Scilab Textbook Companion for Textbook Heat Transfer Applications for The Practicing Engineer by L. Theodore[1]

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Book Description

Title: Textbook Heat Transfer Applications for The Practicing Engineer

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

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

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

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

Contents

List of Scilab Codes

Chapter 3

Process Variables

Scilab code Exa 3.2 Example2

```

//Variable Declaration:
Q1 = 8.03                              //Years(part 1)
D = 365                                //Days in a year
H = 24                                 //Hours in a day
M = 60                                 //Minutes in an hour
S = 60                                 //Seconds in a
   minute
Q2 = 150                               //Miles per hour(
   part 2)
FM = 5280                              //Feet in a mile
YF = 1.0/3.0                           //Yard in a feet
Q3 = 100                               //Meter per second
   square(part 3)
Cmm = 100                              //Centimeter in a
   meter
FC = 1.0/30.48                         //Feet in a
   centimeter
SsMs = 60**2                           //Second square in a
    minute square
Q4 = 0.03                              //Gram per
```

```
centimeter cube (part 4)
PG = 1.0/454.0                  //Pound in a gram
CF = (30.48)**3                 //Centimeter in a feet

//Calculation:
A1 = Q1*D*H*M*S                 //Seconds (s)
A2 = Q2*FM*YF                   //Yards per hour (yd/hr)
A3 = Q3*Cmm*FC*SsMs             //Feet per min square (ft/min^2)
A4 = Q4*PG*CF                   //Pound per feet cube (lb/ft^3)

//Results:
printf("1. Seconds in %f year is: %f x 10**8 s",Q1,A1/10**8)
printf("2. Yards per hour in %f miles per hour is: %f x 10**5 yd/h",Q2,A2/10**5)
printf("3. Feets per minute square in %f meter per square is: %f  x 10**6 ft/min^2",Q3,A3/10**6)
printf("4. Pounds per feet cube in %f gram per centimeter cube is: %.0f lb/ft^3",Q4,A4)
```

Scilab code Exa 3.3 Example

```
//Variable Declaration:
Q1 = 32.2                   //Gravitational acceleration (ft/s^2) (part 1)
CF = 32.2                   //Conversion factor (lb.ft/lbf.s^2)
M = 100                     //Mass (lb)
SA = 3                      //Surface area (in^2)
FsIs = (1.0/12.0)**2        //Feet square in a inch square
```

```
Q2 = 14.7                    //Atmospheric pressure (
    psi) (part 2)
GP = 35                      //Gauge Pressure (psig)

//Caculations:
F = M*Q1/CF                  //Force (lbf)
P = F/SA/FsIs                //Pressure at the base (
    lbf/ft^2)
Pa = GP+Q2                   //Absolute pressure (
    psia)

//Results:
disp("1. Pressure at the base is:")
disp(P)
disp("lbf/ft^2")

disp("2. Absolute pressure is:")
disp(Pa)
disp("psia")
```

Scilab code Exa 3.4 Example 4

```
//Variable Declaration:
Q1 = 20.0                    //Mass (lb) (part 1)
MH = 1.008                   //Molecular weight of H
    (lb/lbmol)
MO = 15.999                  //Molecular weight of O
    (lb/lbmol)
Q2 = 454                     //Gram in pound (part 2)
Q3 = 6.023*10**23            //Avogadro nuber (part
    3)

//Calculations:
Mol = 2*MH+MO                //Molecular weight of
    water (lb/lbmol)
```

```
A1 = Q1/Mol                    //Pound.moles of water (lbmol)
A2 = Q1*Q2/Mol                 //Gram.moles of water (gmol)
A3 = A2*Q3                     //Molecules of water (molecules)

//Results:
disp("1. Pound.moles of water is:")
disp(A1)
disp("lbmol water")

disp("2. Gram.moles of water is:")
disp(A2)
disp("gmol water")

disp("3. Molecules of water is:")
disp(A3/10**26)
disp(" x 10**26 molecules")
```

Scilab code Exa 3.5 Example 5

```
//Variable declaration:
SG = 0.92                 //Specific gavity of liquid, methanol
DW = 62.4                 //Density of reference substance, water (lb/ft^3)

//Calculation:
DM = SG*DW                //Density of methanol (lb/ft^3)

//Result:
disp("Density of methanol is:")
disp(DM)
```

```
disp("lb/ft^3")
```

Scilab code Exa 3.6 Example 6

```
//Variable declaration:
SG = 0.8                        //Specific Gravity
AV = 0.02                       //Absolute Viscosity (cP)
cP = 1                          //Viscosity of centipoise (cP)
VcP = 6.72 * 10**-4             //Pound per feet.sec in a centipoise (lb/ft.s)
pR = 62.43                      //Reference density (lb/ft^3)

//Calculations:
u = AV*VcP/cP                   //Viscosity of gas (lb/ft.s)
p = SG*pR                       //Density of gas (lb/ft^3)
v = u/p                         //Kinematic viscosity of gas (ft^2/s)

//Result:
disp("Kinematic viscosity of gas is:")
disp(v/10**-7)
disp ("x 10**-7 ft^2/s")
```

Scilab code Exa 3.7 Example

```
//Variable declaration:
X = 7.0                         //Coordinate X of H2SO4
Y = 24.8                        //Coordinate Y of H2SO4
```

```
S = 45                          //Slope

//Calculations:
//From the figure C.1 we found the intersection of
    curves mu = 12cP
mu = 12

//Results:
disp("Absolute viscosity of a 98% sulfuric acid
    solution at 45   C is :")
disp(mu*10**-2)
disp(" g/cm.s")
```

Scilab code Exa 3.8 Example

```
//Variable declaration:
CpM = 0.61                      //Heat capacity of
    methanol (cal/g.  C)
G = 454                         //Grams in a pound
B = 1.0/252.0                   //Btu in a calorie
C = 1.0/1.8                     //Degree celsius in a
    degree fahrenheit

//Calculation:
Cp = CpM*G*B*C                  //Heat capacity in
    English units (Btu/lb.  F)

//Result:
disp("Heat capacity in English units is: ")
disp(Cp)
disp(" Btu/lb.  F")
```

Scilab code Exa 3.9 Example

```
//Variable declaration:
kM = 0.0512                  //Thermal conductivity of methanol (cal/m.s C)
B = 1.0/252.0                //Btu in a calorie
M = 0.3048                   //Meters in a feet
S = 3600                     //Seconds in an hour
C = 1.0/1.8                  //Degree celsius in a degree fahrenheit

//Calculation:
k = kM*B*M*S*C               //Thermal conductivity in English units (Btu/ft.h. F)

//Result:
disp("Thermal coductivity in English units is:")
disp(k)
disp("Btu/ft.h. F")
```

Scilab code Exa 3.11 Example

```
//Variable declaration:
D = 5                        //Diameter of pipe (ft)
V = 10                       //Fluid velocity (ft/s)
p = 50                       //Fluid density (lb/ft^3)
u = 0.65                     //Fluid viscosity (lb/ft.s)
F = 1.0/12.0                 //Feet in an inch
VCp = 6.72*10**-4            //Viscosity of centipoise (lb/ft.s)

//Calculation:
A = D*V*p*F/u/VCp            //Reynolds Number

//Result:
```

```
if(A>2100) then
    printf("The Reynolds number is :%.0f  therefore, the flow is turbulent.",A)
else
    if(A<2100) then
     printf("The Reynolds number is : %f therefore, the flow is not turbulent.",A)
end
end;
```

Scilab code Exa 3.12 Example

```
//Variable declaration:
//For the problem at hand, take as a basis 1 kilogram of water and assume the potential energy to be zero at ground level conditions.
z1 = 0                          //Intial height from ground level (m)
z2 = 10                         //Final height from ground level (m)
PE1 = 0                         //Initial potential energy at z1 (J)
m = 1                           //Mass of water (kg)
g = 9.8                         //Gravitational acceleration (m/s^2)
gc = 1                          //Conversion factor

//Calculations:
PE2 = m*(g/gc)*z2               //Final potential energy at z2 (J)

//Result:
disp("The potential energy of water is :")
disp(PE2)
disp("J ")
```

Chapter 4

The Conservation Law for Momentum

Scilab code Exa 4.1 Example

```
//Variable declaration:
Vx_in = 420                      //Entry Velocity in X direction (m/s)
Vx_out = 0                       //Exit Velocity in X direction (m/s)
Vy_in = 0                        //Entry Velocity in Y direction (m/s)
Vy_out = 420                     //Exit Velocity in Y direction (m/s)
m =  0.15                        //Rate of water entrained by the steam (kg/s)
lb = 1.0/4.46                    //Pound force in a newton force

//Calculations:
Mx_out = m*Vx_out                //Rate of change of momentum at entry in x-direction (kg.m)
Mx_in = m*Vx_in                  //Rate of change of momentum at exit in x-direction  (kg.m)
```

```
My_out = m*Vy_out                   //Rate of change of momentum at entry in y-direction (kg.m)
My_in = m*Vy_in                     //Rate of change of momentum at exit in y-direction  (kg.m)
Fxgc = (Mx_out - Mx_in)*lb          //Force in X direction (lbf)
Fygc = (My_out - My_in)*lb          //Force in X direction (lbf)

//Results:
if Fxgc < 1 then
    printf ("The x-direction supporting force acting on the 90  elbow is : %.1f lbf acting toward the left.",-Fxgc)
else
    printf ("The x-direction supporting force acting on the 90  elbow is : %.1f lbf acting toward the right.",Fxgc)
end

if Fygc < 1 then
    printf ("The y-direction supporting force acting on the 90  elbow is : %.1f lbf acting downwards.",-Fygc)
else
    printf ("The y-direction supporting force acting on the 90  elbow is : %.1f lbf acting upwards.",Fygc)
end
```

Scilab code Exa 4.2 Example

```
//Variable declaration:
Fx = -63                                        //Force component in X direction (N)
```

```
Fy = 63                                   //Force component in Y direction (N)
lbf = 0.22481                             //Pound-forrce in unit newton (lbf)

//Calculations:
Fr = sqrt(Fx**2 + Fy**2)*lbf              //The resultant supporting force (lbf)
u = atand(Fy,Fx)                 //Angle between the positive x axis and the direction of the force (degrees)

//Result:
if ( 0<u & u<90 ) then
    printf ("The supporting force is : %.1f lbf acting at %f    i.e in the northeast direction.",Fr,u)
elseif (90<u & u<180) then
    printf ("The supporting force is : %.1f lbf acting at %f    i.e in the northwest direction.",Fr,u)
elseif (180<u & u<270) then
    printf ("The supporting force is : %.1f lbf acting at %f    i.e in the southwest direction.",Fr,u)
elseif (270<u & u<360) then
    printf ("The supporting force is : %.1f lbf acting at %f    i.e in the southeast direction.",Fr,u)
end
```

Scilab code Exa 4.3 Example

```
//Variable declaration:
R1_in = 10000                    //Rate of fuel fed
```

```
into the boiler (lb/h)
R2_1n = 20000                   //Rate of air fed into the boiler (lb/h)
R3_in = 2000                    //Rate of methane fed into the boiler (lb/h)

//Calculations:
m_in = R1_in + R2_1n + R3_in    //Rate of mass in (lb/h)
m_out = m_in                    //Rate of mass out (lb/h)

//Result:
printf("The rate of the product gases exit from the incinerator is : %.0f lb/h",m_in)
```

Scilab code Exa 4.4 Example

```
//Variable declaration:
E1 = 65                             //Efficiency of spray tower (%)
E2 = 98                             //Efficiency of packed column (%)
m_in = 76                           //Mass flow rate of HCl entering the system (lb/h)

//Calculations:
m1_out = (1 - E1/100.0)*m_in        //Mass flow rate of HCl leaving the spray tower (lb/h)
m2_out = (1 - E2/100.0)*m1_out      //Mass flow rate of HCl entering the packed column (lb/h)
E = (m_in - m2_out)/m_in            //Overall fractional efficiency (%)

//Result:
```

```
printf ("The mass flow rate of HCl leaving the spray tower is : %.2f lb/h HCL",m1_out)
printf ("The mass flow rate of HCl entering the packed column is : %.3f lb/h HCL",m2_out)
printf ("The overall fractional efficiency is : %.2f %%",E*100)
```

Scilab code Exa 4.5 Example

```
//Variable declaration:
m1 = 1000                   //Flowrate data 1 (lb/min)
m2 = 1000                   //Flowrate data 2 (lb/min)
m4 = 200                    //Flowrate data 4 (lb/min)

//Calculations:
m5 = m1 + m2 - m4           //Flowrate data 5 (lb/min)
m6 = m2                     //Flowrate data 6 (lb/min)
m = m5 - m6                 //Flowrate of water lost in operation (lb/min)

//Result:
printf ("The amount of water lost by evaporation in the operation is %.0f lb/min",m)
```

Scilab code Exa 4.6 Example

```
//Variable declaration:
```

```
q1 = 1000.0                  //Volumetric flowrate from tank 1 (gal/day)
q2 = 1000.0                  //Volumetric flowrate from tank 2 (gal/day)
q3 = 2000.0                  //Volumetric flowrate from tank 3 (gal/day)
q4 = 200.0                   //Volumetric flowrate from tank 4 (gal/day)
q5 = 1800.0                  //Volumetric flowrate from tank 5 (gal/day)
q6 = 1000.0                  //Volumetric flowrate from tank 6 (gal/day)
C1 = 4.0                     //Phosphate concentration in tank 1 (ppm)
C2 = 0.0                     //Phosphate concentration in tank 2 (ppm)
C3 = 2.0                     //Phosphate concentration in tank 3 (ppm)
C4 = 20.0                    //Phosphate concentration in tank 4 (ppm)
C5 = 0.0                     //Phosphate concentration in tank 5 (ppm)
C6 = 0.0                     //Phosphate concentration in tank 6 (ppm)
Cf = 120000.0                //conversion factor for water (gal/10**6lb)

//Calculations:
C1q1 = C1*q1/Cf            //Data 1 (lb/day)
C2q2 = C2*q2/Cf            //Data 2 (lb/day)
C3q3 = C3*q3/Cf            //Data 3 (lb/day)
C4q4 = C4*q4/Cf            //Data 4 (lb/day)
C5q5 = C5*q5/Cf            //Data 5 (lb/day)
C6q6 = C6*q6/Cf            //Data 6 (lb/day)

//Results:
if (((C1q1 + C2q2) == C3q3) &  C3q3 == (C4q4 + C5q5)
    & C5q5 == C6q6 & C2q2 == C6q6) then
```

```
    printf("The data appear to be consistent .")
else
    printf ("The data appear to be inconsistent .")
end
```

Scilab code Exa 4.7 Example

```
//Variable declaration:
Dz = 3000                          //Height (ft)
V0 = 500000                        //Flowrate of water (gal/min)
n = 30                             //Turbine efficiency (%)
m = 0.3048                         //Meters in a feet
m3 = 0.00378                       //Meters-cube in a gallon
g = 9.8                            //Gravitational acceleration (m/s^2)
gc = 1                             //Conversion factor
MW = 10**(-6)                      //Megawatt in newton-meter-per-second

//Calculations:
V1 = (V0*m3)*1000.0/60.0           //The mass flow rate of the water in kilograms/second (kg/s)
DPE = V1*g*Dz*m/gc*MW              //The loss in potential energy (MW)
AP = n/100.0*DPE                   //The actual power output (MW)

//Result:
printf ("The power generated by the lake located is : %.1f MW",AP)
```

Scilab code Exa 4.8 Example

```
//Variable declaration:
n = 111.4                       //Flowrate of air stream (lbmol/min)
H1 = 1170                       //Average heat capacity at 200 F (Btu/lbmol)
H2 = 4010                       //Average heat capacity at 600 F (Btu/lbmol)

//Calculation:
Q = n*(H2 - H1)                 //The heat transfer rate (Btu/min)

//Result:
printf ("The heat transfer rate required is: %.2f x 10**5 Btu/min",Q/10**5)
```

Scilab code Exa 4.9 Example

```
//Variable declaration:
n = 600                         //The mass flow rate of fluid (lbmol/min)
Cp_AV = 0.271                   //Heat capacity (Btu/lbmol . F )
T1 = 200                        //Initial temperature( F )
T2 = 600                        //Final temperature( F )

//Calcultaion:
Q = n*Cp_AV*(T2 - T1)           //The required heat rate (Btu/min)
```

```
Q = Q - modulo(Q,1000)

//Result:
printf ("The required heat rate is : %.0f Btu/min",Q)
```

Scilab code Exa 4.10 Example

```
//Variable declaration:
T_c1 = 20                                   //Initial cold fluid temperature ( C)
T_h1 = 82                                   //Initial hot fluid temperature ( C)
T_h2 = 94                                   //Final hot fluid temperature ( C)

//Calculation:
T_c2 = (T_h2 - T_h1 + T_c1)                 //Final cold fluid temperature ( C)

//Result:
printf ("The heat transfer rate is: %.0f  C",T_c2)
printf ("There is a printing mistake in book regarding unit of the final result.")
```

Scilab code Exa 4.11 Example

```
//Variable declaration:
Q = -5.5*10**6                        //The heat transferred out from the gas (W)
Cp = 1090.0                           //The average heat capacity of the gas (J/(kg .  C))
```

```
m = 9.0                          //The gas mass flow rate (kg/s)
T1 = 650                         //The gas inlet temperature ( C )

//Calculation:
T2 = Q/(m*Cp)+T1                 //The gas outlet temperature ( C )

//Result:
printf("The gas outlet temperature is : %.0f  C", T2)
```

