(3.14*N))//Pitch circle diameter of the
```

```

    wheel in m
32 Ns=((N*sqrt(po*10^3))/nh^(5/4))//Specific speed
33 jr=(D/d)//Jet ratio
34 nob=(jr/2)+15//Number of buckets
35 nobb=ceil(nob)//Rounding off to next integer
36 W=((V1-Vb)*(1-(nn*cosd(a)))*Vb)/9.81//Workdone per
    kg in kg.m/kg
37 nth=((W/nh)*de)//Hydraulic efficiency in percent
38
39 //Output
40 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

```

1
2 clc
3 clear
4 //Input data
5 gh=35//Gross head in m
6 md=2//Mean diameter in m
7 N=145//Speed in rpm
8 a=30//Angle in degrees
9 oa=28//Outlet angle in degrees
10 x=7//Percentage of gross head lost
11 y=8//Reduction in relative velocity in percent
12
13 //Calculations

```

```

14 H=((100-x)/100)*gh//Net head in m
15 V1=sqrt(2*9.81*H)//Velocity in m/s
16 Vb=(3.14*md*N)/60//Velocity in m/s
17 b1=atand((V1*sind(a))/((V1*cosd(a))-Vb))//Angle in
    degrees
18 Vr1=((V1*sind(a))/sind(b1))//Velocity in m/s
19 Vr2=((100-y)/100)*Vr1//Velocity in m/s
20 Vw1=(V1*cosd(a))//Velocity in m/s
21 Vw2=(Vb-(Vr2*cosd(a)))//Velocity in m/s
22 E=((Vb*(Vw1-Vw2))/9.81)//Workdone in kg.m/kg
23 nb=(E/gh)*100//Hydraulic efficiency in percent
24
25 //Output
26 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

```

1
2 clc
3 clear
4 //Input data
5 P=10000//Power in kW
6 h=12//Head in m
7 Nr=2//Speed ratio
8 Fr=0.65//Flow ratio
9 x=0.3//Diameter of hub is 0.3 times the external
    diameter of the vane
10 on=94//Overall efficiency in percent
11
12 //Calculations
13 Q=(P/(9.81*h*(on/100)))//Discharge in m^3/s
14 Vr1=(Fr*sqrt(2*9.81*h))//Velocity in m/s
15 Ab=(Q/Vr1)//Area of flow in m^2
16 D=sqrt(((Ab*4)/3.14)/(1-x^2))//Diameter of runner in

```

```

    m
17 Vb=(Nr*sqrt(2*9.81*h))//Velocity in m/s
18 N=((Vb*60)/(3.14*D))//Speed in rpm
19 f=50//Taking frequency as 50 Hz
20 p=(120*50)/N//Number of poles
21 N1=(120*f)/int(p)//Speed in rpm
22 Ns=(N1*sqrt(P))/h^(5/4)//Specific speed
23
24 //Output
25 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

```

1
2 clc
3 clear
4 //Input data
5 P=10000//Power in kW
6 h=25//Head in m. In textbook it is given wrong as 2
    m
7 N=135//Speed in rpm
8 h1=20//Head in m
9
10 //Calculations
11 Ns=((N*sqrt(P))/h^(5/4))//Specific speed
12 N1=sqrt(h1/h)*N//Speed in rpm
13 P2=P/(h/h1)^(3/2)//Power in kW
14
15 //Output
16 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

```
1
2 clc
3 clear
4 //Input data
5 Q=175//Discharge in m3/s
6 h=18//Head in meter
7 N=150//Speed in rpm
8 oe=82//Overall efficiency in percent
9 Ns1=460//Maximum specific speed
10 Ns2=350//Maximum specific speed
11 d=1000//Density in kg/m3
12
13 //Calculations
14 P=(d*Q*9.81*h*(oe/100)*10-3)//power in kW
15 P1=((Ns1*h(5/4))/N)2//Power in kW
16 n1=P/P1//No. of turbains
17 P2=((Ns2*h(5/4))/N)2//Power in kW
18 n2=ceil(P/P2)//No. of turbains
19
20 //Output
21 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

```
1
2 clc
3 clear
4 //Input data
```

```

5  Ns=210// Specific speed
6  P=30//Power in MW
7  N=180//Speed in rpm
8  Q=0.6//Discharge in m^3/s
9  h=4.5//Head in m
10 e=88//Efficiency in percent
11 d=1000//Density in kg/m^3
12
13 // Calculations
14 Pm=(d*Q*9.81*h*(e/100)*10^-3)//Power in kW
15 Nm=(Ns*h^(5/4))/sqrt(Pm)//Speed in rpm
16 Hp=((N*sqrt(P*1000))/Ns)^(4/5)//Head in m
17 Dpm=(Nm/N)*sqrt(Hp/h)//Scale ratio
18 Qp=(P*10^6)/(d*9.81*Hp*(e/100))//Discharge in m^3/s
19
20 //Output
21 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

