Scilab Textbook Companion for Heat Transfer: Principles And Applications by B. K. Dutta[1]

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Book Description

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

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

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

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

Contents

List of Scilab Codes

Chapter 2

Steady State conduction In one dimension

Scilab code Exa 2.1 STEADY STATE RATE OF HEAT GAIN

```
//Example 2.1
//(a)calculate  the steady state rate of heat gain .
//(b), th etemp. of interfaces of composite wall.
//(c)the percentage of total heat transfer
   resistance.
//additional thickness of cork.
//Given
A=1              //m^2, area
//for inner layer (cement)
ti=0.06          //m, thickness
ki=0.72          //W/m C,  thermal conductivity
Ti=-15           //C, temprature
//for middle layer (cork)
tm=0.1           //m, thickness
km=0.043         //W/m C,  thermal conductivity
//for outer layer(brick)
to=0.25          //m, thickness
ko=0.7           //W/m C,  thermal conductivity
To=30            //C, temprature
```

```

//Calculation
//Thermal resistance of outer layer  //C/W
Ro=to/(ko*A)
//Thermal resistance of middle layer   //C/W
Rm=tm/(km*A)
//Thermal resistance of inner layer    //C/W
Ri=ti/(ki*A)
Rt=Ro+Rm+Ri
tdf=To-Ti          //temp driving force
//(a)
Q=tdf/Rt        //rate of heat gain
printf("the rate of heat gain is %f W\n",Q)

//(b)
//from fig. 2.4
td1=Q*to/(ko*A)    //C temp. drop across the brick layer
T1=To-td1          //interface temp. between brick and cork
//similarly
td2=Q*tm/(km*A)    //C temp. drop across the cork layer
T2=T1-td2          //C, interface temp. between cement and cork
printf("interface temp. between brick and cork is %f C\n",T1)
printf("interface temp. between cement and cork is %f C\n",T2)


//(c)
Rpo=Ro/Rt          //thermal resistance offered by brick layer
Rpm=Rm/Rt          //thermal resistance offered by cork layer
Rpi=Ri/Rt          //thermal resistance offered by cement layer
```

```
printf("thermal resistance offered by brick layer is %f percent\n",Rpo*100)
printf("thermal resistance offered by cork layer is %f percent\n",Rpm*100)
printf("thermal resistance offered by cement layer is %f percent\n",Rpi*100)

//second part
x=30                  //percentage dec in heat transfer
Q1=Q*(1-x/100)        //W, desired rate of heat flow
Rth=tdf/Q1            //C/W, required thermal resistance
Rad=Rth-Rt            //additional thermal resistance
Tad=Rad*km*A
printf("Additional thickness of cork to be provided =%f cm",Tad*100)
```

Scilab code Exa 2.2 Rate of heat loss

```
//Exm[ple 2.2
//Page no. 15
//Given
//outer thickness of brickwork (to) & inner thickness (ti)
to=0.15      //m
ti=0.012     //m
//thickness of intermediate layer(til)
til=0.07     //m
//thermal conductivities of brick  and wood
kb=0.70      //W/m celcius
kw=0.18      //W/m celcius
//temp. of outside and inside wall
To=-15      //celcius
Ti=21       //celcius
//area
A=1         //m^2
```

```
//(a)solution
//Thermal resistance of brick , wood and insulating
    layer
TRb=to/(kb*A)    //C/W
TRw=ti/(kw*A)    //C/W
TRi=2*TRb        //C/W
//Total thermal resistance
TR=TRb+TRw+TRi   //C/W
//Temp. driving force
T=Ti-To          //C
//Rate of heat loss
Q=T/TR
printf("Rate of heat loss is %f W\n",Q)
//(b)thermal conductivities of insulating layer
k=til/(A*TRi)
printf("thermal conductivities of insulating layer
   is %f W/m C",k)
```

Scilab code Exa 2.3 fraction of resistance

```
//Example 2.3
//Page no. 19
//Given
//Length & Inside rdius of gas duct
L=1          //m
ri=0.5       //m
//Properties of inner and outer layer
ki=1.3       //W/m C, thermal conductivity of inner
   bricks
ti=0.27      //m, inner layer thickness
ko=0.92      //W/m C, thermal conductivity of special
   bricks
to=0.14      //m, outer layer thickness
Ti=400       //C, inner layer temp.
To=65        //C, outer layer temp.
```

```

//calculation
r_=ri+ti   //m, outer radius of fireclay  brick layer
ro=r_+to   //m, outer radius of special brick layer
//Heat transfer resistance
//Heat transfer resistance of fireclay brick
R1=(log(r_/ri))/(2*%pi*L*ki)
//Heat transfer resistance of special brick
R2=(log(ro/r_))/(2*%pi*L*ko)
//Total resistance
R=R1+R2
//Driving force
T=Ti-To
//Rate of heat loss
Q=T/(R)
printf("Rate of heat loss is %f W",Q)
//interface temp.
Tif=Ti-(Q*R1)
printf("interface temp.is  %f C",Tif)
//Fractional resistance offered  by the special brick layer
FR=R2/(R1+R2)
printf("Fractional resistance offered  by the special brick layer is %f ",FR)
```

Scilab code Exa 2.4 `Calculate Temprature`

```

//Example 2.4
//Calculate(a) hot end temprature'
//(b) temprature fradient at both the ends
//(c) the temprature at 0.15m away from the cold end.
//Given
```

```
d1=0.06          //m, one end diameter of steel rod
d2=0.12          //m,other end diameter of steel rod
l=0.2            //m length of rod
T2=30            //C, temp. at end 2
Q=50             //W, heat loss
k=15              //W/m c, thermal conductivity of rod

//NUMERIC PART
//T=265.8-(7.07/(0.06-0.15*x))........(a)
//(a)
x1=0
//from eq. (a)
T1=265.8-(7.07/(0.06-0.15*x1))
printf("The hot  end temp. is %f C\n",T1)
//(b)  from eq. (i)
C=50                     //integration constant
//from eq. (i)
D1=-C/(%pi*d1^2*k)    //D=dT/dx, temprature gradient
printf("The temprature gradient at hot end is %f C/m\n",D1)
//similarly
D2=-1179                 //at x= 0.2m
printf("The temprature gradient at cold end is %f C/m\n",D2)

//(c)
x2=0.15                  //m, given,
x3=l-x2                  //m, section away from the cold end
//from eq. (a)
T2=265.8-(7.07/(0.06-0.15*x3))
printf("the temprature at 0.15m away from the cold end is %f C",T2)
```

Scilab code Exa 2.5 `calculate refrigeration requirement`

```
//Exaple2.5
//Page no.24
//Given
//inside and outside diameter and Temp.  of sphorical vessel
do=16
t=0.1
Ri=do/2          //m, inside radius
Ro=Ri+t          //m. outside radius
To=27            //C,
Ti=4             //C
k=0.02           //W/m C, thermal conductivity of foam layer
//from eq. 2.23 the rate of heat transfer
Q=(Ti-To)*(4*%pi*k*Ro*Ri)/(Ro-Ri)
printf("the rate of heat transfer is %f W\n",Q)
//Refrigeration capacity(RC)
//3516 Watt= 1 ton
RC=-Q/3516
printf("Refrigeration capacity is %f tons",RC)
```

Scilab code Exa 2.6 calculate temp gradient

```
//Example 2.6
//Calculate the temprature gradient at each end of the rod
//and the temprature midway in the rod at steady state
//Given
d=0.05          //m, diameter of rod
l=0.5           //m, length of rod
T1=30           //CTemp. at  one end (1)
T2=300          //C, temp  at other end (2)
T=poly(0,'T')
k=202+0.0545*T        //W/mC thermal conductivity of
```

```
metal

//CALCULATION OF HEAT FLUX
x1=l/2            //m, at mid plane
//temprature distribution ,
//comparing with quadratic eq. ax^2+bx+c
//and its solution as x=(-b+sqrt(b^2-4*a*c))/2*a
a=1.35*10^-4
b=1
c=-(564*x1+30.1)
T=(-b+sqrt(b^2-4*a*c))/(2*a)
printf("the temprature midway in the rod at steady state is %f C\n",T)

//Temprature gradient at the ends of the rod
x2=0                  //m, at one end
a1=1.35*10^-4
b1=1
c1=-(564*x2+30.1)
T1=(-b1+sqrt(b1^2-4*a1*c1))/(2*a1)
k1=202+0.0545*T1
C1=113930            //integration constant from eq.(1)
TG1=C1/k1            //C/W, temprature gradient, dT/dx
//similarly
x3=0.5
a2=1.35*10^-4
b2=1
c2=-(564*x3+30.1)
T2=(-b2+sqrt(b2^2-4*a2*c2))/(2*a2)
k2=202+0.0545*T2
TG2=C1/k2
printf("Temprature gradient at one end of the rod is %f C/W\n",TG1)
printf("Temprature gradient at other end of the rod is %f C/W",TG2)
```

Scilab code Exa 2.7 `surface emp and maximun temp`

```
//Example 2.7
//(a)what are the surface tempratures and average temp. of wall.
//(b)calculate the maximum temp. in the wall and its location
//(c)calculate the heat flux at the surface.
//(d)if there is heat generation then what is the
// average volumetric rate of heat generation?
//Given
x=poly(0,'x')
//temprature distribution in wall
T=600+2500*x-12000*x^2
t=0.3              //m, thickness of wall
k=23.5             //W/m c  thermal conductivity of wall

//Calculation
x1=0
T1=600+2500*x1-12000*x1^2     //C, at surface
x2=0.3
T2=600+2500*x2-12000*x2^2     //C, at x=0.3
Tav=1/t*integrate('600+2500*x-12000*x^2','x',0,0.3)
printf("At the surface x=0, the temp. is %f C\n",T1)
printf("At the surface x=0.3m, the temp. is %f C\n",T2)
printf("Rhe average temprature of the wall is %f C",Tav)

//(b)
D=derivat(T)                    //D=dT/dx
//for maximum temprature D=0
x3=2500/24000
```

```
printf("The maximum temprature occurs at %f m\n",x3)
Tmax=600+2500*x3-12000*x3^2
printf("The maximum temp. is %f C\n",Tmax)

//(c)
D1=2500-24000*x1            //at x=0, temprature gradient
Hf1=-k*D1                   //W/m^2, heat flux at left surface(x=0)
D2=2500-24000*x2            //at x=0.3, temprature gradient
Hf2=-k*D2                   //W/m^2, heat flux at right surface(x=0.3)
printf("heat flux at left surface is %f W/m^2\n",Hf1)
printf("heat flux at right surface is %f W/m^2\n",Hf2)

//(d)
Qt=Hf2-Hf1                 //W/m^2, total rate of heat loss
Vw=0.3                     //m^3/m^2, volume of wall per unit surface area
Hav=Qt/Vw                  //W/m^3, average volumetric rate
printf("The average volumetric rate if heat genaration is %fW/m^3 ",Hav)
```

Scilab code Exa 2.8 `percentage of total heat`

```
//Example 2.8
//Derive equtations for temprature distribution.
//calculate the maximum temp. in the assembly
//Given
ka=24          //W/mC thermal conductivitiy of
```

```
material A
tA=0.1          //m, thickness of A material
kB=230          //W/mC thermal conductivity of metl B
kC=200          //W/mC thermal conductivity of metal C
tB=0.1          //m, thickness of B metal
tC=0.1          //m, thickness of C metal
TBo=100         //C, outer surface temp. of B wall
TCo=100         //C, outer surface temp. of C wall
Q=2.5*10^5      //W/m^3, heat generated
//NUMERIC PART
//Temprature distribution in A, B and C
x=poly(0,'x')
TA=-5208*x^2+2175*x-74.5
TB=100+96.6*x
TC=155.2-14*x

//position of maximum temprature x,
D=derivat(TA)
//At D=0
x=2175/10416
printf("The maximum temp. will occur at a position %f m\n",x)
x1=x
TA=-5208*x1^2+2175*x1-74.5
printf("The maximum temprature is %f C",TA)
```

Scilab code Exa 2.9 `temprature distribution`

```
//Example 2.9
//(a) derive eq. for temprature distribution
//(b) find the maximum temp.
//Given
di=0.15       //m, inner diameter
do=0.3        //m, outer diameter
Q1=100*10^3   //W/,m^3,inner  rate of heat generation
```

```
Q2=40*10^3    //W/m^3, outer rate of heat generation
Ti=100        //C, temp.at inside surface
To=200        //C, temp. at outside surface
k1=30         //W/m C, thermal conductivity of
   material for inner layer
k2=10         //W/m C, thermal conductivity of
   material for outer layer

//Calculation
//T1=364+100*log(r)-833.3*r^2              (1)
//T2=718+216*log(r)-1000*r^2               (2)
//(b)from eq. 1
r=sqrt(100/2*833.3)
printf("This radial position does not fall within
   layer 1.\n Therefore no temprature maximum occurs
    in this layer.")
//similarly
printf(" Similarly no temprature maximum occurs in
   layer 2.\n")
ro=di         //m, outer boundary
Tmax=To
printf("The maximum temprature at the outer boundary
    is %f C",Tmax)
```

Chapter 3

Heat transfer coefficient

Scilab code Exa 3.1 CALCULATE TIME REQUIRED

```
//Example 3.1
//calculate the time required for reduction .
//Given
di=0.06          //m, initial diameter of iceball
T1=30            //C, room temp.
T2=0             //ice ball temp.
h=11.4           //W/m^2 C, heat transfer coefficient
x=40             //% for reduction
rho=929          //kg/m^3, density of ice
Lv=3.35*10^5     //j/kg, latent heat of fusion
// m=4/3*%pi*r^3       //kg,mass of ice ball
//rate of melting=-dm/dt
//rate of heat adsorption =-4*%pi*r^2*rho*dr/dt*
   lamda
//at initial time t=0
C1=di/2          //constant of integration
//if the volume of the ball is reduced by 40% of the
    original volume
r=((1-x/100)*(di/2)^3)^(1/3)
//time required for melting using eq. 1
t=(di/2-r)/(h*(T1-T2)/(rho*Lv))
```

```
printf("The time required for melting the ice is %f s",t)
```

Scilab code Exa 3.2 TIME FOR HEATING COIL

```
//Example 3.2
//calculate the time required for the  heating coil.
//Given
P=1*10^3            //W, electrical heating capacity
V=220               //V, applied voltage
d=0.574*10^-3       //m, diameter of wire
R=4.167             //ohm, electrical resistance
Tr=21               //C, room temp.
h=100               //W/m^2 C, heat transfer coefficient
rho=8920            //kg/m^3, density of wire
cp=384              //j/kg C, specific heat of wire
percent=63          //%, percent of the steady state
//Calculation
R_=V^2/P            //ohm, total electrical resistance
l=R_/R              //m, length of wire
A=%pi*d*l           //m^2, area of wire
Tf=P/(h*A)+Tr       //final temp.
dtf=Tf-Tr           //C. steady state temp. rise
//temp. of wire after 63% rise
T=Tr+(percent/100)*dtf
//rate of heat accumulation on the wire
//d/dt(m*cp*T)                              (1)
//rate of heat loss
//h*A*(T-Tr)..........................(2)
//heat balance eq.          (1)=(2)
m=%pi*d^2*l*rho/4   //kg. mass of wire
//integrating heat balance eq.
t=integrate('1/((P/(m*cp))-((h*A)/(m*cp))*(T-Tr))','
```

```
T',21,322)
printf("The time required for the heating coil is %f s",t)
```

Scilab code Exa 3.3 Steady State temprature distribution

```
//Example 3.3
//(a)calculate the heat transfer coefficient
//(b)what can be said about the same at the other surface of wall.
//(c)what is average volumetric rate of heat generation
//given
t=0.2              //m, thickness of wall
x=poly(0,'x')      //position in the wall
T=250-2750*x^2     //C, steady state temp. distribution
k=1.163            //W/m C, thermal conductivity of material
Ta=30              //C, ambient temp

//calculation
//(a) at x=0.2   let T=T1 at x=x1
x1=0.2
T1=250-2750*x1^2
//let     D=dT/dx
D=derivat(T)
D=-5500*0.2        //C/m, at x=0.2
h=-k*D/(T1-Ta)
printf(" the heat transfer coefficient is %f W/m^2 C, \n",h)

//(b)at other surface of wall, x=0=x2 (say)
x2=0
a=-5500*0
printf("So there is no heat flow at other surface of
```

```
    the wall \n")

//(c)
A=1                //m^2, area
Vw=A*x1            //m^3, volume of wall
HL=h*(T1-Ta)       //W, heat loss from unit area
Vav=HL/x1
printf("average volumetric rate of heat generation
   is %f W/m^3",Vav)
```

Scilab code Exa 3.4 THICKNESS OF INSULATION

```
clc;
clear;
//Example 3.4
//calculate the thickness of insulation
//and the rate of heat loss per meter length of pipe
   .
//Given
id=97*10^-3          //m,internal diameter of steam
   pipe
od=114*10^-3         //m,outer diameter of steam pipe
pr=30                //bar, absolute pressure os
   saturated steam
Ti=234                 //C, temp. at 30 bar absolute
   pressure
Ts=55                //C, skin temp.
To=30                //C, ambient temp.
kc=0.1               //W/m C, thermal conductivity of
    wool
kw=43                //W/m C, thermal conductivity of
    pipe
h=8                  //W/m^2 C, external air film
   coefficient
L=1                  //m, assume length
```

```
//Calculation
ri=id/2                    //m,
r1=(114*10^-3)/2            //m,outer radius of steam pipe

//thermal resistance of insulation
//Ri=log(ro/r1)/(2*%pi*L*kc)
//Thermal resistance of pipe wall
Rp=log(r1/ri)/(2*%pi*L*kw)
//RT=Ri+Rp
DF=Ti-Ts                   //C, driving force
//At steady state the rate of heat flow through the insulation
// and the outer air film are equ

//by trial and error method :
deff('[x]=f(ro)','x=(Ti-Ts)/(log(ro/r1)/kc+log(r1/ri)/kw)-(h*ro*(Ts-To))')
ro=fsolve(0.1,f)
th=ro-r1              //m, required thickness of insulation
Q=2*%pi*ro*h*L*(Ts-To)
printf("The rate of heat loss is %f W,",Q)
```

