Scilab Textbook Companion for Heat And Mass Transfer - A Practical Approach by Y. A. Cengel[1]

Created by
Alina Patel
Btech Part II
Chemical Engineering
Institute of technology,Banaras Hindu University
College Teacher
Prof. Subir Das
Cross-Checked by

May 23, 2016

[1]Funded by a grant from the National Mission on Education through ICT, http://spoken-tutorial.org/NMEICT-Intro. This Textbook Companion and Scilab codes written in it can be downloaded from the "Textbook Companion Project" section at the website http://scilab.in

Book Description

Title: Heat And Mass Transfer - A Practical Approach

Author: Y. A. Cengel

Publisher: McGraw - Hill, New York

Edition: 3

Year: 2006

ISBN: 978-007-125739-8

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

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

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

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

Contents

List of Scilab Codes

Chapter 1

Introduction and basic concepts

Scilab code Exa 1.1 ab12

```
clear;
clc;

//Example 1.1(Heating of a copper ball)

//(a)
//density of the copper ball
rho= 8950;//[kg/m^3]
//Diameter of the copper ball
D=0.1;//[m]
//mass of the ball
m=rho*(%pi/6)*(D^3);//[kg]
//Specific Heat of copper
Cp=0.395;//[kJ/Kg/m^3]
//Initial Temperature
T1=100;//[degree C]
//Final Temperature
T2=150;//[degree C]
// The amount of heat transferred to the copper ball
    is simply the change in it's internal energy and
    is given by
```

```
// Energy transfer to the system=Energy increase of
   the system
Q=(m*Cp*(T2-T1));
disp("kJ",Q,"Heat needs to be transferred to the
   copper ball to heat it from 100 to 150 degree
   celsius is ")
//b
//Time interval for which the ball is heated
dT=1800;//[seconds]
Qavg=(Q/dT)*1000;//[W]
disp("W",Qavg,"Average Heat Transfer by the iron
   ball is ")

//(c)
//Heat Flux
qavg=(Qavg/(%pi*(D^2)));//[W/m^2]
disp("W/m^2",qavg,"Average flux is")
```

Scilab code Exa 1.2 ab13

```
clear;
clc;

//Example 1.2(Heating of water in an Electric Teapot
   )
//Mass of liquid water
m1=1.2,m2=0.5;//[Kg]
//Initial Temperature
t1=15;//[Degree Celcius]
//Final Temperature
t2=95;//[Degree Celcius]
//Specific heat of water
cp1=4.186;//[kJ/kG.K]
//Specific heat capacity of teapot
cp2=.7;//[]
```

```
Em=(m1*cp1*(t2-t1))+(m2*cp2*(t2-t1));//[kJ]
//Rating of Electric Heating Equipment
Em1=1.2;//[kJ/s]
dt=(Em/Em1)/60;//[seconds]
disp("minutes",round(dt),"of heat is","kJ",Em,"Time
    needed for this heater to supply ")
```

Scilab code Exa 1.3 ab14

```
clear;
clc;

//Example1.3[Heat Loss from Heating Ducts in a
    Basement]
//Given:-
T_in=60+273;//Temperature of hot air while entering
    the duct[K]
T_out=54+273;//Temperature of hot air while leaving
    the duct[K]
T_avg=(T_in+T_out)/2;//Average temperature of air[K]
Cp=1.007;//[kJ/kg]
disp("kJ/kg",Cp,"K is",T_avg,"The constant pressure
    specific heat of air at the average temperature
    of")
P=100;//Pressure of air while entering the duct[kPa]
R=0.287;//Universal Gas Constant[kPa.(m^3/kg).K]
v=5;//Average velocity of flowing air[m/s]
neta=0.8;//Efficiency of natural gas furnace
ucost=1.60;//Cost of natural gas in that area[$/
    therm],where 1therm=105,500kJ
//Solution;-
rho=P/(R*T_in);//The density of air at the inlet
    conditions is[kg/m^3]
Ac=0.20*0.25;//Cross sectional area of the duct[m^2]
m_=rho*v*Ac;//[kg/s]
```

```
disp("kg/s",m_,"mass flow rate of air through the duct is")
Q_loss=m_*Cp*(T_in-T_out);//[kJ/s]
disp("kJ/s",Q_loss,"The rate of heat loss by the air is")
cost=(Q_loss*3600)*(ucost)*(1/105500)*(1/neta);//[$/h]
disp("per hour",cost,"$"," Cost of heat loss to the home owner is")
```

Scilab code Exa 1.4 ab15

```
clear;
clc;

//Example1.4 (Electric Heating of a House at High Elevation)

//(a)
t1=10+273;//Initial temperature of house[K]
t2=20+273;//Temperature after turning on heater[K]
tavg=(t1+t2)/2;//Average temperature[K]
cp=1.007;//[kJ/kg.K]
cv=.720;//[kJ/kg.K]
disp("kJ/kg.K",cp,"and",cv,"K",tavg,"at the average temperature of","The specific heat capacities of air")
A=200;//The floor area[m^2]
h=3;//Height of room[m]
V=A*h;//Volume of the air in the house[m^3]
P=84.6;//Pressure [kPa]
R=0.287;//Universal gas constant[kPa.m^3/kg.K]
m=(P*V)/(R*t1);//[kg]
disp("kg",m,"Mass of air in the room is")
Eincv=m*cv*(t2-t1);
```

```
disp("kJ",Eincv,"The amount of energy transferred to air at constant volume is ")
u_cost=0.075;//Unit cost of energy[$/kWh]
Cost1=(Eincv*u_cost)/(3600);//[$]
disp(Cost1,"Cost of Energy is $")

//(b)
Eincp=m*cp*(t2-t1);//[kJ]
disp("kJ",Eincp,"The amount of energy transferred to air at constant is ")
Cost2=(Eincp*u_cost)/3600;//[$]
disp(Cost2,"Cost of Energy is $")
```

Scilab code Exa 1.5 ab16

```
clear;
clc;

//Example1.5 (The cost of Heat loss through a Roof)

//(a)
k=0.8;//The thermal conductivity of the roof[W/m.degree.C]
A=6*8;//Area of the roof[m^2]
t1=15;//temperature of inner surface roof[degree C]
t2=4;//temperature of outer surface roof[degree C]
L=0.25;//thickness of roof[m]
Q_=k*A*(t1-t2)/L;//[W]
disp("W",Q_,"The steady rate of heat transfer through the roof is")

//(b)
dt=10;//time period[h]
Q=Q_*dt/1000;//[kWh]
u_cost=0.08;//Unit cost of energy[$/kWh]
```

```
Cost=Q*u_cost;//[$]
disp(Cost,"and its cost is $","kWh",Q,"The amount of heat lost through the roof")
```

Scilab code Exa 1.6 ab16

```
clear;
clc;

//Example1.6 (Measuring the Thermal Conductivity of a Material)
V=110;//Voltage diffrence b/w thermocouples[V]
I=0.4;//Current drawn by thermocouples[A]
We=V*I;//[W]
disp("W",We,"The electrical power consumed by the resistance heater and converted to heat is")
q_=We/2;//[W]
disp("W",q_,"The rate of heat flow through each sample")
dT=15;//Temperature drop in the direction of heat flow[degree C]
l=.03;//length for which temperature change is measured[m]
D=.05;//diameter of cylinder[m]
a=(%pi*D^2)/4;//Cross-sectional area of the cylinder [m^2]
K=(q_*l)/(a*dT);//[W/m.degreeC]
disp("W/mC",K,"The thermal conductivity of the sample is")
```

Scilab code Exa 1.7 ab17

```
clear;
```

```
clc;

//Example1.7[Conversion between SI and English Units]
W_to_btu_p_h=3.41214;//Conersion from Watt to btu per hour[btu/h]
m_to_ft=3.2808;//Conversion from meter to english unit feet[ft]
deg_C_to_deg_F=1.8;//Conversion from degree Celcius to degree Farenhiet
W_per_m_deg_C=W_to_btu_p_h/(m_to_ft*deg_C_to_deg_F);//Conversion factor for 1W/m.degree Celcius[Btu/h.ft.degree Farenhiet]
k_brick=0.72*W_per_m_deg_C;//[Btu/h.ft.degree Farenhiet]
disp("Btu/h.ft.degree Farenhiet",k_brick,"The thermal conductivity of the brick in English units is")
```

Scilab code Exa 1.8 ab18

```
clear;
clc;

//Example1.8[Measuring Convection Heat Transfer coefficient]
//Given:-
T_ambient=15;//Temperature of room[degree Celcius]
T_surface=152;//Temperature of surface of wire[degree Celcius]
L=2;//Length of wire[m]
D=0.003;//Diameter of wire[m]
V=60;//Voltage drop across the current wire[Volts]
I=1.5;//Current flowing in the wire[amp]
//Solution:-
```

```
//When steady conditions are reached, the rate of heat loss from the wire equals the rate of heat generation in the wire as a result of resistance heating
Q_=V*I;//[W]
disp("W",Q_,"The rate of heat generated in the wire as a result of resistance heating is")
As=%pi*D*L;//Surface Area of the wire[m^2]
//Using Newton's Law of Cooling
//and assuming all heat loss in wire to occur by convection
h=Q_/(As*(T_surface-T_ambient));//[W/m^2.degree Celcius]
disp("W/m^2.degree Celcius",h,"The convection Heat Transfer coefficient is" )
```

Scilab code Exa 1.9 ab19

```
clear;
clc;

//Example1.9[Radiation Effect on Thermal Comfort]
//Given:-
T_room=22+273;//Temperature fo room[K]
T_wntr=10+273;//Average Temperature of inner surfaces of walls,floors and the cieling in winter[K]
T_smmr=25+273;//Average Temperature of inner surfaces of walls,floors and the cieling in summer[K]
T_outr=30+273;//Average outer surface temperature of the person[K]
A=1.4;//The exposed surface area[m^2]
e=0.95;//Emissivity of person
sigma=5.67*(10^(-8));//Stefan's constant
```

```
Q_rad_wntr=e*sigma*A*((T_outr^4)-(T_wntr^4));//[W]
Q_rad_smmr=e*sigma*A*((T_outr^4)-(T_smmr^4));//[W]
disp("W",Q_rad_smmr,"and",round(Q_rad_wntr),"The net
    rates of radiation heat transfer from the body
   to the surrounding walls,ceiling , and floor in
   winter and summer are respectively")
```

Scilab code Exa 1.10 ab20

```
clear;
clc;

//Example1.10[Heat Loss from a Person]
//Given:-
T_room=20+273;//Temperature of breezy room[K]
T_outr=29+273;//Average outer surface temperature of
    the person[K]
As=1.6;//Exposed Surface Area[m^2]
h=6;//Convection Heat transfer coefficient[W/m^2.K]
e=0.95;//Emissivity of person
sigma=5.67*(10^(-8));//Stephan's constant[W/m^2.
   degree Celcius]
Q_conv=h*As*(T_outr-T_room);//[W]
disp("W",Q_conv,"Rate of convection heat transfer
   from the person to the air in the room is")
Q_rad=e*sigma*As*((T_outr^4)-(T_room^4));//[W]
disp("W",Q_rad,"The rate of convection heat transfer
    from the person to the surrounding walls,cieling
   ,fllor is")
Q_total=Q_conv+Q_rad;//[W]
disp("W",round(Q_total),"The rate of total heat
   transfer from the body is ")
```

Scilab code Exa 1.11 ab21

```
clear;
clc;

//Example1.11[Heat transfer between two Isothermal Plates]
//Given:-
T1=300,T2=200;//Temperatures of two large parallel isothermal plates[K]
L=0.01;//distance between both plates[m]
e=1;//Emissivity of plates
A=1;//Surface area of plates[m^2]
T_avg=(T1+T2)/2;//Average temperature[K]
sigma=5.67*(10^(-8));//Stefan's constant[W/m^2.K^4]
//Solution (a)[space between plates is filled with air]
k_air=0.0219;//The thermal conductivity of aair at the average temperature[W/m.K]
Q_cond=k_air*A*(T1-T2)/L;//[W]
Q_rad=e*sigma*A*((T1^4)-(T2^4));//[W]
disp("W",round(Q_rad),"and",Q_cond,"The rates of conduction and radiation heat transfer between the plates through the air layer are respectively")
Q_total_a=Q_cond+Q_rad;//[W]
disp("W",round(Q_total_a),"Net rate of heat transfer is")
disp("The heat transfer rate in reality will be higher because of the natural convection currents that are likely to occur in the air space between the plates")
//Solution (b)[space between the plates is evacutaed]
disp("when the air space b/w the plates is evacuted there is no conduction or convection,and the only heat transfer between the plates will be by radiation. ")
```

```
disp("Therefore")
Q_total_b=Q_rad;//[W]
disp("W",round(Q_total_b),"Net rate of heat transfer
    is")
//Solution (c)[space between the plates is filled
   with urethane insulation]
k_insu=0.026;//At average temperature thermal
   conductivity of urethane insulation [W/m.K]
disp("An opaque solid material placed b/w the two
   plates blocks direct radiation heat transfer
   between the plates")
Q_cond_c=k_insu*A*(T1-T2)/L;//[W]
Q_total_c=Q_cond_c;//[W]
disp("W",round(Q_total_c),"The net rate of heat
   transfer through the urethane insulation is")
//Solution (d)[the distance between the plates is
   filled with superinsulation]
k_super=0.00002;//At average temperature thermal
   conductvity of superinsulation[W/m.K]
disp("The layers of superinsulation prevent any
   direct radiation heat transfer between the plates
   ")
Q_cond_d=k_super*A*(T1-T2)/L;//[W]
Q_total_d=Q_cond_d;//[W]
disp("W",Q_total_d,"The net rate of heat transfer
   through the layer of superinsulation is")
```

Scilab code Exa 1.13 ab22

```
clear;
clc;

//Example1.13[Heating of a Plate by Solar Energy]
//Given:-
a=0.6;//absorptivity of exposed surface of plate
```

```
q_incident=700;//Rate at which solar radiation
    incident on the plate [W/m^2]
T_surr=25+273;//Surrounding air temperature[K]
h=50;//Combined radiation and convection heat
    transfer coefficient[W/m^2.K]
//Solution
//Temperature keeps on increasing till a point comes
     at which the rate of heat loss from the plate
    equals the rate of solar energy absorbed, and the
     temperature of the plate no longer changes
T_surface=T_surr+(a*(q_incident)/h);//[K]
disp("degree Celcius",T_surface-273,"The plate
    surface temperature is")
```

Scilab code Exa 1.14 ab23

```
clear;
clc;

//Example1.14[Non-linear equation in two variable]
//x1=x, x2=y
function[f]=f2(x)
f(1)=x(1)-x(2)-4;
f(2)=x(1)^2+x(2)^2-x(1)-x(2)-20;
deff('[f]=f2(x)',['f_1=x(1)-x(2)-4','f_2=x(1)^2+x(2)
    ^2-x(1)-x(2)-20'])
//To get the desired output assign an initial value
    such as x0=[1,1], [xs,fxs,m]=fsolve(x0',f2)
```

Chapter 2

Heat Conduction Equation

Scilab code Exa 2.2 ab24

```
clear;
clc;

//Example2.2[Heat Generation in a Hair Dryer]
//Given:-
E_gen=1200;//[Total rate of heat generation]
L=80;//Length of wire[cm]
D=0.3;//Diameter of wire[cm]
//Solution:-
V_wire=%pi*(D^2)*L/4;//Volume of the wire[cm^3]
e_gen=E_gen/V_wire;//[W/cm^3]
As=%pi*D*L;//Suface Area of wire[m^2]
Q_=E_gen/As;//[W/cm^2]
disp("W/cm^2",Q_,"and","W/cm^3",round(e_gen),"The
   rate of heat generation in the wire per unit
   volume and heat flux on the outer surface of the
   wire as a result of this heat generation are
   respectively")
```

Scilab code Exa 2.4 ab25

```
clear;
clc;

//Example2.3[Heat Conduction in a Resistance Heater]
//Given:-
E_gen=2000;//Total rate of heat generation in the wire [W]
L=0.5;//Length of cyllindrical shaped wire[m]
D=0.004;//Diameter of wire[m]
k_heater=15;//Thermal conductivity of wire[W/m.K]
//Solution:-
//The resistance wire is considered to be a very long cylinder since its length is more than 100 times its diameter.Heat is generated uniformly in the wire and the conditions on the outer surface of the wire are uniform.Hence it is reasonable to expect the temperature int he wire to vary in radial r direction only and thus heat transfer to be one dimensional,T=T(r)
V_wire=%pi*(D^2)*L/4;//Volume of the wire[m^3]
e_gen=E_gen/V_wire;// [W/m^3]
disp("W/m^3",e_gen,"The rate of heat generation in the wire per unit volume is")
const=e_gen/k_heater;
disp("= 0",const,"The equation governing the variation of temperature int he wire is simply (1/r)d/dr(r.dT/dr)+")
```

Scilab code Exa 2.5 ab26

```
clear;
clc;

```

```
//Example2.5[Cooling of a Hot Metal Ball in Air]
//Given:-
T_ball=300;//Temeprature of ball[degree Celcius]
T_surr=25;//Temperature of ambient air[degree
    Celcius]
//Solution:-
//The ball in initially at a uniform temperature and
    is cooled uniformly from the entire outer
    surface.Also, the temperature within the ball
    changes with the radial distance r and the time t
    . T=T(r,t)
disp("The thermal conductivity is given to be
    variable,and there is no heat generation in the
    ball, therefore the differential equation
    governing the variation of temperature in the
    ball is")
disp("(1/(r^2)d/dr((r^2)k(dT/dr))=rho*c(dT/dt)")
```

Scilab code Exa 2.6 ab27

```
clear;
clc;

//Example2.6[Heat Conduction in a Short Cylinder]
//Given:-
//Radius R and height h of the small cylinder
T=300;//Temperature of cylinder[degree Celcius]
T_ambient=20;//Temperature of ambient air[degree
    Celcius]
//Variation is thermal conductivity is negligible
//The cylinder is cooled unifromly from the top and
    bottom surfaces in the z-direction as well as the
    lateral surface in the radial r-direction.Also
    Temperature at any point in the ball changes with
    time during cooling. Therefore this is a two
```

```
   dimensional transient heat conduction problem i.e
   . T=T(r,z,t)
disp("The differential equation governing the
   variation of temperature in the billet is ")
disp("((1/r)(d/dr)(k*r(dT/dr)))+((d/dz)(k(dT/dz)))=
   rho*c(dT/dt)")
disp("In case of constant thermal conductivity it
   reduces to")
disp("((1/r)(d/dr)(r(dT/dr)))+(d^2)T/(dz^2)=(1/a)(dT
   /dt)")
```

Scilab code Exa 2.7 ab28

```
clear;
clc;

//Example2.7[Heat Flux boundary Condition]
//Given:-
Q=800;//Heat transfer rate[W]
D=0.2;//Diameter of pan[m]
L=0.003;//Thickness of pan[m]
T_in=110;//T(L) Temperature of the inner surface of
   the pan[degree Celcius]
neta=0.9;//Percent of total heat transferred to the
   pan
//Solution;-
//The inner and outer surfaces of the bottom section
    of the pan can be represented by x=0 and x=L,
   respectively. During steady operation the
   temperature will depend on x only and thus T=T(x)
   .
//Solution:-
actual_Q=neta*Q;//90 percent of the 800W is
   transferred to the pan at that surface
A=%pi*(D^2)/4;//Bottom Surface Area[m^2]
```

```
disp("-k*dT(0)/dx=q_")
q_=actual_Q/(1000*A);//[kW/m^2]
//The boundary condition on this surface can be expressed as
disp("degree Celcius",T_in,"T(L)=")
disp("m",L,"where L=")
```

Scilab code Exa 2.8 ab29

```
clear;
clc;

//Example2.8[Convection and Insulation Boundary Conditions]
//Given:-
T_steam=200;//Temperature of steam[degree Celcius]
r_in=0.08;//Inner radii of pipe[m]
r_out=0.085;//Outer radii of pipe[m]
h=65;//convection heat transfer coefficient on the inner surface of the pipe[W/m^2.K]
//Heat transfer through the pipe material predominantly is in the radial direction and thus can be approximated as being one-dimensional
disp("Taling the direction of heat transfer to be the positive r direction, the boundary condition on that surface can be expressed as")
disp("-k(dT(r_in,t)/dr)=h(T_steam-T(r1))")
//The pipe is said to be well insulated on the outside, and thus heat loss through the outer surface of the pipe can be assumed to be negligible.
disp("Then the boundary at the outer surface can be expressed as")
disp("dT(r_out,t)/dr=0")
```

Scilab code Exa 2.9 ab30

```
clear;
clc;

//Example2.9[Combined Convection and Radiation Condition]
//Given:-
T_ball=300;//Temperature of spherical metal ball[degree Celcius]
T_ambient=27;//Temperature of ambient air[degree Celcius]
k=14.4;//Thermal conductivity of the ball material[W/m.K]
h=25;//average convection heat transfer coefficient on the outer surface of the ball[W/m^2.K]
e=0.6;//Emissivity of outer surface of the ball
T_surr=290;//
//This is one-dimensional transient heat transfer problem since the temperature within the ball changes with the radial distance r and the time t i.e. T=T(r,t)
//Taking the moment the ball is removed from the oven to be t=0
disp("The initial condition can be expressed as")
disp("T(r,0)=T_ball")
disp("degree Celcius",T_ball)
//The problem possesses symmetry about the mid point (r=0) since the isotherms in this case are concentric spheres, and thus no heat is crossing the mid point of the ball.
disp("The boundary condition at the midpoint i.e. r=0 can be expressed as dT(0,t)/dr=0")
//The heat conducted to the outer surface of the
```

```
ball is lost to the environment by convection and radiation.
disp("Taking the direction of heat transfer to be the positive r direction, the boundary condition on the outer surface can be expressed as")
disp("−k(dT(r_out,t)/dr)=h[T(r_out)−T_ambient]+e*sigma[(T(r_out)^4)−(T_ambient^4)]")
```

Scilab code Exa 2.10 ab31

```
clear;
clc;

//Example2.10[Combined Convection, Radiation and Heat Flux]
//Given:−
T_surf1=20;//Ambient temperature in the interior of the house[degree Celcius]
T_surf2=5;// Ambient temperature outside the house[degree Celcius]
L=0.2;// Thickness of the wall[m]
a=0.5;// absorptivity of outer surface of wall
h_in=6;//Convection heat transfer coefficient for inner surface of wall[W/m^2.degree Celcius]
h_out=25;//Convection heat transfer coefficient for outer surface of wall[W/m^2.degree Celcius]
k=0.7;//The thermal conductivity of wall material[W/m.degree Celcius]
e=0.9;//Emissivity of outer surface of wall
//Solution:−
//The heat transfer though the wall is given to be steady and one dimensional and thus temperature depends on x only i.e. T=T(x)
disp("The boundary condition ont the inner surface of the wall at x=0 can be expressed as −k(dT(0)/
```

```
dx)=h_in[T_surf1-T(0)]")
disp("degree Celcius",T_surf1,"and","W/m^2.degree Celcius",h_in,"where h_in and T_surf are respectively ")
disp("The boundary condition on the outer surface at x=L can be expressed as ")
disp("-kdT(L)/dx=h_out[T(L)-T_surf2]+e*sigma[(T(L)^4)-(T_sky^4)]-a*q_solar")
disp("where T_sky is temperature of the sky and q_solar is the incident solar heat flux")
```

Scilab code Exa 2.11 ab32

```
clear;
clc;

//Example2.11[Heat Conduction in a Plane Wall]
//Given:-
k_wall=1.2;//Thermal conductivity of wall[W/m.degree Celcius]
L=0.2;//Thickness of wall[m]
As=15;//Surface area[m^2]
T1=120,T2=50;//The two sides of the wall are maintained at these constant temperatures[degree Celcius]
//Solution (a)
disp("Differential equation can be expressed as d^2(T)/(dx^2)=0")
disp("with boundary conditions ")
disp("degree Celcius",T1,"T(0)=T1=")
disp("degree Celcius",T2,"T(L)=T2=")
disp("integrating this we get,")
disp("dT/dx=C1", ,"where C1 is an arbitrary constant")
disp("integrating we obtain temperature to follow
```

```
following relation :-")
disp("and substituting values in above equation","T(x)=((T2-T1)/L)*x+T1 ")
T3=(((T2-T1)/L)*(0.1))+T1;
disp("degree Celcius",T3,"The value of temperature at x=0.1m is")
Q_wall=-k_wall*As*((T2-T1)/L);//[W]
disp("W",Q_wall,"The rate of heat conduction through the wall is")
```