```

1
2  clc
3  clear
4  //Input data
5  x=1/5//Scale model
6  h=1.5//Head in m
7  P=5//Power in kW
8  N=450//Speed in rpm
9  h1=30//Head in m
10
11 // Calculations
12 N1=(x*N)/sqrt(h/h1)//Speed in rpm
13 Ns=(N*sqrt(P))/h^(5/4)// Specific speed

```

```

14 P1=((Ns*h1^(5/4))/N1)^2//Power in kW
15
16 //Output
17 printf('Speed is %3.0f rpm \n Power is %3.0f kW',N1,
        P1)

```

---

#### Scilab code Exa 10.16 Efficiency

```

1
2 clc
3 clear
4 //Input data
5 h=19//Head in m
6 Q=3//Flow rate in m^3/s
7 N=600//Speed in rpm
8 h1=5//Head in m
9
10 //Calculations
11 N1=N/sqrt(h/h1)//Speed in rpm
12 Q1=Q/sqrt(h/h1)//Discharge in m^3/s
13
14 //Output
15 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

```

1
2 clc
3 clear
4 //Input data
5 Q=350//Discharge in m^3/s
6 h=30//Head in m

```

```

7 e=87//Turbine efficiency in percent
8 f=50//Frequency in Hz
9 p=24//Number of poles
10 Ns1=300//Specific speed
11 Ns2=820//Specific speed
12 d=1000//Density of water in kg/m^3
13
14 //Calculations
15 N=(120*f)/p//Speed in rpm
16 P=d*Q*9.81*h*(e/100)*10^-3//Power in kW
17 P1=((Ns1*h^(5/4))/N)^2//Power in kW
18 n1=P/P1//No. of turbines
19 P2=((Ns2*h^(5/4))/N)^2//Power in kW
20 n2=ceil(P/P2)//No. of turbines
21
22 //Output
23 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

```

1
2 clc
3 clear
4 //Input data
5 h=27//Head in m
6 A=430//Area in sq.km
7 R=150//Rainfall in cm/year
8 pr=65//Percentage of rainfall utilised
9 pe=95//Penstock efficiency in percent
10 te=80//Turbine efficiency in percent
11 ge=86//Generator efficiency in percent
12 lf=0.45//Load factor
13 d=1000//Density of water in kg/m^3

```

```

14
15 // Calculations
16 Q=A*10^6*(R/100)*(pr/100)//Discharge in m^3 per year
17 Qs=(Q/(365*24*3600))//Quantity of water per second
    in m^3
18 P=(pe/100)*(te/100)*(ge/100)*d*Qs*9.81*h*10^-3//
    Power in kW
19 plc=(P/lf)//Peak load capacity in kW
20 C=(plc/(2*(ge/100)))//Capacity of each unit in kW
21
22 //Output
23 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

```

1
2 clc
3 clear
4 //Input data
5 q=[30,25,20,0,010,50,80,100,110,65,45,30]//Mean
    discharge in millions of cu.m per month
    respectively
6 h=90//Head in m
7 n=86//Overall efficiency in percent
8
9 // Calculations
10 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
11 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

```

```

12 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
13 D=[110,100,90,80,70,60,50,40,30,25,20,10,0] //
    Discharge per month in million m3
14 pt
    =[8.3,16.7,25,25,25,33.3,41.7,50,66.7,75,83.3,91.7,100]
    //Percentage time
15 Po=((Qm*106*9.81*h*(n/100))/(30*24*3600*1000)) //
    Power developed in MW
16
17 //Output
18 subplot(121)
19 plot(y,Q)//Graph Discharge(million m3/month) vs
    Month
20 xtitle('Discharge(million m3/month) vs Month','
    Months','Discharge(million m3/month)')
21 subplot(122)
22 plot(pt,D)//Graph percentage time vs Discharge(
    million m3/month)
23 xtitle('percentage time vs Discharge(million m3/
    month)','percentage time','Discharge(million m3/
    month)')
24 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