Scilab code Exa 4.12 Example

```
//Variable declaration:
n = 3500.0                       //Inlet flowrate of water (gal/min)
Cp_W = 75.4                      //Heat capacity of water (J/(gmol .  C)
p = 62.4                         //Density of water (lb/ft^3)
M = 24*60.0                      //Minutes in a day (min/day)
G = 7.48                         //Gallons in a feet cube (gal/ft^3)
gm = 454.0                       //Grams in a pound (g/lb)
J = 1054.0                       //Joules in a Btu (J/Btu)
g = 18.0                         //Grams in a gmol (g/gmol)
F = 1.8                          //Degree fahrenheit in a degree celcius ( F)
Ti = 38.0                        //Initial
```

```
temperature ( F )
Tf = 36.2                    //Final temperature ( F )

//Calculations:
T= Ti-Tf                     //Temperature loss ( F )
m = n*p*M/G                  //Mass flow rate of water (lb/day)
Cp = Cp_W*gm/J/g/F           //Heat capacity in cosistent units (Btu/(lb. F))
Q = m*Cp*T                   //Rate of heat flow from water (Btu/day)

//Result:
printf("The rate of Btu removed from the water per day is : %.2f x 10**8 Btu/day.",Q/10**8)
printf("There is a calculation mistake in the book regarding the final result.")
```

Chapter 5

Gas Laws

Scilab code Exa 5.1 Example

```
//Variable declaration:
qi = 3500                          //Initial volumetric flow rate of gas (acfm)
Ti = 100.0                         //Initial temperature ( F )
Tf = 300.0                         //Final temperature ( F )

//Calculation:
Ti_R = Ti+460                      //Initial temperatur in Rankine scale ( R )
Tf_R = Tf+460                      //Final temperatur in Rankine scale ( R )
qf = qi*(Tf_R/Ti_R)                //Final volumetric flow rate of gas (acfm)

//Result:
printf("The final volumetric flow rate of gas is : %.0f acfm",qf)
```

Scilab code Exa 5.2 Example

```
//Variable declaration:
qi = 3500                          //Initial volumetric
    flow rate of gas (acfm)
Pi = 1.0                           //Iitial pressure (
   atm)
Pf = 3.0                           //Final pressure (
   atm)

//Calculation:
qf = qi*(Pi/Pf)                    //Final volumetric
   flow rate of gas (acfm)

//Result:
printf("The volumetric flow rate of the gas (100 F ,
    1 atm) is: %.0f acfm",qf)
```

Scilab code Exa 5.3 Example

```
//Variable declaration:
qi = 3500                          //Initial volumetric
    flow rate of the gas (acfm)
Pi = 1.0                           //Initial pressure (
   atm)
Pf = 3.0                           //Final pressure (
   atm)
Tf = 300.0+460.0                   //Final temperature
   in Rankine scale ( R )
Ti = 100.0+460.0                   //Initial
   temperature in Rankine scale ( R )

```

```
//Calculation:
qf = qi*(Pi/Pf)*(Tf/Ti)          //Final volumetric flow rate of the gas (acfm)

//Result:
printf("The volumetric flow rate of the gas at 300 F temperature is : %.0f acfm",qf)
```

Scilab code Exa 5.4 Example

```
//Variable declaration:
P = 14.7                    //Absolute pressure of air (psia)
MW = 29                     //Molecular weight of air (lb/lbmol)
T = 75+460                  //Temperature in Rankine scale ( R)
R = 10.73                   //Universal gas constant (ft^3.psi/lbmol. R)

//Calculation:
p = P*MW/R/T                //Density of air (lb/ft^3)

//Result:
printf("The density of air at 75 F and 14.7 psia is : %.4f lb/ft^3",p)
```

Scilab code Exa 5.5 Example

```
//Variable declaration:
n = 1                           //Molar flow rate of gas (lbmol/h)
```

```
R = 10.73                     //Universal gas constant (ft^3.psi/lbmol. R)
T = 60+460                    //Temperature in Rankine scale ( R)
P = 14.7                      //Absolute pressure of gas (psia)

//Calculation:
V = n*R*T/P                   //Volume of gas (ft^3)

//Result:
printf("The volume of given ideal gas is : %.1f ft^3",V)
```

Scilab code Exa 5.6 Example

```
//Variable declaration:
P = 1.2                       //Abslute pressure of gas (psia)
MW = 29                       //Molecular weight of gas (g/gmol)
R = 82.06                     //Universal gas constant (atm.cm^3/gmol.K)
T = 20+273                    //Temperature in Kelvin (K)

//Calculation:
p = P*MW/R/T                  //Dendity of gas (g/cm^3)

//Result:
printf("The density of given gas is : %.5f g/cm^3",p)
```

Scilab code Exa 5.7 Example

```
//Variable declaration:
R = 10.73                          //Universal gas constant (psia . ft^3/lbmol .  R)
T = 70+460                         //Temperature in Rankine scale ( R)
v = 10.58                          //Specific volume (ft^3/lb)
P = 14.7                           //Absolute pressure (psia)

//Calculation:
MW = R*T/v/P                       //Molecular weight of gas (lb/lbmol)

//Result:
printf("The molecular weight of the gas is : %.2f lb/lbmol.",MW)
printf("It appears that the gas is HCl (i.e., hydrogen chloride).")
```

Scilab code Exa 5.8 Example

```
//Variable declaration:
qs = 30000                         //Volumetric flow rate at standard conditions (scfm)
Ta = 1100+460                      //Actual absolute temperature in Rankine scale ( R)
Ts = 60+460                        //Standard absolute temperature in Rankine scale ( R)

```

```
//Calculation:
qa = qs*Ta/Ts                    //Volumetric flow
    rate at actual conditions (acfm)

//Result:
printf("The volumetric flow rate in actual cubic
    feet per minute is : %.0f acfm",qa)
```

Scilab code Exa 5.9 Example

```
//Variable declaration:
qs = 1000                        //Volumetric flow
    rate at standard conditions (scfm)
Ta = 300+460                     //Actual absolute
    temperature in Rankine scale ( R )
Ts = 70+460                      //Standard absolute
    temperature in Rankine scale ( R )
A = 2.0                          //Inlet area of
    stack (ft^2)

//Calculations:
qa = qs*Ta/Ts                    //Volumetric flow
    rate at actual conditions (acfm)
v = qa/A/60                      //Velocity of gas (
    ft/s)

//Result:
printf("The velocity of the gas through the stack
    inlet is : %.0f ft/s",v)
```

Scilab code Exa 5.10 Example

```
//Variable declaration:
```

```
qs1 = 5000.0                    //Volumetric flow rate of C6H5Cl at standard conditions (scfm)
qs2 = 3000.0                    //Volumetric flow rate of air at standard conditions (scfm)
Ta = 70+460.0                   //Actual absolute temperature in Rankine scale ( R)
Ts = 60+460.0                   //Standard absolute temperature in Rankine scale ( R)
V = 387.0                       //Volume occupied by one lbmol of any ideal gas (ft^3)
M1 = 112.5                      //Molecular weight of C6H5Cl (lb/lbmol)
M2 = 29.0                       //Molecular weight of air (lb/lbmol)
T = 60.0                        //Absolute temperature ( F)

//Calculations:
qa1 = qs1*(Ta/Ts)               //Volumetric flow rate of C6H5Cl at actual conditions (acfm)
qa2 = qs2*(Ta/Ts)               //Volumetric flow rate of air at actual conditions (acfm)
n1 = qa1/V                      //Molar flow rate of C6H5Cl (lbmol/min)
n2 = qa2/V                      //Molar flow rate of air (lbmol/min)
m1 = n1*M1*T                    //Mass flow rate of C6H5Cl (lb/h)
m2 = n2*M2*T                    //Mass flow rate of air (lb/h)
m_in = m1+m2                    //Total mass flow rate of both streams entering the oxidizer (lb/h)
m_out = m_in                    //Total mass flow rate of both streams exit the cooler (lb/h)

//Result:
printf("The rate of the products exit the cooler is : %.0f lb/h",m_out)
```

Scilab code Exa 5.11 Example

```
//Variable declaration:
p = 0.15                          //Partial pressure
    of SO3 (mm Hg)
P = 760.0                         //Atmospheric
    pressure (mm Hg)
m = 10**6                         //Particles in a
    million

//Calculation:
y = p/P                           //Mole fraction of
    SO3
ppm = y*m                         //Parts per million
    of SO3 (ppm)

//Result:
printf("The parts per million of SO3 in the exhaust
    is : %.0f ppm.",ppm)
```

Chapter 6

Heat Exchanger Pipes and Tubes

Scilab code Exa 6.1 Example

```
//Variable declaration:
NPS = 2                         //Nominal pipe size (inch)
SN = 40                         //Schedule number

//Calculation:
//From Table 6.2, we obtain that the inside diameter of steel pipe is ID = 2.067 in.
ID = 2.067

//Result:
printf("The inside diameter of steel pipe is : %f in.",ID)
```

Scilab code Exa 6.2 Example

```
//Variable declaration:
NPS = 3                           //Nominal pipe size (
   inch)
SN = 40                           //Schedule number

//Calculation:
//From Table 6.2, we obtain that the inside diameter
    of steel pipe is ID = 3.068 in, outside diameter
    OD = 3.5 in, wal thickness WT = 0.216 in, and
   pipe weight PW = 7.58 lb/ft.
ID = 3.068
OD = 3.5
WT = 0.216
PW = 7.58

//Result:
printf("The inside diameter of steel pipe is : %f in
   ",ID)
printf("The outside diameter of steel pipe is : %f
   in",OD)
printf("The wall thickness of steel pipe is : %f in"
   ,WT)
printf("The weight of steel pipe is : %f  lb/ft.",PW
   )
```

Scilab code Exa 6.3 Example

```
//Variable declaration:
ID = 0.957                        //Inside diameter of
   pipe (in)
OD = 1.315                        //Outside diameter of
   pipe (in)
WT = 0.179                        //Wall thickness of pipe
    (in)
PW = 2.17                         //Weight of pipe (lb/ft)
```

```
//Calculation:
//From Table 6.2, it indicates that the steel pipe
   is 1 inch schedule 80.
NSP = 1
SN = 80

//Result:
printf("The nominal size of the pipe is : %f in.",
   NSP)
printf("The schedule number of the pipe is: %f .",SN
   )
```

Scilab code Exa 6.4 Example

```
//Variable declaration:
S = 3/4                              //Tube size (in)
BWG = 16                             //Birmingham Wire
   Gauge number (gauge)

//calculation:
//From table 6.3, we get:
ID = 0.620                           //Internal diameter
   of tube (in)
WT = 0.065                           //Wall thickness of
   tube (in)
OD = ID+2*WT                         //Outside diameter
   of tube (in)
EA = 0.1963                          //External area per
   foot (ft)

//Result:
printf("The inside diameter is : %f in",ID)
printf("The wall thickness is : %f in",WT)
printf("The outside diamater is : %f in",OD)
```

```
printf("The external area per foot per foot : %f ft"
    ,EA)
```

Scilab code Exa 6.11 Example

```
//Variable declaration:
a = 1                              //Length of cross-
    section (m)
b = 0.25                           //Width of cross-
    section (m)
v = 1*10**-5                       //Kinematic
    viscosity of air (m^2/s)
Re = 2300.0                        //Reynolds Number
cm = 100                           //Cenitmeters in a
    meter

//Calculation:
Dh = 2*a*b/(a+b)                   //Hydraulic diameter
     of duct (m)
V = Re*v/Dh*cm                     //Maximum air
    velocity (cm/s)

//Result:
printf("The maximum air velocity before the flow
    becomes turbulent is : %.1f cm/s.",V)
```

Scilab code Exa 6.12 Example

```
//Variable declaration:
q = 0.486                          //Flow rate of fluid
     (ft^3/s)
D = 2.0/12.0                       //Diameter of tube
    in feet (ft)
```

```
pi = 3.14                               //Value of pi
p = 70.0                                //Density of fluid (lb/ft^3)
u = 0.1806                              //Viscosity of fluid (lb/ft)

//Calculation:
V = 4*q/pi/D**2                         //Flow velocity (ft/s)
Re = D*V*p/u                            //Reynolds Number

//Result:
if(Re<2100) then
    printf("The flow is laminar.")
elseif(Re>2100) then
    printf("The flow is turbulant.")
end
```

Scilab code Exa 6.13 Example

```
//Variable declaration:
//From example 6.12, we have:
D = 2.0/12.0                            //Diameter of pipe in feet (ft)
Re = 1440.0                             //Reynolds number

//Calculation:
Lc = 0.05*D*Re                          //Length of pipe (ft)

//Result:
printf("The pipe length to ensure a fully developed flow is: %f ft.",Lc)
printf("This is an abnormally long calming length for a pipe (or tube) in a heat exchanger.")
```

Scilab code Exa 6.14 Example

```
//Variable declaration:
u = 6.72*10**-4                         //Viscosity of water (lb/ft.s)
p = 62.4                                //Density of water (lb/ft^3)
//For laminar flow:
Re = 2100.0                             //Reynolds number
//From table 6.2, we have:
D = 2.067/12.0                          //Inside diameter of pipe (ft)

//Calculation:
V = Re*u/D/p                            //Average velocity of water flowing (ft/s)

//Result:
printf("The average velocity of water flowing is: %.2f ft/s.",V)
```

Chapter 7

Steady State Heat Conduction

Scilab code Exa 7.1 Example

```
//Variable declaration:
Q = 3000.0                //The rate of heat flow through the glass window (W)
L = 0.01                  //Thickness of glass window (m)
A = 3.0                   //Area of heat transfer (m^2)
TC = 10+273               //Temperature at the outside surface (K)
k = 1.4                   //Thermal onductivity of glass (W/m.K)

//Calculation:
TH = TC+Q*L/k/A           //Temperature at the inner surface (K)

//Result:
printf("The temperature at the inner surface is : %.1f K",TH)
printf("The temperature at the inner surface is : %.1f  C",TH-273)
```

Scilab code Exa 7.2 Example

```
//Variable declaration:
k = 0.026                   //Thermal conductivity of insulating material (Btu/ft.h. F)
L = 1.0                     //Thickness of insulating material (ft)
TC = 70.0                   //Temperature on the cold side surface ( F)
TH = 210.0                  //Temperature on the hot side surface ( F)
c = 0.252                   //Kilocalorie per hour in a Btu per hour
m = 0.093                   //meter square in a feet square

//Calculation:
DT = TH-TC                  //Change in temperature ( F)
Q1 = k*DT/L                 //Rate of heat flux throughthe wall (Btu/f^t2.h.)
Q2 = Q1*c/m                 //Rate of heat flux throughthe wall in SI units (kcal/m^2.h)

//Result:
printf("The rate of heat flux in Btu/ft^2.h is : %.3f Btu/ft^2.h.",Q1)
printf("The rate of heat flux in SI units is : %.3f kcal/m^2.h.",Q2)
```

Scilab code Exa 7.3 Example

```
//Variable declaration:
TH = 1592.0                    //Temperature of inside surface (K)
TC = 1364.0                    //Temperature of outside surface (K)
H = 3.0                        //Height of furnace wall (m)
W = 1.2                        //Width of furnace wall (m)
L = 0.17                       //Thickness furnace wall (m)
m = 0.0929                     //Meter square per second in a feet square per second
Btu = 3.412                    //Btu per hour in a Watt
Btu2 = 0.3171                  //Btu per feet square hour in a watt per meter square

//Calculation:
Tav = (TH+TC)/2                //Average wall temperature (K)
//From Table in Appendix:
p = 2645.0                     //Density of material (kg/m^3)
k = 1.8                        //Thermal conductivity (W/m.K)
Cp = 960.0                     //Heat capacity of material (J/kg.K)
a = k/(p*Cp)/m                 //Thermal diffusivity (ft^2/s)
t = (TC-TH)/L                  //Temperature gradient ( C /m)
A = H*W                        //Heat transfer area (m^2)
Q1 = k*A*(TH-TC)/L*Btu         //Heat transfer rate (Btu/h)
Q2 = k*(TH-TC)/L*Btu2          //Heat transfer flux (Btu/h.ft^2)
```

```
R = L/(k*A)                         //Thermal resistance ( C /W)

//Result:
printf("The temperature gradient is : %.0f  C /m.",t)
printf("The heat transfer rate is : %.0f Btu/h",Q1)
printf("The heat transfer flux is : %.1f Btu/h.ft^2.",Q2)
```

Scilab code Exa 7.4 Example

```
//Variable declaration:
TH = 25.0                       //Temperature at inner suface of wall ( C )
TC = -15.0                      //Temperature at outer suface of wall ( C )
L = 0.3                         //Thickness of wall (m)
k = 1.0                         //Thermal conductivity of concrete (W/m)
A = 30.0                        //Sueface area of wall (m^2)

//Calculation:
DT = TH-TC                      //Driving force for heat transfer ( C ) (part 2)
R = L/(k*A)                     //Thermal resistance ( C /W) (part 3)
Q = DT/R/10**3                  //Heat loss through the wall (kW)

//Result:
printf("1. Theoretical part.")
printf("2. The driving force for heat transfer is : %f  C .",DT)
```

```
printf("3. The heat loss through the wall is : %f kW.",Q)
```

Scilab code Exa 7.5 Example

```
//Variable declaration:
TC = 27.0                        //Inside temperature of walls ( C )
TH = 68.7                        //Outside temperature of walls ( C )
LC = 6*0.0254                    //Thickness of concrete (m)
LB = 8*0.0254                    //Thickness of cork-board (m)
LW = 1*0.0254                    //Thickness of wood (m)
kC = 0.762                       //Thermal conductivity of concrete (W/m.K)
kB = 0.0433                      //Thermal conductivity of cork-board (W/m.K)
kW = 0.151                       //Thermal conductivity of wood (W/m.K)

//Calculation:
RC = LC/kC                       //Thermal resistance of concrete (K/W)
RB = LB/kB                       //Thermal resistance of cork-board (K/W)
RW = LW/kW                       //Thermal resistance of wood (K/W)
Q = (TC-TH)/(RC+RB+RW)           //Heat transfer rate across the wall (W)
T = -(Q*RW-TC)                   //Interface temperature between wood and cork-board (K)

//Result:
```

```
printf("The heat transfer rate across the wall is : %.3f  W.",Q)
printf("The interface temperature between wood and cork-board is : %.1f    C .",T)
printf("The interface temperature between wood and cork-board is : %.1f  K.",T+273)
```

