Scilab Textbook Companion for
Heat Transfer
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Book Description

Title: Heat Transfer

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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

Conduction

Scilab code Exa 2.1 `Thickness of insulation`

```
clc;
clear;
printf("Example 2.1 \n Page no. 2.18\n Part-(a)")
A=1; //sq metre
printf("Area of heat transfer,A=%f m^2\n",A)
Q=450; // W/ sq mtre
printf("Rate of heat loss/unit area=%f W/m^2\n",Q)
dT=400; // K
printf("Temperature difference across insulation layer\t,dT=%f K\n",dT)
k=0.11 //W/(m.K)
printf("For asbestos,k=%f\n",k)
//Q=(k* A*dT)/x
x=(k*A*dT)/Q
X=x*1000;

//for fire clay insulation
k=0.84; // W/(m.K)
printf("For fire clay insulation,k=%f W/(m.K)\n",k);
x=(k*A*dT)/Q;
X=x*1000;
```

```
printf("Ans.(A).Thickness of asbestos is: %f m=%f mm\n",x,X)
printf("Ans.(B)Thickness of fire clay insulation is: %f m =%f mm\n",x,X)
```

Scilab code Exa 2.2 `Heat loss per metre`

```

clc;
printf("Example 2.2,\nPage no.2.18\n");
L=1 // m
printf("Length of ppipe,L = %f m\n",L);
r1=(50/2) // in mm
r1=r1/1000 // in m
printf("r1=%f m\n",r1);
r2=(25+3)/1000 // m
printf("r2=%f m\n",r2)
rm1=(r2-r1)/log(r2/r1);
printf("rm1=%f m\n",rm1)
k1=45 //W/(m.K)
R1=(r2-r1)/(k1*(2*%pi*rm1*L)) // K/W
printf("Thermal resistance of wall pipe=R1=%f K/W\n",R1);
printf("For inner lagging:\n") ;
k2=0.08 //W/(m.K)
ri1=0.028 //m
ri2=(ri1+r1) // m
rmi1=(ri2-ri1)/log(ri2/ri1)
R2=(ri2-ri1)/(k2*2*%pi*rmi1*L)
printf("Thermal resistance of inner lagging=R2=%f K/W",R2);
printf("For  outer lagging:\n") ;
k3=0.04 //W/(m.K)
ro1=0.053 //m
ro2=(ro1+0.04) // m
```

```
rmo1=(ro2-ro1)/log(ro2/ro1)
R3=(ro2-ro1)/(k3*2*%pi*rmo1*L)
printf("Thermal resistance of inner lagging=R2=%f K/W\n",R3);
R=R1+R2+R3
Ti=550 //K //inside
To=330 //K  // outside
dT=Ti-To; //Temperature difference
Q=dT/R
printf("Rate of heat loss per metre of pipe,Q=%f W/m",Q)
```

Scilab code Exa 2.3 Heat Loss

```
clear;
clc;
printf("Example 2.3")
//Given
r1=44 //  [mm]
r1=r1/1000   //[m]
r2=0.094    //  [m]
r3=0.124   //  [m]
T1=623   //Temperature at outer surface of wall in[K]
T3=313   //Temperature at outer surface of outer insulation   [K]
k1=0.087   //Thermal conductivity of insulation layer 1..in  [W/m.K]
k2=0.064   //Thermal conductivity of insulation layer 2   [W/m.K]
l=1     // Length of pipe    [m]
rm1=(r2-r1)/log(r2/r1)   //log mean radius of insulation layer 1  [m]
rm2=(r3-r2)/log(r3/r2)   //log mean radius of insulation layer 2[m]
//Putting values in following eqn:
```

```
Q= (T1-T3)/((r2-r1)/(k1*2*%pi*rm1*l)+(r3-r2)/(k2*2*%pi*rm2*l));
printf(”Heat loss per meter pipe is %f W/m”,Q)
```

Scilab code Exa 2.4 `Heat loss`

```
clc;
clear;
//Example 2.4
printf(”Example 2.4”)
//Given
A=1 //Heat transfer area  [sq m]
x1=0.229  // thickness of fire brick in [m]
x2=0.115  // thickness of insulating brick in [m]
x3=0.229  // thickness of building brick in [m]
k1=6.05  //thermal conductivity of fir brick  [W/(m.K)]
k2=0.581  //thermal conductivity of insulating brick [W/m.K]
k3=2.33  //thermal conductivity of building brick [W/m.K]
T1=1223  // inside temperature [K]
T2=323 // Outside temperature[K]
dT=T1-T2  //Overall temp drop [K]
R1=(x1/k1*A) //thermal resistance 1
R2=(x2/k2*A) // Thermal resistance 2
R3=(x3/k3*A) //Thermal resistance 3
Q=dT/(R1+R2+R3) //w/SQ m
Ta=-((Q*R1)-T1)  //from  Q1=Q=(T1–Ta)/(x1/k1*A)
//Similarly
Tb=(Q*R3)+T2;
printf(”Interface temperature:\n i–Between  FB–IB=%f K  \nii–Between IB–PB=%fK”,Ta,Tb);
```

Scilab code Exa 2.5 `Heat loss`

```
clc;
clear;
//Example 2.5
printf("Example 2.5\nPage 2.23")
//Given
A=1;  //let [sq m]
x1=0.23;   //thickness of fir brick layer[m]
x2=0.115;   // [m]
x3=0.23;   //[m]
T1=1213;  //Temperature of furnace [K]
T2=318;   //Temperature of furnace  [K]
dT=T1-T2;  //[K]
k1=6.047;   //W/(m.K) (fire brick)
k2=0.581;   //W/(m.K) (insulating brick)
k3=2.33;   //W/(m.K) (building brick)
Q_by_A=dT/((x1/k1)+(x2/k2)+(x3/k3))  //Heat lost per unit Area in Watt

R1=(x1/k1)  //Thermal resistance
R1=0.04     //Approximate
R2=(x2/k2)
R2=0.2025      //Approximate
R3=(x3/k3)
R3=0.1      //Approximate
Ta=T1-((dT*R1)/(R1+R2+R3))
Tb=((dT*R3)/(R1+R2+R3))+T2
Tb=565          //Approximation
printf("\nAnswer:Heat loss per unit area is %f W=%f J/s\n",Q_by_A,Q_by_A);
printf("\nAnswer:\n Ta=%f K =Temperature at the interface between fire brick and insulating brick\n Tb=%d K Temperature at the interface between
```

```
   insulating and building brick\n",Ta,Tb)
```

Scilab code Exa 2.7 `Heat loss`

```
clc
printf("Example 2.7,Page no 2/26 \n");
printf("Part-(a)\n");
A=1; // sq metre
x1=114 // mm
x1=114/1000 // metre
k1=0.138 // W/(m.K)
R1= x1/(k1*A)
x2=229 //mm
x2= x2/1000  // metre
k2=1.38  // W/m.K
R2=x2/(k2*A)
dT=1033-349
//Heat loss
Q=dT/(R1+R2)
printf("ANSWER:Heat loss  from 1 sq metre wall=%f W"
   ,Q);
printf("Part(b)\n");
//contact resistance=cr
cr=0.09 //K/W
R=R1+R2+cr
Q=dT/R
printf("ANSWER:Heat loss from 1 sq metre when
   resistance present=%f W",Q);
```

Scilab code Exa 2.8 `Loss per area`

```
clear;
clc;
```

```
//Example 2.8
printf("Example 2.8 \n")
//Given:
x1=0.02   //[m]
x2=0.01   //[m]
x3=0.02   //[m]
k1=0.105   //W/(m.k)
k3=k1   //W/(m.K)
k2=0.041   //W/(m.K)
T1=303
T2=263
dT=T1-T2    //[K]
Q_by_A=dT/((x1/k1)+(x2/k2)+(x3/k3))
R=0.625   //K/W
Tx=293    //K
Rx=0.9524    //K/W
x=R*(T1-Tx)/(dT*Rx)
x=x*100   //mm
printf("The temperature of 293 K will be reached at point %f mm from the outermost wall surface of the ice-box",x)
```

Scilab code Exa 2.9 `Heat loss`

```
clc
printf("Example 2.9,Page 2.28\n");
//Given
ID=50 //mm;
dT=(573-303);
printf("Internal diameter,ID=%f mm",ID);
r1=ID/2 //mm
r1=r1/1000 // metres
OD=150 // mm
printf("Outer diameter,OD=%f mm",OD);
r2=OD/2 // mm
```

```
r2=75/1000 // m
//Thermal conductivity
k=17.45 // W/(m.K)
//Solution
printf(”Q/A=dT/(r2−r1)/k\n”);
A1=4*%pi*(r1^2);
A2=4*%pi*(r2^2);
A=sqrt(A1*A2)
Q=(A*k*dT)/(r2-r1)
printf(”ANSWER:\nHeat loss=Q=%f W”,Q);
```

Scilab code Exa 2.10 `Heat Passed`

```
clear;
clc;
//Example 2.10
printf(”Example 2.10”)
A= 1 //sq m
x1=0.15
x2=0.01
x4=0.15
T1=973  //[K]
T2=288  //[K]
dT=T1-T2  //[K]
//Thermal conductivities
k1=1.75
k2=16.86
k3=0.033
k4=5.23
//in absence of air gap,sum of thermal resistances
sR=(x1/k1*A)+(x2/k2*A)+(x4/k4*A)
Q= dT/sR
printf(”Heat lost per sq meter is %d W/sq m”,Q);
//When heat loss,Q=1163,then new resistance =sR1
Q1=1163  //[W/sq m]
```

```
sR1=dT/Q1
//width of air gap be w then
w=(sR1-sR)*k3*A  //  [m]
w=w*1000  //in  [mm]
printf("Width of air gap is %f mm",w);
```

Scilab code Exa 2.11 Insulated pipe

```
clear;
clc;
//Example 2.11
printf("Example 2.11");
d1=300  //[mm]
r1=d1/2  //  [mm]
r1=r1/1000  //[m]
r2=r1+0.05  //[m]
r3=  r2+0.04  //[m]
x1=0.05  //[m]
x2=0.04  //[m]
k1=0.105  //W/(m.K)
k2=0.07  //W/(m.K)
rm1=  (r2-r1)/log(r2/r1);  //  [m]
rm2=(r3-r2)/log(r3/r2);     //[m]
L=1  //let
A1=%pi*rm1*L  //let L=1
R1=x1/(k1*A1);
A2=%pi*rm2*L
R2=x2/(k2*A2)
T1=623  //[K]
T2=323  //[K]
dT=T1-T2  //[K]
//Part a
Q_by_L=  dT/(R1+R2)   //Heat loss
printf("Heat loss is %f W/m",Q_by_L);
//Part b:
```

```
P=2*%pi*(r1+x1+x2)  //[m]
Q_by_L_peri=Q_by_L/P  //  [W/sq m]

printf("Heat lost per sq meter of outer insulation is %f W/sq m",Q_by_L_peri);
R1=x1/(k1*A1)
sR=0.871+0.827
dT1=dT*R1/sR
printf("Temperature between two layers of insulation =%f K",(T1-dT1) );
```

Scilab code Exa 2.12 Composite brick

```
//Example 2.12
clear;
clc;
printf("Example 2.12\n")
//Given
x1=0.01  //[m]
x2=0.15  //[m]
x3=0.15  //[m]
T1=973  //[K]
T2=423  //[K]
dT=T1-T2;
//Thermal conductivities
k1=16.86  //[W/m.K]
k2=1.75  //[W/m.K]
k3=5.23  //[W/m.K]
k_air=0.0337  //  [W/m.K]
A=1  //[sq m]
sigma_R=(x1/(k1*A)+x2/(k2*A)+x3/(k3*A))
Q=dT/sigma_R  //Heat flow in  [W
Tm= Q*x3/k3  //Temperature drop in magnesite brick
//Interface temperature=iT
iT=T2+Tm  //[K]
```

```
sigma_xbyk= A*dT/1163   //with air gap for reducing heat loss to 1163 per sq m
x_by_k=sigma_xbyk-sigma_R   //x/k for air
t=x_by_k*k_air
t=t*1000;
printf("Width of the air gap is %f mm",t);
```

Scilab code Exa 2.13 Heat flow in a pipe

```
//Example 2.13
printf("Example 2.13 \n");

L=1   //assume  [m]

k1=43.03    //[W/(m.K)]

k2=0.07     //(W/m.K)

T1=423     //inside temperature [K]

T2=305      //  [K]

r1=0.0525     //[mm]

r2=0.0575;    //[m]

r3=0.1075 //[m]
//r3=r3/1000;  //[m]
Q=(2*%pi*L*(T1-T2))/(((log(r2/r1))/k1)+((log(r3/r2))/k2));     //Heat loss per metre

printf("Heat flow per metre of pipe is %f W/m",Q);

printf("Part 2\n");
//T=Temperature of outer surface
```

```
T=T1-(Q*log(r2/r1))/(k1*2*%pi*L);

printf("Temperature at outer surface of steel pipe: %f K",T);

printf("\nPart iii\n");
id=0.105    //inside diametre in [m]

A=%pi*id*1  //inside area in [sq m]

C=Q/(A*(T1-T2));   //conductance per length

printf("Conductance per m length based on inside area is %f W/K",C)
```

Scilab code Exa 2.15 `Thickness of insulation`

```
//Example 2.15
printf("Example 2.15 \n")
A=1  // [sq m]
  x1=0.1    //m
  x2=0.04
  k1=0.7
  k2=0.48
  sigma=x1/(k1*A)+x2/(k2*A)   //K/W
  //Q=4.42*dT
  //Q=dT/sigma
  //with rockwool insulation added,Q_dash=0.75*Q
 k3=0.065     // W/(m.K)
  //Q_dash=dT/sigma+x3/k3*A
  //On solving Q and Q_dash we get
  x3=((1/(0.75*4.42))-sigma)*k3    //[m]
  x3=x3*1000     // [mm]
  printf("Thickness of rockwool insulation required=%f mm",x3)
```

Scilab code Exa 2.16 `Reduction in heat loss in insulated pipe`

```
clc;
clear;
//Example 2.16,Page no 2.36
d1=40;    // Diameter of pipe[mm]
r1=(d1/2)/1000  //Outside radius in [m]
t1=20;     //Insulation 1 thickness in [mm]
t1=t1/1000     //[m]
t2=t1;          //Insulation 2 thickness in[m]
r2=r1+t1;      //radius after 1st insulation  in [m]
r3=r2+t2;      //Radius after second insulation in [m]

//Since Scilab does not handles symbolic constants, we will assume some values:
//(1)
printf(”Let the layer M-1 be nearer to the surface”)
L=1;           //[m]
T1=10;         //Temperature of inner surface of pipe [K]
T2=5;          //Temperature of outer surface of insulation [K]
k=1;           //Thermal conductivity
k1=k;          //For M-1 material
k2=3*k;        //For material M-2
Q1=(T1-T2)/(log(r2/r1)/(2*%pi*L*k1)+log(r3/r2)/(2*%pi*L*k2))

//(2)
printf(”Let the layer of material M-2 be nearer to the surface”);
Q2=(T1-T2)/(log(r2/r1)/(2*%pi*L*k2)+log(r3/r2)/(2*%pi*L*k1))
```

```
printf("Q1=%f and Q2= %f \n For dummy variables unity...\nFor any value of k,T1 and T2,Q1 is always less than Q2",Q1,Q2);
printf("\n So,M-1 near the surface is advisable(i.e Arrangement one will result i ,ess heat loss\n)");
per_red=(Q2-Q1)*100/Q2
printf("Percent reduction in heat loss is %f percent",per_red)
printf("\nNOTE:Slight variation in answers due to less precise calculation in book.If performed manually,this answer stands to be correct")
```

Scilab code Exa 2.17 `Heat loss in a pipe`

```
//Example2.17
T1=523   //[K]
  T2=323   //[K]
  r1=0.05   //[m]
  r2=0.055   //[m]
  r3=0.105   //[m]
  r4=0.155   //[m]
  k1=50      //[W/(m.K)]
  k2=0.06    //[W/(m.K)]
  k3=0.12    //W/(m.K)
  //CASE 1
  Q_by_L1=2*%pi*(T1-T2)/((log(r2/r1))/k1+(log(r3/r2))/k2+(log(r4/r3))/k3)   //[W/m]
  printf("Heat loss=%f W/m",Q_by_L1)
  //Case 2
  Q_by_L2=2*%pi*(T1-T2)/((log(r2/r1))/k1+(log(r3/r2))/k3+(log(r4/r3))/k2)
 perct=(Q_by_L2-Q_by_L1)*100/Q_by_L1
  printf("If order is changed then heat loss=%f W/m",Q_by_L2)
```

```
printf("\n loss of heat is increased by %f percent
    by putting material with higher thermal
    conductivity near the pipe surface",perct)
```

Scilab code Exa 2.18 `Arrangements for heat loss`

```

clc;
clear;
//Example 2.18,Page no 2.38
//Given
//Assume:
L=1     //[m]
r1=0.10     //[m]     Outside radius od pipe
ia=0.025     //inner insulaiton [m]

r2=r1+ia     //Outer radius of inner insulation
r3=r2+ia     //Outer radius of outer insulation
//CASE 1:'a' near the pipe surface
//let k1=1
k1=1;     //Thermal conductivity of A[W/m.K]
//and k2=3k1=3
k2=3;     //Thermal conductivity of B[W/m.K]
//Let dT=1
dT=1
Q1=dT/(log(r2/r1)/(2*%pi*k1*L)+log(r3/r2)/(2*%pi*k2*
   L))
Q1=22.12     //Approximate
//CASE 2:'b' near the pipe surface
Q2=dT/(log(r2/r1)/(2*%pi*k2*L)+log(r3/r2)/(2*%pi*k1*
   L))
Q2=24.39         //Approximation
printf("ANSWER-(i)\nQ1=%f W \nQ2= %f W \nQ1 is less
   than Q2.i.e arrangement A near the pipe surface
   and B as outer layer gives less heat loss\n",Q1,
```

```
Q2);
percent=(Q2-Q1)*100/Q1;     //percent reduction in heat loss
printf("\nANSWER-(ii) \nPercent reduction in heat loss (with near the pipe surface)=%f percent",percent);
```

Scilab code Exa 2.19 `Insulation thickness`

```
clc
clear
printf("Example 2.19.Page no.2.39")
//Given
x1=0.224 // m
k1=1.3 // W/(m.K)
k2=0.346 // W/(m.K)
T1=1588 // K
T2= 299 // K
QA=1830 // W/ sq metre //heat loss
//solution
printf("Q/A=(T1-T2)/x1/k1+x2/k2");
x2=k2*((T1-T2)*1/(QA)-(x1/k1))
x2=x2*1000;
printf("Thickness of insulation=%f mm",x2)
```

Scilab code Exa 2.20 `Heat loss in furnace`

```
//Example 2.20
//Given
//for clay
k1=0.533     //[W/(m.K)]
//for red brick
k2=0.7       //[W/m.K]
```

```
//Case 1
  A=1      //Area
  x1=0.125     //[m]
  x2=0.5       //[m]
  //Resistances
  r1=x1/(k1*A) //Res of fire clay [K/W]
  r2=x2/(k2*A)  //Res of red brick [K/W]
  r=r1+r2
  //Temperatures
  T1=1373     //[K]
  T2=323      //[K]
  Q=(T1-T2)/r //[W/sq m]
  Tdash=T1-Q*r1  //[K]
//Case2
 // Heat loss must remain  unchanged,Thickness of red brick also reduces to its half
  x3=x2/2   //[m]
  r3=x3/(k2*A)  //[K/W]
  Tdd= T2+(Q*r3)    //[K]
  //Thickness of diatomite be x2,km be mean conductivity
  Tm=(Tdash+Tdd)/2   //[K]
  km=0.113+(0.00016*Tm)  //[W/(m.K]
  x2=km*A*(Tdash-Tdd)/Q  //[m]
  x2=x2*1000      //[mm]
  printf("Thickness of diatomite layer=%f mm",x2)
```

Scilab code Exa 2.21 `Rate of heat loss in pipe`

```
//Exaample2.21
//Given
k1=0.7   //common brick   W/((m.K)
k2=0.48  //gypsum layer  [W/(m.K)
k3=0.065 //Rockwool     [W/m.K]
//Heat loss with insulatiob will be 20% of without
```

```
    insulation
A=1        //sq m
x1=0.1     //[m]
x2=0.04 //[m]
R1=x1/(k1*A)    //K/W
R2=x2/(k2*A)    //K/W
R=R1+R2         //K/W
//R3=x3/(k3*A)
QbyQd=0.2
sigRbyRd=QbyQd
x3=(R/QbyQd-R)/15.4 //m
x3=x3*1000          //[mm]
printf("Thickness of rockwool insulation =%f mm",x3)
```

Scilab code Exa 2.22 Heat loss from insulated steel pipe

```
clc;
clear;
//Example 2.22
Ts=451;       //Steam temperature in [K]
Ta=294;       //Air temperature in [K]
Di=25;    //Internal diameter of pipe  [mm]
Di=Di/1000;                //[m]
od=33;    //Outer diameter of pipe   [mm]
od=od/1000;                //[m]
hi=5678; //Inside heat transfer coefficient [W/(m^2.K)]
ho=11.36; //Outsideheat transfer coefficient  [W/(sq m.K)]
xw=(od-Di)/2;     //Thickness of steel pipe  [m]
k2=44.97;         //k for steel in W/(m.K)
k3=0.175;         //k for rockwool in W/(m.K)
ti=38/1000;            //thickness of insulation in [m]
r1=Di/2;          //[m]
```

```
r2=od/2;          //[m]
rm1=(r2-r1)/log(r2/r1);       //[m]
r3=r2+ti;               //[m]
rm2=(r3-r2)/log(r3/r2);   //[m]
Dm1=2*rm1;                //[m]
Dm2=2*rm2;                //[m]
//Rate of heat loss = dT/(sigma_R)
L=1;              //[m]
R1=1/(hi*%pi*Di*L);   //[K/W]
R2=xw/(k2*%pi*Dm1*L);
R3=(r3-r2)/(k3*%pi*Dm2*L);
Do=(od+2*ti) ;            //[mm]
R4=1/(ho*%pi*Do*L);                //[m]
sigma_R=R1+R2+R3+R4;
//Heat loss
dT=Ts-Ta;                 //[K]
Q=dT/sigma_R;             //Heat loss [W/m]
printf("\nAns:Rate of heat loss is %f W/m",Q);
printf("\n NOTE:Slight variation in final answer due
    to lack of precision in calculation of R1,R2,R3
   and R4.In book an approximate values of these is
   taken\n ")
```

Scilab code Exa 2.23 Heat loss from furnace

```
clc;
//Example 2.23
T1=913      //[K]
T=513      //[K]
T2=313       //[K]
//Q=(T1-T)/(x/(k*A))
//Q=(T-T2)/(1/(h*A))
//x=2k/h
//Q=(T1-T2)/(x/(kA)+1/(h*A))
//Therefore,Q=hA/3*(T1-T2)
```

```
//With increase in thickness(100%)
//x1=4*k/h
//Q2=(T1-T2)/(x1/k*A+1/(h*A))
//Q2=(h*A)/5)*(T1-T2)
//Now
h=1;    //Assume
A=1;    //Assume for calculation
Q1=(h*A/3)*(T1-T2)
Q2=((h*A)/5)*(T1-T2)
percent=(Q1-Q2)*100/Q1      //Percent reduction in heat loss
printf("\nTherefore,Percentage reduction in heat loss is %d percent",percent);
```

Scilab code Exa 2.24 Rate of heat loss

```
clc;
clear;
printf("Example 2.24\n Page no. 2.47");
//given
L=1//m
thp=2//Thickness of pipe; in mm
thi=10//Thickness of insulation; in mm
T1=373//K
T2=298//K
id=30//mm
r1=id/2//mm
r2=r1+thp//mm
r3=r2+thi//mm
//In S.I units
r1=r1/1000 //m
r2=r2/1000//m
r3=r3/1000//m
k1=17.44//W/(m.K)
k2=0.58//W/(m.K)
```

```
hi=11.63//W/(sq m.K)
ho=11.63//W/(sq m.K)
//Solution
Q=(2*%pi*L*(T1-T2))/(1/(r1*hi)+(log(r2/r1))/k1+((log
   (r3/r2))/k2)+(1/(0.02*ho)))
printf("ANSWER: \n Rate of heat loss ,Q=%f W",Q);
```

Scilab code Exa 2.25 `Thickness of insulation`

```
clc;
clear;
//Examplr 2.25
h=8.5 ;        //[W/sq m.K]
dT=175 ;       //[K]
r2=0.0167;             //[m]
Q_by_l=h*2*%pi*r2*dT          //[W/m]
k=0.07 ;           //For insulating material in  [W/m.
   K]
//for insulated pipe--50% reduction in heat loss
Q_by_l1=0.5*Q_by_l       //[w/m]
deff('[x]=f(r3)','x=Q_by_l1-dT/((log(r3/r2))/(2*%pi*
   k)+1/(2*%pi*r3*h))')

//by trial and error method we get:
r3=fsolve(0.05,f)
t=r3-r2           //thickness of insulation in [m]
printf('\n Hence,required thickness of insulation is
    %f m=%f mm or %d m",t,t*1000,round(t*1000));
```

Scilab code Exa 2.26 `Heat loss per metre`

```

//Example 2.26
```

```
//Calculate heat loss per metre length
//Given
id=0.1     //internal diameter in[m]
od=0.12     //outer diameter in [m]
T1=358     //Temperature of fluid    [K]
T2=298     //Temperature of surrounding    [K]
t=0.03     //thickness of insulation      [m]
k1=58     //[W/m.K]
k2=0.2     //W/(m.K) insulating material
h1=720     //inside heat transfer coeff [W/sq m .K]
h2=9       //W/sq m.K
r1=id/2     //[m]
r2=od/2     //[m]
r3=r2+t     //[m]
//Heat loss per meter=Q_by_L
Q_by_L=(T1-T2)/(1/(2*%pi*r1*h1)+log(r2/r1)/(2*%pi*k1)+log(r3/r2)/(2*%pi*k2)+1/(2*%pi*r3*h2)); //W/m
printf("Heat loss per metre length of pipe=%f W",Q_by_L)
```

Scilab code Exa 2.27 `Mineral wool insulation`

```

clc;
clear;
//Example 2.26
//Given:
T1=573;           //[K]
T2=323;          //[K]
T3=298;          //[K]
h1=29;            // Outside heat transfer coefficients [W/sq m.K]
h2=12;           //[W/sq m.K]
r1=0.047;             //Internal radius [m]
r2=0.05;              //Outer radius[m]
```

```
k1=58 ;                 //[W/m.K]
k2=0.052;               //[W/m.K]
//Q=(T1-T2)/(1/(r1*h1)+log(r2/r1)/k1+log(r3/r2)/k2)=(T2-T3)/(1/(r3*h2))
deff('[x]=f(r3)','x=(T1-T2)/(1/(r1*h1)+log(r2/r1)/k1+log(r3/r2)/k2)-(T2-T3)/(1/(r3*h2))')
//by trial and error method :
r3=fsolve(0.05,f)
t=r3-r2                //Thickness of insulation in [m]
//Q=h2*2*%pi*r3*L*(T2-T3)
Q_by_l=h2*2*%pi*r3*(T2-T3)       //[W/m]
printf("\n Thicknesss of insulation is %d mm \n Rate of heat loss per unit length is %f W/m",round(t*1000),Q_by_l);
```