```
1
2 clc
3 clear
4 //Input data
5 C=3.5//Capacity in litres
6 P=13.1//Indicated power in kW/m^3
7 N=3600//Speed in rpm
8 ve=82//Volumetric efficiency in percent
9 p1=1.013//Pressure in bar
10 T1=25+273//Temperature in K
11 rp=1.75//Pressure ratio
12 ie=70//Isentropic efficiency in percent
13 me=80//Mechanical efficiency in percent
14 g=1.4//Ratio of specific heats
15 R=0.287//Gas constant in kJ/kg.K
16 Cp=1.005//Specific heat in kJ/kg.K
17
18 //Calculations
19 EC=(C/1000)//Engine capacity in m^3
```

```

20 Vs=(N/2)*EC//Swept volume in m3
21 Vui=(ve/100)*Vs//Unsupercharged induced volume in m
    ^3/min
22 dp=(rp*p1)//Blower delivery pressure in bar
23 T2sT1=(rp)^((g-1)/g)//Ratio of temperatures
24 T2s=(T2sT1*T1)//Temperature in K
25 dT21=(T2s-T1)/(ie/100)//Difference in temperature in
    K
26 T2=dT21+T1//Temperature in K
27 EV=(Vs*dp*T1)/(p1*T2)//Equivalent volume in m3/min
28 iiv=EV-Vui//Increase in induced volume in m3/min
29 iip=(P*iiv)//Increase in indicated power in kW
30 iipi=((dp-p1)*100*Vs)/60//Increase in induced power
    due to increase in induction pressure in kW
31 tiip=iip+iipi//Total increase in indicated power in
    kW
32 tibp=tiip*(me/100)//Total increase in brake power in
    kW
33 ma=(dp*100*Vs)/(60*R*T2)//Mass of air in kg/s
34 WI=(ma*Cp*(T2-T1))//Work input to heater in kW
35 Pb=(WI/(me/100))//Power required in kW
36 NI=tibp-Pb//Net increase in brake power in kW
37
38 //Output
39 printf('Net increase in brake power is %3.2f kW',NI)

```

---

### Scilab code Exa 11.2 Temperature of air

```

1
2 clc
3 clear
4 //Input data
5 p1=0.97//Pressure in bar
6 t1=30+273//Temperature in K
7 p2=2.1//Pressure in bar

```

```

8 af=18//Air fuel ratio
9 t3=580+273//Temperature in K
10 p3=1.9//Pressure in bar
11 p4=1.06//Pressure in bar
12 iec=0.75//Isentropic efficiency of compressor
13 iet=0.85//Isentropic efficiency of turbine
14 cpa=1.01//Specific heat for air in kJ/kg.K
15 ga=1.4//Ratio of specific heats
16 cpex=1.15//Specific heat in kJ/kg.K
17 gex=1.33//Ratio of specific heats
18
19 //Calculations
20 t2s=t1*(p2/p1)^((ga-1)/ga)//Tempeature in K
21 t21=(t2s-t1)/iec//Temperature in K
22 t2=t21+t1//Temperature in K
23 T2=t2-273//Temperature in degree C
24 t3t4s=(p3/p4)^((gex-1)/gex)//Ratio of temperatures
25 t4s=(t3/t3t4s)//Temperature in K
26 t4=t3-((t3-t4s)*iet)//Temperature in K
27 T4=t4-273//Temperature in degree C
28 mp=((cpex*(1+(1/af))*(t3-t4))-(cpa*(t2-t1)))/(cpex
    *(1+(1/af))*(t3-t4))*100//Percentage of
    mechanical power loss
29
30 //Output
31 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

```

1
2 clc
3 clear
4 //Input data
5 a=215 //Current in A
6 v=210 //Voltage in V
7 e=85 //Efficiency in percent
8 q=11.8 //Quantity of fuel supplied in kg/h
9 cv=43 //Calorific value in MJ/kg
10 af=18 //Air fuel ratio
11 w=560 //Water in litres/h
12 tw=38 //Temeparature in degree C
13 te=97 //Temeparature in degree C
14 cp=1.04 //Specific heat in kJ/kg.K
15 ta=30 //Temeparature in degree C
16 l=32 //Percentage lost
17 sw=4.187 //Specific heat in kJ/kg.K
18
19 // Calculations
20 P=(a*v)/1000 //Power in kW
21 BP=(P/(e/100)) //Brake power in kW
22 E=(q/3600)*cv*1000 //Energy supplied in kW
23 mg=(q/3600)*(1+af) //Rate of gases in kg/s
24 he=(mg*cp*(te-ta))+((w/3600)*sw*tw) //Heat carried
    away by exhaust gases in kW
25 hj=(l/100)*E //Heat lost to jacket cooling water in
    kW
26 pBP=(BP/E)*100 //Percentage
27 pE=(E/E)*100 //Percentage
28 phe=(he/E)*100 //Percenatge
29 phj=(hj/E)*100 //Percenatge
30
31 //Output
32 printf('          ENERGY BALANCE
    SHEET \n
    kW)          (in percent)\n 1. Brake power
    %3.2 f          (in