Scilab code Exa 7.6 Example

```
//Variable declaration:
D1s = 4.0                                     //Glass wool inside diameter (in)
D2s = 8.0                                     //Glass wool outside diameter (in)
D1a = 3.0                                     //Asbestos inside diameter (in)
D2a = 4.0                                     //Asbestos outside diameter (in)
TH = 500.0                                    //Outer surface temperature of pipe (  F)
TC = 100.0                                    //Outer surface temperature of glass wool (  F)
La = 0.5/12.0                                 //Thickness of asbestos (ft)
Lb = 2.0/12.0                                 //Thickness of glss wool (ft)
ka = 0.120                                    //Thermal conductivity of asbestos (Btu/h.ft.  F)
kb = 0.0317                                   //Thermal conductivity of asbestos (Btu/h.ft.  F)
pi = %pi

//Calculation:
Aa = (pi*(D2a-D1a)/12.0)/log(D2a/D1a) //Area of asbestos (ft^2)
```

```
Ab = (pi*(D2s-D1s)/12.0)/log(D2s/D1s) //Area of glass wool (ft^2)
Q1 = (TH-TC)/(La/(ka*Aa)+Lb/(kb*Ab))    //Steady-state heat transfer per foot of pipe (Btu/h.)
Q2 = Q1
//Result:
printf("The steady-state heat transfer per foot of pipe, Z, is : %.1f  x z Btu/h.",Q1)
printf("The steady-state heat transfer factorizating out Z is : %.1f  Btu/h.ft.",Q2)
```

Scilab code Exa 7.7 Example

```
//Variable declaration:
//From example 7.6:
TH = 500                                     //Outer surface temperature of pipe (  F )
Lb = 2.0/12.0                                //Thickness of glss wool (ft)
kb = 0.0317                                  //Thermal conductivity of asbestos (Btu/h.ft.  F )
Ab = 1.51                                    //Area of glass wool (ft^2)
Q = 103.5                                    //Steady-state heat transfer per foot of pipe (Btu/h.)
La = 0.5/12.0                                //Thickness of asbestos (ft)
ka = 0.120                                   //Thermal conductivity of asbestos (Btu/h.ft.  F )
Aa = 0.91                                    //Area of asbestos (ft^2)
TC = 100                                     //Outer surface temperature of glass wool (  F )

//Calculation:
```

```
Ti_b = -((Lb*Q)/(kb*Ab)-TH)              //Interfacial temperature of glass wool layer ( F )
Ti_a = (Q*La)/(ka*Aa)+TC                 //Interfacial temperature of asbestos layer ( F )

//Result:
printf("The interfacial temperature of glass wool layer is : %.0f  F .",Ti_b)
printf("The interfacial temperature of asbestos layer is : %.1f  F .",Ti_a)
```

Scilab code Exa 7.8 Example

```
//Variable declaration:
syms z
syms h
syms k

pi = %pi


T = 100*cos((pi*z)/(2*h))         //Temperature of solid slab

//Calculation:
DT = diff(T,z)                    //Temperature at z
Q = -k*(DT)                       //Heat flux in slab (Btu/s.ft^2)
disp(typeof(Q))
Q1 = subst(0,z,Q)                 //Heat flux in slab at z =  Btu/s.ft^2)

Q2 = subst(h,z,Q)                  //Heat flux in slab at z = h (Btu/s.ft^2)

```

```
//Result:
disp("The heat flux in slab is : ")
disp(Q)
disp("Btu/s.ft^2.")

disp("The heat flux in slab at z = 0 is : ")
disp(Q1)
disp("Btu/s.ft^2.")

disp("The heat flux in slab at z = h is :5   ")
disp(Q2)
disp(" Btu/s.ft^2.")
```

Chapter 8

Unsteady State Heat Conduction

Scilab code Exa 8.4 Example

```
//Variable declaration:
k = 9.1                    //Thermal coductivity of steel rod (Btu/h.ft. F)
p = 0.29*1728              //Density of steel rod (lb/ft^3)
Cp = 0.12                  //Heat capacity of steel rod (Btu/lb. F)
P = 15+14.7                //Absolute pressure (psia)
Ta = 71.0                  //Initial temperature ( F)
L = 20.0/12.0              //Length of rod (ft)
t = 30.0/60.0              //Time taken (h)
x = 0.875/12.0             //Length from one of end (ft)
pi = %pi
e = %e

//From assumption:
n = 1.0                    //First term
//From tables in Appendix:
```

```
Ts = 249.7                    //Saturated steam temperature (  F )

//Calculation:
a = k/(p*Cp)                  //Thermal diffusivity  (ft^2/s)
T = Ts+(Ta-Ts)*(((n+1)*(-1)**2 + 1 )/pi)*e**((-a*((n*pi)/L)**2)*t)*sin((n*pi*x)/L) //Temperature 0.875 inches from one of the ends after 30 minutes (  F )

//Result:
printf ("The temperature 0.875 inches from one of the ends after 30 minutes is : %.0f    F .",T)
```

Chapter 9

Forced Convection

Scilab code Exa 9.1 Example

```
//Variable declaration:
D = 1.0                          //Diamete of vessel (ft)
L = 1.5                          //Length of vessel (ft)
T1 = 390.0                       //Surface temperature of vessel ( F )
T2 = 50.0                        //Surrounding temperature of vessel ( F )
h = 4.0                          //Convective heat transfer coefficient (Btu/h.ft. F )
pi = %pi

//Calculation:
A = pi*D*L+2*pi*(D/2)**2         //Total heat transfer area (ft^2)
Q = h*A*(T1-T2)                  //Rate of heat transfer (Btu/h)
R = 1/(h*A)                      //Thermal resistance ( F .h/Btu)

//Result:
printf("The thermal resistance of vessel wal is : %
```

```
.4f F.h/Btu.",R)
```

Scilab code Exa 9.2 Example

```
//Variable declaration:
//From example 9.1:
R = 0.0398                          //Theral resistance
    ( F.h/Btu)
Btu = 3.412                         //Btu/h in a watt
C = 1.8                             //Change in degree
    fahrenheit for a degree change in celsius
K = 1                               //Change in degree
    celsius for a unit change in Kelvin

//Calculation:
Rc = R*Btu/C                        //Thermal resistance
     in degree cesius per watt ( C/W)
Rk = Rc/K                           //Thermal resistance
     in Kelvin per watt (K/W)

//Result:
printf("The thermal resistance in  C/W is : %.3f
     C/W.",Rc)
printf("The thermal resistance in K/W is : %.3f  K/W
    .",Rk)
```

Scilab code Exa 9.3 Example

```
//Variable declaration:
h = 48.0                        //Convective heat
    transfer coefficient (Btu/h.ft. F)
A = 2*1.5                       //Total heat transfer
    area (ft^2)
```

```
Ts = 530.0                          //Surface temperature of plate ( F )
Tm = 105.0                          //Maintained temperature of opposite side of plate ( F )
kW = 3.4123*10**3                   //Units kW in a Btu/h

//Calculation:
Q = h*A*(Ts-Tm)                     //Heat transfer rate in Btu/h (Btu/h)
Q1 = Q/kW                           //Heat transfer rate in kW (kW)

//Result:
printf("The heat transfer rate in Btu/h is : %f Btu/h.",Q)
printf("The heat transfer rate in kW is : %.2f kW.",Q1)
```

Scilab code Exa 9.4 Example

```
//Variable declaration:
TS = 10+273                             //Outer surface temperature of wall (K)
Q = 3000.0                              //Heat transfer rate (W)
h = 100.0                               //Convection coefficient of air (W/m^2)
A = 3.0                                 //Area of glass window (m^2)

//Calculation:
TM = TS-Q/(h*A)                         //Bulk temperature of fluid (K)

//Result:
```

```
printf("The bulk temperature of fluid is : %f K.",TM)
printf("The bulk temperature of fluid is : %f  C.",TM-273)
```

Scilab code Exa 9.5 Example

```
//Variable declaration:
h = 24.0                    //Plant operating hour per day (h/day)
d = 350.0                   //Plant operating day per year (day/yr)

//Calculation:
N = h*d                     //Operating hours per year (h/yr)
//From example 9.1:
Q = 8545.0                  //Rate of energy loss (Btu/h)
Qy = Q*N                    //Steady-state energy loss yearly (Btu/yr)

//Result:
printf("The yearly steady-state energy loss is : %.2f x 10^7 Btu/yr.",Qy/10**7)
```

Scilab code Exa 9.7 Example

```

//Variable declaration:
x = 0.3                         //Length from the leading age of the plate (m)
```

```
L = 1.2                                   //Length of plate (m)
TS = 58.0                                 //Surface temperature of plate ( C )
Ta = 21.0                                 //Temperature of flowing air ( C )

//Calculation:
hx = 25/x**0.4                            //Local heat transfer coefficient at 0.3m (W/m^2.K) (Part 1)
syms y                                    //Length
hy = 25/y**0.4                            //hx at the end of the plate (W/m^2.K)
h = integrate(hy, y,0,L)/L      //Average heat transfer coefficient (W/m^2.K)
Q = hx*(TS-Ta)                            //Heat flux at 0.3m from leading edge of plate (W/m^2)
hL = 25/L**0.4                            //Local heat transfer coefficient at plate end (W/m^2.K) (Part 2)
r = h/hL                                  //Ratio h/hL at the end of the plate

//Result:
printf("1. The heat flux at 0.3 m from the leading edge of the plate is : %.0f  W/m^2.",Q)
printf("2. The local heat transfer coefficient at the end of the plate is : %.1f  W/m^2.K.",hL)
disp("3. The ratio h/hL at the end of plate is : ")
disp(r)
```

Scilab code Exa 9.8 Example

```
//Variable declaration:
//From example 9.7:
```

```
b = 1.0                          //Width of plate (m)
L = 1.2                          //Length of plate (m)
TS = 58.0                        //Surface temperture of plate ( C )
Ta = 21.0                        //Air flow temperature ( C )
h = 38.7                         //Average heat transfer coefficient (W/m^2.K)

//Calculation:
A = b*L                          //Area for heat transfer for the entire plate (m^2)
Q = h*A*(TS-Ta)                  //Rate of heat transfer over the whole length of the plate (W)
Q = round(Q*10**-1)/10**-1

//Result:
printf("The rate of heat transfer over the whole length of the plate is : %.1f W.",Q)
```

Scilab code Exa 9.9 Example

```
//Variable declaration:
m = 0.075                                //Mass rate of air flow (kg/s)
D = 0.225                                //Diameter of tube (m)
mu = 208*10**-7                          //Dynamic viscosity of fluid (N)
Pr = 0.71                                //Prandtl number
k = 0.030                                //Thermal conductivity of air (W/m.K)

//Calculation:
Re = 4*m/(%pi*D*mu)                       //Reynolds
```

```
number
//From equation 9.26:
Nu = 0.023*(Re**0.8)*(Pr**0.3)        //Nusselt number
h = (k/D)*Nu                          //Heat transfer coefficient of air (W/m^2.K)

//Result:
printf("The Heat transfer coefficient of air is : %.2f  W/m^2.K.",h)
```

Scilab code Exa 9.10 Example

```
//Variable declaration:
D = 0.902/12.0                    //Inside diameter of tube (ft)
T_in = 60.0                       //Temperature water entering the tube ( F )
T_out = 70.0                      //Temperature water leaving the tube ( F )
V = 7.0                           //Average wave velocity water (ft/s)
p = 62.3                          //Density of water (lb/ft^3)
mu = 2.51/3600.0                  //Dynamic viscosity of water (lb/ft.s)
Cp = 1.0                          //Viscosity of centipoise (Btu/lb. F )
k = 0.34                          //Thermal conductivity of water (Btu/h.ft. F )

//Calculation:
Re = D*V*p/mu                     //Reynolds Number
Pr = Cp*mu/k*3600                 //Prandtl number
//From equation 9.26:
Nu = 0.023*(Re**0.8)*(Pr**0.4)    //Nusselt number
```

```
h = (k/D)*Nu                         //Average film heat transfer coefficient (Btu/h.ft^2. F )

//Result:
printf("The required average film heat transfer coefficient is : %.0f  Btu/h.ft^2. F .",h)
```

Scilab code Exa 9.11 Example

```
//Variable declaration:
P = 1.0132 * 10**5                   //Air pressure (Pa)
T = 300.0+273.0                      //Air temperature (K)
V = 5.0                              //Air flow velocity (m/s)
D = 2.54/100.0                       //Diameter of tube (m)
R = 287.0                            //Gas constant (m^2/s^2.K)
//From Appendix:
Pr = 0.713                           //Prandtl number of nitrogen
mu = 1.784*10**(-5)                  //Dynamic viscosity of nitrogen (kg/m.s)
k = 0.0262                           //Thermal conductivity of nitrogen (W/m.K)
Cp = 1.041                           //Heat capacity of nitrogen (kJ/kg.K)

//Calculation:
p = P/(R*T)                          //Density of air
Re = D*V*p/mu                        //Reynolds number
//From table 9.5:
Nu = 0.023*(Re**0.8)*(Pr**0.3)       //Nusselt number
h = (k/D)*Nu                         //Heat transfer
```

```
    coefficient (W/m^2.K)

//Result:
printf("The required Heat transfer coefficient is : %.2f  W/m^2.K.",h)
```

Scilab code Exa 9.12 Example

```
//Variable declaration:
T1 = 15.0                      //Water entering temperature ( C )
T2 = 60.0                      //Water leaving temperature ( C )
D = 0.022                      //Inside diameter of tube (m)
V = 0.355                      //Average water flow velocity (m/s)
TC = 150.0                     //Outside wall temperature ( C )
//From Appendix:
p = 993.0                      //Density of water (kg/m^3)
mu = 0.000683                  //Dynamic viscosity of water (kg/m.s)
Cp = 4.17*10**3                //Heat capacity of water (J/kg.K)
k = 0.63                       //Thermal conductivity of water (W/m.K)

//Calculation:
Tav1 = (T1+T2)/2.0             //Average bulk temperature of water ( C )
Re = D*V*p/mu                  //Reynolds number
Pr = Cp*mu/k                   //Prandtl number
Tav2 = (Tav1+TC)/2.0           //Fluid's average wall
```

```
temperature ( C )
//From Appendix:
mu_w = 0.000306                    //Dynamic viscosity of
    fluid at wall (kg/m.s)
//From Table 9.5:
h = (k/D)*0.027*Re**0.8*Pr**0.33*(mu/mu_w)**0.14
    //Heat transfer coefficient for water (W/m^2.K)

//Result:
printf("The heat transfer coefficient for water is :
    %.1f  W/m^2.K.",h)
```

Scilab code Exa 9.13 Example

```
//Variable declaration:
//From example 9.7:
h = 38.7                           //Average heat transfer
    coefficient (W/m^2.K)
L = 1.2                            //Length of plate (m)
k = 0.025                          //Thermal conductivity
    of air (W/m)

//Calculation:
Bi = h*L/k                         //Average Biot number

//Result:
printf("The average Biot number is : %.0f ",Bi)
```

Scilab code Exa 9.14 Example

```
//Variable declaration:
k = 60.0                           //Thermal conductivity
    of rod (W/m.K)
```

```
p = 7850.0                    //Density of rod (kg/m^3)
Cp = 434.0                    //Heat capacity of rod (J/kg.K)
h = 140.0                     //Convection heat transfer coefficient (W/m^2.K)
D = 0.01                      //Diameter of rod (m)
kf = 0.6                      //Thermal conductivity of fluid (W/m.K)
L = 2.5                       //Length of rod (m)
Ts = 250.0                    //Surface temperature of rod ( C )
Tf = 25.0                     //Fluid temperature ( C )

//Calculation:
//Case 1:
a = k/(p*Cp)                  //Thermal diffusivity of bare rod (m^2/s)
//Case 2:
Nu = h*D/kf                   //Nusselt number
//Case 3:
Bi = h*D/k                    //Biot number of bare rod
//Case 4:
Q = h*(%pi*D*L)*(Ts-Tf)        //Heat transferred from rod to fluid (W)

//Result:
printf("1. The thermal diffusivity of the bare rod is : %.2f  x 10^-5 m^2/s.",a/10**-5)
printf("2. The nusselt number is : %.2f .",Nu)
printf("3. The Biot number is : %.4f .",Bi)
printf("4. The heat transferred from the rod to the fluid is : %.0f  W.",Q)
```

Chapter 10

Free Convection

Scilab code Exa 10.1 Example

```
//Variable declaration:
Gr = 100.0                      //Grashof number
Re = 50.0                       //Reynolds number

//Calculation:
LT = Gr/Re**2                   //Measure of influence
    of convection effect

//Result:
if (LT<1.0) then
    printf("The free convection effects can be
        neglected.")
elseif (LT>1.0) then
    printf("The free convection effects can not be
        neglected.")
end
```

Scilab code Exa 10.2 Example

```
//Variable declaration:
Ts = 110.0+273.0                    //Surface temperature of plate (K)
Too = 30.0+273.0                    //Ambient air temperature (K)
L = 3.5                             //Height of plate (m)
g = 9.807                           //Gravitational acceleration (m^2/s)

//Calculation:
Tf = (Ts+Too)/2                     //Film temperature (K)
DT = Ts - Too                       //Temperature difference between surface and air (K)
//From appendix:
v = 2.0*10**-5                      //Kinematic viscosity for air (m^2/s)
k = 0.029                           //Thermal conductivity for air (W/m.K)
Pr = 0.7                            //Prandtl number
B = 1.0/Tf                          //Coefficient of expansion (K^-1)
Gr = g*B*DT*L**3/v**2               //Grashof number
Ra = Gr*Pr                          //Rayleigh number

//Result:
printf("The Grashof number is : %.2f  x 10^11 .",Gr/10**11)
printf("The Rayleigh number is : %.2f  x 10^11 .",Ra/10**11)
```