Scilab code Exa 2.28 Furnace wall

```

clc;
clear;
//Example 2.28
//Calculate heat loss per sq m and temperature of outside surface
//Given
A=1 //assume [sq m]
x1=0.006     //[m]
x2=0.075     //[m]
x3=0.2     //[m]
k1=39     //[W/m.K]
k2=1.1     //[W/m.K]
k3=0.66     //[W/m.K]
h0=65     //W/sq m .K
T1=900     //K
T2=300     //K
sigma_R=(x1/(k1*A)+x2/(k2*A)+x3/(k3*A)+1/(h0*A));
```

```
//To calculate heat loss/sq m area
Q=(T1-T2)/sigma_R     //[W/sq m]
printf("Heat loss per sq metre area is: %f W/sq m",Q);
//Q/A=T-T2/(1/h0), where T=Temp of outside surface
//So, T=T2+Q/(A*h0)
T=Q/(A*h0)+T2     //[K]
printf("Temperature of utside surface of furnace is: %f K (%f degree C)",T,T-273)
```

Scilab code Exa 2.29 `Thickness of insulating brick`

```

clear;
clc;
//Example 2.29
//Determine necessary thickness of insulation brick
//Given
A=1     //Assume [sq m]
x1=0.003     //[m]
x3=0.008     //[m]
k1=30     //[W/m.K]
k2=0.7     //[W/m.K]
k3=40     //[W/m.K]
T1=363     //[K]
T=333     //[K]
T2=300     //[K]
h0=10     //W/sq m.K
//Q=(T1-T2)/(x1/(k1*A)+x2/(k2*A)+x3/(k3*A)+1/(h0*A))
//Also,Q=(T-T2)/(1/(h0*A))
//So, (T1-T2)/((x1/(k1*A)+x2/(k2*A)+x3/(k3*A)+1/(h0*A))=(T-T2)/(1/(h0*A))
//or,x2=k2*A((T1-T2)/((T-T2)*h0*A)-1/(h0*A)-x1/(k1*A)-x3/(k3*A))
x2=k2*A*((T1-T2)/((T-T2)*h0*A)-1/(h0*A)-x1/(k1*A)-x3
```

```
   /(k3*A)); //[m]
printf("Thicknessof insulating brick required is %f
   mm",x2*1000);
```

Scilab code Exa 2.30 `Heat flow through furnace wall`

```

clear;
clc;
//Example 2.30
//Given
hi=75           //[W/sq m.K)
x1=0.2     //m
x2=0.1     //[m]
x3=0.1     //[m]
T1=1943     //[K]
k1=1.25     //W/m.K
k2=0.074     ///W/m.K
k3=0.555     //W/m.K
T2=343     //K
A=1     //assume [sq m]
sigma_R=1/(hi*A)+x1/(k1*A)+x2/(k2*A)+x3/(k3*A);
//Heat loss per i sq m
Q=(T1-T2)/sigma_R     //[W]
//if T=temperature between chrome brick and koalin
   brick then
//Q=(T1-T)/(1/(hi*A)+x1/(k1*A))
//or T=T1-(Q*(1/(hi*A)+x1/(k1*A)))
T=T1-(Q*(1/(hi*A)+x1/(k1*A)));     //[K]
printf("Temperature at inner surface of middle layer
   =%f K(%f degree C)",T,T-273);
//if Tdash=temperature at the outer surface of
   middel layer,then
//Q=(Tdash-T2)/(x3/(k1*A))
//or Tdash=T2+(Q*x3/(k3*A))
```

```
Tdash=T2+(Q*x3/(k3*A))      //[K]
printf("Temperature at outer surface of middle layer
   =%f K (%f degree C)",Tdash,Tdash-273);
```

Scilab code Exa 2.31 `Heat loss in pipe`

```

clear;
clc;
//Example 2.31
//Calculate:(a) Heat loss per unit length
//(b)Reduction in heat loss
//Given
hi=10      //W/sq m.K
h0=hi      //W/sq.m.K
r1=0.09      //m
r2=0.12      //m
t=0.05      //thickness of insulation [m]
k1=40      //W/m.K
k2=0.05      //W/m.K
T1=473      //K
T2=373      //K
Q_by_L=2*%pi*(T1-T2)/(1/(r1*hi)+log(r2/r1)/k1+1/(r2*
   h0));      //W/m
printf("Ans (a) Heat loss=%f W/m ",Q_by_L)
//After addition of insulation:
r3=r2+t;      //radius of outer surface of insulaiton
Q_by_L1=2*%pi*(T1-T2)/(1/(r1*hi)+log(r2/r2)/k1+log(
   r3/r2)/k2+1/(r3*h0));      // W
Red=Q_by_L-Q_by_L1      //Reduciton in heat loss in [W
   /m]
percent_red=(Red/Q_by_L)*100      //% Reduction in
   heat loss
printf("Ans (b) Percent reduction in heat loss is %f
    percent",percent_red)
```

Scilab code Exa 2.32 `Heat flux through layers`

```

clear;
clc;
//Example 2.32
//Determine: i-Heat flux across the layers and
//ii-Interfacial temperature between the layers

//Given
T1=798     //K
T2=298     //K
x1=0.02     //m
x2=x1     //m
k1=60     //W/m.K
k2=0.1     //W/m.K
hi=100     //W/sq m.K
h0=25     //W/sq m.K
Q_by_A=(T1-T2)/(1/hi+x1/k1+x2/k2+1/h0);     //W/sq m
printf("Ans (i)- Heat flux across the layers is %f W/sq m",Q_by_A);
//If Tis the interfacial temperature between steel plate and insulating material
//Q_by_A=(T-T2)/(x2/k2+1/h0)
T=Q_by_A*(x2/k2+1/h0)+T2
printf("Ans-(ii)-Interfacial temperature between layers is %f K (%f degree C)",T,T-273);
```

Scilab code Exa 2.33 `Conductive conductance furnace wall`

```

```

```

clc;
clear;
//Example 2.33
//Determine Temperature at the outer surface of wall and convective conductance on the outer wall
    //Temperature of hot gas:
T1=2273     //K
    //Ambient aur temperature:
T4=318     //K
    //Heat flow by radiation from gases to inside surface of wall:
Qr1_by_A=23260     //[W/sq m]
    //Heat transfer coefficient on inside wall:
hi=11.63     //W/sq m.K
    //Thermal conductivity of wall:
K=58     //W.sq m/K
    //Heat flow by radiation from external surface to ambient:
Qr4_by_A=9300    //W/sq m.
    //Inside Wall temperature:
T2=1273     //K

Qr1=Qr1_by_A     //W  for
A=1     //sq m

Qc1_by_A=hi*(T1-T2)     //W/sq m
Qc1=Qc1_by_A     //for A=1 sq m
    //Thermal resistance:
R=1/K     //K/W per sq m
//Now Q=(T2-T3)/R,i.e
//External wall temp T3=T2-Q*R
//Q entering wall=
Q_enter=Qr1+Qc1     //W
T3=T2-Q_enter*R     //K
T3=673      //Approximate
//Heat loss due to convection:
Qc4_by_A=Q_enter-Qr4_by_A     //W/sq m
```

```
//Qc4_by_A=h0*(T3-T4)
//or  h0=Qc4_by_A/(T3-T4)
h0=Qc4_by_A/(T3-T4)     //W/sq m.K
//Result
printf("Convective conductance is: %f W/sq m.K",h0)
```

Scilab code Exa 2.34 `Critical radius of insulation`

```
clc;
clear;
//Example 2.34
//Given
T1=473     //[K]
T2=293     //[K]
k=0.17     //W/(m.K)
h=3     //W/(sq m.K)
h0=h     //W/sq m.K
rc=k/h     //m
r1=0.025     //Inside radius of insulaiton [mm]
q_by_l1=2*%pi*(T1-T2)/(log(rc/r1)/k+1/(rc*h0))     //Heat transfer with insulation in W/m
//Without insulation:
q_by_l2=h*2*%pi*r1*(T1-T2)     //W/m
inc=(q_by_l1-q_by_l2)*100/q_by_l2     //Increase of heat transfer
printf("When covered with insulation,\n heat loss=%f W \n When without insulation,heat loss= %f W \n percent increase =%f percent",q_by_l1,q_by_l2,inc);
k=0.04     //Fibre glass insulaiton W/(sq m.K)
rc=k/h     //Critical radius of insulaiton
printf("In this case the avlue of rc=%f m is less than the outside radius of pipe (%f),\n So additon of any fibre glass would cause a decrease in the heat transfer \n",rc,r1)
```

Scilab code Exa 2.36 `Critical radius of pipe`

```

clear;
clc;
//Example 2.36
//Calculate the heat loss per metre of pipe and
   outer surface temperature
//Given
k=1     //Thermal conductivity in [W/sq m.K]
h=8     //Het transfer coeff in W/sq m.K
rc=k/h  //Critical radius in m
T1=473    //K
T2=293    //K
r1=0.055    //Outer radius =inner radius in [m]
Q_by_L=2*%pi*(T1-T2)/(log(rc/r1)/k+1/(rc*h))
printf("Heat loss per meter of pipe is %f W/m",
   Q_by_L)
//For outer surface
//Q_by_L=2*%pi*(T-T2)/(1/rc*h)
// implies that, T=T2+Q_by_L/(rc*2*%pi)
T=T2+Q_by_L/(rc*2*%pi*h)    //K
printf("Outer surface temperature is: %f K(%f degree
    C)",T,T-273)
```

Scilab code Exa 2.37 `Time required for steel ball`

```

clc;
clear;
//Example 2.37
```

```
//Calculate the time required for a ball to attain a
    temperature of 423 K
//Given
k_steel=35    //W/m.K
Cp_steel=0.46    //kJ/(kg*K)
Cp_steel=Cp_steel*1000    //J/(kg*K)
h=10    //W/sq m.K
rho_steel=7800    //kg/cubic m
dia=50    //mm
dia=dia/1000    //m
R=dia/2      //radius in m
A=4*%pi*R^2  //Area  in sq m
V=A*R/3      //Volume in cubic meter
Nbi=h*(V/A)/k_steel
//As Nbi<0.10,internal temp gradient is negligible
T=423    //K
T0=723    //K
T_inf=373    //K
//(T-T_inf)/(T0-T_inf)=e^(-h*At/rho*Cp*V)
t=-rho_steel*Cp_steel*R*log((T-T_inf)/(T0-T_inf))
   /(3*h);    //s
printf("Time required for a ball to attain a
   temperature of 423 K is %f s= %f h",t,t/(3600))
```

Scilab code Exa 2.38 Steel ball quenched

```

clc;
clear;
//Example 2.38
//Given
dia=50    //mm
dia=dia/1000    //m
r=dia/2    //radius in m
h=115    //W/sq m.K
```

```
rho=8000 //kg/cubic m
Cp=0.42     //kJ/kg.K
Cp=Cp*1000     //J/(kg*K)
A=4*%pi*r^2     //Area in sq m
V=A*r/3     //Volume in cubic m
T=423     //K
T_inf=363     //K
T0=723     //K
//(T-T_inf)/(T0-T_inf)=e^(-3ht/(rho*Cp*r))
t=-rho*Cp*r*log((T-T_inf)/(T0-T_inf))/(3*h);     //Time in seconds
printf("Time taken by centre of ball to reach a temperature of 423 K is %f s (=%f minutes",t,t/60);
```

Scilab code Exa 2.39 `Ball plunged in a medium`

```

clc;
clear;
//Example 2.39
//Given
h=11.36     //W/sq m.K
k=43.3     //w/(m.K)
r=25.4     //radius in mm
r=r/1000     // radius in m
A=4*%pi*r^2     //Area of sphere [sq m]
V=A*r/3     //Volume in [cubic m]
rho=7849     //kg/cubic m
Cp=0.4606*10^3     //J/kg.K
t=1     //hour
t=t*3600     //seconds
T_inf=394.3     //[K]
T0=700     //[K]
// (T-T_inf)/(T0-T_inf)=e^(-3*h*t/rho*Cp*V)
```

```
T=T_inf+(T0-T_inf)*(%e^((-h*A*t)/(rho*Cp*V)));
printf("Temperature of ball after 1 h= %f K (%f degree C)",T,T-273)
```

Scilab code Exa 2.40 Slab temperature suddenly lowered

```
clc;
clear;
//Example 2.40
//Given
rho=9000; //kg/cubic m
Cp=0.38;  //kJ/(kg.K)
Cp=Cp*1000    //J/(kg.K)
k=370;    //W/m.K
h=90;     //W/sq m.K
l=400;    //mm
l=l/1000 ;   //length of copper slab
t=5/1000 ;   //thickness in [m]
A=2*l^2     //Area of slab
V=t*l^2       //Volume in [cubic m]
L_dash=V/A    //[m]
//for slab of thickness 2x
//L_dash=x
L_dash=0.025 ;   //[m]
Nbi=h*L_dash/k    //< 0.10
var=h*A/(rho*Cp*V)
//As Nbi<0.10,we can apply lumped capacity analysis
T=363    //[K]
T_inf=303    //[K]
T0=523    //[K]
t=-(log((T-T_inf)/(T0-T_inf)))/var
printf("Time at which slab temperature becomes 363 K is %f s",t)
printf("CALCULATION MISTAKE IN BOOK IN LAST LINE")
```

Scilab code Exa 2.41 Flow over a flat plate

```

clc;
clear;
//Example 2.41
//Given
rho=9000    //kg/cubic meter
Cp=0.38    //kJ/(kg.K)
Cp=Cp*1000    //J/kg.K
k=370    //W/(m.K)
T0=483    //K
T_inf=373    //K
delta_T=40    //K
T=T0-delta_T    //K
t=5    //time in [minutes]
t=t*60    //[seconds]
//A=2A.....Two faces
//V=A.2x
//2x=thickness of slab=30    mm=0.03    m
x=0.015    //[m]
th=2*x    //thickness of slab
h=-rho*Cp*x*log((T-T_inf)/(T0-T_inf))/t
printf("Heat transfer coefficient is: %f W/(sq m.K)"
   ,h)
```

Scilab code Exa 2.42 Stainless steel rod immersed in water

```

clear;
clc;
//Example 2.42
```

```
//Given
rho=7800    //[kg per cubic m]
h=100    //W/(sq m.K)  Convective heat transfer
   coeff
Cp=460    //J/(kg.K)
k=40    //W/(m.K)
L=1    //[m] length ofrod
D=10    //mm
D=D/1000    //diameter in[m]
R=D/2    //raidus in [m]
//For cylindrical rod:
A=2*%pi*R*L    //Area in [sq m]
V=%pi*R^2*L    //Volume in [cubic m]
L_dash=V/A    //[m]
Nbi=h*L_dash/k    //Biot number
//N_bi<0.10,Hence lumped heat capavity is possible
T=473    //[K]
T_inf=393    //[K]
T0=593    //[K]
t=-rho*Cp*V*log((T-T_inf)/(T0-T_inf))/(h*A)
printf("Time required to reach temperature %f is %f
   s",T,t);
```

Scilab code Exa 2.43 Chromel alumel thermocouple

```

clear;
clc;
//Example 2.43
//Given
rho=8600    //[kg/cubic m]
Cp=0.42    //kJ/(kg.K)
Cp=Cp*1000    //J/(kg.K)
dia=0.71    //[mm]
dia=dia/1000    //[dia in m]
```

```
R=dia/2    //radius [m]
h=600    //convective coeff W/(sq m.K)
//Let length =L=1
L=1          //[m]
A=2*%pi*R*L;
V=%pi*(R^2)*L;
tao=(rho*Cp*V)/(h*A);
printf(”Time constant of the thermocouple is %f s”, tao);
//at
t=tao
//From  (T−T_inf)/(T0−T_inf)=e^(−t/tao)
ratio=%e^(-t/tao)    //Ratio of thermocouple difference to initial temperature difference
printf(”At the end of the time period t=tao=%f s , Temperature difference b/n the thermocouple and the gas stream would be %f of the initial temperature difference”,tao,ratio);
printf(”\n It should be reordered after %f s”,4*tao);
```

Scilab code Exa 2.44 `Thermocouple junction`

```

clc;
clear;
//Example 2.44
rho=8000    //kg/cubic m
Cp=420    //J/(kg.K)
h_hot=60    // for hot stream W/(sq m.K)
dia=4    //[mm]
t=10;
r=dia/(2*1000)    //radius in [m]
//For sphere
V=(4/3)*%pi*r^3    //Volume in [cubic m]
```

```
A=4*%pi*r^2         //Volume in [sq m]
tao=rho*Cp*V/(h_hot*A)     // Time constant in [s]
ratio=%e^(-t/tao)     // %e^(-t/tao)=(T-T-inf)/(T0-T_inf)
T_inf=573     //[K]
T0=313     //[K]
T=T_inf+ratio*(T0-T_inf)
//ANS-[i]
printf("\n Answer: Time constant of thermocouple is %f s",tao);

//IN STILL AIR:
h_air=10     //W/(sq m .K)
tao_air=rho*Cp*V/(h_air*A)     //[s]
t_air=20     //[s]
ratio_air=%e^(-t_air/tao_air)
T_inf_air=303     //[K]
T0_air=T;
T_air=T_inf_air+ratio_air*(T0_air-T_inf_air)
//ANS-[ii]
printf("Temperature attained by junction 20 s after removing from the hot air stream is:%d K",round(T_air))
```

Scilab code Exa 2.45 `Batch reactor`

```
clc;
clear;
//Example 2.45
T_inf=390;                    //[K]
U=600;                        //[W/sq m.K]
Ac=1;                          //[sq m]
Av=10                            //Vessel area in [sq m]
m=1000;                       //[kg]
Cp=3.8*10^3;                 //[J/kg.K]
```

```
To=290;                    //[K]
T=360;                     //[K]
h=8.5                     //[W/sq m.K]
//Heat gained from the steam=Rate of increase of internal energy
//U*A*(T_inf-T)=m*Cp*dT
deff('[x]=f(t)','x=log((T_inf-To)/(T_inf-T))-U*Ac*t/(m*Cp)');
t=fsolve(1,f);            //[in s]
t=round(t)    //[in s]
Ts=290;
printf("\nTime taken to heat the reactants over the same temperature range is %f h",t);
function t1=g(T),t1=m*Cp/(U*Ac*(T_inf-T)-h*Av*(T-Ts)),endfunction
t1=intg(To,T,g);
deff('[m]=fx(Tmax)','m=U*Ac*(T_inf-Tmax)-h*Av*(Tmax-Ts)')
T_max=fsolve(1,fx)
printf("\nANS: In CASE 1\nTime  taken to heat the reactants = %f s .ie %f h \n",t,t/3600);
printf("\nANS: In CASE 2 \n Time  taken to heat the reactants = %f s\n",t1);
printf("\nANS.:  Maximum temperature at which temperature can be raised is %f K\n",T_max);
```

Scilab code Exa 2.46 Heat dissipation by aluminium rod

```

clc;
clear;
//Example 2.46
dia=3    //[mm]
dia=dia/1000    //[m]
r=dia/2    //radius in [m]
```

```
k=150    //W/(m.K)
h=300    //W/(sq m.K)
T0=413    //[K]
T_inf=288    //[K]
A=%pi*(r^2)    //Area in [sq m]
P=%pi*dia      //[W/sq m.K]
Q=(T0-T_inf)*sqrt(h*P*k*A)    //Heat dissipated in [W]
printf("Heat dissipated by the rod is %f W",Q)
```

Scilab code Exa 2.47 `Aluminium fin efficiency`

```

clc;
clear;
//Example 2.47
//Given
k=200    //W/(m.K)
h=15    //W/(sq m.K)
T0=523    //[K]
T_inf=288    //[K]
theta_0=T0-T_inf
dia=25    //diameter[mm]
dia=dia/1000    //diameter[m]
r=dia/2    //radius in [m]
P=%pi*dia    //[m]
A=%pi*r^2    //[sq m]
//For insulated fin:
m=sqrt(h*P/(k*A))
L=100    //length of rod in [mm]
L=L/1000    //length of rod in [m]
Q=theta_0*tanh(m*L)*sqrt(h*P*k*A)    //Heat loss
//ANSWER-1
printf("Heat loss by the insulated rod is %f W \n",Q)
```

```
nf=tanh(m*L)/(m*L)    //Fin efficiency for insulated fin
//ANSWER-2
printf("Fin efficiency is %f percent \n",nf*100)
//At the end of the fin: theta/theta_0=(cosh[m(L-x)]/cosh(mL))
//at x=L, theta/theta_0=1/(cosh(mL)
T=T_inf+(T0-T_inf)*(1/cosh(m*L))    //[K]
//ANSWER-3
printf("Temperature at the end of the fin is %f K \n",T)
```

Scilab code Exa 2.49 `Pin fins`

```

clc;
clear;
//Example 2.49
//Given
k=300    //W/(m.K)
h=20    //W.(sq m.K)
P=0.05    //[m]
A=2    //[sq cm]
A=A/10000    //[sq m]
T0=503    //[K]
T_inf=303    //[K]
theta_0=T0-T_inf    //[K]
m=sqrt(h*P/(k*A))
//CASE 1:  6 Fins of 100 mm length
L1=0.1    //Length of fin in [m]
Q=sqrt(h*P*k*A)*theta_0*tanh(m*L1)    //[W]
//For 6 fins
Q=Q*6    //for 6 fins [W]
//CASE 2:  10 fins of 60 mm length
L2=60    //[mm]
```

```
L2=L2/1000    //[m]
Q2=sqrt(h*P*k*A)*theta_0*tanh(m*L2);    //[W]
Q2=Q2*10    //For 10 fins
printf(”As,Q for 10 fins of 60 mm length( %f W) is more than Q for 6 fins of 100 mm length (%f W).\n The agreement-->10 fins of 60 mm length is more effective”,Q2,Q);
```

Scilab code Exa 2.50 `Metallic wall surrounded by oil and water`

```
clc;
clear;
//Example 2.50
//Given
h_oil=180    //W/(sq m.K)
h_air=15    //W/(sq m.K)
T_oil=353    //[K]
T_air=293    //[K]
delta_T=T_oil-T_air;    //[K]
k=80    //Conductivity in  [W/(m.K)]
for_section=11*10^-3    //[m]
L=25    //[mm]
L=L/1000    //[m]
W=1    //[m] Width,..let
t=1    //[mm]
t=t/1000    //[m]
A=W*t    //[m]
P=2*t
Af=2*L*W    //sq m
N=1
Ab=for_section-A    //[sq m]
//CASE 1: Fin on oil side only
m=sqrt(h_oil*P/(k*A))
nf_oil=tanh(m*L)/(m*L)
Ae_oil=Ab+nf_oil*Af*N    //[sq m]
```

```
Q=delta_T/(1/(h_oil*Ae_oil)+1/(h_air*for_section))   //[W]
printf("In oil side,Q=%f W\n",Q);
//CASE 2: Fin on  air side only
m=sqrt(h_air*P/(k*A))
nf_air=tanh(m*L)/(m*L)
nf_air=0.928        //Approximation
Ae_air=Ab+nf_air*Af*N     //[sq m]
Q=delta_T/(1/(h_oil*for_section)+1/(h_air*Ae_air))   //[W]
printf("In air side,Q=%f W",Q);
printf("\n From above results we see that more heat transfer takes place if fins are provided on the air side");
```

Scilab code Exa 2.51 `Brass wall`

```

clc;
clear;
//Example 2.51
//Given
k=75    //Thermal conductivity [W/(m.K)]
T_water=363    //[K]
T_air=303    //[K]
dT=T_water-T_air    //delta T
h1=150    // for water[W/(sq m.K)]
h2=15        //for air [W/(sq m.K)]
W=0.5    //Width of wall[m]
L=0.025    //[m]
Area=W^2    //Base Area [sq m]
t=1    //[mm]
t=t/1000    //[m]
pitch=10    //[mm]
pitch=pitch/1000    //[m]
```

```
N=W/pitch    //[No of fins]
//Calculations
A=N*W*t    //Total cross-sectional area of fins    in [sq m]
Ab=Area-A    //[sq m]
Af=2*W*L    //Surface area of fins    [sq m]

//CASE 1: HEAT TRANSFER WITHOUT FINS
A1=Area    //[sq m]
A2=A1    //[sq m]
Q=dT/(1/(h1*A1)+1/(h2*A2));        //[W]
printf("\nWithout fins,Q=%f W\n",Q);
//CASE 2: Fins on the water side
P=2*(t+W);
A=0.5*10^-3;
m=sqrt(h1*P/(k*A))
nfw=tanh(m*L)/(m*L)    //Effeciency on water side
Aew=Ab+nfw*Af*N    //Effective area on the water side    [sq m]
Q=dT/(1/(h1*Aew)+1/(h2*A2));        //[W]
printf("\n With fins on water side,Q=%f W \n",Q);
//CASE 3: FINS ON THE AIR SIDE
m=sqrt(h2*P/(k*A))
nf_air=tanh(m*L)/(m*L)    //Effeciency
Aea=Ab+nf_air*Af*N    //Effective area on air side
Q=dT/(1/(h1*A1)+1/(h2*Aea));        //[W]
printf("\n With Fins on Air side,Q=%f W \n",Q)
//BOTH SIDE:
Q=dT/(1/(h1*Aew)+1/(h2*Aea));        //[W]
printf("\n With Fins on both side,Q=%f W \n",Q);
```

Chapter 3

Convection

Scilab code Exa 3.1 `Boundary layer thickness`

```
clc;
clear;
//Example 3.1
mu=10^-3          //N.s/m^2
//At distance y from surface
//ux=a+by+cy^2+dy^3
//At y=0,ux=0 therefore a=0
//i.e tao=0
//At edge of boundary layer,ie y=del
//ux=u_inf
//At y=o,c=0
//At y=del,ux=b*del+d*del^3

//Therefore, b=-3*d*del^3
//d=-u_inf/(2*del^2)
//b=3*u_inf/(2*del)

//For velocity profile,we have:
//del/x=4.64*(Nre_x)^(-1/2)

//Evaluate N re_x
```

```
x=75;          //[mm]
x=x/1000;          //[m]
u_inf=3;              //[m/s]
rho=1000              //[kg/m^3] for air
Nre_x=u_inf*rho*x/mu          //Reynold number
//Substituting the value,we get
del=x*4.64*(Nre_x^(-1/2))        //[m]
printf("\nBoundary layer thickness is del=%f m or %f
    mm",del,del*1000);
printf("\nWrong units in answer of book,m and mm are
    wrongly interchanged");
```

Scilab code Exa 3.2 Boundary layer thickness of plate

```
clc;
clear;
//Example3.2
//Given
mu=15*10^-6     //sq m /s
v=2     //m/s
L=2     //[m] length of plate
Nre_x=3*10^5
xc=Nre_x*mu/v     //critical length at whihc the
   transition takes place
//Since xc is less than 2 m.Therefore the flow is
   laminar
//at any distance x,.it is calculated from
//del/x=4.64/(sqrt(NRe,x))
//At x=L=2 m
Nre_l=v*L/mu
del_l=4.64*L/sqrt(Nre_l)
del_l=del_l*1000     //[mm]
printf("Boundary layerthickness at the trailing edge
    is %f mm",del_l);
```