```

```

%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
f          %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

```

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

```

```

22 cpx=1.01//Specific heat of dry exhaust gases in kJ/
    kg.K
23 cpw=4.187//Specific heat of water in kJ/kg.K
24
25 //Calculations
26 ip=(mep*100*(1/1000)*(3.14/4)*(d/1000)^2*N)/60//
    Indicated Power in kW
27 bp=((2*3.14*N*(NL*(1/2)))/60)/1000//Brake power in
    kW
28 nm=(bp/ip)*100//Mechanical efficiency in percent
29 qs=(Fc*cv*10^3)//Heat supplied in kJ
30 qip=(ip*t*60)//Heat equivalent of ip in kJ
31 qcw=(cw*cpw*(Wo-Tw))//Heat carried away by cooling
    water in kJ
32 tm=(Fc*a)//Toatl mass of exhaust gas in kg
33 ms=(st*Fc)//Mass of steam formed in kg
34 mde=(tm-ms)//Mass of dry exhaust gas in kg
35 Ed=(mde*cpx*(Te-Ta))//Energy carried away by dry
    exhaust gases in kJ
36 Es=(ms*((cpw*(100-Ta))+2257.9+(cp*(Te-100))))//
    Energy carried away by steam in kJ
37 TE=(Ed+Es)//Total energy carried away by exhaust
    gases in kJ
38 ue=(qs-(qip+qcw+TE))//Unaccounted energy in kJ
39 pqip=(qip/qs)*100//Percentage
40 pqcw=(qcw/qs)*100//Percentage
41 pTE=(TE/qs)*100//Percentage
42 pue=(ue/qs)*100//Percentage
43
44 //Output
45 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

```

1
2 clc
3 clear
4 //Input data
5 Vbm=360//Blade velocity in m/s
6 b1=20//Blade angle at inlet in degrees
7 a2=b1//Angle in degrees
8 b2=52//Blade angle at exit in degrees
9 a1=b2//Angle in degrees
10 R=50//Degree of reaction in percent
11 dm=0.45//Mean diameter of the blade in m
12 bh=0.08//Mean blade height in m
13
14 //Calculations
15 Vf=(Vbm/(tand(b2)-tand(b1)))//Velocity in m/s
16 rt=(dm/2)+(bh/2)//Mean radius in m
17 Vbt=(Vbm*(rt/(dm/2)))//Velocity in m/s
18 Vw1m=Vf*tand(a1)//Velocity in m/s
19 Vw1t=(Vw1m*((dm/2)/rt))//Velocity in m/s
20 dVw1=(Vf*(tand(b1)+tand(b2))*Vbm)/Vbt//Velocity in m
    /s
21 rr=(dm/2)-(bh/2)//Radius in m
22 Vbr=(Vbm*(rr/(dm/2)))//Velocity in m/s
23 Vw1r=(Vw1m*((dm/2)/rr))//Velocity in m/s
24 Vr2=Vf/cosd(b2)//Velocity in m/s

```

```

25 dVwr=((Vw1m+((Vr2*sind(b2))-Vbm))*Vbm)/Vbr // Velocity
    in m/s
26 a1r=atand(Vw1r/Vf) // Angle in degrees
27 a2r=atand((dVwr-Vw1r)/Vf) // Angle in degrees
28 b1r=atand((Vw1r-Vbr)/Vf) // Angle in degrees
29 b2r=atand((Vbr+(Vf*tand(a2r)))/Vf) // Angle in degrees
30 a1t=atand(Vw1t/Vf) // Angle in degrees
31 a2t=atand((dVw1-Vw1t)/Vf) // Angle in degrees
32 b1t=atand((Vw1t-Vbt)/Vf) // Angle in degrees
33 b2t=atand((Vbt+(Vf*tand(a2t)))/Vf) // Angle in degrees
34 Rt=((Vf*(tand(b2t)-tand(b1t)))/(2*Vbt))*100 // Degree
    of reaction at the tip in percent
35 Rr=((Vf*(tand(b2r)-tand(b1r)))/(2*Vbr))*100 // Degree
    of reaction at the root in percent
36
37 //Output
38 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 %3.2
    f 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