Scilab code Exa 10.3 Example

```
//Variable declaration:
```

```
//From example 10.2:
Ra = 1.71*10**11                  //Rayleigh number

//Result:
if (Ra>10**9) then
    printf("The convection flow category is turbulent.")
elseif(Ra<10**9) then
    printf("The convection flow category is laminar.")
end
```

Scilab code Exa 10.4 Example

```
//Variable declaration:
//From Table 10.1:
c = 0.1                           //Constant c
m = 1.0/3.0                       //Constant for turbulent free conection
//From example 10.2:
Ra = 1.71*10**11                  //Rayleigh number
k = 0.029                         //Thermal conductivity (W/m.K)
L = 3.5                           //Thickness of plate (m)

//Calculation:
Nu = c*Ra**m                      //Average Nusselt number
h = Nu*k/L                        //Average heat transfer coefficient (W/m^2.K)

//Result:
printf("The average heat transfer coefficient is : %
```

```
.1f W/m^2.K .",h)
```

Scilab code Exa 10.6 Example

```
//Variable declaration:
Ts = 200.0+460.0                //Surface temperature of pipe ( R )
Too = 70.0+460.0                //Air temperature ( R )
D = 0.5                         //Diameter of pipe (ft)
R = 0.73                        //Universal gas constant (ft^3.atm.R^ 1 .lb.mol^ 1 )
P = 1.0                         //Atmospheric pressure (Pa)
MW = 29.0                       //Molecular weight of fluid (mol)
//From Appendix:
mu = 1.28*10**-5                //Absolute viscosity (lb/ft.s)
k = 0.016/3600.0                //Thermal conductivity (Btu/s.ft. F )
g = 32.174                      //Gravitational acceleration (ft/s^2)

//Calculation:
Tav = (Ts+Too)/2                //Average temperature ( R )
v = R*Tav/P                     //kinematic viscosity (ft^3/lbmol)
p = MW/v                        //Air density (lb/ft^3)
B = 1.0/Tav                     //Coefficient of expansion ( R^-1)
DT = Ts-Too                     //Temperature
```

```
difference ( R )
Gr = D**3*p**2*g*B*DT/mu**2      //Grashof number
//From equation 10.5:
Cp = 0.25                        //Air heat capacity (Btu/lb. F )
Pr = Cp*mu/k                     //Prandtl number
GrPr = 10**8.24                  //Rayleigh number
//From Holman^(3):
Nu = 10**(1.5)                   //Nusselt number
h = Nu*(k/D)*3600.0              //Air heat transfer film coefficient (Btu/h.ft. F )

//Result:
printf("The required air heat transfer film coefficient is : %.2f Btu/h.ft. F .",h)
```

Scilab code Exa 10.7 Example

```
//Variable declaration:
Ts = 120.0+460                   //Surface temperature of plate ( R )
Too = 60.0+460                   //Ambient temperature of nitrogen ( R )
L = 6                            //Height of plate (ft)
//From Appendix:
p = 0.0713                       //Air density (lb/ft^3)
k = 0.01514                      //Thermal conductivity (Btu/h.ft. F )
v = 16.82*10**-5                 //Kinematic viscosity (ft^2/s)
Pr = 0.713                       //Prandtl number
g = 32.2                         //Gravitational acceleration (ft/s^2)
```

```

//Calculation:
Tf = (Ts+Too)/2                    //Mean film temperature ( R )
B = 1.0/Tf                         //Coefficient of expansion ( R^-1)
Gr = g*B*(Ts-Too)*L**3/v**2        //Grashof number
Ra = Gr*Pr                         //Rayleigh number
//From equation 10.13(Table 10.2) and costants from Table 10.1:
h = 0.10*(k/L)*Ra**(1.0/3.0)       //Free convection heat transfer coefficient (Btu/h.ft^2. F )

//Result:
printf("The free convection heat transfer coefficient is : %.3f Btu/h.ft^2. F .",h)
printf("There is a calculation mistake in the book for calculating Gr, so, value of h alters from that given.")
```

Scilab code Exa 10.8 Example

```
//Variable declaration:
//From example:
h = 0.675                          //Free convection heat transfer coefficient (Btu/h.ft^2. F )
A = 6.0*8.0                        //Area of plate (ft^2)
Ts = 120.0                         //Surface temperature of plate ( F )
Too = 60.0                         //Ambient temperature of nitrogen ( F )

//Calculation:
Q = h*A*(Ts-Too)                   //Heat loss (Btu/h)
```

```
Q = round(Q * 10**-1)/10**-1

//Result:
printf("The heat loss is : %f  Btu/h .",Q)
printf(" The h obtained in the previous example differs , therefore , Q obtained here also differs from that given in book.")
```

Scilab code Exa 10.9 Example

```
//Variable declaration:
Ts = 113.0+273.0                    //Surface temperature of bulb (K)
Too = 31.0+273.0                    //Ambient air temperature (K)
D = 0.06                            //Diameter of sphere (m)
g = 9.8                             //Gravitational acceleration (m/s^2)

//Calculation:
Tf = (Ts+Too)/2                     //Mean temperature (K)
//From Appendix:
v = (22.38*10**-5)*0.0929           //Kinematic viscosity (m^2/s)
Pr = 0.70                           //Prandtl number
k = 0.01735*1.729                   //Thermal conductivity (W/m.K)
B = 1.0/(Tf)                        //Coefficient of expansion (K^-1)
Gr = g*B*(Ts-Too)*D**3/v**2         //Grashof number
Ra = Gr*Pr                          //Rayleigh number

```

```
//From equation 10.13:
h = (k/D)*0.6*Ra**(1.0/4.0)          //Heat
    transferred from bulb (W/m^2.K)

//Result:
printf("The heat transferred from bulb to air is : %
    .2f  W/m^2.K.",h)
```

Scilab code Exa 10.10 Example

```
//Variable declaration:
//From example 10.9:
h = 9.01                        //Heat transferred from
    bulb (W/m^2.K)
D = 0.06                        //Diameter of sphere (m)
Ts = 113.0+273.0                //Surface temperature of
     bulb (K)
Too = 31.0+273.0                //Ambient air
    temperature (K)

//Calculation:
A = %pi*D**2                     //Surface area of bulb
    (m^2)
Q = h*A*(Ts-Too)                //Heat transfer lost by
    free convection from light bulb (W)

//Result:
printf("The heat transfer lost by free convection
    from light bulb is : %.2f  W .",Q)
```

Scilab code Exa 10.11 Example

```
//Variable declaration:
```

```
//From example 10.9-10.10:
Q = 8.36                          //Heat transfer lost by free convection from light bulb (W)

//Calculation:
E = Q/100.0*(100.0)               //Percent energy lost by free convection (%)

//Result:
printf("The percentage of the energy lost by free convection is : %.2f %%.",E)
printf("The energy lost fraction is : %.4f .",E/100.0)
```

Scilab code Exa 10.13 Example

```
//Variable declaration:
F = 50.0                          //Buoyancy flux of gas (m^4/s^3)
u = 4.0                           //wind speed (m/s)

//Calculation:
xc = 14*F**(5.0/8.0)              //Downward distance (m)
xf = 3.5*xc                       //distance of transition from first stage of rise to the second stage of rise (m)
Dh = 1.6*F**(1.0/3.0)*u**-1*xf**(2.0/3.0)    //Plume rise (m)

//Result:
printf("The plume rise is : %.0f m .",Dh)
```

Chapter 11

Radiation

Scilab code Exa 11.3 Example

```
//Variable declaration:
syms l                                          //Wavelength
    (mu.m)
I = 40*exp(-l**2)                               //Intensity
    of radiation (Btu/h.ft^2.mu.m)

//Calculation:
E = eval(integrate(I, l,0,%inf))                         //
    Total emissive power (Btu/h.ft^2)

//Result:
printf("The total emissive power is : %.1f Btu/h.ft
    ^2.",E)
```

Scilab code Exa 11.4 Example

```
//Variable declaration:
l = 0.25                                    //Wavelength (mu
    .m)
```

```
//From equation 11.4:
lT = 2884                                   //Product of wavelength and absolute temperature (mu.m. R )

//Calculation:
T = lT/l                                    //Sun's temperature ( R )
T1 = round(T * 10**-2)/10**-2
T = T - 460
T460 = round(T * 10**-3)/10**-3

//Result:
printf("The Sun s temperature is : %f  R .",T1)
printf("The Sun s temperature in fahrenheit scale is : %f  F .",T460)
```

Scilab code Exa 11.5 Example

```
//Variable declaration:
T1 = 1500.0+460.0                           //Absolute temperature 1 ( R )
T2 = 1000.0+460.0                           //Absolute temperature 2 ( R )

//Calculation:
X = T1**4/T2**4                             //Ratio of quantity of heat transferred
x = 100*(T1**4-T2**4)/T2**4                 //Percentage increase in heat transfer (%)

//Result:
printf("The ratio of the quantity/rate of heat transferred is : %.2f .",X)
printf("The percentage increase in heat transfer is : %.0f %%",x)
```

Scilab code Exa 11.6 Example

```
//Variable declaration:
T1 = 1200.0+460.0                          //Absolute temperature of wall 1 ( R)
T2 = 800.0+460.0                           //Absolute temperature of wall 2 ( R)

//Calculation:
//From equation 11.23:
X = 0.173*((T1/100.0)**4-(T2/100.0)**4) //Heat removed from colder wall (Btu/h.ft^2)

//Result:
printf("The heat removed from the colder wall to maintain a steady-state is : %.0f Btu/h.ft^2.",X)
```

Scilab code Exa 11.7 Example

```
//Variable declaration:
s = 0.173                         //Stefan-Boltzmann constant (Btu/h.ft^2. R)
EH = 0.5                          //Energy transferred from hotter body (Btu/h.ft^2)
EC = 0.75                         //Energy transferred to colder body (Btu/h.ft^2)
TH = 1660.0                       //Absolute temperature of hotter body ( R)
TC = 1260.0                       //Absolute temperature of colder body ( R)

```

```
//Calculation:
E = s*((TH/100.0)**4-(TC/100.0)**4)/((1.0/EH)+(1.0/EC)-1.0) //Net energy exchange per unit area (Btu/h.ft^2)
E = round(E*10**-1)/10**-1

//Result:
printf("The net energy exchange per unit area is : %f Btu/h.ft^2.",E)
```

Scilab code Exa 11.8 Example

```
//Variable declaration:
//From example 11.6-11.7:
E1 = 8776.0                         //Energy exchange between black bodies (Btu/h.ft^2)
E2 = 3760.0                         //Energy exchange between non-black bodies (Btu/h.ft^2)

//Calculation:
D = (E1-E2)/E1*100                  //Percent difference in energy (%)

//Result:
printf("The percent difference relative to the black body is: %.1f %%.",D)
```

Scilab code Exa 11.9 Example

```
//Variable declaration:
s = 0.173*10**-8                              //Stefan-Boltzmann constant (Btu/h.ft^2. R )
```

```
TH = 300.0+460.0                        //Absolute temperature of external surface ( R )
TC = 75.0+460.0                         //Absolute temperature of duct ( R )
//From Table 6.2:
AH = 0.622                              //External surface area of pipe (ft^2)
//From Table 11.2:
EH = 0.44                               //Emissivity of oxidized steel
AC = 4.0*1.0*1.0                        //External surface area of duct (ft^2)
EC = 0.23                               //Emissivity of galvanized zinc

//Calculation:
FE = 1.0/(1.0/EH+((AH/AC)*(1.0/EC-1.0))) //Emissivity correction factor
Q = FE*AH*s*(TH**4-TC**4)                //Net radiation heat transfer (Btu/h.ft)

//Result:
printf("The net radiation heat transfer is : %.2f Btu/h.ft^2.",Q)
printf("There is a calculation error in book.")
```

Scilab code Exa 11.10 Example

```
//Variable declaration:
TH = 140.0+460.0                    //Absolute outside temperature of pipe (ft^2)
TC = 60.0+460.0                     //Absolute temperature of surrounding atmosphere (ft^2)
A = 10.0                            //Area of pipe (ft^2)
```

```
E = 0.9                                //Emissivity of pipe

//Calculation:
Q = E*A*0.173*((TH/100.0)**4-(TC/100.0)**4) //Heat loss due to radiation (Btu/h)
Q = round(Q*10**-1)/10**-1

//Result:
printf("The heat loss due to radiation is : %f Btu/h.",Q)
```

Scilab code Exa 11.11 Example

```
//Variable declaration:
//Froma example 11.10:
Q = 880.0                  //Heat loss due to radiation (Btu/h)
A = 10.0                   //Area of pipe (ft^2)
TH = 140.0                 //Absolute outside temperature of pipe ( F )
TC = 60.0                  //Absolute temperature of surrounding atmosphere ( F )

//Calculation:
hr = Q/(A*(TH-TC))         //Radiation heat transfer coefficient (Btu/h.ft^2. F )

//Result:
printf("The radiation heat transfer coefficient is : %.1f Btu/h.ft^2. F .",hr)
```

Scilab code Exa 11.12 Example

```
//Variable declaration:
D = 0.0833                          //Diameter of tube (ft)
L = 2.0                             //Length of tube (ft)
h = 2.8                             //Heat transfer coefficient (Btu/h.ft^2.  F )
Ta1 = 1500.0+460.0                  //Temperature of hot air in furnace (  R )
Ta2 = 1350.0+460.0                  //Temperature of hot air in the furnace brick walls (  R )
Tt = 600.0+460.0                    //Surface temperature of tube (  R )
E = 0.6                             //Surface emissivity of tube
s = 0.1713*10**-8                   //Stefan-Boltzmann constant
pi = %pi

//Calculation:
//Case 1:
A = pi*D*L                          //Area of tube (ft^2)
Qc = round(h*A*(Ta1-Tt)*10**-1)/10**-1          //Convection heat transfer from air to tube (Btu/h)
Qr = round(E*s*A*(Ta2**4-Tt**4)*10**-2)/10**-2 //Radiation feat transfer from wall to tube (Btu/h)
Q = Qr+Qc                           //Total heat transfer (Btu/h)
//Case 2:
Qp = Qr/Q*100                       //Radiation percent
//Case 3:
hr = Qr/(A*(Ta2-Tt))                //Radiation heat transfer coefficient (Btu/h.ft^2.  F )
//Case 4:
T = Ta2-Tt                          //Temperature difference (  F )
```

```

//Result:
printf("1. The convective heat transferred to the metal tube is : %f Btu/h.",Qc)
printf("   The radiative heat transferred to the metal tube is : %f Btu/h.",Qr)
printf("   The total heat transferred to the metal tube is : %f Btu/h .",Q)
printf("2. The percent of total heat transferred by radiation is : %.1f %%.",Qp)
printf("3. The radiation heat transfer coefficient is : %.1f Btu/h.ft^2. F .",hr)
if (T > 200) then
    printf("4. The use of the approximation Equation (11.30), hr = 4EsTav^3, is not appropriate.")
elseif (T < 200) then
    printf("4. The use of the approximation Equation (11.30), hr = 4EsTav^3, is appropriate.")
end
```

Scilab code Exa 11.13 Example

```
//Variable declaration:
Q = 5.0                          //Radiation heat transfer (W)
E = 1.0                          //Emissivity of filament
s = 5.669*10**-8                 //Stefan-Boltzmann constant
T1 = 900.0+273.0                 //Light bulb temperature (K)
T2 = 150.0+273.0                 //Glass bulb temperature (K)

```

```
//Calculation:
A = Q/(E*s*(T1**4-T2**4))          //Surface area of the filament (m^2)

//Result:
printf("The surface area of the filament is : %.2f cm^2",A*10**4)
```

Scilab code Exa 11.14 Example

```
//Variable declaration:
T1 = 127.0+273.0                    //Surface temperature (K)
T2 = 20.0+273.0                     //Wall temperature (K)
T3 = 22.0+273.0                     //Air temperature (K)
s = 5.669*10**-8                    //Stefan-Boltzmann constant
e = 0.76                            //Surface emissivity of anodized aluminium
D = 0.06                            //Diameter of %pipe (m)
L = 100.0                           //Length of %pipe (m)
h = 15.0                            //%pipe convective heat transfer coefficient (W/m^2.K)

//Calculation:
Eb = s*T1**4                        //Emissive energy of %pipe (W/m^2)
E = e*Eb                            //Emissive power from surface of %pipe (W/m^2)
A = %pi*D*L                          //Surface area of %pipe (m^2)
```

```
Qc = h*A*(T1-T3)                    //Convection heat transfer to air (W)
Qr = e*s*A*(T1**4-T2**4)            //Radiation heat transfer rate (W)
Q = Qc+Qr                           //Total heat transfer rate (Btu/h)
Tav = (T1+T2)/2.0                   //Average temperature (K)
hr = 4*e*s*Tav**3                   //Radiation heat transfer coefficient (W/m^2.K)

//Result:
printf("The emissive power from surface of %%pipe is : %.0f W/m^2.",E)
printf("The convection heat transfer to air is : %.1f kW.",Qc/10**3)
printf("The radiation heat transfer rate is : %.1f kW",Qr/10**3)
printf("The radiation heat transfer coefficient is : %.1f W/m^2.K.",hr)
```