Scilab code Exa 3.5 8 percent SOLUTION OF ALCOHOL

```
//Example 3.5
//calculate
//(a)effective thickness of air and liquid films.
//(b)the overall heat transfer coefficient based on i.d of pipe.
//(c)the overall heat transfer coefficient based on od of insulation.
//(d)the percentage of total resistance  offered by air film.
```

```
//(e)the rate of heat loss per meter length of pipe.
//(f)insulation skin temp.

//given
w1=8                //%, solubility of alcohol
w2=92               //%, solubility of water
k1=0.155            //W/m C, thermal conductivity of alcohol
k2=0.67             //W/m C thermal conductivity of water
ka=0.0263           //W/m C thermal conductivity of air
kw=45               //W/m Cthermal conductivity of pipe wall
ki=0.068            //W/m C , thermal cond. of glass
id=53*10^-3         //m, internal diameter of pipe
od=60*10^-3         //m, outer  diameter of pipe
t=0.04              //m, thickness of insulation
hi=800              //W/m^2 C, liquid film coefficient
ho=10               //W/m^2 C, air film coefficient
L=1                 //m, length of pipe
T1=75               //C, initial temp.
T2=28               //C, ambient air temp.
//calculation
//(a)
km=(w1/100)*k1+(w2/100)*k2-0.72*(w1/100)*(w2/100)*(-(k1-k2))
deli=km/hi         //m, effective thickness of liquid film
delo=ka/ho         //m, effective thickness of air film
printf("effective thickness of air  is %f mm",deli*10^3)
printf("effective thickness of liquid films is %f mm.",delo*10^3)
//(b)
Ai=2*%pi*id/2*L          //m^2, inside area
ri=id/2                  //m,inside radius of pipe
r_=od/2                  //m, outside radius of pipe
ro=r_+t                  //m, outer radius of insulation
```

```
Ao=2*%pi*ro*L          //m^2, outer area
//from eq. 3.11, overall heat transfer coefficient
Ui=1/(1/hi+(Ai*log(r_/ri))/(2*%pi*L*kw)+(Ai*log(ro/r_))/(2*%pi*L*ki)+Ai/(Ao*ho))
printf("the overall heat transfer coefficient based on i.d of pipe is %f W/m^2 C",Ui)

//(c)
//frim eq. 3.14
Uo=Ui*Ai/Ao
printf("the overall heat transfer coefficient based on od of pipe is %f W/m^2 C",Uo)

//(d)
R=1/(Ui*Ai)            //C/W, total heat transfer resistance
Rair=1/(Ao*ho)         //C/W, heat transfer resistance of air film
p=Rair/R
printf("the percentage of total resistance  offered by air film. is %f percent",p*100)

//(e)
Q=Ui*Ai*(T1-T2)
printf("Rate of heat loss is %f W",Q)

//(f)
Ts=Uo*Ao*(T1-T2)/(ho*Ao)+T2
printf("insulation skin temp.is %f C",Ts)
```

Scilab code Exa 3.6 Insulated flat headed

```
//Example 3.6
//calcu;ate the temp. of the liquid entering the bank.
```

```
//also calculate the insulation skin temp. at the flat
//top surface and at the cylindrical surface.
//Given
id=1.5                    //m, internal diameter of tank
h=2.5                     //m, height of tank
t1=0.006                  //m, thickness of wall
t2=0.04                   //m, thickness of insulation
Ta=25                     //C, ambient temp.
T1=80                     //C, outlet temp. of liquid
cp=2000                   //j/kg C, specific heat of liquid
FR=700/3600               //KG/s, Liquid flow rate

//Calculation
ri=id/2+t1                //m, inner radius of insulation
ro=ri+t2                  //m, outer radius of insulation
ki=0.05                   //W/m C, thermal conductivity of insulation
hc=4                      //W/m^2 C, heat transfer coefficient at cylindrical surface
ht=5.5                    //W/m^2 C, heat transfer coefficient at flat surface
l=h+t1+t2                 //m, height of the top of insulation
//fromm eq. 3.10
//heat transfer resistance of cylindrical wall
Rc=log(ro/ri)/(2*%pi*l*ki)+1/(2*%pi*ro*l*hc)
//heat transfer resistance of flat insulated top surface
Ri=(1/(%pi*ro^2))*((ro-ri)/ki+1/ht)
tdf=T1-Ta                 //C, temp. driving force
Q=tdf/Rc + tdf/Ri           //W, total rate of heat loss
Tt=Q/(FR*cp)+T1            //C, inlet temp. of liquid
printf("Inlet liquid temp. should be %f C \n",Tt)
Q1=tdf/Ri    //W, rate of heat loss from flat surface
```

```
T1=Q1/(%pi*ro^2*ht)+Ta
printf(" the insulation skin temp. at the flat top
    surface is %f C \n",T1)
//similarly
T2=38
printf("similarly  the insulation skin temp at
    cylindrical surface is %f C",T2)
```

Scilab code Exa 3.7 rate of heat transfer

```
//Example 3.7
//what is the heat imput to the boiling.
//Given
id=2.5*10^-2                //m, internal diameter of
    glass tube
t=0.3*10^-2                 //m, thickness of wall
l=2.5                       //m, length of nichrome
    wire
L=0.12                      //m, length of steel
    covered with heating coil
Re=16.7                     //ohm, electrical
    resistance
ti=2.5*10^-2                //m, thickness of layer of
     insulation
kg=1.4                      //W/m C, thermal
    conductivity of glass
ki=0.041                    //W/m C, thermal
    conductivity of insulation
T1=91                       //C, boiling temp. of
    liquid
T2=27                       //C, ambient temp.
ho=5.8                      //W/m ^2 C outside air
    film coefficient
V=90                        //V,  voltage

```

```
//Calculation
Rc=Re*l                          //ohm, resistance of heating coil
Q=V^2/Rc                         //W, rate of heat generation
ri=id/2                          //m, inner radius of glass tube
r_=ri+t                          //m, outer radius of glass tube
ro=r_+ti                          //m,outer radius of insulation
//heat transfer resistance of glass wall
Rg=log(r_/ri)/(2*%pi*L*kg)
//combined resistance of insulation and outer air film
Rt=log(ro/r_)/(2*%pi*L*ki)+1/(2*%pi*ro*L*ho)
//Rate of heat input to the boiling liquid in steel=Q1=(Ts-T1)/Rg
//Rate of heat loss through insulation ,Q2=(Ts-To)/(Rt)
//Q1+Q2=Q
Ts=(Q+ T1/Rg +T2/Rt)/(1/Rg +1/Rt)
Q1=(Ts-T1)/Rg
Q2=Q-Q1
printf("the heat imput to the boiling.is %f W",Q1)
```

Scilab code Exa 3.8 `A 10 gauge electrical copper`

```
//Example 3.8
//determine(a) maximum allowable current
//(b) the corresponding remp. at the centre of wire and
//at the outer  surface of insulation
//Given
ri=1.3*10^-3               //m, radius of 10 gauge wire
```

```
t=1.3*10^-3                  //m, thickness of rubber
   insulation
Ti=90                        //C, temp. 0f insulation
To=30                        //C, ambient temp.
h=15                         //W/m^2 C, air film
   coefficient
km=380                       //W/m C, thermal cond. of
   copper
kc=0.14                      //W/m C, thermal cond. of
   rubber(insulation)
Rc=0.422/100                 //ohm/m, eletrical
   resistance of copper wire

//NUMERIC CALCULATIONS
Tcmax=90                     //X, the maximum temp. in
   insulation
ro=ri+t                      //m, outside radius of 10
   gauge wire
Sv=((Tcmax-To)*(2*kc/ri^2))/(log(ro/ri)+kc/(h*ro))
//from eq.(xii), Sv=I^2*rho/(%pi*ri^2)
I=(%pi*ri^2*Sv/Rc)^0.5          //A, Current strength
printf("maximum allowable current is %f A\n",I)

//(b) at r=0
Tm=To+(ri^2*Sv/2)*(1/km+(log(ro/ri))/kc+1/(h*ro))
printf("remp. at the centre of wire is %f C\n",Tm)
//at r=ro
Tc=30+(ri^2*Sv/(2*kc))*(kc/(h*ro))
printf("The temprature at the outer surface of
   insulation is %f C",Tc)
```

Scilab code Exa 3.9 Heat generating slab A

```
//Example 3.9
//(a) calculate the temp. at the surface of slab A.
```

```
//what is the maximum Temp. in A.
//(b)determine the temp. gradient at both the
//surfaces of each of the slabs A,B  and C.
//(c)calculate the value of h1 & h2.

//Given
tA=0.25            //m, thickness of slab A
tB=0.1             //m, thickness of slab B
tC=0.15            //m, thickness of slab C
kA=15              //W/m C, thermal comductivity of slab A
kB=10              //W/m C, thermal comductivity of slab B
kC=30              //W/m C, thermal comductivity of slab C
x=poly(0,'x')      //m, distance from left surface of B
//Temprature distribution in slab A
TA=90+4500*x-11000*x^2
T1=40              //C, fluid temp.
T2=35              //C, medium temp.

//calculation
//(a)
x1=tB
TA1=90+4500*x1-11000*x1^2
//similarly at the right surface
x2=tA+tB
TA2=90+4500*x2-11000*x2^2
//let dTA/dx=D
D=derivat(TA)
D=0                //for maximum temp.
x3=4500/22000
TAmax=90+4500*x3-11000*x3^2
printf("At x=0.1 the temp. at the surface of slab A is %f C\n",TA1)
printf("At x=0.35 the temp. at the surface of slab A is %f C\n",TA2)
```

```
printf(" the maximum Temp. in A occurs at  %f m\n",x3)
printf(" the maximum Temp. in A is %f TAmax \n",TAmax)

//(b)
//At the interface 2
D1=4500-2*11000*x1        //C/W, D1=dTA/dx, at x=0.1
//At the interface 3
D2=4500-2*11000*x2        //D12=dTA/dx, at x=0.35
//Temprature gradient in slab B and C
//by using the continuity of heat flux at interface (2)
D3=-kA*D1/(-kB)           //D3=dTB/dx,  at x=0.1
//at interface (1)
D4=D3                     //D4=dTB/dx  at x=0
//similarly
D5=-1600                  //C/W, dTB/dx, x=0.35
D6=D5                     //at interface 4
printf("temp. gradient at interface 2 of the slabs A is %f C/W\n",D1)
printf("temp. gradient at interface 3 of the slabs A is %f C/W\n",D2)
printf("temp. gradient at interface 2 of the slabs B is %f C/W\n",D3)
printf("temp. gradient at interface 1 of the slabs B is %f C/W\n",D4)
printf("temp. gradient at interface 3 of the slabs Cis %f C/W\n",D5)
printf("temp. gradient at interface 4 of the slabs C is %f C/W\n",D6)

//(c)
//from D3=3450  and TB=beeta1*x+beeta2
beeta1=3450
beeta2=85
x=0
TB=beeta1*x+beeta2
```

```
//similary
TC=877.5-1600*x
h1=-kB*D4/(T1-TB)
//similarly
h2=1129
printf("The heat transfer coefficient at one surface of solid fluid interface is %fW/m^2 C\n",h1)
printf("The heat transfer coefficient at other surface of solid fluid interface is %fW/m^2 C",h2)
```

Scilab code Exa 3.10 `percentage increase in rate`

```
//Example 3.10
//calcuate the percentage increase in the rate of heat transfer
//for the finned tube over the plain tube.
//Given
id=78*10^-3          //m, actual internal dia of pipe
tw=5.5*10^-3         //m, wall thickness
nl=8                 //no. of longitudinal fins
tf=1.5*10^-3         //m, thickness of fin
w=30*10^-3           //m,breadth of fin
kf=45                //W/m C, thermal conductivity of fin
Tw=150               //C, wall temp.
To=28                //C, ambient temp.
h=75                 //W/m^2C, surface heat transfer coefficient

//Calculation
//from eq. 3.27
e=sqrt(2*h/(kf*tf))
n=(1/(e*w))*tanh(e*w)  //efficiency of fin
```

```
L=1                   //m, length of fin
Af=2*L*w              //m^2, area of  single fin
Atf=nl*Af               //m^2 total area of fin
Qmax=h*Atf*(Tw-To)    //W, maximum rate of heat transfer
Qa=n*Qmax               //W, actual rate of heat transfer
Afw=L*tf                //m^2, area of contact of fin with pipe wall
Atfw=Afw*nl             //m^2 , area of contact of all fin with pipe wall
ro=id/2+tw              //m, outer  pipe radius
A=2*%pi*L*ro            //m^2  area per meter
Afree=A-Atfw            //m^2, free outside area of finned pipe
//Rate of heat transfer from free area of pipe wall
Q1=h*Afree*(Tw-To)  //W,
//total rate of hewat gtransfer from finned pipe
Qtotal=Qa+Q1            //W
//Rate of heat transfer fromm unfinned pipe
Q2=h*A*(Tw-To)
per=(Qtotal-Q2)/Q2
printf("the percentage increase in the rate of heat transfer is %f percent ",per*100)
```

Scilab code Exa 3.11 `Pre stresed multilayered shell`

```
//Example 3.11
//Calculate
//(a) Is there any thermal contact resistance at the interface between the layer?
//(b) if so calculate the contact resistance and
//express it in contact heat transfer coefficient
//(c) Calculate the temp. jump.

```

```
//Given
id=90*10^-2         //m, internal diameter of steel
od=110*10^-2        //m, outer diameter of steel
Ti=180              //C, inside temp. of steel
To=170              //C, outside temp. of steel
k=37               //W/m C, thermal conductivity of alloy
Q=5.18*10^3         //W, Rate of heat loss

//calculation
ri=id/2             //m, inside radius of shell
ro=od/2             //m, outside radius of shell
r_=0.5              //m, boundary between the layers
L=1                 //m, length of shell
//Rate of heat transfer in the absence of contact resistance
Q1=2*%pi*L*k*(Ti-To)/(log(ro/ri))
printf("Rate of heat transfer in the absence of contact resistance is %f KW\n",Q1/1000)
printf("The actual rate of heat loss is 5.18kW is much less than this value.\n So there is a thermal contact resistance at the interface between the layers \n")

//(b)
Ri=(log(r_/ri)/(2*%pi*L*k))  //C/W, Resistance of inner layer
Ro=(log(ro/r_)/(2*%pi*L*k))  //C/W, Resistance of outer layer
Rc=((Ti-To)/(Q))-(Ri+Ro)     //C/W, contact resistance
printf("The contact resistance is %f C/W \n",Rc)
Ac=2*%pi*L*r_                //m^2, area of contact surface of shell
hc=1/(Ac*Rc)                 //W/m^2 c, contact heat transfer coefficient
printf("contact heat transfer coefficient is %f W/m^2 C \n",hc)
```

```
//(c)
dt=Q/(hc*Ac)
printf("The temprature jump is %f C",dt)
```

Scilab code Exa 3.12 critical insulation thickness

```
//Example 3.12
// calculate the critical thickness.
d=5.2*10^-3          //m, diameter of copper wire
ri=d/2               //inner radius of insulation
kc=0.43              //W/m C, thermal conductivity of
   PVC
Tw=60                //C, temp. 0f wire
h=11.35              //W/m^2 C, film coefficient
To=21                //C, ambient temp.
//calculation
Ro=kc/h              //m,critical outer radius of
   insulation
t=Ro-ri
printf("the critical thickness is %f mm",t*10^3)
```

Scilab code Exa 3.13 critical insulation thickness

```
//Example 3.13
// calculate the critical insulation thickness.
d=15*10^-2           //m, length of steam main
t=10*10^-2           //m, thickness of insulation
ki=0.035             //W/m C, thermal conductivity of
   insulation
h=10                 //W/m^2 C, heat transfer
   coefficient
//calculation
```

```
//from eq. 3.29
ro=ki/h
printf("ro= %f cm \n",ro*10^3)
printf("Radius of bare pipe is larger than outer
   radius of insulation \n So critical  insulation
   thickness does not exist ")
```

Scilab code Exa 3.14 `optimum thickness`

```
//Example 3.14
//calculate  the optimum thickness.
//Given
Ti=172              //C, saturation temp.
To=20               //C, ambient temp.
Cs=700              //per ton, cost of steam
Lv=487              //kcal/kg, latent heat of steam
ho=10.32            //kcal/h m^2 C, outer heat transfer
    coefficient
kc=0.031            //W/m C, thermal conductivity of
   insulation
n=5                 //yr, service life of insulation
i=0.18             //Re/(yr)(Re), interest rate
//Calculation
di=0.168            //m, inner diameter of insulation
//Cost of insulation
Ci=17360-(1.91*10^4)*di          //Rs/m^3
Ch=Cs/(1000*Lv)                  //Rs/cal, cost of
   heat energy in steam
sm=1/(1+i)+1/(1+i)^2+1/(1+i)^3+1/(1+i)^4+1/(1+i)^n
//from eq. 3.33
ri=di/2            //m  inner radius of insulation
L=1                //m, length of pipe
//Pt=Ch*sm*2*%pi*ri*L*(  1/(((ri/kc)*('log(ro/ri)'))+
   ri/(ho*ro)))*7.2*10^3*(Ti-To)+%pi*(ro^2-ri^2)*L*
   Ci
```

```
//On differentiating , dpt/dro=-957.7*((1/ro)-(0.003/ro^2))/(log(ro)+(0.003/ro)+2.477)^2
deff('[x]=f(ro)','x=-957.7*((1/ro)-(0.003/ro^2))/(log(ro)+(0.003/ro)+2.477)^2+98960*ro')
ro=fsolve(0.1,f)
t=ro-ri
printf("The optimum insulation thickness is %f mm",t*1000)
```

Chapter 4

Forced Convection

Scilab code Exa 4.2 `Air flow over a flat plate`

```
//Example 4.2
//Determine
//(a)local heat transfer coefficient .
//(b)the average heat transfer coefficient
//the rate of heat loss from the surface.

//Given
l=2                         //m, length of flat surface
T1=150                      //C, surface temp.
p=1                         //atm, pressure
T2=30                       //C, bulk air  temp.
V=12                        //m/s, air velocity

//Calculation
Tf=(T1+T2)/2               //C, mean air film temp.
mu=2.131*10^-5               //m^2/s, viscosity
k=0.031                      //W/m C, thermal conductivity
rho=0.962                    //kg/m^3, density of air
cp=1.01                      //kj/kg C, specific heat of air
```

```
Pr=cp*10^3*mu/k                    //Prandtl no.
Remax=l*V*rho/mu              //maximum Reynold no.
Re=5*10^5                     //Reynold no. during
    transition to turbulent flow
L_=(Re*mu)/(V*rho)            //m, distance from the
    leading edge
//for laminar flow heat transfer coefficient h,
//h16.707*x^-(1/2)
//(a)
//h2=31.4*x^(-1/5)
//b
hav=22.2
//c
Q=hav*l*p*(T1-T2)
printf("The rate of heat loss is %f W",Q)
```

Scilab code Exa 4.3 temprature of wire

```
//Example 4.3
//what will be the temp. of the wire at steady state
    .
//Given
d=7.24*10^-4                   //m, diameter of wire
l=1                            //m, length of wire
I=8.3                          //A, current in a wire
R=2.625                        //ohm/m, electrical
    resistance
V=10                           //m/s, air velocity
Tb=27                          //C, bulk air temp.
//the properties at bulk temp.
mu=1.983*10^-5                 //m^2/s, viscosity
k=0.02624                      //W/m C, thermal
    conductivity
rho=1.1774                     //kg/m^3, density of
    air
```

```
cp=1.0057                          //kj/kg C, specific heat of air

//calculation
Pr=cp*10^3*mu/k                    //Prandtl no.
Re=d*V*rho/mu                      // Reynold no.
//from eq. 4.19, nusslet no.
Nu=0.3+(0.62*Re^(1/2)*Pr^(1/3)/(1+(0.4/Pr)^(2/3))^(1/4))*(1+(Re/(2.82*10^5))^(5/8))^(4/5)
hav=Nu*k/d                         //W/m^2 C, average heat transfer coefficient
Q=I^2*R                            //W, rate of electrical heat generation
A=%pi*d*l
dt=Q/(hav*A)                       //C,temp. difference
T=dt+Tb                            //C, steady state temp.
printf("The steady state temprature is %f C\n",T)
//REVISED CALCULATION
Tm=(T+Tb)/2                        //C, mean air film temp.
//the properties at Tm temp.
mu1=2.30*10^-5                       //m^2/s, viscosity
k1=0.0338                            //W/m C, thermal conductivity
rho1=0.878                           //kg/m^3, density of air
cp1=1.014                            //kj/kg C, specific heat of air
Re1=d*V*rho1/mu1                     // Reynold no.
Pr1=(1.014*10^3*2.30*10^-5)/k1                   //Prandtl no.
//from eq. 4.19, nusslet no.
Nu1=0.3+(0.62*Re1^(1/2)*Pr1^(1/3)/(1+(0.4/Pr1)^(2/3))^(1/4))*(1+(Re1/(2.82*10^5))^(5/8))^(4/5)
hav1=Nu1*k1/d                         //W/m^2 C, average heat transfer coefficient
dt1=Q/(hav1*A)                       //C,temp. difference
```

```
T1=dt1+Tb                          //C, steady state
    temp.
printf("The recalculated value  is almost equal to
    previous one.")
```