Scilab code Exa 2.13 ab33

```
clear;
clc;

//Example2.13[Heat Conduction in the Base Plate of an Iron]
//Given:-
k=15;//[W/m.degree Celcius]
A=300*10^(-4);//Base Area[m^2]
L=0.005;//Thickness[m]
T_surr=20;//Temp of surrounding[degree Celcius]
h=80;//Convection het transfer coefficient[W/m^2.degree Celcius]
Q=1200;//[W]
//Solution:-
q=Q/A;//[W/m^2]
disp("W/m^2",q,"Uniform Heat Flux to whicj inner surface of the base plate is subjected")
//Integration Constants
C1=-q/k;
C2=T_surr+(q/h)+(q*L/k);
T_0=T_surr+q*((L/k)+(1/h));//[degree Celcius]
T_L=T_surr+q*(1/h);//[degree Celcius]
disp("respectively","degree Celcius",T_L,"and","
```

```
degree Celcius",round(T_0),"The temperatures at the inner and outer surfaces of the plate i.e. at x=0 and x=L are")
```

Scilab code Exa 2.14 ab34

```
clear;
clc;

//Example2.14[Heat Conduction in a Solar Heated Wall]
//Given:-
L=0.06;//Thickness of wall[m]
k=1.2;//Thermal Conductivity[W/m.degree Celcius]
e=0.85;//Emissivity
a=0.26;//Solar absorptivity
T1=300;//Temp of Inner surface of Wall[K]
q_solar=800;//Incident rate of solar radiation[W/m^2]
T_space=0;//Temp of outer space[K]
//Solution:-
//Integrating results into
function[f]=temp(T)
    f(1)=(((a*q_solar)-(e*5.67*10^(-8)*T(1)^4))*(L/k))+T1-T(1);
    deff('[f]=temp(T)',['f_1(T)=(((a*q_solar)-(e*5.67*10^(-8)*T(1)^4))*(L/k))+T1-T(1)'])
endfunction

    disp("K",xs,"The outer surface temperature is ")
    //First execute the program with x0=[1] then [xs,fxs,m]=fsolve(x0',temp) then re-execute to obtain correct output as for 1st exeution 'xs' is undefined
    q=k*(T1-xs)/L;
```

```
disp("W/m^2",round(q),"The steady rate of heat
   conduction through the wall is")
```

Scilab code Exa 2.15 ab35

```
clear;
clc;

//Example2.15[Heat Loss through a Steam Pipe]
//Given:-
L=20;//Pipe Length[m]
k=20;//[W/m.degree Celcius]
r1=0.06;//Inner Radius[m]
r2=0.08;//Outer Radius[m]
T1=150;//Temp of inner surface[degree Celcius]
T2=60;//Temp of outer surface[degree Celcius]
//Solution:-
//Integrating differential equation we get T(r)=
   C1logr+C2, where C1 and C2 are
C1=(T2-T1)/log(r2/r1);
C2=T1-((T2-T1/log(r2/r1))*log(r1));
Q_cyl=2*%pi*k*L*(T1-T2)/(log(r2/r1));
disp("kW",round(Q_cyl/1000),"The rate of heat
   conduction through the pipe is")
```

Scilab code Exa 2.16 ab36

```
clear;
clc;

//Example2.16[Heat Conduction through a Spherical
   Shell]
//Given:-
```

```
r1=0.08;//Inner Radius[m]
r2=0.1;//Outer radius[m]
k=45;//Thermal conductivity[W/m.degree Celcius]
T1=200;//Temperature of inner surface[degree Celcius]
T2=80;//Temperarure of outer surface[degree Celcius]
//Solution:-
//Integrating the differential equation twicw we get T(r)=-C1/r+C2, where
C1=r1*r2*(T1-T2)/(r2-r1);
C2=((r2*T2)-(r1*T1))/(r2-r1);
Q_sphere=4*%pi*k*r1*r2*(T1-T2)/(r2-r1);
disp("kW",Q_sphere/1000,"The rate of heat conduction through the container wall is")
```

Scilab code Exa 2.17 ab37

```
clear;
clc;

//Example2.17[Centerline Temperature of a Resistance Heater]
//Given:-
k=15;//Thermal conductivity of heater wire[W/m.K]
E_gen=2000;//Total heat generation[W]
l=0.5;//Length of resistance heater wire[m]
D=0.004;//Diameter of wire[m]
Ts=105;//Outer sorface Temperarure[degree Celcius]
//Solution:-
V_wire=%pi*(D^2)*l/4;//Volume of wire[m^3]
e_gen=E_gen/V_wire;// [W/m^3]
disp("W/m^3",e_gen,"The heat generation per unit volume of the wire is")
Tc=Ts+(e_gen*(D^2)/(4*4*k));//[degree Celcius]
disp("degree Celcius",round(Tc),"The center
```

```
    temperature of the wire is ")
```

Scilab code Exa 2.18 ab38

```
clear;
clc;

//Example2.18[Variation of Temperature in a
    Resistance Heater]
//Given:-
k=13.55;//[W/m.degree Celcius]
ro=0.005;//[m]
e_gen=4.3*10^7;//rate of resistance heating[W/m^3]
Ts=108;//Surface temperature[degree Celcius]
//Solution:-
//Integrating we get
//T(r)=Ts+((e_gen*(ro^2-r^2)/4k))
T_0=Ts+((e_gen*ro^2)/(4*k));
disp("degree Celcius",round(T_0),"The temperature at
    the centreline,r=0 is")
```

Scilab code Exa 2.19 ab39

```
clear;
clc;

//Example2.19[Heat Conduction in a two layer medium]
//Given:-
k_wire=15,k_ceramic=1.2;//[W/m.degree Celcius]
r1=0.002,r2=0.007;//[m]
e_gen=50*10^6;//[W/m^3]
Ts=45;//[degree Celcius]
//Solution:-
```

```
T1=(((e_gen*(r1^2)*log(r2/r1))/(2*k_ceramic))+Ts);//
    [degree Celcius]
disp("degree Celcius",T1,"The Interface temperature
    is")
T_wire=T1+((e_gen*(r1^2))/(4*k_wire));//[degree
    Celcius]
disp("degree Celcius",T_wire,"The temperature at the
     centreline(r=0) is")
disp("Thus the temperature of the centreline is
    slightly above the interface temperature")
```

Scilab code Exa 2.21 ab40

```
clear;
clc;

//Example2.21[Heat Conduction through a Wall with k(
   T)]
//Given:-
//k varies with temperature as k=k0(1+bT)
k0=38;// [W/m]
b=9.21*(10^(-4));//[k^(-1)]
h=2,w=0.7,t=0.1;//Height,width and thickness of
    plates respectively[m]
T1=600,T2=400;//Temperature maintained on the two
    sides of the plate[K]
//Solution:-
A=h*w;//Surface area of plate[m^2]
Tavg=(T1+T2)/2;//Average temperature of plate[K]
kavg=k0*(1+(b*Tavg));// [W/m.K]
disp("W/m.K",kavg,"The average thermal conductivity
    of the medium is")
Q_=kavg*A*(T1-T2)/t;// [W]
disp("kW",round(Q_/1000),"The rate of heat
    conduction through the plate is")
```

Chapter 3

steady Heat Conduction

Scilab code Exa 3.1 ab41

```
clear;
clc;
//Example 3.1 [Heat Loss through a Wall]

//assumptions:-
//1)Heat transfer through the wall is steady
//2)Heat transfer is one-imensional
//Properties:
k=0.9;//[W/m.K]
disp("W/m.K",k,"The thermal conductivity is given to be")
//Heat transfer through the wall is by conduction
A=(3*5);//[m^2]
disp("m^2",A,"The area of the wall is")
T1=16;//temperature of inner wall[degree Celcius]
T2=2;//Temperature of Outer wall[degree Celcius]
delta_T=T1-T2;//Temperature Gradient[degree Celcius]
L=0.3;//Length of wall along which heat is being transferred[m]
R_wall=L/(k*A);//[degree Celcius/W]
disp("degree Celicus/W",R_wall,"Thermal Resistnace
```

```
offered by the wall is")
Q_=(delta_T/R_wall);//[W]
disp("W",Q_,"The steady rate of heat transfer through the wall is ")
```

Scilab code Exa 3.2 ab42

```
clear;
clc;

//Example 3.2[Heat Loss through a Single Pane Window]
//Assumptions :-
//1)Heat transfer through the window is steady
//2)Heat transfer through the wall is one dimensional
k=0.78;//[W/m.K]
disp("W/m.K",k,"The thermal conductivity is given to be")
L=0.008;//Thickness of glass window[m]
A=(0.8*1.5);//Area of the window[m^2]
T_1=20;//Temeprature of inner surface of glass window[dgree Celcius]
T_2=-10;//Temeprature of outer surface of glass window[dgree Celcius]
h_in=10;//Heat transfer coefficient on the inner surface of the window[W/m^2]
h_out=40;//Heat transfer coefficient on the outer surface of the window[W/m^2]
//Convection Resistance
R_conv1=1/(h_in*A);//[degree Celcius/W]
R_conv2=1/(h_out*A);//[degree Celcius/W]
//Conduction Resistance
R_cond=L/(k*A);//[degree Celcius/W]
//Net Resistance are in series
```

```
R_total=R_conv1+R_conv2+R_cond;//[degree Celcius/W]
disp("degree Celcius/W",R_total,"The total Resistance offered by glass window")
Q_=(T_1-T_2)/R_total;//[W]
disp("W",Q_,"Steady rate of Heat Transfer through the window is")
//Knowing the rate of Heat Transfer
T1=T_1-(Q_*R_conv1);//[degree Celciusthe inner surface temperature of the window glass can be determined from]
disp("degree Celcius",T1,"Inner Surface Temperature of the window glass")
```

Scilab code Exa 3.3 ab43

```
clear;
clc;

//Example3.3[:Heat Loss through double pane windows]
//Given:-
k_g=0.78;//Thermal conductitvity of glass [W/m.K]
k_a=0.026;//Thermal conductivity of air space[W/m.K]
L_g=.004;//Thickness of glass layer[m]
L_a=0.01;//Thickness of air space[m]
h_in=10;//ConvectionHeat transfer coefficient on the inner surface of the window[W/m^2]
h_out=40;//ConvectionHeat transfer coefficient on the outer surface of the window[W/m^2]
T_1=20;//Outer wall Temperature [degree Celcius]
T_2=-10;//Inner wall Temperature [degree Celcius]
//Solution:-
A=(0.8*1.5);//Area of glass window[m^2]
//Convection Resistances
R_conv1=1/(h_in*A);//Due to convection heat transfer between inner atmosphere and glass[degree
```

```
Celcius/W]
R_conv2=1/(h_out*A);//Due to convection heat transfer between outer atmosphere and glass[degree Celcius/W]
//Conduction Resistances
R_cond1=L_g/(k_g*A);//Due to conduction heat transfer through the glass[degree Celcius/W]
R_cond2=R_cond1;//Glass Medium is seperated by air spac hence two glass mediums are created[degree Celcius/W]
R_cond3=L_a/(k_a*A);//Due to conduction heat transfer through the air space[degree Celcius/W]
//Net Resistance offered by window is the sum of all the individual resistances written in the oreder of their occurence
R_total=R_conv1+R_cond1+R_cond2+R_cond3+R_conv2;//[degree Celcius/W]
disp("degree Celcius/W",R_total,"The net resistance offered is")
Q_=(T_1-T_2)/R_total;//[W]
disp("W",Q_,"The steady rate of Heat transfer through the window is")
//Inner surface temperature of the window is given by
T1=T_1-(Q_*R_conv1);//[degree Celcius]
disp("degree Celcius",T1,"Inner Surface Temperature of the window is")
```

Scilab code Exa 3.4 ab44

```
clear;
clc;

//Example3.4[Equivalent Thickness for Contact Resistance]
```

```
//Given:−
k=237;//Thermal conductivity of aluminium[W/m.K]
L=0.01;//Thickness of aluminium plate[m]
hc=11000;//Thermal contact conductance[W/m^2.K]
//Solution:−
Rc=1/hc;// [m^2.K/W]
disp("Since thermal contact resistance is the
    inverse of thermal contact conductance")
disp("m^2.K/W",Rc,"Hence Therml contact Resistance
    is")
//For a unit surface area, the thermal resistance of
     a flat plate is defined as
R=L/k;
//Equivalent thickness for R=Rc
L=k*Rc;// [m]
disp("cm",(100*L),"Equivalent thickness is")
```

Scilab code Exa 3.5 ab45

```
clear;
clc;

//Example3.5[Contact Reistance of Transistors]
//Given:−
k=386;//Thermal Conductivity of Copper[W/m.K]
hc=42000;//Contact Conductance coreesponding to
    copper−aluminium interface for the case of
    1.17−1.4 micron roughness and 5MPa[pressure,
    which is close to given to what we have[W/m^2.K]
Ac=.0008;//Contact area b/w the case and the plate[m
    ^2]
A=0.01;//Plate area for each resistor[m^2]
L=0.01;//Thickness of plate[m]
ho=25;//Heat tranfer coefficient for back surface
T_1=20;//Ambient Temperature[degree Celcius]
```

```
T_2=70;//Maximum temperature of case[degree Celcius]
//Solution:-
//Resistances Offered
R_interface=1/(hc*Ac);//Resistance offered at the copper aluminium interface[degree Cecius/W]
R_plate=L/(k*A);//conduction resistance offered by coppr plate[degree Cecius/W]
R_conv=1/(ho*A);//Convection resistance offerd by back surface of casing[degree Cecius/W]
R_total=R_interface+R_plate+R_conv;//[degree Cecius/W]
disp("degree Cecius/W",R_total,"The total thermal Tesistance is")
Q_=(T_2-T_1)/R_total;//[W]
disp("W",Q_,"The rate of heat transferred is")
delta_T=Q_*R_interface;//[degree Celcius]
disp("degree Celcius",delta_T,"The temperature jump at the interface is given by")
```

Scilab code Exa 3.6 ab46

```
clear;
clc;

//Example3.6[Heat Loss through a Composite Wall]
//Given:-
//We consider a 1m deep and 0.25 m high portion of the wall since it is representative of the entire wall
//Assuming any cross-section of the wall normal to the x-direction to be isothermal
k_b=0.72;//thermal conductivity of bricks[W/m.K]
k_p=0.22;//thermal conductivity of plaster layers[W/m.K]
k_f=0.026;//thermal conductivity of foam layers[W/m.
```

```
K]
T_in=20;//Indoor Temperature[dgeree Celcius]
T_out=-10;//Outdoor Temperature[dgeree Celcius]
h_in=10;//Inner heat transfer coefficient[W/m^2.K]
h_out=25;//Outer heat transfer coefficient[W/m^2.K]
L_f=0.03;//Thickness of foam layer[m]
L_p=0.02;//Thickness of plaster[m]
L_b=0.16;//Thickness of brick wall[m]
L_c=0.16;//Thickness of central plaster layer[m]
A1=(0.25*1);//[m^2]
A2=(0.015*1);//[m^2]
A3=(0.22*1);//[m^2]
//Resistances offered:-
R_in=1/(h_in*A1);//Resistance to conevction heat transfer from inner surface[degree Celcius/W]
R1=L_f/(k_f*A1);//Conduction Resistance offered by outer foam layer[degree Celcius/W]
R2=L_p/(k_p*A1);//Conduction Resistance offered by Outer side Plaster Wall[degree Celcius/W]
R6=R2;//Conduction Resistance offered by Inner side Plaster Wall[degree Celcius/W]
R3=L_c/(k_p*A2);//Conduction Resistance offered by one side central Plaster wall[degree Celcius/W]
R5=R3;//Conduction Resistance offered by other side central Plaster wall[degree Celcius/W]
R4=L_b/(k_b*A3);//Conduction Resistance offered by Brick Wall[degree Celcius/W]
R_out=1/(h_out*A1);//Convection Resistance from outer surface[degree Celcius/W]
//R_in,R1,R2,R6,R_out are connected in series
//R3,R4,R5 are connected in parallel
R_mid=1/((1/R3)+(1/R4)+(1/R5));//Effective Parrallel Resistance
R_total=(R_in+R1+R2+R_mid+R6+R_out);//[degree Celcius/W]
disp("degree Celcius/W",R_total,"Net Resistance offered is")
Q_=(T_in-T_out)/R_total;//[W]
```

```
disp("W",Q_,"The steady rate of heat transfer
    through the wall is")
Q_p=Q_/A1;//[W/m^2]
disp("W/m^2",Q_p,"Heat Transfer per unit area is")
A_total=3*5;//Total Area of wall[m^2]
Q_total=Q_p*A_total;//[W]
disp("W",Q_total,"Thr rate of heat transfer through
    the entire wall")
```

Scilab code Exa 3.7 ab47

```
clear;
clc;

//Example3.7[Heat Transfer to a Spherical Container]
//Radiation effect is being considered. For the
    black tank emissivity=1
//Given:-
k=15;//thermal conductivity of stainless steel[W/m.
    degree Celcius]
T_ice=0+273;//temeperature of iced water[K]
T_tank=22+273;//temperature of tank stored at room
    temperature[K]
h_in=80;//Heat Transfer Coefficient at the inner
    surface of the tank[W/m^2.degree Celcius]
h_out=10;//Heat Transfer Coefficient at the outer
    surface of the tank[W/m^2.degree Celcius]
heat_f=333.7;//Heat of fusion of water at
    atmospheric pressure[kJ/kg]
e=1;//emissivity of tank
sigma=5.67*(10^(-8));//Stefan's [W/m^2.K^4]
D1=3;//inner diameter[m]
D2=3.04;//Outer diameter[m]
//Solution:-
//a)
```

```
A1=(%pi)*(D1^2);//Inner Surface area of the tank[m^2]
A2=(%pi)*(D2^2);//outer Surface area of the tank[m^2]
disp("The radiation heat transfer coefficient is given by ")
disp("h_rad=e*sigma*((T2^2)+(T_tank^2))*(T2+T_tank)")
disp("But we dont know the outer surface temperature T2 of the tank. hence we assume a T2 value")
disp("since heat transfer inside the tank is larger ")
T2=5+273;//[K]
disp("K",T2,"Therefore taking T2 =")
h_rad=e*sigma*((T2^2)+(T_tank^2))*(T2+T_tank);//[W/m^2.K]
disp("W/m^2.degree Celcius",h_rad,"The radiation heat transfer coefficient is determined to be")
//Individual Thermal Resistances Offered
R_in=1/(h_in*A1);//Resistance to convetion from inner side of tank[degree Celcius/W]
R_sphere=((D2-D1)/2)/(4*%pi*k*(D1/2)*(D2/2));//Resistance to conduction due to ice sphere[degree Celcius/W]
R_out=1/(h_out*A2);//Resistance to convection from outer side of tank[degree Celcius/W]
R_rad=1/(h_rad*A2);//Resistance to radiation heat transfer[degree Celcius/W]
//R_out and R_rad are in parallel connection,
R_eq=(1/((1/R_out)+(1/R_rad)));//[degree Celcius/W]
//R_in,R_sphere and R_eq are connected in series
R_total=R_in+R_sphere+R_eq;//[degree Celcius/W]
Q_=(T_tank-T_ice)/R_total;//[W]
disp("W",Q_,"The steady rate of heat transfer to the iced water is")
disp("We determine outer surface temperature to check the validity of assumption")
T2=T_tank-(Q_*R_eq);//[K]
```

```
disp("K",T2)
disp("which is sufficiently close to 278 K")
//b)
delta_t=24;//Time duration[h]
Q=Q_*delta_t*(3600/1000);//[kJ]
disp("kJ",Q,"The total amount of heat transfer
    during a 24 hour period is")
//It takes 333.7 kJ of energy to melt 1kg of ice at
    0 degree Celcius
m_ice=Q/heat_f;//[kg]
disp("kg",m_ice,"The amount of ice that will melt
    during 24h period is")
```

Scilab code Exa 3.8 ab48

```
clear;
clc;

//Example3.8[Heat Loss through an Insulated Steam
    Pipe]
//Given:-
T_steam=320;//[degree Celcius]
T_surr=5;//[degree Celcius]
k_iron=80;//Thermal conductivity of cast iron[W/m.
    degree Celcius]
k_insu=0.05;//Thermal conductivity of glass wool
    insulation[W/m.degree Celcius]
h_out=18;//Covection heat transfer coefficient
    outside the pipe[w/m^2.degree Celcius]
h_in=60;//Covection heat transfer coefficient
    insideside the pipe[w/m^2.degree Celcius]
D_in=0.05;//Inner diameter of pipe[m]
D_out=0.055;//Outer diameter of pipe[m]
t=0.03;//Thickness of insulation[m]
r=(D_out/2)+t;//Effective outer radius[m]
```

```
L=1;//Length of pipe[m]
//Solution:-
//Areas of surfaces exposed to convection
A1=2*%pi*(D_in/2)*L;//Inner Area of pipe[m^2]
A2=2*%pi*(r)*L;//Outer Area of pipe[m^2
//Individual Thermal Resistances
R_conv_in=1/(h_in*A1);//Resistance to convetion from inner surface of pipe[degree Celcius/W]
R_pipe=(log(D_out/D_in))/(2*%pi*k_iron*L);//Resitance to conduction through iron pipe[degree Celcius/W]
R_insu=(log(r/(D_out/2)))/(2*%pi*k_insu*L);//Resistance to conduction through insulation[degree Celcius/W]
R_conv_out=1/(h_out*A2);//Resistance to convetion from outer surface of insulation on pipe[degree Celcius/W]
//All resistances are in series
R_total=R_conv_in+R_pipe+R_insu+R_conv_out;//Total Resistance[degree Celcius]
Q_=(T_steam-T_surr)/R_total;//[W]
disp("W",Q_,"The Steady rate of heat loss from the steam per m length of pipe is")
delta_T_pipe=Q_*R_pipe;//[degree Celcius]
delta_T_insu=Q_*R_insu;//[degree Celcius]
disp("degree Celcius",delta_T_insu,"and",delta_T_pipe,,"The temperature drop across the pipe and the insulation is respectively")
```

Scilab code Exa 3.9 ab49

```
clear;
clc;

//Example3.9[Heat Loss from an Insulated Electric
```

```
Wire]
//Given:-
k_insu=0.15;//[W/m.degree Celcius]
V=8;//Voltage drop across wire[Volts]
I=10;//Current flowimg through the wire[Amperes]
T_atm=30;//Temperature of atmosphere to which wire is exposed[degree Celcius]
h=12;//heat transfer coefficient[W/m^2.degree Celcius]
L=5;//length of wire[m]
D=0.003;//diameter of wire[m]
t=0.002;//thickness of insulation[m]
r=(D/2)+t;//Effective radius[m]
//Solution:-
//Rate of heat generated in the wire becomes equal to the rate of heat transfer
Q_=V*I;//[W]
disp("W",Q_,"Heat generated in the wire is")
A2=2*%pi*r*L;//Outer surface area[m^2]
//Resistances offered
R_conv=1/(h*A2);//Convection resistance for the outer sueface of insulation[degree Celcius/W]
R_insu=(log(r/(D/2)))/(2*%pi*k_insu*L);//Conduction resitance for the plastic insulation[degree Celcius/W]
//Effective Resistance
R_total=R_conv+R_insu;//[degree Celcius/W]
//Interface Temperature can be determined from
T1=T_atm+(Q_*R_total);//[degree Celcius]
disp("degree Celcius",T1,"The interface temperature is")
//Critical radius
r_cr=k_insu/h;//[m]
disp("mm",r_cr*1000,"The critical radius of insulation of the plastic cover is")
//Larger value of critical radius ensures that increasing the thickness of insulation upto critical radius will increase the rate of heat
```

```
transfer
```

Scilab code Exa 3.10 ab50

```
clear;
clc;

//Example3.10[Maximum Power dissipation of a
    Transistor]
//Given:-
T_ambient=25;//Ambient temperature[degree Celcius]
T_case=85;//Maximum temperature of the case[degree
    Celcius]
R_case_ambient=20;//Resistance for convection b/w
    case and ambient [degree Celcius/W]
//Solution:-
Q_=(T_case-T_ambient)/R_case_ambient;//[W]
disp("W",Q_,"The given power transistor should not
    be operated at power levels above")
disp("if is its case temperature is not to exceed 85
     degree Celcius")
```

Scilab code Exa 3.11 ab51

```
clear;
clc;

//Example3.11[Selecting a Heat Sink for a Transistor
    ]
//Given:-
Q_=60;//Rate of heat transfer from given transistor
    at at full power[W]
```

```
T_ambient=30;//Temperature of ambient air[degree Celcius]
T_case=90;//Maximum temperature of case[degree Celcius]
//Solution:-
R_sink=(T_case-T_ambient)/Q_;//[degree Celcius/W]
disp("degree Celcius/W",R_sink,"The thermal resistance b/w the transistor attached to the heat sink and the ambient air for the specified temperature difference is ")
```