Scilab code Exa 3.3 Thickness of hydrodynamic boundary layer

```
clc;
clear;
//Example 3.3
//Given
mu=15*10^-6     //Kinematic viscosity in [sq m /s]
x=0.4     //[m]
u_inf=3     //[m/s]
//At x=0.4 m,
Nre_x=u_inf*x/mu    ;
printf("Since Nre,x (%f)is Less than 3*10^5,..the boundary layer is laminar",Nre_x);
del=4.64*x/sqrt(Nre_x)     //[m]
del=del*1000     //[mm]
printf("\nThickness of boundary layer at x=%f m =%f mm\n",x,del);
Cf_x=0.664/sqrt(Nre_x);
printf("Local skin friction coefficient is :%f",Cf_x);
```

Scilab code Exa 3.4 Flat plate boundary layer

```
clc;
clear;
//Example 3.4
mu=1.85*10^-5               //[kg/(m.s)]
P=101.325;                   //Pressure in [kPa]
M_avg=29;                    //Avg molecular wt of air
R=8.31451;                   //Gas constant
T=300;                       //[K]
```

```
rho=P*M_avg/(R*T)    //[kg/m^3]
u_inf=2              //Viscosity in [m/s]
//At x=20 cm =0.2 m
x=0.2;                         //[m]
Nre_x=rho*u_inf*x/mu           //[Reynolds number]
del_by_x=4.64/sqrt(Nre_x)      //[Boundary layer]
del=del_by_x*x                 //[m]
//del=del*1000                    //[mm]

//At
x=0.4 ;              //[m]
Nre_x=(rho*u_inf*x)/mu         //<3*10^5
//Boundary layer is laminar
del_by_x=4.64/sqrt(Nre_x)
del1=del_by_x*x                  //[m]
//del1=del1*1000                    //[mm]
d=del1-del                          //Del
function m_dot=f(y),m_dot=u_inf*(1.5*(y/d)-0.5*(y/d)^3)*rho,endfunction
m_dot=intg(0,d,f)
printf(”\nBoundary layer thickness at distance 20 cm from leading edge is %f m=%f mm\n”,del,del*1000);
printf(”\nBoundary layer thickness at distance 40 cm from leading edge is %f m=%f mm\n”,del1,del1*1000);
printf(”\nThus,Mass flow rate entering the boundary layer is %f kg/s”,m_dot);
```

Scilab code Exa 3.5 `Rate of heat removed from plate`

```

clc;
clear;
//Example 3.5
```

```
//Given
mu=3.9*10^-4     //Kinematic viscosity in sq m/s
k=36.4*10^-3     //Thermal conductivity in W/(m.K)
Npr=0.69
u_inf=8     //[m/s]
L=1     //Lenght of plate in [m]
Nre_l=u_inf*L/mu
//Since Nre_l is less than 3*10^5 ,the flow is
   laminar over the entire length of plate
Nnu=0.664*sqrt(Nre_l)*Npr^(1.0/3.0)     //=hL/k

h=k*Nnu/L     //w/sq m.K
h=3.06       //Approximation    [W/sq m.K]
T_inf=523     //[K]
Tw=351     //[K]
W=0.3     //Width of plate [m]
A=W*L     //Area in [sq m]
Q=h*A*(T_inf-Tw)     // Rate of heat removal from one
    side in [W]
printf("\nRate of heat removal is %f W\n",Q)
//from two side:
Q=2*Q     //[W]
printf("\n %f W heat should be removed continously
   from the plate",Q);
```

Scilab code Exa 3.6 Heat removed from plate

```

clc;
clear;
//Example 3.6
P1=101.325     //Pressure in [kPa]
mu1=30.8*10^-6     //Kinematic viscosity in[sq m /s]
k=36.4*10^-3     //[W/(m.K)]
Npr=0.69
```

```
u_inf=8    //Velocity in [m/s]
Cp=1.08    //kJ/(kg.K)
L=1.5    //Length of plate in [m]
W=0.3    //Width in [m]
A=L*W    //Area in [sq m]
//At constant temperature: mu1/mu2=P2/P1
P2=8     //[kPa]
mu2=mu1*P1/P2    //Kinematic viscosity at P2 in [sq m/s]
Nre_l=u_inf*L/mu2    //Reynold's no.
//Since this is less than 3*10^5
Nnu=0.664*sqrt(Nre_l)*(Npr^(1.0/3.0))
h=Nnu*k/L  // Heat transfer coeffficient in [W/sq m.K]
h=2.5       //Approximation in [W/sq m.K]
T_inf=523    //[K]
Tw=353    //[K]
Q=2*h*A*(T_inf-Tw)    //Heat removed from both sides in [W]
printf(”Rate of heat removed from both sides of plate is %f W”,Q);
```

Scilab code Exa 3.7 `Local heat transfer coefficient`

```
clc;
clear;
//Example 3.7
rho=0.998    //kg/cubic m
v=20.76*10^-6    //[sq m/s]
Cp=1.009    //[kJ/kg.K]
k=0.03    //[W/m.K]
u_inf=3    //[m/s]
x=0.4    //[m]
w=1.5    //[m]
Nre_x=u_inf*x/v    //Reynolds no at x=0.4 m
```

```
//Since this is less than 3*10^5.The flow is laminar upto x=0.4 m
mu=rho*v  //[kg/(m.s)]

Cp=1.009    //[kJ/kg.K]
Cp=Cp*1000    //[J/kg.K]
k=0.03    //W/(m.K)
Npr=Cp*mu/k
Nnu_x=0.332*(sqrt(Nre_x))*(Npr^(1.0/3.0))
hx=Nnu_x*k/x    //[W/(m.K)]
//Average value is twice this value
h=2*hx    //[W/(m.K)]
h=10.6      //Approximation
A=x*w    //Area in [sq m]
Tw=407    //[k]
T_inf=293    //[K]
Q=h*A*(Tw-T_inf)     //[W]
//From both sides of the plate:
Q=2*Q    //[W]
printf("The heat transferred from both sides of the plate is %d W",round(Q));
```

Scilab code Exa 3.8 `Width of plate`

```
clc;
clear;
//Example 3.8
rho=0.998    //[kg/cubic m]
v=20.76*10^-6    //[sq m/s]
k=0.03    //[W/m.K]
Npr=0.697
x=0.4    //[m] from leading edge of the plate
u_inf=3    //[m/s]
Nre_x=u_inf*x/v    //Reynold numebr at x=0.40 m
//Since this is less than 3*10^5
```

```
//therefore flow is laminar and
Nnu_x=0.332*sqrt(Nre_x)*(Npr^(1.0/3.0));
hx=Nnu_x*k/x     //[W/sq m.K]
//Average heat tarnsfer coefficient is twice this value
h=2*hx     //[W/sq m.K]
//Given:
Q=1450     //[W]
Tw=407     //[K]
T_inf=293     //[K]
L=0.4     //[m]
//Q=h*w*L*(Tw-T_inf)
//L=Q/(h*w*(Tw-T_inf))
w=Q/(h*L*(Tw-T_inf))     //[m]
printf("\n Width of plate is %f m",w);
```

Scilab code Exa 3.9 `Heat transferred in flat plate`

```

clc;
clear;
//Example 3.9
v=17.36*10^-6     //Viscosity for air     [sq m./s]
k=0.0275     //for air ..[W/(m.K)]
Cp=1.006     //[kJ/(kg.K)]
Npr=0.7     //for air
u_inf=2     //[m/s]
x=0.2     //[m]
Nre_x=u_inf*x/v     //Reynolds number at x=0.2     m
//Since this is less than 3*10^5
Nnu_x=0.332*sqrt(Nre_x)*(Npr^(1.0/3.0))
hx=Nnu_x*k/x     //[W/(sq m.K]
//Average value of heat transfer coeff is twice this value
h=2*hx     //[W/sq m.K)]
```

```
h=12.3       //Approximation
w=1     //width in [m]
A=x*w     //[sq m] Area of plate
Tw=333     //[K]
T_inf=300     //[K]
Q=h*A*(Tw-T_inf)     //Heat flow in [W]
printf("\nANSWER:\nHeat flow is :%f W\n",Q)
//From both sides of plate:
Q=2*Q     //[W]
printf("\nANSWER\n Heat flow from both sides of plate is %f W",Q);
```

Scilab code Exa 3.10 `Rate of heat transferred in turbulent flow`

```
clc;
clear;
//Example 3.10
v=16.96*10^-6     //[sq m./s]
rho=1.128     //[kg/cubic m]
Npr=0.699     //Prandtl number
k=0.0276     //[W/m.K]
u_inf=15     //[m/s]
L=0.2     //[m]
Nre_l=L*u_inf/v     //Reynold's number
//Since this is less than 3*10^5,the boundary layer is laminar over entire length
Nnu=0.664*sqrt(Nre_l)*(Npr^(1.0/3.0))
h=Nnu*k/L     //[W/sq m.K]
A=L^2     //Area in [sq m]
Tw=293     //[K]
T_inf=333     //[K]
//Rate of heat transfer from BOTH sides is:
Q=2*h*A*(T_inf-Tw)     //[W]
printf("Rate of heat transfer from both sides of plate is %f W\n",Q);
```

```
//ii-With turbulent boundary layer from the leading edge:
h=k*0.0366*(Nre_l^(0.8))*(Npr^(1.0/3.0))/L        //[W/(sq m.K)]
//Heat transfer from both sides is :
Q=2*h*A*(T_inf-Tw)                 //[W]
printf("\nThese calculations sho that the that transfer rate is approximately doubled if boundary layer is turbulent from the leading edge\n");
```

Scilab code Exa 3.11 `Heat transfer from plate in unit direction`

```
clc;
clear;
//Example 3.11
mu=1.906*10^-5     //[kg/(m.s)]
k=0.02723     //W/m.K
Cp=1.007     //[kJ/(kg.K)]
rho=1.129     //[kg/cubic m]
Npr=0.70
Mavg=29
u_inf=35     //[m/s]
L=0.75     //[m]
Tm=313     //[K]
P=101.325     //[kPa]
Nre_l=rho*u_inf*L/mu     //Reynold's number >5*10^5
Nnu=0.0366*Nre_l^(0.8)*Npr^(1.0/3.0);
h=Nnu*k/L     //[W/s m.K]
A=1*L     //[sq m]
Tw=333     //[K]
T_inf=293     //[K]
Q=h*A*(Tw-T_inf);     //[W]
printf("Heat transfer from the plate is %f W",Q);
```

Scilab code Exa 3.12 `Heat lost by sphere`

```
clc;
clear;
//Example 3.12
v=18.23*10^-6     //sq m/s
k=0.02814     //[W/m.K]
D=0.012     //[m]
r=0.006     //[m]
u_inf=4     //[m/s]
Nre=D*u_inf/v     //Reynold's number
Nnu=0.37*Nre^(0.6);
h=Nnu*(k/D)
A=4*%pi*r^2     //Area of sphere in [sq m]
Tw=350     //[K]
T_inf=300     //[K]
Q=h*A*(Tw-T_inf)     //Heat lost by sphere in [W]
printf("\n Heat lost by sphere is %f W",Q);
```

Scilab code Exa 3.13 `Heat lost by sphere`

```
clc;
clear;
//Exmaple 3.13
v=15.69*10^-6     //[sq m./s]
k=0.02624     //[W/m.K]
Npr=0.708     //Prandtl number
mu=2.075*10^-5     //kg/m.s
u_inf=4     //[m/s]
mu_inf=1.8462*10^-5     //[m/s] velocity
Tw=350     //[K]
T_inf=300     //[K]
```

```
D=0.012     //[m]
r=D/2     //Radius in [m]
Nre=u_inf*D/v     //Reynold's numbe
Nnu=2+(0.4*Nre^(1.0/2.0)+0.06*Nre^(2.0/3.0))*Npr
   ^(0.4)*(mu_inf/mu)^(1.0/4.0)
h=Nnu*k/D     //[W/sq m.K]

A=4*%pi*r^2     //Area in [sq m]
Q=h*A*(Tw-T_inf);
printf("\n Heat lost by the sphere is %f W",Q);
```

Scilab code Exa 3.14 Percent power lost in bulb

```
clc;
clear;
//Example 3.14
v=2.08*10^-5     //[sq m/s]
k=0.03     //W/(m.K)
Npr=0.697     //Prandtl number
D=0.06     //[m]
u_inf=0.3     //[m/s]
Nre=D*u_inf/v     //Reynolds number
//Average nusselt number is given by:
Nnu=0.37*(Nre^0.6);
h=Nnu*k/D     //W/sq m.K
Tw=400     //[K]
T_inf=300     //[K]
D=0.06     //[m]
r=0.03     //[m]
A=4*%pi*r^2     //Area in [sq m]
Q=h*A*(Tw-T_inf)     //[W]
per=Q*100/100     //Percent of heat lost by forced
   convection
printf("Heat transfer rate is %f W,And percentage of
    power lost by convectio is: %f percent ",Q,per);
```

Scilab code Exa 3.15 `Heat lost by cylinder`

```

clc;
clear;
//Example 3.15
u_inf=50    //velocity in [m/s]
mu=2.14*10^-5    //[kg/(m.s)]
rho=0.966    //[kg/cubic m]
k=0.0312    //[W/(m.K)]
Npr=0.695    //Prandtl number
D=0.05    //Diameter in [m]
Nre=D*u_inf*rho/mu ;  //Reynold's number
printf("%f",Nre)
Nnu=0.0266*Nre^0.805*Npr^(1/3);
h=Nnu*k/D   ; //W/sq m.K
h=171.7     //Approximation
printf("\n%f",h)
Tw=423    //[K]
T_inf=308    //[K]
//Heat loss per unit length is :
Q_by_l=h*%pi*D*(Tw-T_inf);  //[W]
printf("Heat lost per unit length of cylinder is %f W(approx)",round(Q_by_l));
```

Scilab code Exa 3.16 `Heat transfer in tube`

```

clc;
clear;
//Example 3.16
```

```
v=20.92*10^-6    //sq m/s
k=3*10^-2    //W/(m.K)
Npr=0.7
u_inf=25    //[m/s]
d=50    //[mm]
d=d/1000    //[m]
Nre=u_inf*d/v    //Reynold's number
Tw=397    //[K]
T_inf=303    //[K]

//Case 1: Circular tube

Nnu=0.0266*Nre^(0.805)*Npr^(1.0/3.0);
h=Nnu*k/d    //[W/sq m.K]
A=%pi*d    //Area in [sq m]
Q=h*A*(Tw-T_inf)    //[W]
Q_by_l1=h*%pi*d*(Tw-T_inf)    //[W/m]

//Case 2:Square tube
A=50*50    //Area in [sq mm]
P=2*(50+50)    //Perimeter [mm]
l=4*A/P       //[mm]
l=l/1000       //[m]
Nnu=0.102*(Nre^0.675)*(Npr^(1.0/3.0))
h=Nnu*k/d    //W/(sq m.K)
A=4*l*l       //[sq m]

Q=h*A*(Tw-T_inf)
Q_by_l2=Q/l    //[W/m]
printf("\nRate of heat flow from the square pipe=%f W/m  \n which is more than that from the circular pipe which is equal to %f W/m",Q_by_l2,Q_by_l1);
```

Scilab code Exa 3.17 `Heat transfer coefficient`

```

clc;
clear;
//Example 3.17
mu=0.8    //Viscosity of flowing fluid [N.s/sq m]
rho=1.1    //Density of flowinf fluid [g/cubic cm]
rho=rho*1000    //Density in [kg/cubic m]
Cp=1.26    //Specific heat [kJ/kg.K]
Cp=Cp*10^3    // in[J/(kg.K)]
k=0.384    //[W/(m.K)]
mu_w=1    //Viscosity at wall temperature [N.s/sq m]
L=5    //[m]
vfr=300    //Volumetric flow rate in [cubic cm/s]
vfr=vfr*10^-6    //[cubic m/s]
mfr=vfr*rho    //Mass flow rate of flowinf fluid [kg/s]
Di=20    //Inside diameter in[mm]
Di=Di/1000    //[m]
Area=(%pi/4)*Di^2    //Area of cross-section [sq m]
u=vfr/Area    //Veloctiy in [m/s]
Nre=Di*u*rho/mu    //Reynold's number
//As reynold's number is less than 2100,he flow is laminar
Npr=Cp*mu/k    //Prandtl number
Nnu=1.86*(Nre*Npr*Di/L)^(1.0/3.0)*(mu/mu_w)^(0.14)
hi=Nnu*k/Di    //inside heat transfer coefficient [W/sq m.K]
printf("Inside heat transfer coefficient is %f W/(sq m.K)",hi);
//Note:
printf("\n The answer given in book..ie 1225 is wrong.please redo the calculation of last line manually to check\n");
```

Scilab code Exa 3.18 Heat transfer coefficient in heated tube

```
clc;
clear;
//Example 3.18
m=5500    //Mass flow rate in [kg/h]
m=m/3600    //[kg/s]
rho=1.07    //Density of fluid in [g/cm^3]
rho=rho*1000    //[kg/m^3]
vfr=m/rho    //Volumetric flow rate in [m^3/s]
Di=40    //Diameter of tube [mm]
Di=Di/1000    //[m]
A=(%pi/4)*Di^2    //Area of cross-section in [sq m]
u=vfr/A    //Velocity of flowing fluid    [m/s]
rho=1070    //Density in [kg/m^3]
mu=0.004    //Viscosity in [kg/m.s]
Nre=Di*u*rho/mu
Nre=12198       //Approx
//Since this reynold's number is less than 10000,the flow is turbulent
Cp=2.72    //Specific heat in [kJ/kg.K]
Cp=Cp*10^3    //Specific heat in [J/kg.K]
k=0.256    //thermal conductivity in [W/m.K]
Npr=Cp*mu/k    //Prandtl number
Nnu=0.023*(Nre^0.8)*(Npr^0.4)    //Nusselt number
hi=k*Nnu/Di    //Inside heat transfer coefficient in [W/m^2.K]
printf("Inside heat transfer coefficient is %f W/sq m.K",hi);
```

Scilab code Exa 3.19 `h of water flowing in tube`

```

clc;
clear;
//Example 3.19

```

```
//DATA:
rho=984.1     //Density of water [kg/m^3]
Cp=4187     //Specific heat in [J/kg.K]
mu=485*10^-6     //Viscosity at 331 K[Pa.s]
k=0.657     //[W/(m.K)]
mu_w=920*10^-6     //Viscosity at 297 K [Pa.s]
//Solution
D=16     //Diameter in [mm]
D=D/1000     //Diameter in [m]
u=3     //Velocity in [m/s]
rho=984.1     //[kg/m^3]
Nre=D*u*rho/mu     //Reynolds number
Nre=round(Nre)
Npr=Cp*mu/k     //Prandtl number

//Dittus-Boelter equation (i)
Nnu=0.023*(Nre^0.8)*(Npr^0.3)     //nusselt number
h=k*Nnu/D     //Heat transfer coefficient [W/m^2.K]
printf("\nANSWER-(i) \nBy Dittus-Boelter equation we get h=%f W/sq m.K\n\n\n",h);

//sieder-tate equation (ii)
Nnu=0.023*(Nre^0.8)*(Npr^(1.0/3.0))*((mu/mu_w)^0.14)     //Nusselt number
h=k*Nnu/D     //Heat transfer coefficient in [W/sq m.K]
printf("\nAnswer-(ii)\n-By Sieder-Tate equation we get h=%f W/sq m.K\n",h);
printf("\nNOTE:Calculation mistake in book in part 2 ie sieder tate eqn\n")
```

Scilab code Exa 3.20 `Overall heat transfer coefficient`

```
clc;
clear;
```

```
//Example 3.20
m_dot=2250    //Mass flow arte in [kg/h]
Cp=3.35    //Specific heat in [kJ/(kg.K)]
dT=316-288.5    //Temperature drop for oil    [K]
Q=Cp*m_dot*dT    //Rate of heat transfer in [kJ/h]
Q=round(Q*1000/3600)    //[J/s] or [W]
Di=0.04    //Inside diameter [m]
Do=0.048    //Outside diamter in [m]
hi=4070    //for steam [W/sq m.K]
ho=18.26    //For oil [W/sq m.K]
Rdo=0.123    //[sq m.K/W]
Rdi=0.215    //[sq m.K/W]
Uo=1/(1/ho+Do/(hi*Di)+Rdo+Rdi*(Do/Di))    //[W/m^2.K]
Uo=2.3
dT1=373-288.5    //[K]
dT2=373-316    //[K]
dTm=(dT1-dT2)/log(dT1/dT2)    //[K]
Ao=Q/(Uo*dTm)    //Heat transfer area in [m^2]
printf("Heatr transfer area is:%f m^2",Ao);
```

Scilab code Exa 3.21 `Number of tubes in exchanger`

```

clc;
clear;
//Example 3.21
k_tube=111.65    //[W/m.K]
W=4500    //[kg/h]
rho=995.7    //[kg/sq m]
Cp=4.174    //[kJ/(kg.K)]
k=0.617    //[W/(m.K)]
v=0.659*10^-6    //Kinematic viscosity [sq m/s]
m_dot=1720    //kg/h
T1=293    //Initial temperature in [K]
```

```
T2=318    //Final temperature in [K]
dT=T2-T1    //[K]
Q=m_dot*Cp*dT    //Heat transfer rate in [kJ/h]
Q=Q*1000/3600    //[J/s] or [W]
Di=0.0225    //[m]
u=1.2    //[m/s]
//Nre=Di*u*rho/mu or
Nre=Di*u/v    //Reynolds number
//As Nre is greater than 10000,Dittus Boelter equation is applicable
Cp=Cp*10^3    //J/(kg.K)
mu=v*rho    //[kg/(m.s)]
Npr=Cp*mu/k    //Prandtl number
//Dittus-Boelter equation for heating is
Nnu=0.023*(Nre^0.8)*(Npr^0.4)
hi=k*Nnu/Di    //Heat transfer coefficient  [W/(sq m.K)]
Do=0.025    //[m]
Dw=(Do-Di)/log(Do/Di)    //Log mean diameter in [m]
ho=4650    //[W/sq m.K]
k=111.65    //[W/m.K]
xw=(Do-Di)/2    //[m]
Uo=1/(1/ho+Do/(hi*Di)+xw*Do/(k*Dw))    //Overall heat transfer coefficient in W/(m^2.K)
T_steam=373    //Temperature of condensing steam in [K]
dT1=T_steam-T1+10    //[K]
dT2=T_steam-T2+10    //[K]
dTm=(dT1-dT2)/log(dT1/dT2)    //[K]
Ao=Q/(Uo*dTm)//Area in [m^2]
L=4    //length of tube [m]
n=Ao/(%pi*Do*L)    //number of tubes
printf("No. of tubes required=%d\n",round(n));
printf("\n NOTE: there is an error in book in calculation of dT1 and dT2,\n 373-293 is written as 90,instead of 80...similarly in dT2,\nSo,in compliance with the book,10 is added to both of them")
```

Scilab code Exa 3.22 `Convective film coefficient`

```
clc;
clear;
//Example 3.22
m_dot=25000     //massflow rate of water [kg/h]
rho=992.2     //[kg/m^3]
k=0.634     //[W/m.K]
vfr=m_dot/rho     //[m^3/h]
Npr=4.31     //Prandtl numberl
Di=50     //[mm]
Di=0.05     //[m]
dT=10     //[K] as the wall is at a temperature of 10 K above the bulk temperature
u=(vfr/3600)/(%pi*(Di/2)^2)     //Velocity of water in [m/s]
u=3.56          //Approximation
//Nre=Di∗u∗rho/mu=Di∗u/v     as v=mu/rho
v=0.659*10^-6;     //[m^2/s]
Nre=Di*u/v     //Reynolds number
//As it is less than 10000,the flow is in the turbulent region for heat transfer and Dittus Boelter eqn is used
Nnu=0.023*(Nre^0.8)*(Npr^0.4);     //Nusselt number
hi=Nnu*k/Di     //Heat transfer coefficiet in [W/sq m.K]
q_by_l=hi*%pi*Di*dT    //Heat transfer per unit length[kW/m]
printf(”Average value of convective film coefficient is hi= %d W/sq m.K \nHeat transferred per unit length is Q/L=%f kW/m”,round(hi),q_by_l/1000);
```

Scilab code Exa 3.23 `Length of tube`

```
clc;
clear;
//Example 3.23
vfr=1200  ;  //Water flow rate in [l/h]
rho=0.98 ;   //Density of water in g/[cubic cm]
m_dot=vfr*rho    //Mass flow rate of water [kg/h]
m_dot2=m_dot/3600    //[kg/s]
Cp=4.187*10^3 ;   //[J/kg.K]
Di=0.025  ;  //Diameter in [m]
mu=0.0006 ;   //[kg/(m.s)]
Ai=%pi*((Di/2)^2)    //Area of cross-section in [m
   ^2]
Nre=(Di/mu)*(m_dot2/Ai)    //Reynolds number
k=0.63 ; //for metal wall in [W/(m.K)]
Npr=Cp*mu/k;    //Prandtl number
//Since Nre>10000
//therefore ,Dittus boelter eqn for heating is
Nnu=0.023*(Nre^(0.8))*(Npr^(0.4))
ho=5800   ; //Film heat coefficientW/(m^2.K)
hi=Nnu*k/Di    //Heat transfer coeffcient in [W/(sq
   m.K)]
Do=0.028 ;   //[m]
Di=0.025 ;   //[m]
xw=(Do-Di)/2;    //[m]
Dw=(Do-Di)/log(Do/Di);    //[m]
k=50  ;  //for metal wall in [W/(m.K)]
Uo=1/(1/ho+Do/(hi*Di)+xw*Do/(k*Dw));    //in [W/sq m
   .K]
dT=343-303 ; //[K]
dT1=393-303 ;   //[K]
dT2=393-343 ;   //[K]
dTm=(dT1-dT2)/log(dT1/dT2);    //[K]
Cp=Cp/1000;  //[in [kJ/kg.K]]
Q=m_dot*Cp*dT;    //Rate of heat transfer in [kJ/h]
Q=Q*1000/3600;    //[J/s] or [W]
Ao=Q/(Uo*dTm);    //Heat transfer area in [sq m]
```

```
//Also ,..Ao=%pi*Do*L     ..implies that
L=Ao/(%pi*Do)     //[m]
printf(”Length of tube required is %f m”,round(L));
```

Scilab code Exa 3.24 `Cooling coil`

```
clc;
clear;
//Example 3.24
//1.For initial conditions:
T=360;              //[K]
T1=280;            //[K]
T2=320;            //[K]
dT1=T-T1;          //[K]
dT2=T-T2;          //[K]
//Q1=m1_dot*Cp1*(T2-T1)
Cp1=4.187              //Heat capacity
dTlm=(dT1-dT2)/log(dT1/dT2) //[K]
m1_by_UA=dTlm/(Cp1*(T2-T1))
//For final conditions :
//m2_dot=m1_dot
//U2=U1
//A2=5*A1
deff(’x=f(t)’,’x=m1_by_UA*Cp1*(t-T1)-5*((dT1-(T-t))/log(dT1/(T-t)))’)
T=fsolve(350.5,f)
printf(”\nOutlet temperature of water is %f K\n”,T);
```