```

1
2 clc
3 clear
4 //Input data
5 N=16000 //Speed in rpm
6 T1=17+273 //Temperature in K

```

```

7 rp=4//Pressure ratio
8 in=82//Isentropic efficiency in percent
9 s=0.85//Slip factor
10 a=20//Angle in degrees
11 d=200//Diameter in mm
12 V=120//Velocity in m/s
13 cp=1.005//Specific heat in kJ/kg.K
14 g=1.4//Ratio of specific heats
15
16 //Calculations
17 T2sT1=(rp)^((g-1)/g)//Temperature ratio
18 T2s=T1*T2sT1//Temeprature in K
19 dTs=(T2s-T1)//Temperature difference in K
20 dT=dTs/(in/100)//Temperature difference in K
21 Wc=(cp*dT)//Power input in kJ/kg
22 Vb1=(3.14*(d/1000)*N)/60//Velocity in m/s
23 Vw1=(V*sind(a))//Pre-whirl velocity in m/s
24 Vb2=sqrt(((Wc*1000)+(Vb1*Vw1))/s)//Velocity in m/s
25 d2=((Vb2*60)/(3.14*N))*1000//Tip diameter in mm
26
27 //Output
28 printf('Impeller tip diameter is %3.0f mm',d2)

```

---

### Scilab code Exa 11.7 Workdone factor

```

1
2 clc
3 clear
4 //Input data
5 T1=25+273//Temperature in K
6 rp=6//Pressure ratio
7 Vb=220//Mean velocity in m/s
8 b1=45//Angle in degrees
9 a2=b1//Angle in degrees
10 b2=15//Angle in degrees

```

```

11 a1=b2//Angle in degrees
12 R=50//Degree of reaction in percent
13 n=10//Number of stages
14 in=83//Isentropic efficiency in percent
15 cp=1.005//Specific heat in kJ/kg.K
16 g=1.4//Ratio of specific heats
17
18 //Calculations
19 V1=(Vb/(sind(b2)+(cosd(a1)*tand(a2))))//Velocity in
    m/s
20 V2=(V1*cosd(b2))/cosd(b1)//Velocity in m/s
21 dVw=(V2*sind(a2))-(V1*sind(a1))//Velocity in m/s.
    Textbook answer is wrong. Correct answer is 127 m
    /s
22 T2sT1=rp^((g-1)/g)//Temperature ratio
23 T2s=(T2sT1*T1)//Temperature in K
24 dTs=(T2s-T1)//Temperature difference in K
25 dT=(dTs/(in/100))//Temperature difference in K
26 W=(cp*dT)//Workdone in kJ/kg
27 w=(W*10^3)/(Vb*dVw*n)//Work done factor
28
29 //Output
30 printf('Workdone factor of the compressor is %3.2f',
    w)

```

---

#### Scilab code Exa 11.8 Airfuel ratio

```

1
2 clc
3 clear
4 //Input data
5 p1=1//Pressure in bar
6 T1=20+273//Temperature in K
7 Tm=900+273//Maximum temperature in K
8 rp=6//Pressure ratio

```