Scilab code Exa 3.12 ab52

```
clear;
clc;

//Example3.12[Effect of fins on Heat transfer from steam pipes]
//Given:-
k_fin=180;//thermal conductivity of aluminium alloy fins[W/m.degree Celcius]
D_tout=0.03;//Outer diameter of tube[m]
D_fout=0.06;//Outer diameter of circular fins[m]
t=0.002;//thickness of fin[m]
s=0.003;//distance between fins attached to the tube[m]
n=200;//number of fins per meter of tube
L=1;//length of tube[m]
T_surr=25;//Surrounding temperature[degree Celcius]
T_wall=120;//Temperature of wall of the tube[degree Celcius]
h=60;//Combined heat transfer coefficient[W/m^2.degree Celcius]
//Solution:-
disp("In case of no fins")
```

```
A_nf=%pi*D_tout*L;//Area of tube with no fins attached[m^2]
//Using Newton's Law of cooling
Q_nf=h*A_nf*(T_wall-T_surr);//[W]
disp("W",Q_nf,"Rate of heat transfer when no finis attached")
//The efficiency of the circular fins attached to a circular tube is plotted in Fig 3.43
L_fin=(D_fout-D_tout)/2;//[m]
//In this case we have following corrected parameters
r2c=(D_fout+t)/2;//[m]
Lc=L_fin+(t/2);//[m]
Ap=Lc*t;//[m^2]
r=r2c/(D_tout/2);
alpha=(Lc*sqrt(Lc))*sqrt(h/(k_fin*Ap));//efficiency
disp(alpha)
//for above value of alpha efficiency is found out from the plot in fig 3.43
neta=0.96;
A_f=2*%pi*((r2c^2)-((D_tout/2)^2));//Area of tube with fins attached to it[m^2]
Q_f_max=h*A_f*(T_wall-T_surr);//maximum rate of heat transfer[W]
Q_f=neta*Q_f_max;//Heat transfer through tube with fins is efficiency times the maximum rate of heat transfer[W]
disp("W",Q_f,"Heat transfer due to the finned tube")
//From unfinned portion
A_uf=%pi*D_tout*s;//Unfinned area between two consecutive fins[m^2]
Q_uf=h*A_uf*(T_wall-T_surr);//[W]
disp("W",Q_uf,"Heat transfer from the unfinned portion of the tube is")
//Since there are 200 fins per meter of the tube hence 200 interfin spacing
Q_tf=n*(Q_f+Q_uf);//[W]
disp("W",Q_tf,"The total Heat transfer from the
```

```
    finned tube is")
Q_increase=Q_tf-Q_nf;//[W]
disp("W",Q_increase,"The increase in heat transfer
    from the tube per meter of length as a result of
    the addition of fins is")
eff=Q_tf/Q_nf;//Effectiveness
disp(eff,"The rate of heat transfer from the steam
    tube increases by a factor of")
disp("as a result of adding fins")
```

Scilab code Exa 3.13 ab53

```
clear;
clc;

//Example3.13[Heat Loss from Buried Steam Pipes]
//Given:-
T_esurf=10;//Surface temperatur of earth[degree
    Celcius]
T_psurf=80;//Outer surface temperature of pipe[
    degree Celcius]
k_soil=0.9//Thermal Conductivity of soil[W/m.degree
    Celcius]
L=30;//Length of pipe[m]
D=0.1;//Diameter of pipe[m]
z=0.5;//Depth at which pipe is kept[m]
//Solution:-
//Calculating shape factor
if(z>(1.5*D))then
 S=(2*%pi*L)/(log((4*z)/D)), end;//[m]
 disp(S,"Shape factor is")
 Q_=S*k_soil*(T_psurf-T_esurf);//[W]
 disp("W",Q_,"The steady rate of heat transfer from
     the pipe is")
```

Scilab code Exa 3.14 ab54

```
clear;
clc;

//Example3.14[Heat Transfer between Hot and Cold Water pipes]
//Given:-
T_hot=70;//Surface Temperature of hot pipe[degree Celcius]
T_cold=15;//Surface Temperature of cold pipe[degree Celcius]
L=5;//Length of both pipes[m]
D=0.05;//Diameter of both the pipes[m]
z=0.3;//Distance between centreline of both the pipes[m]
k=0.75;//Thermal Conductivity of the concerte[W/m.degree Celcius]
//Solution:-
//Calculating Shape Factor
S=(2*%pi*L)/(acosh(((4*(z^2))-(D^2)-(D^2))/(2*D*D)));//[m]
disp("m",S,"Shave factor for given configuration is")
Q_=S*k*(T_hot-T_cold);//[W]
disp("W",Q_,"The steady rate of heat transfer between the pipes becomes")
```

Scilab code Exa 3.15 ab55

```
clear;
clc;
```

```

//Example3.15[Cost of Heat Loss through walls in winter]
//Given:-
R_va_insu=2.3;//thickness to thermal conductivity ratio[m^2.degreeCelcius/W]
L1=12;//length of first wall of house[m]
L2=12;//length of second wall of house[m]
L3=9;//length of third wall of house[m]
L4=9;//length of fourth wall of house[m]
H=3;//height of all the walls[m]
T_in=25;//Temperature inside house[degree Celcius]
T_out=7;;//average temperature of outdoors on a certain day[degree Celcius]
ucost=0.075;//Unit Cost of elctricity[$/kWh]
h_in=8.29,h_out=34.0;//Heat transfer coefficients for inner and outer surface of the walls respectively[W/m^2.degree Celcius]
v=24*(3600/1000);//velocity of wind[m/s]
//Solution:-
//Heat transfer Area of walls=(Perimeter*Height)
A=(L1+L2+L3+L4)*H;//[m^2]
//Individual Resistances
R_conv_in=1/(h_in*A);//Convection Resistance on inner surface of wall[degree Celcius/W]
R_conv_out=1/(h_out*A);//Convection Resistance on outer surface of wall[degree Celcius/W]
R_wall=R_va_insu/A;//Conduction resistance to wall[degree Celcius/W]
//All resistances are in series
R_total=R_conv_in+R_wall+R_conv_out;//[degree Celcius/W]
Q_=(T_in-T_out)/R_total;//[W]
disp("W",Q_,"The steady rate of heat transfer through the walls of the house is")
delta_t=24;//Time period[h]
Q=(Q_/1000)*delta_t;//[kWh/day]
disp("kWh/day",Q,"The total amount of heat lost
```

```
    through the walss during a 24 hour period ")
cost=Q*ucost;//[$/day]
disp("per day",cost,"Cost of heat consumption is $")
```

Scilab code Exa 3.16 ab56

```
clear;
clc;

//Example3.16[The R-value of a Wood Frame Wall]
//Given:-
f_area_insu=0.75;//area fraction for the insulation
    section
f_area_stud=0.25;//area fraction for the stud
R_bstud=3.05;//Total unit thermal resistance of
    section between studs[m^.degree Celcius/W]
R_atstud=1.23;//Total unit thermal resistance of
    section at studs[m^.degree Celcius/W]
P=50;//Perimeter of the building[m]
H=2.5;//height of the walls[m]
T_in=22;//Temperature inside the walls[degree
    Celcius]
T_out=-2;//Temperature outside the walls[degree
    Celcius]
//Solution:-
U_bstud=1/R_bstud;//[W/m^2.degree Celcius]
U_atstud=1/R_atstud;//[W/m^2.degree Celcius]
Total_U=(f_area_insu*U_bstud)+(f_area_stud*R_atstud)
    ;//[W/m^2.degree Celcius]
disp("W/m^",Total_U,"Overall U factor is")
disp("degree Celcius.m^2/W",(1/Total_U),"Overall
    unit thermal Resistance is")
///Since glazing constitutes 20% of the walls,
A_wall=(0.80)*P*H;//[m^2]
Q_=Total_U*A_wall*(T_in-T_out);//[W]
```

```
disp("W",Q_,"The rate of heat loss through the walls
    under design conditions is")
//Answer is slighthly different from book because of
    no of digits after decimal pont used here is
   quite large
```

Scilab code Exa 3.17 ab57

```
clear;
clc;

//Example13.17[The R value of a Wall with Rigid Foam
   ]
//Given:-
//using values from previous example
R_old=2.23;//AS written in book[m^2.degree Celcius/W
   ]
//R value of of the fibreboard and the foam
   insulation, respectively
R_removed=0.23;//[m^2.degree Celcius/W]
R_added=0.98;//[m^2.degree Celcius/W]
//Solution:-
R_new=R_old-R_removed+R_added;//[m^2.degree Celcius/
   W]
increase=((R_new-R_old)/R_old)*100;
disp("m^2.degree Celcius/W",R_old,"Old R value is")
disp("m^2.degree Celcius/W",R_new,"New R value is")
disp(increase,"Percent increase in R-value")
```

Chapter 4

Transient Heat Conduction

Scilab code Exa 4.1 ab61

```
clear;
clc;

//Example4.1[Temperature Measurement by Thermocouples]
//Given:-
//Temperature of a gas stream is to be measured by a thermocouple whose junction can be approximated as a sphere
D=0.001;//Diameter of junction sphere[m]
//Properties of the junction
k=35;//Thermal conductivity[W/m.degree Celcius]
rho=8500;//desity[kg/m^3]
Cp=320;//Specific heat[J/kg.degree Celcius]
h=210;//Convection heat transfer coefficient between junction and the gas[W/m^2.degree Celcius]
//Solution:-
//V=(%pi/6)*(D^3)
Lc=(((%pi/6)*(D^3))/(%pi*(D^2)));//The characteristic length of the junction[m]
Bi=h*Lc/k;//Biot Number
```

```
if(Bi<0.1) then,
disp(Bi,"Since Bi=")
disp("is less than 0.1 hence lumped system is
    applicable and the error involved in this
    approximation is negligible")
end;
b=h/(rho*Cp*Lc);//Exponent time constant[s^(-1)]
disp("s^(-1)",b,"Time constant for given lumped heat
     capacity system")
//In order to read 99% of intial temperature
    difference between the junction and the gas we
    must have ((T(t)-T_end)/(Ti-T_end))=0.01
t=-1*(log(0.01))/b;
disp("seconds",round(t),"Required time is")
```

Scilab code Exa 4.2 ab62

```
clear;
clc;

//Example4.2[Predicting the time of Death]
//Given:-
T_room=20;//Temperature of room[degree Celcius]
T_body_f=25;//Temperature of dead body after some
    time[degree Celcius]
T_body_i=37;//Temperature of dead body just after
    death[degree Celcius]
h=8;//Heat transfer Coefficient[W/m^2.degree Celcius
    ]
L=1.7;//Length of body which is assumed to be
    cylindrical in shape[m]
r=0.15;//Radius of cylindrical body
//Average human body is 72% water by mass, thus we
    assumne body to have properties of water
rho=996;//Density[kg/m^3]
```

```
k=0.617;//Thermal conductivity[W/m.degree Celcius]
Cp=4178;//Specific Heat[J/kg.degree Celcius]
//Solution:-
Lc=(%pi*(r^2)*L)/((2*%pi*r*L)+(2*%pi*(r^2)));//Characteristic length of body[m]
Bi=(h*Lc)/k;//Biot no
if(Bi>0.1) then,
    disp("lumped system analysis is not applicable , but we can still use it to get a rough estimate of time of death")
    b=h/(rho*Cp*Lc);//[s^(-1)]
 x=(T_body_i-T_room)/(T_body_f-T_room);
//exp(-b*t)=x;
t=(1/b)*log(x);//time elapsed[seconds]
disp("hour",t/3600,"As a rough estimate the person dies about")
disp("before the body was found")
```

Scilab code Exa 4.3 ab63

```
clear;
clc;

//Example4.3[Boiling Eggs]
//Given:-
T1=5;//Initial temperature of egg[degree Celcius]
T2=95;//Temperature of Boiling Water[degree Celcius]
h=1200;//Convection heat transfer coefficient of egg[W/m^2.degree Celcius]
r=0.025;//Radius of egg[m]
T3=70;//Final temperature attained by centre of egg[degree Celcius]
k=0.627;//Thermal conductivity[W/m.degree Celcius]
a=0.151*(10^(-6));//Thermal diffusivity[m^2/s]
//Solution:-
```

```
Bi=(h*r)/k;//Biot Number
if(Bi>0.1) then,
disp("the lumped system analysis is not applicable")
//Findinf coefficient for a sphere corresponding to this bi are,
lambda1=3.0754,A1=1.9959;
x=(T3-T2)/(T1-T2);
tau=(-1/(lambda1^2))*log(x/A1);
disp(tau,"Fourier no is")
//Since fourier no is greater than 0.2, cooking time is determined from the definition of fourier no to be
t=(tau*(r^2))/a;//[seconds]
disp("minutes",(t/60),"The time taken for center of egg to reach 70 degree Celcius temperature")
else,
    disp("the lumped system is not applicable")
end
```

Scilab code Exa 4.4 ab64

```
clear;
clc;

//Example4.4[Heating of Brass Plates in an Oven]
T_in=20;//Initial uniform temperature of brass plate [degree Celcius]
T_f=500;//Temperature of the oven[degree Celcius]
t=7*60;//[seconds]
h=120;//combined convection and radiation heat transfer coefficient[W/m^2.degree Celcius]
L=0.04/2;//Thickness of plate 2L=0.004[m]
//Properties of brass at room temperature are:-
k=110;//Thermal conductivity[W/m.degree Celcius]
rho=8530;//density[kg/m^3]
```

```
Cp=380;//Specific Heat Capacity[J.kg.degree Celcius]
a=33.9*(10^(-6));//Thermal Diffusivity[m^2/s]
//Solution:-
Bi1=1/(k/(h*L));
tau1=(a*t)/(L^2);
//For above values of biot no and fourier no we have
p=0.46;// p=(T0-T_f)/(T_in-T_f),where T0 is
    temperature of inner surface of plate at time t
x=L;
Bi2=Bi1;
//For above condition of x/L ratio and Biot number
    we have
q=0.99;//q=(T-T_f)/(T_in-T_f), where T is
    temperature of outer surface of plate after time
    t
T=T_f+((p*q)*(T_in-T_f));//[degree Celcius]
disp("degree Celcius",ceil (T),"The surface
    temperature of the plates when they leave the
    oven will be")
```

Scilab code Exa 4.5 ab65

```
clear;
clc;

//Example4.5[Cooling of a long Stainless Steel
    Cylindrical Shaft]
//Given:-
Ti=600;//Temperature of cylinder just after taking
    it out of the oven[degree Celcius]
h=80;//average heat transfer coefficient[W/m^2.
    degree Celcius]
t=45*60;//Time for cooling[seconds]
r=0.1;//Radius of cylinder[m]
l=1;//Length of cylinder[m]
```

```
//Properties of stainless steel cylinder
k=14.9;//Thermal conductivity[W/m.degree Celcius]
rho=7900;//Density[kg/m^3]
Cp=477;//Specific Heat Capacity[J/kg.degree Celcius]
a=3.95*(10^(-6));//Thermal diffusivity[m^2/s]
T_f=200;//Ambient temperature[degree Celcius]
//Solution:-
Bi1=(h*r)/k;
tau1=(a*t)/(r^2);
//For biot no=Bi1 and fourier no=tau1,we have
p=0.40;//p=(T(0)-T_f)/(Ti-T_f)
T_0=T_f+(p*(Ti-T_f));//[degree Celcius]
disp("degree Celcius",T_0,"The center temperature of the shaft after 45 minutes is")
//Determining actual heat transfer
m=rho*%pi*(r^2)*l;//[kg]
Q_max=m*Cp*(Ti-T_f)*(1/1000);//[kJ]
x=(Bi1^2)*tau1;
//For biot no= Bi1 and (h^2)at/(k^2)=x, we have
y=0.62;//y=Q/Q_max
Q=y*Q_max;//[kJ]
disp("kJ",round(Q),"The total heat transfer from the shaft during 45 minutes of cooling is")
```

Scilab code Exa 4.6 ab66

```
clear;
clc;

//Example4.6[Minimum Burial Depth of Water Pipes to avoid Freezing]
//Given:-
//Soil properties:-
k=0.4;//Thermal conductivity[W/m.degree Celcius]
a=0.15*(10^(-6));//Thermal diffusivity[m^2/s]
```

```
T_in=15;//Initial uniform temperature of ground[
   degree Celcius]
T_x=0;//Temperature after 3 months[degree Celcius]
Ts=-10;//Temperature of surface[degree Celcius]
//Solution:-
//The temperature of the soil surrounding the pipes
   wil be 0 degree Celcius after three months in the
    case of minimum burial depth, therefore we have
x=(h/k)*(sqrt(a*t));
//Since h tends to infinty
x=%inf;
y=(T_x-T_in)/(Ts-T_in);
//For values of x and y we have
neta=0.36;
t=90*24*60*60;//[seconds]
x=2*neta*sqrt(a*t);//[m]
disp("m",x,"Water pipes must be burried to a depth
   of at least ")
disp("so as to avoid freezing under the specified
   harsh winter conditions")
```

Scilab code Exa 4.7 ab67

```
clear;
clc;

//Example4.7[Surface Temperature Rise of Heated
   Blocks]
//Given:-
flux=1250;//Constant solar heat flux [W/m^2]
T=20;//Temperature of black painted wood block[
   degree Celcius]
k_wood=1.26;//Thermal conductivity of wood at room
   temperature [W/m.K]
a_wood=1.1*(10^(-5));//Diffusivity of wood at room
```

```
temperature[m^2/s]
k_aluminium=237;//Thermal conductivity of aluminium at room temperature[W/m.K]
a_aluminium=9.71*(10^(-5));//Diffusivity of aluminium at room temperature[m^2/s]
t=20*60;//[seconds]
//Solution:-
Ts_wood=T+((flux/k_wood)*(sqrt((4*a_wood*t)/%pi)));//[degree Celcius]
Ts_aluminium=T+((flux/k_aluminium)*(sqrt((4*a_aluminium*t)/%pi)));//[degree Celcius]
disp("respectively","degree Celcius",round (Ts_aluminium),"and",ceil (Ts_wood),"The surface temperature fro both the wood and aluminium blocks are ")
```

Scilab code Exa 4.8 ab68

```
clear;
clc;

//Example4.8[Cooling of a Short Brass Cylinder]
//Given:-
Ti=120;//Initial Temperature[degree Celcius]
T_ambient=25;//Temperature of atmospheric air[degree Celcius]
h=60;//convetcion heat transfer coefficient[W/m^2.degree Celcius]
r=0.05;//radius of cylinder[m]
L=0.06;//thickness[m]
a=3.39*(10^(-5));//Diffusivity of brass[m^2/s]
k=110;//Thermal conductivity of brass[W/m.degree Celcius]
t=900;//[seconds]
//Solution (a):-
```

```
disp("At the center of the plane wall")
tau1=(a*t)/(L^2);
Bi1=(h*L)/k;
disp("respectively",Bi1,"and",tau1,"Fourier no and Biot no are")
disp("At the center of the cylinder")
tau2=(a*t)/(r^2);
Bi2=(h*r)/k;
disp("respectively",Bi2,"and",tau2,"Fourier no and Biot no are")
theta_wall_c=0.8;//(T(0,t)-T_ambient)/(Ti-T_ambient)
theta_cyl_c=0.5;//(T(0,t)-T_ambient)/(Ti-T_ambient)
T_center=T_ambient+((theta_wall_c*theta_cyl_c)*(Ti-T_ambient));//[degree Celcius]
disp("degree Celcius",round (T_center),"The temperature at the center of the short cylinder is")
//Solution (b):-
//The centre of the top surface of the cylinder is still at the center of the lonf cylinder(r=0),but at the outer surface of the plane wall(x=L).
x=L;//[m]
y=x/L;
//For Bi=Bi1 and x=1
theta_wall_L=0.98*theta_wall_c;//(T(L,t)-T_ambient)/(Ti-T_ambient)
T_surface=T_ambient+((theta_wall_L*theta_cyl_c)*(Ti-T_ambient));//[degree Celcius]
disp("degree Celcius",round (T_surface),"The temperature at the top surface of the cylinder")
```

Scilab code Exa 4.9 ab69

```
clear;
clc;
```

```
//Example4.9[Heat transfer from a Short Cylinder]
//Given:-
Ti=120;//Initial Temperature[degree Celcius]
T_ambient=25;//Temperature of atmospheric air[degree Celcius]
rho=8530;//density of brass cyliner[kg/m^3]
Cp=0.380;//Specific heat of brass cylinder[kJ/kg.degree Celcius]
r=0.05;//radius[m]
H=0.12;//Height of cylinder[m]
h=60;//convetcion heat transfer coefficient[W/m^2.degree Celcius]
a=3.39*(10^(-5));//Diffusivity of brass [m^2/s]
k=110;//Thermal conductivity of brass[W/m.degree Celcius]
L=0.06;//[m]
t=900;//[seconds]
//Solution:-
m=rho*(%pi*(r^2)*H);//mass of cylinder[kg]
Q_max=m*Cp*(Ti-T_ambient);//[kJ]
disp("At the center of the plane wall")
tau1=(a*t)/(L^2);
Bi1=(h*L)/k;
x=(Bi1^2)*tau1;
//For given x and Bi1
p=0.23;//(Q/Qmax) for plane wall
disp("At the center of the cylinder")
tau2=(a*t)/(r^2);
Bi2=(h*r)/k;
y=(Bi2^2)*tau2;
//For given y and Bi2
q=0.47;//(Q/Qmax) for infinite cylinder
Q=Q_max*(p+(q*(1-p)));//[kJ]
disp("kJ",ceil (Q),"The total heat transfer from the cylinder during the first 15 minutes of cooling is")
```

Scilab code Exa 4.10 ab70

```
clear;
clc;

//Example4.10[Cooling of a Long Cylinder by Water]
Ti=200;//Initial Temperature of aluminium cylinder[
    degree Celcius]
Tf=15;//Temperature of water in which cylinder is
    kept[degree Celcius]
h=120;//Heat transfer Coefficent[W/m^2.degree
    Celcius]
t=5*60;//[seconds]
//Properties of aluminium at room temperature
k=237;//Thermal conductivity[W/m.degree Celcius]
a=9.71*(10^(-5));//Thermal diffusivity[m^/s]
r=0.1;//Radius of cylinder[m]
x=0.15;//[m]
//Solution:-
Bi=(h*r)/k;//Biot number
//Corresponding to this biot no coefficients for a
    cylinder
lambda=0.3126,A=1.0124;
tau=(a*t)/(r^2);
//Using one term approximation
theta0=A*exp(-(lambda^2)*tau);
neta=x/(2*sqrt(a*t));
u=(h*sqrt(a*t))/k;
v=(h*x)/k;
w=(u^2);
theta_semiinfinite=1-erfc(neta)+(exp(v+w)*erfc(neta+
    u));
theta=theta_semiinfinite*theta0;
T_x_t=Tf+(theta*(Ti-Tf));//[degree Celcius]
```

```
disp("degree Celcius",ceil (T_x_t),"the temperature at the center of the cylinder 15cm from the exposed bottom surface")
```

Scilab code Exa 4.11 ab71

```
clear;
clc;

//Example4.11[Refrigerating Steaks while Avoiding Frostbite]
//Given:-
Ti=25;//Initial temperature of steaks[degree Celcius]
Tf=-15;//Temperature of refrigerator[degree Celcius]
L=0.015;//Thickness of steaks[m]
//Properties of steaks
k=0.45;//[W/m.degree Celcius]
rho=1200;//density[kg/m^3]
a=9.03*(10^(-8));//Thermal diffusivity[m^2/s]
Cp=4.10;//Specific Heat [kJ/kg]
T_L=2,T_0=8;//[degree Celcius]
//Solution:-
//In the limiting case the surface temperature at x=L from the centre will be 2 degree C,while midplane temperature is 8 degree C in an environment at -15 degree C we have
x=L;
p=(T_L-Tf)/(T_0-Tf);
//For this value of p we have
Bi=1/1.5;//Biot number
h=(Bi*k)/L;//[W/m^2.degree Celcius]
disp("W/m^2.degree Celcius",h,"The convection heat transfer coefficient should be kept below the value")
```

```
disp("to satisfy the constraints on the temperature
   of the steak during refrigeration")
```

Chapter 5

Numerical Methods in Heat Conduction

Scilab code Exa 5.1 ab71

```
clear;
clc;

//Example5.1[Steady Heat Conduction in a Large Uranium Plate]
//Given:-
L=0.04;//Thickness of plate[m]
k=28;//Thermal conductivity[W/m.degree Celcius]
e_gen=5*(10^6);//Rate of heat generation per unit volume[W/m^3]
h=45;//Heat transfer coefficient[W/m^2]
T_ambient=30;//Ambient temperature[degree Celcius]
//Solutio:-
M=3;//No of nodes
//These nodes are chosen to be at the two surfaces of the plate and the mid point
del_x=L/(M-1);//Nodal Spacing[m]
//Let the nodes be 0,1 and 2. and temperatures at these nodes are
```

```
T0=0;//Temperature at node 0[degree Celcius]
//Finding temperatures at other two nodes using finite difference method
c1=e_gen*(del_x^2)/k;
c2=(-h*del_x*T_ambient/k)-(c1/2);
function[temp]=f1(T)
temp(1)=2*T(1)-T(2)-c1;
temp(2)=T(1)-1.032*T(2)-c2;
deff('[temp]=f1(T)',['temp_1=2*T(1)-T(2)-c1','temp_2=T(1)-1.032*T(2)-c2'])
//To find the solution assume an initial value x0=[a,b]
//then equate [xs,fxs,m]=fsolve(x0',f1)
```