Scilab code Exa 4.4 Calculate Required time

```
//Example 4.4
//Calculate
//(a) what is initial  rate of melting of ice.
//(b)how much time would be needed to melt away 50 %
     of ice
//Given
di=0.04                          //m, diameter of ice
    ball
V=2                              //m/s, air velocity
T1=25                            //C, steam temp.
T2=0
//the properties  of air
mu=1.69*10^-5                    //kg/ms, viscosity
k=0.026                          //W/m C, thermal
    conductivity
rho=1.248                        //kg/m^3, density
cp=1.005                         //kj/kg C, specific
    heat
//propertice of ice
lamda=334                        //kj/kg, heat of
    fusion
rhoice=920                       //kg/m^3 density of
    ice

//calculation
Pr=cp*10^3*mu/k                  //Prandtl no.
Re=di*V*rho/mu                   // Reynold no.
//from eq. 4.19, nusslet no.
```

```
Nu=2+(0.4*Re^0.5+0.06*Re^(2/3))*Pr^0.4
hav=Nu*k/di                        //W/m^2 C, average heat transfer coefficient
Ai=%pi*di^2                        //initial area of sphere
Qi=Ai*hav*(T1-T2)                  //W=J/s, initial rate of heat transfer
Ri=Qi/lamda                        //initial  rate of melting of ice
printf("initial  rate of melting of ice is %f g/s\n",Ri)

//(b)
//mass of ice ball 4/3*%pi*r^3
//Rate of melting= Rm= -d/dt(m)
//Rate of heat input required =-lamda*Rate of melting
//heat balance equation
// -lamda*(Rm)=h*4*%pi*r^2*dt
//integrating and solving
rf=((di/2)^3/2)^(1/3)
//solving eq. 3
t1=1.355*10^-4/(8.136*10^-8)
printf("The required time is is %f s\n",round(t1))
```

Scilab code Exa 4.5 average time

```
//Example 4.5
//calculate the average time of contact .
//Given
Vo=0.5                             //m/s air velocity
T1=800                             //C, initial temp.
T2=550                             //C, final temp.
Tam=500                            //C, air mean temp.
P=1.2                              //atm, pressure
```

```
//the properties of solid particles.
dp=0.65*10^-3                    //m, average particle diameter
cps=0.196                        //kcal/kg C, specific heat
rhos=2550                        //kg/m^3, density
//Properties of air
mu=3.6*10^-5                     //kg/ms, viscosity
k=0.05                           //kcal/hm C, thermal conductivity
rho=0.545                        //kg/m^3, density of air
cp=0.263                         //kcal/kg C, specific heat of air

//calculation
Pr=cp*mu*3600/k                       //Prandtl no.
Redp=dp*Vo*rho/mu                // Reynold no.
//from eq. 4.29(b) heat transfer coefficient
h=(k/dp)*(2+0.6*(Redp)^(1/2)*(Pr)^(1/3))
Tg=500                           //C, gas temp.
//from heat balance equation
// -(dTs/dt)=6h/(dp*rhos*cps)*(Ts-Tg)
t=(dp*rhos*cps/(6*h))*integrate('(1/(Ts-Tg))','Ts',550,800)
printf("the required contact time is %f s",t*3600)
```

Scilab code Exa 4.6 Overall heat transfer coefficient

```
//Example 4.6
//Calculate the required rate of flow of water.
//calculate the overall heat transfer coefficient
//Given
mo_=1000            //kg/h, cooling rate of oil
cpo=2.05            //kj/kg C, specific heat of oil
```

```
T1=70                //C, initial temp. of oil
T2=40                //C, temp. of oil after cooling
cpw=4.17             //kj/kg C, specific heat of water
T3=42                //C, initial temp. of water
T4=28                //C, temp. of oil after cooling
A=3                  //m^2, heat exchange area
//Calculation, rate of flow of water
mw_=mo_*cpo*(T1-T2)/(cpw*(T3-T4))
printf("the required rate of flow of water is %f kg/
   h \n",mw_)
Q=mo_*cpo*(T1-T2)/3600        //kw, heat duty
dt1=T1-T3           //C, hot end temp. difference
dt2=T2-T4            //C, cold end temp. difference
LMTD=(dt1-dt2)/(log(dt1/dt2))  //log mean temp.
   difference
dtm=LMTD
U=Q*10^3/(A*dtm)
printf("the overall heat transfer coefficient is %f
   W/m^2 C",U)
```

Scilab code Exa 4.7 inlet and outlet temprature

```
//Example 4.7
//calculatemthe inlet and outlet temp.of gas.
//Given
Q=38700              //kcal/h, heat duty
W=2000               //kg/h gas flow rate
cp=0.239             //kcal/kg C, specific heat of
   nitrogen
A=10                 //m^2 ,heat exchanger area
U=70                 //kcal/hm^2 C, overall heat
   transfer coefficient
n=0.63               //fin efficiency

//Calculation
```

```
dt=Q/(W*cp)              //C, temp. difference
//To-Ti=dt.........................(i)
dtm=Q/(U*A*n)
//(To-Ti)/(log((160-Ti)/(160-To)))=87.8........(2)
//solving  1  and 2
deff('[x]=f(To)','x=(To-(To-dt))/(log((160-(To-dt))/(160-To)))-87.8')
To=fsolve(100,f)
Ti=To-dt
printf("The inlet temprature is  Ti=%f C\n",round(Ti))
printf("The outlet temprature is To=%f C\n",round(To))
```

Scilab code Exa 4.8 drop in temprature

```
//Example 4.8
//Calculate the drop in temp. of the water.
//Given
V=1.8                    //m/s, velocity of hot water
T1=110                   //C, initial temp.
l=15                     //m, length  of pipe
t=0.02                   //m, thickness of insulation
kc=0.12                  //W/mC,thermal conductivity of insulating layer
ho=10                    //Wm^2 C, outside film coefficient
T2=20                    //C, ambient temp.
//the properties of water at 110 C
mu=2.55*10^-4            //m^2/s, viscosity
k=0.685                  //W/m C, thermal conductivity
rho=950                  //kg/m^3, density of air
cp=4.23                  //kj/kg C, specific heat of air
di=0.035                 //m, actual internal dia. of
```

```
    pipe
ri=di/2                  //m,internal radius
t1=0.0036                //m, actual thickness of 1-1/4 schedule 40 pipe
ro=ri+t1                 //m, outer radius of pipe
r_=ro+t                  //m, outer radius of insulation
kw=43                    //W/mC, thermal conductivity of steel
//calculation
Pr=cp*10^3*mu/k          //Prandtl no.
Re=di*V*rho/mu           // Reynold no.
//from eq. 4.9,  Nusslet no.
Nu=0.023*(Re)^0.88*Pr^0.3
hi=Nu*k/di               //W/m^2 C, average heat transfer coefficient
//the overall coefficient inside area basis Ui
Ui=1/(1/hi+(ri*log(ro/ri))/kw+(ri*log(r_/ro))/kc+ri/(r_*ho))
Ai=%pi*di*l             //m^2, inside area basis
W=%pi*ri^2*V*rho        //kg/s, water flow rate
//from the relation b/w LMTD and rate of heat loss
//deff('[x]=f(To)','x=W*cp*10^3*(T1-To)-Ui*Ai*((T1-To)/log((T1-T2)/(To-T2)))')
//To=fsolve(1,f)

deff('[x]=f(To)','x=(W*cp*10^3)/(Ui*Ai)*(T1-To)-((T1-To)/log((T1-T2)/(To-T2)))')
To=fsolve(100,f)
printf("The outlet eater temp. is %f C",To)
```

Scilab code Exa 4.9 find the temprature

```
//Example 4.9
//at what temp. does the water leave the pipe.
```

```
//Given
T1=28                   //C, inlet temp.
T2=250                  //C,bulk temp.
V=10                    //m/s, gas velocity
l=20                    //m, length of pipe
mw=1*3600               //kg/h, water flow rate
di=4.1*10^-2            //m, inlet diameter
Tm=(T1+T2)/2            //C, mean temp.
ro=0.0484               //m, outside radius
//properties of water
mu=8.6*10^-4            //kg/ms, viscosity
kw=0.528                //kcal/h m C, thermal conductivity
kw_=0.528*1.162         //W/ m C, thermal conductivity
rho=996                 //kg/m^3, density of air
cp=1*4.18               //kj/kg C, specific heat of air
cp_=1                   //kcal/kg C
//properties of flue gas
mu1=2.33*10^-5          //kg/ms, viscosity
ka=0.0292               //kcal/h m C, thermal conductivity
rho1=0.891              //kg/m^3, density of air
cp1=0.243               //kcal/kg C, specific heat of air
Pr=0.69

//calculation
A=%pi/4*di^2            //m^2, cross section of pipe
Vw=1/(rho*A)            //m/s, velocity of warer
Re=di*Vw*rho/mu         // Reynold no.
Pr1=cp*10^3*mu/kw_      //Prandtl no. for water
Nu=0.023*Re^0.8*Pr1^0.4                 //Nusslet no.
//water side heat transfer coefficient  hi
hi=206*kw/di
//gas side heat transfer coefficient    ho
a=41                   //mm, i.d. schedule
Tw=3.7                 //mm, wall thickness
do=a+2*Tw              //mm, outer diameter of pipe
Re1=do*10^-3*V*rho1/mu1     // Reynold no
```

```
//from eq. 4.19, nusslet no.
Nu1=0.3+(0.62*Re1^(1/2)*Pr^(1/3)/(1+(0.4/Pr)^(2/3))
   ^(1/4))*(1+(Re1/(2.82*10^5))^(5/8))^(4/5)
ho=(Nu1*ka/do)*10^3      //kcal/h m^2 C
Uo=1/(ro/(di/2*hi)+1/ho)    //kcal/h m^2 C, overall
   heat transfer coefficient

//Heat balance
A1=%pi*ro*l          //m62, outside area of pipe
//from the formula of LMTD
deff('[x]=f(T2_)','x=mw*cp_*(T2_-T1)-Uo*A1*((T2_-T1)
   /log((T2-T1)/(T2-T2_)))')
T2_=fsolve(1,f)
printf("The exit water temp is %f K",round(T2_))
```

Scilab code Exa 4.10 length of heat exchanger

```
//Example 4.10
//calculate the length of heat exchanger.
//Given
dti=0.0212          //m inner tube
dto=0.0254          //cm, outer tube
dpi=0.035           //cm, outer pipe
mo_=500             //kh/h, cooling rate of oil
To2=110             //C, initial temo. of oil
To1=70              //C, temp. after cooling of oil
Tw2=40              //C, inlet temp. of water
Tw1=29              //C, outlet temp. of water
//properties of oil
cpo=0.478           //kcal/kg C
ko=0.12             //kcal/h m C, thermal conductivity
rho=850             //kg/m^3, density of oil
//properties of water
kw=0.542            //kcal/h m C, thermal conductivity
kw_=(kw*1.162)      //kj/kg C
```

```
muw=7.1*10^-4        //kg/ms, viscosity of water
cpw=1                //kcal/kg C
cpw_=cpw*4.17        //kcal/kg C
rhow=1000            //kg/m^3, density
//calculation
HL=mo_*cpo*(To2-To1)        //kcal/h, heat load of
   exchanger
mw_=HL/(cpw*(Tw2-Tw1))      //kg/h water flow rate
mw_1=mw_/(3600*10^3)        //m^3/s water flow rate
A1=(%pi/4)*(dti)^2          //m^2, flow area of tube
Vw=mw_1/A1                  //m/s water velocity
Rew=dti*Vw*rhow/muw         //Reynold no.
Prw=cpw_*10^3*muw/kw_        //Prandtl no.
Nuw=0.023*Rew^0.8*Prw^0.4 //nusslet no.
//water side heat transfer coefficient   hi
hi=Nuw*kw/dti

//oil side heat transfer coefficient
A2=%pi/4*(dpi^2-dto^2)      //m^2, flow area of
   annulus
Vo=mo_/(3600*rho*A2)        //m/s velocity of oil
de=(dpi^2-dto^2)/dto        //m, equivalent dia of
   annulus
Tmo=(To2+To1)/2             //C,mean oil temp.
muoil=exp((5550/(Tmo+273))-19)  //kg/ms, viscosity
   of oil
Reo=de*Vo*rho/muoil
Pro=cpo*muoil*3600/ko       //prandtl no. for oil

//assume (1st approximation)
Nuo=3.66
ho=Nuo*ko/de               //kcal/h m^2 c
L=1                        //assume length of tube
Ai=%pi*dti*L
Ao=%pi*dto*L
//overall heat transfer coefficient 1st
   approximation
Uo=1/(1/ho+Ao/(Ai*hi))
```

```
LMTD=((To2-Tw2)-(To1-Tw1))/(log((To2-Tw2)/(To1-Tw1))
    )
Ao1=HL/(Uo*LMTD)          //m^2, heat transfer area
Lt=Ao1/(%pi*dto)           //m, tube length
//from eq.  4.8
Nuo1=1.86*(Reo*Pro/(Lt/de))^(1/3)    //Nusslet no.
ho1=Nuo1*ko/de
Tmw=(Tw1+Tw2)/2           //C, mean water temp.
//balancing heat transfer rate of oil and water

//average wall temp. Twall
Twall=((hi*dti*(-Tmw))-(ho1*dto*Tmo))/(-65.71216)
//viscosity of oil at this temp.
muwall=exp((5550/(Twall+273))-19)  //kg/ms,
    viscosity of oil
//Nusslet no.
Nuo2=1.86*(Reo*Pro/(Lt/de))^(1/3)*(muoil/muwall)
    ^0.14
ho2=Nuo2*ko/de
Uo2=1/((1/ho2)+(Ao/(Ai*hi)))
Ao2=HL/(Uo2*LMTD)
Lt_=Ao2/(%pi*dto)
printf("The tube length is %f m",Lt_)
```

Scilab code Exa 4.11 rate of heat transfer

```
//Example 4.11
//calculate the rate of heat transfer to water.
//Given
Ti=260                  //C, initial  temp.
Ts=70                   //C, skin temp.
St=0.15                 //m,space between tubes in
    equilateral triangular arrangement
Sd=St                   //space between tubes
mu=4.43*10^-5                //m^2/s, momentum
```

```
    diffusity
k=0.0375                    //W/m C, thermal conductivity
rho=0.73                    //kg/m^3, density of air
cp=0.248                    //kj/kg C, specific heat of air
V=16                        //m/s, velociity
d=0.06                      //m, outside diameter of tube
Nt=15                       //no. of tubes in transverse row
Nl=14                       //no. of tubes in longitudinal row
N=Nl*Nt                     //total no. of tubes
L=1                         //m, length
//Calculation
Sl=(sqrt(3)/2)*St
Pr=cp*mu*3600*rho/k         //Prandtl no. of bulk air
Pr=0.62
Prw=0.70                    //Prandtl no. of air at wall temp. 70 C
//from eq. 4.25
Vmax=(St/(St-d))*V
//from eq. 4.26
Vmax1=(St/(2*(St-d)))*V
Redmax=d*Vmax/mu
p=St/Sl                    //pitch ratio
p<2
//from table 4.3
m=0.6
C=0.35*(St/Sl)^0.2
h=(k/d)*C*(36163)^m*(Pr)^(0.36)*(Pr/Prw)^(0.25)
//from eq. 4.28
dt=190*exp(-%pi*d*N*h/(rho*V*3600*Nt*St*cp))
LMTD=((Ti-Ts)-(dt))/log((Ti-Ts)/dt)
A=%pi*d*L*N               //m^2, heat transfer area
```

```
Q=h*A*LMTD
printf(" the rate of heat transfer to water.is %f
    kcal/h",Q)
```

Scilab code Exa 4.12 aniline is a tonnage oc

```
//Example 4.12
//Calculate the rise in temp. of water .
//Given
W=0.057                          //m^3/min/tube, flow
    rate of water
W_=W*16.66                       //kg/s. water flow rate
di=0.0212                        //m, inside diameter
Ti=32                            //C, inlet water temp.
Tw=80                            //C, wall temp.
L=3                              //m, length of pip
//Calculation
V=(W/60)*(1/((%pi/4)*di^2))      //m/s, water velocity
//the properties of water at mean liquid temp..
mu=7.65*10^-4                    //m^2/s, viscosity
k=0.623                          //W/m C, thermal
    conductivity
rho=995                          //kg/m^3, density of
    air
cp=4.17                          //kj/kg C, specific
    heat of air

//calculation
Pr=cp*10^3*mu/k                  //Prandtl no.
Re=di*V*rho/mu                   // Reynold no.
//from eq. 4.19, nusslet no.
//from dittus boelter eq.
Nu=0.023*Re^0.8*Pr^0.4           //Prandtl no.
f=0.0014+0.125*Re^-0.32          //friction factor
//Reynold analogy
```

```
St=f/2                              //Stanton no.
Nu1=Re*Pr*St
//Prandtl analogy
St1=(f/2)/(1+5*(Pr-1)*sqrt(f/2))
Nu2=St1*Re*Pr
//colburn analogy
Nu3=Re*Pr^(1/3)*(f/2)
h=Nu3*k/(di)                        //W/m^2 C av heat transfer coefficient
//Q=W_*cp*10^3*(To-Ti)=h*A*LMTD
A=%pi*di*L          //m^2
deff('[x]=f(To)','x=W_*cp*10^3*(To-Ti)-h*A*((To-Ti)/log((Tw-Ti)/(Tw-To)))')
To=fsolve(1,f)
//Revised calculation
Tm=(Ti+To)/2                        //C, mean liquid temp.
//the properties of water at new mean liquid temp..
mu1=6.2*10^-4                          //m^2/s, viscosity
k1=0.623                                //W/m C, thermal conductivity
rho1=991                                //kg/m^3, density of air
cp1=4.17                                //kj/kg C, specific heat of air
//calculation
Pr1=cp1*10^3*mu1/k1                        //Prandtl no.
Re1=di*V*rho1/mu1                         // Reynold no.
//from dittus boelter eq.
f1=0.0014+0.125*Re1^(-0.32)             //friction factor
//colburn analogy
Nu4=Re1*Pr1^(1/3)*(f1/2)
h1=Nu4*k1/(di)                         //W/m^2 C av heat transfer coefficient
deff('[x]=f(To_)','x=W_*cp*10^3*(To_-Ti)-h1*A*((To_-Ti)/log((Tw-Ti)/(Tw-To_)))')
To_=fsolve(1,f)
printf("Outlet temp. of water for one pass through the tubes is %f C",To_)
```