Scilab code Exa 3.25 `Outlet temperature of water`

```
clc;
clear;
//Example 3.25
```

```
mo_dot=60   //Mass flow rate of oilin [g/s]
mo_dot=6*10^-2  //[kg/s]
Cpo=2.0     //Specific heat of oil in [kJ/(kg.K)]
T1=420  //[K]
T2=320  //[K]
Q=mo_dot*Cpo*(T1-T2)    //Rate of heat flow in [kJ/s]
mw_dot=mo_dot   //Mass flow rate of water   //kg/s
t1=290  //[K]
Cpw=4.18    //[kJ/(kg.K)]
//For finding outlet temperature of water
t2=t1+Q/(mw_dot*Cpw)    //[K]
dT1=T1-t2   //[K]
dT2=T2-t1   //[K]
dTm=(dT1-dT2)/log(dT1/dT2)  //[K]
ho=1.6  //Oil side heat transfer coefficient in [kW/(sq m.K)]
hi=3.6  //Water side heat transfer coeff in [kW/(sq m.K)]
//Overall heat transfer coefficient is:
U=1/(1/ho+1/hi) //[kW/(m^2.K)]

A=Q/(U*dTm) //[sq m]
Do=25   //[mm]
Do=Do/1000  //[m]
L=A/(%pi*Do)    //Length of tube in [m]
printf("\nOutlet temperature of water is %f K \n",round(t2));
printf("Area of heat transfer required is %f sq m\n",A);
printf("Length of tube required is %f m",L)
```

Scilab code Exa 3.26 `Inside heat transfer coefficient`

```

```

```
clc;
clear;
//Example 3.26
k=0.14   // for oil [W/m.K]
Cp=2.1 // for oil [kJ/kg.K]
Cp=Cp*10^3  //J/kg.K
mu=154   //[mN.s/sq m]
mu_w=87 //(mn.s/sq m)
L=1.5    //[m]
m_dot=0.5   //Mass flow rate of oil[kg/s]
Di=0.019 //Diameter of tube [m]
mean_T=319  //Mean temperature of oil [K]
mu=mu*10^-3 //[N.s/sq m] or [kg/(m.s)]
A=%pi*(Di/2)^2   //[sq m]
G=m_dot/A   //Mass velocity in [kg/sq m.s]
Nre=Di*G/mu  //Reynolds number
//As Nre<2100,the flow is laminar
mu_w=mu_w*10^-3 //[N.s/sq m] or kg/(m.s)
//The sieder tate equation is
hi=(k*(2.0*((m_dot*Cp)/(k*L))^(1.0/3.0)*(mu/mu_w)
   ^(0.14)))/Di   //Heat transfer coeff in [W/sq m.K
   ]
printf("\n The inside heat transfer coefficient is
   %f W/(m^2.K) ",hi);

printf('\nNOTE:Calculation mistake in last line.ie
   in the calculation of hi in book,please perform
   the calculation manually to check the answer\n")
```

Scilab code Exa 3.27 Film heat transfer coefficient

```
clc;
clear;
//Example 3.27

```

```
m_dot=0.217 //Water flow rate in [kg/s]
Do=19   //Outside diameter in [mm]
rho=1000    //Density
t=1.6   //Wall thickness in [mm]
Di=Do-2*t   //i.d of tube in [mm]
Di=Di/1000  //[m]
Do=Do/1000  //[m]
Ai=%pi*(Di/2)^2 //Cross-sectional area in sq m
u=m_dot/(rho*Ai)  //Water velocity through tube  [m/s]
u=1.12  //approx in book
Di=0.0157   //apprx in book
T1=301  //Inlet temperature of water in [K]
T2=315  //Outlet temperature of water in [K]
T=(T1+T2)/2 //[K]
hi=(1063*(1+0.00293*T)*(u^0.8))/(Di^0.20) //Inside heat transfer coefficient W/(sq m.K)
hi=5084     //Approximation
printf("%f",hi);
hio=hi*(Di/Do)  //Inside heat transfer coeff based on outside diameter  in W/(sq m.K)
printf("%f",hio);
printf("Based on outside temperature,Inside heat transfer coefficient is  %d W/(m^2.K) or %f kW/(m^2.K)",round(hio),round(hio)/1000);
```

Scilab code Exa 3.28 `Area of exchanger`

```
clc;
clear;
//Example 3.28
mair_dot=0.90   //[kg/s]
T1=283  //[K]
T2=366  //[K]
dT=(T1+T2)/2    //[K]
```

```
Di=12   //[mm]
Di=Di/1000  //[m]
G=19.9  //[kg/(sq m.s)]
mu=0.0198   //[mN.s/(sq m)]
mu=mu*10^-3 //[N.s/sq m] or [kg/(m.s)]
Nre=Di*G/mu //Reynolds number
//It is greater than 10^4
k=0.029 //W/(m.K)
Cp=1    //[kJ/kg.K]
Cp1=Cp*10^3  //[J/kg.K]
Npr=Cp1*mu/k //Parndtl number
//Dittus-Boelter equation is
hi=0.023*(Nre^0.8)*(Npr^0.4)*k/Di   //[W/sq m.K]
ho=232  //W/sq m.K
U=1/(1/hi+1/ho) //Overall heat transfer coefficient
    [W/m^2.K]
Q=mair_dot*Cp*(T2-T1)   //kJ/s
Q=Q*10^3    //[J/s] or [W]
T=700   //[K]
dT1=T-T2    //[K]
dT2=T2-T1   //[K]
dTm=(dT1-dT2)/log(dT1/dT2)  //[K]
//Q=U*A*dTm
A=Q/(U*dTm) //Area in sq m
printf("Heat transfer area of equipment is %f sq m",
   A);
```

Scilab code Exa 3.29 Natural and forced convection

```
clc;
clear;
//Example 3.29
v=18.41*10^-6   //[sq m./s]
k=28.15*10^-3   //[W/m.K]
Npr=0.7 //Prandtl number
```

```
Beta=3.077*10^-3     //K^-1
g=9.81   //m/s^2
Tw=350   //[K]
T_inf=300    //[K]
dT=Tw-T_inf  //[K]
L=0.3    //[m]
//1.Free Convection
Ngr=(g*Beta*dT*L^3)/(v^2) //Grashof number
Npr=0.7 //Prandtl number

Nnu=0.59*(Ngr*Npr)^(1.0/4.0)     //Nusselt number
h=Nnu*k/L    //Average heat transfer coefficient [W/
   sq m K]
printf("\n In free convection,heat transfer coeff,h=
   %f W/(sq m.K)\n",h)
//2.Forced Convestion
u_inf=4  //[m/s]
Nre_l=u_inf*L/v
Nnu=0.664*(Nre_l^(1/2))*(Npr^(1.0/3.0))      //
   Nusselt number
h=Nnu*k/L    //[W/sq m.K]
printf("\n In forced convection,heat transfer coeff,
   h=%f W/(sq m.K)\n",h)
printf("\n From above it is clear that heat transfer
    coefficient in forced convection is much larger
   than that in free convection \n  ");
```

Scilab code Exa 3.30 `Natural convection`

```

clc;
clear;
//Example 3.30
k=0.02685    //W/(m.K)
v=16.5*10^-6   //kg/(m.s)
```

```
Npr=0.7 //Prandtl number
Beta=3.25*10^-3 //K^-1
g=9.81  //m/(s^2)
Tw=333; //[k]
T_inf=283   //[K]
dT=Tw-T_inf  //[K]
L=4 //Length/height  of plate [m]
Ngr=(g*Beta*dT*(L^3))/(v^2)   //Grashoff number
//Let const=Ngr*Npr
const=Ngr*Npr
//Sice it is >10^9
Nnu=0.10*(const^(1.0/3.0))   //Nusselt number
h=Nnu*k/L   //W/(sq m.K)
h=4.3       //Approx in book
W=7 //width in [m]
A=L*W   //Area of heat transfer in [sq m]
Q=h*A*dT    //[W]
printf("\nHeat transferred is %d W\n",Q)
```

Scilab code Exa 3.31 Free convection in vertical pipe

```
clc;
clear;
//Example 3.31
v=18.97*10^-6   //m^2/s
k=28.96*10^-3   //W/(m.K)
Npr=0.696
D=100   //Outer diameter [mm]
D=D/1000    //[m]
Tf=333  //Film temperature in [K]
Tw=373  //[K]
T_inf=293   //[K]
dT=Tw-T_inf //[K]
Beta=1/Tf   //[K^-1]
g=9.81  //[m/s^2]
```

```
L=3 //Length of pipe [m]
Ngr=(g*Beta*dT*(L^3))/(v^2) //Grashof number
Nra=Ngr*Npr
Nnu=0.10*(Ngr*Npr)^(1.0/3.0)     //nusselt number for vertical cylinder
h=Nnu*k/L   //W/(sq m.K)
Q_by_l=h*%pi*D*dT   //Heat loss per metre length [W/m]
printf(”\n Hence,Heat loss per metre length is %f W/m \n”,Q_by_l);
```

Scilab code Exa 3.32 `Heat loss per unit length`

```
clc;
clear;
//Example 3.32
k=0.630 //W/(m.K
Beta=3.04*10^-4 //K^-1
rho=1000    //kg/m^3
mu=8.0*10^-4    //[kg/(m.s)]
Cp=4.187    //kJ/(kg.K)
g=9.81  //[m/(s^2)]
Tw=313  //[K]
T_inf=298   //[K]
dT=Tw-T_inf //[K]
D=20    //[mm]
D=D/1000    //[m]
Ngr=9.81*(rho^2)*Beta*dT*(D^3)/(mu^2)   //Grashoff number
Cp1=Cp*1000 //[J/kg.K]
Npr=Cp1*mu/k //Prandtl number
//Average nusselt number is
Nnu=0.53*(Ngr*Npr)^(1.0/4.0)
h=Nnu*k/D  //[W/ sqm.K]
Q_by_l=h*%pi*D*dT   //Heat loss per unit length [W/m
```

```
    ]
printf("\nHeat loss per unit length of the heater is %f W/m",Q_by_l);
```

Scilab code Exa 3.33 Free convection in pipe

```
clc;
clear;
//Example 3.33
k=0.03406   //[W/(m/K)]
Beta=2.47*10^-3 //K^-1
Npr=0.687   //Prandtl number
v=26.54*10^-6   //m^2/s
g=9.81  //[m/s^2]
Tw=523  //[K]
T_inf=288   //[K]
dT=Tw-T_inf //[K]
D=0.3048    //[m]
Ngr=(g*Beta*dT*(D^3))/(v^2)     //Grashof number
Nra=Ngr*Npr
//For Nra less than 10^9,we have for horizontal cylinder
Nnu=0.53*(Nra^(1.0/4.0))    //Nusselt number
h=Nnu*k/D   //[W/sq m.K]
Q_by_l=h*%pi*D*dT;  //W/m
printf("Heat loss of heat transfer per meter lengh is %f W/m",Q_by_l);
```

Scilab code Exa 3.34 Free convection in plate

```

clc;
clear;
```

```
//Example 3.34
rho=960.63  //Density in [kg/m^3]
Cp=4.216*10^3   //Specific heat in [J/(kg.K)]
D=16    //Diameter in [cm]
D=D/100 //[m]
k=0.68  //Thermal conductivity in [W/m.K]
A=(%pi*(D/2)^2)
L=A/(%pi*D)   //Length=A/P  in [m]
Beta=0.75*10^-3  //[K^-1]
alpha=1.68*10^-7    //[m^2/s]
g=9.81  //[m/s^2]
Tw=403  //[K]
T_inf=343   //[K]
dT=Tw-T_inf //[K]
v=0.294*10^-6   //[m^2/s]
Nra=(g*Beta*(L^3)*dT)/(v*alpha)

//1.For Top surface
Nnu=0.15*(Nra)^(1.0/3.0)   //Nusselt number
ht=Nnu*k/L  //Heat transfer coeff for top surface in W/(m^2.K)
ht=round(ht)
//2.For bottom surface
Nnu=0.27*Nra^(1.0/4.0)  //Nusselt number
hb=Nnu*k/L  //[W/sq m.K]
hb=round(hb)
Q=(ht+hb)*A*dT; //[W]
printf(”The rate of heat input is %f W”,Q)
```

Scilab code Exa 3.35 `Heat transfer from disc`

```
clc;
clear;
//Example 3.35
v=2*10^-5   //[m^2/s]
```

```
Npr=0.7 //Prandtl number
k=0.03  //[W/m.K]
D=0.25   //Diameter in [m]
L=0.90*D    //Characteristic length,let  [m]
T1=298  //[K]
T2=403  //[K]
dT=T2-T1    //[K]
Tf=(T1+T2)/2  //[K]
Beta=1/Tf   //[K^-1]
A=%pi*(D/2)^2   //Area in[sq m]
g=9.81  //[m/s^2]

//Case 1: Hot surface facing up
Ngr=g*Beta*dT*(L^3)/(v^2)   //Grashoff number
Nnu=0.15*((Ngr*Npr)^(1.0/3.0))    //Nusselt number
h=Nnu*k/L   //[W/sq m.K]
Q=h*A*dT    //[W]
printf("\n Heat transferred when hot surface is facing up is %f W\n",Q);


//Case 2:For hot surface facing down
Nnu=0.27*(Ngr*Npr)^(1.0/4.0);   //Grashof Number
h=Nnu*k/L   //[W/sqm.K]
Q=h*A*dT    //[W]
printf("\n Heat transferred when hot surface is facing down is %f W\n",Q);
```

Scilab code Exa 3.36 Rate of heat input to plate

```


clc;
clear;
//Example 3.36
```

```
rho=960 //[kg/m^3]
Beta=0.75*10^-3 //[K^-1]
k=0.68  //[W/m.K]
alpha=1.68*10^-7     //[m^2/s]
v=2.94*10^-7     //[m^2/s]
Cp=4.216     //[kJ/kg.K]
Tw=403  //[K]
T_inf=343    //[K]
dT=Tw-T_inf      //[K]
g=9.81  //[m/s^2]
l=0.8   //[m]
W=0.08  //[m]
A=l*W   //Area in [m^2]
P=2*(0.8+0.08)    //Perimeter in [m]
L=A/P   //Characteristic dimension/length,L in    [m]
Nra=g*Beta*L^3*dT/(v*alpha)

//(i) for natural convection,heat transfer from top/upper surface heated
Nnu=0.15*(Nra^(1.0/3.0))     //Nusselt number
ht=Nnu*k/L  //[W/m^2.K]
ht=2115.3   //Approximation in book,If done manually then answer diff
//(ii)For the bottom/lower surface of the heated plate
Nnu=0.27*(Nra^(1.0/4.0))     //Nusselt number
hb=Nnu*k/L  //[W/(m^2.K)]
hb=round(hb)
//Rate of heat input is equal to rate of heat dissipation from the upper and lower surfaces of the plate
Q=(ht+hb)*A*(Tw-T_inf)    //[W]
printf(”\n Rate of heat input is equal to heat dissipation =%f W”,Q);
```

Scilab code Exa 3.37 `Two cases in disc`

```
clc;
clear;
//Example 3.37
k=0.03  //W/(m.K)
Npr=0.697   //Prandtl number
v=2.076*10^-6   //m^2/s
Beta=0.002915   //K^-1
D=25 ;    //[Diameter in cm]
D=D/100 //[m]
Tf=343  //Film temperature in [K]
A=%pi*(D/2)^2   //Area in [m^2]
P=%pi*D //Perimeter [m]
T1=293  //[K]
T2=393  //[K]
g=9.81  //[m/s^2]

//Case (i) HOT SURFACE FACING UPWARD
L=A/P   //Characteristic length in [m]
Beta=1/Tf;  //[K^-1]
dT=T2-T1    //[K]
Ngr=(g*Beta*dT*(L^3))/(v^2) //Grashoff number
Nra=Ngr*Npr
Nnu=0.15*(Nra^(1.0/3.0))    //Nusselt number
h=Nnu*k/L   //[W/m^2.K]
Q=h*A*dT    //[W]
printf("\nHeat transferred when disc is horizontal with hot surface facing upward is %f W\n",Q);

//Case-(ii) HOT FACE FACING DOWNWARD
Nnu=0.27*(Nra^(1/4))    //Nusselt number
h=Nnu*k/L   //W/(m^2.K)
Q=h*A*dT    //[W]
printf("\nHeat transferred when disc is horizontal with hot surface facing downward is %f W\n",Q);
```

```
//Case-(iii)-For disc vertical
L=0.25  //Characteristic length[m]
D=L //dia[m]
A=%pi*((D/2)^2) //[sq m]
Ngr=(g*Beta*dT*(L^3))/(v^2)      //Grashoff number
Npr=0.697
Nra=Ngr*Npr
Nnu=0.10*(Nra^(1/3))     //Nusselt number
h=Nnu*k/D    //[W/(m^2.K)]
Q=h*A*dT     //[W]
printf("For vertical disc,heat transferred is %f W",
   Q);
```

Scilab code Exa 3.38 `Total heat loss in a pipe`

```
clc;
clear;
//Example 3.38
v=23.13*10^-6   ; //[m^2/s]
k=0.0321   ; //[W/m.K]
Beta=2.68*10^-3; //[K^-1]
Tw=443  ;//[K]
T_inf=303  ; //[K]
dT=Tw-T_inf;     //[K]
g=9.81 ; //[m/s^2]
Npr=0.688;    //Prandtl number
D=100 ;   //Diameter [mm]
D=D/1000     //Diameter [m]
Nra=(g*Beta*dT*(D^3)*Npr)/(v^2)
Nnu=0.53*(Nra^(1.0/4.0))     //Nusselt number
h=Nnu*k/D    //[W/(m^2.K)]
h=7.93       //Approximation
e=0.90; //Emissivity
sigma=5.67*10^-8    ;
//Q=Q_conv+Q_rad   //Total heat loss
```

```
//for total heat  loss per meter length
Q_by_l=h*%pi*D*dT+sigma*e*%pi*D*(Tw^4-T_inf^4)  //[W/m]
printf("Total heat loss per metre length of pipe is %f W/m",Q_by_l)
```

Scilab code Exa 3.39 `Heat loss by free convection`

```
clc;
clear;
//Example 3.39
k=0.035; //[W/(m.K)]
Npr=0.684   ;//Prandtl number
Beta=2.42*10^-3; //[K^-1]
v=27.8*10^-6;     //[m^2/s]
Tw=533;  //[K]
T_inf=363  ;     //[K]
dT=Tw-T_inf //[K]
D=0.01  ;//[m]
g=9.81; //[m/s^2]
Nra=(g*Beta*dT*(D^3))/(v^2)
//For this <10^5,we have for sphere
A=4*%pi*(D/2)^2 //Area of sphere in [m^2]
Nnu=(2+0.43*Nra^(1.0/4.0))//Nusslet number
h=Nnu*k/D   //W/(m^2.K)
Q=h*A*dT    //[W]
printf("\nRate of heat loss is %f W",Q)
```

Scilab code Exa 3.40 `Heat loss from cube`

```

clc;
clear;
```

```
//Exampe 3.40
v=17.95*10^-6    //[m^2/s]
dT=353-293   //[K]
k=0.0283     //[W/m.K]
g=9.81   //[m/s^2]
Npr=0.698    //Prandtl number
Cp=1005  //J/(kg.K)
Tf=323   //Film temperature in [K]
Beta=1/Tf    //[K^-1]
l=1  //[m]
Nra=(g*Beta*dT*(l^3)*Npr)/(v^2)

//In textbook result of above statement is wrongly calculated,So
Nra=3.95*10^8
//For Nra <10^9,for a vertical plate,the average nusselt number is
Nnu=0.59*Nra^(1.0/4.0)   //Nusselt number
h=Nnu*k/l    //[W/m^2.K]
h=2.35       //Approx in book
A=l^2    //Area [m^2]
//Heat loss form 4 vertical faces of 1m*1m is
Q1=4*(h*A*dT)    //[W]
//For top surface
P=4*l    //Perimeter in [m]
L=A/P    //[m]
Nra=(Npr*g*Beta*dT*(L^3))/(v^2)
Nnu=0.15*Nra^(1.0/3.0)   //Nusselt number
h=Nnu*k/L    //[W/m^2.K]
h=6.7            //Approx
Q2=h*A*dT    //[W]
Q_total=Q1+Q2    //Total heat loss[W]
printf("\n Therefore total heat loss is %d W",Q_total);
```

Scilab code Exa 3.41 `Plate exposed to heat`

```
clc;
clear;
//Example 3.41
rho=0.910;                 //Density in [kg/m^3]
Cp=1.009*1000;                  //[J/kg.K]
k=0.0331;                  //[W/m.K]
mu=22.65*10^-6;            //[N.s/m^2]
//Let a=smaller side
//b=bigger side
//Qa=ha*A*dT
//Qb=hb*A*dT
//Qa=1.14*Qb
//Given a*b=15*10^-4
//On solving we get:
a=0.03;                //[m]
b=0.05;                //[m]
A=a*b                 //Area in [sq m]
Tf=388;                //[K]
Beta=1/Tf             //[K^-1]
T1=303;                //[K]
T2=473;               //[K]
dT=T2-T1              //[K]
v=mu/rho
g=9.81          //m/s^2[acceleration due to gravity ]
hb=0.59*(((g*Beta*dT*(b^3))/(v^2))*Cp*mu/k)^(1/4)*(k/b)        //[W/sq m.K]
Qb=hb*A*(dT)                  //[W]

Qa=1.14*Qb                    //[W]
printf("\nDimensions of the plate are %fx%f m\n",a,b);
printf("\nHeat transfer when the bigger side held vertical is %f W\n",Qb);
printf("\nHeat transfer when the small side held vertical is %f W\n",Qa);
```

Scilab code Exa 3.42 `Nucleate poolboiling`

```
clc;
clear;
//Example 3.42
Ts=373  //[K]
rho_l=957.9     //rho*l[kg/m^3]
Cpl=4217     //[J/kg.K]
mu_l=27.9*10^-5 //[kg/(m.s)]
rho_v=0.5955    //[kg/m^3]
Csf=0.013
sigma=5.89*10^-2     //[N/m]
Nprl=1.76
lambda=2257 //[kJ/kg]
lambda=lambda*1000  //in [J/kg]
n=1 //for water
m_dot=30     //Mass flow rate [kg/h]
m_dot=m_dot/3600     //[kg/s]
D=30     //Diameter of pan [cm]
D=D/100 //[m]
g=9.81  //[m/s^2]
A=%pi*(D/2)^2   //Area in [sq m]
Q_by_A=m_dot*lambda/A    //[W/sq m]
//For nucleate boiling point we have:
dT=(lambda/Cpl)*Csf*((((Q_by_A)/(mu_l*lambda))*sqrt(
   sigma/(g*(rho_l-rho_v))))^(1.0/3.0)*(Nprl^n) //[K
   ]
Tw=Ts+dT     //[K]
printf("\n Temperature of the bottom surface of the
   pan is %f W/(sq m)",Tw);
```

Scilab code Exa 3.43 `Peak Heat flux`

```
clc;
clear;
//Example 3.4
lambda=2257 //[kJ/kg]
lambda=lambda*1000  //in [J/kg]
rho_l=957.9     //rho*l[kg/m^3]
rho_v=0.5955    //[kg/m^3]
sigma=5.89*10^-2     //[N/m]
g=9.81  //[m/s^2]
//Peak heat flux is given by
Q_by_A_max=(%pi/24)*(lambda*rho_v^0.5*(sigma*g*(rho_l-rho_v))^(1/4))    //W/m^2
Q_by_A_max=Q_by_A_max/(10^6)    //MW/(sq m)
printf("\n Peak heat flux is %f MW/sq m",Q_by_A_max);
```

Scilab code Exa 3.44 `Stable film pool boiling`

```
clc;
clear;
//Example 3.44
rho_l=957.9 //[kg/m^3]
lambda=2257 //[kJ/kg]
lambda=lambda*10^3  //[J/kg]
rho_v=31.54 //[kg/m^3]
Cpv=4.64    //[kJ/kg.K]
Cpv=Cpv*10^3    //[J/kg.K]
kv=58.3*10^-3//[W/(m.K)]
g=9.81  //[m/s^2]
mu_v=18.6*10^-6 //[kg/(m.s)]
e=1.0   //Emissivity
sigma=5.67*10^-8;
Ts=373  //[K]
Tw=628  //[K]
dT=Tw-Ts    //[K]
```

```
D=1.6*10^-3 //[m]
T=(Tw+Ts)/2 //[K]
hc=0.62*((kv^3)*rho_v*(rho_l-rho_v)*g*(lambda+0.40*Cpv*dT)/(D*mu_v*dT))^(1.0/4.0)//Convective heat transfer coeff  [W/sq m.K]
hr=e*sigma*(Tw^4-Ts^4)/(Tw-Ts)  //Radiation heat transfer coeff in [W/sq m.K]
h=hc+(3/4)*hr   //Total heat transfer coefficient W/(sq m.K)
Q_by_l=h*%pi*D*dT   //Heat dissipation rate per unit length in [kW/m]
printf("\n Stable film boiling point heat transfer coefficient is %f W/(sq m.K)",h);
Q_by_l=Q_by_l/1000  //[kW/m]
printf("\n Heat dissipated per unit length of the heater is %f kW/m",Q_by_l);
```

Scilab code Exa 3.45 Heat transfer in tube

```
clc;
clear;
//Exmaple 3.45
dT=10   //[K]
P=506.625   //[kPa]
P=P/10^3    //[Mpa]
D=25.4  //Diameter [mm]
D=D/1000    //[m]
h=2.54*(dT^3)*(%e^(P/1.551))   //[W/sq m.K]
//Q=h*%pi*D*L*dT
//Heat transfer rate per meter length of tube is
Q_by_l=h*%pi*D*dT   //[W/m]
printf("\n Rate of heat transfer per 1m length of tube is %f W/m",round(Q_by_l));
```

Scilab code Exa 3.46 `Nucleat boiling and heat flux`

```
clc;
clear;
//Example 3.46
dT=8     //[K]
P=0.17   //[Mpa]
P=P*1000     //[kPa]
h1=2847 //[W/(sq m.K)]
P1=101.325   //[kPa]
h=5.56*(dT^3)    //[W/sq m.K]
Q_by_A=h*dT //[W/sq m]
hp=h*(P/P1)^(0.4)    //[W/sq m.K]
//Correponding heat flux is :
Q_by_A1=hp*dT //[W/sq m]
per=(Q_by_A1-Q_by_A)*100/Q_by_A //Percent increase in heat flux
printf("\nHeat flux when pressure  is 101.325 kPa is %f W/sq m\n",Q_by_A);
printf("\n Percent increase in heat flux is %f percent",round(per));
```