Scilab code Exa 5.2 ab72

```
clear;
clc;

//Example5.2[Heat transfer from triangular fins]
//Given:-
k=180;//Thermal conductivity of aluminium alloy[W/m.degree Celcius]
L=0.05;//length of fin[m]
b=0.01;//Base thickness of fin[m]
T_surr=25;//Temperature of surrounding[degree Celcius
h=15;//heat transfer coefficient[W/m^2.degree Celcius]
M=6;//No of equally spaced nodes along the fin
//Solution (a)
del_x=L/(M-1);//Nodal Spacing[m]
T0=200;//Temperature at node 0[degree Celcius]
theta=atan(b/2*L);
//sigmaQ_all_sides=kA_left((T_(m-1)-T_m)/del_X)+((T_
```

```
(m+1)-T_m)/del_x)+(hA_conv(T_surr-T_m))=0
//Simplifying above equation we get
disp("((5.5-m)T_(m-1))-((10.008-2m)Tm)+((4.5-m)T_m+1)=-0.29")
//Putting m=1,2,3,4 we get five equations in five unknowns
//Solving these five equations we get temperatures at node 1,2,3,4 and 5 respectively
function[node]=f5(T)
    node(1)=-8.008*T(1)+3.5*T(2)+0*T(3)+0*T(4)+0*T(5)+900.209;
    node(2)=3.5*T(1)-6.008*T(2)+2.5*T(3)+0*T(4)+0*T(5)+0.209;
    node(3)=0*T(1)+2.5*T(2)-4.008*T(3)+1.5*T(4)+0*T(5)+0.209;
    node(4)=0*T(1)+0*T(2)+1.5*T(3)-2.008*T(4)+0.5*T(5)+0.209;
    node(5)=0*T(1)+0*T(2)+0*T(3)+1*T(4)-1.008*T(5)+0.209;
    deff('[node]=f5(T)',['f_1=-8.008*T(1)+3.5*T(2)+0*T(3)+0*T(4)+0*T(5)+900.209','f_2=3.5*T(1)-6.008*T(2)+2.5*T(3)+0*T(4)+0*T(5)+0.209','f_3=0*T(1)+2.5*T(2)-4.008*T(3)+1.5*T(4)+0*T(5)+0.209','f_4=0*T(1)+0*T(2)+1.5*T(3)-2.008*T(4)+0.5*T(5)+0.209','f_5=0*T(1)+0*T(2)+0*T(3)+1*T(4)-1.008*T(5)+0.209'])
    //Solution(b)
 T1=T(1),T2=T(2),T3=T(3),T4=T(4),T5=T(5);
    w=1;//width [m]
    Q_fin=(h*w*del_x/cos(theta))*[(T0+2*(T1+T2+T3+T4)+T5-10*T_surr)];//[W]
    disp("W",Q_fin,"The total rate of heat transfer from the fin is")
    //Solution(c)
    Q_max=(h*2*w*L/cos(theta)*(T0-T_surr));//[W]
neta=Q_fin/Q_max;
disp(neta,"Efficiency of the fin is")
```

Scilab code Exa 5.3 ab73

```
clear;
clc;

//Example5.3[SteadLy Two-Dimensional Heat Conduction
    in L-Bars]
//Given:-
e_gen=2*(10^6);//Heat generated per unit volume[W/m
   ^3]
k=15;//Thermal heat conductivity[W/m.degree Celcius]
T_ambient=25;//Temperature of ambient air[degree
   Celcius]
T_surface=90;//Temperature of the bottom surface[
   degree Celcius]
h=80//convection coefficient[W/m^2]
q_R=5000;//Heat flux to which right surface is
   subjected[W/m^2]
del_x=0.012,del_y=0.012;//Distance between equally
   spaced nodes[m]
//Solution:-
//After substituting values in equations of all nodal
    points finally we have nine equation and nine
   unknowns
function[temp]=f9(T)
    temp(1)=-2.064*T(1)+1*T(2)+0*T(3)+1*T(4)+0*T(5)
       +0*T(6)+0*T(7)+0*T(8)+0*T(9)+11.2;
    temp(2)=1*T(1)-4.128*T(2)+1*T(3)+0*T(4)+2*T(5)
       +0*T(6)+0*T(7)+0*T(8)+0*T(9)+22.4;
    temp(3)=0*T(1)+1*T(2)-2.128*T(3)+0*T(4)+0*T(5)
       +1*T(6)+0*T(7)+0*T(8)+0*T(9)+12.8;
    temp(4)=1*T(1)+0*T(2)+0*T(3)-4*T(4)+2*T(5)
       +109.2;
    temp(5)=0*T(1)+1*T(2)+0*T(3)+1*T(4)-4*T(5)+1*T
```

```
(6)+0*T(7)+0*T(8)+0*T(9)+109.2;
    temp(6)=0*T(1)+0*T(2)+1*T(3)+0*T(4)+2*T(5)
        -6.128*T(6)+1*T(7)+0*T(8)+0*T(9)+212.0;
    temp(7)=0*T(1)+0*T(2)+0*T(3)+0*T(4)+0*T(5)+1*T
        (6)-4.128*T(7)+1*T(8)+0*T(9)+202.4;
    temp(8)=0*T(1)+0*T(2)+0*T(3)+0*T(4)+0*T(5)+0*T
        (6)+1*T(7)-4.128*T(8)+T(9)+202.4;
    temp(9)=0*T(1)+0*T(2)+0*T(3)+0*T(4)+0*T(5)+0*T
        (6)+0*T(7)+1*T(8)-2.064*T(9)+105.2;
    deff('[temp]=f9(T)',['f_1= -2.064*T(1)+1*T(2)+0*
        T(3)+1*T(4)+0*T(5)+0*T(6)+0*T(7)+0*T(8)+0*T
        (9)+11.2','f_2=1*T(1)-4.128*T(2)+T(3)+0*T(4)
        +2*T(5)+0*T(6)+0*T(7)+0*T(8)+0*T(9)+22.4','
        f_3=0*T(1)+T(2)-2.128*T(3)+0*T(4)+0*T(5)+T(6)
        +0*T(7)+0*T(8)+0*T(9)+12.8','f_4=T(1)+0*T(2)
        +0*T(3)-4*T(4)+2*T(5)+109.2','f_5=0*T(1)+T(2)
        +0*T(3)+T(4)-4*T(5)+T(6)+0*T(7)+0*T(8)+0*T(9)
        +109.2','f_6=0*T(1)+0*T(2)+T(3)+0*T(4)+2*T(5)
        -6.128*T(6)+T(7)+0*T(8)+0*T(9)+212.0','f_7=0*
        T(1)+0*T(2)+0*T(3)+0*T(4)+0*T(5)+T(6)-4.128*T
        (7)+T(8)+0*T(9)+202.4','f_8=0*T(1)+0*T(2)+0*T
        (3)+0*T(4)+0*T(5)+0*T(6)+T(7)-4.128*T(8)+T(9)
        +202.4','f_9=0*T(1)+0*T(2)+0*T(3)+0*T(4)+0*T
        (5)+0*T(6)+0*T(7)+T(8)-2.064*T(9)+105.2'])
```

Scilab code Exa 5.4 ab74

```
clear;
clc;

//Example5.4[Heat Loss through Chimneys]
//Given:-
k=1.4;//Thermal conductivity of concrete[W/m.degree
    Celcius]
A=0.2*0.2;//Area of flow section[m^2]
```

```
t=0.2;//Thickness of the wall[m]
Ti=300+273;//Average temperature of gases[K]
hi=70;//Convection heat transfer coefficient inside the chimney[W/m^2]
ho=21;//Convection heat transfer coefficient outside the chimney[W/m^2]
To=20+273;//Temperature od outer air[Kelvin]
e=0.9;//Emissivity
delx=0.1,dely=0.1;//Nodal spacing [m]
//Solution:-
//Substituing values in all nodal equations and and solving these equations we get temperature at all nodes
function[temp]=fu9(T)
    temp(1)=7*T(1)-T(2)-T(3)-2865;
    temp(2)=-T(1)+8*T(2)-2*T(4)-2865;
    temp(3)=-T(1)+4*T(3)-2*T(4)-T(6);
    temp(4)=-T(2)-T(3)+4*T(4)-T(5)-T(7);
    temp(5)=-2*T(4)+4*T(5)-2*T(8);
    temp(6)=-T(2)-T(3)+3.5*T(6)+(0.3645*(10^(-9))*(T(6)^4))-456.2;
    temp(7)=-2*T(4)-T(6)+7*T(7)+(0.729*(10^(-9))*(T(7)^4))-T(8)-912.4;
    temp(8)=-2*T(5)-T(7)+7*T(8)+(0.729*(10^(-9))*(T(8)^4))-912.4;
    temp(9)=-T(8)+2.5*T(9)+(0.3645*(10^(-9))*(T(9)^4))-456.2;
    deff('[temp]=fu9(T)',['f_1=7*T(1)-T(2)-T(3)-2865','f_2=-T(1)+8*T(2)-2*T(4)-2865','f_3=-T(1)+4*T(3)-2*T(4)-T(6)','f_4=-T(2)-T(3)+4*T(4)-T(5)-T(7)','f_5=-2*T(4)+4*T(5)-2*T(8)','f_6=-T(2)-T(3)+3.5*T(6)+(0.3645*(10^(-9))*(T(6)^4))-456.2','f_7=-2*T(4)-T(6)+7*T(7)+(0.729*(10^(-9))*(T(7)^4))-T(8)-912.4','f_8=-2*T(5)-T(7)+7*T(8)+(0.729*(10^(-9))*(T(8)^4))-912.4','f_9=-T(8)+2.5*T(9)+(0.3645*(10^(-9))*(T(9)^4))-456.2'])
T1=T(1),T2=T(2),T3=T(3),T4=T(4),T5=T(5),T6=T(6),T7=T
```

```
(7),T8=T(8),T9=T(9);
T_wall=(0.5*T6+T7+T8+0.5*T9)/(0.5+1+1+0.5);
disp("Kelvin",T_wall,"The average temperature at the outer surface of the chimney weighed by the surface area is")
Q_chimney=(ho*4*0.6*1*(T_wall-To))+(e*5.67*(10^-8)*0.6*1*((T_wall^4)-((260^4))));//[W]
disp("W",Q_chimney,"The heat transfer is")
```

Scilab code Exa 5.5 ab75

```
clear;
clc;

//Example5.5[Transient Heat Conduction in a Large Uranium Plate]
//Given:-
k=28;//[W/m.degree Celcius]
a=12.5*10^(-6);//Thermal diffusivity[m^2/s]
T1_0=200,T2_0=200;//Initial Temperature[degree Celcius]
e_gen=5*10^6;//Heat generated per unit volume[W/m^3]
h=45;//heat transfer coefficient[W/m^2.degree Celcius]
T0=0;//Temperature at node 0[degree Celcius]
L=0.04;//[m]
M=3;//No of nodes
t=15;//[seconds]
//Solution (a):-
delx=L/(M-1);//[m]
//The nodes are 0,1 and 2
tau=(a*t)/(delx^2);//Fourier no
//Substituting this value of tau in nodal equations
//The nodal temperatures T1_1 and T2_1 at t=15sec
T1_1=0.0625*T1_0+0.46875*T2_0+33.482;//[degree
```

```
    Celcius]
T2_1=0.9375*T1_0+0.032366*T2_0+34.386;//[degree
    Celcius]
//Similarly the nodal themperatures T1_2,T2_2 at t1
    =2*t=30sec are
T1_2=0.0625*T1_1+0.46875*T2_1+33.482;//[degree
    Celcius]
T2_2=0.9375*T1_1+0.032366*T2_1+34.386;//[degree
    Celcius]
disp("degree Celcius",T2_2,T1_2,"and",T2_1,T1_1,"
    Temperatures at node 1 and 2 are respectively")
```

Scilab code Exa 5.6 ab76

```
clear;
clc;

//Example5.6[Solar Energy Storage in Trombe Walls]
//Given:-
hin=10;//[W/m^2]
A=3*75;//[m^2]
Tin=21;//[degree Celcius]
k=0.69;//[W/m.degree Celcius]
a=4.44*10^(-7);//diffusivity[m^2/s]
kappa=0.77;
delx=0.06;//The nodal spacing[m]
L=0.3;//Length of wall[m]
Tout=0.6,q_solar=360;//Ambient temperature in degree
     Celcius and Solar Radiation between 7am to 10 am
//Solution:-
M=(L/delx)+1;
disp(M,"No of nodes are")
//Stability Criterion
del_t=(delx^2)/(3.74*a);//[seconds]
disp("s",del_t,"The maximum allowable value of the
```

```
time step is")
//Therefore any step less than del_t can be used to solve this problem,for convinience let's choose
delt=900;//[seconds]
tao=a*delt/(delx^2);
disp(tao,"The mesh Fourier number is")
//Initially at 7am or t=0,the temperature of the wall is said to vary linearly between 21 degree Celcius at node 0 and -1 at node 5
//Temp between two neighbouring nodes is
temp=(21-(-1))/5;//[degree Celcius]
T0_0=Tin;
T1_0=T0_0-temp;
T2_0=T1_0-temp;
T3_0=T2_0-temp;
T4_0=T3_0-temp;
T5_0=T4_0-temp;
T0_1=((1-3.74*tao)*T0_0)+(tao*(2*T1_0+36.5));
T1_1=(tao*(T0_0+T2_0))+(T1_0*(1-(2*tao)));
T2_1=(tao*(T1_0+T3_0))+(T2_0*(1-(2*tao)));
T3_1=(tao*(T2_0+T4_0))+(T3_0*(1-(2*tao)));
T4_1=(tao*(T3_0+T5_0))+(T4_0*(1-(2*tao)));
T5_1=(T5_0*(1-(2.70*tao)))+(tao*((2*T4_0)+(0.70*Tout)+(0.134*q_solar)));
disp("Nodal temperatures at 7:15am are")
disp("degree Celcius",T0_1,"Node0:")
disp("degree Celcius",T1_1,"Node1:")
disp("degree Celcius",T2_1,"Node2:")
disp("degree Celcius",T3_1,"Node3:")
disp("degree Celcius",T4_1,"Node4:")
disp("degree Celcius",T5_1,"Node5:")
Q_wall=hin*A*delt*(((round(T0_1)+T0_0)/2)-Tin);//[J]
disp("J",Q_wall,"The amount of heat transfer during the first time step or during the first 15 min period is")
//Similarly using values from the table given we can find temperature at various nodes after required time interval
```

Chapter 6

Fundamentals of Convection

Scilab code Exa 6.1 ab81

```
clear;
clc;

//Example6.1[Temperature Rise of Oil is a Journal Bearing]
//Given:-
k=0.145;// [W/m.K]
mu=0.8374;//[kg/m.s] or [N.s/m^2]
T1=20;//Temperature of both the plates[degree Celcius]
t=0.002;//Thickness of oil film between the plates[m]
v=12;//Velocity with which plates move[m/s]
//Solution (a):-
//Relation between velocity and temperature variation
disp("T(y)=T0+(mu*(v^2)/(2*k))[(y/L)-((y/L)^2)]")
//Solution(b):-
//The location of maximum temperature is determined by setting dT/dy=0 and solving for y
//(mu*(v^2)/(2*k*L))*(1-(2*y/L))=0
```

```
L=1;//Random initialisation of variable L, where L is length of plates
y=L/2;
//T_max=T(L/2)
T_max=T1+((mu*(v^2)/(2*k))*(((L/2)/L)-(((L/2)^2)/(L^2))));
disp("degree Celcius",ceil(T_max),"Maximum temperature occurs at mid plane and its value is")
//heat flux q0=-kdt/dy|y=0;=-kmu*v^2/(2*k*L)
q0=-(mu*k*(v^2)/(2*k*t))/1000;//Heat flux from one plate [kW/m^2]
qL=-((k*mu*(v^2))*(1-2)/(2*k*t*1000));//Heat flux from another plate[kW/m^2]
disp("kW/m^2",qL,"Heat fluxes at the two plates are equal in magnitude but opposite in sign and the value of magnitude is")
```

Scilab code Exa 6.2 ab82

```
clear;
clc;

//Example6.2[Finding Convection Coefficient from Drag Measurement]
//Given:-
//Properties of air
rho=1.204;//[kg/m^3]
Cp=1007;//[J/kg.K]
Pr=0.7309;//Prandtl number
w=2;//Width of plate[m]
L=3;//Characteristic length of plate[m]
v=7;//velocity of air[m/s]
Fd=0.86;//Total grag force[N]
//Solution:-
```

```
As=2*w*L;//Since both sides of plate are exposed to
    air flow[m^2]
//For flat plates drag force is equivalent to
    friction coefficient Cf
Cf=Fd/(rho*As*(v^2)/2);
h=(Cf*rho*v*Cp)/(2*(Pr^(2/3)));//[W/m^2.degree
    Celcius]
disp("respectively","W/m^2.degree Celcius",h,"and",
    Cf,"Friction Factor and average heat transfer
    coefficient are")
```

Chapter 7

External Forced Convection

Scilab code Exa 7.1 ab91

```
clear;
clc;

//Example7.1[Flow of hot oil over a Flat Plate]
//Given:-
T_oil=60;//Temp of engine oil[degree Celcius]
T_plate=20;//Temp of flat plate[degree Celcius]
Rec=5*10^5;//Critical reynolds number for laminar flow
Tf=(T_oil+T_plate)/2;//Film temperature[degree Celcius]
v=2;//[m/s]
//Properties of engine oil at film temperature
rho=876;//[kg/m^3]
Pr=2962;//Prandtl number
k=0.1444;//[W/m.degree Celcius]
nu=2.485*10^(-4);//dynamic viscosity[m^2/s]
L=5;//Length of plate[m]
ReL=(v*L)/nu;
if(ReL<Rec) then,
   disp("We have laminar flow over the entire plate
```

```
")
    Cf=1.33*(ReL^(-0.5));
    disp(Cf,"The average friction coefficient is")
    //Pressure Drag is zero and thus Cd=Cf for parallel floe over a flat plate
    Fd=Cf*5*1*rho*(v^2)/2;//[N]
    disp("N",Fd,"The drag force acting on the plate per unit width is")
else,
    disp("flow is turbulent")
end
Nu=0.664*(ReL^(0.5))*(Pr^(1/3));//Nusselt Number
disp(ceil(Nu),"Nusselt Number is")
h=k*Nu/L;//[W/m^2.degree Celcius]
disp("W/m^.degree Celcius",h,"Convective heat transfer coefficient is")
Q=h*(5*1)*(T_oil-T_plate);//[W]
disp("W",round(Q),"Heat flow rate is")
```

Scilab code Exa 7.2 ab92

```
clear;
clc;

//Example7.2[Cooling of a Hot Block by Forced Air at High Elevation]
//Given:-
ReC=5*10^5;//critical Reynolds number
v=8;//Velocity of air[m/s]
T_air=20;//Initial Temperature of air[degree Celcius]
T_plate=140;//Temperature of flat plate[degree Celcius]
T_film=(T_air+T_plate)/2;//Film Temperature of air[degree Celcius]
```

```
//Properties of air at film temperature[degree Celcius]
k=0.02953;//[W/m.degree Celcius]
Pr=0.7154;//Prandtl Number
nu=2.097*10^(-5);//Kinematic Viscosity at 1 atm Pressure [m^2/s]
nu_ac=nu/0.823;//Kinematic viscosity at pressure 0.823 atm[m^2/s]
//Solution(a)
L1=6;//Characteristic length of plate along the flow of air[m]
w1=1.5;//width[m]
ReL1=(v*L1)/nu_ac;//Reynolds number
if(ReL1>ReC) then,
    disp("Flow is not laminar")
    //We have average Nusselt Number
    Nu1=((0.037*(ReL1^(0.8)))-871)*(Pr^(1/3));
    disp(ceil(Nu1),"Nusselt Number is")
    h1=k*Nu1/L1;//[W/m^2.degree Celcius]
    As1=w1*L1;//Flow Area of plate[m^2]
    Q1=h1*As1*(T_plate-T_air);
    disp("W",Q1,"Heat Flow Rate is")
else,
    disp("Flow is laminar")
end
//Solution(b)
L2=1.5;//Characteristic length of plate along flow of air[m]
ReL2=v*L2/nu_ac;//Reynolds Number
if(ReL2<Rec) then,
    disp("Flow is laminar")
    Nu2=0.664*(ReL2^(0.5))*(Pr^(1/3));
    disp(ceil(Nu2),"Nusselt Number is")
    h2=k*Nu2/L2;//[W/m^2.degree Celcius]
    Q2=h2*As1*(T_plate-T_air);
    disp("W",ceil(Q2),"The heat transfer rate is")
else,
    disp("Flow is turbulent")
```

```
end
```

Scilab code Exa 7.3 ab93

```
clear;
clc;

//Example7.3[Cooling of Plastic Sheets by Forced Air]
//Given:-
T_p=95;//Temp of plastic Sheet[degree Celcius]
T_air=25;//Temp of air[degree Celcius]
v=3;//Velocity of flowing air[m/s]
L=0.6;//Length of plastic sheet[m]
w=1.2;//width[m]
k=0.02808;//[W/m.degree Celcius]
Pr=0.7202;//Prandtl Number
nu=1.896*10^(-5);//[m^2/s]
rho=1200;//[kg/m^3]
Cp=1700;//[J/kg.degree Celcius]
vp=(9/60);//Velocity of moving plastic[m/s]
tp=0.001;//Thickness of plastic[m]
ReC=5*10^5;//Crictical Reynolds Number
e=0.9;//emissivity
//Solution(a)
L1=2*L;//Considering both sides of plastic sheet[m]
ReL1=v*L1/nu;//Reynolds number
if(ReL1<ReC) then,
    disp("(a) Flow is laminar")
    Nu1=0.664*(ReL1^0.5)*(Pr^(1/3));
    disp(Nu1,"The nusselt number is")
    h=k*Nu1/L1;//[W/m^2.degree Celcius]
    As=L1*w;//[m^2]
    Q_conv=h*As*(T_p-T_air);//[W]
    disp("W",ceil(Q_conv),"The covection heat flow
```

```
rate is")
    Q_rad=e*(5.67*10^(-8))*As*(((T_p+273)^4)-((T_air+273)^4));//[W]
    disp("W",(Q_rad),"Radiation heat transfer rate is")
    Q_total=Q_conv+Q_rad;//[W]
    disp("W",ceil(Q_total),"The rate of cooling of the plastic sheet by combined convection and radiation is")
else
    disp("(a) The Flow is turbulent")
end
//Solution(b)
At=w*tp;//[m^2]
m=rho*At*vp;//ass of th plastic rolling out per unit time[kg/s]
T2=T_p+(-Q_total/(m*Cp));//[degree Celcius]
disp("degree Celcius",T2,"(b) The temperature of the plastic sheet as it leaves the cooling section is")
```

Scilab code Exa 7.4 ab94

```
clear;
clc;

//Example7.4[Drag Force Acting on a Pipe in a River]
//Given:-
T_water=15;//[degree Celcius]
vw=4;//Velocity of water[m/s]
od=0.022;//Outer diameter of pipe[m]
w=30;//width of river[m]
//At 15 degree C properties of water
rho=999.1;//[kg/m^3]
mu=1.138*10^(-3);//viscosity[kg/m.s]
```

```
Re=(rho*vw*od)/mu;//Reynolds number
Cd=1.0;//Dreag coefficient
A=w*od;//Frontal area for flow past a cylinder[m^2]
Fd=Cd*A*rho*(vw^2)/2;//[N]
disp("kN",Fd/1000,"The drag force acting on the pipe
    is")
```

Scilab code Exa 7.5 ab95

```
clear;
clc;

//Example7.5[Heat Loss from a Steam Pipe in Windy
   Air]
d=0.1//diameter of pipe[m]
Ts=110;//Temp of ecternal surface of pipe[degree
   Celcius]
Ta=10;//Temp of air[degree Celcius]
va=8;//Velocity of air[m/s]
Tf=(Ts+Ta)/2;//Film temperature[degree Celcius]
k=0.02808;//[W/m.degree Celcius]
Pr=0.7202;//Prandtl Number
nu=1.896*10^(-5);//Kinematic viscosity[m^2/s]
//Solution:-
Re=(va*d)/nu;//Reynolds Number
Nu=0.3+((0.62*(Re^(0.5))*(Pr^(1/3)))/((1+((0.4/Pr)
   ^(2/3)))^(1/4))*[(1+((Re/282000)^(5/8)))^(4/5)]);
disp(round(Nu),"The nusselt number is")
h=k*Nu/d;//[W/m^2.degree Celcius]
As=%pi*d*1;//Area of pipe per unit length[m^2]
Q=h*As*(Ts-Ta);//[W]
disp("W",ceil(Q),"The rate of heat loss from the
   pipe per unit of its length is")
```