Chapter 5

free convection

Scilab code Exa 5.1 Rate of heat loss

```
//Example 5.1
//Calculate the rate of heat loss .
//Given
T1=65                         //C, furnace temp.
T2=25                         //C, ambient temp.
h=1.5                         //m, height of door
w=1                           //m, width of door
Tf=(T1+T2)/2                  //c, average air film temp.
//Properties of air at Tf
Pr=0.695                      //Prandtl no.
mu=1.85*10^-5                 //m^2/s, viscosity
beeta=1/(Tf+273)              //K^-1. coefficient of volumetric expension
k=0.028                       //W/m C, thermal conductivity
g=9.8                         //m/s^2, gravitational constant
Grl=g*beeta*(T1-T2)*h^3/(mu^2)          //Grashof no.
Ral=Grl*Pr                              //Rayleigh no.
//Nusslet no.
Nul=(0.825+(0.387*(Ral)^(1/6))/(1+(0.492/Pr)^(9/16))
```

```
^(8/27))^2
hav=Nul*k/h                    //average heat transfer coefficient
Ad=h*w                         //m^2, door area
dt=T1-T2                       //temp. driving force
q=hav*Ad*dt                    //W, rate of heat loss
printf("The rate of heat loss is %f W",q)
```

Scilab code Exa 5.2 steady state temprature

```
//Example 5.2
//Calculate the steady state temp. of the plate.
//Given
T1=60                          //C, plate temp.
T2=25                          //C, ambient temp.
h=1
w=1                            //m, width of door
q=170                          //W, rate of heat transfer
Tf=(T1+T2)/2                   //c, average air film temp.
//Properties of air at Tf
Pr=0.7                       //Prandtl no.
mu=1.85*10^-5                  //m^2/s, viscosity
beeta=1/(Tf+273)               //K^-1. coefficient of volumetric expension
k=0.028                        //W/m C, thermal conductivity
g=9.8                          //m/s^2, gravitational constant

//Calculation
A=h*w                          //m^2, plate area
P=2*(h+w)                      //m, perimeter of plate
L=A/P                          //m characteristic length
Grl=g*beeta*(T1-T2)*L^3/(mu^2)        //Grashof no.
Ral=Grl*Pr                            //Rayleigh no.
```

```
//Nusslet no.
Nul=0.54*(Ral)^(1/4)                    //Nusslet no.
hav=Nul*k/L                             //average heat transfer coefficient
Ts=q/(hav*A)+T2
printf("the steady state temp. of the plate is %f C",Ts)
```

Scilab code Exa 5.3 CALCULATE TIME REQUIRED

```
//Example 5.3
//Calculate the time required for cooling of the rod.
//Given
d=0.0254                    //m, diameter of steel rod
l=0.4                       //m, length of rod
T1=80                       //C, initial temp.
T2=30                       //C, ambient temp.
T3=35                       //c, temp. after cooling
rho=7800                    //kg/m^3 ,density of steel rod
cp=0.473                    //kj/kg C. specific heat

//Calculation
m=%pi/4*d^2*l*rho           //kg. mass of cylinder
A=%pi*d*l                   //m^2, area of cylinder
dt=T1-T2                    //c, instantaneous temp. difference
h=1.32*(dt/d)^0.25          //W/m^2 C, heat transfer coefficient
i=integrate('1/(T^(5/4))','T',5,50)
t=i/(3.306*A/(m*cp*10^3))
printf("The required time for cooling is %f hr",t/3600)
```

Scilab code Exa 5.4 Rate of heat loss

```
//Example 5.4
//Calculate the rate of heat loss by free convection per meter length of pipe.
//given
id=78*10^-3                    //m, internal diameter
od=89*10^-3                    //m, outer diameter
Pg=15                          //kg/cm^2, gauge pressure
t=2*10^-2                      //m, thickness of preformed mineral fibre
k=0.05                         //W/m C. thermal conductivity
Ta=25                          //C, ambient air temp.
Pr=0.705                       //Prandtl no.
//assume
Ts=50                          //C, skin temp.
l=1                            //m, length
Ti=200.5                        //C, initial temp.
rs=od/2+t                      //m, outer radius of insulation
ri=od/2                        //m, inner radius of insulation
//Rate of heat transfer through insulation per meter length of pipe
Q=2*%pi*l*k*(Ti-Ts)/(log(rs/ri))          //W
//properties of air at taken at the mean film temp.
Tf=(Ta+Ts)/2                  //C
mu=1.76*10^-5                 //m^2/s. viscosity
beeta=(1/(Tf+273))            //K^-1, coefficient of volumetric expansion
```

```
k1=0.027                          //W/m C, thermal conductivity
ds=2*rs                           //m, outer dia. of insulated pipe
g=9.8                             //m/s^2, gravitational constant
Grd=g*beeta*(Ts-Ta)*ds^3/(mu^2)          //Grashof no.
Rad=Grd*Pr                               //Rayleigh no.
//from eq. 5.9
//Nusslet no.
Nu=(0.60+(0.387*(Rad)^(1/6))/(1+(0.559/Pr)^(9/16))^(8/27))^2
hav=Nu*k1/ds                     //W/ m^2 C, average heat transfer coefficient
Ts=(Q/(%pi*ds*l*hav))+Ta      //C, skin temp.
//revised calculation by assuming
Ts1=70                          //C, skin temp.
//Rate of heat transfer through insulation
Q1=2*%pi*l*k*(Ti-Ts1)/(log(rs/ri))
Tf1=(Ta+Ts1)/2                    //C, average aie mean film temp.
mu1=1.8*10^-5                      //m^2/s. viscosity
beeta1=(1/(Tf1+273))                //K^-1, coefficient of volumetric expansion
k1=0.0275                         //W/m C, thermal conductivity
Pr1=0.703                         //Prandtl no.
Grd1=g*beeta1*(Ts1-Ta)*ds^3/(mu1^2)         //Grashof no.
Rad=Grd1*Pr1                                //Rayleigh no.
//from eq. 5.9
// average heat transfer coefficient , in //W/ m^2 C,
hav1=(0.60+(0.387*(Rad)^(1/6))/(1+(0.559/Pr)^(9/16))^(8/27))^2*(k1/ds)
Ts2=(Q1/(%pi*ds*l*hav1))+Ta
//again assume skin temp.=74
```

```
Ts2=74                               //C, assumed skin temp.
Q3=2*%pi*l*k*(Ti-Ts2)/(log(rs/ri))
printf("the rate of heat loss by free convection per meter length of pipe. is %f W",Q3)
```

Scilab code Exa 5.5 thickness of insulation

```
//Example 5.5
//Calculate , what thickness of insulation should be used
//so that the insulation skin temp. does not exceed 65 C
//Given
Ts=65                                //C, skin temp.
To=30                                //C, ambient temp.
Tw=460                               //C, wall temp.
Tf=(Ts+To)/2                           //C,mean air film temp.
beeta=(1/(Tf+273))                            //K^-1, coefficient of volumetric expansion
g=9.8                                  //m/s^2, gravitational constant
mu=1.84*10^-5                        //m^2/s, viscosity
L=10.5                               //m, height of converter
di=4                                 //m,diameter of converter
Pr=0.705                             //Prandtl no.
k=0.0241                             //kcal/h m C, thermal conductivity

//Calculation
Grl=g*beeta*(Ts-To)*L^3/(mu^2)          //Grashof no.
x=di/L                               //assume di/l=x
y=35/(Grl)^(1/4)                     //assume 35/(Grl)^(3/4)=y
```

```
//printf "x>y""
//for a verticla flat plate, from eq. 5.3
Ral=Grl*Pr                  //Rayleigh no.
//nusslet no.
Nu=(0.825+(0.387*(Ral)^(1/6))/(1+(0.496/Pr)^(9/16))^(8/27))^2
hav=Nu*k/L                  //kcal/h m^2 C, average heat transfer coefficient
//w=poly(0,"w")
//Dav=(4+(4+2*w))/2                    //average diameter
//Aav=%pi*Dav*L                        //average heat transfer area
//Qi=%pi*Dav*L*0.0602*(Tw-Ts)/w        //Rate of heat transfer through insulation
//rate of heat transfer from the outer surface of the insulation by free convection
//Qc=hav*%pi*Dav*L*(Ts-To)
//Qi=Qc
deff('[x]=f(w)','x=%pi*(4+w)*L*0.0602*(Tw-Ts)/w-hav*%pi*(4+2*w)*L*(Ts-To)')
w=fsolve(0.1,f)
printf("The required insulation thickness is %f m",w)
```

Scilab code Exa 5.6 `rate of heat gain`

```
//Example 5.6
//Calculate the rate of heat gain by the cooler surface.
//Given
L=1.6                  //m, height of enclosure
w=0.04                 //m, width of enclosure
b=0.8                  //m, breath
T1=22                  //C, surface temp.
```

```
T2=30                     //C, wall temp.
Tm=(T1+T2)/2              //C, Mean air temp.
Pr=0.7                    //Prandtl no.
//fpr air at 26 C
beeta=1/(Tm+273)          //K^-1. coefficient of
   volumetric expension
mu=1.684*10^-5            //m^2/s,  viscosity
k=0.026                   //W/m C, thermal conductivity
alpha=2.21*10^-5          //m^2/s, thermal diffusity
g=9.8                     //m/s^2, gravitational
   constant
Raw=g*beeta*(T2-T1)*w^3/(mu*alpha)        //Rayleigh
    no.
Nuw=0.42*(Raw)^0.25*Pr^0.012*(L/w)^-0.3   //Nusslet
   no.
h=Nuw*k/w                                 //kcal/h m
   ^2 C, heat transfer coefficient
q=h*(T2-T1)*(L*b)                         //W, the
   rate of heat transfer
printf("the rate of heat  transfer is %f W",q)
```

Scilab code Exa 5.7 Rate of heat loss

```
//example 5.7
//Calculate the rate of heat loss by the combined
   free and forced convection.
//Given
Ts=60                 //C, surface temp
To=30                 //C, bulk temp.
d=0.06                //m, diameter  of pipe
l=1                   //m, length
Tm=(Ts+To)/2
//for air at Tm
rho=1.105                       //kg/m^3, density
cp=0.24                         //kcal/kg C. specific
```

```
    heat
mu=1.95*10^-5                          //kg/m s. viscosity
P=0.7                                  //Prandtl no.
kv=1.85*10^-5                              //m^2/s, kinetic
    viscosity
k=0.0241                               //kcal/f m C, thermal
    conductivity
beeta=(1/(Tm+273))                          //K^-1.
    coefficient of volumetric expension
V=0.3                                  //m/s, velocity
g=9.8                                  //m/s^2, gravitational
     constant
//Calculation of nusslet no.
Rad=g*beeta*(Ts-To)*d^3*P/(kv^2)        //Rayleigh no.
//from eq. 5.9
Nufree=(0.60+(0.387*Rad^(1/6))/(1+(0.559/P)^(9/16))
    ^(8/27))^2
//calculation of forced convection nusslet no.
//from eq. 4.19
Re=d*V/(kv)
Nuforced=0.3+(0.62*Re^(1/2)*P^(1/3)/(1+(0.4/P)^(2/3)
    )^(1/4))*(1+(Re/(2.82*10^5))^(5/8))^(4/5)
Nu=(Nuforced^3+Nufree^3)^(1/3)         //nusslet no.
    for mixed convection
//Nu=h*d/k
h=Nu*k/d                              //kcal/h m^2 C, heat
    transfer corfficient
q=h*%pi*d*l*(Ts-To)
printf("the rate of heat loss per meter length is %f
     kcal/h",q)
```

Chapter 6

Boiling and condensation

Scilab code Exa 6.1 Consider nucleate pool

```
//Example 6.1
//calculate (a) the diameter of cavity on the
   boiling surface
//which produce a bubble nucleus that does not
   collapse .
//(b) what degree of superheat is necessary so that
   a bubble nucleus grow
//in size after detachment from the cavity.
//(a)
Tsat=350              //K, saturated temp.
Tl=Tsat+5             //K, liquid temp.
//By antoine eqn.
T=Tl-273              //C,
pl=exp(4.22658-(1244.95/(T+217.88)))
ST=26.29-0.1161*T     //dyne/cm, Surface tension of
   liquid
ST_=ST*10^-3          //N/m  Surface tension of liquid
Lv=33605              //kj/kgmol, molar heat of
   vaporization
R=0.08314             //m^3  bar/kgmol K, gas costant
r=(2*ST_*R*Tsat^2)/((Tl-Tsat)*pl*(Lv*10^3))
```

```
printf("So a bubble nucleus that has been detached from a cavity will not collapse in the liquid if it is larger than %f micrometer \n",r*10^6)

//(b)
r1=10^-6        //m
//pl1=exp(4.22658-(1244.95/(Tl_-273+217.88)))    //vapour pressure
//ST1=0.02629-1.161*10^-4(Tl_-273)               //surface tension

deff('[x]=f(Tl)','x=(Tl-Tsat)-2*(0.02629-1.161*10^-4*(Tl-273))*R*Tsat^2/(r1*Lv*10^3)')
Tl=fsolve(0.1,f)
T_=(Tl-273.5)-(Tsat-273)
printf("The superheat of the liquid is %f C",round(T_))
```

Scilab code Exa 6.2 rate of boiling of water

```
//Example 6.2
//Calculate the rate of boiling of water .
//Given
d=0.35                    //m, diameter of pan
p=1.013                   //bar, pressure
T1=115                    //C, bottom temp.
T2=100                    //C, boiling temp.
Te=T1-T2                  //C, excess temp.
//For Water
mu1=2.70*10^-4            //Ns/m^2, viscosity
cp1=4.22                  //kj/kg C, specific heat
rho1=958                  //kg/m63. density
Lv1=2257                  //kj/kg, enthalpy of vaporization
```

```
s1=0.059                    //N/m , surface tension
Pr1=1.76                    //Prandtl no.
//For saturated steam
rho2=0.5955
//For the pan
Csf=0.013                   //constant
n=1                         //exponent
g=9.8                       //m/s^2, gravitational constant
//from eq. 6.6   //heat flux
Qs1=mu1*Lv1*(g*(rho1-rho2)/s1)^(1/2)*(cp1*Te/(Csf*Lv1*(Pr1)^n))^3
Rate=Qs1/Lv1                //kg/m^2 s. rate of boiling
Ap=%pi/4*d^2                //m^2, pan area
Trate=Rate*Ap               //kg/s, Total rate of boiling
Trate_=Trate*3600.5         //kg/h. Total rate of boiling
printf("total rate of boiling of water is %f kg/h \n",Trate_)

//using Lienhard's eq.,    //critical heat flux
Qmax=0.149*Lv1*rho2*(s1*g*(rho1-rho2)/(rho2)^2)^(1/4)
//by Mostinski eq.
Pc=221.2                    //critical pressure
Pr=p/Pc                     //reduced pressure
hb=0.00341*(Pc)^(2.3)*Te^(2.33)*Pr^(0.566)      //boiling heat transfer coefficient
hb_=hb/1000                 //kW/m^2 C boiling heat transfer coefficient
Qs2=hb_*(Te)
printf("Qs2 compares reasonably well with the Qs1")
```

Scilab code Exa 6.3 `formaldehyde is one of`

```
//Example 6.3
//Calculate the rate of boiling.
//Given
A=12.5673
B=4234.6
pv=1.813
T1=200                  //C, tube wall temp.
//For methanol
Tc=512.6                //K, critical temp.
w=0.556                 //acentric factor
Zra=0.29056-0.08775*w
R=0.08314              //m^3bar/gmol K, universal gas
    constant
Pc=80.9                //bar, critical temp.
Mw=32                  //g, molecular wt

//Calculation
//Estimation of liquid and vapour properties
//from antoine eq.
T=B/(A-log(pv))        //K, boiling point
Te=(T1+273)-T          //K, excess temp.
Tm=((T1+273)+T)/2      //K, mean temp.

//Liquid properties
//(a)
Tr=T/Tc               //K, reduced temp.
//from Rackett technique
Vm=R*Tc*(Zra)^(1+(1-Tr)^(2/7))/Pc      //m^3/kg mol,
    molar volume
rhol=Mw/Vm                             //kg/m^3,
   density of satorated liquid density
//(b)
//from Missenard technique
T2=348                //K,given data temp.
T3=373                //K,given data temp.
Cp2=107.5             //j/g mol K specific heat at T2
Cp3=119.4             //j/g mol K specific heat at T3
//By linear interpolation at T=353.7 K
```

```
Cp=Cp2+(Cp3-Cp2)*((T-T2)/(T3-T2))     //kj/kg mol C, specific heat at T=353.7 K
Cp_=Cp*0.03125                        //kj/kg C
//(c)Surface tension at given temp.(K)
T4=313
St4=20.96
T5=333
St5=19.4
//By linear interpolation at T=353.7 K
S=17.8                                //dyne/cm, surface temp.
//(d) liquid viscosity
T6=298
MUt6=0.55                             //cP, liquid viscosity at temp=298
MU=((MUt6)^-0.2661+((T-T6)/233))^(-1/0.2661)     //cP
//(e)Prandtl no. a,b,c are constant
a=0.3225
b=-4.785*10^-4
c=1.168*10^-7
kl=a+b*T+c*T^2                        //W/m C, thermal conductivity
Prl=Cp_*1000*MU*10^-3/kl              //Prandtl no.
//(f)heat of vaporization at 337.5 K
Lv=1100                               //kj/kg, enthalpy of vaporization

//Properties of methanol vapour at Tm
//(a)
Vm1=R*Tm/pv                           //m^3/kg mol, molar volume
rhov=Mw/Vm1                           //kg/m^3, density of vapour
//(b) a1,b1,c1,d1 are costants
a1=-7.797*10^-3
b1=4.167*10^-5
c1=1.214*10^-7
```

```
d1=-5.184*10^-11
//thermal conductivity of vapour
kv=a1+b1*Tm+c1*Tm^2+d1*Tm^3     //W/m C
//(c)heat capacity of vapour,  a2,b2,c2,d2 are
   costants
a2=21.15
b2=7.092*10^-2
c2=2.589*10^-5
d2=-2.852*10^-8
//heat capacity of vapour,      in kj/kh mol K
Cpv=a2+b2*Tm+c2*Tm^2+d2*Tm^3

//(d)viscosity of vapour
T7=67
MUt7=112
T8=127
MUt8=132
//from linear inter polation at Tm
MUv=1.364*10^-5                //kg/m s

//from Rohsenow's eq.
Csf=0.027                      //constant
n=1.7                          //exponent value
//from eq. 6.6
g=9.8                          //m/s^2, gravitational
   constant
//heat flux    //kW/m^2
Q=MU*10^-3*Lv*(g*(rhol-rhov)/S*10^-3)^(1/2)*(Cp_*Te
   /(Csf*Lv*(Prl)^n))^3
//from eq. 6.11
//from eq 6.11,  critical heat flux
Qmax=0.131*Lv*(rhov)^(1/2)*(S*10^-3*g*(rhol-rhov))
   ^(1/4)
//dimensionless radius r_
r=0.016
r_=r*(g*(rhol-rhov)/(S*10^-3))^(1/2)
//peak heat flux
Qmax1=Qmax*(0.89+2.27*exp(-3.44*sqrt(r_)))
```

```
//from eq. 6.12
//heat transfer coefficient hb
d=0.032                          //m, tube diameter
hb=0.62*((kv^3)*rhov*(rhol-rhov)*g*(Lv*10^3+0.4*Cpv*Te)/(d*MUv*Te))^(1/4)
Qb=hb*Te                         //kw/m^2, heat flux
BR=Qb*10^-3/Lv                   //kg/m^2s, boilng rate
printf("The boilins rate is %f kg/m^2 h",BR*3600)
```