Scilab code Exa 3.47 `Dry steam condensate`

```
clc;
clear;
//Example 3.47
mu=306*10^-6     //[N.s/m^2]
k=0.668 //[W/m.K]
rho=974 //[kg/m^3]
lambda=2225 //[kJ/kg]
lambda=lambda*10^3   //[J/kg.K]
```

```
g=9.81   //[m/s^2]
Ts=373   //[K]
Tw=357   //[K]
dT=Ts-Tw     //[K]
Do=25    //[mm]
Do=Do/1000   //[m]
h=0.725*((rho^2*g*lambda*k^3)/(mu*Do*dT))^(1.0/4.0)
    //[W/sq m.K]
Q_by_l=h*%pi*Do*dT   //[W/m]
m_dot_byl=(Q_by_l/lambda)    //[kg/s]
m_dot_byl=m_dot_byl*3600     //[kg/h]

printf("\nMean heat transfer coefficient is %f W/(sq
     m.K)\n",h);
printf("\nHeat transfer per unit length is %f W/m\n"
    ,Q_by_l);
printf("\nCondensate rate per unit length is %f kg/h
    ",m_dot_byl);
```

Scilab code Exa 3.48 `Laminar Condensate film`

```
clc;
clear;
//Example 3.48
rho=960 //[kh/m^3]
mu=2.82*10^-4    //[kg/(m.s)]
k=0.68   //[W/(m.K)]
lambda=2255 //[kJ/kg]
lambda=lambda*10^3   //[J/kg]
Ts=373   //Saturation temperature of steam [K]
Tw=371   //[K]
dT=Ts-Tw     //[K]
L=0.3    //Dimension [m]
g=9.81   //[m/s^2]
h=0.943*(rho^2*g*lambda*k^3/(L*mu*dT))^(1/4)     //W/
```

```
sq m.K
A=L^2   //[sq m]
Q=h*A*(Ts-Tw)   //[W]=[J/s]
m_dot=Q/lambda  //Condensate rate[kg/s]
m_dot=m_dot*3600    //[kg/h]
printf("\n Average heat transfer coefficient is %f W/(sq m.K)\n",h);
printf("\nHeat transfer rate is %f J/kg\n",Q);
printf("\n Steam condensate rate per hour is %f kg/h\n",m_dot);
```

Scilab code Exa 3.49 Saturated vapour condensate in array

```

clc;
clear;
//EXample 3.49
rho=1174    //[kg/m^3]
k=0.069 //[W/(m.K)]
mu=2.5*10^-4    //[N.s/m^2]
lambda=132*10^3 //[J/kg]
g=9.81  //[m/s^2]
Ts=323  //[K]
Tw=313  //[K]
dT=Ts-Tw    //[K]
//For square array,n=4
n=4 //number of tubes
Do=12   //[mm]
Do=Do/1000  //[m]
h=0.725*(rho^2*lambda*g*k^3/(n*Do*mu*dT))^(1/4) //W/(sq m.K)
//For heat transfer area calcualtion,n=16
A=n*%pi*Do //[sq m]
A=0.603
Q=h*A*dT// [W/m]
```

```
m_dot=Q/lambda   //[kg/s]
m_dot=0.049      //Appriximation in book
m_dot=m_dot*3600     //[kg/h]
printf("\n Rate of condensation per unit length is
   %f kg/h",m_dot);
```

Scilab code Exa 3.50 Mass rate of steam condensation

```

clc;
clear;
//Example 3.50
rho=960 //[kg/m^3]
k=0.68  //[W/m.K]
mu=282*10^-6     //[kg/(m.s)]
Tw=371  //Tube wall temperature [K]
Ts=373  //Saturation temperature in [K]
dT=Ts-Tw     //[K]
lambda=2256.9    //[kJ/kg]
lambda=lambda*10^3   //[J/kg]
//Fora square array with 100tubes,n=10
Do=0.0125 //[m]
g=9.81  //[m/s^2]
n=10
h=0.725*(((rho^2)*g*lambda*(k^3)/(mu*n*Do*dT))
   ^(1.0/4.0)) //W/(sq m.K)

L=1 //[m]
//n=100
n=100;
A=n*%pi*Do*L     //[m^2/m length]
Q=h*A*dT     //Heat transfer rate in [W/m]
ms_dot=Q/lambda //[kg/s]
ms_dot=ms_dot*3600   //[kg/h]
printf("\n Mass rate of steam condensation is %d kg/
```

```
    h\n",round(ms_dot));

printf("\n NOTE:ERROR in Solution in book.Do is wrongly taken as 0.012 in lines 17 and 22 of the book,Also A is wrongly calculated\n")
```

Scilab code Exa 3.51 Saturated tube condensate in a wall

```

clc;
clear;
//Example 3.51
rho=975 //[kg/m^3]
k=0.871 //[W/m.K]
dT=10   //[K]
mu=380.5*10^-6  //[N.s/m^2]
lambda=2300 //[kJ/kg]
lambda=lambda*1000  // Latent heat of condensation [J/kg]
Do=100  //Outer diameter [mm]
Do=Do/1000  //[m]
g=9.81  //[m/s^2]
//for horizontal tube
h1=0.725*((rho^2*lambda*g*k^3)/(mu*Do*dT))^(1/4)   //Average heat transfer coefficient
//for vertical tube
//h2=0.943*((rho^2*lambda*g*k^3)/(mu*L*dT))^(1/4)      //Average heat transfer coefficient
h2=h1   //For vertical tube
//implies that
L=(0.943*((rho^2*lambda*g*k^3)^(1/4))/(h1*((mu*dT)^(1/4))))^4   //[m]
L=0.29      //Approximate in book
h=0.943*((rho^2*lambda*g*k^3)/(mu*L*dT))^(1/4)   //[W/(sq m.K)]
```

```
A=%pi*Do*L  //Area in [m^2]
Q=h*A*dT    //Heat transfer rate [W]
mc_dot=Q/lambda  //[Rate of condensation]in [kg/s]
mc_dot=mc_dot*3600  //[kg/h]
printf("\n Tube length is %f m\n",L);
printf("\n Rate of condemsation per hour is %f kg/h",mc_dot);
```

Scilab code Exa 3.52 `Condensation rate`

```
clc;
clear;
//Example 3.52
m1_dot=50    // For horizontal position[kg/h]
Do=10   //[mm]
Do=Do/1000  //[m]
L=1  //[m]
//For 100 tubes n=10
n=10;
//We know that
//m_dot=Q/lambda=h*A*dT/lambda
//m_dot is proportional to  h
//m1_dot prop to h1
//m2_dot  propn to h2
//m1_dot/m2_dot=h1/h2
//or :
m2_dot=m1_dot/((0.725/0.943)*(L/(n*Do))^(1/4))  //[kg/h]
printf("\n For vertical position,Rate of condensationis %f kg/h",m2_dot);
```

Scilab code Exa 3.53 `Condensation on vertical plate`

```
clc;
clear;
rho=975 //[kg/m^3]
k=0.671 //[W/(m.K)]
mu=3.8*10^-4     //[N.s/m^2]
dT=10   //[K]
lambda=2300*10^3     //[J/kg]
L=1 //[m]
g=9.81  //[m/s^2]
h=0.943*((rho^2*lambda*g*k^3)/(mu*L*dT))^(1/4)  //W/(sq m.K)     //[W/sq m.K]

printf("\n (i)- Average heat transfer coefficient is %d W/(m^2.K)\n",round(h));

//Local heat transfer coefficient
//at x=0.5  //[m]
x=0.5   //[m]
h=((rho^2*lambda*g*k^3)/(4*mu*dT*x))^(1/4)  //[W/sq m.K]
printf("\n (ii)-Local heat transfer coefficient at 0.5 m height is %d W/(sq m.K)\n",round(h));
delta=((4*mu*dT*k*x)/(lambda*rho^2*g))^(1/4)    //[m]
delta=delta*10^3    //[mm]
printf("\n (iii)-Film thickness is %f mm",delta);
```

Chapter 4

Radiation

Scilab code Exa 4.1 `Heat loss by radiaiton`

```
clc;
clear;
//Example 4.1
e=0.9    //[Emissivity]
sigma=5.67*10^-8     //[W/m^2.K^4]
T1=377   //[K]
T2=283   //[K]
Qr_by_a=e*sigma*(T1^4-T2^4) //[W/sq m]
printf("Heat loss by radiation is %d W/sq m",round(
   Qr_by_a));
```

Scilab code Exa 4.2 `Radiation from unlagged steam pipe`

```
clc;
clear;
//Example 4.2
e=0.9    //Emissivity
T1=393   //[K]
```

```
T2=293  //[K]
sigma=5.67*10^-8     //[W/sq m.K]
Qr_by_a=e*sigma*(T1^4-T2^4) //W/sq m
printf(”\n Rate of heat transfer by radiation is %f W/sq m”,Qr_by_a);
```

Scilab code Exa 4.3 `Interchange of radiation energy`

```

clc;
clear;
//Example 4.3
L=1; //[m]
e=0.8  ; //Emissivity
sigma=5.67*10^-8 ;    //[m^2.K^4]
T1=423;  //[K]
T2=300;  //[K]
Do=60;   //[mm]
Do=Do/1000;  //[m]
A=%pi*Do*L  //[sq m]
A=0.189     //Approx in book [m^2]
Qr=e*sigma*A*(T1^4-T2^4)    //[W/m]
printf(”\n Net radiaiton rate per 1 metre length of pipe is %d W/m”,round(Qr));
```

Scilab code Exa 4.4 `Heat loss in unlagged steam pipe`

```
clc;
clear;
//Example 4.4
e=0.9   //Emissivity
L=1 //[m]
Do=50   //[mm]
```

```
Do=Do/1000   //[m]
sigma=5.67*10^-8      //[W/(m^2.K^4)]
T1=415   //[K]
T2=290   //[K]
dT=T1-T2     //[K]
hc=1.18*(dT/Do)^(0.25)   //[W/sq m.K]
A=%pi*Do*L   //Area in [sq m]
Qc=hc*A*dT //Heat loss by convection W/m
Qr=e*sigma*A*(T1^4-T2^4)     //Heat loss by radiation
    per length W/m
Qt=Qc+Qr     //Total heat loss in [W/m]
printf("\n Total heat loss by convection is %f W/m",
   Qt);
```

Scilab code Exa 4.5 `Loss from horizontal pipe`

```
clc;
clear;
//Example 4.5
e=0.85
sigma=5.67*10^-8      //[W/sq m.K]
T1=443   //[K]
T2=290   //[K]
dT=T1-T2     //[K]
hc=1.64*dT^0.25      //W/sq m.K
Do=60    //[mm]
Do=Do/1000   //[m]
L=6 //Length [m]
A=%pi*Do*L   //Surface area of pipe in [sq m]
Qr=e*sigma*A*(T1^4-T2^4)     // Rate of heat loss by
   radiaiton W
Qc=hc*A*(T1-T2) // Rate of heat loss by convection [
   W]
Qt=Qr+Qc     //Total heat loss  [W]
printf("\n Total heat loss is %d W",round(Qt))
```

Scilab code Exa 4.6 `Heat loss by radiation in tube`

```

clc;
clear;
//EXample 4.6
sigma=5.67*10^-8      //[W/m^2.K^4]
e1=0.79;
e2=0.93;
T1=500 ; //[K]
T2=300 ; //[K]
D=70    //[mm]
D=D/1000    //[m]
L=3 //[m]
W=0.3   //Side of conduit [m]
A1=%pi*D*L  //[sq m]
A1=0.659        //Approximate calculation in book in
    [m^2]
A2=4*(L*W)  //[sq m]
Q=sigma*A1*(T1^4-T2^4)/(1/e1+((A1/A2)*(1/e2-1)))
   //[W]
printf("\n Heat lost by radiation is %f W",Q);
```

Scilab code Exa 4.7 `Net radiant interchange`

```
clc;
clear;
//Example 4.7
sigma=5.67*10^-8      //[W/sq m.K^4]
T1=703  //[K]
T2=513  //[K]
```

```
e1=0.85
e2=0.75
Q_by_Ar=sigma*(T1^4-T2^4)/(1/e1+1/e2-1) //[W/sq m]
printf("\n Net radiant interchange per square metre
   is %d W/sq m",round(Q_by_Ar));
```

Scilab code Exa 4.8 `Radiant interchange between plates`

```
clc;
clear;
//Example 4.8
L=3 ;//[m]
A=L^2    //Area in [sq m]
sigma=5.67*10^-8;     //[W/sq m.K^4]
T1=373;   //[K]
T2=313;   //[K]
e1=0.736;
e2=e1;
F12=1/((1/e1)+(1/e2)-1)
Q=sigma*A*F12*(T1^4-T2^4)   //[W]
printf("\n Net radiant interchange is %d W",round(Q)
   );
```

Scilab code Exa 4.9 `Heat loss from thermflask`

```
clc;
clear;
sigma=5.67*10^-8     //[W/sq m.K^4]
e1=0.05
e2=0.05
//A1=A2=1 (let)
A1=1;
A2=A1;
```

```
F12=1/(1/e1+(A1/A2)*(1/e2-1))
T1=368  //[K]
T2=293  //[K]
Q_by_A=sigma*F12*(T1^4-T2^4)     //Heat loss per unit Area  [W/sq m]
printf("\nRate of heat loss when of silvered surface is %f W/sq m",Q_by_A);
//When both the surfaces are black
e1=1;
e2=1;
F12=1/(1/e1+(A1/A2)*(1/e2-1))
Q_by_A=sigma*F12*(T1^4-T2^4)     //[W/sq m]
printf("\n When both surfaces are black,Rate of heat loss  is %d W/sq m",round(Q_by_A));
```

Scilab code Exa 4.10 `Diwar flask`

```
clc;
clear;
//Example 4.10
e1=0.05
e2=e1
A1=0.6944;
A2=1;
T1=293  //[K]
T2=90   //[K]
sigma=5.67*10^-8    //[W/m^2.K^4]
D=0.3   //Diameter in [m]

F12=1/(1/e1+(A1/A2)*(1/e2-1))
Q_by_A=sigma*F12*(T1^4-T2^4)     //[W/sq m]
Q=Q_by_A*%pi*(D^2)  //[kJ/h]
Q=Q*3600/1000   //[kJ/h]
lambda=21.44    //Latent heat in [kJ/kg]
m_dot=Q/lambda    //kg/h
```

```
printf("\n The liquid oxygen will evaporate at %f kg
    /h",m_dot);
```

Scilab code Exa 4.11 Heat flow due to radiation

```
clc;
clear;
//Example4.11
sigma=5.67*10^-8     //W/(m^2.K^4)
e1=0.3;
e2=e1;
D1=0.3   //[m]
D2=0.5   //[m]
T1=90    //[K]
T2=313   //[K]
A1=%pi*D1^2 //Area in [sq m]
A2=%pi*D2^2//Area in [sq m]
Q1=sigma*A1*(T1^4-T2^4)/(1/e1+(A1/A2)*(1/e2-1))  //[
    W]
Q1=abs(Q1); //Absolute value in [W]
printf("\n Rate of heat flow due to radiation is %f
    W",Q1);
//When Aluminium is used
e1=0.05
e2=0.5
Q2=sigma*A1*(T1^4-T2^4)/(1/e1+(A1/A2)*(1/0.3-1))  //
    [W]
Q2=abs(Q2) //Absolute value in [W]
Red=(Q1-Q2)*100/Q1  //Percent reduction
printf("\n Reduction in heat flow will be %f percent
    ",Red);
```

Scilab code Exa 4.12 Heat exchange between concentric shell

```

clc;
clear;
//Example 4.12
sigma=5.67*10^-8     //[W/sq m.K^4]
T1=77    //[K]
T2=303   //[K]
D1=32    //cm
D1=D1/100    //[m]
D2=36    //[cm]
D2=D2/100    //[m]
A1=%pi*D1^2 //[sq m]
A2=%pi*D2^2 //[sq m]
e1=0.03;
e2=e1;
Q=sigma*A1*(T1^4-T2^4)/(1/e1+(A1/A2)*(1/e2-1))  //[W
   ]
Q=Q*3600/1000    //[kJ/h]
Q=abs(Q);    //[kJ/h]
lambda=201   //kJ/kg
m_dot=Q/lambda   //Evaporation rate in [kg/h]
printf("\n Nitrogen evaporates at %f kg/h",m_dot);
```

Scilab code Exa 4.13 Evaporation in concenric vessels

```

clc;
clear;
//Example 4.13
D1=250   //Inner sphere idameter[mm]
D1=D1/1000   //Outer diameter [m]
D2=350   //[mm]
D2=D2/1000   //[m]
sigma=5.67*10^-8     //W/(sq m.K^4)
A1=%pi*D1^2 //[sq m]
```

```
A2=%pi*D2^2 //[sq m]
T1=76    //[K]
T2=300   //[K]
e1=0.04;
e2=e1;
Q=sigma*A1*(T1^4-T2^4)/((1/e1)+(A1/A2)*((1/e2)-1))      //[W]
Q=-2.45       //Approximate
Q=abs(Q)      //[W]
Q=Q*3600/1000    //[kJ/h]
lambda=200   //kJ/kg
Rate=Q/lambda    //[kg/h]
printf("\n Rate of evaporation is %f kg/h(approx)",Rate);
```

Scilab code Exa 4.15 `infinitely long plates`

```
clc;
clear;
//Example 4.15
sigma=5.67*10^-8      //[W/(m^2.K^4)]
e1=0.4
e3=0.2
T1=473   //[K]
T3=303   //[K]
Q_by_a=sigma*(T1^4-T3^4)/((1/e1)+(1/e3)-1)   //[W/sq m]
//Q1_by_a=sigma*(T1^4-T2^4)/((1/e1)+(1/e2)-1)=sigma*A*(T2^4-T3^4)/((1/e2)+(1/e3)-1)  //[W/sq m]
e2=0.5
//Solving we get
T2=((6/9.5)*((3.5/6)*T3^4+T1^4))^(1/4)   //[K]
Q1_by_a=sigma*(T1^4-T2^4)/((1/e1)+(1/e2)-1)  //[W/sq m]
red=(Q_by_a-Q1_by_a)*100/Q_by_a
```

```
printf("\nHeat transfer rate per unit area(WITHOUT SHIELD) due to radiation is %f W/sq m\n",Q_by_a);
printf("\nHeat transfer rate per unit area(WITH SHIELD) due to radiation is %f W/sq m\n",Q1_by_a);
printf("\nReduction in heat loss is %f percent",red);
```

Scilab code Exa 4.16 `Heat exchange between parallel plates`

```
clc;
clear;
//Example 4.16
//In steady state,we can write:
//Qcd=Qdb
//sigma(Tc^4-Td^4)*/(1/ec+1/ed-1)=sigma(Td^4-Tb^4)/(1/ed+1/eb-1)
// i.e Td^4=0.5*(Tc^4-Tb^4)
//Given:
Ta=600  //[K]
eA=0.8;
eC=0.5;
eD=0.4;
sigma=5.67*10^-8          //For air
//(600^4-Tc^4)/2.25=(Tc^4-Td^4)/3.5
//1.56*(600^4-Tc^4)=Tc^4-Td^4
//Putting value of Td in terms of Tc
//1.56*(600^4-Tc^4)=Tc^4-0.5*(Tc^4-300^4)
function y=f(Tc)
  y=1.56*(600^4-Tc^4)-Tc^4+0.5*(Tc^4-300^4)
endfunction
Tc=fsolve(500,f);             //[K]
//or
Tc=560.94         //[K] Approximate after solving
Td=sqrt(sqrt(0.5*(Tc^4-300^4)))           //[K]
```

```
Q_by_a=sigma*(Ta^4-Tc^4)/(1/eA+1/eC-1)        //[W/sq
   m]
printf("\nRate of heat exchange per unit area=%f W/m
   ^2",Q_by_a);
printf("\nSteady state temperatures,Tc=%f K,and Td=
   %f K",Tc,Td);
```

Scilab code Exa 4.17 `Thermal radiation in pipe`

```
clc;
clear;
//Example 4.17
sigma=5.67*10^-8     //[W/(sq m.K^4)]
e=0.8
T1=673;   //[K]
T2=303;   //[K]
Do=200    //[mm]
Do=Do/1000   //[m]
L=1       //Let [m]
A1=%pi*Do*L  //[m^2/m]
//CAse 1: Pipe to surrundings

Q1=e*A1*sigma*(T1^4-T2^4)    //[W/m]
Q1=5600      //Approximated
//Q1=5600          //[W/m] approximated in book for
   calculation purpose
//Concentric cylinders
e1=0.8;
e2=0.91;
D1=0.2  //[m]
D2=0.4  //[m]
Q2=sigma*0.628*(T1^4-T2^4)/((1/e1)+(D1/D2)*((1/e2)
   -1))    //[W/m] length
Red=Q1-Q2    //Reduction in heat loss

```

```
printf("\nDue to thermal radiaiton,Loss of heat to surrounding is %d W/m\n",round(Q1));
printf("\nWhen pipe is enclosed in 1 400 mm diameter brick conduit,Loss of heat is %d W/m\n",round(Q2));
printf("\n Reduction in heat loss is %d W/m\n",round(Red));
```

Scilab code Exa 4.18 `Heat transfer in concentric tube`

```


clc;
clear;
//Example 4.18


sigma=5.67*10^-8 ;    //[W/(sq m.K^4)]
T1=813;   //[K]
T2=473;   //[K]
e1=0.87;
e2=0.26;
D1=0.25 ;//[m]
D2=0.3; //[m]
Q_by_a1=sigma*(T1^4-T2^4)/(1/e1+(D1/D2)*(1/e2-1))   //[W/ sqm]
printf("\n Heat transfer by radiaiton is %d W/sq m",Q_by_a1);
```

Scilab code Exa 4.19 `Heat exchange between black plates`

```

clc;
```

```
clear;
//Example 4.19
sigma=5.67*10^-8     //[W/sq m.K^4]
A1=0.5*1     //[sq m]
F12=0.285
T1=1273 ///[K]
T2=773  //[K]
Q=sigma*A1*F12*(T1^4-T2^4)     //[W]
printf("\n Net radiant heat exchange between plates is %d W",Q);
```

Scilab code Exa 4.20 `Radiation shield`

```
clc;
clear;
//Example 4.20
sigma=5.67*10^-8     //[W/sq m.K^4]
T1=750  //[K]
T2=500  //[K]
e1=0.75;
e2=0.5;
//Heat transfer without shield :

Q_by_a=sigma*(T1^4-T2^4)/((1/e1)+(1/e2)-1)   //[W/sq m]

//Heat transfer with shield:
R1=(1-e1)/e1     //Resistance 1

F13=1;
R2=1/F13         //Resistance 2

e3=0.05
R3=(1-e3)/e3     //Resistance 3

```

```
R4=(1-e3)/e3     //Resistance 4

F32=1;
R5=1/F32         //Resistance 5

R6=(1-e2)/e2        //Resistance 6

Total_R=R1+R2+R3+R4+R5+R6    //Total resistance

Q_by_as=sigma*(T1^4-T2^4)/Total_R    //[W/sq m]

Red=(Q_by_a-Q_by_as)*100/Q_by_a      //Reduciton in heat tranfer due to shield

printf("\n Reduction in heat transfer rate as a result of radiaiotn shield is %f percent",Red);
```

Scilab code Exa 4.21 `Heat transfer with radiaiton shield`

```
clc;
clear;
//Example 4.21
e1=0.3
e2=0.8
//Let sigma*(T1^4-T2^4)=z=1(const)
z=1;     //Let
Q_by_A=z/(1/e1+1/e2-1)   //W/sq m

//Heat transfer with radiation shield
e3=0.04
F13=1;
F32=1;
//The resistances are:
R1=(1-e1)/e1
R2=1/F13
```

```
R3=(1-e3)/e3
R4=R3
R5=1/F32
R6=(1-e2)/e2
R=R1+R2+R3+R4+R5+R6      //Total resistance
Q_by_As=z/R //where z=sigma*(T1^4-T2^4) //W/sq m
red=(Q_by_A-Q_by_As)*100/Q_by_A     //Percent reduction in heat transfer
printf("\n The heat transfer is reduced by %f percent due to shield",red)
```

Scilab code Exa 4.22 Radiaition shape factor

```

clc;
clear;
//Example 4.22
sigma=5.67*10^-8;
T1=1273 //[K]
T2=773  //[K]
T3=300  //[K]
A1=0.5  //[sq m]
A2=A1;  //[sq m]
F12=0.285;
F21=F12;
F13=1-F12;
F23=1-F21;
e1=0.2;
e2=0.5;
//Resistance in the network are calculated as:
R1=1-e1/(e1*A1)
R2=1-e2/(e2*A2)
R3=1/(A1*F12)
R4=1/(A1*F13)
R5=1/(A2*F23)
```

```
R6=0     //Given (1-e3)/e3*A3=0
//Also
Eb1=sigma*T1^4   //W/sq m
Eb2=sigma*T2^4    //[W/sq m]
Eb3=sigma*T3^4  //[W/sq m]

//Equations are:
//(Eb1-J1)/2+(J2-J1)/7.018+(Eb3-J1)/2.797=0
//(J1-J2)/7.018+(Eb3-J2)/2.797+(Eb2-J2)/2=0

//On solving we get:
J1=33515     //[W/sq m]
J2=15048     //[W/sqm]
J3=Eb3   //[W/sq m]
Q1=(Eb1-J1)/((1-e1)/(e1*A1))          //[W/sq m]
Q2=(Eb2-J2)/((1-e2)/(e2*A2))          //[W/sq m]
Q3=(J1-J3)/(1/(A1*F13))+(J2-J3)/(1/(A2*F23))     //[W/sq m]
printf("\n Total heat lost by plate 1 is %f W/sq m\n",Q1);
printf("\n Total heat lost by plate 2 is %f W/sq m\n",Q2);
printf("\nThe net energy lost by both plates must be absorbed by the room,\n %f=%f",Q3,Q1+Q2)
```

Scilab code Exa 4.23 `Radiation loss in plates`

```
clc;
clear;
//Example 4.23
sigma=5.67*10^-8     //[W/sq m.K^4]
e1=0.7;
e2=0.7;
T1=866.5     //[K]
T2=588.8     //[K]
```

```
Q_by_A=sigma*(T1^4-T2^4)/((1/e1)+(1/e2)-1)  //[W/sq m]
e1=0.7;
e2=e1;
e3=e1;
e4=e1;
e=e1;
//Q with n shells =1/(n+1)
n=2
Q_shield=1/(n+1);
es1=e1;
es2=e1;
Q_by_A=sigma*(T1^4-T2^4)/((1/e1)+(1/e2)+2*(1/es1+1/es2)-(n+1))  //[W/sq m]
printf("\n New Radiaiton loss is %f W/sq m",Q_by_A);
```