Scilab code Exa 7.6 ab96

```
clear;
clc;

//Example7.6[Cooling of a Steel Ball by Forced Air]
//Given:-
rho=8055;//[kg/m^3]
Cp=480;//[J/kg.degree Celcius]
To=300;//Temp of oven[degree Celcius]
Ta=25;//Temp of air[degree Celcius]
va=3;//Velocity of air[m/s]
Ts=200;//Dropped temp of surface of ball[degree
    Celcius]
Ts_avg=(Ts+To)/2;//[degree Celcius]
d=0.25;//[m]
mu_s=2.76*10^(-5);//Dynamic Viscosity at average
    surface temperature[kg/m.s]
//Properties of air at 25 degree Celcius
k=0.02551;//[W/m.degree Celcius]
nu=1.562*10^(-5);//kinematic viscosity[m^2/s]
mu=1.849*10^(-5);//Dynamic viscosity of air at 25
    degree C[kg/m.s]
//Solution:-
Re=va*d/nu;//[Reynolds Number]
Nu=2+[(0.4*(Re^(1/2)))+(0.06*(Re^(2/3)))]*(Pr^(0.4))
    *((mu/mu_s)^(1/4));
disp(ceil(Nu),"The Nusselt number is")
h=k*Nu/d;//[W/m^2.degree Celcius]
As=%pi*(d^2);//[m^2]
Q_avg=h*As*(Ts_avg-Ta);//[W]
disp("W",ceil(Q_avg),"The average rate of heat
    transfer from Newtons Law of cooling is")
m=rho*%pi*(d^3)/6;//[kg]
```

```
Q_total=m*Cp*(To-Ts);//[J]
disp("J",Q_total,"The total heat transferred from
   the ball is")
delta_t=Q_total/Q_avg;//[s]
disp("hour",delta_t/3600,"The time of cooling is")
```

Scilab code Exa 7.7 ab97

```
clear;
clc;

//Example7.7[Preheating Air by Geothermal Water in a
    Tube Bank]
//Given:-
Ta_in=20;//Temp of air whileentering the duct[degree
    Celcius]
v=4.5;//mean velocity[m/s]
T_tw=120;//Temp of geothermal water[degree Celcius]
od=0.015;//Outer Diameter of tubes[m]
SL=0.05,ST=0.05;//Longitudinal and transverse
   pitches[m]
//Properties of air at mean temp
k=0.02808;//[W/m.K]
rho=1.059;//[kg/m^3]
Cp=1007;//[J/kg.K]
Pr=0.7202;//Prandtl no
Pr_s=0.7073;//Prandtl no at temp = 120 degree C
mu=2.008*10^(-5);//Viscosity[kg/m.s]
rho_in=1.204;//density of air at inlet conditions[kg
   /m^3]
//Solution:-
v_max=(ST*v)/(ST-od);//maximu velocity[m/s]
Re=rho*v_max*od/mu;//Reynolds Number
disp(Re,"Reynolds number is")
Nu=0.27*(Re^(0.63))*(Pr^(0.36))*((Pr/Pr_s)^0.25);
```

```
disp(Nu,"The nusselt number is")
Nl=6;//No of rows of tubes
Nt=10;//No of tubes in each row
F=0.945;//For Nl=6, correction factor
Nu_Nl=F*Nu;
h=Nu_Nl*k/od;//[W/m^2.degree Celcius]
N=Nl*Nt;//Total no of tubes
//For unit tube length
As=N*%pi*od*1;//[m^2]
m=rho_in*v*(Nt*ST*1);//[kg/s]
disp("kg/s",m,"Mass flow rate of air is")
Te=T_tw-((T_tw-Ta_in)*exp((-As*h)/(m*Cp)));//[degree Celcius]
disp("degree Celcius",Te,"Fluid exit temperature is")
T_ln=(((T_tw-Te)-(T_tw-Ta_in))/(log((T_tw-Te)/(T_tw-Ta_in))));//[degree Celcius]
disp("degree Celcius",T_ln,"Log mean temperature difference is")
Q=h*As*T_ln;//[W]
disp("W",Q,"Rate of heat transfer is")
//For given Re and SL/od ratio friction coefficient is
f=0.16;
delta_P=Nl*f*rho*(v_max^2)/2;//[Pa]
disp("Pa",delta_P,"The pressure drop across the tube bank is")
```

Scilab code Exa 7.8 ab98

```
clear;
clc;

//Example7.8[Effect of insulation on Surface Temperature]
```

```
//Given:-
Ti=120;//Initial temp of hot water[degree Celcius]
k_pipe=15;//W/m.degree Celcius
ri=0.008,ro=0.01;//Inner and outer radii[m]
t=0.002;//Thickness of pipe[m]
To=25;//Ambient temperature[degree Celcius]
Ts=40;//Maximum Temp of outer surface of insulation[degree Celcius]
hi=70,ho=20;//Heat transfer coefficients inside and outside of the pipe[W/m^2.degree Celcius]
k_insu=0.038;//[W/m.degree Celcius]
L=1;//section of pipe[m]
//Solution:-
//Areas of surfaces exposed to convection
A1=2*%pi*ri*L;//[m^2]
//Individual Thermal Resistances
R_conv1=1/(hi*A1);//[degree Celcius/W]
R_pipe=(log(ro/ri))/(2*%pi*k_pipe*L);//[degree Celcius/W]
//R_insu=(log(r3/ri))/(2*%pi*k_insu*L)
//R_conv2=1/(ho*2*%pi*r3*L)
//R_total=R_conv1+R_conv2+R_pipe+R_insu
//Q=(Ti-To)/R_total;
//Q=(Ts-To)/R_conv2;
//Equating both Q we get
function[r]=radius(r3)
    r(1)=1884*r3(1)*(0.284+0.0024+4.188*log((r3(1))/0.01)+(1/(125.6*r3(1))))-95;
    deff('[r]=radius(r3)',['radius_3=1884*r3(1)*(0.284+0.0024+4.188*log((r3(1))/0.01)+(1/(125.6*r3(1))))-95'])
endfunction
    disp("m",xs,"The outer radius of the insulation is")
    t=xs-ro;//[m]
    disp("cm",100*t,"The minimum thickness of fibreglass insulation required is")
    ///Correct output will be displayed after
```

```
   executing the codes once and then re-executin
    them
```

Scilab code Exa 7.9 ab99

```
clear;
clc;

//Example7.9[Optimum Thickness of insulation]
//Given:-
k_insu=0.024;//[Btu/h.ft^2.degree Farenhiet]
Ts=180;//temp of exposed surface of oven[degree F]
Ta=75;//temp of ambient air[degree F]
L=12;//length[ft]
d=8;//Diameter[m]
time=5840;//[h/year]
ho=3.58;//Heat transfer coefficient on the outer
   surface[tu/h.ft^2.degree F]
unit_c1=0.75;//[$/therm]
unit_c2=2.70;//Unit cost of insulation[4/ft^2]
neta=0.8;//Efficiency
//Solution:-
As=(2*%pi*((d/2)^2))+(2*%pi*L*d/2);//Exposed surface
    area[ft^2]
disp(As)
Q=ho*ceil(As)*(Ts-Ta);//[Btu/h]
Q_total=(1/neta)*Q*time/(100000);//[therms]
disp("Therms",Q_total,"The total amount of heat loss
    from the surrounding is")
annual_c1=Q_total*unit_c1;//[$/year]
disp("per year",annual_c1,"The annual fuel cost of
   the oven before insulation is $")
R_conv=1/(ho*ceil(As));
R_insu=(1/12)/(k_insu*ceil(As));//Thickness id 1inch
    or 1/12 ft
```

```
Q_insu=(Ts-Ta)/(R_conv+R_insu);//[Btu/hr]
Q_insu_total=(1/neta)*Q_insu*time*(1/100000);//[therms]
disp("therms",Q_insu_total,"Total energy consumption by oven on being insulated")
annual_c2=Q_insu_total*unit_c1;//[$/yr]
insu_cost=(unit_c2*ceil(As));//Insulation cost[$]
Total_c=annual_c2+insu_cost;//[$]
disp(Total_c,"The sum of insulation cost and heat loss costs is $")
```

Chapter 8

Internal Forced Convection

Scilab code Exa 8.1 ab101

```
clear;
clc;

//Example8.1[Heating of water in a tube by Steam]
//Given:-
id=0.025;//Internal diameter[m]
Tin=15;//Initial temp[degree Celcius]
m_=0.3;//Flow rate[kg/s]
h=800/1000;//avg heat transfer coefficient[W/m^2.
   degree Celcius]
Tf=115;//Final temp of water[degree Celcius]
Ts=120;//[degree Celcius]
Hs=2203;//Heat of condensation of steam at 120
   degree Celcius[kJ/kg]
Tavg=(Tin+Tf)/2;//[degree Celcius]
Cp=4187;//Sp Heat of water at Tavg[J/kg.degree
   Celcius]
//Solution:-
Q_=m_*Cp*(Tf-Tin)/1000;//[kW]
disp("kW",Q_,"The rate of heat transfer is")
del_Tf=Ts-Tf;//[degree Celcius]
```

```
del_Tin=Ts-Tin;//[degree Celcius]
ln_del_T=(del_Tf-del_Tin)/(log(del_Tf/del_Tin));//[degree Celcius]
disp("degree Celcius",ln_del_T,"Logrithmic Mean temperature difference is")
A=Q_/(h*ln_del_T);//[m^2]
disp("m^2",A,"Heat Transfer surface area is")
l=A/(%pi*id);//[m]
disp("m",round(l),"Required tube length is")
```

Scilab code Exa 8.2 ab102

```
clear;
clc;

//Example8.2[Pressure Drop in a tube]
//Given:-
Tw=5;//Temperature of water[degree Celcius]
//Properties of water at Tw
rho=999.9;//[kg/m^3]
mu=1.519*10^(-3);//Viscosity[kg/m.s]
d=0.003;//diameter[m]
l=10;//length[m]
v_avg=0.9;//Average flow velocity[m/s]
//Solution:-
Re=(rho*v_avg*d)/mu;
disp(Re,"The reynolds number is ")
f=64/ceil(Re);
disp(f,"Friction factor is")
del_P=f*l*rho*(v_avg^2)/(2*d);//[N/m^2]
disp("kPa",del_P/1000,"The Pressure drop is ")
V=v_avg*(%pi*(d^2))/4;//[m^3/s]
disp("m^3/s",V,"Volumetric flow rate is")
W_pump=V*del_P;//[W]
disp("W",W_pump,"Mechanical Power Input of")
```

```
disp("is needed to overcome the frictional losses in the flow due to viscosity")
```

Scilab code Exa 8.3 ab103

```
clear;
clc;

//Example8.3[Flow of Oil in a Pipeline through a Lake]
//Given:-
Ts=0;//Temp of lake[degree Celcius]
Ti=20;//Temp of oil[degree Celcius]
d=0.3;//Diameter[m]
l=200;//length of pipe[m]
//At 20 degree Celcius
rho=888.1;//[kg/m^3]
nu=9.429*10^(-4);//Kinematic viscosity[m^2/s]
k=0.145;//[W/m.degree Celcius]
Cp=1880;//[J/kg.degree Celcius]
Pr=10863;//Prandtl Number
v_avg=2;//[m/s]
//Solution(a)
Re=v_avg*d/nu;
disp(ceil(Re),"The Reynolds number is")
Lt=0.05*Re*Pr*d;//[m]
disp("m",Lt,"The thermal entry length is")
Nu=3.66+((0.065*(d/l)*Re*Pr)/(1+(0.04*(((d/l)*Re*Pr)^(2/3)))));
h=(k*Nu)/d;//[W/m^2.degree Celcius]
As=%pi*d*l;//[m^2]
m_=rho*%pi*((d/2)^2)*v_avg;//[kg/s]
Te=Ts-((Ts-Ti)*exp((-h*As)/(m_*Cp)));//[degree Celcius]
disp("degree Celcius",Te,"Exit temperature of oil is
```

```
   ")
//Solution(b):-
ln_del_T=(Ti-Te)/(log((Ts-Te)/(Ts-Ti)));//[degree
   Celcius]
disp("degree Celcius",ln_del_T,"The logrithmic mean
   temperature difference is")
Q=h*As*ln_del_T;// [W]
disp("W",Q,"The rate of heat loss from the oil are")
//Solution(c)
f=64/Re;//Friction factor is
del_P=l*rho*(v_avg^2)/(2*d);// [N/m^2]
disp(del_P);
W_pump=m_*del_P/rho;// [kW]
disp("pump just to overcome the friction in the pipe
    as the oil flows","kW",W_pump/1000,"We need a")
```

Scilab code Exa 8.4 ab104

```
clear;
clc;

//Example8.4[Pressure Drop in a Water tube]
Tw=15;//temp of water while entering[degree Celcius]
rho=999.1;//[kg/m^3]
mu=1.138*10^(-3);//Viscosity[kg/m.s]
id=0.05;//Internal diameter[m]
V=5.5*10^(-3);//Flow rate[m^3/s]
l=60;//length of tube[m]
e=0.002*10^(-3);// [m]
//Solution:-
v=V/(%pi*(id^2)*(1/4));//Mean Velocity[m/s]
Re=rho*v*id/mu;
disp(Re,"Reynolds Number is")
//Flow is turbulent
r=e/id;//Relative roughness of the tube
```

```
function[Func]=fric(fac)
    Func(1)=(1/(fac(1)^(1/2)))+(2*log((0.00004/3.7)
       +(2.51/(122900*fac(1)^(1/2)))));
    deff('[Func]=fric(fac)',['fric_1=(1/(fac(1)
       ^(1/2)))+(2*log((0.00004/3.7)+(2.51/(122900*
       fac(1)^(1/2)))))'])
endfunction
disp(xs,"Friction Factor is")
del_P=xs*l*rho*(v^2)/(2*id);//[kPa]
disp("Pa",del_P,"The pressure drop is")
W_pump=V*del_P;//[W]
disp("W",W_pump,"The required poer input tp overcome
    the frictional losses in the tube is")
```

Scilab code Exa 8.5 ab105

```
clear;
clc;

//Example8.5[Heating of water by Resistance Heaters
   in a tube]
Ti=15;//Initial Temp[degree Celcius]
Tf=65;//Final Temp[degree Celcius]
d=0.03;//Internal diameter[m]
l=5;//length[m]
V=10*10^(-3);//flow rate of water[m^3/s]
Tavg=(Ti+Tf)/2;//[degree Celcius]
//Properties of water at Tavg
rho=992.1;//[kg/m^3]
Cp=4170;//[J/kg.degree Celcius]
k=0.631;//[W/m.degree Celcius]
nu=0.658*10^(-6);//[m^2/s]
Pr=4.32;//Prandtl Number
//Solution:-
Ac=%pi*(d^2)*(1/4);//[m^2]
```

```
As=%pi*d*l;//[m^2]
m_=rho*V*(1/60);//[kg/s]
Q_=m_*Cp*(Tf-Ti)/1000;//[kW]
disp("kW",Q_,"The power rating of the heater is")
qs=Q_/As;//[kW/m^2]
disp("kW/m^2",qs,"Heat flux is")
v_avg=V/(Ac*60);//[m/s]
Re=v_avg*d/nu;//[Reynolds Number]
Lt=10*d;//Entry length [m]
Nu=0.023*(Re^(0.8))*(Pr^(0.4));
disp(Nu,"The nussel number is")
h=k*Nu/d;//[W/m^2]
Ts=Tf+(qs*1000/h);//[degree Celcius]
disp("degree Celcius",round(Ts),"The surface
    temperature of the pipe at the exit becomes")
```

Scilab code Exa 8.6 ab106

```
clear;
clc;

//Example8.6[Heat Loss from the ducts of a Heating
    System]
Ti=80;//Inlet temp[degree Celcius]
A=0.2*0.2;//Area of cross section[m^2]
l=8;//Length of tube[m]
V=0.15;//[m^3/s]
Td=60;//Temperature of duct[degree Celcius]
//Properties of air at inlet conditions
rho=0.9994;//[kg/m^3]
Cp=1008;//[J/kg.degree Celcius]
k=0.02953;//[W/m.degree Celcius]
nu=2.097*10^(-5);//[m^2/s]
Pr=0.7154;//Prandtl number
//Solution:-
```

```
Dh=4*A/(4*0.2);//Hydraulic Diameter[m]
v_avg=V/A;//[m/s]
Re=v_avg*Dh/nu;
disp(Re,"Reynolds number is")
Lt=10*Dh;//Entry length
Nu=0.023*(Re^(0.8))*(Pr^(0.3));
h=Nu*k/Dh;//[W/m^2.degree Celcius]
As=4*0.2*l;//[m^2]
m_=rho*V;//[kg/s]
Te=Td-((Td-Ti)*exp((-h*As)/(m_*Cp)));//[degree
    Celcius]
disp("degree Celcius",Te,"The exit temperature of
    air is")
ln_delT=(Ti-Te)/(log((Td-Te)/(Td-Ti)));//[degree
    Celcius]
Q=h*As*ln_delT;//[W]
disp("respectively","W",round(Q),"and","degree
    Celcius",ln_delT,"The logrithmic mean temperature
     difference and the rate of heat loss from the
    air are")
```

Scilab code Exa 8.7 ab107

```
clear;
clc;

//Example8.7[Non-isothermal fully developed Friction
     in the Transition Region]
//Given:-
q=8;//Wall heat flux[kW/m^2]
xm=0.34;//Mass fraction
d=0.0158;//Inside diameter[m]
V=1.32*10^(-4);//Flow rate[m^3/s]
Pr=11.6;//Prandtl Number
nu=1.39*10^(-6);//[m^2/s]
```

```
p=1.14;//(mu_b/mu_s)i.e. ratio of viscosities of two substances
Gr=60800;//Grashof number
//Solution:-
Ac=%pi*(d^2)*(1/4);//[m^2]
Re=(V/Ac)*d/nu;
disp(Re,"Reynolds number is")
//For bell mouth inlet shape
Cf1=((1+((round(Re)/5340)^(-0.099)))^(-6.32))*(p^(-2.58-0.42*(60.800^(-0.41))*(11.6^0.265)));
disp(Cf1,"For bell mouth inlet friction coefficient is")
//For square edged inlet Case
Cf2=(0.0791/(Re^(0.25)))*(p^(-0.25));
disp(Cf2,"For square edged inlet case coefficient of friction is")
```

Scilab code Exa 8.8 ab108

```
clear;
clc;

//Example8.8[Heat transfer in the Transition Region]
//Given:-
xm=0.6;//mass fraction of glycol
V=2.6*10^(-4);//Flow rate[m^3/s]
d=0.0158;//inside diameter[m]
Gr=51770;//grashof number
Pr=29.2;//Prandtl number
nu=3.12*10^(-6);//[m^2/s]
p=1.77;//mu_t/mu_s
q=90;//A particular loctaion x with x/d=q
//Solution:-
Ac=%pi*(d^2)/4;
Re=(V/Ac)*d/nu;
```

```
disp(Re,"Reynolds Number is")
//Value of Re lies in transition Region
Nu_lam=1.24*(((Re*Pr/q)+(0.025*((Gr*Pr)^(0.75))))^(1/3))*(p^(0.14));
Nu_tur=0.023*(Re^(0.8))*(Pr^0.385)*(q^(-0.0054))*(p^(0.14));
//(a)
Nu_tran_a=Nu_lam+((exp((1766-Re)/276)+(Nu_tur^(-0.955)))^(-0.955));
disp(Nu_tran_a,"(a) Nusselt number for re-entrant inlet is")
Nu_tran_b=Nu_lam+((exp((2617-Re)/207)+(Nu_tur^(-0.950)))^(-0.950));
disp(Nu_tran_b,"(b) Nusselt number for square edged inlet is")
Nu_tran_c=Nu_lam+((exp((6628-Re)/237)+(Nu_tur^(-0.980)))^(-0.980));
disp(Nu_tran_c,"(c) Nusselt number for bell mouth inlet is")
```

Chapter 9

Natural Convection

Scilab code Exa 9.1 ab111

```
clear;
clc;

//Example9.1[Heat Loss from Hot Water Pipes]
//Given:-
l=6;//Length[m]
d=0.08;//diameter[m]
T_room=20;//[degree Celcius]
Ts=70;//Surface temperature of pipe[degree Celcius]
Tf=(Ts+T_room)/2;//Film temperature[degree Celcius]
//Properties of air at Tf
k=0.02699;//[W/m.degree Celcius]
Pr=0.7241;//Prandtl number
nu=1.750*10^(-5);//[m^2/s]
b=(1/(Tf+273));//[K^-1]
g=9.81;//Acc dur to gravity[m/s^2]
e=1;//Emissivity
//Solution:-
Lc=d;//Characteristic length[m]
Ra_d=g*b*(Ts-T_room)*(d^3)*Pr/(nu^2);
disp(Ra_d,"The Rayleigh number is")
```

```
Nu=((0.6+((0.387*(Ra_d^(1/6)))/((1+((0.559/Pr)^(9/16)))^(8/27))))^2);
disp(Nu," The natural convection Nusselt number is")
h=k*Nu/d;//[W/m^2.degree Celcius]
As=%pi*d*l;//[m^2]
Q=h*As*(Ts-T_room);//[W]
disp("by natural convection","W",round(Q),"The pipe loses heat to the air in the room at a rate of")
Q_rad=e*As*(5.76*10^(-8))*(((Ts+273)^4)-((T_room+273)^4));//[W]
disp("W",ceil(Q_rad),"The radiation heat transfer is")
```

Scilab code Exa 9.2 ab112

```
clear;
clc;

//Example9.2[Cooling of a Plate in different orientaions]
L=0.6;//side of square plate[m]
T_surr=30;//[degree Celcius]
Tp=90;//Temp of plate[degree Celcius]
Tf=(Tp+T_surr)/2;//Film temperature[degree Celcius]
//Properties of air at Tf
k=0.02808;//[W/m.degree Celcius]
Pr=0.7202;//Prandtl number
nu=1.896*10^(-5);//Kinematic viscosity[m^2/s]
b=1/(Tf+273);//[K^-1]
g=9.81;//Acc due to gravity[m/s^2]
//Solution (a)
Lc_a=L;//Characteristic length
Ra_1=g*b*(Tp-T_surr)*(L^3)*Pr/(nu^2);
disp(Ra_1,"(a) The Rayleigh no is")
Nu_a=((0.825+(0.387*(Ra_1^(1/6)))/((1+((0.492/Pr)
```

```
^(9/16)))^(8/27)))^2);
disp(Nu_a,"The natural convection Nusselt number is")
h_a=k*Nu_a/L;//[W/m^2.degree Celcius]
As=L^2;//[m^2]
Q_a=h_a*As*(Tp-T_surr);//[W]
disp("W",ceil(Q_a),"Heat loss to the surrounding is")
//Solution (b)
Lc_b=As/(4*L);//[m]
Ra_2=g*b*(Tp-T_surr)*(Lc_b^3)*Pr/(nu^2);
disp(Ra_2,"(b) The Rayleigh number is")
Nu_b=0.54*(Ra_2^(1/4));
disp(Nu_b,"The natural convection Nusselt number is")
h_b=k*Nu_b/Lc_b;//[W/m^2.degree Celcius]
Q_b=h_b*As*(Tp-T_surr);//[W]
disp("W",round(Q_b),"Heat Loss is")
//Solution (c)
Lc_c=Lc_b
Nu_c=(0.27*Ra_2^(1/4));
disp(Nu_c,"(c) Natural convection Nusselt number")
h_c=k*Nu_c/Lc_c;//[W/m^2.degree Celcius]
Q_c=h_c*As*(Tp-T_surr);//[W]
disp("W",Q_c,"Heat Loss is")
Q_rad=e*(5.67*10^(-8))*As*(((Tp+273)^4)-((T_surr+273)^4));//[W]
disp("W",round(Q_rad),"Radiation heat loss is")
```

Scilab code Exa 9.3 ab113

```
clear;
clc;

//Example9.3[Optimum Fin Spacing of a Heat Sink]
```

```
//Given:-
w=0.12;//width[m]
l=0.18;//length[m]
t=0.001;//thickness[m]
H=0.024;//height[m]
Ts=80;//Bast temperature[degree Celcius]
T_surr=30;//[degree Celcius]
Tf=(Ts+T_surr)/2;//[degree Celcius]
//Properties of air at film temperature
k=0.02772;//[W/m.degree Celcius]
Pr=0.7215;//Prandtl number
nu=1.847*10^(-5);//[m^2/s]
b=1/(Tf+273);//[K^-1]
g=9.81;//[m/s^2]
//Solution:-
Ra_l=g*b*(Ts-T_surr)*(l^3)*Pr/(nu^2);
disp(Ra_l,"The Rayleigh number is")
S_opt=2.714*l/(Ra_l^(0.25));//[m]
disp("mm",S_opt*100,"The optimum spacing is")
n=w/(S_opt+t);
disp(round(n),"The no of for this optimum fin spacing are")
Nu_opt=1.307;//Optimum Nusselt number
h=Nu_opt*k/S_opt;//[W/m^2.degree Celcius]
Q=h*2*round(n)*l*H*(Ts-T_surr);//[W]
disp("W",Q,"The rate of natural convection heat transfer")
```