Scilab code Exa 6.4 A mixture of benzene

```
//Example 6.4
//Calculate the physical properties of the liquid.

//Given
W1=200               //kg/h, rate of entering toluene
muv=10^-5            //kg/m s, viscosity of toluene vapour
mul=2.31*10^-4       //kg/m s, viscosity of  benzene
rhol=753             //kg/m^3, density of benzene
rhov=3.7             //kg/m^3, density of toluene vapour
Cpl=1968             //j/kg C, specific heat of benzene
kl=0.112             //W/m C, thermal conductivity of  benzene
T1=160               //C tube wall temp.
T2=120               //C , saturated temp.
Te=T1-T2             //C, excess temp.
Lv=3.63*10^5         //j/kg, enthalpy of vaporization
s=1.66*10^-2         //N/m, surface tension
//Calculation of hc & hb
w=0.125              //m, mean step size
d=0.0211             //, internal diameter of tube
G=W1/(3600*%pi/4*(d^2))          //kg/m^2 s, mass
```

```
flow rate
Re1=G*(1-w)*d/mul                    //Reynold no.
Prl=Cpl*mul/kl                       //Prandtl no.
//from eq. 6.23
x=(w/(1-w))^(0.9)*(rhol/rhov)^(0.5)*(muv/mul)^0.1
    //let x=1/succepsibility
//from eq. 6.22
F=2.35*(x+0.231)^0.736             //factor signifies '
    liquid only reynold no.' to a two phase reynold
    no.
//from eq. 7.21
Re2=10^-4*Re1*F^1.25               //Reynold no.
//from eq. 6.18
S=(1+0.12*Re2^1.14)^-1             //boiling supression
    factor
//from eq. 6.15
hc=0.023*Re1^(0.8)*Prl^(0.4)*(kl/d)*F   //W/m^2 C,
    forced convection boiling part
//from eq. 6.16
mulv=(1/rhov)-(1/rhol)                   //m^3/kg,
    kinetic viscosity of liquid vpaour
dpsat=Te*Lv/((T2+273)*mulv)             //N/m^2, change
    in saturated presssure
//nucleate boiling part hb
hb=1.218*10^-3*(kl^0.79*Cpl^0.45*rhol^0.49*Te^0.24*
    dpsat^0.75*S/(s^0.5*mul^0.29*Lv^0.24*rhov^0.24))
h=hc+hb                                 //W/m^2 C, total
    heat transfer coefficient

//calculation of required heat transfer area
a=5                                      //%, persentage
    change in rate of vaporization
W2=W1*a/100                              //kg/h, rate of
    vaporization
W2_=W2/3600                              //kg/s
Q=W2_*Lv                                 //W, heat load
A=Q/(h*Te)                               //m^2, area of heat
     transfer
```

```
l=A/(%pi*d)                          //m, required length of tube
//from table 6.2
Tl=0.393
printf("The total tube length is %f m",Tl)
```

Scilab code Exa 6.5 Saturated vapour pressure

```
//Example 6.5
//Calculate the rate of  condensation of propane.
//GIVEN
rhol=483                             //kg/m^3, density of liquid propane
mul=9.1*10^-5                        //P ,viscosity of liquid propane
kl=0.09                              //W/m K, thermal conductivity of liquid propane
Lv=326                               //kj/kg. enthalpy of vaporization
Cpl=2.61                             //kj/kg K, specific heat of liquid propane
T1=32
T2=25                                //C, surface temp.
p1=11.2
rhov=24.7                           //kg/m^3, density of vapour
g=9.8
h=0.3
//Calculation
Lv1=Lv+0.68*Cpl*(T1-T2)
//h=0.943*(g*Lv1*10^3*rhol*(rhol-rhov)*kl^3/(mul*L*(T1-T2)))^(1/4)
//Q=h*(L*1)*(T1-T2)
//m=Q/(Lv1*10^3)=1.867*10^-2*L^(3/4)
Ref=30
```

```
//from the relation  4*m/mu=Re
L=(Ref*mul/(4*1.867*10^-2))^(4/3)
m=1.867*10^-2*L^(3/4)          //rate of condensation for laminar flow
//from eq. 6.32
//Nu1=h_/kl*(mul^2/(rhol*(rhol-rhov)*g))^(1/3)=Ref/(1.08*(Ref)^(1.22)-5.2)
Lp=h-L          //length of plate over which flow is wavy
A=Lp*1           //m^2 area of condensation

h_=poly(0,"h_")
//Rate of condensation over total length=m(laminar)+m(wavy)
m2=m+h_*A*(T1-T2)/(Lv1*10^3)
Ref1=4*m2/mul

deff('[x]=f(h1)','x=h1/kl*(mul^2/(rhol*(rhol-rhov)*g))^(1/3)-(29.76+0.262*h1)/(1.08*(29.76+0.262*h1)^(1.22)-5.2)')
h1=fsolve(1000,f)   //W/m^2C
m2=m+h1*A*(T1-T2)/(Lv1*10^3)
Ref1=4*m2/mul
m2=m+h1*A*(T1-T2)/(Lv1*10^3)
printf("Total rate of condensation is %f kg/h",m2*3600)
```

Scilab code Exa 6.6 `Trichloro ethylene`

```
//Example 6.6
//Calculate the rate of condensation  of TCE
//(a)on a single horizontal tube
//(b) in a condenser
//Given
//data fot TCE
```

```
T1=87.4                          //C, normal boiling point
T2=25                            //C, surface temp.
Lv=320.8                         //kj/kg, heat of vaporization
cp=1.105                         //kj/kg C, specific heat
mu=0.45*10^-3                    //P. liquid viscosity
k=0.1064                         //W/m C, thermal conductivity
rhol=1375                        //kg/m^3, liquid density
rhov=4.44                        //kg/m^3, density of  vapour
Tm=(T1+T2)/2                     //C, mean film temp.
d=0.0254                         //m, outside diameter of tube
l=0.7                            //m, length
g=9.8                            //m/s^2, gravitational constant
//Calculation
//(a) from eq. 6.34
Lv1=Lv+0.68*cp*(T1-T2)
h=0.728*(g*Lv1*10^3*rhol*(rhol-rhov)*k^3/(mu*d*(T1-T2)))^(1/4)
A=%pi*d*l                        //m^2, area of tube
Q=h*A*(T1-T2)                    //W, rate of heat transfer
m=(Q/Lv1)/1000                   //kg/s rate of condensation
printf("Rate of condensation is %f kg/h \n",m*3600)

//(b)  from eq. 6.35
N=6                              //No. of tubes in vertical tire
h1=0.728*(g*Lv1*10^3*rhol*(rhol-rhov)*k^3/(N*mu*d*(T1-T2)))^(1/4)
```

```
TN=36                                       //total no. of tubes
TA=TN*%pi*d*l                                //m^2, total area
Q1=h1*TA*(T1-T2)                              //W, rate of heat
    transfer
m1=(Q1/Lv1)/1000                             //kg/s rate of
   condensation
printf("Rate of condensation is %f kg/h \n \n",m1
   *3600)
//from chail's corelation
h2=(1+0.2*cp*(T1-T2)*(N-1)/(Lv1))
printf("thus there will be increase in the
   calculated rate of heat transfer and in rate of
   condensation as %f percent",18.7)
```

Scilab code Exa 6.7 Saturated vapour

```
//Example 6.7
//What fraction of vapour woll condense .

//Given
Gv=20                      //kg/m^2 s, mass flow rate of
    benzene
di=0.016                   //m, tube diameter
muv=8.9*(10^-6)            //P, viscosity
Lv=391                     //kj/kg., enthalpy of
   vaporization
cpl=1.94                   //kj/kg C, specific heat
Tv=80                      //C, normal boiling point of
   benzene
Tw=55                      //C, wall temp.
g=9.8                      //m/s^2, gravitational
   constant
rhol=815                   //kg/m^3, density of benzene
rhov=2.7                   //kg/m^3, density of benzene
   vapour
```

```
kl=0.13                     //W/m C, thermal conductivity
mu=3.81*10^-4               //P, viscosity of benzene
l=0.5                       //m, length  of tube

//calculation
Rev=di*Gv/muv               //Reynold no. of vapour
//from eq. 6.38
Lv1=Lv+(3/8)*cpl*(Tv-Tw)
//heat transfer corfficient  , h
h=0.555*(g*rhol*(rhol-rhov)*kl^3*Lv1*10^3/(di*mu*(Tv-Tw)))^(1/4)
Aavl=%pi*di*l               //m^2, available area
Q=Aavl*h*(Tv-Tw)            //W, rate of heat transfer
m=Q/(Lv1*10^3)              //kg/s, rate of condensation of benzene
Ratei=Gv*(%pi/4)*di^2        //kg/s rate of input of benzene vapour
n=m/Ratei
printf("fraction of input vapour condensed is %f",n*100)
```

Chapter 7

radiation heat transfer

Scilab code Exa 7.3 `the sun may be considered`

```
//Example 7.3
//calculate (a)the fraction of solar radiation falls in visible range
//(b) the fraction occurs on the left of  visible range
//(c) the fraction ooccurs on right on visible range
//(d)wavelength and frequency of maximum spectral emissive power
//(e)the maximum spectral emissive power
//(f)the hemispherical total emissive power
//Given
Ts=5780                 //K, surface temp.
//CAlculation
//(a)
lamda1=0.4          //micrometer, starting visible spectrum range
lamda2=0.7          //micrometer,ending visible spectrum range
E1=lamda1*Ts        //micrometer K,
E2=lamda2*Ts        //micrometer K,
//from table 7.2
```

```
//fraction of radiation lying between 0 and lamda1
F1=0.1229
//fraction of radiation lying between 0 and lamda2
F2=0.4889
//the fraction of radiation falls betweem lamda1 & lamda 2
F3=F2-F1
printf("the fraction of radiation falls in visible range is %f \n",F3)
//(b)
F4=F1
printf("the fraction of radiation on the left of visible range is %f \n",F4)
//(c)
F5=1-F2
printf("the fraction in right of visible range is %f \n",F5)
//(d)
//from wein's displacement law
lmax=2898/Ts
printf("The maximum wavelength is %f micrometer is",lmax)
c=2.998*10^8        //m/s, speed of light
mu=c/lmax
printf("The frequency is %f s^-1\n",mu)
//(e)
//from eq. 7.4
h=6.6256*10^-34          //Js planck's constant
k=1.3805*10^-23          //J/K, boltzman constant
Eblmax=(2*%pi*h*c^2*(lmax*10^-6)^-5)/((exp(h*c/(lmax*10^-6*k*Ts)))-1)
printf("the maximum spectral emissive power is %f W/m^2\n",Eblmax)
//(f)
s=5.668*10^-8            //stephen costant
Eb=s*Ts^4
printf("the hemispherical total emissive power is %f W/m^2",Eb)
```

Scilab code Exa 7.4 `wavelength`

```
//Example 7.4
//Determine the surface temp of blackbody and
//wavelength of maximum emission.
//Find the range of the spectrum in which the
    wavelength falls

//Variables declaration
Eb=4000            //W/m sq, Total emmisive power
s=5.669*10^-8   //Stephen boltzman constant

//Calculation
T=(Eb/s)^0.25   //k, surface temp. of black body
ym=2898/T       //micro meter,
//By weins law : Max. wavelength of emmision is
    inversaly proportional
//to temprature. and constant is 2898 micrometer.

//Result
printf("Surface temp. is %f C",T)
printf("wavength is  %f micrometer ",ym)
printf(" from fig 7.1 it  falls in the infrared
    region of spectrum.")
```

Scilab code Exa 7.5 `spectral emissivity`

```
//Example 7.5
//calculate (a) total (hemispherical) emissive power
//(b) total (hemispherical) emissivity
//Given
```

```
T=1500          //K, surface temprature
//from fig 7.7
e1=0.2       //emissivity ,when wavelength(l1) is 0<l1<2 micrometer
e2=0.6       //emissivity ,when wavelength(l2) is 2<l2<6 micrometer
e3=0.1       //emissivity ,when wavelength(l3) is 6<l3<10 micrometer
e4=0         //emissivity ,when wavelength(l4) is l4>10 micrometer
//from table 7.2
F1=0.2733          //fraction of energy in  wavelength(l1)
F2=0.89-F1         //fraction of energy in  wavelength(l2)
F3=0.9689-0.89     //fraction of energy in  wavelength(l3)
//Calculation
s=5.669*10^-8      //stephen's constant
Eb=s*T^4           //emissive power
E=(e1*F1+e2*F2+e3*F3)*Eb
printf("total (hemispherical) emissive power is %f W/m^2\n",E)
//(b)
e=E/(s*T^4)
printf("total (hemispherical) emissivity of the surface is %f",e)
```

Scilab code Exa 7.6 `fraction of radiation`

```
//Example 7.6
//Calculate the fraction of radiation emitted by the surface.
ri=5          //cm ,inside radius  of ring
w=3           //cm, width
```

```
ro=ri+w         //cm, outside radius
L=20            //cm, surface distance

//view factor along surface dA1-A2
F1=2*integrate('20^2*r/(20^2+r^2)^2','r',0,ri)
//view factor along surface dA1-A2"
F2=2*integrate('20^2*r/(20^2+r^2)^2','r',ri,ro)
printf("fraction of radiation passes through hole
   %f \n",F1)
printf("fraction of radiation intercepted by the
   ring %f ",F2)
```

Scilab code Exa 7.8 `relevant view factor`

```
//Example 7.8
//Consider an enclosure consisting of a hemisphere
//of diameter d and a flat surface
//of the same diameter.
//Find the relevant view factor

//Variables declaration
F11=0           //view factor
d=1              //let it be
printf("view factor F11 = %f" ,F11)

//Calculation
F12=1-F11    //view factor
printf( "view factor F22 =%f",F12)

A1=((%pi)*d^2)/4    //sq m, area
A2=((%pi)*d^2)/2    //sq m, area
F21=A1/A2              //from eq . 7.26
printf("view factor F21 =%f", F21)
F22=1-F21
//Results
```

```
printf("view factor=%f",F22)
```

Scilab code Exa 7.9 determine the view factors

```
// Example7.9
//Consider an enclousure formed by closing one end
//of a cylinder( diameter= D,height=H)by a flat surface
//and the other end by hemispherical dome.
//Determine the view factor of all the surfaces of the enclousure
//if height is twice the diameter.
//1,2,3,4 are given surface of enclosure in fig.7.21

//Variable declaration
s=3           //no. of surface
tvf=s^2      //total view factor
//using the result of example 7.8
F11=0
F33= 0.5
printf("view factor F11 =%f",F11)
printf("view factor F33 =%f",F33)

//Calculation & Results
R1=0.25       //R=d/2*h &h=2d
R2=0.25
X=1+((1+R2^2)/(R1^2))
F14=(0.5)*(X-sqrt((X^2)-4*(R2/R1)^2))
printf("view factor F14 =%f",F14)
F13=F14
printf("view factor F13 =%f",F13)
F12=1-F11-F13   // from eq. 7.31 for surface 1
printf("view factor F12 =%f",F12)

```

```
d=1  //say
A1=(%pi*(d^2))/4
A3=(%pi*(d^2))/2
F31=A1*F13/(A3)
printf("view factor F31 =%f",F31)

// from eq. 7.31 for surface 3
F33=0.5
F32=1-F31-F33
printf("view factor F32 =%f",F32)

//for surface 2
A2=2*%pi*d^2
F21=A1*F12/A2
printf("view factor F21 =%f",F21)
F23=A3*F32/A2
printf("view factor F23 =%f",F23)
F22=1-F21-F23
printf("view factor F22 =%f",F22)
```

Scilab code Exa 7.10 view factors

```
//Example 7.10
//Calculate the view factors of the surfaces.
//Given
ds=0.3          //m, diameter of shell
r1=0.1          //m, distance from the  centre
//Calculation
//by the defination of view factor
F12=1
printf("The view factor from surface 1 to 2 is %f\n"
   ,F12)
//F21
R=ds/2           //m, radius of sphere
r2=sqrt(R^2-r1^2)
```

```
A1=%pi*r2^2       //m^2 area
A2=2*%pi*R^2+2*%pi*R*sqrt(R^2-r2^2)
//from reciprocity relation
F21=(A1/A2)*F12
printf("The view factor from surface 2 to 1 is %f\n"
   ,F21)
```

Scilab code Exa 7.12 a carbon steel sphere

```
//Example 7.12
//calculate the time required for ball to cool down.
//Given
d=0.3        //m, diameter of steel sphere
Ti=800       //K, initial temp. of sphere
T2=303       //C,ambient temp.
T1=343        //C, final tempreture
rho=7801    //kg/m^3, density of steel
cp=0.473    //kj/kg C, specific heat of steel
//calculation
R=d/2      //m, radius of sphere
A1=4*%pi*R^2    //m^2, area of sphere
m=4/3*%pi*R^3*rho   //m^3, mass of sphere
F12=1                  //view factor
s=5.669*10^-8          //stephen Boltzman's constant
//-dT1/dt=A1*F12*s*(T^4-T2^4)/(m*cp)
I=integrate('(1/(T1^4-T2^4))','T1',343,800)
t=I/(A1*F12*s/(m*cp*10^3))
printf("The time required for the ball to cool is %f
    h",t/3600)
```

Scilab code Exa 7.13 A schedule pipe

```
//Example 7.13
```

```
//Calculate the net rate of heat loss
//from unit length of pipe by radiation if
//(a) tha pipe surface is considered black
//(b) the pipe surface has an emissivity of 0.74

//Variables declaration
d=0.114             //m, dia.o f pipe
l=1                    //m,  length of pipe
A=(%pi)*d*l   //m sq,   area
e1=1                //emmisivity of black body
F12= 1              //view factor, 1:pipe surface, 2:
    room walls
s=5.67*10^-8     //stephen boltzman constant
T1= 440             //K, steam temp.
T2=300              //K, wall temp.
//Caluclation
Q12=A*e1*F12*s*(T1^4-T2^4)   //net rate of radiative
    heat loss

//Results
printf("(a) Net rate of radiative heat loss Q12 =%f
   W \n",Q12)
//Part-b
e2=0.74
Q12=A*e2*F12*s*(T1^4-T2^4)   //net rate of radiative
    heat loss
printf("(b) Net rate of radiative heat loss Q12 =%f
   W",Q12)
```