Scilab code Exa 11.15 Example

```
//Variable declaration:
//From example 11.14:
Qc = 15.0                       //Convection heat transfer coefficient (W/m^2.K)
hr = 7.2                        //Radiation heat transfer coefficient (W/m^2.K)

//Calculation:
X = hr/(Qc+hr)*100.0            //Percent heat transfer by radiation (%)

//Result:
```

```
printf("The percent heat transfer by radiation is : %.1f %%.",X)
```

Scilab code Exa 11.16 Example

```
//Variable declaration:
FV = 1.0                                //Correction factor
//From example 11.9:
FE = 0.358                              //Emissivity correction factor
TH = 300.0+460.0                        //Absolute temperature of external surface ( R )
TC = 75.0+460.0                         //Absolute temperature of duct ( R )
AH = 0.622                              //Area of pipe (ft^2)
s = 0.173*10**-8                        //Stefan-Boltzmann constant

//Calculation:
Q = FV*FE*AH*s*(TH**4-TC**4)            //Heat transfer rate (Btu/h.ft)

//Result:
printf("The heat transfer rate is : %.2f Btu/h.ft",Q)
printf("Since, Q obtained in (11.9) is 96.96 Btu/h.ft, the solution does not match with book.")
```

Scilab code Exa 11.17 Example

```
//Variable declaration:
```

```
//From figure 11.2:
L = 1.0                                      //Space between plates (m)
X = 0.5                                      //Length of plate (m)
Y = 2.0                                      //Width of plate (m)
s = 5.669*10**-8                             //Stefan-Boltzmann constant
TH = 2000.0+273.0                            //Temperature of hotter plate (K)
TC = 1000.0+273.0                            //Temperature of colder plate (K)
Btu = 0.2934*10**-3                          //Btu/h in a KW

//Calculation:
A = X*Y                                      //Area of plate (m^2)
Z1 = Y/L                                     //Ratio of width with space
Z2 = X/L                                     //Ratio of length with space
//From figure 11.2:
FV = 0.18                                    //Correction factor
FE = 1.0                                     //Emissivity correction factor
Q1 = FV*FE*s*A*(TH**4-TC**4)                 //Net radiant heat exchange between plates (kW)
Q2 = Q1/Btu                                  //Net radiant heat exchange between plates in Btu/h (Btu/h)
Q1 = round(Q1*10**-2)/10**-2

//Result:
printf("The net radiant heat exchange between plates is : %f kW.",Q1)
```

```
printf("The net radiant heat exchange between plates
    in Btu/h is : %.2f  x 10^8 Btu/h.",Q2/10**8)
```

Chapter 12

Condensation and Boiling

Scilab code Exa 12.2 Example

```
//Variable declaration:
C = 1                          //Number of constituents
P = 1                          //Number of phases

//Calculation:
F = C-P+2                      //Number of degrees of freedom

//Result:
printf("The number of degrees of freedom is : %.2f .",F)
```

Scilab code Exa 12.4 Example

```
//Variable declaration:
//From steam tables:
U1 = 1237.1                        //Internnal energy of gas (Btu/lb)
```

```
U2_g = 1112.2                    //Internal energy of gas (Btu/lb)
U2_l = 343.15                    //Internal energy of liquid (Btu/lb)

//Calculation:
Q = 0.5*(U2_g+U2_l)-1*U1         //Heat removed (Btu/lb)

//Result:
printf("Heat removed from the system during the process is : %.1f Btu/lb.",Q)
```

Scilab code Exa 12.5 Example

```
//Variable declaration:
T1 = 99.0                        //Mean film temperature ( C)
T2 = 98.0                        //Plate surface temperature ( C)
g = 9.807                        //Gravitational acceleration (m/s^2)
//From Appendix:
T3 = 100.0                       //Saturation temperatre ( C)
h_vap1 = 970.3                   //Latent heat of steam in Btu/lb (Btu/lb)
h_vap2 = 2.255*10**6             //Latent heat of steam in J/kg (J/kg)
p_v = 0.577                      //Density of steam (kg/m^3)
p_l = 960.0                      //Density of liquid water condensate (kg/m^3)
mu_l = 2.82*10**-4               //Absolute viscosity of liquid water condensate (kg/m.s)
```

```
k = 0.68                            //Thermal conductivity of water (W/m.K)
//From table 12.2
Z = 0.4                             //Height of rectangular plate (m)
Pw = 0.2                            //Wetted perimeter of rectangular plate (m)
syms h                              //Average heat transfer coefficient (W/m^2.K)

//Calculation:
A = Z*Pw                            //Heat transfer area of plate (m^2)
R = A/Pw                            //Ratio A/Pw (m)
v_l = mu_l/p_l                      //Kinematic viscosity of liquid water condensate (m^2/s)
Co1 = (h/k)*(v_l**2/g/(1-p_v/p_l))**(1/3)    //Condensation number (in terms of the average heat transfer coefficient)
Re = 4*h*Z*(T3-T2)/(mu_l*h_vap2)    //Reynolds number in terms of the average heat transfer coefficient
//From equation 12.14:
CO1 = 0.0077*Re**Z                  //Co in terms of Reynolds number for flow type 1
x1 = solve(h,Co1-CO1)               //Solving heat transfer coefficient (W/m^2.K)
h1 =x1(2);                          //Average heat transfer coefficient for flow type 1 (W/m^2.K)
Re1 = subst(h1,h,Re)                //Reynolds number for flow type 1
CO2 = 1.874*Re**(-1/3)              //Co in terms of Reynolds number for flow tupe 2
x2 = solve(Co1-CO2,h)               //Solving average heat transfer coefficient for flow type 2 (W/m^2.K)
h2 = x2(1);                         //Average heat transfer coefficient for flow type 2 (W/m^2.K)
```

```
Re2 = subst(h2,h,Re)                    //Reynolds number for flow type 2
h2 = round(h2*10**-1)/10**-1

//Result:
printf("The type of condensation flow type 2 is laminar.")
disp("And the condensation heat transfer coefficient is : ")
disp(h2)
disp("W/m^2.K.")
```

Scilab code Exa 12.6 Example

```
//Variable declaration:
//From example 12.5:
Re = 73.9                       //Reynolds number
mu_l = 2.82*10**-4              //Absolute viscosity of liquid water condensate (kg/m.s)
Pw = 0.2                        //Wetted perimeter of rectangular plate (m)
h = 14700.0                     //Heat transfer coefficient (W/m^2.K)
T_sat = 100.0                   //Saturation temperature ( C )
Ts = 98.0                       //Surface temperature ( C )
A = 0.2*0.4                     //Heat transfer area of plate (m^2)

//Calculation:
m1 = Re*mu_l/4.0                //Mass flow rate of condensate (kg/m.s)
m = Pw*m1                       //Mass flow rate of condensate (kg/s)
```

```
Co = (3.038*10**-5)*h                //Condensation number
Q = h*A*(T_sat-Ts)                   //Heat transfer rate (W)

//Result:
printf("1. The mass flow rate of condensate is : %.4f kg/m.s.",m1)
printf("2. The heat transfer rate is : %.2f kW.",Q/10**3)
```

Scilab code Exa 12.7 Example

```
//Variable declaration:
T_sat = 126.0                        //Saturation temperature ( F )
T = 64.0                             //Surface temperature of tube ( F )
g = 32.2                             //Gravitational acceleration (ft^2/s)
D = 4.0/12.0                         //Outside diameter of tube (ft)

//Calculation:
Tf = (T_sat+T)/2.0                    //Mean film temperature ( F )
//From approximate values of key properties:
h_vap = 1022.0                       //Latent heat of steam (Btu/lb)
p_v = 0.00576                        //Density of steam (lb/ft^3)
p_l = 62.03                          //Density of liquid (lb/ft^3)
k_l = 0.364                          //Thermal conductivity of liquid (Btu/h.ft. F )
```

```
mu_l = 4.26*10**-4                  //Absolute viscosity of liquid water condensate (lb/ft.s)
h = 0.725*((p_l*(p_l-p_v)*g*h_vap*k_l**3)/(mu_l*D*(T_sat-T)/3600.0))**(1.0/4.0)    //Average heat transfer coefficient (Btu/h.ft^2. F)

//Result:
printf("The average heat transfer coefficient is : %.1f Btu/h.ft^2. F.",h)
```

Scilab code Exa 12.9 Example

```
//Variable declaration:
Qs1 = 9800.0                        //Heat flux (W/m^2)
Ts1 = 102.0                         //Original surface temperature ( C)
Ts2 = 103.0                         //New surface temperature ( C)
Tsat = 100.0                        //Saturation temperature ( C)

//Calculation:
h1 = Qs1/(Ts1-Tsat)                 //Original heat transfer coefficient (W/m^2.K)
DT1 = (Ts1 - Tsat)                  //Original excess temperature ( C)
DT2 = (Ts2 - Tsat)                  //New excess temperature ( C)
n = 0.25                            //Value of n for laminar flow
h2 = h1*(DT2/DT1)**(n)              //New heat transfer coefficient (W/m^2.K)
Qs2 = h2*(Ts2-Tsat)                 //New heat flux (W/m^2)
```

```
//Result:
printf("The new heat flux is : %.0f W/m^2.K .",Qs2)
```

Scilab code Exa 12.10 Example

```
//Variable declaration:
//From example 12.9:
Ts1 = 102.0                    //Original surface temperature ( C )
Ts2 = 103.0                    //New surface temperature ( C )
Tsat = 100.0                   //Saturation temperature ( C )

//Calculation:
DTe1 = (Ts1 - Tsat)            //Original excess temperature ( C )
DTe2 = (Ts2 - Tsat)            //New excess temperature ( C )

//Result:
printf("The original excess temperature is: DTe = %f C .",DTe1)
printf("The new excess temperature is: DTe = %f C .",DTe2)
if ((DTe1 < 5) & (DTe2 < 5)) then
    printf("The assumption of the free convection mechanism is valid since DTe < 5 C .")
end
```

Scilab code Exa 12.11 Example

```
//Variable declaration:
//From example 12.9:
Cp = 4127.0                              //heat capacity (J/kg . K)
DTe = 3.0                                //New excess temperature ( C )
h_vap = 2.26*10**6                       //latent heat of vaporization (J/kg)

//Calculation:
Ja_L = Cp*DTe/h_vap                      //Liquid Jakob number

//Result:
printf("The liquid Jakob number is : %.5f",Ja_L)
```

Scilab code Exa 12.12 Example

```
//Variable declaration:
Ts = 106.0                          //Surface temperature ( C )
Tsat = 100.0                        //Saturation temperature ( C )

//Calculation:
DTe = Ts-Tsat                       //Excess temperature ( C )
//From table 12.5:
C1 = 5.56                           //Constant C1
n1 = 3.0                            //Constant n1
C2 = 1040.0                         //Constant C2
n2 = 1.0/3.0                        //Constant n2
P = 1.0                             //Absolute pressure (atm)
Pa = 1.0                            //Ambient absolute
```

```
pressure (atm)

//Calculation:
h1 = C1*DTe**n1*(P/Pa)**0.4        //Boiling water heat transfer coefficient (W/m^2)
Qs1 = h1*DTe                       //Surface flux (W/m^2)
h2 = C2*DTe**n2*(P/Pa)**0.4        //Second Boiling water heat transfer coefficient (W/m^2)
Qs2 = h2*DTe                      //Second Surface flux (W/m^2)

//Result:

if (Qs1/10**3 > 15.8 & Qs1/10**3 < 236) then
    printf("The boiling regime is : %.1f kW/m^2 .",Qs1/10**3)
    printf("The heat transfer coefficient is : %.0f W/m^2 .",h1)
elseif (Qs1/10**3 < 15.8) then
    printf("The boiling regime is : %.2f kW/m^2 .",Qs2/10**3)
    printf("The heat transfer coefficient is : %.0f W/m^2.",h2)
end
```

Scilab code Exa 12.13 Example

```
//Variable declaration:
//From example 12.12:
Qs1 = 11340.0                      //Surface flux (W/m^2)
D = 0.3                            //Diameter of electric heater (m)

```

```
//Calculation:
A = %pi*(D/2.0)**2                    //Surface area of heater (m^2)
Qs = Qs1*A                            //Heat transfer rate (W)

//Result:
printf("The rate of heat transfer is : %.0f W.",Qs)
```

Chapter 13

Refrigeration and Cryogenics

Scilab code Exa 13.1 Example

```
//Variable declaration:
LR = 7.5/12.0                    //Thickness of refractory (ft)
LI = 3.0/12.0                    //Thickness of insulation (ft)
LS = 0.25/12.0                   //Thickness of steel (ft)
kR = 0.75                        //Thermal conductivity of refractory
kI = 0.08                        //Thermal conductivity of insulation
kS = 26.0                        //Thermal conductivity of steel
TR = 2000.0                      //Average surface temperature of the inner face of the refractory ( F )
TS = 220.0                       //Average surface temperature of the outer face of the steel ( F )

//Calculation:
```

```
DT = TR-TS                                   //Temperature difference ( F )
Q = DT/(LR/kR+LI/kI+LS/kS)                   //Heat loss (Btu/h.ft^2)(here representing Qdot/A)

//Result:
printf("The heat loss is : %.0f Btu/h.ft^2 .",Q)
```

Scilab code Exa 13.2 Example

```
//Variable declaration:
LR = 7.5/12.0                                //Thickness of refractory (ft)
kR = 0.75                                    //Thermal conductivity of refractory
TR = 2000.0                                  //Average surface temperature of the inner face of the refractory ( F )
Q = 450.0                                    //Heat loss (Btu/h.ft^2)

//Calculation:
TI = TR - Q*(LR/kR)                          //Temperature of the boundary where the refractory meets the insulation ( F )

//Result:
printf("The temperature of the boundary where the refractory meets the insulation is : %.0f  F .",TI)
```

Scilab code Exa 13.3 Example

```
//Variable declaration:
QbyA = 70000.0                    //Total heat loss
    (Btu/h)
Q = 450.0                         //Heat loss (Btu/h.
    ft^2)

//Calculation:
A = QbyA/Q                        //Area available
    for heat transfer (ft^2)

//Result:
printf("The area available for heat transfer is : %
    .1f ft^2 .",A)
```

Scilab code Exa 13.9 Example

```
//Variable declaration:
h_out = 390.0                     //Enthalpy of the
    fluid that exits from the evaporator (kJ/kg)
h_in = 230.0                      //Enthalpy of the
    fluid that enters the unit (kJ/kg)

//Calculation:
QC = h_out - h_in                 //Heat absorbed by
    the evaporator (kJ/kg)

//Result:
printf("The heat absorbed by the evaporator is : %.0
    f kJ/kg.",QC)
```

Scilab code Exa 13.10 Example

```
//Variable declaration:
```

```
//From example 13.9:
TS = -10.0+273.0                       //Fluid s saturation temperature expressed in Kelvin (K)
QC = 160.0                             //Heat absorbed by the evaporator (kJ/kg)

//Calcuation:
DS = QC/TS                             //Fluid s change in entropy(kJ/kg.K)

//Result:
printf("The fluids change in entropy across the evaporator is : %.2f kJ/kg.K.",DS)
```

Scilab code Exa 13.11 Example

```
//Variable declaration:
//From figure 13.2:
h1 = 390.0                       //Fluid enthalpy on entering the compressor (kJ/kg)
h2 = 430.0                       //Fluid enthalpy on leaving the compressor (kJ/kg)
h3 = 230.0                       //Fluid enthalpy on leaving the condenser (kJ/kg)

//Calculation:
QH = h2 - h3                     //Heat rejected from the condenser (kJ/kg)
W_in = h2 - h1                   //Change in enthalpy across the compressor (kJ/kg)
QC = QH - W_in                   //Heat absorbed by the evaporator (kJ/kg)

//Result:
printf("The heat absorbed by the evaporator of the
```

```
    refrigerator is : %.0f kJ/kg.",QC)
```

Scilab code Exa 13.12 Example

```
//Variable declaration:
//From example 13.11:
W_in = 40.0                  //Change in enthalpy
    across the compressor (kJ/kg)
QC = 160.0                   //Heat absorbed by the
    evaporator (kJ/kg)

//Calculation:
COP = QC/W_in               //Refrigerator s C.O.P
    .

//Result:
printf("the refrigerators C.O.P. is : %.0f .",COP)
```

Scilab code Exa 13.13 Example

```
//Variable declaration:
h1 = 548.0                          //Steam enthalpy
     at the entry and exit to the boiler (kJ/kg)
h2 = 3989.0                         //Steam enthalpy
     at the entry and exit to the turbine (kJ/kg)
h3 = 2491.0                         //Steam enthalpy
     at the entry and exit to the pump (kJ/kg)
QH = 2043.0                         //Heat rejected
    by the condenser (kJ/kg)

//Calculation:
h4 = h3 - QH                        //Steam enthalpy
     at the entry and exit to the condenser (kJ/kg)
```

```
Qb = h2 - h1                                    //Enthalpy change across the boiler (kJ/kg)

//Result:
printf("The enthalpy change across the boiler is : %.0f kJ/kg.",Qb)
```

Scilab code Exa 13.14 Example

```
//Variable declaration:
//From example 13.4:
h1 = 548.0                                      //Steam enthalpy at the entry and exit to the boiler (kJ/kg)
h2 = 3989.0                                     //Steam enthalpy at the entry and exit to the turbine (kJ/kg)
h3 = 2491.0                                     //Steam enthalpy at the entry and exit to the pump (kJ/kg)
h4 = 448.0                                      //Steam enthalpy at the entry and exit to the condenser (kJ/kg)
Qb = 3441.0                                     //Enthalpy change across the boiler (kJ/kg)

//Calculation:
Wt = h2 - h3                                    //Work produced by the turbine (kJ/kg)
Wp = h1 - h4                                    //Work used by the pump (kJ/kg)
W_net = Wt - Wp                                 //Net work by subtracting the pump work from the turbine work (kJ/kg)
n_th = W_net/Qb                                 //Thermal efficiency

//Result:
printf("The thermal efficiency is : %.1f %%.",n_th
```