Scilab code Exa 9.4 ab114

```
clear;
clc;

//Example9.4[Heat Loss through a Double Pane Window]
//Given:-
```

```
H=0.8;//Height[m]
L=0.02;//Air gap[m]
w=2;//Width[m]
T1=12,T2=2;//Glass Surface temperatures across the
    air gap
Tavg=(T1+T2)/2;//[degree Celcius]
k=0.02416;//[W/m.degree Celcius]
Pr=0.7344;//Prandtl Number
nu=1.4*10^(-5);//Kinematic Viscosity[m^2/s]
g=9.81;//[m/s^2]
//Solution:-
Lc=L;//Characteristic length
b=1/(Tavg+273);//[K^-1]
Ra_L=g*b*(T1-T2)*Pr*(Lc^3)/(nu^2);
disp(Ra_L,"The Rayleigh Number is")
Nu=0.42*(Ra_L^(1/4))*(Pr^(0.012))*((H/L)^(-0.3));
disp(Nu,"The Nusselt Number is")
As=H*w;//[m^2]
h=k*Nu/L;//[W/m^2.degree Celcius]
Q=h*As*(T1-T2);
disp("W",Q,"Rate at which Heat is Lost through the
    window is")
```

Scilab code Exa 9.5 ab115

```
clear;
clc;

//Example9.5[Heat Transfer through a Spherical
    Enclosure]
//Given:-
Di=0.2;//Inner Diameter[m]
Do=0.3;//Outer Diameter[m]
Ti=320,To=280;//The surface temperatures of two
    spheres enclosing the air[K]
```

```
Tavg=(Ti+To)/2;//[K]
//Properties at Tavg
k=0.02566;//[W/m.K]
Pr=0.7290;//Prandtl Number
nu=1.58*10^(-5);//[m^2/s]
b=(1/Tavg);
g=9.81;//[m/s^2]
//Solution:-
Lc=(Do-Di)/2;//Characteristic length[m]
Ra_L=g*b*(Ti-To)*(Lc^3)*Pr/(nu^2);
disp(Ra_L,"The Rayleigh Number is")
Fsph=Lc/(((Di*Do)^4)*(((Di^(-7/5))+(Do^(-7/5))))^5));
keff=0.74*k*((Pr/(0.861+Pr))^(1/4))*((Fsph*Ra_L)^(1/4));//[W/m.K]
disp(Fsph,keff)
Q=keff*(%pi*Di*Do/Lc)*(Ti-To);//[W]
disp("W",Q,"The rate of heat transfer between the spheres is")
```

Scilab code Exa 9.6 ab116

```
clear;
clc;
//Example9.6[Heating Water in a Tube by Solar Enegy]
//Given:-
Ts=40;//Glass Temp[degree Celcius]
T_surr=20;//Surrounding temperature[degree Celcius]
Tavg=(Ts+T_surr)/2;//[degree Celcius]
Do=0.1;//[m]
Di=0.05;//[m]
L=1;//[m]
//Properties of glass at Tavg
k=0.02588;//[W/m.degree Celcius]
Pr=0.7282;//Prandtl Number
```

```
nu=1.608*10^(-5);//[m^2/s]
b=1/(Tavg+273);//[K^-1]

Q=30;//Rate pof absorpto\ion of solar radiation[W]
g=9.81;//[m/s^2]
//Solution:-
Ao=%pi*Do*L;//Heat transfer surface area of the glass cover[m^2]
Ra_D=g*b*(Ts-T_surr)*(Do^3)*Pr/(nu^2);
disp(Ra_D,"The Rayleigh Number is")
Nu=((0.6+((0.387*(Ra_D^(1/6)))/((1+((0.550/Pr)^(9/16)))^(8/27))))^2);
disp(Nu,"The Nusselt number is")
ho=k*Nu/Do;//[W/m^2.degree Celcius]
Qo=ho*Ao*(Ts-T_surr);//[W]
disp("W",Qo,"The rate of natural convection heat transfer from the glass cover to the ambient air is")
//Value of Qo is less than 30W so assuming a higher temp of glass cover
T_surr1=41;//[degree Celcius]
Ts1=90;//[degree Celcius]
Tavg1=(T_surr1+Ts1)/2;//[degree Celcius]
b1=1/(Tavg1+273);//[K^-1]
Lc=(Do-Di)/2;//Characteristic length [m]
Ra_L1=g*b1*(Ts1-T_surr1)*(Lc^3)*Pr/(nu^2);
disp(Ra_L1,"The Rayleigh number on assuming higher temperatures")
Fcyl=((log(Do/Di))^4)/((Lc^3)*(((Di^(-3/5))+(Do^(-3/5)))^5));
keff=0.386*k*((Pr/(0.861+Pr))^(1/4))*((Fcyl*Ra_L1)^(1/4));//[W/m.degree Celcius]
Q1=2*%pi*keff*(Ts1-T_surr1)/(log(Do/Di));//[W]
disp("W",Q1,"The rate of heat transfer between the cylinders is")
//Obtained value of Q1 is more than 30 W, so using hit and trial aand suuming more values we get the tube temperature to be 82 degree Celcius,
```

```
disp("Therefore tube will reach an equilibrium
    temperature of 82 degree Celcius when the pump
    fails")
```

Scilab code Exa 9.7 ab117

```
clear;
clc;

//Example9.7[U factor for Center of glass Section of
     Windows]
//Given:-
e=0.84;//Emissivity
//For winter season
hi=8.29;//[W/m^2.degree Celcius]
ho=34.0;//[W/m^2.degree Celcius]
//Solution:-
e_eff=1/((1/e)+(1/e)-1);//Effective emissivity of
    air space
//the effective emissivity and an average air space
    temperature of 0 degree Celcius read
h_space=7.2;//[W/m^2.degree Celcius]
U_center=1/((1/hi)+(1/ho)+(1/h_space));//[W/m^s.
    degree Celcius]
disp("W/m^2.degree Celcius",U_center,"The center of
    glass U-factor value is")
```

Scilab code Exa 9.8 ab118

```
clear;
clc;

```

```
//Example9.8[Heat Loss through Aluminium Framed
    Windows]
//Given:-
H=1.2;//Height[m]
w=1.8;//Width[m]
Ti=22;//Inside temp[degree Celcius]
To=-10;//Outside temp[degree Celcius]
U_a=6.63,U_b=3.51,U_c=1.92,hi=8.3;//[W/m^.degree
    Celcius]
//Solution:-
A_win=h*w;//[m^2]
Q_win_a=U_a*A_win*(Ti-To);//[W]
T_glass_a=Ti-(Q_win_a/(hi*A_win));//[degree Celcius]
disp("degree Celcius",T_glass_a,"(a) The Inner
    surface temperature of the window glass is")
Q_win_b=U_b*A_win*(Ti-To);//[W]
T_glass_b=Ti-(Q_win_b/(hi*A_win));//[degree Celcius
disp("degree Celcius",T_glass_b,"(b) The Inner
    surface temperature of the window glass is")
Q_win_c=U_c*A_win*(Ti-To);//[W]
T_glass_c=Ti-(Q_win_c/(hi*A_win));//[degree Celcius]
disp("degree Celcius",T_glass_c,"(c) The Inner
    surface temperature of the window glass is")
```

Scilab code Exa 9.9 ab119

```
clear;
clc;

//Example9.9[U-Factor of a Double-Door Window]
//Given:-
A_win=1.8*2.0;//[m^2]
A_glazing=2*1.72*0.94;//[m^2]
U_c=3.24,U_e=3.71,U_f=2.8;//U factors for the center
     edge and frame sections respectively [W/m^2.
```

```
degree Celcius]
//Solution:-
A_frame=A_win-A_glazing;//[m^2]
A_center=2*(1.72-0.13)*(0.94-0.13);//[m^2]
A_edge=A_glazing-A_center;//[m^2]
U_win=((U_c*A_center)+(U_e*A_edge)+(U_f*A_frame))/A_win;//[W/m^2.degree Celcius]
disp("W/m^2.degree Celcius",U_win,"The overall U factor of the entire window is")
```

Chapter 10

Boiling and Condensation

Scilab code Exa 10.1 ab121

```
clear;
clc;

//Example10.1[Nucleate Boiling of Water in a Pan]
Ts=108;//Temp of surface of bottom of pan[degree
    Celcius]
Tsat=100;//Saturation temp of water[degree Celcius]
D=0.3;//Diameter[m]
//Properties of water at the saturation temp
rho_l=957.9;//Density of liquid[kg/m^3]
rho_v=0.6;//Density of vapour[kg/m^3]
Pr_l=1.75;//Prandtl no of liquid
mu_l=0.282*10^(-3);//Viscosity of liquid[kg/m.s]
Cp_l=4217;//Specific Heat of liquid[J/kg.degree
    Celcius]
h_fg=2257*10^3;//[J/kg]
sigma=0.0589;//[N/m]
g=9.81;//Acc due to gravity[m/s^2]
Csf=0.0130,n=1.0;
//Solution(a):-
q_nuc=mu_l*h_fg*((g*(rho_l-rho_v)/sigma)^(1/2))*((
```

```
Cp_l*(Ts-Tsat)/(Csf*h_fg*(Pr_l^n)))^3);//[W/m^2]
A=%pi*(D^2)/4;//Surface Area of bottom of the pan[m
^2]
Q_boiling=A*q_nuc;//[W]
disp("W",Q_boiling,"(a) The rate of heat transfer
during nucleate boiling becomes ")
//Solution(b):-
m=Q_boiling/h_fg;//[kg/s]
disp("kg/s",m,"The rate of Evaporation of water is")
```

Scilab code Exa 10.2 ab122

```
clear;
clc;

//Example10.2[Peak Heat Flux in Nucleate Boiling]
D=0.01;//[m]
Tsat=100;//Saturation Temperature[degree Celcius]
sigma=0.0589;//[N/m]
//Properties of water at saturation temperature
rho_l=957.9;//[kg/m^3]
rho_v=0.6;//[kg/m^3]
h_fg=2257*10^3;//[J/kg]
mu_l=0.282*10^(-3);//[kg/m.s]
Pr_l=1.75;//Prandtl number
Cp_l=4217;//[J/kg.degree Celcius]
Csf=0.0130,n=1.0;
g=9.81;//[m/s^2]
//Solution:-
L_=(D/2)*((g*(rho_l-rho_v)/sigma)^(1/2));//
dimensionless Parameter
//For this value of L_ we have
C_cr=0.12;//Constant
q_max=C_cr*h_fg*((sigma*g*(rho_v^2)*(rho_l-rho_v))
^(1/4));//[W/m^2]
```

```
disp("W/m^2",q_max,"The maximum or critical heat flux is")
Ts=(((q_max/(mu_l*h_fg*((g*(rho_l-rho_v)/sigma)^(1/2))))^(1/3))*(Csf*h_fg*Pr_l^n)/Cp_l)+Tsat;//[degree Celcius]
disp("degree Celcius",round(Ts),"The surface temperature is")
```

Scilab code Exa 10.3 ab123

```
clear;
clc;

//Example10.3[Film Boiling of Water on a Heating Element]
//Given:-
D=0.005;//[m]
e=0.05;//Emissivity
Ts=350;//Surface temperature[degree Celcius]
Tsat=100;//[degree Celcius]
Tf=(Ts+Tsat)/2;//[degree Celcius]
g=9.81;//[m/s^2]
//Properties of water at Tsat
rho_l=957.9;//[kg/m^3]
h_fg=2257*10^3;//[J/kg]
//Properties of vapor at film temp
rho_v=0.444;//[kg/m^3]
Cp_v=1951;//[J/kg.degree Celcius]
mu_v=1.75*10^(-5);//[kg/m.s]
k_v=0.0388;//[W/m.degree Celcius]
//Solution:-
q_film=0.62*(((g*(k_v^3)*rho_v*(rho_l-rho_v)*(h_fg+(0.4*Cp_v*(Ts-Tsat))))/(mu_v*D*(Ts-Tsat)))^(1/4))*(Ts-Tsat);//[W/m^2]
disp("W/m^2)",q_film,"The film boiling heat flux is"
```

```
)
q_rad=e*(5.67*10^(-8))*(((Ts+273)^4)-((Tsat+273)^4))
   ;//[W/m^2]
disp("W/m^2",q_rad,"The radiation heat flux is")
q_total=q_film+(3/4)*q_rad;//[W/m^2]
disp("W/m^2",q_total,"The total heat flux is")
Q_total=(%pi*D*1)*q_total;//[W]
disp("W",Q_total,"The rate of heat transfer from the
    heating element to the water is")
```

Scilab code Exa 10.4 ab124

```
clear;
clc;

//Example10.4[Condensation of steam on a Vertical
   Plate]
//Given:-
Tsat=100,Ts=80;//[degree Celcius]
Tf=(Ts+Tsat)/2;//[degree Celcius]
L=2,w=3;//Dimensions of Plate[m]
g=9.81;//[m/s^2]
//Properties of water at Tsat
h_fg=2257*10^3;//[J/kg]
rho_v=0.60;//[kg/m^3]
//Properties of liquid water at Tf
rho_l=965.3;//[kg/m^3]
mu_l=0.315*10^(-3);//[kg/m.s
Cp_l=4206;//[J/kg.degree Celcius]
k_l=0.675;//[W/m.degree Celcius]
nu_l=0.326*10^(-6);//[m^2/s]
//Solution (a)
h_fg_m=h_fg+0.68*Cp_l*(Tsat-Ts);//[J/kg]
disp("J/kg",h_fg_m,"The modified latent heat of
   vapourization is")
```

```
Re=((4.81+((3.70*L*k_l*(Tsat-Ts)*((g/nu_l^2)^(1/3)))/(mu_l*h_fg_m)))^(0.820));
disp(ceil(Re),"For wavy laminar flow Reynolds number is")
h=(Re*k_l*((g/nu_l^2)^(1/3)))/((1.08*(Re^(1.22)))-5.2);//[W/m^2.degree Celcius]
disp("W/m^2.degree Celcius",h,"The conensation heat transfer coefficient is")
As=w*L;//[m^2]
Q=h*As*(Tsat-Ts);//[W]
disp("W",Q,"The rate of heat transfer during condensation process is")
//Solution (b)
m=Q/h_fg_m;//[kg/s]
disp("kg/s",m,"The rate of condensation of steam is")
```

Scilab code Exa 10.5 ab125

```
clear;
clc;

//Example10.5[Condensation of steam on a Vertical Tilted Plate]
//Given:-
Tsat=100,Ts=80;//[degree Celcius]
Tf=(Ts+Tsat)/2;//[degree Celcius]
L=2,w=3;//Dimensions of Plate[m]
g=9.81;//[m/s^2]
//Properties of water at Tsat
h_fg=2257*10^3;//[J/kg]
rho_v=0.60;//[kg/m^3]
//Properties of liquid water at Tf
rho_l=965.3;//[kg/m^3]
mu_l=0.315*10^(-3);//[kg/m.s
```

```
Cp_l=4206;//[J/kg.degree Celcius]
k_l=0.675;//[W/m.degree Celcius]
nu_l=0.326*10^(-6);//[m^2/s]
theta=(%pi/6);//Angle at which plate is tilted[radians]
//Solution (a)
h_fg_m=h_fg+0.68*Cp_l*(Tsat-Ts);//[J/kg]
disp("J/kg",h_fg_m,"The modified latent heat of vapourization is")
Re=((4.81+((3.70*L*k_l*(Tsat-Ts)*((g/nu_l^2)^(1/3)))/(mu_l*h_fg_m)))^(0.820));
disp(ceil(Re),"For wavy laminar flow Reynolds number is")
h=((Re*k_l*((g/nu_l^2)^(1/3)))/((1.08*(Re^(1.22)))-5.2))*((cos(theta))^(1/4));//[W/m^2.degree Celcius]
disp("W/m^2.degree Celcius",h,"The conensation heat transfer coefficient is")
As=w*L;//[m^2]
Q=h*As*(Tsat-Ts);//[W]
disp("W",Q,"The rate of heat transfer during condensation process is")
//Solution (b)
m=Q/h_fg_m;//[kg/s]
disp("kg/s",m,"The rate of condensation of steam is")
```

Scilab code Exa 10.6 ab126

```
clear;
clc;

//Example10.6[Condensation of Steam on horizontal Tubes]
//Given:-
```

```
Tsat=40;//[degree Celcius]
D=0.03;//[m]
Ts=30;//Outer Surface temperature of tube[degree Celcius]
Tf=(Ts+Tsat)/2;//Film Temperature[degree Celcius]
g=9.81;//[m/s^2]
//Properties of water at the saturation temp
h_fg=2407*10^3;//[J/kg]
rho_v=0.05;//[kg/m^3]
//Properties of liquid water at the film temperature
rho_l=994;//[kg/m^3]
Cp_l=4178;//[J/kg.degree Celcius]
mu_l=0.720*10^(-3);//[kg/m.s]
k_l=0.623;//[W/m.degree Celcius]
//Solution (a)
h_fg_m=h_fg+0.68*Cp_l*(Tsat-Ts);//[J/kg]
disp("J/kg",h_fg_m,"(a) The modified latent heat of vapourisation is")
h_hori=0.729*(((g*(rho_l^2)*h_fg_m*(k_l^3))/(mu_l*D*(Tsat-Ts)))^(1/4));//[W/m^2.degree Celcius]
disp("W/m^2.degree Celcius",h_hori,"The heat transfer coefficient for condensation on a single horizontal tube is")
As=%pi*D*1;//[m^2]
Q=h_hori*As*(Tsat-Ts);//[W]
disp("W",Q,"The rate of heat transfer during condensation Process is")
//Solution (b)
m=Q/h_fg_m;//[kg/s]
disp("kg/s",m,"(b) The rate of condensation of steam is")
```

Scilab code Exa 10.7 ab127

```
clear;
```

```
clc;

//Example10.7[Condensation of Steam on horizontal Tube Banks]
//Given:-
Tsat=40;//[degree Celcius]
D=0.03;//[m]
Ts=30;//Outer Surface temperature of tube[degree Celcius]
Tf=(Ts+Tsat)/2;//Film Temperature[degree Celcius]
g=9.81;//[m/s^2]
N=3;//No of tubes in a vertical tier
N_total=12;//Total number of tubes
//Properties of water at the saturation temp
h_fg=2407*10^3;//[J/kg]
rho_v=0.05;//[kg/m^3]
//Properties of liquid water at the film temperature
rho_l=994;//[kg/m^3]
Cp_l=4178;//[J/kg.degree Celcius]
mu_l=0.720*10^(-3);//[kg/m.s]
k_l=0.623;//[W/m.degree Celcius]
//Solution (a)
h_fg_m=h_fg+0.68*Cp_l*(Tsat-Ts);//[J/kg]
disp("J/kg",h_fg_m,"(a) The modified latent heat of vapourisation is")
h_hori_N=(0.729*(((g*(rho_l^2)*h_fg_m*(k_l^3))/(mu_l*D*(Tsat-Ts)))^(1/4)))*(1/(N^(1/4)));//[W/m^2.degree Celcius]
disp("W/m^2.degree Celcius",h_hori_N,"The heat transfer coefficient for condensation 12 horizontal tube is")
As=%pi*D*1*N_total;//[m^2]
Q=h_hori_N*As*(Tsat-Ts);//[W]
disp("W",Q,"The rate of heat transfer during condensation Process is")
//Solution (b)
m=Q/h_fg_m;//[kg/s]
disp("kg/s",m,"(b) The rate of condensation of steam
```

```
is")
```

Scilab code Exa 10.8 ab128

```
clear;
clc;

//Example10.8[Replacing a Heat Pipe by a Copper Rod]
//Given:-
L=0.3;//[m]
D=0.006;//[m]
Q=180;//[W]
del_T=3;//Temperature Difference [degree Celcius]
//Properties of copper at room temperature
rho=8933;//[kg/m^3]
k=401;//[W/m.degree Celcius]
//Solution:-
A=Q*L/(k*del_T);//[m^2]
d=sqrt(4*A/%pi);//[m]
disp("cm",ceil(100*d),"The diameter of the copper pipe is")
m=rho*A*L;//[kg]
disp("kg",round(m),"Mass of the copper rod is")
```

Chapter 11

Heat Exchangers

Scilab code Exa 11.1 ab131

```
clear;
clc;

//Example11.1[Overall Heat Transfer Coefficient of a
    Heat Exchanger]
D_in=0.02;//Diameter of inner tubes[m]
Di_out=0.03;//Inner Diameter of Outer tubes[m]
mw=0.5;//Mass Flow Rate of water[kg/s]
mo=0.8;//Mass Flow rate of oil[kg/s]
Tw=45;//Average Temp of water[degree Celcius]
To=80;//Average Temp of oil [degree Celcius]
//Properties of water at Tw
rho_w=990.1;//[kg/m^3]
Pr_w=3.91;//Prandtl Number
k_w=0.637;//[W/m.degree Celcius]
nu_w=0.602*10^(-6);//[m^2/s]
//Properties of oil at To
rho_o=852;//[kg/m^3]
Pr_o=499.3;//Prandtl Number
k_o=0.138;//[W/m.degree Celcius]
nu_o=3.794*10^(-5);//[m^2/s]
```

```
//Solution:-
Vw=mw/(rho_w*(%pi*(D_in^2)/4));//[m/s]
disp("m/s",Vw,"The average velocity of water in the
    tube is")
Re_w=Vw*D_in/nu_w;
disp(Re_w,"The Reynolds number for flow of water in
    the tube is")
Nu_w=0.023*(Re_w^(0.8))*(Pr_w^(0.4));
disp(Nu_w,"The nusselt no for turbulent water flow")
hi=k_w*Nu_w/D_in;//[W/m^2.degree Celcius]
//For oil flow
Dh=Di_out-D_in;//Hydraulic Diameter for the annular
    space[m]
Vo=mo/(rho_o*(%pi*((Di_out^2)-(D_in^2))/4));//[m/s]
disp("m/s",Vo,"The average velocity for flow of oil
    is")
Re_o=Vo*Dh/nu_o;
disp(Re_o,"The Reynolds number for flow of oil is")
Nu_o=5.45;//Nusselt number for flow of oil usign the
     table 11.3 and interpolating for value
    corresponding to Di_out/D_in
ho=Nu_o*k_o/Dh;//[W/m^2.degree Celcius]
U=(1/((1/hi)+(1/ho)));//[W/m^2.degree Celcius]
disp("W/m^2.degree Celcius",U,"The overall heat
    transfer Coefficient for the given heat exchanger
     is")
```

Scilab code Exa 11.2 ab132

```
clear;
clc;

//Example11.2[Effect of Fouling on the Overall Heat
    Transfer Coefficient]
//Given:-
```

```
k=15.1;//[W/m^2.degree Celcius]
Di=0.015;//Inner Diameter[m]
Do=0.019;//Outer Diameter[m]
Di_s=0.032;//Inner diameter of outer shell[m]
L=1;//[m]
hi=800;//W/m^2.degree Celcius
ho=1200;//[W/m^2.degree Celcius]
Rfi=0.0004;//[m^2.degree Celcius/W]
Rfo=0.0001;//[m^2.degree Celcius/W]
//Solution (a):-
Ai=%pi*Di*L;//[m^2]
Ao=%pi*Do*L;//[m^2]
Ra=(1/(hi*Ai))+(Rfi/Ai)+((log(Do/Di))/(2*%pi*k*L))+(
    Rfo/Ao)+(1/(ho*Ao));//[m^2.degree Celcius/W]
disp("m^2.degree Celcius/W",Ra,"The thermal
    Resistance for an unfinned shell and tube heat
    exchanger with fouling on both heat transfer
    surfaces is")
//Solution (b):-
Ui=1/(Ra*Ai);//[W/m^2.degree Celcius]
Uo=1/(Ra*Ao);//[W/m^2.degree Celcius]
disp("respectively","W/m^2.degree Celcius",Uo,"and",
    Ui,"The overall Heat transfer Coefficients based
    on the inner and outer surfaces of the tube are")
```

Scilab code Exa 11.3 ab133

```
clear;
clc;

//Example11.3[The Condensation of Steam in a
    Condenser]
//Given:-
Th_in=30,Th_out=30,Tc_in=14,Tc_out=22;//Inlet and
    Outlet temperatures of hot and cold liquids [
```

```
degree Celcius]
A=45;//[m^2]
U=2100;//[W/m^2.degree Celcius]
h_fg=2431;//Heat of vapourisation of water at Th_i[kJ/kg]
Cp=4184;//Specific heat of cold water [J/kg]
//Solution:-
del_T1=Th_in-Tc_out;//[degree Celcius]
del_T2=Th_out-Tc_in;//[degree Celcius]
del_T_lm=(del_T1-del_T2)/(log(del_T1/del_T2));//[degree Celcius]
disp("degree Celcius",del_T_lm,"The logrithmic Mean temperature difference is")
Q=U*A*del_T_lm;//[W]
disp("W",Q,"The heat transfer rate in the condenser is")
mw=Q/(Cp*(Tc_out-Tc_in));//[kg/s]
disp("kg/s",mw,"The mass flow rate of the cooling water is")

ms=(Q/(1000*h_fg));//[kg/s]
disp("kg/s",ms,"The rate of condensation of steam is")
```