Scilab code Exa 7.14 `view factors and rate of loss`

```
//Example 7.14
// a.Calculate i-View factors F12 and //F21,ii-
    Calculate net rate of radiant energy gain by
    inner surface.
```

```
//(b) Hence calculate the rate of loss
//of saturated liquid nitrogen at 1 atm pressure
//stored in a double walled spherical Dewar flask.

//Variable declaration
F12=1                    //view factor
r1=0.15                  //m inner radius of phere
r2=0.155                //m , outer radius

//Calculation
A1=4*(%pi)*r1^2   //sq m inner area
A2=4*(%pi)*r2^2   //sq m, outer area
F21=A1/A2
h=200                      //J/g, heat of vaporization of nitrogen
s=5.669*10^-8       // boltzman constant
T2=298                   //K, temp. of outer wall
T1=77                    //K, Temp. of inner wall
e1=0.06                  //emmisivity
e2=0.06                  //emmisivity
x=((1-e1)/(e1*A1))+(1/(A1*F12))+((1-e2)/(e2*A2))
Q1net=(s*(T2^4-T1^4))/(x)

//Result-a-i
printf("a-i) View factor F12 = %f",F12)
printf("view factor F21 = %f",F21)
//Result- b
printf("(ii) The net rate of heat gain Q1net =%f J/s",Q1net)
nl=Q1net/h
nl=nl*3600           //g/h
printf("(b) Rate of nitrogen loss = %f g/h",nl)
```

Scilab code Exa 7.15 Net rate of radient heat

```
//Example 7.15
//Calculate the net rate of radiant heat transfer to the wall.

//Given
x=0.15               //m, length of opening on a furnace
y=0.12               //m, width of opening on a furnace
x1=6                 //m, width of wall
y1=5                 //m, height of wall
e2=0.8               //emissivity of wall
T1=1400              //C, furnace temp.
T2=35                //C, wall temp.
T3=273               //C, standard temp.
s=5.669*10^-8       //stephen boltzman's constant
//in fig. 7.29
l1=2                 //m, l1=AF
l2=1.5               //m, l2=AH
h=3                  //m, E=dA1
//for the dA1-A2 pair the equation is
F1=(1/(2*%pi))*((l2/(sqrt(l2^2+h^2)))*tanh(l1/(sqrt(l2^2+h^2)))+(l1/(sqrt(l1^2+h^2)))*tanh(l2/(sqrt(l1^2+h^2))))
//Similarly
//for the dA1-A3 pair the equation is
F2=0.1175
//for the dA1-A4 pair the equation is
F3=0.1641
//for the dA1-A5 pair the equation is
F4=0.0992
//view factor b/w the opening (dA1)and the wall (W) is
F5=F1+F2+F3+F4
//Calculation of radient heat exchange
dA1=x*y
Aw=x1*y1
Eb1=s*(T1+T3)^4
```

```
Ebw=s*(T2+T3)^4
F6=dA1*F5/Aw
Q=dA1*F5*e2*(Eb1*(1-(1-e2)*F6)-Ebw)
printf("the net rate of radiant heat transfer to the
    wall is %f W",Q)
```

Scilab code Exa 7.16 the base of rectangular

```
//Example 7.16
//Part-a-If the side walls are perfectly insulated
//and the surfaces are diffuse gray
//with an emissivity 0.7
//,Calculate the required net rate of heat supplied
    to base.
//b- If the skin temp. of the outside of the top
    wall is 60 degree celcius
//and heat loss frim this surface occurs
//to a big factory shade at 30 degree celcius
//calculate the convective heat transfer coefficient

//Variable declaration
l=3             //m, length of wall
w=2             //m,  width of, wall
d=3             //m
R1=l/d
A1=l*w          //sq m,area  1: front part
A2=A1           //sq m ,  area, 2"back part
e1=0.7          //emmisivity
e2=0.7          //emmisivity
T1=673          //k
T2=523          //k
s=5.669*10^-8  //stephen boltzman constant
//Calculation
F12= 0.148  //view factor ,from fig. 7.12
x=(A1+A2-2*A1*F12)/(A2-(A1*(F12^2)))+((1/e1)-1)+(A1/
```

```
   A2)*((1/e2)-1)

//Results
Q1net=-1*A1*(s*(T2^4-T1^4))/(x)
printf("the net rate of radiant heat loss =%f kW \n"
   ,Q1net/1000)
// (b)
F24=1          //from fig 7.12
T20=333        //K, outer surface temp. of surface 2
T4=303         //K, ambient temp
Q2rad=A2*e2*F24*s*(T20^4-T4^4)
q=Q1net-Q2rad
q1=q/1000        // Kw
h=q/(A2*(T20-T4))
printf("convective heat transfer coeff. =%f W/sq m C
   ",h)
```

Scilab code Exa 7.17 two parallel disks

```
//Example 7.17
//calculate the net rate of exchange of radiation
   between the disks.
//given
r1i=0.1          //m, inner radius of disk 1
r1o=0.2          //m, outer radius of disk 1
r2i=0.12         //m, inner radius of disk 2
r2o=0.25         //m, outer radius of disk 2
h=0.08           //m, distance between the disks
R2=r2o/h
R1=r1o/h
X=1+(1+R1^2)/R2^2
F23_14=1/2*(X-sqrt(X^2-4*(R1/R2)^2))
//calculation of F23_4
R2_=r2o/h
R1_=r1i/h
```

```
X_=1+(1+R1_^2)/R2_^2
F23_4=1/2*(X_-sqrt(X_^2-4*(R1_/R2_)^2))      //view
    factor
//similarly
F3_14=0.815           //view factor
F34=0.4               //view factor
A23=%pi*r2o^2         //area
A3=%pi*r2i^2
A1=%pi*(r1o^2-r1i^2)
//from eq. 1
F12=A23*(F23_14-F23_4)/A1-(A3*(F3_14-F34))/A1
//calculation of the rate of radiative heat exchange
//given
T1=1000             //K, temprature of disk 1
T2=300              //K, temprature of disk 2
s=5.669*10^-8       //stephen's Boltzman constant
e1=0.8              //emissivity
e2=0.7
A2=%pi*(r2o^2-r2i^2)
F1s=1-F12
F2s=1-(A1*F12/A2)
//calculation
//let some quantities equal to
a=(1-e1)/(e1*A1)
b=1/(A1*F12)
c=(1-e2)/(e2*A2)
d=1/(A1*F1s)
e=1/(A2*F2s)
f=s*T1^4
g=s*T2^4
//from eq. 7.42(a)
//(f-J1)/a=(J1-J2)/b+J1/d
//(g-J2)/c=(J2-J1)/b+J1/e
//solving two eqns by matrix
A=[-0.0564,0.5036;0.4712,-0.0564]
B=[161.847;21376.31]
X=inv(A)*B

```

```
J1=X([1])
J2=X([2])
//net rate of radiation exchange
Q12net=(J1-J2)/b
printf("net rate of radiation exchange b/w disk 1
    and 2 is %f W/m^2",Q12net)
```

Scilab code Exa 7.18 rate of heat gain

```
//Example 7.18
//calculate the rate of heat gain by the liquid.
//Given
di=0.0254         //m, inner diameter of tube
Ti=77             //K, liquid temprature
do=52.5*10^-3     //m, pipe internal diameter
To=270            //K, wall temprature
l=1               //m, length of tube
e1=0.05           //emissivity of tube wall
e2=0.1            //emissivity of pipe wall
e3=0.02           //emissivity for inner surface of
    radiation field
e4=0.03           //emissivity for outer surface of
    radiation field
s=5.669*10^-8     //stephen boltzman costantl
//Calculation
ds=(do+di)/2      //m, diameter of radiation shield
Ao=%pi*do*l       //m^2, outer pipe area
As=%pi*ds*l       //m^2, shield area
Ai=%pi*di*l       //m^2, inner pipe area
//View factors
//for the long cylindrical enclosure made up of the
    outer pipe and the shield
Fso=1      //because outer surface of shield cant see
    itself
Fos=As/Ao
```

```
Fsi=Ai/As
//now assume
//(1-e2)/e2+ 1/Fos +Ao*(1-e4)/(As*e4)=x
//(1-e3)/e3 +1/Fsi +(1/Fsi)*(1-e1)/e1=y
x=(1-e2)/e2+ 1/Fos +Ao*(1-e4)/(As*e4)
y=(1-e3)/e3 +1/Fsi +(1/Fsi)*(1-e1)/e1
//solving the equations for heat transfer from the outer pipe and inner pipe
deff('[x]=f(Ts)','x=(Ao*(To^4-Ts^4)/x)-(Ai*(Ts^4-Ti^4)/x)')
Ts=fsolve(1,f)
Qos=(Ao*s*(To^4-Ts^4))/x
printf("The net rate of heat gain of tube is %f W",Qos)
```

Scilab code Exa 7.20 carbon dioxide gas

```
//Example 7.20
//Calculate the spectral extinction coefficient.
//Given
T=300          //K, temprature
per=91         //percent, adsorbed radiation
lam=4.2        //micrometer, wavelength radiation
L=0.1          //m, path length
//calculation
// I2/I1=f
f=1-per/100    //fraction of incident radiation transmitted
//from eq. 7.69
a=-log(f)/L
printf("the spectral extinction coefficient is %f m^-1",a)
```

Scilab code Exa 7.21 `hot flue gas`

```
//Example 7.21
//Calculate the rate of heat transfer .
//Given
Ts=800          //C, wall temp.
Tg=1100         //C. burner temprature
CO2=8           //percent , composition of CO2 in flue gas
M=15.2          //percent , composition of moisture in flue gas
a=0.4           //m, length of  duct
b=0.4           //width of duct
h=15            //W/m^2 C, heat transfer coefficient
P=1             //atm  pressure
//CAlCULATION of Eg(Tg)
pc=CO2/100*P          //atm, partial pressure of CO2
pw=M/100*P           //atm, partial pressure of moisture
l=1                  //m, length of duct
V=a*b*l              //m^3, volume of duct
A=1.6*l              //m^2 area of duct
Le=3.6*(V/A)         //m, mean beam length

pc*Le
pw*Le
Tg_=Tg+273
Ts_=Ts+273
//from fig 7.38
Ec=0.06
Eg=0.048              //from fig 7.39
//a correction dE need to be calculated
pw/(pc+pw)
pc*Le+pw*Le
//from fig. 7.39
dE=0.003
Eg_Tg=Ec+Eg-dE       //emissivity at temp. Tg

```

```
//Calculation of alpha
pc*Le*Ts/Tg
//from fig. 7.37
Ec1=0.068
//from fig. 7.38
Ew1=0.069
Cc=1                    //correction factor
Cw=1                    //correction factor
d_alpha=dE              //AT 1 ATM TOTAL PRESSURE
alpha=Cc*Ec1*(Tg_/Ts_)^0.65+Cw*Ew1*(Tg_/Ts_)^0.45-dE
//radiant  heat ransfer rate
s=5.669*10^-8                      //stephen's boltzman constant
Qrad=A*s*(Eg_Tg*Tg_^4-alpha*Ts_^4)       //kW
Qconv=h*A*(Tg-Ts)    //kW, convective heat transfer rate
Q=Qrad+Qconv
printf("The total rate of heat transfer from the gas to the wall is %f kW",Q/1000)
```

Chapter 8

Heat Exchanger

Scilab code Exa 8.1 Benzene from condenser

```

//Example 8.1
//page no. 303
//Given
//for  Benzene
Mb=1000                     //Kg, mass of benzene
T1=75                       //C initial temp. of benzene
T2=50                      //C final temp. of benzene
Cp1=1.88                    //Kj/Kg C. specific heat of benzene
mu1=0.37                    //cP. viscosity of benzene
rho1=860                    //kg/m^3, density
k1=0.154                    //W/m K. thermal conductivity

//for water
Tav=35                      //C av, temp.
Cp2=4.187                    //specific heat
mu2=0.8                     //cP. viscosity
k2=0.623                    //W/m K. thermal conductivity
T3=30                       //C. initial temp.
T4=40                       //C final temp.
```

```
//Calculation
//(a)
HD=Mb*Cp1*(T1-T2)    //Kj/h, heat duty
WR=HD/(Cp2*(T4-T3))   //kg/h Water rate
printf("the heat duty of the exchanger is %f kj/h",HD)
printf("the water flow rate is %f kg/h",WR)

//(b)
//tube side (water) calculations
//given
di1=21              //mm, inner diameter of inner tube
do1=25.4            //mm, outer dia. of inner tube
t=2.2              //mm/ wall thickness
kw=74.5            //W/m K. thermal conductivity of the wall
di2=41             //mm, inner diameter of outer pipe
do2=48             //mm, outer diameter of outer pipe

FA1=(%pi/4)*(di1*10^-3)^2     //m^2, flow area
FR1=WR/1000
v1=FR1/(FA1*3600)                          //m/s, velocity
Re1=(di1*10^-3)*v1*1000/(mu2*10^-3)   //Reynold no.
Pr1=Cp2*1000*(mu2*10^-3)/k2           //Prandtl no.
//using dittus boelter eq.
Nu1=0.023*(Re1)^(0.8)*(Pr1)^(0.3)     //nusslet no.
h1=Nu1*k2/(di1*10^-3)                 //W/m^2 C, heat transfer coefficient

//Outer side (benzene) calculation
FA2=(%pi/4)*(di2*10^-3)^2-(%pi/4)*(do1*10^-3)^2    //flow area
wp=%pi*(di2*10^-3+do1*10^-3)                       //wettwd perimeter
dh=4*FA2/wp                                        //hydrolic diameter
bfr=Mb/rho1                                        //
```

```
m^3/h benzene flow rate
v2=bfr/(FA2*3600)                              //m/s, velocity
Re2=dh*v2*rho1/(mu1*10^-3)                     //Reynold no
Pr2=Cp1*10^3*(mu1*10^-3)/k1                    //Prandtl no.
Nu2=0.023*(Re2)^(0.8)*(Pr2)^(0.4)              //nusslet no.
h2=Nu2*k1/(dh)                                 //W/m^2 C, heat transfer coefficient
printf("heat transfer coefficient based on inside area  is %f W/m^2 C \n",h1)
printf("heat transfer coefficient based on outside area  is %f W/m^2 C \n",h2)

//Calculation of clean  overall heat transfer coefficient , outside area basis
//from eq. 8.28
//given
l=1      //assume , length
Ao=%pi*do1*10^-3*l
Ai=%pi*di1*10^-3*l
Am=(do1*10^-3-di1*10^-3)*%pi*l/(log(do1*10^-3/(di1*10^-3)))

//overall heat transfer coefficient
Uo=1/((1/h2)+(Ao/Am)*((do1*10^-3-di1*10^-3)/(2*kw))+(Ao/Ai)*(1/h1))
Ui=Uo*Ao/Ai

//Calculation of LMTD
dt1=T1-T4
dt2=T2-T3
LMTD=(dt1-dt2)/log(dt1/dt2)     //log mean temp. difference correction factor
Q=HD*1000/3600                  //W, heat required
Ao_=Q/(Uo*LMTD)                 //m^@, required area
```

```
len=Ao_/(%pi*do1*10^(-3))          //m, tube length
    necessary

//(c)
la=15                              //m ,actual length
Aht=(%pi*do1*10^(-3)*la)
Udo=Q/(Aht*LMTD)                   //W/m^2 C, overall
    heat transfer coefficient with dirt factor
//from eq. 8.2
Rdo=(1/Udo)-(1/Uo)                 //m^2 C/W
printf("overall heat transfer coefficient outside
    area basis is %f W/m^2 C \n",Uo)
printf("overall heat transfer coefficient inside
    area basis is %f W/m^2 C \n",Ui)
printf("The fouling factor is %f m^2 C/W",Rdo)
```

Scilab code Exa 8.2 design procedure

```
//Example 8.2
//Page no. 309

//Given
Cp=50              //tpd, plant capacity
T1=135             //C, Temp.
T2=40              //C temp.
T3=30              //C temp.
dt1=(T1-T2)        //C hot end temp.
dt2=(T2-T3)        //C cold end temp.
//Properties of ethylbenzene
rho1=840           //kg/m^3, density
cp1=2.093          //kj/kg K , specific heat
T=87.5             //C
mu1=exp(-6.106+1353/(T+273)+5.112*10^-3*(T+273)
    -4.552*10^-6*((T+273)^2))
k1=0.2142-(3.44*10^-4)*(T+273)+(1.947*10^-7)*(T+273)
```

```
^2
k1_=k1*0.86            //kcal/h m K
//properties of water
rho2=993        //kg/m^3, density
mu2=8*10^-4     //kg/m s , viscosity
cp2=4.175       //kj/kg K , specific heat
k2=0.623        //W/m K, thermal conductivity
k2_=k2*0.8603   //kcal/h m^2 K
//Calculation
//(i) Energy balance
Cp=Cp*1000/24             //kg/h, plant capacity
Cp=2083         //approx.
HD=Cp*cp1*dt1         //kj/h, Heat duty
HD_=HD*0.238837           //kcal/h
wfr=HD/(cp2*dt2)

//(ii)
mu1=mu1         //cP, viscosity of ethylbenzene
k1=k1           //W/m K, thermal conductivity of ethylbenzene

//(iii)
//LMTD calculation
LMTD=(dt1-dt2)/log(dt1/dt2)
//assume
Udo=350                 //kcal/h m^2 C, overall coefficient
A=HD_/(Udo*LMTD)        //m^2, area required

//(iv)
id=15.7               //mm, internal diameter of tube
od=19                 //mm, outer diameter of tube
l=3000                //mm, length
OSA=%pi*(od*10^-3)*(l*10^-3)   //m^2. outer surface area
n=A/OSA                          //no. of tubes required
fa=n*(%pi/4)*(id*10^-3)^2       //m^2, flow arae
```

```
lv=(wfr/1000)/(3600*fa)         //m/s, linear velocity

//(v)
n1=44                 //total no. of tubes that can be accomodated in a 10 inch shell
np=11                 //no. of tubes in each pass
//(vi)
bf=0.15              //m, baffel spacing
//(vii)
//estimation of heat transfer coefficient
//Tube side (water)
fa1=(%pi/4)*(id*10^-3)^2*np     //m^2, flow area
v1=(wfr/1000)/(3600*fa1)        //m/s, velocity
Re=(id*10^-3)*v1*rho2/mu2       //Reynold no.
//from fig . 8.11(a)
jh=85                           //colburn factor
//jh=(hi*di)/k*(cp*mu/k)^-1/3
//assume,   (cp*mu/k)=x
hi=jh*(k2_/(id*10^-3))*(cp2*1000*mu2/k2)^(1/3)   //kcal/h m^2 C

//shell side(organic)
c=(25.4-od)*10^-3             //m, clearance b/w 2 adjacent tubes
B=bf                          //m, baffel spacing
p=0.0254                      //m,radius of 1 tube
Ds=0.254                      //m, inside diameter of shell
//from eq. 8.32
As=c*B*Ds/p                   //m^2, flow area
Gs=Cp/As                      //kg/m^2 h, mass flow rate of shell fluid
do=od/10                      //cm, outside diameter of shell
//from eq. 8.31
Dh=4*((0.5*p*100)*(0.86*p*100)-((%pi*(do)^2)/8))/((%pi*do)/2)
Dh_=Dh*10^-2                 //m, hydrolic diameter
```

```
Re1=(Dh_*Gs)/(3600*(mu1*10^-3))   //Reynold no.
//from fig 8.11(b)
jh1=32                            //colburn factor
ho=jh1*(k1_/Dh_)*((6)^(1/3))
//from eq. 8.28
ratio=od/id                       //ratio=Ao/Ai
Rdo=0.21*10^-3                    //outside dirt factor
Rdi=0.35*10^-3                    //inside dirt factor
Udo=1/((1/ho)+Rdo+(ratio)*Rdi+(ratio)*(1/hi))

//SECOND TRIAL
//estimation of heat transfer coefficient
//Tube side (water)
np1=12               //
fa2=(%pi/4)*(id*10^-3)^2*np1    //m^2, flow area
v2=(wfr/1000)/(3600*fa2)       //m/s, velocity
Re2=(id*10^-3)*v2*rho2/mu2      //Reynold no.
//from fig . 8.11(a)
jht=83                          //colburn factor
//jh=(hi*di)/k*(cp*mu/k)^-1/3
//assume,   (cp*mu/k)=x
hit=jht*(k2_/(id*10^-3))*(cp2*1000*mu2/k2)^(1/3)  //kcal/h m^2 C

//shell side
c2=(25.4-od)*10^-3              //m, clearance b/w 2 adjacent tubes
B2=0.1                          //m, baffel spacing
p2=0.0254                       //m,radius of 1 tube
Ds2=0.254                       //m, inside diameter of shell
//from eq. 8.32
As2=c2*B2*Ds2/p2                //m^2, flow area
Gs2=Cp/As2                      //kg/m^2 h, mass flow rate of shell fluid
do2=od/10                       //cm, outside diameter
```

```
    of shell
//from eq. 8.30
Dh2=4*((p2*100)^2-((%pi*(do2)^2)/4))/((%pi*do2))
Dh2_=Dh2*10^-2                    //m, hydrolic diameter
Re2=(Dh2_*Gs2)/(3600*(mu1*10^-3))
//from fig 8.11(b)
jh2=48                           //colburn factor
ho2=jh2*(k1_/Dh2_)*((6)^(1/3))
//from eq. 8.28
ratio=od/id                       //ratio=Ao/Ai
Rdo2=0.21*10^-3                   //outside dirt factor
Rdi2=0.35*10^-3                   //inside dirt factor
Udo2=1/((1/ho2)+Rdo+(ratio)*Rdi+(ratio)*(1/hit))

//from eq. 8.10(a)
tauc=(T2-T3)/(T1-T3)             //Temprature ratio
R=(T1-T2)/(T2-T3)                //Temprature ratio
Ft=0.8                           //LMTD correction ftor
Areq=HD_/(Udo2*Ft*LMTD)          //area required
tubes=48                         //no. of tubes
lnt=4.5                          //length of 1 tube
Aavl=(%pi*od*10^-3)*tubes*lnt          //available area
excA=((Aavl-Areq)/Areq)*100             //% excess area

//Pressure drop calculation
//Tube side
//from eq. 8.33
Gt=wfr/(3600*fa2)              //kg/m^2 s, mass flow
   rate of tube fluid
n2=4                           //tube passes
fit=1                          //dimensionless viscosity
    ratio
g=9.8                          //gravitational constant
f=0.0037                       //friction factor
dpt=f*Gt^2*lnt*n2/(2*g*rho2*id*10^-3*fit)       //kg/
   m^2, tube side pressure drop

//eq.8.35
```

```
dpr=4*n2*v2^2*rho2/(2*g)                    //kg/m^2, return tube pressure loss
dpr_=dpr*9.801                              //N/m^2
tpr=dpt+dpr                                 //kg/m^2, total pressure drop
//shell side
fs=0.052                                    //friction factor for shell
bf1=0.1                                     //m, baffel spacing
Nb=lnt/bf1-1                                //no. of baffles
dps=fs*(Gs2/3600)^2*Ds*(Nb+1)/(2*g*rho1*Dh2_*fit)    //kg/m^2, shell side pressure drop
dps_=dps*9.81                               //N/m^2, shell side pressure drop
printf("Tube side Pressure drop is %f N/m^2 \n",dpr_)
printf("Shell side Pressure drop is %f N/m^2 ",dps_)
```