*100)

Scilab code Exa 13.15 Example

```
//Variable declaration:
//From table 13.4:
x3 = 0.9575                              //Mass fraction
    vapour at point 3
h3 = 2491.0                              //Steam enthalpy
     at the entry and exit to the pump (kJ/kg)
s3 = 7.7630                              //Entropy at the
     entry and exit to the pump (kJ/kg.K)
s4 = 1.4410                              //Entropy at the
     entry and exit to the condenser (kJ/kg.K)
//From example13.14:
h4 = 448.0                               //Steam enthalpy
     at the entry and exit to the condenser (kJ/kg)

//Calculation:
Q_out = h3 - h4                          //Heat rejected
    (kJ/kg)
DS = s3 - s4                             //Process change
     in entropy (kJ/kg)
T3 = Q_out/DS                            //Temperature at
     point 3 (K)

//Result:
printf("The temperature at point 3 is : %.0f  K.",T3
    )
printf("Or, the temperature at point 3 is : %.0f   C
    .",T3-273)
```

Chapter 14

Introduction to Heat Exchangers

Scilab code Exa 14.1 Example

```
//Variable declaration:
scfm = 20000.0                    //Volumetric flow rate of air at standard conditions (scfm)
H1 = 1170.0                       //Enthalpy at 200 F (Btu/lbmol)
H2 = 14970.0                      //Enthalpy at 2000 F (Btu/lbmol)
Cp = 7.53                         //Average heat capacity (Btu/lbmol. F)
T1 = 200.0                        //Initial temperature ( F)
T2 = 2000.0                       //Final temperature ( F)

//Calculation:
n = scfm/359.0                    //Flow rate of air in a molar flow rate (lbmol/min)
DH = H2 - H1                      //Change in enthalpy (Btu/lbmol)
```

```
DT = T2 - T1                    //Change in temperature ( F )
Q1 = n*DH                       //Heat transfer rate using enthalpy data (Btu/min)
Q2 = n*Cp*DT                    //Heat transfer rate using the average heat capacity data (Btu/min)

//Result:
printf("The heat transfer rate using enthalpy data is : %.2f x 10^5 Btu/min.",Q1/10**5)
printf("The heat transfer rate using the average heat capacity data is : %.2f  x 10^5 Btu/min.",Q2/10**5)
```

Scilab code Exa 14.2 Example

```
//Variable declaration:
n = 1200.0                  //Flow rate of air in a molar flow rate (lbmol/min)
Cp = 0.26                   //Average heat capacity (Btu/lbmol. F )
T1 = 200.0                  //Initial temperature ( F )
T2 = 1200.0                 //Final temperature ( F )

//Calculation:
DT = T2 - T1                //Change in temperature ( F )
Q = n*Cp*DT                 //Required heat rate (Btu/min)

//Result:
printf("The required heat rate is : %.2f x 10^5 Btu/min.",Q/10**5)
```

Scilab code Exa 14.3 Example

```
//Variable declaration:
Tc1 = 25.0                    //Initial temperature of cold fluid ( C )
Th1 = 72.0                    //Initial temperature of hot fluid ( C )
Th2 = 84.0                    //Final temperature of hot fluid ( C )

//Calculation:
//From equation 14.2:
Tc2 = (Th2-Th1)+Tc1           //Final temperature of cold fluid ( C )

//Result:
printf("The final temperature of the cold liquid is : %f  C .",Tc2)
printf("There is a printing mistake in unit of final temperature in book.")
```

Scilab code Exa 14.4 Example

```
//Variable declaration:
Ts = 100.0                    //Steam temperature at 1 atm ( C )
Tl = 25.0                     //Fluid temperature ( C )

//Calculation:
DTlm = Ts - Tl                //Log mean temperature difference ( C )
```

```

//Result:
printf("The LMTD is : %f  C.",DTlm)
```

Scilab code Exa 14.5 Example

```
//Variable declaration:
Ts = 100.0                          //Steam temperature at 1 atm ( C)
T1 = 25.0                           //Initial fluid temperature ( C)
T2 = 80.0                           //Final fluid temperature ( C)

//Calculation:
DT1 = Ts - T1                       //Temperature difference driving force at the fluid entrance ( C)
DT2 = Ts - T2                       //Temperature driving force at the fluid exit ( C)
DTlm = (DT1 - DT2)/log(DT1/DT2) //Log mean temperature difference ( C)

//Result:
printf("The LMTD is : %.1f  C.",DTlm)
printf("There is a calculation mistake regarding final result in book.")
```

Scilab code Exa 14.6 Example

```
//Variable declaration:
T1 = 500.0                          //Temperature of hot fluid entering the heat exchanger ( F)
```

```
T2 = 400.0                          //Temperature of hot fluid exiting the heat exchanger ( F )
t1 = 120.0                          //Temperature of cold fluid entering the heat exchanger ( F )
t2 = 310.0                          //Temperature of cold fluid exiting the heat exchanger ( F )

//Calculation:
DT1 = T1 - t2                       //Temperature difference driving force at the heat exchanger entrance ( F )
DT2 = T2 - t1                       //Temperature difference driving force at the heat exchanger exit ( F )
DTlm = (DT1 - DT2)/(log(DT1/DT2))   //LMTD (driving force) for the heat exchanger ( F )

//Result:
printf("The LMTD (driving force) for the heat exchanger is : %.0f  F .",DTlm)
```

Scilab code Exa 14.7 Example

```
//Variable declaration:
m = 8000.0                  //Rate of oil flow inside the tube (lb/h)
Cp = 0.55                   //Heat capacity of oil (Btu/lb. F )
T1 = 210.0                  //Initial temperature of oil ( F )
T2 = 170.0                  //Final temperature of oil ( F )
t = 60.0                    //Tube surface temperature ( F )

```

```
//Calculation:
DT = T2 - T1                         //Change in temperature ( F )
Q = m*Cp*DT                          //Heat transferred from the heavy oil (Btu/h)
DT1 = T1 - t                         //Temperature difference driving force at the pipe entrance ( F )
DT2 = T2 - t                         //Temperature difference driving force at the pipe exit ( F )
DTlm = (DT1 - DT2)/(log(DT1/DT2))    //LMTD (driving force) for the heat exchanger ( F )

//Result:
printf("The heat transfer rate is : %.0f Btu/h.",Q)
printf("The LMTD for the heat exchanger is : %.0f F .",DTlm)
```

Scilab code Exa 14.8 Example

```
//Variable declaration:
T1 = 138.0                           //Temperature of oil entering the cooler ( F )
T2 = 103.0                           //Temperature of oil leaving the cooler ( F )
t1 = 88.0                            //Temperature of coolant entering the cooler ( F )
t2 = 98.0                            //Temperature of coolant leaving the cooler ( F )

//Calculation:
//For counter flow unit:
DT1 = T1 - t2                        //Temperature difference driving force at the cooler entrance ( F )
DT2 = T2 - t1                        //Temperature difference driving force at the cooler exit ( F )
```

```
DTlm1 = (DT1 - DT2)/(log(DT1/DT2))    //LMTD (driving force) for the heat exchanger ( F )
//For parallel flow unit:
DT3 = T1 - t1                         //Temperature difference driving force at the cooler entrance ( F )
DT4 = T2 - t2                         //Temperature difference driving force at the cooler exit ( F )
DTlm2 = (DT3 - DT4)/(log(DT3/DT4))    //LMTD (driving force) for the heat exchanger ( F )

//Result:
printf("The LMTD for counter-current flow unit is : %.1f  F .",DTlm1)
printf("The LMTD for parallel flow unit is : %.1f  F .",DTlm2)
```

Scilab code Exa 14.10 Example

```
//Variable declaration:
A = 1.0                        //Surface area of glass (m^2)
h1 = 11.0                      //Heat transfer coefficient inside room (W/m^2.K)
L2 = 0.125*0.0254              //Thickness of glass (m)
k2 = 1.4                       //Thermal conductivity of glass (W/m.K)
h3 = 9.0                       //Heat transfer coefficient from window to surrounding cold air (W/m^2.K)

//Calculation:
R1 = 1.0/(h1*A)                //Internal convection resistance (K/W)
R2 = L2/(k2*A)                 //Conduction
```

```
    resistance through glass panel (K/W)
R3 = 1.0/(h3*A)                //Outside convection
     resistance (K/W)
Rt = R1+R2+R3                  //Total thermal
    resistance (K/W)
U = 1.0/(A*Rt)                 //Overall heat
    transfer coefficient (W/m^2.K)

//Result:
printf("The overall heat transfer coefficient is : %
    .1f W/m^2.K.",U)
```

Scilab code Exa 14.11 Example

```
//Variable declaration:
Dx = 0.049/12.0                      //Thickness of
    copper plate (ft)
h1 = 208.0                           //Film
    coefficient of surface one (Btu/h.ft^2. F)
h2 = 10.8                            //Film
    coefficient of surface two (Btu/h.ft^2. F)
k = 220.0                            //Thermal
    conductivity for copper (W/m.K)

//Calculation:
U = 1.0/(1.0/h1+Dx/k+1.0/h2)         //Overall heat
    transfer coefficient (Btu/h.ft^2. F)

//Result:
printf("The overall heat transfer coefficient is : %
    .2f Btu/h.ft^2. F.",U)
```

Scilab code Exa 14.12 Example

```
//Variable declaration:
Do = 0.06                          //Outside diameter of pipe (m)
Di = 0.05                          //Inside diameter of pipe (m)
ho = 8.25                          //Outside coefficient (W/m^2.K)
hi = 2000.0                        //Inside coefficient (W/m^2.K)
R = 1.33*10**-4                    //Resistance for steel (m^2.K/W)

//Calculation:
U = 1.0/(Do/(hi*Di)+R+1.0/ho)      //Overall heat transfer coefficient (W/m^2. K)

//Result:
printf("The overall heat transfer coefficient is : %.2f W/m^2. K.",U)
```

Scilab code Exa 14.14 Example

```
//Variable declaration:
Di = 0.825/12.0                    //Pipe inside diameter (ft)
Do = 1.05/12.0                     //Pipe outside diameter (ft)
Dl = 4.05/12.0                     //Insulation thickness (ft)
l = 1.0                            //Pipe length (ft)
kp = 26.0                          //Thermal conductivity of pipe (Btu/h.ft. F)
kl = 0.037                         //Thermal conductivity of insulation (Btu/h.ft. F)
```

```
hi = 800.0                                  //Steam film coefficient (Btu/h.ft^2. F)
ho = 2.5                                    //Air film coefficient (Btu/h.ft^2. F)
pi = %pi

//Calculation:
ri = Di/2.0                                 //Pipe inside radius (ft)
ro = Do/2.0                                 //Pipe outside radius (ft)
rl = Dl/2.0                                 //Insulation radius (ft)
Ai = pi*Di*l                                //Inside area of pipe (ft^2)
Ao = pi*Do*l                                //Outside area of pipe (ft^2)
Al = pi*Dl*l                                //Insulation area of pipe (ft^2)
A_Plm = (Ao-Ai)/log(Ao/Ai)                  //Log mean area for steel pipe (ft^2)
A_Ilm = (Al-Ao)/log(Al/Ao)                  //Log mean area for insulation (ft^2)
Ri = 1.0/(hi*Ai)                            //Air resistance (m^2.K/W)
Ro = 1.0/(ho*Al)                            //Steam resistance (m^2.K/W)
Rp = (ro-ri)/(kp*A_Plm)                     //Pipe resistance (m^2.K/W)
Rl = (rl-ro)/(kl*A_Ilm)                     //Insulation resistance (m^2.K/W)
U = 1.0/(Ai*(Ri+Rp+Ro+Rl))                  //Overall heat coefficient based on the inside area (Btu/h.ft^2. F)

//Result:
printf("The overall heat transfer coefficient based on the inside area of the pipe is : %.3f  Btu/h.
```

```
ft ^2.  F .",U)
```

Scilab code Exa 14.15 Example

```
//Variable declaration:
//From example 14.14:
Di = 0.825/12.0                                    //%pipe inside diameter (ft)
L = 1.0                                            //%pipe length (ft)
Ui = 0.7492                                        //Overall heat coefficient (Btu/h.ft^2.  F )
Ts = 247.0                                         //Steam temperature (  F )
ta = 60.0                                          //Air temperature (  F )

//Calculation:
Ai = %pi*Di*L                                       //Inside area of %pipe (ft^2)
Q = Ui*Ai*(Ts-ta)                                  //Heat transfer rate (Btu/h)

//Result:
printf("The heat transfer rate is : %.1f Btu/h.",Q)
```

Scilab code Exa 14.16 Example

```

//Variable declaration:
hw = 200.0                               //Water heat coefficient (Btu/h.ft^2.  F )
```

```
ho = 50.0                        //Oil heat coefficient (Btu/h.ft^2. F)
hf = 1000.0                      //Fouling heat coefficient (Btu/h.ft^2. F)
DTlm = 90.0                      //Log mean temperature difference ( F)
A = 15.0                         //Area of wall (ft^2)

//Calculation:
X = 1.0/hw+1.0/ho+1.0/hf         //Equation 14.34 for constant A
U = 1.0/X                        //Overall heat coeffocient (Btu/h.ft^2. F)
Q = U*A*DTlm                     //Heat transfer rate (Btu/h)
Q = round(Q*10**-1)/10**-1

//Result:
printf("The heat transfer rate is : %f Btu/h.",Q)
```

Scilab code Exa 14.17 Example

```

T = 80.0                         //Pipe surface temperature ( F)
t1 = 10.0                        //Brine inlet temperature ( F)
syms DT2                         //Discharge temperature of the brine solution ( F)
```

```
m = 20*60                          //Flowrate of brine solution (lb/h)
Cp = 0.99                          //Heat capacity of brine solution (Btu/lb. F )
U1 = 150                           //Overall heat transfer coefficient at brine solution entrance (Btu/h.ft^2. F )
U2 = 140                           //Overall heat transfer coefficientat at brine solution exit (Btu/h.ft^2. F )
A = 2.5                            //Pipe surface area for heat transfer (ft^2)

//Calculation:
DT1 = T-t1                         //Temperature approach at the pipe entrance ( F )
Q = m*Cp*(DT1-DT2)                 //Energy balance to the brine solution across the full length of the pipe (Btu/h)
DT1m = (DT1-DT2)/log(DT1/DT2)      //Equation for the LMTD
QQ = A*(U2*DT1-U1*DT2)/log(U2*DT1/U1/DT2)    //Equation for the heat transfer rate (Btu/h)
E = QQ-Q                           //Energy balance equation
R = integrate(E,DT2,1.2)
    //
DT = 51.6254331484575                        //Log mean temperature difference
t2 = T-DT                          //In discharge temperature of the brine solution ( F )
t2c = 5/9*(t2-32)                  //In discharge temperature of the brine solution in  C (c/5 = (F-32)/9)
_Q_ = eval(subst(DT,DT2,Q))                //Heat transfer rate (Btu/h)

Q1 = round(_Q_*10**-1)/10**-1
```

```
Q2 = round(_Q_/3.412*10**-2)/10**-2

//Result:
printf("The temperature approach at the brine inlet side is : %.1f  F.",DT1)
printf("Or, the temperature approach at the brine inlet side is : %.1f  C.",DT1/1.8)
printf("The exit temperature of the brine solution is : %.2f  F.",t2)
printf("Or, the exit temperature of the brine solution is : %.1f  C.",(t2-32)/1.8)
printf("The rate of heat transfer is : %f Btu/h.",Q1)
printf("Or, the rate of heat transfer is : %f W.",Q2)
```

Chapter 15

Double Pipe Heat Exchangers

Scilab code Exa 15.2 Example

```
//Variable declaration:
Q = 12000.0                         //Heat transfer rate (Btu/h)
U = 48.0                            //Overall heat coefficient (Btu/ft^2.h..)
DTlm = 50.0                         //Log mean temperature difference (.)

//Calculation:
A = Q/(U*DTlm)                      //Area of exchanger (ft^2)

//Result:
printf("The area of the exchanger is : %.0f ft^2 .",A)
```

Scilab code Exa 15.3 Example

```
//Variable declaration:
Q = 56760                     //Heat transfer rate (Btu/h)
U = 35.35                     //Overall heat coefficient (Btu/ft.h..)
A = 32.1                      //Area of exachanger (ft^2)
t1 = 63.0                     //Outlet cold water temperature (.)
T1 = 164                      //Outlet hot water temperature (.)
T2 = 99                       //Inlet hot water temperature (.)
syms t2                     //Inlet cold water temperature (.)

//Calculation:
DTlm = Q/(U*A)                //Log mean temperature difference (.)
dT1 = T1-t1                   //Temperature approach at pipe outlet (.)
dT2 = T2-t2                   //Temperature approach at pipe inlet (.)
Eq = (dT2-dT1)/log(dT2/dT1)-DTlm
R = eval(subst(0,t2,Eq))              //Inlet cold water temperature (.)

//Result:
disp("The inlet cold water temperature is : ")
disp(round(R))

// There is some mistake in calculation in book. Please calculate manually.
```

Scilab code Exa 15.4 Example

```
//Variable declaration:
m = 14.6                              //Flow rate of water inside the tube (lb/min)
Cp = 1                                //Heat capacity of water (Btu/lb..)
t2 = 79                               //Initial temperature of water (.)
t1 = 63                               //Final temperature of water (.)
//From example 15.3:
Q1 = 56760                            //Old heat transfer rate (Btu/h)

//Calculation:
Q2 = m*Cp*(t2-t1)                     //New heat transfer rate (Btu/min)

//Result:
printf("The new heat transfer rate is : %.0f Btu/min.",Q2)
printf("Or, the new heat transfer rate is : %.0f Btu/h.",Q2*60)
if (Q1==Q2) then
    printf("This result agree with the Qu02d9 provided in the problem statement. Shakespeare is wrong, nothing is rotten there.")
else
    printf("This result does not agree with the Qu02d9 provided in the problem statement. Shakespeare is right, something is indeed rotten.")
end
```