Scilab code Exa 11.4 ab134

```
clear;
clc;

//Example11.4[Heating Water in a Counter Flow Heat Exchanger]
//Given:-
mw=1.2,mgw=2;//Mass Flow rate of water and geothermal fluid[kg/s]
U=640;//Overall Heat transfer Coefficient[W/m^2.
```

```
degree Celcius]
Di=0.015;//[m]
Tw_out=80,Tw_in=20;//Outlet and Inlet temp of water[degree Celcius]
Tgw_in=160;//Inlet temp of geothermal fluid[degree Celcius]
Cp_w=4.18,Cp_gw=4.31;//Specific Heats of water and geothermal fluid[kJ/kg.degree Celcius]
//Solution:-
Q=mw*Cp_w*(Tw_out-Tw_in);//[kW]
disp("kW",ceil(Q),"The rate of heat transfer in the heat exchanger is")
Tgw_out=(Tgw_in-(ceil(Q)/(mgw*Cp_gw)));//[degree Celcius]
disp("degree Celcius",Tgw_out,"The outlet temp of geothermal fluid is")
del_T1=Tgw_in-Tw_out;//[degree Celcius]
del_T2=Tgw_out-Tw_in;//[degree Celcius]
del_T_lm=(del_T1-del_T2)/(log(del_T1/del_T2));//[degree Celcius]
disp("degree Celcius",del_T_lm,"The logrithmic Mean temperature difference is")
As=1000*ceil(Q)/(U*del_T_lm);//[m^2]
disp("m^2",As,"The surface area of the heat exchanger is")
L=As/(%pi*Di);//[m]
disp("m",round(L),"The length of the tube is")
```

Scilab code Exa 11.5 ab135

```
clear;
clc;

//Example11.5[Heating of Glycerine in a Multipass Heat Exchanger]
```

```
//Given:-
//A 2,4 shell and tube heat exchanger
D=0.02;//Diameter[m]
L=60;//Length of tube[m]
Th_in=80,Th_out=40,Tc_in=20,Tc_out=50;//Inlet and Outlet temperatures water and glycerine[degree Celcius]
hi=160,ho=25;//Convective Heat transfer coefficients on both side of tube[W/m^2.degree Celcius]
Rf=0.0006;//Fouling Resistance[m^2.degree Celcius/W]
//Solution:-
As=%pi*D*L;//[m^2]
del_T1=Th_in-Tc_out;//[degree Celcius]
del_T2=Th_out-Tc_in;//[degree Celcius]
del_T_lm=(del_T1-del_T2)/log(del_T1/del_T2);//[degree Celcius]
disp("degree Celcius",del_T_lm,"The log mean temperature difference for the counter flow arrangement is")
F=0.91;//Correction Factor
//(a)
Ua=1/((1/hi)+(1/ho));// [W/m^2.degree Celcius]
disp("W/m^2.degree Celcius",Ua,"In case of no fouling, the over all heat transfer coefficient is")
Qa=Ua*As*F*del_T_lm;// [W]
disp("W",ceil(Qa),"And the rate of heat transfer is")
//(b)
Ub=1/((1/hi)+(1/ho)+(Rf));// [W/m^2.degree Celcius
disp("W/m^2.degree Celcius",Ub,"When there is fouling on one of the surfaces, the overall heat transfer coefficient is")
Qb=Ub*As*F*del_T_lm;// [W]
disp("W",round(Qb),"And the rate of heat transfer is")
```

Scilab code Exa 11.6 ab136

```
clear;
clc;

//Example11.6[Cooling of Water in an Automotive Radiator]
//Given:-
m=0.6;//Mass Flow rate of water[kg/s]
Th_in=90,Th_out=65,Tc_in=20,Tc_out=40;//[degree Celcius]
Di=0.005;//[m]
L=0.65;//[m]
n=40;//No of tubes
Cp=4195;//[J/kg.degree Celcius]
//Solution:-
Q=m*Cp*(Th_in-Th_out);//[W]
disp("W",Q,"The rate of heat transfer in the radiator from the hot water to the air is")
Ai=n*%pi*Di*L;//[m^2]
del_T1=Th_in-Tc_out;//[degree Celcius]
del_T2=Th_out-Tc_in;//[degree Celcius]
del_T_lm=(del_T1-del_T2)/log(del_T1/del_T2);//[degree Celcius]
disp("degree Celcius",del_T_lm,"The log mean temperature difference for the counter flow arrangement is")
F=0.97;//Correction Factor for this situation
Ui=Q/(Ai*F*del_T_lm);//[W/m^2.degree Celcius]
disp("W/m^2.degree Celcius",round(Ui),"the overall heat transfer coefficient is")
```

Scilab code Exa 11.7 ab137

```
clear;
clc;

//Example11.6[Cooling of Water in an Automotive Radiator]
//Given:-
m=0.6;//Mass Flow rate of water[kg/s]
Th_in=90,Th_out=65,Tc_in=20,Tc_out=40;//[degree Celcius]
Di=0.005;//[m]
L=0.65;//[m]
n=40;//No of tubes
Cp=4195;//[J/kg.degree Celcius]
//Solution:-
Q=m*Cp*(Th_in-Th_out);//[W]
disp("W",Q,"The rate of heat transfer in the radiator from the hot water to the air is")
Ai=n*%pi*Di*L;//[m^2]
del_T1=Th_in-Tc_out;//[degree Celcius]
del_T2=Th_out-Tc_in;//[degree Celcius]
del_T_lm=(del_T1-del_T2)/log(del_T1/del_T2);//[degree Celcius]
disp("degree Celcius",del_T_lm,"The log mean temperature difference for the counter flow arrangement is")
F=0.97;//Correction Factor for this situation
Ui=Q/(Ai*F*del_T_lm);//[W/m^2.degree Celcius]
disp("W/m^2.degree Celcius",round(Ui),"the overall heat transfer coefficient is")
```

Scilab code Exa 11.8 ab138

```
clear;
```

```
clc;

//Example11.8[Using the Effectiveness- NTU Method]
//Given:-
mc=1.2,mh=2;//Mass Flow rate of water and geothermal fluid[kg/s]
U=640;//Overall Heat transfer Coefficient[W/m^2.degree Celcius]
Di=0.015;//[m]
Tc_out=80,Tc_in=20;//Outlet and Inlet temp of water[degree Celcius]
Th_in=160;//Inlet temp of geothermal fluid[degree Celcius]
Cp_c=4.18,Cp_h=4.31;//Specific Heats of water and geothermal fluid[kJ/kg.degree Celcius]
//Solution:-
Ch=mh*Cp_h;//[kW/degree Celcius]
Cc=mc*Cp_c;//[kW/degree Celcius]
if(Ch>Cc) then,
    Cmin=Cc;
    c=Cmin/Ch;
else
    Cmin=Ch;
    c=Cmin/Cc;
end
Q_max=Cmin*(Th_in-Tc_in);//[kW]
disp("kW",Q_max,"The maximum heat transfer rate is")
Q_ac=mc*Cp_c*(Tc_out-Tc_in);//[kW]
e=Q_ac/Q_max;
disp(e,"The effectiveness of the heat exchanger is")
NTU=(1/(c-1))*log((e-1)/(e*c-1));
disp(NTU,"The NTU of this counter flow heat exchanger is")
As=NTU*Cmin*1000/U;//[m^2]
disp("m^2",As,"The heat transfer surface area is")
L=As/(%pi*Di);//[m]
disp("m",round(L),"The length of the tube is")
```

Scilab code Exa 11.9 ab139

```
clear;
clc;

//Example11.9[Cooling Hot Oil by Water in Multipass
   Heat Exchanger]
//Given:-
Cp_c=4.18,Cp_h=2.13;//Specific Heats of water and
   oil[kJ/kg]
mc=0.2,mh=0.3;//Mass Flow rate of oil and water [kg/
   s]
Th_in=150,Tc_in=20;//[degree Celcius]
n=8;//No of tubes
D=0.014;//[m]
L=5;//[m]
U=310;//Overall Heat transfer Coefficient[W/m^2.
   degree Celcius]
//Solution:-
Ch=mh*Cp_h;//[kW/degree Celcius]
Cc=mc*Cp_c;//[kW/degree Celcius]
if(Ch>Cc) then,
    Cmin=Cc;
    c=Cmin/Ch;
else
    Cmin=Ch;
    c=Cmin/Cc;
end
Q_max=Cmin*(Th_in-Tc_in);//[kW]
disp("kW",Q_max,"The maximum heat transfer rate is")
As=n*%pi*D*L;//[m^2]
disp("m^2",As,"Heat transfer Surface Area is")
NTU=U*As/Cmin;
disp(NTU,"The NTU of this heat exchanger is")
```

```
e=0.47;//Determined from fig 11.26(c)using value of NTU and c
Q=e*Q_max;//[kW]
Tc_out=Tc_in+(Q/Cc);//[degree Celcius]
Th_out=Th_in-(Q/Ch);//[degree Celcius]
disp("degree Celcius",Tc_out,"to","degree Celcius",Tc_in,"The temperature of cooling water will rise from")
disp("degree Celcius",Th_out,"to","degree Celcius",Th_in,"as it cools the hot oil from")
```

Scilab code Exa 11.10 ab140

```
clear;
clc;

//Example11.10[Installing a Heat Exchanger to Save Energy and Money]
//Given:-
Cp=4.18;//[kJ/kg.degree Celcius]
Th_in=80,Tc_in=15;//Inlet temperatures of hot and cold water[degree Celcius]
m=15/60;//[kg/s]
e=0.75;//Effectiveness
t=24*365;//Operating Hours[hours/year]
neta=0.8;//Eficiency
cost=1.10;//[$/therm]
//Solution:-
Q_max=m*Cp*(Th_in-Tc_in);//[kJ/kg.degree Celcius]
disp("kJ/kg.degree Celcius",Q_max,"Maximun Heat recover is")
Q=e*Q_max;//[kJ/s]
E_saved=Q*t*3600;//[kJ/year]
disp("kJ/year",E_saved,"The energy saved during an entire year will be")
```

```
F_saved=(E_saved/neta)*(1/105500);//[therms]
disp("therms/year",F_saved,"Fuel savings will be")
M_saved=F_saved*cost;//[$/year]
disp("per year",M_saved,"The amount of money saved
    is $")
```

Chapter 12

Fundamentals of Thermal Radiation

Scilab code Exa 12.1 ab141

```
clear;
clc;

//Example12.1[Radiation Emission from a Black Ball]
//Given:-
T=800;//Temperature of suspended ball[K]
D=0.2;//Diameter[m]
C1=3.74177*10^8;//[(micrometer^4)/m^2]
C2=1.43878*10^4;//[micrometer.K]
lambda=3;//[micrometer]
//Solution (a):-
Eb=(5.67*10^(-8))*(T^4);//[W/m^2]
disp("of energy in the form of energy in the form of
    electromagnetic radiation per second per m^2","
   kJ",Eb/1000,"The ball emits")
//Solution(b):-
As=%pi*(D^2);//[m^2]
disp("m^2",As,"The total Surface area of the ball is
   ")
```

```
del_t=5*60;//[seconds]
Q_rad=Eb*As*del_t;//[J]
disp("kJ",Q_rad/1000,"The total amount of radiation energy emitted from the entire ball is")
//Solution (c)
Eb_lambda=C1/((lambda^5)*((exp(C2/(lambda*T)))-1));//[W/m^2.micrometer]
disp("W/m^2.micrometer",round(Eb_lambda),"The spectral blackbody emissive power")
```

Scilab code Exa 12.2 ab142

```
clear;
clc;

//Example12.2[Emission of Radiation from a Lightbulb]
//Given:-
T=2500;//Temp of the filament[K]
lambda1=0.4,lambda2=0.76;//Visible ranfe[micrometer]
f1=0.000321,f2=0.053035;//The black body radiation functions corresponding to lamda1*T and lambda2*T
//Solution:-
f3=f2-f1;
disp(f3,"Fraction of radiation emitted between the two given wavelengths is")
lambda_max=2897.8/T;//[micrometer]
disp("micron",lambda_max,"The wavelength at which the emission of radiation from the filament peaks is")
```

Scilab code Exa 12.3 ab143

```
clear;
clc;

//Example12.3[Radiation Incident on a small surface]
//Given:-
A1=3^10^(-4);//[m^2]
T1=600;//[k]
A2=5*10^(-4);//[m^2]
theta1=%pi*55/180,theta2=%pi*40/180;//[Radian]
r=0.75;//[m]
//Solution:-
w_2_1=(A2*cos(theta2))/(r^2);//[Steradian]
disp("sr",w_2_1,"The solid angle subtended by a2
    when viewed from A1 is")
I1=(5.67*10^(-8))*(T1^4)/(%pi);//[W/m^2.sr]
disp("W/m^2.sr",I1,"The Intensity of radiation
    emitted by A1 is")
Q1_2=I1*(A1*cos(theta1))*w_2_1;//[W]
disp("W",Q1_2," is ","Steradian",w_2_1,"through the
    solid angle","radians",theta1,"The rate of
    radiation energy emitted by A1 in the direction
    of")
```

Scilab code Exa 12.4 ab144

```
clear;
clc;

//Example12.4[Emissivity of a surface and emissive
    Power]
e1=0.3;//For 0<= lambda <= 3micron
e2=0.8;//3micron<=lambda<=7micron
e3=0.1;//7micron<=lamda<infinity
lambda1=3,lambda2=7;//[micron]
T=800;//[K]
```

```
//Solution:-
p=lambda1*T;//[micron.K]
q=lambda2*T;//[micron.K]
//Hence blackbody radiation functions are
f1=0.140256;
f2=0.701046;
f0_1=f1-0;
f2_inf=1-f2;
e_T=e1*f1+e2*(f2-f1)+e3*(1-f2);
disp(e_T,"Average emissivity of the surface is")
E=e_T*(5.67*10^(-8))*(T^4);//[W/m^2]
disp("W/m^2",E,"The Emissive Power of the surface is")
```

Scilab code Exa 12.5 ab145

```
clear;
clc;

//Example12.6[Selective Absorber and Reflective Surfaces]
//Given:-
G_D=400,G_d=300;//Direct and diffuse components of solar radiation [W/m^2]
Ts=320,T_sky=260;//[K]
theta=20*%pi/180
//Solution:-
G_solar=(G_D*cos(theta))+G_d
//(a)
ab_a=0.9,e_a=0.9;//Grey absorber surface
q_net_rad_a=ab_a*G_solar+e_a*(5.67*10^(-8))*((T_sky^4)-(Ts^4));//[W/m^2]
disp("W/m^2",round(q_net_rad_a),"(a) The net radiation heat transfer is")
//(b)
```

```
ab_b=0.1,e_b=0.1;//Grey reflector surface
q_net_rad_b=ab_b*G_solar+e_b*(5.67*10^(-8))*((T_sky^4)-(Ts^4));// [W/m^2]
disp("W/m^2",round(q_net_rad_b),"The net radiation heat transfer is")
//(c)
ab_c=0.9,e_c=0.1;//Selective Absorber surface

q_net_rad_c=ab_c*G_solar+e_c*(5.67*10^(-8))*((T_sky^4)-(Ts^4));// [W/m^2]
disp("W/m^2",round(q_net_rad_c),"The net radiation heat transfer is")
//(d)
ab_d=0.1,e_d=0.9;//Selective reflector surface
q_net_rad_d=ab_d*G_solar+e_d*(5.67*10^(-8))*((T_sky^4)-(Ts^4));// [W/m^2]
disp("W/m^2",round(q_net_rad_d),"The net radiation heat transfer is")
```

Scilab code Exa 12.6 ab146

```
clear;
clc;

//Example12.6[Installing Reflective Films on Windows]
//Given:-
A_glazing=40;// [m^2]
SHGC_wof=0.766,SHGC_wf=0.261;// [kWh/year]
unit_c_e=0.08;// [$/kWh]
unit_c_f=0.5;// [$/therm]
COP=2.5,neta=0.80;
//Solution:-
//For the months of June,July,August and Sepetember
Q_summer=5.31*30+4.31*31+3.93*31+3.28*30;// [kWh/year
```

```
]
//For the months oct,Nov,Dec,Jan,Feb,Mar,Apr
Q_winter=2.80*31+1.84*30+1.54*31+1.86*31+2.66*28+3.43*31+4.00*30; //[kWh/year]
c_l_d=Q_summer*A_glazing*(SHGC_wof-SHGC_wf);//[kWh/year]
disp("kWh/year",c_l_d,"The decrease in the annual cooling load is")
h_l_i=Q_winter*A_glazing*(SHGC_wof-SHGC_wf);//[kWh/year]
disp("kWh/year",h_l_i,"The increase in annual heating load is")
d_c_c=c_l_d*(unit_c_e)/COP;//[$/year]
i_h_c=h_l_i*(unit_c_f/29.31)/neta;//[$/year]
disp(" per year",i_h_c,"and $",d_c_c,"The corresponding decrease in cooling costs and the increase in heating costs are $")
Cost_s=d_c_c-i_h_c;//[$/year]
disp(" per year",Cost_s,"The net annual cost savings due to the reflective film is $")
I_cost=20*A_glazing;//[$]
disp(I_cost,"The implementation Cost of installing films is $")
pp=I_cost/Cost_s;//[years]
disp("years",pp,"Payback Period is")
```

Chapter 13

Radiation Heat Transfer

Scilab code Exa 13.1 ab151

```
clear;
clc;

//Example13.1[View Factors Associated with two Concentric Spheres]
//Solution:-
//The outer surface of the smaller sphere and inner surface of the larger sphere form a two surface enclosure
N=2;
disp("View Factors",N^2,"This enclosure involves ")
x=(1/2)*N*(N-1);
disp("view factor directly",x,"W need to determine only")
F11=0;
F12=1;
disp("The Two view Factors")
disp(F11,"Since no radiation leaving surface 1 strikes itself..... F11=")
disp(F12,"Since all radiation leaving surface 1 strikes surface 2   F12=")
```

```
disp("F12= ((r1/r2)^2)")
disp("F22= 1-((r1/r2)^2)")
disp("where r1 and r2 are radius of surface 1 and
   surface 2")
```

Scilab code Exa 13.2 ab152

```
clear;
clc;

//Example13.2[Fraction of Radiation Leaving through
   an Opening]
//Given:-
r1=0.1;//Radius of enclosure[m]
L=0.1;//Length of Enclosure[m]
r2=0.05,r3=0.08;//Inner and outer radii of the ring[
   m]
//Solution:-
//Using Chart in Fig 13.7
F12=0.11;
F13=0.28;
F1_ring=F13-F12;
disp(F1_ring,"The fraction of the radiation leaving
   the base cyllinder enclosure that escapes through
    coaxial ring opening at its top surface is")
```

Scilab code Exa 13.3 ab153

```
clear;
clc;

//Example13.3[View Factors Associated with a
   Tetragon]
```

```
//Given:-
//A pyramid with square base and it's sides being
    isoceles triangle
//Solution:=
F11=0;//Since base is a flat surface
//F12=F13=F14=F15=x
x=(1-F11)/4;
disp("of total radiation",x,"Each side pf the four
    surfaces of the pyramid recieves")
```

Scilab code Exa 13.5 ab155

```
clear;
clc;

//Example13.5[The Crossed-Strings Method for View
    Factors]
a=12,b=5;//With od long parallel plates[cm]
c=6;//Distance between the plates
L1=a,L2=b,L3=c;
L4=sqrt((7^2)+(6^2));
L5=sqrt((5^2)+(6^2));
L6=sqrt((12^2)+(6^2));
F12_1=((L5+L6)-(L3+L4))/(2*L1);
F13=(L1+L3-L6)/(2*L1);
F14=(L1+L4+L5)/(2*L1);
F12_2=1-F13-F14;
disp(F12_1,"Therefore from two different methods
    F12_1=F12_2=",F13,"F13=",F14,"F14=")
```

Scilab code Exa 13.6 ab156

```
clear;
```

```
clc;

//Example13.6[Radiation Heat Transfer in a Black
    Furnace]
//Given:-
F12=0.2;
A=5*5;//Area of 1 surface of cube[m^2]
Tb=800,Tt=1500,Ts=500;//Temperature of base top and
    the side surfaces of the furbace[K]
//Solution:-
F11=0;
Q11=0;
F13=1-F11-F12;
Q13=A*F13*(5.67*10^(-8))*((Tb^4)-(Ts^4));//[kW]
disp("kW",round(Q13/1000),"The net rate of heat
    transfer from surface1 to surface3 is")
Q12=A*F12*(5.67*10^(-8))*((Tb^4)-(Tt^4));//[kW]
disp("kW",round(Q12/1000),"The net rate of radiation
    heat transfer from siurface1 to surface2 is")
Q1=Q11+Q12+Q13;//[kW]
disp("kW",round(Q1/1000),"Rhe net radiation heat
    transfer from the base surface is")
```

Scilab code Exa 13.7 ab157

```
clear;
clc;

//Example13.7[Radiation Heat Transfer between
    Parallel Plates]
//Given:-
T1=800,T2=500;//Temp of parallel plates[K]
e1=0.2,e2=0.7;//Emissivities
//Solution:-
q12=(5.67*10^(-8))*((T1^4)-(T2^4))/((1/e1)+(1/e2)-1)
```

```
;
disp("is transferred from plate 1 to plate 2 by radiation per unit surface area of either plate","W",round(q12),"The net heat at the rate of")
```

Scilab code Exa 13.8 ab158

```
clear;
clc;

//Example13.8[Radiation Heat Transfer in Cylindrical Furnace]
//Given:-
ro=1,H=1;//Radius amd height of cylinder[m]
e1=0.8,e2=0.4;//Emissivities
T1=700,T2=500;//Top and base temperatures of furnace [K]
T3=400;//Side durface temperature[K]
F11=0,F12=0.38;
//Solution:-
A1=%pi*(ro^2);//[m^2]
A2=A1;//[m^2]
A3=2*%pi*ro*H;//[m^2]
F13=1-F11-F12;
F21=F12;//Top and Bottom are symmetric
F31=F13*(A1/A3);
F23=F13;
F32=F31;
function[i]=rad(J)
    i(1)=J(1)+(((1-e1)/e1)*((F12*(J(1)-(J(2))))+(F13*((J(1))-(J(3))))))-((T1^4)*(5.67*10^(-8)));
    i(2)=J(2)+(((1-e2)/e2)*((F21*(J(2)-J(1)))+(F23*(J(2)-J(3)))))-((T2^4)*(5.67*10^(-8)));
    i(3)=J(3)-((T3^4)*(5.67*10^(-8)));
    deff('[i]=rad(J)',['i_1=J(1)+(((1-e1)/e1)*((F12
```

```
*(J(1)-(J(2))))+(F13*((J(1))-(J(3))))))-((T1
^4)*(5.67*10^(-8)))','i_2=J(2)+(((1-e2)/e2)
*((F21*(J(2)-J(1)))+(F23*(J(2)-J(3)))))-((T2
^4)*(5.67*10^(-8)))','i_3=J(3)-((T3^4)
*(5.67*10^(-8)))'])
disp(J(3),J(2),J(1))
Q1=A1*((F12*(J(1)-J(2)))+(F13*(J(1)-J(3))));//[kW]
Q2=A2*((F21*(J(2)-J(1)))+(F13*(J(2)-J(3))));//[kW]
Q3=A3*((F31*(J(3)-J(1)))+(F32*(J(3)-J(2))));//[kW]
disp("kW",Q3/1000,Q2/1000,Q1/1000,"The net rates of radiation heat transfer at the three surfaces are")
```

Scilab code Exa 13.9 ab159

```
clear;
clc;

//Example13.9[Radiation Heat Transfer in a Triangular Furnace]
//Given:-
A1=1,A2=1,A3=1;//Area of each side[m^2]
T1=600,T2=1000;//[K]
e=0.7;
F12=0.5,F13=0.5,F23=0.5;//Symmetry
//Solution:-
Eb1=5.67*10^(-8)*(T1^4);//[W/m^2]
Eb2=5.67*10^(-8)*(T2^4);//[W/m^2]
Q=(Eb2-Eb1)/(((1-e)/(A1*e))+((((A1*F12)+(1/((1/(A1*F13))+(1/(A2*F23))))))^(-1)));//[kW]
disp("kW",round(Q/1000),"Heat at the rate of")
disp("must be supplied to the heated surface per
```

```
unit lemgth of the duct to maintain steady operation in the furnace")
```