Scilab code Exa 8.3 The effectiveness

```
//Example 8.3
//How will the heat teansfer rate and the exit oil temp.
//be affected if the water flow rate is increased by 20 %

//Given
//for hot stream
Wh=10000                  //kg/h, Rate of leaving a hydrolic system by the oil
Cph=0.454                 //Kcal/Kg C, specific heat of oil
Th1=85                    //C initial temp. of oil
Th2=50                    //C final temp. of oil
```

```
//For  cold stream
Cpc=1                    //Kcal/Kg C, specific heat of water
Tc2=30                    //C final temp. of water
Tc1=38                    //C initial temp. of water
//from heat balance eq.
//kg/h, Rate of leaving a hydrolic system by the water
Wc=Wh*Cph*(Th1-Th2)/(Cpc*(Tc1-Tc2))
//For the hot stream
Cmin=Wh*Cph                //Kcal/h C.Taking hot stream as min. stream
//For cold stream
Cmax=Wc*Cpc                //Kcal/h C.Taking cold stream as max. stream
Cr=Cmin/Cmax                //Capacity ratio
n=(Th1-Th2)/(Th1-Tc2)       //effectiveness factor
//From eq. 8.57
//No. of transfer units
NTU=-(1+(Cr)^2)^-(1/2)*log(((2/n)-(1+Cr)-(1+(Cr)^2)^(1/2))/((2/n)-(1+Cr)+(1+(Cr)^2)^(1/2)))
Ud=400                     //kcal/h m^2C , overall dirty heat transfer coefficient
//from eq. 8.53
A=(NTU*Cmin)/Ud            //Area required
//if the water rate is increased by 20 %,
a=20
Wc_=Wc+(Wc*(a/100))
Cmax_=Wc_*Cpc
Cr_=Cmin/Cmax_
//From eq. 8.56
n_=2*((1+Cr_)+(1+(Cr_)^2)^(1/2)*(1+exp(-(1+(Cr_)^2)^(1/2)*NTU))/(1-exp(-(1+(Cr_)^2)^(1/2)*NTU)))^(-1)
Th2_=Th1-(n_*(Th1-Tc2))
q1=Wh*Cph*(Th1-Th2)    //kcal/h previous rate of heat transfer
```

```
q2=Wh*Cph*(Th1-Th2_)    //kcal/h new rate of heat transfer
//increase in rate of heat transfer
dq=(q2-q1)/q1
printf('the heat teansfer rate will be affected by %f percent ",dq*100 )
```

Scilab code Exa 8.4 Thermal design

```
//Example 8.4
//calculate the time required to heat the charge.

//given
p=0.0795               //m. pitch of the coil
d1=0.0525             //m, coil diameter
h=1.464                 //m, height of the limpetted section
d2=1.5                  //m, diameter of batch polymerization reactor
d3=0.5                  //m, diameter of agitator
rpm=150               //speed of agitator
rho=850                //kg/m3, density of monomer
rho1=900              //kg/m3, density of fluid
mu=0.7*10^-3     //poise , viscosity of monomer
mu1=4*10^-3      //poise , viscosity of fluid
cp=0.45                //kcal/kg C, specific heat of monomer
cp1=0.5                //kcal/kg C, specific heat of fluid
k=0.15                  //kcal/h mC, thermal conductivity of monomer
k1=0.28                //kcal/h mC, thermal conductivity of fluid
Rdi=0.0002           //h m2 C/kcal , fouling factor for vessel
```

```
Rdc=0.0002          //h m2 C/kcal, fouling factor for coil
Tci=120               //C, initial temp. of coil liquid
Tvi=25                 //C, initial temp. of vessel liquid
Tvf=80                 //C, final temp. of vessel liquid

//calculation
a=%pi*d2*h        //outside area of the vessel
x=60                   //%.  added of the unwetted area to the wetted area
ao=((d1+(x/100)*(p-d1))/p)*a  //m^2,effective outside heat transfer area of vessel
ai=6.9                            //m^2,inside heat transfer area of vessel
                                   //same as outside area , if thickness is very small
//vessel side heat transfer coefficient
Re=(d3^2*(rpm/60)*rho)/mu       //reynold no.
Pr=((cp*3600)*(mu))/k
//from eq. 8.66
y=1                                //x=mu/muw=1
Nu=0.74*(Re^(0.67))*(Pr^(0.33))*(y^(0.14))          //Nusslet no
hi=Nu*(k/d2)                                         //heat transfer coefficient

//coil side heat transfer coefficient
v=1.5                  //m/s, linear velocity of fluid
fa=((%pi/4)*d1^2)      //m2, flow area of coil
fr=v*fa*3600            //m3/h , flow rate of the fluid
Wc=fr*rho               //kg/h , flow rate
dh=(4*(%pi/8)*d1^2)/(d1+(%pi/2)*d1)      //m,hydrolic
```

```
diameter of limpet coil
Re1=v*rho1*dh/mu1                                    //coil reynold no.
Pr1=cp1*mu1*3600/k1                                  //prandtl no. of the coil fluid
//from eq. 8.68
d4=0.0321                                            //m, inside diameter of the tube
Nu1=0.021*(Re1^(0.85)*Pr1^(0.4)*(d4/d2)^(0.1)*y^0.14)
hc=Nu1*(k1/dh)                                 //coil side coefficient

U=1/((1/hi)+(ai/(hc*ao))+Rdi+Rdc)       //overall heat transfer corfficient
//from eq. 8.63
beeta=exp(U*ai/(Wc*cp1))
Wv=2200                                        //kg, mass of fluid vessel
t=(beeta/(beeta-1))*((Wv*cp)/(Wc*cp1))*log((Tci-Tvi)/(Tci-Tvf))
printf("the time required to heat the charge %f min",t*60)
```

Chapter 9

Evaporetion and Evaporators

Scilab code Exa 9.1 single effect evaporator calculation

```
//Example 9.1
// page no.391
//calculate the rate at which heat must
//be supplied if evapiration occurs at
//(i) 1 atm pressure
//a vaccum of 650 mm Hg
//given data
ro=1020        // kg/m^3, density of feed
sf=4.1         //kj/kg C,specific heat of the feed
sp=3.9         //kj/kg C,specific heat of the product
ci=5       //initial concentration
cw=100-ci     //conc. of  water
cf=40         //final conc.
rate=100      //m^3/day, rate of conc. of aq.
   solution
ft=25         // C, feed temp.
//calculation
//materiel balance
Wf=rate*ro     //Kg. feed entering
Ms=ro*ci       //Kg mass of solute
Mw=ro*cw       //kg,mass of water
```

```
fc=cw/ci       //kg,feed concentration
pc=(100-cf)/cf // kg,product concentration
wlwp=Ms*pc       //Kg, water leaving with the product
Ws=Mw-wlwp      //kg,water evaporated
Wp=wlwp+Ms      // kg, product
//energy balance
rt=0               //C reference temp.
ef=sf*(ft-rt)    //kj/kg,enthlpy of the feed
//case i
Tp=100             //temp. of the product (because the
   solute has a 'high molecular wt' the boiling pt
   elevation is neglected)
ip=sp*(Tp-rt)    //kj/kg, enthalpy of the product
iv=2680            //kj/kg, enthalpy of the vapour
   generated at 100 C and 1 atm pr. from the steam
   table
//refer to fig. 9.23
//from energy balance eq. (Wf*if+qs=Wv*iv+Wp*ip)
qs=Ws*iv+Wp*ip-Wf-ef  //Wv=Ws
printf("The rate at which heat must be supplied at 1
    atm pressure is %f kj/ day\n",qs)

//case ii
//650 mm Hg vaccum=110 mmHg pressure
bp=53.5            //C, boiling point of water
ip2=sp*(bp-rt)   //kj/kg, enthalpy of the product
es=2604            //kj/kg, enthalpy of the saturated
   steam (from steam table)
//from energy balnce eq.
qs2=Wp*ip+Ws*es-Wf-ef
printf("The rate at which heat must be supplied at a
    pressure of 600 mm Hg is %f kj/day ",qs2)
```

Scilab code Exa 9.2 SINGLE EFFECT EVAPORATOR CALCULATION

```
//Example 9.2
//Page no. 393
//calculae the steam requirement and the no. of tubes
//if the height of the calandria is 1.5 m.

//given
ci=10            //%,initial concentration
cf=40            //%, final conc
Wf=2000         //kg/h, feed rate
ft=30            //C feed temp.
rp=0.33          //kg/cm^2, reduced pressure
bt1=75            //C,boiling point temp.
sst=115           //C, saturated steam temp.
l=1.5              // m,height of calandria
sh=0.946         //kcal/kg C, specific heat of liquir
lh=556.5         //kcal/kg latent heat of steam
bt2=345          //K, boiling point of water
h=2150           //kcal/h m^2 C, overall heat transfer coefficient
si=2000*(ci/100)  //kg/h, solids in
wi=1800           //kg/h,wate in
Wp=si/(cf/100)    //kg/h, product out
Wv=Wf-Wp          //evaporation rate
ef=sh*(ft-bt1)
ip=0
lamda_s=529.5   //kcal/kg, lamda_s=is-il
bpe=(273+bt1)-345  //boiling point elevation.
//from eergy balance eq.
Ws=(Wp*ip+Wv*lh-Wf*ef)/lamda_s
q=Ws*lamda_s        //kcal/h,rate of heat transfer
A=q/(h*(sst-bt1))    // m^2
di=0.0221             //m,inside diameter
At=%pi*l*di         //m^2, area of a single tube
N=A/At              //no. of tubes
printf("The steam required is %f kg/h\n",Ws)
printf("No. of tube are %f",N)
```

Scilab code Exa 9.3 SINGLE EFFECT EVAPORATION

```
//Example9.3
//calculate
//i)the steam lr. to be used in the calandria
//ii)heat transfer rate required
//iii) the steam requirement.
//given data
Wf=2000          //kg/h, feed rate
ci=8            //% initial conc.
cf=40            //% final conc.
ft=30           //C, feed temp.
vp=660          //mm Hg, vaccum pressure
ssp=8           // bar absolute, saturated steam pr.
//calculation
sr=Wf*(ci/100)   //kg/h, solid rate
Wp=sr/(cf/100)    //kg/h,concentrated product rate
ap=760-vp          //mm Hg, absolute pressure in the evaporator
bt=325            //K,boiling temp. of water
l_s=2380          //kj/kg, latent heat
R=8.303           //gas constant
w=40               //g,mass of solute
M=18             //g,molecular wt of solvent
W=60             //g,mass of the solvent
m=2000           //g,molecular wt of solute
dtb=(R*bt^2*w*M)/(l_s*W*m)      //C, boiling point elevation
bp=bt+dtb        //k,boiling point of 40% solution
dt=70          //C, from given data flux becomes maximum at a temp. drop =70 C
st=bp+dt       //K,saturation temp. of steam in the steam chest
Sp=2.15        // bar, from steam table, saturation lr
```

```
   . of steam at this temp.

sh=4.2        //kj/kg C, specific heat of product
rt=0          //C reference teml.
ef=sh*(ft-rt)  // kj/kg, enthalpy of the feed
ip=sh*(54-rt)  //kj/kg, enthalpy of the product
iv=2607        //kj/kg, enthalpy of vapour produced
//from eq 9.6
Wv=1600        //enthalpy of evaporation
q=Wp*ip+Wv*iv-Wf*ef   //kj/h, heat transfe rate
   required
hvp=2188       //kj/kg, heat of vaporization of
   saturated steam at 397 K
rs=q/hvp       //kg/h, rate of steam supply
printf("The steam pressure to be used in the
   calandria is %f bar(abs)\n",Sp);
printf("The heat transfer rate required is %f Kj/h\n
   ",q);
printf("Rate of steam supply is %f kg/h",rs);
```

Scilab code Exa 9.4 MULTIPLE EFFECT EVAPORATION

```
//Example 9.4
//calculate the evaporator areas and the steam
   economy.
//given
Wf=6000      //kg/h, feed rate
ci=2         //%, initial concentration
cf=35        //%, final conc.
ft=50         //C, feed temp.
ssp=2        //bar abs, saturated steaam pr.
sep=0.0139   //bar abs, maintained temp. in second
   effect
h1=2000      //W/m^2 K, overall heat transfer
   coeffcient in 1st effect
```

```
h2=1500      //W/m^2 K, overall heat transfer
   coefficient in 2nd effect
cp=4.1       //kj/kg k,specific heat

//calculation
si=Wf*(ci/100) //kg/h, solid in
wi=5880       //kg/h, water in
Wp=si/(cf/100)  //kg/h product out
wo=Wp*(1-cf/100) //kg/h, water out with the product
ter=wi-wo       //kg/h, total evaporation rate

//boiling temp. in the first effect
T1=120        //C,Temprature
l_s1=2200     //kj/kg, latent heat
T2=12         //C,boiling point in second effect
l_s2=2470    // kj/kg  in second effect
  tatd=T1-T2    // C,tatd=dt1+dt2 =T1-T2  , total
     available temp. drop
//from eq. 9.20
  //h1*dt1=h2*dt2
  //solving above two equations by matrix
  A=[1,1;2000,-1500]
  C=[108;0]

  X=inv(A)*C

  dt1=X([1])
  dt2=X([2])
  t1=T1-dt1    //temp. of steam leaving the first
     effect
  t2=T2-dt2    //temp. of steam leaving second
     effect
//energy balance over the 1st effect , from eq.9.14
rt1=t1
  ef=cp*(ft-t1)   //kj/kg,enthalpy of feed
  i1=0
  lam_s1=2330     //kj/kg
  is1=lam_s1
```

```
  //Wf*ef+Ws*l_s=(Wf-Ws1)*i1+Ws1*is1
  //substituting we get,
  //Ws1=0.9442*Ws-253.4..........(1)
  //energy balance over second effect
  //from eq 9.15
 //(Wf-Ws1)*i1+Ws1*lam_s1=(Wf-Ws1-Ws2)*i2+Ws2*is2
  rt2=t2
  lam_s2=2470
  is2=lam_s2
  i2=0
  // substituting we get
  //Ws2=0.8404*Ws1+617.5............(2)
  //ter,Ws1+Ws2=5657...............(3)
  //solving by matrix method
  A=[0.9442,-1,0;0,0.8404,-1;0,1,1]
  B=[253.4;-617.5;5657]
  X=inv(A)*B
Ws=X([1])
  Ws1=X([2])
  Ws2=X([3])

  //evaporator area
  A1=Ws*l_s1/(h1*dt1)  //for 1st effect
  A2=Ws1*lam_s1/(h2*dt2)  //for second effect

  //revised calculation
  //taking
  dt1_=48
  dt2_=60
  T1_=T1-dt1_
  T2_=T2-dt2_
  ls1_=2335
  ls2_=2470
  // energy balance over first effect gives
  //Ws1=0.9422Ws-231.8.........(4)
  //energy balance over second effect gives
  //Ws2=0.8457Ws1+579.5......(5)
  //solving eq 3,4,5
```

```
P=[0.9422,-1,0;0,0.8457,-1;0,1,1]
Q=[231.8;-579.5;5657]
Y=inv(P)*Q
Ws_=Y([1])
Ws1_=Y([2])
Ws2_=Y([3])

//eveporator area for 1st & 2nd effect in m^2
A1_=Ws_*l_s1/(h1*dt1_)
A2_=Ws1_*ls1_/(h2*dt2_)
EA=(A1_+A2_)/2
SE=(Ws1_+Ws2_)/Ws_
printf("The evaporator area is %f square metre \n",EA);
printf("Steam economy is %f",SE);
```