```

9 e=0.7//Effectiveness of regenerator
10 ma=210//Rate of air flow in kg/s
11 CV=40800//Calorific value in kJ/kg
12 ic=0.82//Isentropic efficiencies of both the
    compressors
13 it=0.92//Isentropic efficiencies of both the turbine
14 cn=0.95//Combustion efficiency
15 mn=0.96//Mechanical efficiency
16 gn=0.95//Generator efficiency
17 cp=1.005//Specific heat of air in kJ/kg.K
18 cpg=1.08//Specific heat of gas in kJ/kg.K
19 g1=1.4//Ratio of specific heats for air
20 g=1.33//Ratio of specific heats for gas
21
22 //Calculations
23 pi=sqrt(p1*rp)//Intermediate pressure in bar
24 T2sT1=(pi/p1)^((g1-1)/g1)//Temperature ratio
25 T2s=(T2sT1*T1)//temperature in K
26 T2=((T2s-T1)/ic)+T1//Temperature in K
27 T4s=(T1*(rp/pi)^((g1-1)/g1))//Temperature in K
28 T4=((T4s-T1)/ic)+T1//Temperature in K
29 T7s=(Tm/(rp/p1)^((g-1)/g))//Temperature in K
30 T7=Tm-(it*(Tm-T7s))//Temperature in K
31 T5=(e*(T7-T4))+T4//Temperature in K
32 mf=1/((cp*(Tm-T5))/((CV*cn)-(cp*(Tm-T5))))//Air fuel
    ratio
33 Wgt=((1+(1/mf))*cpg*(Tm-T7))//Workdone by turbine in
    kJ/kg of air
34 Wc=(cp*((T2-T1)+(T4-T1))//Workdone by compressor in
    kJ/kg of air
35 Wnet=(Wgt-Wc)//Net workdone in kJ/kg of air
36 Q=(CV*cn)/mf//Heat supplied in kJ/kg of air
37 ncy=(Wnet/Q)*100//Cycle efficiency in percent
38 PO=(Wnet*ma*mn*gn)/10^3//Power output in MW
39 Fc=(ma*3600*(1/mf))//Fuel consumption per hour in kg
40 SFC=(Fc/(PO*10^3))//Specific fuel consumption in kg/
    kW.h
41

```

```
42 //Output
43 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

```
1
2 clc
3 clear
4 //Input data
5 V=64000//Volume in m^3
6 Q=8300//Discharge in m^3/hr
7 p1=1//Pressure in bar
8 T1=20+273//Temperature in K
9 p2=100//Pressure in bar
10 pn=70//Polytropic efficiency in percent
11 pt=60//Peaking turbine efficiency in percent
12 g=1.4//Ratio of specific heats
13 cp=1.005//Specific heat in kJ/kg.K
14 R=0.287//Gas constant in kJ/kg.K
15
16 //Calculations
17 T2sT1=(p2/p1)^((g-1)/g)//Temperature ratio
18 T2s=(T1*T2sT1)//Temperature in K
19 T21=(T2s-T1)/(pn/100)//Difference in Temperatures in
    K
20 T2=(T21+T1)-273//Temperature in degree C
```

```

21 v=(R*T1)/(p2*100)//Specific volume in m^3/kg
22 mf=(Q/(v*3600))//Mass flow rate in kg/s
23 E=(mf*cp*T21)/1000//Rate of energy storage in MW
24 t=(V/Q)//Storage time in hour
25 tE=(E*t)//Total energy storage in MWh
26 Ed=(tE*(pt/100))//Total energy delivered by the
    peaking turbine in MWh
27
28 //Output
29 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

```

1
2 clc
3 clear
4 //Input data
5 V=175000//Volume in m^3
6 d=4//Diameter in m
7 U=1.5//Overall heat transfer coefficient in W/m^2.K
8 p2=2//Pressure in bar
9 p1=20//Pressure in bar
10 Ta=20//Ambient temperature in degree C
11 cp=4.35//Specific heta of water in kJ/kg.K
12 e=96//Efficiency in percent
13 ppe=25//Peaking plant efficiency in percent
14
15 //Calculations
16 //At 20 bar
17 T1=212.37//Saturation temperature in degree C
18 hf1=908.5//Enthalpy in kJ/kg

```

```

19 vf1=0.0011766 // Specific volume in m^3/kg
20 //At 2 bar
21 T2=120.23 // Saturation temperature in degree C
22 hf2=504.8 // Enthalpy in kJ/kg
23 vf2=0.0010605 // Specific volume in m^3/kg
24 ad=(1/2)*((1/vf1)+(1/vf2)) // Average density of water
    in kg/m^3
25 tc=(d*ad*cp*1000)/(4*U*3600) // Time constant in h
26 ts=(log(1/(1-((1-((e/100)))/((T1-Ta)/(T1-T2)))))))*tc
    // Storage time in h
27 m=(V/vf1) // Mass of water needed in kg
28 E=(m*(hf1-hf2))/(3600*10^3) // Total energy stored in
    MWh
29 Ed=(E*(e/100)*(ppe/100)) // Energy delivered in MWh
30
31 // Output
32 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)

```

---