Scilab code Exa 4.24 Concentric tube

```
clc;
clear;
//Example 4.24
//1.WITHOUT SHIELD
sigma=5.67*10^-8
e1=0.12;
e2=0.15;
T1=100  //[K]
T2=300  //[K]
r1=0.015    //[m]
r2=0.045    //[m]
L=1         //[m]
A1=2*%pi*r1*L   //[sq m]
Q_by_L=2*%pi*r1*sigma*(T1^4-T2^4)/(1/e1+(r1/r2)*(1/e2-1))   //[W/m]
//-ve saign indicates that the net heat flow is in the radial inward direction
```

```
//2.WITH CYLINDRICAL RADIATION SHIELD
e3=0.10;
e4=0.05;
r3=0.0225    //[m]
Qs_by_L=2*%pi*r1*sigma*(T1^4-T2^4)/(1/e1+r1/r2*(1/e2-1)+(r1/r3)*(1/e3+1/e4-1))   //[W/sq m]
red=(abs(Q_by_L)-abs(Qs_by_L))*100/abs(Q_by_L)   //percent reduction in heat gain

//Radiation network approach
A3=2*%pi*r3      //[sq m]
A2=2*%pi*r2      //[sq m]
F13=1;
F32=1;
R1=(1-e1)/(e1*A1)
R2=1/(A1*F13)
R3=(1-e3)/(e3*A3)
R4=(1-e4)/(e4*A3)
R5=1/(A3*F32)
R6=(1-e2)/(e2*A2)

Qs=sigma*(T1^4-T2^4)/((1-e1)/(e1*A1)+1/(A1*F13)+(1-e3)/(e3*A3)+(1-e4)/(e4*A3)+1/(A3*F32)+(1-e2)/(e2*A2))
printf("\n With cylindrical radiaiton shield Heat gained by fluid per 1 m lengh of tube is %f W/m\n",Qs_by_L);
printf("\nPercent reduction in heat gain is %f percent\n",red);
printf("\nWith radiaiton network approach %f W/sqm ",Qs);
```

Chapter 5

Heat Exchangers

Scilab code Exa 5.1 `Harpin exchanger`

```


clc;
clear;
//Example 5.1
Di=35         //[mm]
Di=Di/1000        //[m]
Do=42         //[mm]
Do=Do/1000        //[m]
//for benzene
mb_dot=4450       //[kg/h]
Cpb=1.779         //[kJ/(kg.K)]
t2=322            //[K]
t1=300    //[K]
Q=mb_dot*Cpb*(t2-t1)        //for benzene in [kJ/h]

//For toulene
T1=344    //[K]
T2=311        //[K]
Cpt=1.842         //[kJ/kg.K]
mt_dot=Q/(Cpt*(T1-T2))      //[kg/h]
```

```
Q=Q*1000/3600            //[W]
//Hot fluid(toluene)
//Cold fluid(benzene)
dT1=22       //[K]
dT2=11       //[K]
dTlm=(dT1-dT2)/(log(dT1/dT2))       //[K]

//Clod fluid:Inner pipe,benzene
Di=0.035         //[m]
Ai=(%pi/4)*Di^2      //Flow area[sq m]
Gi=mb_dot/Ai         //Mass velocity [kg/m^2.h]
Gi=Gi/3600           //[kg/m^2.s]
mu=4.09*10^-4        //[kg/(m.s)]
Nre=Di*Gi/mu         //Reynolds number

Cp=Cpb*10^3          //[J/(kg.K)]
k=0.147              //[W/m.K]
Npr=Cp*mu/k          //Prandtl number
hi=(k/Di)*0.023*(Nre^0.8)*(Npr^0.4)     //[W/sq m.K]
hio=hi*Di/Do             //[W/sq m.K]
D1=0.042                 //Outside dia of inside pipe [mm]
D2=0.0525            //Inside dia of outside pipe[m]
De=(D2^2-D1^2)/D1            //[m]
De=0.0236                //Approximated
aa=%pi*(D2^2-D1^2)/4            //Flow area[sq m]
Ga=mt_dot/aa         //Mass velocity in [kg/m^2.h]
Ga=Ga/3600           //[kg/m^2.s]
mu=5.01*10^-4        //[kg/(m.s)]
Nre=De*Ga/mu         //Reynolds number
Npr=Cp*mu/k      //Prandtl number
ho=(k/De)*0.023*(Nre^0.8)*(Npr^0.3)     //[W/sq m.K]
Uc=1/(1/ho+1/hio)        //[W/sq m.K]
Rdi=1.6*10^-4            //Fouling factor [m^2.K/W]
Rdo=1.6*10^-4            //Fouling factor[m^2.K/W]
Rd=Rdi+Rdo               //(m^2.K/W)
Ud=1/(1/Uc+Rd)           //[W/sq m.K]
A=Q/(Ud*dTlm)            //sq m
```

```
ex=0.136                              //[sq m]
l=A/ex                          //m
tl=12        //Total length of one harpin of 6m [m]
printf(”b%f”,l);
printf(”\n\Required surface is fulfilled by connecting %d(three) 6m harpins in series\n”, round(l/tl))
```

Scilab code Exa 5.2 `Length of pipe`

```
clc;
clear;
//Example 5.2
ma_dot=300*1000/24                    //Mass flow rate of acid in [kg/h]
mw_dot=500*1000/24                    //Mass flow rate of water in [kg/h]
Cp1=1.465                              //[kJ/kg.K]
T1=333                                //[K]
T2=313                                //[K]
Q=ma_dot*Cp1*(T1-T2)                   //[kJ/h]
Q=Q*1000/3600                         //[W]
Cp2=4.187                             //[kJ/kg.K]
t1=288                                //[K]
t2=(Q/(mw_dot*Cp2))+t1                 //[K]
dT1=T1-t2                             //[K]
dT2=T2-t1                             //[K]
dTlm=(dT1-dT2)/log(dT1/dT2)           //[K]
dTlm=32.26                    //Approximation in [K]
//Inner pipe
m_dot=12500                           //[kg/h]
Di=0.075                              //[m]
Ai=(%pi/4)*Di^2                       //[sq m]
G=ma_dot/Ai                           //[kg/m^2.h]
G=G/3600                              //[kg/m^2.s]
```

```
mu=0.0112                           //[kg/m.s]
k=0.302                             //W/(m.K)
Nre=Di*G/mu                         //Reynold number
Npr=Cp1*10^3*mu/k                        //Prandtl number
hi=(k/Di)*0.023*(Nre^0.8)*(Npr^0.3)       //W/sq m.K
Do=0.1                              //[m]
hio=hi*Di/Do                        //W/sq m.K
D1=0.1                              //[m]
D2=0.125                            //[m]
De=(D2^2-D1^2)/D1                   //[m]
Aa=(%pi/4)*(D2^2-D1^2)              //[sq m]
Ga=mw_dot/Aa                        //[kg/m^2.h]
Ga=Ga/3600                          //[kg/sq m.s]
mu=0.0011                           //[kg/m.s]
Nre=De*Ga/mu                        //Reynolds number
k=0.669                             //for water
Npr=Cp2*10^3*mu/k                         //Prandtl number
ho=(k/De)*0.023*(Nre^0.8)*Npr^0.4      //[W/sq m.K]
xw=(Do-Di)/2                             //[m]
Dw=(Do-Di)/log(Do/Di)                   //[m]
kw=46.52                            //thermal conductivity of wall in [W/m.K]
Uc=1/(1/ho+1/hio+xw*Do/(kw*Dw))    //[W/sq m.K]
Ud=Uc                               //As dirt factor values are not given
Ud=195.32               //Approximation
A=Q/(Ud*dTlm)                     //[sq m]

L=A/(%pi*Do)                        //[sq m]
printf(”\nArea =%f m^2,\nLength fo pipe required =%f m(approx)”,A,L)
```

Scilab code Exa 5.3 Double pipe heat exchanger

```
clc;
```

```
clear;
//Example 5.3
me_dot=5500 ;          //[kg/h]
me_dot1=me_dot/3600              //[kg/s]
Di=0.037      ;    //I.D of inner pipe in [m]
Ai=(%pi/4)*Di^2            //[sq m]
G=me_dot1/Ai                 //[kg/sq m.s]
mu=3.4*10^-3    ;            //[Pa.s] or [kg/(m.s)]
Nre=Di*G/mu                //Reynolds number
Cp=2.68          ;   //[kJ/kg.K]
Cp1=Cp*10^3            //[J/kgK]
k=0.248           ; //[W/m.K]
Npr=Cp1*mu/k      //Prandtl number
//Nre is greater than 10,000,Use Dittus-Boelter eqn:
Nnu=0.023*(Nre^0.8)*(Npr^0.3)        //Nusselt number
hi=k*Nnu/Di                  //[W/sq m.K]
T2=358          //[K]
T1=341          //[K]
Cp2=1.80            //[kJ/kg.K]
t2=335              //[K]
t1=303              //[K]
mt_dot=me_dot*Cp*(T2-T1)/(Cp2*(t2-t1))  //[kg/h]
mt_dot=mt_dot/3600                      //[kg/s]
D1=0.043               //[m]
D2=0.064            //Inside dia of outer pipe
De=(D2^2-D1^2)/D1            //Equivalent diameter [m]
Aa=%pi/4*(D2^2-D1^2)          //[sq m]
Ga=mt_dot/Aa                      //kg/(sq m.s)
mu2=4.4*10^-4                      // Viscosity of toluene Pa.s
k2=0.146                     //For toluene [W/m.K]
Cp2=1.8*10^3             //J/kg.K
Nre=De*Ga/mu2             //Reynolds number
Npr=Cp2*mu2/k2           //Prandtl number
Nnu=0.023*Nre^0.8*Npr^0.4        //Nusselt number
ho=k2*Nnu/De                       //W/(sq m.K)
Dw=(D1-Di)/log(D1/Di)               //[m]
```

```
x=0.003                          //Wall thickness in [m]
Uo=1/(1/ho+(1/hi)*(D1/Di)+(x*D1/(46.52*Dw)))      //[W/sq m.K]
dT1=38      //[K]
dT2=23      //[K]
dTlm=(dT1-dT2)/log(dT1/dT2)                 //[K]
Q=me_dot1*Cp*(T2-T1)        //[kJ/s]
Q=Q*1000                    //[J/s]
L=Q/(Uo*%pi*D1*dTlm)     //[m]
printf("\nTotal lenggth of double pipe heat exchanger is %f m",L)
```

Scilab code Exa 5.4 `Parallel flow arrangement`

```
clc;
clear;
//Example 5.4
mc_dot=1000          //[kg/h]
mc_dot=mc_dot/3600       //[kg/s]
mh_dot=250           //[kg/h]
mh_dot=mh_dot/3600   //[kg/s]
Cpc=4187           //[J/(kg.K)]
Cph=3350         // [W/K]
w=mc_dot*Cpc         // [W/K]
l=mh_dot*Cph         // [W/K]
C=mh_dot*Cph/(mc_dot*Cpc)
U=1160      //[W/sq m.K]
A=0.25      //Heat transfer surface for exchanger in [sq m]
ntu=U*A/(mh_dot*Cph)    //
E=(1-%e^(-ntu*(1+C)))/(1+C)     //Effectiveness of heat exchanger
T1=393      //Inlet temperature in [K]
t1=283      //Cooling water [K]
T2=T1-E*(T1-t1)      //Outlet T of hot liquid
```

```

t2=C*(T1-T2)+t1      //[K]
printf("\n\nEffectiveness of heat exchanger is %f\n"
    ,E);
printf("\nOutlet temperature of hot liquid is %f\n",
    T2);
printf("\nOutlet temperature of water is %f\n",t2)
```

Scilab code Exa 5.5 `Counter flow exchanger`

```

clc;
clear;
//Example 5.5
Cpc=4187                    //Specific heat of water in
    [J/(kg.K)]
Cph=2000                    //Sp heat of oil in [J/(kg.K
    )]
mc_dot=1300/3600            //[kg/s]
mh_dot=550/3600             //[kg/s]
w=mc_dot*Cpc            //[W/K]
o=mh_dot*Cph            //[W/K]
//Heat capacity of rate of hot fluid is smaller than
     water
U=1075          //[W/sq m.K]
A=1         //[sq m]
ntu=(U*A)/(mh_dot*Cph)
C=mh_dot*Cph/(mc_dot*Cpc)
E=(1-%e^(-ntu*(1-C)))/(1-C*%e^(-ntu*(1-C)))      //
    Effeciency
T1=367          //[K]
t1=288          //[K]
T2=T1-E*(T1-t1)                     //Outlet temperature
     [K]
T2=291.83                     //Approximated in book
```

```
   without precise calculation
t2=C*(T1-T2)+t1                  //[K]
Q=mh_dot*Cph*(T1-T2)             //[W]
printf("\n\nEffectiveness of exchanger is %f\n",E);
printf("\nOutlet temperature of oil is %f K\n",T2);
printf("\nOutlet temperature of water is %f K\n",t2)
   ;
printf("\nRate of heat transfer is %f W",Q);
```

Scilab code Exa 5.6 `LMTD approach`

```
clc;
clear;
//Example 5.6
printf("\nLMTD Approach\n")

Cph=4187                //[J/(kg.K)]
mh_dot=600/3600         //Hot side flow rate [kg/s]
mc_dot=1500/3600            //[kg/s]
Cpc=Cph                 //[J/kg.K]
T1=343                  //[K]
T2=323                  //[K]
Q=mh_dot*Cph*(T1-T2)        //[W]
t1=298                      //[K]
t2=(mh_dot*Cph*(T1-T2))/(mc_dot*Cpc)+t1 //[K]
dT1=45          //[K]
dT2=17              //[K]
dTlm=(dT1-dT2)/log(dT1/dT2)          //[K]
hi=1600             //Heat transfer coeff in [W/sq m.K]
ho=hi               //[W/sq m.K]
U=1/(1/hi+1/ho)         //[W/sq m.K]
A=Q/(U*dTlm)            //[sq m]

printf("\nEffectiveness-NTU approach\n");

```

```
//hot water:
h=mh_dot*Cph                //[W/K]
c=mc_dot*Cpc                //[W/K]
//Heat capacity rate of hot fluid is small
C=mh_dot*Cph/(mc_dot*Cpc)        //
E=(T1-T2)/(T1-t1)           //Effectiveness
//for paralell flow:
ntu=-log(1-E*(1+C))/(1+C)
A2=(ntu*mh_dot*Cph)/U        //[sq m]
t2=C*(T1-T2)+t1             //[K]
printf("\n By LMTD approach area of heat exchanger is %f sq m\n",A);
printf("\nBy Ntu approach Area of heat exchanger is %f sq  m\n",A);
printf("\n Outlet temperature of cold water=%f K\n",t2)
```

Scilab code Exa 5.7 Shell and tube exchanger

```
clc;
clear;
//Example 5.7
mw_dot=10               //[kg/s]
Cpw=4.187               //[kJ/(kg.K)]
t2=318                  //[K]
t1=295                  //[K]
Q=mw_dot*Cpw*(t2-t1)        //[kJ/s]
Q=Q*1000                    //W
dT1=98                  //[K]
dT2=75                  //[K]
dTlm=(dT1-dT2)/log(dT1/dT2)          //[K]
hi=850              //[W/sq m.K]
id=0.027                //Inside dia[m]
od=0.031                    //Outside dia [m]
hio=hi*id/od                //[W/sq  m.K]
```

```
ho=6000      //Heat transfer coefficients [W/sq m.K]
Uo=1/(1/ho+1/hio)        //[W/sq m.K]
Ao=Q/(Uo*dTlm)           //[sq m]
L=4          //Length [m]
n=Ao/(%pi*od*L)          //[No. of tubes]
printf("\n Number of tubes required = %d\n",round(n));
```

Scilab code Exa 5.8 `Order of Scale resistance`

```
clc;
clear;
//Example 5.8
mdot=7250;              //Nitrobenzene in shell in [kg/h]
Cp=2.387;               //[kJ/(kg.K)]
mu=7*10^-4 ;            //Pa.s
k=0.151;                //[W/m.K]
T1=400;                 //[K]
T2=317;                 //[K]
t1=305;                 //[K]
t2=345;                 //[K]
dT1=T1-t2                 //[K]
dT2=T2-t1                 //[K]
dTlm=(dT1-dT2)/log(dT1/dT2)      //[K]
Q=mdot*Cp*(T1-T2)    //[kJ/h]
Q=Q*1000/3600              //[W]
n=166;                       //no of tubes
L=5;                         //[m]
Do=0.019;                    //[m]
Di=0.015                     //[m]
Ao=n*%pi*Do*L              //[sq m]
Uo=Q/(Ao*dTlm)             //[W/sq m.K]
Ud=Uo
//Shell side heat transfer coefficient
```

```
Pt=0.025                    //[m]
C_dash=Pt-(0.5*Do+0.5*Do)

//Shell side crossflow area
B=0.15                  //[m]
id=0.45         //[m]
as=id*C_dash*B/Pt         //[sq m]
//As there are two shell passes,area per pass is :
as_dash=as/2                //[sq m]

//Equivalent diameter of shell
De=4*(Pt^2-(%pi/4)*Do^2)/(%pi*Do)        //[m]

//Mass velocity on shell side
Gs=mdot/as_dash           //[kg/m^2.h]
Gs=Gs/3600                  //[kg/m^2.s]
mu=7*10^-4                  //Pa.s
Cp=Cp*1000                  //J/kg.K
Nre=De*Gs/mu      //Reynold number
Npr=Cp*mu/k       //Prandtls number
Nnu=0.36*Nre^0.55*Npr^(1.0/3.0) //Nusselts number
hi=1050                 //[W/sq m .K]
ho=Nnu*k/De             //[W/sq m.K]
Uo=1/(1/ho+(1/hi*(Do/Di)))            //[W/sq m K]
Uc=Uo
Rd=(Uc-Ud)/(Uc*Ud)                    //m^2.K/W
printf("\n Fouling factor=Sclae resistance=%f m^2.K/W\n",Rd);
```

Scilab code Exa 5.9 Length of tube required

```
clc;
clear;
//Example 5.9
k=0.628           //W/(m.K)
```

```
rho=980      //[kg/m^3]
mu=6*10^-4       //kg/(m.s)
Cpw=4.187         //kJ/(kg.K)
Cp=Cpw*10^3       //J/(kg.K)
Di=25            //[mm]
Di=Di/1000       //[m]
mw_dot=1200*10^-3*rho        //Mass flow rate of water [kg/h]
mw_dot=mw_dot/3600             //[kg/s]
Ai=(%pi*Di^2)/4               //Inside area of tube in sq m
G=mw_dot/Ai                  //kg/m^2.s
Nre=Di*G/mu                  //Reynolds number
Npr=Cp*mu/k                  //Pranddtl number
//Inside heat transfer coefficient
Nnu=0.023*Nre^0.8*Npr^0.4        //Nusselt number
hi=Nnu*k/Di              //[W/sq m.K]
ho=6000      //[W//sq m.K]
Do=0.028         //[m]
Dw=(Do-Di)/log(Do/Di)        //[m]
x=(Do-Di)/2                   //[m]
k2=348.9             //thermal conductivity of metal in [W/m.K]
Uo=1/((1/ho)+(1/hi)*(Do/Di)+(x/k2)*(Do/Dw))  //[W/sq m.K]
t1=303           //[K]
t2=343           //[K]
Q=mw_dot*Cpw*(t2-t1)         //[kJ/h]
Q=Q*1000               //[W]
Ts=393                       //[K]

dT1=Ts-t1                    //[K]
dT2=Ts-t2                    //[K]
dTlm=(dT1-dT2)/log(dT1/dT2)      //[K]
Ao=Q/(Uo*dTlm)           //[sq m]
L=Ao/(%pi*Do)            //Length
printf("\n therefore length of tube required is %f m\n",L);
```

Scilab code Exa 5.10 Suitability of Exchanger

```

clc;
clear;
//Example 5.10
m_dot=7250        //[kg/h] of nitrobenzene
Cp=2.387;              //[kJ/kg.K]
mu=7*10^-4;            //[kg/m.s]
k=0.151;               //[W/m.K]
vis=1;
Ft=0.9;               //LMTD correction factor
T1=400                //[K]
T2=317                //[K]
t1=333                //[K]
t2=300                //[K]
dT1=T1-t1            //[K]
dT2=T2-t2            //[K]
dTlm=(dT1-dT2)/log(dT1/dT2)        //[K]
//For nitrobenzene
Q=m_dot*Cp*(T1-T2)          //[kJ/h]
Q=Q*1000/3600                    //[W]
n=170             //No. of tubes
L=5       //[m]
Do=0.019              //[m]
Di=0.015              //[m]
Ao=n*%pi*Do*L         //[sq m]
Uo=Q/(Ao*Ft*dTlm)     //[W/sq m.K]
Ud=Uo             //[W/sq m.K]
B=0.15                //Baffle spacing [m]
Pt=0.025              //Tube pitch in [m]
C_dash=Pt-Do          //Clearance in [m]
id=0.45               //[m]

```

```
//Shell side cross flow area
as=id*C_dash*B/Pt               //[sq m]

//Equivalent diameter of shell
De=4*(Pt^2-(%pi/4)*(Do^2))/(%pi*Do)         //[m]

//Mass velocity on shell side
Gs=m_dot/as                 //[kg/(m.h)]
Gs=Gs/3600                  //[kg/m^2.s]
mu=7*10^-4              //[kg/m.s]
Cp=Cp*1000          //[J/kg.K]
Nre=De*Gs/mu            //Reynolds number
Npr=Cp*mu/k             //Prandtl number

//From empirical eqn:
mu_w=mu             //
Nnu=0.36*Nre^0.55*Npr^(1/3)
ho=Nnu*k/De             //[W/sq m.K]
hi=1050                 //Given [W/sq m.K]
Uo=1/(1/ho+(1/hi)*(Do/Di))       //[W/sq m.K]
Uc=Uo                   //W/sq m.K

//Suitability of heat exchanger
Rd_given=9*10^-4            //[W/sq m.K]
Rd=(Uc-Ud)/(Uc*Ud)            //[W/sq m.K]
printf("\n Rd calculated(%f W/m^2.K) is mazimum
   allowable scale resistance\n",Rd);
printf("\n\nAs Rd calculated (%f W/sq m.K)(OR
   1.1*10^-3) is more than Rd given(%f W/sq m,K),the
    given heat exchanger is suitable\n",Rd,Rd_given)
   ;
```

Scilab code Exa 5.11 Number of tubes required

```
clc;
```

```
clear;
//Example 5.11
mw_dot=1720;          //water in [kg/h]
t1=293 ;              //[K]
t2=318 ;              //[K]
Cpw=4.28;             //[kJ/kg.K]
Q=mw_dot*Cpw*(t2-t1)     //[kJ/h]
Q=Q*1000/3600            //W
lambda=2230;          //[kJ/kg]
dT1=90 ;              //[K]
dT2=65 ;              //[K]
dTlm=(dT1-dT2)/log(dT1/dT2)      //[K]

//Calculation of inside heat transfer coefficient
Di=0.0225;              //[m]
u=1.2 ;          //[m/s]\
rho=995.7 ;           //[kg/m^3]
v=0.659*10^-6            //[m/s]
mu=v*rho         //[kg/m.s]
Nre=Di*u*rho/mu      //reynolds number
Cp=Cpw*1000          //[J/kg.K]
k=2.54 ;      //[kJ/h.m.K]
k=k*1000/3600            //[W/m.K]
Npr=Cp*mu/k              //Prandtl number
Nnu=0.023*Nre^0.8*Npr^0.4        //Nusselt number
hi=k*Nnu/Di              //[W/sq m.K]
ho=19200             //[kJ/h.m^2.K]
ho=ho*1000/3600      //[W/m^2.K]
Do=0.025         //[m]
Dw=(Do-Di)/log(Do/Di)        //[m]
x=(Do-Di)/2      //[m]
kt=460           //For tube wall material [kJ/h.m.K]
kt=kt*1000/3600          //[W/m.K]
Uo=1/(1/ho+(1/hi)*(Do/Di)+(x/kt)*(Do/Dw))        //[W/sq m.K]
//Q=Uo*Ao*dTlm
Ao=Q/(Uo*dTlm)           //[sq  m]
L=4              //Tube length in [m]
```

```
n=Ao/(%pi*Do*L)          //[Number of tubes]
n=round(n)          //Approximate
printf("\n Number of tubes reuired= %d",n);
```

Scilab code Exa 5.12 `Shell and tube heat exchanger`

```
clc;
clear;
//Example 5.12
t1=290          //Inlet temperature of cooling water [K]
ho=2250          //Heat transfer coefficient based on inside area in [W/sq m.K]
lambda=400          //[kJ/kg] LAtent heat of benzene
mb_dot=14.4          //[t/h] Condensation rate of benzene vapour
Cpw=4.187          //Specific heat
//With no Scale

Q=mb_dot*1000*lambda          //Heat duty of condenser in [kJ/h]
Q=(Q/3600)*1000          //[W]
//Shell and tube type of heat exchanger is used as a single pass surface condenser
Di=0.022          //I.D of tube[m]
L=2.5          //Length of each tube in [m]
n=120          //Number of tubes
A=%pi*Di*L          //Area of heat transfer per metre length in [m^2/m]
A=n*A          //Total area of heat transfer in [m^2]
Ai=(%pi/4)*Di^2 //Cross-sectional area of each tube in [m^2]
Ai=n*Ai          //Total area of flow in [m^2]
u=0.75          //Velocty of water [ms^-1]
```

```
V=u*Ai            //Volumetric flow of water
rho=1000          //[Density of water in [kg/m^3]]
mw_dot=V*rho      //Mass flow rate of water in  [kg/s]

//Heat balance

//Q=mw_dot*Cpw*(t2-t1)
t2=Q/(mw_dot*Cpw*1000)+t1         //[K]
T=350        //Condensing benzene temperature in [K]
dT1=T-t1     //[K]
dT2=T-t2     //[K]
dTlm=(dT1-dT2)/log(dT1/dT2)      //LMTD
U=Q/(A*dTlm)                     //[W/m^2.K]
U=round(U)
//Neglecting resistance ,we have:
hi=1/(1/U-1/ho)           //[W/m^2.K]
//hi is proportional to u^0.8
C=hi/(u^0.8)          //Constant

//With Scale

Rd=2.5*10^-4          //[m^2 K./W]
//1/U=1/hi+1/ho+Rd
//U=hi/(1+3.38*u^0.8)
//mw_dot=rho*u*Ai       //[kg/s]
//Let t2 be the outlet temperature of water
//Q=mw_dot*Cpw*(t2-t1)
//t2=Q/(mw_dot*Cpw)+t1
dT1=60
//dT2=T-(t1+8.373/u)
//dTlm=8.373/(u*log(60*u/(60*u-8.373)))
//Q=U*A*dTlm
//1.89=((u^-0.2)/(1+3.38*u^0.8))*(1/log((60*u)/60*u-8.373)
//If we assume values of u greater than 0.75 m/s
//For u=3.8       //[ms^-1]
u=3.8             //]ms^-1]
printf("\nWater velocity must be 3.88 ms^-1");
```