Scilab code Exa 9.5 MULTIPLE EFFECT EVAPORATION

```
//Example 9.5
//Determine the maximum no. of effects to be used.
//given
ssp=3.32      //bar abs, saturated steam pr.
rp=0.195      // bar abs, residual pr. in the condenser
tl=41       //K, sun of temp. losses because of BPE
mt=8         //k,minimum available temp. driving force
//calculation
sst=410      //K,saturated steam temp.
st=333         //K,corresponding saturation temp. when pressure in the last effect is 0.195 bar
ttd=sst-st     //K,total temp. difference
atd=ttd-tl     // K,available temp. drop across the unit
n=atd/mt      //maximum no. of effect
```

```
printf("Maximum no. of effects are %f",n);
```

Scilab code Exa 9.6 MULTIPLE EFFECT EVAPORATION

```
//Example  9.6
//Calculate the heat transfer area required
//(assuming equal area for the three effects)
//Rate of steam consumption , Steam economy

//given
fc=9.5       //%,feed concentration
  pc=50      //%, product conc.
  ft=40      // C,feed temp.
  er=2000       //kg NaOH/h, evaporation rate
 vp=714      //mm Hg, vaccum pr. in last effect
  //heat transfer coefficients , W/m^2 C
  h1=6000    //for first effect
  h2=3500    //for second effect
  h3=2500    //for third effect

  //calculatiin
  Wf=er/(fc/100)  //kg/h, 2 tons NaOH per hour, feed
      rate
  Wp=er/(pc/100)  //kg/h, product rate
  ter=Wf-Wp  //kg/h, total evaporation  rate
  //steam
  p=3.3       //bar,assumed saturated
  //from steam table
  Ts=137      //C,temp.
  l_s=2153    //kj/kg, latent heat
  pl=760-vp   //mm Hg,pressure in the last effect
  bp=37       //C,boiling point of water
  //refer to fig. 9.24
  attd=Ts-bp  //C,apparent total temp. drop
  //let assume the following evaporation rate for
```

```
three effects in kg/h
ev1=5600
ev2=5680
ev3=5773
//conc. in three effects
c1=er/(Wf-ev1)
c2=er/(Wf-ev1-ev2)
c3=0.5    //given
//boiling point elevations in three effects in C
bpe1=3.5
bpe2=8
bpe3=39
attda=attd-(bpe1+bpe2+bpe3)  //actual total temp. drop available
//temp. drop in three effects
//from eq. 9.23
dt1=attda*((1/h1)/((1/h1)+(1/h2)+(1/h3)))
dt2=attda*((1/h2)/((1/h1)+(1/h2)+(1/h3)))
dt3=attda*((1/h3)/((1/h1)+(1/h2)+(1/h3)))

//from table 9.4
//enthalpy of solution in three effects in  kj/kg
i1=486
i2=385
i3=460
//enthalpy of vapour generated for three effects in kj/kg
is1=2729
is2=2691
is3=2646
//Enthalpy of condensate over effect 1,2,3 in kj/kg
il1=0
il2=519
il3=418
//Enthalpy balance over effect 1
ef=145      //kj/kg,enthalpy of feed
//from energy balance eq.
```

```
//Ws1=0.96Ws-3200......(1)
//enthalpy balanc over effect 2
//Ws2=0.9146Ws1+922...........(2)
//enthalpy balanc over effet 3
//Ws3=1.073Ws2+0.0343Ws1-722........(3)
//ter=Ws1+Ws2+Ws3=17053..........(4)

//Solving above four eqns by matrix
A=[0.96,-1,0,0;0,0.9146,-1,0;0,0.0343,1.073,-1;0,1,1,1]
B=[3200;-922;722;17053]
X=inv(A)*B
Ws=X([1])
Ws1=X([2])
Ws2=X([3])
Ws3=X([4])

//calculation of heat transfer areas iver effect 1, 2 ,3
A1=Ws*l_s*10^3/(h1*dt1*3600)
A2=Ws1*(is1-il2)*10^3/(h2*dt2*3600)
A3=Ws2*(is2-il3)*10^3/(h3*dt3*3600)

//Revised dt
avar=(A1+A2+A3)/3
dt1_=(A1/avar)*dt1
dt2_=(A2/avar)*dt2
dt3_=attda-dt1_-dt2_

//from table 9.5
//enthalpy of vapour generated over effect 1,2,3 in kj/kg
is1_=2720
is2_=2685
is3_=2646
//enthalpy of soln on 1,2,3 in kj/kg
i1_=470
```

```
i2_=380
i3_=460
//enthalpy of condensate over effect 1 ,2,3 in kj/kg
il1_=0
il2_=513
il3_=412
//enthalpy balance ove effect 1,2,3 gives
Ws_=8854
Ws1_=5432
Ws2_=5812
Ws3_=5809
//revised heat transfer areas for effect 1 ,2,3 in m^2
A1_=Ws_*l_s*1000/(h1*dt1_*3600)
A2_=Ws1_*(is1_-il2_)*10^3/(h2*dt2_*3600)
A3_=Ws2_*(is2_-il3_)*10^3/(h3*22.5*3600)
avar_=(A1_+A2_+A3_)/3
SE=ter/Ws_

printf("The areas are now reasonably close  \n")
printf("Steam Rate is % f Kg/h \n",Ws_)
printf("Steam economy is %f",SE)
```

Scilab code Exa 9.7 MULTIPLE EFFECT EVAPORATION

```
//Exalple 9.7
//Calculate the increase in evaporation capacity attainable
//also the % change in cost of concentrating a ton of feed.
//Given
Wf=3000          //kg/h,feed
  fc=8          //%, feed concentration
  pc=40         //% product concentration
```

```
  si=Wf*(fc/100)       //kg,solid in
  pr=si/(40/100)       //g/h, product rate
 ft=60           //C,feed temp.
  er=Wf-pr             //kg/h, evaporation rate
  cost=120000    //total cost per year
  p1=4.5        //bar, low pressure steam
  scpt=700         //per ton.  cost of steam
  cp=0.764         //  kcal/kg, specific heat

//from table 9.6
  eep=1         //atm existing evaporator pressure
  oop=400000      // peryear ,other operatingcost
  oop_=600000      //per yr, for proposed condition
  wd=300          //days per year.working days
  wh=wd*24         //working hr

  //EXISTING OPERATING CONDITION
  rt=0          //C,reference temp.
  ef=eep*(ft-rt)    //kcal/kg, enthalpy of feed
  pt=100      //C,product temp.
  i1=cp*(pt-rt)    //kcal/kg, enthalpy of soln
  is1=639        //kcal/kg,enthalpy of vapour generated at 1 atm (from steam table)
  l_s=496       //kcal/kg,latent heat of steam at 4.5 bar
  T=425       //K
  //heat balance
  Ws=(er*is1+pr*i1-Wf*ef)/l_s       //kg/h, steam required
  q=Ws*l_s        //ton/ hr,heat supplied
  x=q/(T-(pt+273))   //x=Ud*A
  //hourly cost
  sc=Ws/1000*(scpt)     // /perh, steam cost
  lc=100              //per h,labour cost
  oc=oop/(wh)      // per h,othe cost
  tc=sc+lc+oc   //total cost
  C=tc/(Wf/1000)      // per ton,cost per ton of feed

```

```
  //PROPOSED OPERATING CONDITION
  bpl=320          //K, boiling point of liquid
  dt=T-bpl
  q_=x*dt      //kcal/h, rate of heat supply
  sr=q_/l_s    //steam rate ton per hr
 pt_=47       //C, product temp .
  ep=cp*(pt_-rt)     //kcal/kg. enthalpy of product
  ev=618          //kcal/kg, enthalpy of vapour generated
  //heat balance
  //24Wf_-582Ws1_=2825000   ..........(1)
  //material balance
  // 4Wf_-5Ws1_=0   .............(2)
  //solving by matrix method
  a=[24,-582;4,-5]
  b=[-2825000;0]
  x_=inv(a)*b
  Wf_=x_([1])
  Ws1_=x_([2])
  ic=(Wf_-Wf)/Wf
printf("The increase in evaporation capacity ic %f percentage \n",ic*100)
  sr_=Ws1_/1000     //ton per hr ,steam rate
  //hourly cost
  sc_=Ws1_*scpt    //steam cost
  lc_=200       //labour cost rs.200/ h
  oc_=oop_/wh  // other cost
  tc_=sc_/1000+lc_+oc_
  C_=tc_/(Wf_/1000)  //cost per ton of feed
  ps=(C-C_)/C
  printf(" The percentage change in the cost of concentrating a ton of feed is %f percentage",ps*100)
```

Scilab code Exa 9.8 Mechanical vapour compression

```

//Example 9.8
//make a mechanical vapour recompression calculation.
//given
q=2200          //kj/kg heat of condensation of steam
//from example 9.1
Qr=2.337*10^8       //kj/day  rate of heat supply
//calculation
Rate=Qr/q           //kg/day steam supply rate
Rate_=1.062*10^5    //approximate value
E=2800              //kj/kg enthalpy of compressed vapour
T=175.7             //C, temprature
Ts=121              //C Saturation temprature
E1=2700             //enthalpy at saturation temprature
q1=T-Ts             //Superheat of vapour
T1=100              //C hot water temprature
E2=419               //Enthalpy at hot water temp.
x=(E-E1)/(E1-E2)     //water supplied per kg of superheated steam
S=1.044              //steam obtained after desuperheating
R1=8.925*10^4        //kg/day rate of vapour generation
R2=S*R1              //Rate of recompressed sat. steam
R2_=9.318*10^4        //approximate value
SR=Rate_-R2_
printf("Make up steam required is %f kg/day",round(SR))
```

Chapter 10

UNSTEADY STATE AND MULTIDIMENSIONAL HEAT CONDUCTION

Scilab code Exa 10.8 MUMERICAL CALCULATION OF UNSTEADY STATE HEAT CONDUCTION

```
//Example no. 10.8
//Page no. 444
//Calculate the bottom surface , mid plane ,top surface temperatures
//of the slab after 4 hours
//given
l=0.05                          //m,thickness of margarine  slab
ro=990                          //Kg/m^3, density of margarine slab
cp=0.55                         //Kcal/kg C, ddpecific heat of slab
k=0.143                         //kcal/h mC,   thermal conductivity of slab
Ti=4                            //C, initial temp
To=25                           //C, ambient temp.
t=4                             //hours, time
```

```
h=8                              //kcal/h m^2 C
//calculation
Fo=k*t/(ro*cp*l^2)              //, fourier no.
Bi=h*l/k                         //Biot no.
//from fig. 10.6 a
Tcbar=0.7                        //Tcbar=(Tc-To)/(Ti-To)
Tc=To+Tcbar*(Ti-To)              //C, centre temp.
//from fig 10.6 b
//(T-To)/(Tc-To)=0.382
T=0.382*(Tc-To)+To               //c,top surface temp.
//again from fig. 10.6 b
Tm=0.842*(Tc-To)+To              //, mid plane temp.
printf("The bottom surface temperature of given slab
    is %f C",Tc);
printf("The top surface temperature of given slab is
    %f C",T);
printf("The  mid plane temperature of given slab is
   %f C",Tm);
```

Scilab code Exa 10.9 NUMERIC CALCULATION OF UNSTEADY STATE HEAT CONDUCTION

```
//Example10.9
//Page no. 449
//calculate   :  (i) time required for the cantre-
    line temp.
//to drop down to 200 C
//(ii)the temp. at half radius  at that moment
//(iii)the amount of heat that has been  transfered
    to the liquid
// by that time per  metre   length of the shaft
//given data
Ti=870                                     //C, initial temp
    .
To=30                                      //C, ambient
   temp.
```

```
Tc=200                                   //C, centre line temp.
h=2000                                   //W/m^2 C, surface heat transfer coefficient
a=0.05                                   //m, radius of cylinder
k=20                                     //W/m C, thermal conductivity
ro=7800                                  //kg/m^3, density
cp=0.46*10^3                             //j/kg C, specific heat

//calculation
//i
Bi=h*a/k                                 //Biot no.
alpha=k/(ro*cp)                          //m^2/C, thermal diffusivity
Tcbar=(Tc-To)/(Ti-To)                    // dimensionless centre line temp.
//from fig 10.7 a
fo=0.51                                  //fourier  no. fo=alpha*t/a^2
t=fo*a^2/alpha                           //s, time

//ii
//at the half radius, r/a=0.5 & Bi=5
T=To+0.77*(Tc-To)                        //from fig. 10.7 b

//iii
x=Bi^2*fo
//for x =12.75 & Bi=5.0. fig.10.9 b gives
//q/qi=0.83
qi= %pi*a^2*(1)*ro*cp*(Ti-To)    //kj, initial amount of heat energy
                                 //present in 1 m length of shaft
q=0.83*qi                        //j, amount of heat transfered
```

```
printf("(i) time required for the cantre-line temp.
   to drop down to 200 C is %f s",t);
printf("(ii)the temp. at half radius  at that moment
    is %f C ",T);
printf("(iii)the amount of heat that has been
   transfered to the liquid is  %f Kj",q*10^(-3));
```

Chapter 11

Boundary layer heat transfer

Scilab code Exa 11.1 `water at 25 degree celcius`

```
//Example 11.1
//page no. 478
//a−Calculate Boundary layer thickness at x=0.5 m
//b−Calculate local drag coeff at x=0.5 m
//c−Force req to hold the plate in position
//d−shear stress at a plane, distant t/2 from the
    surface at x = 0.5 m
//Variable declaration

v =1 //m/s
//temprature
T=25            // degree celcius
//length of plate,l=1m
l=1             //m
//width of plate,w=0.5m
w=0.5 //m
//angle of incidence,theta=0 degree
theta=0         //degree

//Calculation
//for water at 25 degree celcius ,momentum
```

```
diffusivity ,
MD=8.63*(10^-7)  // m^2/s
//local Reynold no.
x=0.5 //m
Re=x*v/MD
//from Eq. 11.39,the boundary layer thickness is
t=5*x/(Re^0.5)


//Results
printf ("i) Boundary layer thickness is%f  m\n",t)

//local drag coefficient
//CD=local drag force per unit area (F)/kinetic energy per unit volume(KE)
//F=0.332*rho*v^2*Re^0.5 and KE= 0.5*rho*v^2
CD=0.332*v^2*(Re^-0.5)/(0.5)*v^2

printf("Local drag coefficient is %f \n",CD)

//From eq 11.44, the drag force acting on one side of the plate is
//kinetic viscocity
mu=8.6*(10^-4)
fd=0.664*mu*v*(l*v/MD)^0.5*w
//the total force acting on both sides of the plate

tfd=2*fd
printf("total drag force is %f  N \n",tfd)

//shear stress at any point in the boundary layer
//at a point in the boundary layer,
x=0.5 //m
y=t/2
// n=blasius dimensionless variable
n=y/(MD*x/v)^0.5
//From table 11.1, at n=2.5,f"(n)=0.218
//shear stress= tau
```

```
fn=0.218 //f"(n)=fn
tau=(mu*v*(v/(MD*x))^0.5)*fn
printf("Shear stress is %f N/m^2",tau)
```

Scilab code Exa 11.2 air at 30 degree celcius

```
//Example 11.2
//Page no. 488
//Calculate the thermal boundary layer thickness &
//local heat transfer coefficient 0.75 m from the
   leading edge.

//Variable declaration
Ts=200              // C,temp. of air
Ta=30               //C, temp .of surface
Va=8                //m/s, velocity of air
d=0.75              //m, distant from leading edge

//Calculation
Tm=(Ts+Ta)/2        //C, Mean temp. of boundary layer
mu=2.5*10^-5       //m^2/s, viscosity
P=0.69              //prndatl no.
k=0.036             //W/m c, thermal conductivity
Re=d*Va/mu          //reynold no.
t=5*d/(Re^0.5*P^(1/3))                //m, thermal
   boundary layer thickness
printf("Thermal boundary layer thickness is %f mm \n
   ",t*10^3)

N=(0.332*Re^(0.5)*P^(1/3))    //Nusslet no.
h=k*N/d                                             //heat
   transfer coefficent
printf("heat transfer coeff is %f W/m^2 C",h)
```

Scilab code Exa 11.3 A thin metal plate

```
//Example 11.3
//Page No. 489
//given
//Free strean velocity (v1) and temp.(t1) on side 1
v1=6 //m/s
t1=150 //degree celcius
//same on side 2
v2=3 //m/s
t2=50 //degree celcius
//distant
x=0.7 //m
//The plate temp. is assumed to be equal to the mean of the bulk air temp on the two sides of the plates
T=100 //degree celcius
//Side 1
//mean air temp.
tm1=(T+t1)/2
//From thermophysical properties:kinetic viscosity (kv),Prandtl no.(P), thermal conductivity (k)
kv1=2.6*10^-5 //m^2/s
P1=0.69
k1=0.0336 //W/m degree celcius
//Reynold no.
Re1=x*v1/kv1
//Nusslet no(N1)
a=1/3
N1=0.332*(Re1)^0.5*P1^a
h1=k1*N1/x
//Side 2 of the plate
tm2=(T+t2)/2
//Similarly
```

```
kv2=2.076*(10)^-5 //m^2/s
P2=0.70
k2=0.03 //W/m degree celcius
Re2=x*v2/kv2
N2=0.332*(Re2)^0.5*P2^a
h2=k2*N2/x
//overall heat transfer coeff.
U=h1*h2/(h1+h2)
//The local rate of heat exchange
RH=U*(t1-t2)
printf("Local rate of heat exchange is  %f W/m2\n\n",RH)
//the plate temp is given by
TP=t2+(t1-t2)*U/h2
printf("Plate temperature is :%f Celsius \n",TP)
```

Scilab code Exa 11.4 calculate the temprature

```
//Example 11.4
//Calculate the temprature of the plate after 1 hour
//if its initial temp, is 120 C

//Given
T1=120                              //C, initial temp.
T2=25                               //C, Final temp.
Tm=(T1+T2)/2                        //C, mean temp.
rho=8880                            //kg/m^3, density of plate
//Properties of air at mean temp.
mu=2.07*10^-5                       //m^2/s, viscosity
Pr=0.7                              //Prandtl no.
k=0.03                              //W/m C, thermal conductivity
```

```
l=0.4                                    //m, length of plate
w=0.3                                    //m, width of plate
d=0.0254                                 //m, thickness of plate
Vinf=1                                   //m/s, air velocity
Re=l*Vinf/mu                             //REynold no.

//from eq. 11.90 (b)
Nu=0.664*(Re)^(1/2)*(Pr)^(1/3)           //average Nusslet no.
//Nu=l*h/k
h=Nu*k/l                                 //W/m^2 C, heat transfer coefficient
//Rate of change of temp. is given by
A=2*l*w                                  //m^2. area of plate
t=1*3600                                 //s, time
cp=0.385*10^3                            //j/kg K, specific heat
m=l*w*d*rho                              //kg, mass of plate

//-d/dt(m*cp8dt)=A*hv*(T1-T2)
//appling the boundary condition
T=(T1-T2)*exp(-A*h*t/(m*cp))+T2
printf("The temprature of plate after 1 hour is %f C",round(T))
```

Scilab code Exa 11.5 Prandtl analogy

```
//Example 11.5
//Page no. 508
```

```
//given
//Reynold no (Re),friction factor(f),Prandlt no. (P)
Re=7.44*(10^4)
f=0.00485
P=5.12
x=P-1            //assume
//according to Von Karmen analogy
N=((f/2)*Re*P)/(1+(5*sqrt(f/2))*(x+log(1+(5/6)*x)))
printf("Nusslet no is: %f \n",N)
//printf("The prandtl analogy predicts Nu=458.7")
```