Scilab code Exa 13.10 ab160

```
clear;
clc;

//Example13.10[Heat Transfer through a Tubular Solar Collector]
k=0.02588;//[W/m.degree Celcius]
Pr1=0.7282,Pr2=0.7255;//Prandtl no
nu1=1.608*(10^(-5)),nu2=1.702*10^(-5);//[m^2/s]
T1=20,T2=40;//[degree Celcius]
Tavg=((T1+T2)/2)+273;//[K]
Do=0.1,L=1;//Dimensions of glass tube[m]
Di=0.05;//Inner diameter of tube[m]
Q_glass=30;//Rate of heat transfer from the outer surface of the glass cover[W]
g=9.81;//[m^2/s]
eo=0.9,ei=0.95;//Emissivity
//Solution:-
Ao=%pi*Do*L;//Heat transfer surface area of the glass cover[m^2]
disp(Ao,Tavg)
Ra_Do=g*Tavg*(T2-T1)*(Do^3)*Pr1/(nu1);
disp(Ra_Do,"The Rayleigh number is")
Nu=((0.6+((0.387*(Ra_Do^(1/6)))/((1+((0.559/Pr1)^(9/16)))^(8/27))))^2);
disp(Nu,"The nusselt number is")
ho=k*Nu/Do;//[W/m^2.degree Celcius]
Qo_conv=ho*Ao*(T2-T1);//[W]
Qo_rad=eo*5.67*10^(-8)*Ao*(((T2+273)^4)-((T1+273)^4));//[W]
Qo_total=Qo_conv+Qo_rad;//[W]
```

```
disp("W",Qo_total,"The total rate of heat loss from the glass cover
Lc=(Do-Di)/2;//The characteristic length
Ai=%pi*Di*L;//[m^2]
//Assuming
T_tube=54,T_cover=26;//Temperature of tube and glass cover[degree Celcius]
T_avg=((T_tube+T_cover)/2)+273;//[K]
Ra_L=g*T_avg*(T_tube-T_cover)*(Lc^3)*Pr2/(nu2);
disp(Ra_L,"The Rayleigh number in this case is")
F_cyl=((log(Do/Di))^4)/((Lc^3)*(((Di^(-3/5))+(Do^(-3/5)))^5));
k_eff=0.386*k*((Pr2/(0.861+Pr2))^(1/4))*((F_cyl*Ra_L)^(1/4));
disp("W/m.degree Celcius",k_eff,"The effective thermal conductivity is")
QL_conv=2*%pi*k_eff*(T_tube-T_cover)/(log(Do/Di));
disp("W",QL_conv,"The rate of heat transfer between the cylinders by convection is")
QL_rad=((5.67*10^(-8))*Ai*(((T_tube+273)^4)-((T_cover+273)^4)))/((1/ei)+(((1-eo)/eo)*(Di/Do)));
disp("W",QL_rad,"The radiation rate of heat transfer is")
QL_total=QL_conv+QL_rad;//[W]
disp("W",QL_total,"The total rate of heat loss from the glass cover is")
```

Scilab code Exa 13.11 ab161

```
clear;
clc;

//Example13.11[Radiation Shields]
//given:-
e=0.1;//Emissivity of aluminium sheet
```

```
T1=800,T2=500;//Temperatures of two parallel plates[K]
e1=0.2,e2=0.7;//Emissivities of plates
//So9lution:-
q12=((5.67*10^(-8))*((T1^4)-(T2^4)))/((1/e1)+(1/e2)-1+(1/e)+(1/e)-1);//[W/m^2]
disp("W/m^2",round(q12),"Radiation Heat Transfer")
```

Scilab code Exa 13.12 ab162

```
clear;
clc;

//Example13.12[Radiation Effect on Temperature Measurements]
//Given:-
Tw=400,Tth=650;//Temperature of duct wall and hota air flowing in it[K]
e=0.6;//emissivity
h=80;//Heat transfer coefficient[W/m^2.K]
//Solution:-
Tf=Tth+((e*5.67*10^(-8)*((Tth^4)-(Tw^4)))/h);//[K]
disp("K",round(Tf),"The temperature of actual air is")
```

Scilab code Exa 13.13 ab163

```
clear;
clc;

//Example13.13[Effective Emissivity of Combustion Gases]
```

```
d=5,H=5;//Diameter and height of cylindrical furnace
    [m]
T=1200;//Temp of gases[K]
P=2;//Pressure[atm]
yN2=0.8,yH2O=0.08,yO2=0.07,yCO2=0.05;//Volumetric
    Composition
//Solution:-
Pc=yCO2*P;//[atm]
Pw=yH2O*P;//[atm]
disp("atm",Pw,"and","atm",Pc,"The partial pressures
    of CO2 and H2O are")
L=0.6*d;//[m]
x=Pc*L,y=Pw*L;//[m.atm]
ec_1=0.16,ew_1=0.23;//Emissivity of CO2 and H2O at 1
     atm pressure
Cc=1.1,Cw=1.4;//Pressure Correction Factors are
del_e=0.048;//Emissivity correction factor at T=1200
    K
e_g=Cc*ec_1+Cw*ew_1-del_e;
disp(e_g,"The effectivity of the combustion gases is
    ")
```

Scilab code Exa 13.14 ab164

```
clear;
clc;

//Example13.14[Radiation Heat Transfer in a
    Cylindrical Furnace]
//Given:-
Ts=600;//Wall Temperature[K]
d=5,H=5;//Diameter and Height of cylindrical furnace
Tg=1200,eg=0.45;//Average gas temperature and
    average emissivity of the combustion gases
Pc=0.10,L=3,Pw=0.16;//From Previous examples
```

```
//Solution:-
x=Pc*L*Ts/Tg;//[m.atm]
y=Pw*L*Ts/Tg;//[m.atm]
ec_1=0.11,ew_1=0.25;//Emissivities of CO2 and H2O
    corresponding to 600K and 1atm
Cc=1.1,Cw=1.4;//Correction Factors
a_c=Cc*((Tg/Ts)^(0.65))*(ec_1);
a_w=Cw*((Tg/Ts)^(0.45))*ew_1;
disp(a_w,"and",a_c,"The absorptivities of CO2 and
    H2O are")
del_a=0.027;
a_g=a_c+a_w-del_a;
disp(a_g,"The absorptivity of the combustion gases
    is")
As=(%pi*d*H)+(%pi*(d^2)/2);//[m^2]
disp("m^2",round(As),"the surface area of the
    cylindrical surface is")
Q_net=round(As)*(5.67*10^(-8))*((eg*(Tg^4))-(a_g*(Ts
    ^4)));
disp("W",Q_net,"The net rate of radiation heat
    transfer from the combustion gases to walls of
    the furnace is")
```

Scilab code Exa 13.15 ab165

```
clear;
clc;

//Example13.15[Effect of Clothing on Thermal Comfort
    ]
h_rad=4.7,h_conv=4.0;//The radiation and convection
    heat transfer coefficient[W/m^2.degree Celcius]
R_clo=0.6*0.155;//Thermal resistance of clothing[m
    ^2.degree Celcius/W]
T_skin=33,T_amb=22;//Skin and Ambient temperature[
```

```
degree Celcius]
As=1.8;//Surface area of an average man
//Solution:-
h_comb=h_conv+h_rad;//combined heat transfer coefficient [W/m^2.degree Celcius]
Q_sen_clo=As*(T_skin-T_amb)/(R_clo+(1/h_comb));//[W]
disp("W",Q_sen_clo,"The sensible heat loss from this person when clothed is")
//On removing the clothes
//R_clo=0 Clothing resistance on removing clothes
//Setting both heat transfer rates equal to determine new ambient air temperature
T_amb_new=T_skin-(Q_sen_clo*(1/h_comb)/As)//[degree Celcius]
disp("degree Celcius",T_amb_new,"The ambient temperature now is")
```

Chapter 14

Mass Transfer

Scilab code Exa 14.1 ab171

```
clear;
clc;

//Example14.1[Determining Mass Fractions from Mole
    Fractions]
//Given:-
yN2=0.781,yO2=0.209,yAr=0.01;//Mole fractions
M_N2=28,M_O2=32,M_Ar=39.9;//Molar Masses
//Solution:-
M_air=yN2*M_N2+yO2*M_O2+yAr*M_Ar;//[kg/kmol]
disp("kg/kmol",M_air,"The molar mass of air is")
w_N2=yN2*M_N2/M_air;
w_O2=yO2*M_O2/M_air;
w_Ar=yAr*M_Ar/M_air;
disp("respectively","percent",100*w_Ar,"and","
    percent",100*w_O2,",","percent",100*w_N2,"The
    mass fractions of N2, O2 and Ar in dry standard
    atmosphere are")
```

Scilab code Exa 14.2 ab172

```
clear;
clc;

//Example14.2[Mole Fraction of Water Vapor at the
    surface of a Lake]
//Given:-
P_vapor=1.705;//Partial Pressure of water vapor in
    the air at the lake surface is saturation
    pressure of watre at 15 degree Celcius[kPa]
T_lake=15;//[degree Celcius]
P=92;//Atmospheric pressure at lake level [kPa]
//Solution:-
y_vapor=P_vapor/P;
disp(y_vapor,"The mole fraction of water vapor in
    the air at the surface of lake is")
y_water=1-y_vapor;//Since water contains dissolved
    air
disp(y_water,"Mole fraction of liquid water in lake"
    )
```

Scilab code Exa 14.3 ab173

```
clear;
clc;

//Example14.3[Mole Fraction of Dissolved Air in
    Water]
//Given:-
P_vapor=1.96;//The partial presure of water vapor in
     the air at the lake surface is the saturation
    pressure of water at 17 degree Celcius
H=62000;//Henry's constant for air dissolved in
    water at 290K[bar]
```

```
P=92;//Atmospheric Pressure at lake level[kPa]
//Solution:-
P_dryair=P-P_vapor;//[kPa]
disp("bar",P_dryair/100,"The partial pressure of dry
    air is")
y_dryair=(P_dryair/100)/H;
disp(y_dryair,"The mole fraction of air in the water
    is")
```

Scilab code Exa 14.4 ab174

```
clear;
clc;

//Example14.4[Diffusion of Hydrogen Gas into a
   Nickel Plate]
//Given:-
s=0.00901;//Solubility of hydrogen in nickel at 358K
   [kmol/m^3.bar]
P_H2=300/100;//[bar]
M_H2=2;//Molar Mass of hydrogen[kg/kmol]
//Solution:-
C_H2=s*P_H2;//[kmol/m^3]
disp("kmol/m^3",C_H2,"The molar density of hydrogen
   in the nickel at the interface is")
rho_H2=C_H2*M_H2;//[kg/m^3]
disp("kg/m^3",rho_H2,"Mass Density of hydrogen is")
```

Scilab code Exa 14.5 ab175

```
clear;
clc;

```

```
//Example14.5[Diffusion of Hydrogen through a Spherical Container]
//Given:-
CA1=0.087,CA2=0;//Molar concentration of hydrogen in the nickel at inner and outer surfaces[kmol/m^3]
r2=4.8/2;//Outer radius[m]
t=0.06;//Thickness of shell[m]
D_AB=1.2*(10^(-12));//Diffusion coefficient for hydrogen in the nickel at the specified temperature is[m^2/s]
M_H2=2;//Molar Mass of H2[kg/kmol]
//Solution:-
r1=((2*r2)-(2*t))/2;//Inner radius[m]
N_diff=4*%pi*r1*r2*D_AB*(CA1-CA2)/(r2-r1);
disp("kmol/s",N_diff,"The molar flow rate of hydrogen through the shell by diffusion is")
m_diff=M_H2*N_diff;
disp("kg/s",m_diff,"The mass flow rate of hydrogen is")
```

Scilab code Exa 14.6 ab176

```
clear;
clc;

//Example14.6[Condensation and Freezing of Moisture in Walls]
Ti=20,To=-16;//Indoor and outdoor temperatures[degree Celcius]
R_wall=3.05;//Total thermal resistance of the wall[m^2.degree Celcius/W]
A=1;//Heat transfer area[m^2]
R_ext=0.40;//The thermal resistance of the exterior part of the wall beyond the insulation[m^2.degree Celcius/W]
```

```
Rv_int=0.012+0.0004,Rv_ext=0.0138+0.019;//Indoor and outdoor vapor resistances[Pa.m^2.s/ng]
phi1=0.6,phi2=0.7;//Indoor and outdoor Relative Humidity
Psat1=2340,Psat2=151;//Indoor and outdoor saturation pressures[Pa]
//Solution:-
Q_wall=A*(Ti-To)/R_wall;//[W]
disp("W",Q_wall,"The rate of heat transfer through unit area of wall is")
T_I=To+(Q_wall*R_ext);
disp("degree Celcius",T_I,"The temperature of outer sheathing interface is")
P=234;//The saturation pressure of water at temp T_I [Pa]
Pv1=phi1*Psat1;
Pv2=phi2*Psat2;
disp("Pa",round(Pv2),"and","Pa",Pv1,"The vapor pressure at the indoor and the outdoor is")
mv_int=A*(Pv1-P)/Rv_int;
mv_ext=A*(P-Pv2)/Rv_ext;
disp("ng/s",mv_ext,"and","ng/s",mv_int,"The rate of moisture flow through the interior and exterior parts of the wall is")
mv_freezing=mv_int-mv_ext;
disp("ng/s",mv_freezing,"The moisture is freezing in the insulation at the rate of")
```

Scilab code Exa 14.7 ab177

```
clear;
clc;

//Example14.7[Hardening of Steel by the diffusion of carbon]
```

```
//Given:-
D_AB=4.8*10^(-10);//Diffusion coefficient of carbon in steel at the furnace temperature [m^2/s]
wA_i=0.0015;//Initial carbon concentration
wA_e=0.012;//Equilibrium concentration of carbon
wA_t=0.01;//Concentration of carbon after desired time
x=0.0005;//Diffusion distance[m]
//Solution:
a=(wA_t-wA_i)/(wA_e-wA_i);
//Tthe argument whose complimentary error function is a=0.81 is 0.17
t=(x^2)/(4*D_AB*(0.17^2));//[seconds]
disp("seconds",round(t),"Time taken to reach desired level of hardening is")
```

Scilab code Exa 14.8 ab178

```
clear;
clc;

//Example14.8[Venting of Helium into the Atmosphere by Diffusion]
//Given:-
D_AB=7.2*10^(-5);//Diffusion coefficient of air in helium[m^2/s]
M_He=4,M_air=29;//Molar masses of helium and air[kg/kmol]
D=0.005;//Internal diameter of tube[m]
L=15;//Length of tube[m]
R1=8.314;//Universal Gas Constant[kPa.m^3/kmol.K]
R2=2.0769;//Universal Gas Constant[kPa.m^3/kg.K]
T=298;///Ambient temperature[K]
//Solution:-
A=%pi*(D^2)/4;//Flow area[m^2]
```

```
P_He0=1,P_HeL=0;//Pressure of helium at x=0 i.e.
    bottom of tube and at x=L i.e. at the top of the
    tube [atm]
N_He=D_AB*A*(P_He0-P_HeL)*(101.3)/(R1*T*L);
disp("kmol/s",N_He,"The molar flow rate of Helium is
    ")
m_He=N_He*M_He;
disp("kg/s",m_He,"Mass flow rate of helium is")
N_air=-N_He;//Equimolar counter diffusion process
m_air=N_air*M_air;
disp("kg/s",m_air,"The flow rate of air into the
    pipeline is")
w_air=m_air/(m_air+m_He);
disp("which is negligible",w_air,"Mass fraction of
    air in the helium pipeline is")
m_net=m_He+m_air;//[kg/s]
//Taking density of mixture at x=0 to be the density
     of helium as the mass fraction of air at the
    bottom is very small
rho=P_He0*101.325/(R2*T);//[kg/m^3]
V=m_net/(rho*A);//[m/s]
disp("m/s",V,"The average flow velocity at the
    bottom of the tube is")
```

Scilab code Exa 14.9 ab179

```
clear;
clc;

//Example14.9[Measuring Diffusion Coefficient by the
     Stefan tube]
//Given:-
D=0.03;//Diameter of tube[m]
P=83.5;//Atmospheric Pressure at an elevation of
    1600m[kPa]
```

```
T=20+273;//Ambient temperature[K]
R=8.314;//Universal Gas Constant[kPa.m^3/kmol.K]
P_vapor0=2.34;//The saturation pressure of water at 20 degree Celcius[kPa]
M_vapor=18;//Molar mass of water vapor[kg/kmol]
x=0.4;//Distance from water surface to the open end of the tube[m]
//Solution:-
//water vapor is species A
yA0=P_vapor0/P;
disp(yA0,"The mole fraction of water vapor (species A) at the Interface is")
yAL=0;//mole fraction of water vapor on the top of the tube
C=P/(R*T);//[kmol/m^3]
A=%pi*(D^2)/4;//[m^2]
disp("m^2",A,"The cross sectional area of tube")
m_vapor=(1.23*10^(-3))/(15*24*3600);//Rate of evaporation [kg/s]
N_vapor=m_vapor/M_vapor;
disp("kmol/s",N_vapor,"The molar flow rate of vapor is")
D_AB=(N_vapor/A)*(x/C)/log((1-yAL)/(1-yA0));
disp("m^2/s",D_AB,"Binary diffusion coefficient of water vapor in air at 20 degree Celcius and 83.5 kPa")
```

Scilab code Exa 14.10 ab180

```
clear;
clc;

//Example14.10[Mass Convection inside a Circular Pipe]
//Given:-
```

```
D=0.015;//Inner Diameter[m]
T=300;//Temp of air[K]
P=1;//Pressure of air[atm]
v=1.2;//Average velocity of air[m/s]
nu=1.58*10^(-5);//Viscosity[m^2/s]
//Solution:-
//Water is Species Aand air is species B
D_AB=(1.87*10^(-10))*(T^2.072)/P;//[m^2/s]
disp("m^2/s",D_AB,"The mass diffusivity of water
   vapor in air at 300K is")
Re=v*D/nu;
disp(round(Re),"The Reynolds number for internal
   flow is")
if(Re<2300) then
    disp("laminar Flow")
    Sh=3.66;//Sherwood number equals to Nusselt
       number
    h_mass=Sh*D_AB/D;//[m/s]
    disp("m/s",h_mass,"The mass transfer coefficient
        is")
else
    disp("Flow is not laminar")
end
```

Scilab code Exa 14.11 ab181

```
clear;
clc;

//Example14.11[Analogy between Heat and Mass
   Transfer]
//Given:-
//Napthalene is species A and air is species B
M_A=128.2;//Molar Mass of A[kg/kmol]
M_air=29;//Molar mass of B[kg/kmol]
```

```
P=101325;//Pressure of Air[Pa]
T=298;//Temperature[K]
D_AB=0.61*10^(-5);//[m^2/s]
v=2;//Stream velocity[m/s]
rho=1.184;//Density of air[kg/m^3]
Cp=1007;//Specific Heat[J/kg.K]
a=2.141*10^(-5);//Absorptivity[m^2/s]
w_inf=0;//Mass fraction of napthalene at free stream
    conditions
P_As=11;//Vapor Pressure of Napthalene at surface[Pa
   ]
mA=12*10^(-3);//Mass of napthalene sublimated[kg]
delta_t=15*60;//time of sublimation[s]
As=0.3;//surface area of the body[m^2]
//Solution:-
w_As=(P_As/P)*(M_A/M_air);
disp(w_As,"Mass fraction at the surface is")
m_evap=mA/delta_t;//[kg/s]
disp("kg/s",m_evap,"The rate of evaporation of
   napthalene is")
h_mass=m_evap/(rho*As*(w_As-w_inf));
disp("m/s",h_mass,"The mass convection coefficient
   is")
//Using analogy between heat and mass transfer
h_heat=rho*Cp*h_mass*((a/D_AB)^(2/3));//[W/m^2.
   degree Celcius]
disp("W/m^2.degree Celcius",round(h_heat),"The
   average heat transfer coefficient is")
```

Scilab code Exa 14.12 ab182

```
clear;
clc;

//Example14.12[Evaporative Cooling of a Canned Drink
```

```
]
//Given:-
//Water is species A and air is species B
M_A=18,M_B=29;;//Molar Masses of water and air[kg/kmol]
D_AB=2.5*10^(-5);//Diffusivity of water vapor in air[m^2/s]
T_inf=30;//Ambient Temperature[degree Celcius]
T_avg=(20+T_inf)/2;//Average temperature
P=101.325;//Atmospheric Pressure[kPa]
//Properties of A at 20 degree Celcius
h_fg=2454;//[kJ/kg]
Pv1=2.34;//Saturation vapor pressure[kPa]
Pv2=4.25;//Vapor Pressure at 30 degree Celcius[kPa]
//Properties of air at average temperature and 1 atm
Cp=1.007;//[kJ/kg]
a=2.141*10^(-5);//[m^2/s]
phi=0.4;//Relative Humidity
//Solution:-
Le=a/D_AB;
disp(Le,"The Lewis Number is")
Pv_inf=phi*Pv2;//[kPa]
disp("kPa",Pv_inf,"The vapor pressure of air away from the surface is")
Ts=T_inf-(h_fg*M_A*(Pv1-Pv_inf)/(Cp*(Le^(2/3))*M_B*P));
disp("degree Celcius",Ts,"The temperature of the drink can be lowered to")
```

Scilab code Exa 14.13 ab183

```
clear;
clc;

//Example14.13[Heat Loss from Uncovered Hot Water
```

```
Baths]
//Given:-
Ts=50+273;//Uniform temperature of water[K]
T_surr=20+273;//Average temperature of surrounding surfaces[K]
T_inf=25+273;//Ambient temperature[K]
As=3.5*1;//Surface area of water bath[m^2]
p=2*(3.5+1);//Perimeter of top surface of water bath[m]
e=0.95;//Emissivity of liquid water
phi=0.52;//Relative Humidity
Rv=0.4615;//Universal Gas Constant[kPa.m^3/kg.K]
Ra=0.287;//Universal Gas Constant[kPa.m^3/kg.K]
g=9.81;//[m^2/s]
//solution:-
//(a)
Q_rad=e*As*(5.67*10^(-8))*((Ts^4)-(T_surr^4));
disp("W",round(Q_rad),"The radiation heat loss from the water to the surrounding surface is")
//(b)
Tavg=(Ts+T_inf)/2;//Average temperature[degree Celcius]
P=92;//Atmospheric pressure[kPa]
//At average temperature Tavg and Pressure P, Properties of dry air:-
k=0.02644;//[W/m.degree Celcius]
Pr=0.7262;//Prandtl number, independent of pressure
a=(2.312*10^(-5))/P;//Absorptivity[m^2/s]
nu=(1.849*10^(-5));//Kinematic viscosity[m^2/s]
//At T_surr properties of water are:-
h_fg=2383;//[kJ/kg]
Pvs=12.35;//[kPa]
Psat=3.17;//Saturation Pressure of water at surface temp[kPa]
//The air at surface is saturated therefore vapor pressure at surface is simple the saturation pressure of water at the surface temperature
Pv_inf=phi*Psat;//[kPa]
```

```
//At the surface
rho_vs=Pvs/(Rv*Ts);
disp("kg/m^3",rho_vs,"Density of water vapor at the surface is")
rho_as=(P-Pvs)/(Ra*Ts);
disp("kg/m^3",rho_as,"Density of air at the surface is")
rho_s=rho_vs+rho_as;
disp("kg/m^3",rho_s,"Density of mixture at the surface is")
//Away from the surface
rho_vinf=Pv_inf/(Rv*T_inf);
disp("kg/m^3",rho_vinf,"Density of vapor away from the surface is")
rho_ainf=(P-Pv_inf)/(Ra*T_inf);
disp("kg/m^3",rho_ainf,"Density of air away from the surface is")
rho_inf=rho_ainf+rho_vinf;
disp("kg/m^3",rho_inf,"The density of mixture away from the surface is")
Lc=As/p;
disp("m",Lc,"The characteristic length is")
Gr=g*(rho_inf-rho_s)*(Lc^3)/(((rho_inf+rho_s)/2)*(nu^2));
disp(Gr,"The Grashof number is")
Nu=0.15*((Gr*Pr)^(1/3));
disp(Nu,"The Nusselt number is")
h_conv=Nu*k/Lc;
disp("W/m^2.degree Celcius",h_conv,"The convection heat transfer coefficient is")
Q_conv=h_conv*As*(Ts-T_inf);
disp("W",ceil(Q_conv),"The natural convection heat transfer rate is")
//(c)
D_AB=(1.87*10^(-10))*(Tavg^2.072)/(P/101.325);
disp("m^2/s",D_AB,"The mass diffusivity of water vapor in air at the average temperature is")
Sc=nu/D_AB;
```

```
disp(Sc,"The Schmidt Number is")
Sh=0.15*((Gr*Sc)^(1/3));
disp(Sh,"The Sherwood Number is")
h_mass=Sh*D_AB/Lc;
disp("m/s",h_mass,"The mass transfer coefficient is")
mv=h_mass*As*(rho_vs-rho_vinf);
disp("kg/s",mv,"The evaporation rate is")
Q_evap=mv*h_fg;
disp("kW",Q_evap,"The rate of heat transfer by evaporation is")
Q_total=Q_rad+Q_conv+1000*Q_evap;
disp("W",Q_total,"The total rate of heat transfer from the water to the surrounding air and surfaces is")
```