Scilab code Exa 15.5 Example

```
//Variable declaration:
T1 = 210.0                              //Initial temperature of oil (.)
T2 = 170.0                              //Final temperature of oil (.)
T3 = 60.0                               //Surface temperature of oil (.)
m = 8000.0                              //Flow rate of oil inside tube (lb/h)
cp = 0.55                               //Heat capacity of oil (Btu/lb..)
U = 63.0                                //Overall heat teansfer coefficient (Btu.h.ft^2..)

//Calculation:
DT1 = T1-T3                             //Temperature difference 1 (.)
DT2 = T2-T3                             //Temperature difference 2 (.)
DTlm = (DT1-DT2)/log(DT1/DT2)           //Log mean temerature difference (.)
Q = m*cp*(T1-T2)                        //Heat transferred (Btu/h)
A = Q/(U*DTlm)                          //Heat transfer area (ft^2)

//Result:
printf("The required heat transfer area is : %.2f ft^2 .",A)
```

Scilab code Exa 15.6 Example

```
//Variable declaration:
T1 = 140.0                              //Initial temperature of hot water (.)
```

```
T2 = 110.0                                  //Final temperature of hot water (.)
T3 = 60.0                                   //Initial temperature of cold water (.)
T4 = 90.0                                   //Initial temperature of cold water (.)
DTlm2 = 50.0                                //Log mean temerature difference for countercurrent flow, a constant (.) (part 2)
m = 100.0*60                                //Water flow rate (lb/h)
cp = 1.0                                    ////Heat capacity of water (Btu/lb..)
U = 750.0                                   //Overall heat teansfer coefficient (Btu.h.ft^2..)

//Calculation:
DT1 = T1-T3                                 //Temperature difference 1 (.) (part 1)
DT2 = T2-T4                                 //Temperature difference 2 (.)
DTlm1 = (DT1-DT2)/log(DT1/DT2)              //Log mean temerature difference (.)
Q = m*cp*(T1-T2)                            //Heat transferred (Btu/h)
Ap = Q/(U*DTlm1)                             //Heat transfer area for parallel flow (ft^2)
Ac = Q/(U*DTlm2)                            //Heat transfer area for counter flow (ft^2)

//Result:
printf("1. The double pipe co-current flow is : %.2f ft^2 .",Ap)
printf("1. The double pipe countercurrent flow is : %.2f ft^2 .",Ac)
```

Scilab code Exa 15.8 Example

```
//Variable declaration:
uC = 3.7*10**-4                                    //
    Viscosity of benzene (lb/ft.s)
uH = 2.05*10**-4                                   //
    Viscosity of water @200 . (lb/ft.s)
u2 = 2.16*10**-4                                    //
    Viscosity of water @192 . (lb/ft.s)
pC = 54.8                                          //
    Density of benzene (lb/ft^3)
pH = 60.13                                         //
    Density of water (lb/ft^3)
cpC = 0.415                                        //
    Specific heat capacity of benzene (Btu/lb..)
cpH = 1                                            //
    Specific heat capacity of water (Btu/lb..)
sgC = 0.879
kC = 0.092                                         //
    Thermal conductivity of benzene (Btu/h.ft..)
kH = 0.392                                         //
    Thermal conductivity of water @200 .  (Btu/h.ft
    ..)
k2 = 0.390                                       //
    Thermal conductivity of water @192 .  (Btu/h.ft
    ..)
mC = 2500                                        //Flow
    rate of benzene (lb/s)
mH = 4000                                          //
    Flow rate of water (lb/s)
Re = 13000                                         //
    Reynolds number
dTc = 120-60                                        //
    Difference in temperature heating for benzene
```

```
Tw = 200                                    //Temperatperature of hot water (.)
//For 2-inch schedule 40 pipe
Ai = 0.541                                  //Inside area of pipe (ft^2/ft)
Ao = 0.622                                  //Outside area of pipe (ft^2/ft)
Di = 2.067                                  //Inside diameter of pipe (inch)
Do =  2.375                                 //Outside diameter of pipe (inch)
Si = 0.0233                                 //Inside surface area of pipe (ft^2)
dXw = 0.128                                 //Width of pipe (ft)
pi = %pi

//For 4-inch schedule 40 pipe
Dio = 4.026                                 //Inside diameter of pipe (inch)
Doi = Do                                    //Outside diameter of pipe (inch)
kw = 26

//Calculations:
function [a] = St(Re,Pr)                    //Dittus Boelter equation
    a = 0.023*Re**-0.2*Pr**-0.667
endfunction

//For inside tubes:
Dicalc = 4*mC/(Re*pi*uC)/3600               //Inside diameter (ft)
mHcalc = Re*pi*uH*(Doi+Dio)/4*3600/12       //Mass flow rate of water (lb/h)
Q = mC*cpC*dTc                              //Heat in water (Btu/h)
dTH = Q/mH                                  //
```

```
Temperature difference of water (.)
THo = Tw - dTH                                    //Outlet temperature of water (.)
THav = (Tw+THo)/2                                 //Average temperature of water (.)
//For benzene:
PrC = cpC*uC/kC*3600                              //Prandtl number
StC = round(St(13000, PrC) * 10**5)/10**5                //Stanton number
hi = StC*cpC*mC/Si                                //Heat transfer coefficient (Btu/h.ft^2..)
//For water:
ReH = 4*mH/3600/(pi*u2*(Doi+Dio)/12)              //Reynolds number
PrH = cpH*(u2)/k2*3600                            //Prandtl number
StH = round(St(ReH, PrH) * 10**5)/10**5   //Stanton number
Sann = pi/4*(Dio**2-Doi**2)/144                   //Surface area of annulus (ft^2)
ho = round(StH*cpH*mH/Sann)                       //Heat transfer coefficient (Btu/h.ft^2..)
//For pipe:
Dlm = (Do-Di)/log(Do/Di)*12                  //Log mean difference in diameter (ft)
Uo = 1/(Do/Di/hi + dXw*Do/kw/Dlm + 1/ho)          //Overall heat transfer coefficient (Btu/h.ft^2..)
dTlm = (124.4-80)/log(124.4/80)                   //Log mean temperature difference (.)
L = Q/(Uo*0.622*dTlm)                             //Length of pipe (ft)

//Result:
printf("The required length of pipe: %.1f ft",L)
```

Scilab code Exa 15.10 Example

```
//Variable declaration:
MC = 2000.0
mc = 1000.0
U = 2000.0
A = 10.0
T1 = 300.0
t1 = 60.0
e = %e

//Calculation:
B = 1.0/mc
b = 1.0/MC
x = B/b
y = U*(B-b)
T2 = ((x-y)*T1 + x*(e-y)*t1)/(2*e-1)
t2 = t1+(T1-T2)/x

//Result:
printf("T2 = : %.0f ",T2)
printf("t2 = : %.0f ",t2)
```

Scilab code Exa 15.11 Example

```

//Variable declaration:
h1 = 1200.0                    //Hot film coefficient (Btu/h.ft^2..)
h2 = 1175.0                    //Cold film coefficient (Btu/h.ft^2..)
```

```
L = 200.0                                //Length of pipe (ft)
MC = 30000.0
mc = 22300.0
T1 = 300.0                               //Inlet temperature of hot fluid in pipe (.)
t1 = 60.0                                //Inlet temperature of cold fluid in pipe (.)
syms T2                                 //Outlet temperature of hot fluid .
syms t2                                 //Outlet temperature of cold fluid .
//From table 6.2:
ID = 2.067                               //Inside diameter of pipe (in)
OD = 2.375                               //Outside diameter of pipe (in)
Dx = 0.154                               //Thickness of pipe (in)
Ai = 0.541                               //Inside sectional area of pipe (ft^2/ft)
k = 25.0                                 //Thermal conductivity of pipe (Btu/h)

//Calculation:
Ui = 1.0/((1.0/h1) +(Dx/(k*12.0))+(1.0/(h2*(OD/ID))))    //Overall heat transfer coefficient (Btu/h.ft^2..)
Ai1 = Ai*L                               //Inside area of pipe (ft^3/ft)
QH = MC*(T1-T2)                          //Heat transfer rate of hot fluid (Btu/h)
QC = mc*(t2-t1)                          //Heat transfer rate of cold fluid (Btu/h)
t2ht = 195                               //t2 by hit and trial
[x] = fsolve(T2,QC-QH)
T2 = x(1)
```

```
DTlm = (T1-t1-T2+t2)/log((T1-t1)/(T2-t2))  //Log mean temperature difference (.)
Q = Ui*Ai1*subst(t2ht,t2,DTlm)      //Total heat transfer rate (Btu/h)

//Result:
disp("T2 :")
disp(subst(t2ht,t2,T2))

disp("t2 :")
disp(subst(t2ht,t2,t2))

disp("Qdot :")
disp(Q/10**6)
disp("x 10**6 Btu/h")
```

Scilab code Exa 15.12 Example

```

//Variable declaration:
B = 3.33*10**-5
b = 4.48*10**-5
//From example 15.11:
A = 108.2                          //Inside area of pipe (ft^3/ft)
U = 482                            //Overall heat transfer coefficient (Btu/h.ft^2..)
MC = 30000.0
mc = 23000.0
T1 = 300.0                         //Inlet temperature of hot fluid in pipe (.)
t1 = 60.0                          //Inlet temperature of cold fluid in pipe (.)
e = %e

```

```
//Calculation:
//From equation 15.28:
T2 = ((B/b)*(e**(U*A*(B-b))-1)*t1+T1*(B/b-1))/((B/b)*e**(U*A*(B-b))-1) //Outlet temperature of hot fluid (.)
//From equation 15.32:
t2 = ((b/B)*(e**(U*A*(b-B))-1)*T1+t1*(b/B-1))/((b/B)*e**(U*A*(b-B))-1) //Outlet temperature of cold fluid (.)
DT = ((T2-t1)-(T1-t2))/(log((T2-t1)/(T1-t2))) //Log mean difference temperature (.)
Q1 = U*A*DT                             //Heat transfer rate of hot fluid (Btu/h)
Q2 = MC*(T1-T2)                         //Heat transfer rate of cold fluid (Btu/h)
Q2 = round(Q2 * 10**-3)/10**-3
//Result:
printf("The heat load is : %f Btu/h.",Q2)
```

Scilab code Exa 15.14 Example

```
//Variable declaration:
Ts = 100.0                          //Saturation temperature (u00b0C)
t1 = 25.0                           //Initial temperature of water (u00b0C)
t2 = 73.0                           //Final temperature of water (u00b0C)
m = 228.0/3600.0                    //Mass flow rate of water (kg/s)
cp = 4174.0                         //Heat capacity of water (J/kg.K)
m_s = 55.0/3600.0                   //Mass flow rate of steam (kg/s)
h_vap = 2.26*10**26                 //Latent heat of
```

```
condensation (J/kg)
k = 54.0                            //Thermal conductivity for 0.5% carbon steel (W/m.K)
rii = 0.013                         //Inner radius of inner %pipe of the double %pipe heat exchanger (m)
roi = 0.019                         //Outer radius of inner %pipe of the double %pipe heat exchanger (m)
Rf = 0.0002                         //Fouling factor (m^2.K/W)
Uc = 0.00045                        //Clean overall heat transfer coefficient (W/m^2.K)

//Calculation:
DT1 = Ts-t1                         //Temperature driving force at end 1 (K)
DT2 = Ts-t2                         //Temperature driving force at end 2 (K)
DTlm = (DT1-DT2)/(log(DT1/DT2))     //Log mean difference temperature (u00b0C)
Cw =m*cp                            //Capacitance rate of water (W/K)
Q = Cw*(t2-t1)                      //Heat transfer rate (W)
Qmax1 = Cw*(Ts-t1)                  //Maximum heat term from the water stream (W)
Qmax2 = m_s*h_vap                   //Maximum heat term from the steam (W)
E = Q/Qmax1                         //Effectiveness
Lmin = (Q*(log(roi/rii)))/(2*%pi*k*(Ts-t1))     //Minimum required length of heat exchanger (m)
Ud = 1.0/(1.0/Uc+Rf)                //Dirty overall heat transfer coefficient (W/m^2.K)
ud = round(1/Ud * 10**-1)/10**-1

//Result:
printf("1. The temperature profile of the water and
```

```
steam along the length of the exchanger is : %.0f
 C .",DTlm)
printf("2. Effectiveness of energy from steam to
heat the water is : %.3f .",E)
printf("3. The minimum length of the heat exchanger
is : %.3f m .",Lmin)
printf("4. The dirty overall heat transfer
coefficient : %.5f W/m^2.K",Ud)
printf("5. U_dirty: %f  W/m^2.K",ud)
```

Scilab code Exa 15.15 Example

```
//Variable declaration:
Q = 12700.0                    //Heat transfer rate (W)
Ud = 2220.0                    //Dirty overall heat
    transfer coefficient (W/m^2.K)
DTlm = 47.0                    //Log mean difference
    temperature (u00b0C)
rii = 0.013                    //Inner radius of inner
    %pipe of the double %pipe heat exchanger (m)
//Calculation:
A = Q/(Ud*DTlm)                //Heat transfer area (m
    ^2)
L = A/(2*%pi*rii)               //Tube length (m)

//Result:
printf("The heat transfer area is : %.4f m^2.",A)
printf("The length of the heat exchanger is : %.2f m
    .",L)
```

Scilab code Exa 15.16 Example

```
//Variable declaration:
```

```
Ud = 2220.0                      //Dirty overall heat
    transfer coefficient (W/m^2.K)
A = 0.1217                       //Heat transfer area (m
    ^2)
Cw = 264.0                       //Capacitance rate of
    water (W/K)

//Calculation:
NTU = (Ud*A)/Cw                  //Number of transfer
    units of the exchanger

//Result:
printf("The number of transfer units (NTU) of the
    exchanger is : %.2f .",NTU)
```

Scilab code Exa 15.18 Example

```
//Variable declaration:
Ao = 1.85                                //Area of heat
    exchanger (ft^2)

//Calculation:
//From figure 15.6:
y = 0.560*10**-3                         //Intercept 1/
    UoAo (..h/Btu)
ho = 1.0/(Ao*y)                          //Thermal
    conductivity for heat exchanger (Btu/h.ft^2..)

//Result:
printf("Thermal conductivity for the heat exchanger
    is : %.0f Btu/h.ft^2.. .",ho)
```

Scilab code Exa 15.19 Example

```
//Variable declaration:
//From figure 15.7:
a = 0.00126
b = 0.0276

//Calculation:
ho = 1.0/a                                  //The value of
   ho (Btu/h.ft^2..)

//Result:
printf("Thermal conductivity is : %.0f Btu/h.ft^2..
   .",ho)
```

Scilab code Exa 15.20 Example

```
//Variable declaration:
Di = 0.902/12.0                             //Inside
   diameter of tube (ft)
Do = 1.0/12.0                               //Outside
   diameter of tube (ft)
k = 60.0                                    //Thermal
   conductivity of tube (Btu/h.ft^2..)

//Calculation:
//From example 15.19:
a = 0.00126
Dr = (Do - Di)/2.0                          //Radial
   thickness of tube wall  (ft)
Rw = Dr/k                                   //Resistance of
   wall (Btu/h..)
ho = 1.0/(a-Rw)                             //The revised ho
    (Btu/h.ft^2..)

//Result:
printf("The revised ho is : %.0f Btu/h.ft^2.. .",ho)
```

Scilab code Exa 15.21 Example

```
//Variable declaration:
a1 = 0.00044                        //Term 'a' for U_clean
a2 = 0.00089                        //Term 'a' for U_dirty

//Calculation:
Rs = a2 - a1                        //Resistance associated
    with the scale
hs = 1.0/Rs                         //Scale film coefficient
    (Btu/h.ft^2..)

//Result:
printf("The scale film coefficient neglecting the
    wall resistance is: %.0f Btu/h.ft^2.. .",hs)
```

Chapter 16

Shell and Tube Heat Exchangers

Scilab code Exa 16.5 Example

```
//Variable declaration:
//From figure 16.13, for ideal countercurrent heat exchanger:
T1 = 150.0                          //Inlet temperature of hot fluid ( F)
T2 = 100.0                          //Outet temperature of hot fluid ( F)
t1 = 50.0                           //Inlet temperature of cold fluid ( F)
t2 = 80.0                           //Outet temperature of hot fluid ( F)
//From figure 16.14, for shell and tube exchanger:
T_1 = 50.0                          //Inlet temperature of cold fluid ( F)
T_2 = 80.0                          //Outet temperature of hot fluid ( F)
t_1 = 150.0                         //Inlet temperature of hot fluid ( F)
t_2 = 100.0                         //Outet temperature
```

```
    of hot fluid ( F)

//Calculation:
DT1 = T1 - t2                       //Temperature driving force 1 ( F)
DT2 = T2 - t1                        //Temperature driving force 1 ( F)
DTlm1 = ((DT1-DT2)/log(DT1/DT2))  //Log mean temperature driving force for ideal countercurrent heat exchanger ( F)
P = (t2-t1)/(T1 - t1)             //Dimensionless ratio P
R = (T1-T2)/(t2-t1)               //Dimensionless ratio R
//From figure 16.7:
F = 0.925                         //Correction Factor
DTlm2 = F*DTlm1                   //Log mean temperature driving force for shell and tube exchanger ( F)

//Result:
printf("The log mean temperature difference for ideal system is : %.1f F.",DTlm1)
printf("The log mean temperature difference for real system is : %.2f F.",DTlm2)
```