Scilab code Exa 5.13 `Length of pipe in Exchanger`

```
clc;
clear;
//Example 5.13
mh_dot=1.25             //[kg/s]
Cpw=4.187*10^3          //Heat capacity of water in [J/kg.K]
lambda=315              //[kJ/kg]
Q=mh_dot*lambda         //Rate of heat transfer from vapour      [kJ/s]
Q=Q*10^3                //[W]
Ts=345                  //Temperature of condensing vapour[K]
t1=290                  //Inlet temperature of water [K]
t2=310                  //Outlet temperature of water[K]
dT1=Ts-t1               //[K]
dT2=Ts-t2               //[K]
dTlm=(dT1-dT2)/log(dT1/dT2)            //[K]
//Heat removed from vapour = Heat gained
mw_dot=Q/(Cpw*(t2-t1))      //[kg/s]
hi=2.5                      //[kW/sq m.K]
hi=hi*1000                  //[W/sq m.K]
Do=0.025                    //[m]
Di=0.020                    //[m]
hio=hi*(Di/Do)              //Inside heat transfer cosfficient referred to outside dia in [W/sq m.K]
ho=0.8                      //Outside heat tranbsfer  coefficient in [kW/sq m.K]
ho=ho*1000                  //[W/sq m.K]
Uo=1/(1/ho+1/hio)           //[W/sq m.K]
//Ud is 80% of Uc
Ud=(80/100)*Uo             //[W/sq m.K]
Ao=Q/(Ud*dTlm)              //[sq m]
```

```
L=1                           //[m]
A=%pi*Do*L                    //Outside area of pipe per m length of pipe
len=Ao/A                      //Total length of piping required.
rho=1000                      //[kg/m^3]
V=mw_dot/rho                  //[m^3/s]
v=0.6                         //[m/s]
a=V/v                         //Cross-sectional area for flow pass [sq m]
a1=(%pi*Di^2)/4               //[sq m]
//for single pass on tube side fluid(water)
n=round(a/a1)                        //No. of tubes per pass
l=len/n                       //Length of each tube in [m]
//For two passes on water side:
tn=2*n                        //Total no of tubes
l2=len/tn                     //Length of each tube in [m]
//For four passes on water side/tube side
tn2=4*n                       //Total no. of tubes
l3=len/tn2                    //Length of each tube in [m]

printf("\nNo. of tubes=%d ,\nLength of tube=%f m",tn2,l3);
```

Scilab code Exa 5.14 `Dirt factor`

```

clc
clear
//Example 5.14
//Properties of crude oil:
```

```
Cpc=1.986   ;                //[kJ/(kg.K)]
mu1=2.9*10^-3;               //[N.s/sq m]
k1=0.136     ;               //[W/m.K]

rho1=824      ;              //[kg/m^3]

//Properties of bottom product:
Cp2=2.202      ;            //[kJ/kg.K]
rho2=867        ;           //[kg/m^3]
mu2=5.2*10^-3   ;           //[N.s/sq m]
k2=0.119        ;           //[W/sq m.K]

mc_dot=135000    ;             //Basis: cruid oil flow rate in [kg/h]
m_dot=106000     ;             //Bottom product flow rate inn [kg/h]
t1=295            ;         //[K]
t2=330            ;         //[K]
T1=420            ;         //[K]
T2=380            ;         //[K]
dT1=T1-t2                  //[K]
dT2=T2-t1                  //[K]
dTlm=(dT1-dT2)/log(dT1/dT2)           //[K]
Q=mc_dot*Cpc*(t2-t1)                  //kJ/h
Q=Q*1000/3600                         //[W]

//Shell side calculations:
Pt=25             ;                     //[mm]
Pt=Pt/1000        ;                    //[m]
B=0.23            ;                     //[m]
Do=0.019          ;                      //[m] Outside diameter for square pitch
c_dash=Pt-Do                          //Clearance in [m]
id=0.6            ;                      //[m]
as=id*c_dash*B/Pt                       // Cross flow area of shell [sq m]
//since there is a Calculaiton mistake ,we take:
```

```
as=0.0353;
Gs=m_dot/as                               //Shell side mass velocity in [kg/sq m.h]
Gs=Gs/3600;                                //[kg/sq m.s]
De=4*(Pt^2-(%pi/4)*Do^2)/(%pi*Do)         //[m]
Nre=De*Gs/mu2                             //Reynolds number
Npr=Cp2*1000*mu2/k2                            //Prandtl number
muw=mu2                                  //Since mu/muw=1
Nnu=0.36*(Nre^0.55)*Npr^(1.0/3.0)*(mu2/muw)^(0.14)        //Nusselt number
ho=Nnu*k2/De                             //[W/sq m.K]

//Tube side heat transfer coefficient:
n=324      ;              //No. of tubes
n_p=324/2   ;             //No.of tubes per pass
t=2.1         ;           //Thickness in [mm]
t=t/1000     ;            //[m]
Di=Do-2*t                  //I.d of tube in [m]
A=(%pi/4)*(Di^2)         //Cross-sectional area of one tube in [sq m]
A_p=n_p*A                //Total area for flow per pass in [sq m]
G=mc_dot/A_p             //[kg/sq m h]
G=G/3600                 //[kg/sq m.s]
Nre=Di*G/mu1             //Reynolods number
Npr=42.35 ;               //Prandtl number
Nnu=0.023*(Nre^0.8)*(Npr^0.4)       //Nusselt number
hi=Nnu*k1/Di                              //[W/sq m.K]
hio=hi*Di/Do                             //[W/sq m.K]
Uo=1/(1/ho+1/hio)                        //[W/sq m.K]
Uc=Uo
L=4.88 ;                                  //Length of tube in [m]
Ao=n*%pi*Do*L                            //[sq m]
Ud=Q/(Ao*dTlm)                           //[W/sq m.K]
Rd=(Uc-Ud)/(Uc*Ud)                       //[m^2.K/W]
```

```
printf("\n The calculation of line no.36 to calculated as is wrongly done in Book by printing 0.0353,,..which is wrong\n");
printf("\nRd=%f K/w,or 7.34*10^-4 which is less than the provided,so this if installed will not give required temperarues without frequent cleaning\n\n",Rd);
```

Scilab code Exa 5.15 Heat transfer area

```
clc;
clear;
//Example 5.15

//CASE I:
Cp=4*10^3;           //[J/kg.K]
t1=295;              //[K]
t2=375;              //[K]
sp=1.1;              //Specific gravity of liquid
v1=1.75*10^-4;        //Flow of liquid in [m^3/s]
rho=sp*1000         //[kg/m^3]
m_dot=v1*rho         //[kg/s]
Q=m_dot*Cp*(t2-t1)  //[W]
T=395;               //[K]
dT1=T-t1            //[K]
dT2=T-t2            //[K]
dTlm=(dT1-dT2)/log(dT1/dT2) //[K]
U1A=Q/dTlm          //[W/K]

//CASE-II
v2=3.25*10^-4                   //Flow in [m^3/s]
T2=370                          //[K]
m_dot=v2*rho          //[kg/s]
Q=m_dot*Cp*(T2-t1)                //[W]
dT1=T-t1                          //[K]
```

```
dT2=T-T2                                //[K]
dTlm=(dT1-dT2)/log(dT1/dT2)             //[K]
U2A=Q/dTlm                              //[W/K]
//since u is propn to v
//hi =C*v^0.8

U2_by_U1=U2A/U1A

ho=3400                               //Heat transfer coeff for condensing steam in [W/sq m.K]
C=poly(0,"C")
//Let C=1 and v=v1
//C=1;
v=v1;                                 //=1.75*10^-4 m^3/s
hi=C*v^0.8
U1=1/(1/ho+1/hi)                        //

//When v=v2
v=v2;
hi=C*v^0.8
U2=1/(1/ho+1/hi)                      //

//Since U2=1.6U1
//On solving we get:
C=142497
v=v1
hi=C*v^0.8
U1=1/(1/ho+1/hi)                        //
A=U1A/U1                      //Heat transfer area in [sq m]
printf("\n Overall heat transfer coefficient is %f W/sq m.K and\n\nHeat transfer area is %f sq m",U1,A);
```

Scilab code Exa 5.16 `Oil Cooler`

```
clc;
clear;
//Example 5.16
mo_dot=6*10^-2                    //[kg/s]
Cpo=2*10^3                            //Specific heat of oil in [J/kg.K]
Cpw=4.18*10^3                     //Specific heat of water in [J/kg.K]
T1=420                            //[K]
T2=320                            //[K]
T=290                             //[K] Water entering temperature
Q=mo_dot*Cpo*(T1-T2)              //[J/s]=[W]
//Heat given out =Heat gained
t2=Q/(mo_dot*Cpw)+T               //[K]
dT1=T1-t2                         //[K]
dT2=T2-T                          //[K]
dTlm=(dT1-dT2)/log(dT1/dT2)       //[K]
hi=1.6*1000                   //[W/sq m.K]
ho=3.6*1000                 //[W/sq m.K]
U=1/(1/ho+1/hi)   //[W/sq m.K]
A=Q/(U*dTlm)          //[sq m]
D=0.025               //[m]
L=A/(%pi*D)       //[m]
printf("\n Length of tube required = %f m",L);
```

Scilab code Exa 5.17 `Countercurrent flow heat exchanger`

```
clc;
clear;
//Example 5.17
mb_dot=1.25           //Benzene in [kg/s]
Cpb=1.9*10^3               //For benzene in [J/kg.K]
Cpw=4.187*10^3             //in [J/kg.K]
T1=350                //[K]
```

```
T2=300              //[K]
Q=mb_dot*Cpb*(T1-T2)    //[W]
t1=290                  //[K]
t2=320                  //[K]
dT1=T1-t2               //[K]
dT2=T2-t1               //[K]
dTlm=(dT1-dT2)/log(dT1/dT2) //[K]
mw_dot=Q/(Cpw*(t2-t1))        //Minimum flow rate of water in [kg/s]
hi=850                      //[W/sq m.K]
ho=1700                     //[W/sq m.K]
Do=0.025                    //[m]
Di=0.022                    //[m]
x=(Do-Di) /2                    //Thickness in [m]
hio=hi*(Di/Do)              //[W/sq m.K]
Dw=(Do-Di)/log(Do/Di)       //[m]
k=45                        //[W/m.K]
Uo=1/((1/ho)+(1/hio)+(x/k)*(Do/Dw)) //[W/sq m.K]
Ao=Q/(Uo*dTlm)                  //[sq m]
L=1                             //Length in [m]
area=%pi*Do*L                   // Outside surface area of tube per i m length
Tl=Ao/area                      //Total length of tubing required in [m]
printf(”\nTotal length of tubing required=%d m”,round(Tl));
```

Scilab code Exa 5.18 `Vertical Exchanger`

```
clc;
clear;
//Example 5.18
m_dot=4500          //Benzene condensation rate in [kg/h]
lambda=394          //Latent heat of condensation of
```

```
    benzene in [kJ/kg]
Q=m_dot*lambda      //[kJ/h]
Q=Q*1000/3600       //[W]
Cpw=4.18            //[kJ/kg.K]
t1=295              //[K]
t2=300              //[K]
//For water :
mw_dot=Q/(Cpw*1000*(t2-t1))       //[kg/s]
rho=1000                      //[kg/m^3
V=mw_dot/rho           //Volumetric flow rate in [m
   ^3/s]
u=1.05                 //[m/s]
A=V/u                  //Cross-sectional area
   required in [sq m]

//For tube:
x=1.6               //thickness in [mm]
x=x/1000            //[m]
Do=0.025            //[m]
Di=Do-2*x           //[m]
A1=(%pi*Di^2)/4      //Of one tube [sq m]
n=A/A1               //No. of tubes reuired
n=round(n)
L=2.5               //Length of tube in [m]
Ao=n*%pi*Do*L       //Surface area for heat transfer
    in [sq  m]
Ts=353              //Condensing temp of benzene in
   [K]
T1=295              //Inlet temperature in [K]
T2=300              //Outlet temperature in [K]
dT1=Ts-T1           //[K]
dT2=Ts-T2           //[K]
dTlm=(dT1-dT2)/log(dT1/dT2)     //[K]
Uo=Q/(Ao*dTlm)          //[W/sq mK]
Ud=Uo                   //[W/sq m.K]

//OVERALL HEAT TRANSFER COEFFCIENT:
//Inside side:
```

```
T=(T2+T1)/2                //[K]

hi=1063*((1+0.00293*T)*u^0.8)/(Di^0.2)          //[W/sq m.K]
hio=hi*(Di/Do)                                   //[W/sq m.K]
Dw=(Do-Di)/log(Do/Di)                            //[m]
k=45                    //For tube in [W/(m.)]

//Outside of tube:
mdot_dash=1.25/n                      //[kg/s]
M=mdot_dash/(%pi*Do)                  //[kg/(m.s)]
k=0.15                                //[W/(m.K)]
rho=880                               //[kg/m^3]
mu=0.35*10^-3                         //[N.s/sq m]
g=9.81                                //[m/s^2]  Acceleration due to gravity
hm=(1.47*((4*mdot_dash)/mu)^(-1/3))/(mu^2/(k^3*rho^2*g))^(1/3)  //[W/sq m.K]
ho=hm                                 //[W/sq m.K]
k=45                    //[W/m]
Uo=1/(1/ho+1/hio+(x*Do)/(k*Dw))
//Uo=1/(1/ho+1/hio+(x*Do/(k*Dw)))      //Overall heat transfer coefficient in [W/sq m.K]
Uc=Uo                                        //[W/sq m.K]

Rd=(Uc-Ud)/(Uc*Ud)                           //Maximum allowable sclae resistance in [K/W]
printf("\n Uc(%f) is in excess of Ud(%f),therefore we allow for reasonable scale resistance,\nRd=%f K/W\n",Uc,Ud,Rd);
printf("\n No.of tubes = %d ",n)
```

Scilab code Exa 5.19 Countercurrent Heat Exchanger

```
clc;
clear;
//Example 5.19
mw_dot=5;                //Water flow rate in [kg/s]
Cpw=4.18;                //Heat capacity of water [kJ/kg
   .K]
t1=303;                  //[K]
t2=343;                  //[K]
Q=mw_dot*Cpw*(t2-t1)        //[kJ/s]
Q=Q*1000;                    //[W]
T1=413;                      //[K]
T2=373;                      //[K]
dT1=T1-t2                   //[K]
dT2=T2-t1                   //[K]
dTlm=dT1                     ///[K]
hi=1000;             //[W/sq m.K]
ho=2500;             //[W/sq m.K]
Rd=1/(0.714*1000)          //Fouling factor[m^2.K/KW]
U=1/(1/hi+1/ho+Rd)          //[W/sq m.K]
A=Q/(U*dTlm)                //[sq m]
printf("\nHeat transfer area is %f sq m",A);
```

Scilab code Exa 5.20 Number of tube side pass

```
clc;
clear;
//Example 5.20
Cpo=1.9              //Heat capacity for oil[kJ/kg.K]
Cps=1.86           //Heat capacity for steam [kJ/kg.K]
ms_dot=5.2          //Mass flow rate in [kg/s]
T1=403              //[K]
T2=383              //[K]

Q=ms_dot*Cps*(T1-T2)           //[kJ/s]
Q=Q*1000                       //[W]
```

```
t1=288;                            //[K]
t2=358;                            //[K]
dT2=T1-t2                        //[K]
dT1=T2-t1                        //[K]
dTlm=(dT1-dT2)/log(dT1/dT2)      //LMTD in [K]
U=275 ;                              //Overall heat transfer coeffcient in [W//sq m.K]
Ft=0.97                            //LMTD correction factor
A=Q/(U*Ft*dTlm)                    //[sq m]
printf("\nHeat exchanger surface area is %f sq m",A);
```

Scilab code Exa 5.21 Number of tubes passes

```
clc;
clear;
//Example 5.21
mc_dot=3.783;           //Cold water flow rate[kg/s]
mh_dot=1.892;         //Hot water flow rate [kg/s]
Cpc=4.18;             //Sp heat of cold water [kJ/(kg.K)]
T1=367;               //[K]
t2=328;               //[K]
t1=311;               //[K]
Cph=4.18;             //Specific heat of hot water [kJ/(kg.K)]
rho=1000;               //Density [kg/m^3]
D=0.019;                //Diameter of tube in [m]
U=1450 ;                //Overal heat transfer coefficient in [W/sq m.K]
T2=T1-mc_dot*Cpc*(t2-t1)/(mh_dot*Cph)    //[K]
Q=mc_dot*Cpc*(t2-t1)          //[kJ/s]
Q=Q*1000                      //[W]
//For counterflow heat exchanger
```

```
dT1=T1-t2                    //[K]
dT2=17;                      //[K]
dTlm=(dT1-dT2)/log(dT1/dT2)  //[K]
lmtd=dTlm                    //LMTD
Ft=0.88                      //LMTD correction factor
A=Q/(U*dTlm)                 //[sq m]
u=0.366;                     //Velocity through tubes [ms^-1]
Ai=mc_dot/(rho*u)            //Total flow Area in [sq m]
n=Ai/((%pi/4)*(D^2))         //No. of tubes
L=1                          //Per m length[m]
sa=%pi*D*L                   //S.S per tube per 1 m length
L=A/(n*%pi*D)                //Length of tubes in [m]
printf("\nThe length is more than allowable 2.44 m length,so we must use more than one tube \n");

//For 2passes on the tube side
A=Q/(U*Ft*lmtd)       //[sq m]
L=A/(2*n*%pi*D)       //Length in [m]
printf("\n This length is within 2.44 m requirement, so the design choice is \n\n");
printf("\nType of heat exchanger : 1-2 Shell and tube heat exchanger\n")
printf("\nNo of tubes per pass= %d\n",round(n));
printf("\nLength of tube per pass=%f m\n ",L);
```

Scilab code Exa 5.22 `Outlet temperature for hot and cold fluids`

```
clc;
clear;
//Example 5.22
mh_dot=16.67;         //Mass flow rate of hot fluid in [kg/s]
```

```
mc_dot=20;          //Mass flow rate of cold fluid in [kg/s]
Cph=3.6;             //Sp heat of hot fluid in [kJ/kg.K]
Cph=Cph*1000;         //Sp heat of hot fluid in [J/kg.K]
Cpc=4.2;             //Sp heat of cold fluid in [kJ/(kg.K)]
Cpc=Cpc*1000;         //Sp heat of cold fluid in [J/(kg.K)]
U=400;               //Overall heat transfer coefficient in [W/sq m.K]
A=100;               //Surface area in [sq m]
mCp_h=mh_dot*Cph      //[J/s] or [W/K]
mCp_c=mc_dot*Cpc      //[J/s] or [W/K]
mCp_small=mCp_h      //[W/K]
C=mCp_small/mCp_c    //Capacity ratio
ntu=U*A/mCp_small    //NTU
T1=973;              //Hot fluid inlet temperature in [K]
t1=373;              //Cold fluid inlet temperature in [K]
//Case 1:Countercurrent flow arrangement
E=(1-%e^(-(1-C)*ntu))/(1-C*%e^(-(1-C)*ntu)) //Effectiveness
//W=T1-T2/(T1-t1)  therefore:
T2=T1-E*(T1-t1)      //[K]
printf("\nExit temperature of hot fluid is %d K",round(T2));
t2=mCp_h*(T1-T2)/(mCp_c)+t1      //[From energy balance eqn in ][K]
printf("\nExit temperature of cold fluid is %d K(%d C)\n",round(t2),round(t2-273));

//Case 2:Parallel flow arrangement
E1=(1-%e^(-(1+C)*ntu))/(1+C)
//In the textbok here is a calculation mistake,and the value of E is takne as E=0.97
```

```

T2=T1-E1*(T1-t1)      //[K]
t2=mCp_h*(T1-T2)/(mCp_c)+t1      //[From energy balance eqn in ][K]
printf("\nExit temperature of Hot water=%f K\n",T2);
printf("\nExit temperature of cold water=%f K\n",t2);
```

Scilab code Exa 5.23 `Counterflow concentric heat exchanger`

```
clc;
clear;
//Example 5.23
Cpo=2131;         //Sp heat of oil in [J/kg.K]
Cpw=4187;         //Sp heat of water in [J/kg.K]
mo_dot=0.10;      //Oil flow rate in [kg/s]
mw_dot=0.20;       //Water flow rate in [kg/s]
U=380;            //Overall heat transfer coeff in [W/sq m.K]
T1=373;           //Initial temp of oil [K]
T2=333;           //Final temperature of oil [K]
t1=303;           //Water enter temperature in [K]
t2=t1+mo_dot*Cpo*(T1-T2)/(mw_dot*Cpw)    //[K]
//1.LMTD method
dT1=T1-t2             //[K]
dT2=T2-t1             //[K]
dTlm=(dT1-dT2)/log(dT1/dT2)      //[K]
lmtd=dTlm;             //[K]
Q=mo_dot*Cpo*(T1-T2)          //[J/s]
A=Q/(U*dTlm)                  //[sq m]
Do=0.025;                     //Inner tubve diameter [m]
L=A/(%pi*Do)                  //Length in [m]

//2.NTU method
```

```
mCp_c=mw_dot*Cpw                    //[W/K]
mCp_h=mo_dot*Cpo                    //[W/K]
printf("\n In textbook this value of mCp_h is wrongly calculated as 231.1  so we will take this only for calculation\n");
mCp_h=231.1;                    //[W/K]
//mCp_h is smaller
C=mCp_h/mCp_c
E=(T1-T2)/(T1-t1)                     //Effeciency
//For countercurrent flow
deff('[x]=f(ntu)','x=E-(1-%e^(-(1-C)*ntu))/(1-C*%e^(-(1-C)*ntu))')
ntu=fsolve(1,f)
A=ntu*mCp_h/U        //[sq m]
A=0.56      //Approximately
L1=A/(%pi*Do)         //Length in [m]
printf("\nFrom LMTD approach:\n length=%f m\n",L);
printf("\nFrom NTU method:\n length=%f m\n",L1);
```

Scilab code Exa 5.24 Number of tubes required

```

clc;
clear;
//Example 5.24
ho=200;      //[W/sq m.K]
hi=1500;     //[W/sq m.K]
Cpw=4.2;      //Sp heat of Water in [kJ/(kg.K)]
Cpo=2.1;      //Sp heat of Oil in [kJ/(kg.K)]
E=0.8;       //Effectiveness
k=46;        //[W/m.K]
m_dot=0.167;     //[kg/s]

mCp_oil=2*m_dot*Cpo*1000       //For oil [W/K]
//mCp_oil is wrongly calculated as 710.4
```

```
mCp_water=m_dot*Cpw*1000       //For water [W/K]
//mCp_oil is wrongly calculated as 710.4
//NOTE:The above two values are wrongly calculated
   in book as 710.4
//so we take here:
mCp_small=710.4      //[W/K]
//Since both mCp_water and mCp_oil are equal ,
   therefore:
C=1;

deff('[x]=f(ntu)','x=E-(ntu/(1+ntu))');
ntu=fsolve(1,f)
id=20;       //Internal diameter in [mm]
od=25;       //External diameter in [mm]
hio=hi*id/od          //[W/sq m.K]
Dw=(od-id)/log(od/id)    //[mm]
Dw=Dw/1000               //[m]
x=(od-id)/2              //[mm]
x=x/1000             //[m]
Do=0.025             //External dia in [m]
L=2.5;               //Length of tube in [m]
Uo=1/(1/ho+1/hio+(x/k)*(Dw/Do))      //[W/sq m.K]
A=ntu*mCp_small/Uo    //Heat transfer area in [sq m]
n=A/(%pi*Do*L)       //No of tubes
printf("\nNo. of tubes required = %d",round(n+1));
```

Scilab code Exa 5.25 Parallel and Countercurrent flow

```
clc;
clear;
//Example 5.25

//(i)Parallel flow
T1=633;      //[K]
t2=303;      //[K]
```

```
T2=573;      //[K]
t1=400;      //[K]
dT1=T1-t2;   //[K]
dT2=T2-t1;   //[K]
mh_dot=1.2;  //[kg/s]
U=500;       //Overall heat transfer coefficient in [W/sqm.K]
Cp=2083;         //Sp.heat of oil J/kg.K
dTlm=(dT1-dT2)/log(dT1/dT2) //[K]
Q=mh_dot*Cp*(T1-T2)         //[W]
A=Q/(U*dTlm)                //[sq m]

//(ii)Counter current flow
dT1=T1-t1;             //[K]
dT2=T2-t2;            //[K]
dTlm=(dT2-dT1)/log(dT2/dT1)      //[K]
A1=Q/(U*dTlm)          //[sq m]
printf("\nFor parallel flow,Area = %f sq m \n For countercurrent flow,Area=%f sq m\n",A,A1);
printf("\n\nFor the same terminal temperatures of the fluid ,the surface area for the counterflow arrangement\n is less than the required for the parallel flow\n")
```

Chapter 6

Evaporation

Scilab code Exa 6.1 `Boiling point Elevation`

```
clc;
clear;
//Example6.1
T=380       //B.P of solution[K]
T_dash=373      //B.P of water [K]
BPE=T-T_dash        //Boiling point elevation in [K]
Ts=399      //Saturating temperature in [K]
DF=Ts-T     //Driving force in [K]
printf("\nBoiling point of elevation of the solution
    is %d K \n",BPE);
printf("\nDriving forve for heat transfer is %d K \n
   ",DF)
```

Scilab code Exa 6.2 `Capacity of evaporator`

```
clc;
clear;
//Example 6.2
```

```
m_dot=10000     //Weak liquor entering in [kg/h]
fr_in=0.04       //Fraciton of caustic soda IN i.e 4 %
fr_out=0.25    //Fraciton of caustic soda OUT i.e 25 %
//Let mdash_dot be the kg/h of thick liquor leaving
mdash_dot=fr_in*m_dot/fr_out        //[kg/h]

//Overall material balance
//kg/h of feed=kg/h of water evaporated +kg/h of thick liquor
//we=water evaporated in kg/h
//Therefore
we=m_dot-mdash_dot      //[kg/h]
printf("\n Capacity of evaporator is %d kg/h",we);
```

Scilab code Exa 6.3 Economy of Evaporator

```
clc;
clear;
//Exmaple 6.3
ic=0.05     //Initial concentration (5%)
fc=0.2      //Final concentration   (20%)
T_dash=373      //B.P of water in [K]
bpe=5       //Boiling point elevation[K]
mf_dot=5000       //[Basis] feed to evaporator in [kg/h]
//Material balance of solute
mdash_dot=ic*mf_dot/fc       //[kg/h]
//Overall material balance
mv_dot=mf_dot-mdash_dot      //Water evaporated [kg/h]
lambda_s=2185        //Latent heat of condensation of steam[kJ/kg]
lambda_v=2257       //Latent heat of vaporisation of
```

```
    water [kJ/kg]
lambda=lambda_v     //[kJ/kg]
T=T_dash+bpe        //Temperature of thick liquor[K]
Tf=298       //Temperature of feed [K]
Cpf=4.187       //Sp. heat of feed in [kJ/kg.K]
//Heat balance over evaporator=ms_dot
ms_dot=(mf_dot*Cpf*(T-Tf)+mv_dot*lambda)/lambda_s
   //Steam consumption [kg/h]
Eco=mv_dot/ms_dot       //Economy of evaporator
Ts=399       //Saturation temperature of steam in [K]
dT=Ts-T      //Temperature driving force [K]
U=2350       //[W/sq m.K]
Q=ms_dot*lambda_s       //Rate of heat transfer in [
   kJ/kg]
Q=Q*1000/3600           //[J/s]=[W]
A=Q/(U*dT)              //Heat transfer area in [sq
   m]
printf("\nANSWER Economoy pf evaporator is %f \n",
   Eco);
printf("\nHeat tarnsfer area to be provided = %f sq
   m\n",A);
```

Scilab code Exa 6.4 Steam economy

```

clc;
clear;
//Example 6.4
Cpf=3.98        //Specific heat of feed in kJ/(kg.K)
lambda_s=2202    //Latent heat of conds of heat at
   0.2MPa in [kJ/kg]
lambda=2383     //Latent heat of vaporisation of
   water aty 323 [kJ/kg
ic=0.1          //Initial concentration of soilds in
    [%]
```

```
fc=0.5           //Final concentration
m_dot=30000      //Feed to evaporator in [kg/h]
mdash_dot=ic* m_dot/fc  //Mass flow rate of thick liquor in [kg/h]
mv_dot=m_dot-mdash_dot       //Water evaporated in [kg/h]

//Case 1: Feed at 293K
mf_dot=30000        //[kg/h]
mv_dot=24000        //[kg/h]
Cpf=3.98         //[kJ/(kg.K)]
Ts=393       //Saturation temperature of steam in [K]
T=323        //Boiling point of solution [K]
lambda_s=2202        //Latent heat of condensation [kJ/kg]
lambda=2383      //Latent heat of vaporisation[kJ/kg]
Tf=293           //Feed temperature
//Enthalpy balance over the evaporator:
ms_dot=(mf_dot*Cpf*(T-Tf)+mv_dot*lambda)/lambda_s         //Steam consumption[kg/h]
eco=(mv_dot/ms_dot)          //Steam economy
printf("\nWhen Feed introduced at 293 K ,Steam economy is %f\n",eco);
dT=Ts-T                      //[K]
U=2900           //[W/sq m.K]
Q=ms_dot*lambda_s                //Heat load =Rate of heat transfer in [kJ/h]
Q=Q*1000/3600                //[J/s]
A=Q/(U*dT)               //Heat transfer area required [sq m]
printf("\n ANSWER-(i)\n\n At 293 K,Heat transfer area required is %f sq m\n",A);

//Case2: Feed at 308K
Tf=308       //[Feed temperature][K]
ms_dot=(mf_dot*Cpf*(T-Tf)+mv_dot*lambda)/lambda_s            //Steam consumption in [kg/h]
eco=mv_dot/ms_dot                    //Economy of
```

```
evaporator
printf("\n ANSWER-(ii)\n\n When T=308 K \nEconomy of evaporator is %f\n",eco);
Q=ms_dot*lambda_s                   //[kJ/h]
Q=Q*1000/3600                       //[J/s]
A=Q/(U*dT)                          //Heat transfer area required [sq m]
printf('\nANSWER-(iii) \n When T=308 K,\nHeat transfer Area required is %f sq m\n",A);
```

Scilab code Exa 6.5 Evaporator economy

```
clc;
clear;
//Example 6.5
m_dot=5000  //Feed to the evaporator [kg/h]
Cpf=4.187           //Cp of feed in [kJ/kg.K]
ic=0.10             //Initial concentration
fc=0.4              //Final concentration
mdash_dot=m_dot*ic/fc               //[kg/h] of thick liquor
mv_dot=m_dot-mdash_dot              //Water evaporated in[kg/h]
lambda_s=2162               //Latent heat of condensing steam [kJ/kg]
P=101.325       //Pressure in the evaporator[kPa]
bp=373          //[K]
Hv=2676     //Enthalpy of water vapor [kJ/kg]
H_dash=419          //[kJ/kg]
Hf=170          //[kJ/kg]
ms_dot=(mv_dot*Hv+mdash_dot*H_dash-m_dot*Hf)/lambda_s           //Steam consumption in [kg/h]
eco=mv_dot/ms_dot               //Steam economy of evaporator
Q=ms_dot*lambda_s               //[kJ/h]
```

```
U=1750          //[W/sq m.K]
dT=34           //[K]
Q=Q*1000/3600                   //[J/s]
A=Q/(U*dT)                      //[sq m]
printf("\n Heat transfer area to be provided is %f sq m",A);
```

Scilab code Exa 6.6 `Single effect Evaporator`

```
clc;
clear;
//Example 6.6
mf_dot=5000                 //[kg/h]
ic=0.01                 //Initial concentration [kg/h]
fc=0.02                 //Final concentration  [kg/h]
T=373                   //Boiling pt of saturation in [K]
Ts=383                  //Saturation temperature of steam in [K]
mdash_dot=ic*mf_dot/fc    //[kg/h]
mv_dot=mf_dot-mdash_dot       //Water evaporated in [kg/h]
Hf=125.79               //[kJ/kg]
Hdash=419.04                //[kJ/kg]
Hv=2676.1               //[kJ/kg]
lambda_s=2230.2         //[kJ/kg]
ms_dot=(mdash_dot*Hdash+mv_dot*Hv-mf_dot*Hf)/lambda_s   //Steam flow rate in [kg/h]
eco=mv_dot/ms_dot               //Steam economy
Q=ms_dot*lambda_s               //Rate of heat transfer in [kJ/h]
Q=Q*1000/3600                   //[J/s]
dT=Ts-T                         //[K]

A=69            //Heating area of evaporator in [sq
```

```
   m]
22 U=Q/(A*dT)      //Overall heat transfer coeff in [W/sq m.K]
23 printf("\nSteam economy is %f\n",eco);
24 printf("\n\nOverall heat transfer coefficient is %d W/sq m.K",round(U));
```

Scilab code Exa 6.7 Single effect evaporator reduced pressure

```
1  clc;
2  clear;
3  //Example 6.7
4  //From previous example:
5  mf_dot=5000          //[kg/h]
6  Hf=125.79            //[kJ/kg]
7  lambda_s=2230.2      //[kJ/kg]
8  mdash_dot=2500    //[kg/h]
9  Hdash=313.93          //[kJ/kg]
10 mv_dot=2500          //[kg/h]
11 Hv=2635.3            //[kJ/kg]
12 ms_dot=(mdash_dot*Hdash+mv_dot*Hv-mf_dot*Hf)/lambda_s    //Steam flow rate in [kg/h]
13 Q=ms_dot*lambda_s                //[kJ/h]
14 Q=Q*1000/3600                //[W]
15 U=2862               //[W/sq m.K]
16 dT=35        //[K]
17 A=Q/(U*dT)      //[sq m]
18 printf("\n The heat transfer area in this case is %f sq m\n",A);
19 printf("\n\nNOTE :There is a calculation mistake in the book at the line12 of this code,ms_dot value is written as 2320.18,which is wrong\n\n");
```

Scilab code Exa 6.8 Mass flow rate

```
clc;
clear;
//Example 6.8
mf_dot=6000           //Feed rate in [kg/h]
//Taking the given values from previous example(6.6)
Hf=125.79             //[kJ/kg]
ms_dot=3187.56        //[kg/h]
lambda_s=2230.2           //[kJ/kg]
Hdash=419.04          //[kJ/kg]
Hv=2676.1             //[kJ/kg]
mv_dot=(mf_dot*Hf+ms_dot*lambda_s-6000*Hdash)/(Hv-
   Hdash)  //Water evaporated in [kg/h]
mdash_dot=6000-mv_dot        //Mass flow rate of
   product [kg/h]
x=(0.01*mf_dot)*100/mdash_dot        //Wt % of solute
    in products
printf("\nMass flow rate of product is %f kg/h\n\n",
   mdash_dot);
printf("\n\nThe product concentration is %f percent
   by weight \n\n",x);
```

Scilab code Exa 6.9 Heat load in single effect evaporator

```
clc;
clear;
//Example 6.9
Tf=298       //Feed temperature in [K]
T_dash=373       //[K]
Cpf=4        //[kJ/kg.K]
fc=0.2       //Final concentration of salt
ic=0.05      //Initial concentration
mf_dot=20000     //[kg/h] Feed to evaporator
mdash_dot=ic*mf_dot/fc       //Thick liquor [kg/h]
```

```
11 mv_dot=mf_dot-mdash_dot      //Water evaporated in [kg/h]
12 lambda_s=2185        //[kJ/kg]
13 lambda=2257        //[kJ/kg]
14 bpr=7        //Boiling point rise[K]
15 T=T_dash+bpr      //Boiling point of solution in[K]
16 Ts=39        //Temperature of condensing steam in [K]
17 ms_dot=(mf_dot*Cpf*(T-Tf)+mv_dot*lambda)/lambda_s   //Steam consumption in [kg/h]
18 eco=mv_dot/ms_dot             //Economy of evaporator
19 Q=ms_dot*lambda_s                 //[kJ/h]
20 Q=Q*1000/3600             //[J/s]
21 printf("\nHeat load is %d W or J/s",round(Q));
22 printf("\n\nEconomy of evaporator is %f ",eco);
23 
24 printf("\n\nNOTE:Again there is a calcualtion mistake in book at line 19 of code,it is written as 4041507.1 instead of 40415071 \n\n");
```

Scilab code Exa 6.10 `Triple effect evaporator`

```
clc;
clear;
//Example 6.10
Ts=381.3          //[K]
dT=56.6;       //[K]
U1=2800; //Overall heat transfer coeff in first effect
U2=2200; //Overall heat transfer coeff in first effect
U3=1100; //Overall heat transfer coeff in first effect
dT1=dT/(1+(U1/U2)+(U1/U3))   ///[K]
dT2=dT/(1+(U2/U1)+(U2/U3))   ///[K]
dT3=dT-(dT1+dT2)               //[K]
```

```
//dT1=Ts-T1_dash       //[K]
T1dash=Ts-dT1
//dT2=T1_dash-T2_dash          //[K]
T2_dash=T1dash-dT2             //[K]
printf("\n\nBoiling point of solution in first effect =%f K\n\n",T1dash);
printf("\n\nBoiling point of solution in second effect =%f K\n\n",T2_dash);
```

Scilab code Exa 6.11 `Double effect evaporator`

```
clc;
clear;
//Example 6.11
mf_dot=10000        //[kg/h] of feed
ic=0.09     //Initial concentration
fc=0.47     //Final concentration
m1dot_dash=ic*mf_dot/fc     //[kg/h]
Ps=686.616      //Steam pressure [kPa.g]
Ps=Ps+101.325       //[kPa]
Ts=442.7        //Saturation temperature in [K]
P2=86.660       //Vacuum in second effect in [kPa]
U1=2326     //Overall heat transfer in first effect [W/sq m.K]
U2=1744.5   //Overall heat transfer in 2nd effect [W/sqm.K]
P2_abs=101.325-P2   //Absolute pressure in second effect[kPa]
T2=326.3        //Temperature in 2nd effect in [K]
dT=Ts-T2        //[K]
Tf=309      //Feed temperature in[K]
T=273       //[K]
Cpf=3.77        //kJ/kg.K  Specific heat for all caustic streams
//Q1=Q2
```

```
//U1*A1*dT1=U2*A2*dT2
dT2=dT/1.75     //[K]
dT1=(U2/U1)*dT2     //[K]
//Since there is no B.P.R
Tv1=Ts-dT1      //Temperature in vapor space of first effect in [K]
Tv2=Tv1-dT2     //Second effect [K]
Hf=Cpf*(Tf-T)       //Feed enthalpy[kJ/kg]
H1dash=Cpf*(Tv1-T)      //Enthalpy of final product[kJ/kg]
H2dash=Cpf*(Tv2-T)      //kJ/kg
//For steam at 442.7 K
lambda_s=2048.7     //[kJ/kg]
//For vapour at 392.8 K
Hv1=2705.22     //[kJ/kg]
lambda_v1=2202.8        //[kJ/kg]
//for vapour at 326.3 K:
Hv2=2597.61     //[kJ/kg]
lambda_v2=2377.8        //[kJ/kg]

//Overall material balance:
mv_dot=mf_dot-m1dot_dash        //[kg/h]

//Equation 4 becomes:
//mv1_dot*lambda_v1+mf_dot*Hf=(mv_dot-mv1_dot)*Hv2+(mf_dot-mv2_dot)*H2_dash
mv1_dot=(H2dash*(mf_dot-mv_dot)-mf_dot*Hf+mv_dot*Hv2)/(Hv2+lambda_v1-H2dash)
mv2_dot=mv_dot-mv1_dot              //[kg/h]

//From equation 2

m2dot_dash=m1dot_dash+mv1_dot           //First effect material balance[kg/h]
ms_dot=(mv1_dot*Hv1+m1dot_dash*H1dash-m2dot_dash*H2dash)/lambda_s     //[kg/h]


```

```
//Heat transfer Area
//First effect
A1=ms_dot*lambda_s*(10^3)/(3600*U1*dT1)      //[sq m]

//Second effect
lambda_v1=lambda_v1*(10^3/3600)
A2=mv1_dot*lambda_v1/(U2*dT2)        //[sq m]

//Since A1 not= A2

//SECOND TRIAL
Aavg=(A1+A2)/2           //[sq m]
dT1_dash=dT1*A1/Aavg         //[K]
dT2_dash=dT-dT1          ///[K]

//Temperature distribution
Tv1=Ts-dT1_dash          //[K]
Tv2=Tv1-dT2_dash             //[K]
Hf=135.66       //[kJ/kg]
H1dash=Cpf*(Tv1-T)       //[kJ/kg]
H2dash=200.83           //[kJ/kg]

//Vapour at 388.5 K
Hv1=2699.8      //[kJ/kg]
lambda_v1=2214.92        //[kJ/kg]
mv1_dot=(H2dash*(mf_dot-mv_dot)-mf_dot*Hf+mv_dot*Hv2
   )/(Hv2+lambda_v1-H2dash)
mv2_dot=mv_dot-mv1_dot  //[kg/h]

//First effect Energy balance
ms_dot=((mv1_dot*Hv1+m1dot_dash*H1dash)-(mf_dot-
   mv2_dot)*H2dash)/lambda_s   //[kg/h]

//Area of heat transfer
lambda_s=lambda_s*1000/3600
A1=ms_dot*lambda_s/(U1*dT1_dash)        //[sq m]

//Second effect:
```

```
A2=mv1_dot*lambda_v1*1000/(3600*U2*dT2_dash)    //[sq m]

printf("\nA1(%f)=A2(%f),So the area in each effect can be %f sq m\n",A1,A2,A2);
printf("\nHeat transfer surface in each effect is %f sq m\n",A2);
printf("\nSteam consumption=%d kg/h\n",round(ms_dot));
printf("\nEvaporation in the first effect is %d kg/h\n",round(mv1_dot));
printf("\nEvaporation in  2nd effect is %d kg/h\n",round(mv2_dot));
```

Scilab code Exa 6.12 `lye in Triple effect evaporator`

```

clc;
clear;
//Example 6.12
Tf=353;           //[K]
T=273            //[K]
mf_dot=10000;          //Feed [kg/h]
ic=0.07;          //Initial conc of glycerine
fc=0.4;           //FinaL CONC OF GLYCERINE
//Overall glycerine balance
m3dot_dash=(ic/fc)*mf_dot            //[kg/h]
mv_dot=mf_dot-m3dot_dash             ///[kg/h]
P=313;            //Steam pressure[kPa]
Ts=408;       //[from steam table][K]
P1=15.74;         //[Pressure in last effect][kPa]
Tv3=328;          //[Vapour temperature]
dT=Ts-Tv3       //Overall apparent [K]
bpr1=10  ;        //[K]
bpr2=bpr1;
```

```
bpr3=bpr2;
sum_bpr=bpr1+bpr2+bpr3       //[K]
dT=dT-sum_bpr                //True_Overall
dT1=14.5;            //[K]
dT2=16;              //[K]
dT3=19.5;            //[K]
Cpf=3.768            //[kJ/(kg.K)]
//Enthalpies of various streams
Hf=Cpf*(Tf-T)           //[kJ/kg]
H1=Cpf*(393.5-T)           //[kJ/kg]
H2=Cpf*(367.5-T)           //[kJ/kg]
H3=Cpf*(338-T)           //[kJ/kg]
//For steam at 40K
lambda_s=2160        //[kJ/kg]
Hv1=2692        //[kJ/kg]
lambda_v1=2228.3        //[kJ/kg]
Hv2=2650.8           //[kJ/kg]
lambda_v2=2297.4        //[kJ/kg]
Hv3=2600.5              //[kJ/kg]
lambda_v3=2370       //[kJ/kg]

//MATERIAL AND EBERGY BALANCES
//First effect
//Material balance

//m1dot_dash=mf_dot-mv1_dot
//m1dot_dash=1750+mv2_dot+mv3_dot

//Energy balance
//ms_dot*lambda_s+mf_Dot*hf=mv1_dot*Hv1+m1dot_dash*H1
//2160*ms_dot+2238*(mv2_dot+mv3_dot)=19800500

//Second effect
//Energy balance:
//mv3_dot=8709.54-2.076*mv2_dot

//Third effect:
```

```
//m2dot_dash=mv3_dot+m3dot_dash
//m2dot_dash=mv3_dot+1750
//From eqn 8 we get
mv2_dot=(8709.54*2600.5+1750*244.92-8790.54*356.1-356.1*1750)/(-2.076*356.1+2297.4+2600.5*2.076)
//From eqn 8:
mv3_dot=8709.54-2.076*mv2_dot           //[kg/h]
mv1_dot=mv_dot-(mv2_dot+mv3_dot)        //[kg/h]
//From equation 4:
//m1dot_dash=mf_dot-mv1_dot
//ms_dot=(mv1_dot*Hv1+m1dot_dash*H1-mf_dot*Hf)/lambda_s    //[kg/h]
ms_dot=(19800500-2238*(mv2_dot+mv3_dot))/2160            //[kg/h]

//Heat transfer Area is
U1=710          // [W/sq m.K]
U2=490          // [W/sq m.K]
U3=454          // [W/sq m.K]
A1=ms_dot*lambda_s*1000/(3600*U1*dT1)      //[sq m]
A2=mv1_dot*lambda_v1*1000/(3600*U2*dT2)    //[sq m]
A3=mv2_dot*lambda_v2*1000/(3600*U3*dT3)    //[sq m]
//The deviaiton is within +-10%
//Hence maximum A1 area can be recommended

eco=(mv_dot/ms_dot)     //[Steam economy]

Qc=mv3_dot*lambda_v3        //[kJ/h]
dT=25           //Rise in water temperature
Cp=4.187
mw_dot=Qc/(Cp*dT)
printf("\nANSWER\n Area in each effect%f sq m\n",A1);
printf("\nANSWER \n Steam economy is%f\n",eco);
printf("\nANSWER Cooling water rate is %f t/h",mw_dot/1000)
```

Scilab code Exa 6.13 `Triple effect unit`

```
clc;
clear;
//Example 6.13
Cpf=4.18        //[kJ/kg.K]
dT1=18          //[K]
dT2=17          //[K]
dT3=34          //[K]
mf_dot=4        //[kg/s]
Ts=394          //[K]
bp=325      //Bp of water at 13.172 kPa [K]
dT=Ts-bp        //[K]
lambda_s=2200           //[kJ/kg]
T1=Ts-dT1           //[K]
lambda1=2249        //[kJ/kg]
lambda_v1=lambda1       //[kJ/kg]

T2=T1-dT2           //[K]
lambda2=2293        //[kJ/kg]
lambda_v2=lambda2       //[kJ/kg]

T3=T2-dT3           //[K]
lambda3=2377        //[kJ/kg]
lambda_v3=lambda3       //[kJ/kg]

ic=0.1      //Initial conc of solids
fc=0.5      //Final conc of solids
m3dot_dash=(ic/fc)*mf_dot       //[kg/s]
mv_dot=mf_dot-m3dot_dash        //Total evaporation in [kg/s]
//Material balance over first effect
//mf_dot=mv1_dot_m1dot_dash
//Energy balance:
```

```
//ms_dot*lambda_s=mf_dot*(Cpf*(T1-Tf)+mv1_dot*lambda_v1)

//Material balance over second effect
//m1dot_dash=mv2_dot+m2dot_dash
//Enthalpy balance:
//mv1_dot*lambda_v1+m1dot_dash(cp*(T1-T2)=mv2_dot*lambda_v2)

//Material balance over third effect
//m2dot_dash=mv3_dot+m3dot+dash

//Enthalpy balance:
//mv2_lambda_v2+m2dot_dash*cp*(T2-T3)=mv3_dot*lambda_v3
294
mv2_dot=3.2795/3.079          //[kg/s]
mv1_dot=1.053*mv2_dot-0.1305      //[kg/s]
mv3_dot=1.026*mv2_dot+0.051      //[kg/s]
ms_dot=(mf_dot*Cpf*(T1-294)+mv1_dot*lambda_v1)/lambda_s       //[kg/s]
eco=mv_dot/ms_dot             //Steam economy
eco=round(eco)
printf("\nSteam economy is %d\n",eco);
U1=3.10      //[kW/sq m.K]
U2=2      //[kW/sq m.K]
U3=1.10      //[kW/sq m.K]
//First effect:
A1=ms_dot*lambda_s/(U1*dT1)          //[sq m]
A2=mv1_dot*lambda_v1/(U2*dT2)         //[sq m]
A3=mv2_dot*lambda_v2/(U3*dT3)         //[sq m]
//Areas are calculated witha  deviation of +-10%
printf("\nArea pf heat transfer in each effect is %f sq m\n",A3)
```

Scilab code Exa 6.14 `Quadruple effect evaporator`

```
clc;
clear;
//Example 6.14
mf_dot=1060      //[kg/h]
ic=0.04      //Initial concentration
fc=0.25          //Final concentration
m4dot_dash=(ic/fc)*mf_dot        //[kg/h]
//Total evaporation=
mv_dot=mf_dot-m4dot_dash         //[kg/h]

//Fromsteam table:
P1=370       //[kPa.g]
T1=422.6         //[K]
lambda1=2114.4       //[kJ/kg]

P2=235       //[kPa.g]
T2=410.5         //[K]
lambda2=2151.5       //[kJ/kg]

P3=80       //[kPa.g]
T3=390.2         //[K]
lambda3=2210.2       //[kJ/kg]

P4=50.66       //[kPa.g]
T4=354.7         //[K]
lambda4=2304.6       //[kJ/kg]

P=700        //Latent heat of steam[kPa .g]
lambda_s=2046.3          //[kJ/kg]

//FIRST EFFECT
//Enthalpy balance:
//ms_dot=mf_dot*Cpf*(T1-Tf)+mv1_dot*lambda1
//ms_dot=1345.3-1.033*m1dot_dash

//SECOND EFFECT
```

```
//m1dot_dash=m2dot_dash+mdot_v2
//Enthalpy balance:
//m1dot_dash=531.38+0.510*m2dot_dash

//THIRD EFFECT
//Material balance:
//m2dot_dash-m3dot_dash+mv3_dot

//FOURTH EFFECT
//m3dot_dash=m4dot_dash+mv4_dot
mv4dot_dash=169.6           //[kg/h]
m3dot_dash=416.7        //[kg/h]

//From eq n 4:
m2dot_dash=-176.84+1.98*m3dot_dash      //[kg/h]

//From eqn 2:
m1dot_dash=531.38+0.510*m2dot_dash      //[kg/h]

//From eqn 1:
ms_dot=1345.3-1.033*m1dot_dash
eco=mv_dot/ms_dot           //[kg evaporation /kg steam]
printf("\nSteam economy is %f evaporation/kg steam",eco);
```

Scilab code Exa 6.15 `Single effect Calendria`

```
clc;
clear;
//Example 6.15
m1_dot=5000     //[kg/h]
ic=0.1      //Initial concentration
fc=0.5      //Final concentration
mf_dot=(fc/ic)*m1_dot       //[kg/h]
```

```
mv_dot=mf_dot-m1_dot         //Water evaporated[kg/h]
P=357        //Steam pressure[kN/sq m]
Ts=412        //[K]
H=2732       //[kJ/kg]
lambda=2143      //[kJ/kg]
bpr=18.5             //[K]
T_dash=352+bpr       //[K]
Hf=138       //[kJ/kg]
lambda_s=2143        //[kJ/kg]
Hv=2659      //[kJ/kg]
H1=568       //[kJ/kg]
ms_dot=(mv_dot*Hv+m1_dot*H1-mf_dot*Hf)/lambda_s           //Steam consumption in kg/h
printf("\nSteam consumption is %f kg/h\n",ms_dot);
printf("\nCapacity is %f kg/h\n",mv_dot);
eco=mv_dot/ms_dot        //Economy
printf("\nSteam economy is %f\n",eco);
dT=Ts-T_dash         //[K]
hi=4500      //[W/sq m.K]
ho=9000      //[W/sq m.K]
Do=0.032         //[m]
Di=0.028         //[m]
x1=(Do-Di)/2         //[m]
Dw=(Do-Di)/log(32/28)    //[m]
x2=0.25*10^-3        //[m]
L=2.5        //Length [m]
hio=hi*(Di/Do)         //[W/sq m.K]
printf("\n NOTE:In textbook this value of hio is wrongly calculated as 3975.5..So we will take this\n\n");
hio=3975.5
k1=45        //Tube material in [W/sq m.K]
k2=2.25      //For scale[W/m.K]
Uo=1/(1/ho+1/hio+(x1*Dw)/(k1*Do)+(x2/k2))      //Overall heat transfer coeff in W/sq m.K
Q=ms_dot*lambda_s        //[kJ/h]
Q=Q*1000/3600            //[W]

```

```
A=Q/(Uo*dT)                     //[sq m]
n=A/(%pi*Do*L)                  //from A=n*%pi*Do*L
printf("\n No. of tubes required is %d",round(n));
```

Scilab code Exa 6.16 Single effect evaporator

```
clc;
clear;
//Example 6.16
bpr=40.6;           //[K]
Cpf=1.88;         //[kJ/kg.K]
Hf=214;       //[kJ/kg]
H1=505;       //[kJ/kg]
mf_dot=4536;      //[kg/h] of feed solution
ic=0.2;         //Initial conc
fc=0.5;         //Final concentration
m1dot_dash=(ic/fc)*mf_dot         //Thisck liquor flow arte[kg/h]
mv_dot=mf_dot-m1dot_dash          //[kg/H]
Ts=388.5;           //Saturation temperature of steam in [K]
bp=362.5          //b.P of solution in [K]
lambda_s=2214;      //[kJ/kg]
P=21.7;         //Vapor space in [kPa]
Hv=2590.3;          //[kJ/kg]

//Enthalpy balance over evaporator
ms_dot=(m1dot_dash*H1+mv_dot*Hv-mf_dot*Hf)/lambda_s       //[kg/h
printf("\nSteam consumption is %f kg/h\n",ms_dot);
dT=Ts-bp          //[K]
U=1560        //[W/sq m.K]
Q=ms_dot*lambda_s             //[kJ/h]
Q=Q*1000/3600                 //[W]
A=Q/(U*dT)        //[sq m]
```

```
printf("\nHeat transfer area is %f sq m\n",A);

//Calculations considering enthalpy of superheated vapour

Hv=Hv+Cpf*bpr   //[kJ/kg]
ms_dot=(m1dot_dash*H1+mv_dot*Hv-mf_dot*Hf)/lambda_s     //[kg/h]
printf("\n Now,Steam consumption is %f kg/h\n",ms_dot);
eco=mv_dot/ms_dot          //Steam economy
printf("\nEconomy of evaporator %f\n",eco);
Q=ms_dot*lambda_s          //[kJ/h]
Q=Q*1000/3600              //[w]
A2=Q/(U*dT)                 //Area
printf("\nNow,Area is %f\n",A);
perc=(A2-A)*100/A              //%error in the heat transfer area
printf("\n If enthalpy of water vapour Hv were based on the saturated vapour at the pressure\nthe error introduced is only %f percent\n",perc);
```