Scilab code Exa 16.6 Example

```
//Variable declaration:
T1 = 400.0                        //Temperature of fluid entering the shell ( F)
T2 = 250.0                        //Temperature of fluid leaving the shell ( F)
t1 = 100.0                        //Temperature of fluid entering the tube ( F)
```

```
t2 = 175.0                        //Temperature of fluid leaving the tube ( F)

//Calculation:
DT1 = T1 - T2                     //Temperature driving force 1 ( F)
DT2 = t2 - t1                     //Temperature driving force 1 ( F)
DTlm1 = ((DT1-DT2)/log(DT1/DT2))  //Log mean temperature driving force for ideal countercurrent heat exchanger ( F)
P = (t2-t1)/(T1 - t1)             //Dimensionless ratio P
R = (T1-T2)/(t2-t1)               //Dimensionless ratio R
//From figure 16.8:
F = 0.985                         //Correction factor
DTlm2 = F*DTlm1                   //Log mean temperature driving force for shell and tube exchanger ( F)

//Result:
printf("The log mean temperature difference between the hot fluid and the cold fluid is : %.1f F.",DTlm2)
```

Scilab code Exa 16.7 Example

```
//Variable declaration:
//From example 16.5:
P1 = 0.30                          //Dimensionless ratio P
R1 = 1.67                          //Dimensionless ratio R
//From example 16.6:
```

```
P2 = 0.30                              //Dimensionless ratio P
R2 = 1.67                              //Dimensionless ratio R

//Calculation:
//Applying Equation 16.27:
F1 = 0.92                              //Correction Factor
//Applying Equation 16.33:
F2 = 0.985                             //Correction Factor
//From example 16.6:
LMTD1 = 59.4                           //Log mean temperature driving force 1 for ideal countercurrent heat exchanger ( F)
LMTD2 = 108.0                          //Log mean temperature driving force 2 for ideal countercurrent heat exchanger ( F)
DTlm1 = F1*LMTD1                       //Log mean temperature driving force 1 for shell and tube exchanger ( F)
DTlm2 = F2*LMTD2                       //Log mean temperature driving force 2 for shell and tube exchanger ( F)

//Result:
printf("The log mean temperature difference for real system (in example 16.5) is : %.2f F.",DTlm1)
printf("The log mean temperature difference for real system (in example 16.6) is : %.1f F .",DTlm2)
```

Scilab code Exa 16.8 Example

```
//Variable declaration:
t2 = 75.0                              //Temperature of water leaving the shell ( C)
```

```
t1 = 35.0                              //Temperature of water enteringing the shell ( C)
T2 = 75.0                              //Temperature of oil leaving the tube ( C)
T1 = 110.0                             //Temperature of oil entering the tube ( C)
m = 1.133                              //Mass flowrate of water (kg/s)
cp = 4180.0                            //Heat capacity of water (J/kg.K)
F = 0.965                              //Correction factor
U = 350.0                              //Overall heat transfer coefficient (W/m^2.K)

//Calculation:
Q = m*cp*(t2-t1)                       //Heat load (W)
DT1 = T1-t2                            //Temperature driving force 1 ( C)
DT2 = T2-t1                            //Temperature driving force 2 ( C)
DTlm1 = (DT1-DT2)/log(DT1/DT2)+273.0   //Countercurrent log-mean temperature difference (K)
DTlm2 = F*DTlm1                        //Corrected log-mean temperature difference (K)
A = Q/(U*DTlm2)                        //Required heat transfer area (m^2)

//Result:
printf("The required heat-transfer area is : %.3f m^2.",A)
```

Scilab code Exa 16.10 Example

```
//Variable declaration:
```

```
t2 = 84.0                              //Temperature of water leaving the tube ( C)
t1 = 16.0                              //Temperature of water entering the tube ( C)
m1 = 10000.0/3600.0                    //Mass flowrate of water (kg/s)
T2 = 94.0                              //Temperature of oil leaving the shell ( C)
T1 = 160.0                             //Temperature of oil entering the shell ( C)

//Calculation:
Tw = (t1+t2)/2.0                       //Average bulk temperature of water ( C)
To = (T1+T2)/2.0                       //Average bulk temperature of oil ( C)
//From table 16.1:
p1 = 987.0                             //Density of water (kg/m^3)
cp1 = 4176.0                           //Heat capacity of water (J/kg. C)
p2 = 822.0                             //Density of oil (kg/m^3)
Q = m1*cp1*(t2-t1)                     //Heat load (W)
cp2 = 4820.0                           //Heat capacity of oil (J/kg. C)
m2 = Q/(cp2*(T1-T2))                   //Mass flowrate of oil (kg/s)
DT1 = T2-t1                            //Temperature driving force 1 ( C)
DT2 = T1-t2                            //Temperature driving force 2 ( C)
DTlm1 = ((DT1-DT2)/log(DT1/DT2))  //Log mean temperature driving force for ideal countercurrent heat exchanger ( C)
P = (t2-t1)/(T1 - t1)                  //Dimensionless ratio P
R = (T1-T2)/(t2-t1)                    //Dimensionless
```

```
ratio R
//From figure 16.7:
F = 0.965                               //Correction factor
DTlm2 = F*DTlm1                         //Log mean temperature driving force for 1-4 shell and tube exchanger ( C)

//Result:
printf("1. The heat load is : %.3f  MW .",Q/10**6)
printf("2. The countercurrent flow log mean temperature difference is : %.0f C .",DTlm1)
printf("3. The F correction factor and the corrected log mean temperature difference is : %.1f C .",DTlm2)
```

Scilab code Exa 16.11 Example

```
//Variable declaration:
//From example 16.10:
U = 350.0                               //Over all heat transfer coefficient (W/m^2. C)
DTlm = 74.3                             //Log mean temperature driving force for 1-4 shell and tube exchanger ( C)
Q = 788800.0                            //Heat load (W)
Nt = 11.0                               //Number of tubes per pass
Np = 4.0                                //Number of passes
Di = 0.0229                             //Inside diameter of tube (m)
pi = %pi

//Calculation:
A = Q/(U*DTlm)                          //Heat transfer area required for heat exchanger (m^2)
```

```
N = Nt*Np                              //Total number of tubes
L = A/(pi*Di*N)                        //Tube length (m)

//Result:
printf("The heat transfer area required for the heat exchanger is : %.2f m^2 .",A)
printf("The length of the tubes required for the heat exchanger is : %.1f ft",L*3.28)
```

Scilab code Exa 16.18 Example

```
//Variable declaration:
//From example 16.10:
m1 = 2.778                             //Mass flowrate of water (kg/s)
cp1 = 4176.0                           //Heat capacity of water (J/kg. C)
cp2 = 4820.0                           //Heat capacity of oil (J/kg. C)
m2 = 2.48                              //Mass flowrate of oil (kg/s)
t2 = 84.0                              //Temperature of water leaving the tube ( C)
t1 = 16.0                              //Temperature of water entering the tube ( C)
T2 = 94.0                              //Temperature of oil leaving the shell ( C)
T1 = 160.0                             //Temperature of oil entering the shell ( C)
U = 350.0                              //Over all heat transfer coefficient (W/m^2. C)
A = 30.33                              //Heat transfer area required for heat exchanger (m^2)

```

```
//Calculation:
C1 = m1*cp1                              //Capacitance rate of water (W/ C)
C2 = m2*cp2                              //Capacitance rate of oil (W/ C)
Q = C1*(t2-t1)                           //Heat load of water (W)
Qmax = C1*(T1-t1)                        //Maximum heat load of water (W)
E = Q/Qmax                               //Effectiveness
if (C1<C2) then
    Cmin = C1                            //Minimum capacitance rate (W/ C)
    Cmax = C2                            //Maximum capacitance rate (W/ C)
else
    Cmin = C2                            //Minimum capacitance rate (W/ C)
    Cmax = C1                            //Maximum capacitance rate (W/ C)
end
NTU = U*A/Cmin                           //Number of transfer units
C = Cmin/Cmax                            //Capacitance rate ratio

//Result:
printf("The effectiveness is : %.3f .",E)
printf("The number of transfer units is : %.3f",NTU)
printf("The capacitance rate ratio is : %.3f",C)
```

Scilab code Exa 16.19 Example

```
//Variable declaration:
//From table 16.4:
```

```
Cw = 11680.3                          //Capacitance rate of water (W/ C)
t2 = 65.0                             //Temperature of water leaving the tube ( C)
t1 = 20.0                             //Temperature of water entering the tube ( C)
T2 = 107.3                            //Temperature of steam leaving the shell ( C)
T1 = 107.3                            //Temperature of steam entering the shell ( C)
hv = 2.238*10**6                      //Latenet heat of condensation for steam (J/kg)
U = 2000.0                            //Overall heat transfer coefficient (W/m^2. C)

//Calculation:
Q = Cw*(t2-t1)                        //Heat load (W)
m2 = Q/hv                             //Steam condensation rate (kg/s)
DT1 = T2-t1                           //Temperature driving force 1 ( C)
DT2 = T1-t2                           //Temperature driving force 2 ( C)
DTlm1 = ((DT1-DT2)/log(DT1/DT2))  //Log mean temperature driving force for ideal countercurrent heat exchanger ( C)
F = 1.0                               //Correction factor (since , T2 = T1)
DTlm2 = F*DTlm1                       //Log mean temperature driving force for shell and tube exchanger ( C)
A1 = Q/(U*DTlm2)                      //Heat transfer area using LMTD method (m^2)
E = (t2-t1)/(T1-t1)                   //Effectiveness
//From figure 16.18:
NTU = 0.7                             //Number of transfer units
A2 = (NTU*Cw)/U                       //Heat transfer area
```

```
using E–NTU method (m^2)

//Result:
printf("The heat transfr area for the exchanger (using LMTD method) is : %.2f m^2 .",A1)
printf("The heat transfr area for the exchanger (using E–NTU method) is : %.1f m^2",A2)
```

Scilab code Exa 16.21 Example

```
//Variable declaration:
//From table 16.5:
t2 = 75.0                          //Temperature of water leaving the shell ( C)
t1 = 35.0                          //Temperature of water entering the shell ( C
T2 = 75.0                          //Temperature of oil leaving the tube ( C)
T1 = 110.0                         //Temperature of oil entering the tube ( C)
mw = 1.133                         //Mass flowrtae of water (kg/s)
cpw = 4180.0                       //Heat capacity of water (J/kg.K)
cpo = 1900.0                       //Heat capacity of oil (J/kg.K)
p = 850.0                          //Density of oil (kg/m^3)
Di = 0.01905                       //Inside diameter of tube (m)
V = 0.3                            //Average velocity of oil flow inside the tube (m/s)
Np = 2.0                           //Number of passes
Uc = 350.0                         //Overall heat transfer coefficient for clean heat exchanger (W/
```

```
   m^2)
Rf = 0.00027                       //Fouling factor (m^2.K/w)
pi = %pi

//Calculation:
Cw = mw*cpw                        //Water capacitance rate (W/K)
Q = Cw*(t2-t1)                     //Heat load (W)
Co = Q/(T1-T2)                     //Oil capacitance rate (W/K)
mo = Co/cpo                        //Total flowrate of oil (kg/s)
if (Cw<Co) then
    Cmin = Cw                      //Minimum capacitance rate (W/K)
    Cmax = Co                      //Maximum capacitance rate (W/K)
else
    Cmin = Co                      //Minimum capacitance rate (W/K)
    Cmax = Cw                      //Maximum capacitance rate (W/K)
end
m_ot = p*V*(pi/4.0)*Di**2          //Oil flowrate per tube (kg/s)
Nt = mo/m_ot                       //Number of tubes per pass
N = Nt*Np                          //Number of tubes
DT1 = T2-t1                        //Temperature driving force 1 ( C)
DT2 = T1-t2                        //Temperature driving force 2 ( C)
DTlm1 = ((DT1-DT2)/log(DT1/DT2))   //Log mean temperature driving force for ideal countercurrent heat exchanger ( C)
P = (t2-t1)/(T1 - t1)              //Dimensionless parameter P
```

```
R = (T1-T2)/(t2-t1)                //Dimensionless parameter R
//From figure 16.7:
F = 0.81                           //Correction factor
DTlm2 = F*DTlm1                    //Log mean temperature driving force for shell and tube exchanger ( C)
Ud = 1.0/(1.0/Uc+Rf)               //Dirty overall heat transfer coefficient (W/m^2.K)
A = Q/(Ud*DTlm2)                   //Required heat transfer area (m^2)
L = A/(N*pi*Di)                    //Tube length (m)
N = round(N*10**-1)/10**-1

//Result:
printf("1. The mass flow rate of the oil is : %.2f kg/s .",mo)
printf("2. The minimum and maximum heat capacity rate is : %.0f and %.1f  W/K",Cmin,Cmax)
printf("3. The heat load , Q is  : %.0f W .",Q)
printf("4. The total number of tubes is : %f ",N)
printf("5. The tube length is : %.1f m .",L)
```

Scilab code Exa 16.22 Example

```
//Variable declaration:
//From example 16.22:
t2 = 75.0                          //Temperature of water leaving the shell ( F)
t1 = 35.0                          //Temperature of water entering the shell ( F)
T2 = 75.0                          //Temperature of oil leaving the tube ( F)
T1 = 110.0                         //Temperature of oil entering the tube ( F)
```

```
U = 320.0                             //Overall heat transfer coefficient (W/m^2.K)
A = 19.5                              //Required heat transfer area (m^2)
Cmin = 4736.0                         //Minimum capacitance rate (W/K)

//Calculation:
DT1 = t2-t1                           //Actual water temperature change ( F)
DT2 = T1 - t1                         //Maximum water temperature change ( F)
E = DT1/DT2                           //Effectiveness
NTU = (U*A)/Cmin                      //Number of transfer units

//Result:
printf("The effectiveness is : %.3f .",E)
printf("The NTU is : %.3f",NTU)
```

Chapter 17

Fins and Extended Surfaces

Scilab code Exa 17.1 Example

```
//Variable declaration:
w1 = 1.5                          //Thicknessof fin (in)
L = 12.0                          //Length of fin (in)
w2 = 0.1                          //Thickness of fin(in)

//Calculation:
Af = 2*w1*L                        //Face area of fin (in
    ^2)
At = Af + L*w2                     //Total area of fin (in
    ^2)

//Result:
printf("The face area of the fin is : %.0f in^2 ",Af
    )
printf("The face area of the fin is : %.2f ft^2 .",
    Af/12**2)
printf("The total area of the fin is : %.1f in^2 .",
    At)
printf("The total area of the fin is : %.3f ft^2 .",
    At/12**2)
```

Scilab code Exa 17.3 Example

```
//Variable declaration:
rf = 6.0/12.0                    //Outside radius of fin
    (ft)
ro = 4.0/12.0                    //Outside radius of
    %pipe (ft)
t = 0.1/12.0                     //Thickness of fin (ft)

//Calculation:
Af = 2*%pi*(rf**2-ro**2)          //Face area of fin (ft
    ^2)
At = Af + 2*%pi*rf*t              //Total area of fin (ft
    ^2)

//Result:
printf("The total fin area is : %.3f ft^2 .",At)
```

Scilab code Exa 17.4 Example

```
//Variable declaration:
L = 3.0*0.0254                       //Height of fin (m)
t = 1.0*0.0254                       //Thickness of fin (
   m)
h = 15.0                             //Heat transfer
    coefficient (W/m^2.K)
k = 300.0                            //Thermal
    conductivity (W/m.K)

//Calculation:
Lc = L + t/2.0                       //Corrected height
    of fin (m)
```

```
Ap = Lc*t                          //Profile area of fin (m^2)
x = sqrt((Lc**3*h)/(k*Ap))         //x-coordinate of figure 17.3
//From figure 17.3:
nf = 98.0                          //Fin efficiency

//Result:
printf("The fin efficiency is : %f %%",nf)
```

Scilab code Exa 17.5 Example

```
//Variable declaration:
//From example 17.4:
X = 0.1246                         //X-coordinate of figure 17.3

//Calculation:
//Applying equation (A) from Table 17.3:
Y = 4.5128*X**3 - 10.079*X**2 - 31.413*X + 101.47

//Result:
printf("The fin efficiency is : %.1f %%",Y)
```

Scilab code Exa 17.6 Example

```
//Variable declaration:
w = 0.2/100.0               //Width of fin (m)
t = 0.2/100.0               //Thickness of fin (m)
L = 1.0/100.0               //Length of fin (m)
h = 16.0                    //Heat transfer coefficient (W/m^2.K)
```

```
k = 400.0                //Thermal conductivity of fin (W/m.K)
Tc = 100.0               //Circuit temperature ( C)
Ta = 25.0                //Air temperature ( C)

//Calculation:
P = 4*w                  //Fin cross-section parameter (m)
Ac = w*t                 //Cross-sectional area of fin (m^2)
Lc = L+Ac/P              //Corrected height of fin (m)
m = sqrt((h*P)/(k*Ac))   //Location of minimum temperature (m^-1)
Q = (sqrt(h*P*k*Ac))*(Tc-Ta)*atan(h)*(m*Lc)        //Heat transfer from each micro-fin (W)

//Result:
printf("The heat transfer from each micro-fin is : %.2f W .",Q)
```

Scilab code Exa 17.8 Example

```
//Variable declaration:
h1 = 13.0                        //Air-side heat transfer coefficient (W/m^2.K)
A = 1.0                          //Base wall area (m^2)
L = 2.5/100                      //Length of steel fins (m)
L2 = 1.5/10**3                   //Length of steel wall (m)
k = 13.0                         //Thermal conductivity of fin (W/m.K)
k1 = 38.0                        //Thermal
```

```
conductivity of steel wall (W/m.K)
h2 = 260.0                          //Water side heat transfer coefficient (W/m^2.K)
T4 = 19.0                           //Air temperature (C)
T1 = 83.0                           //Water temperature ( C)
t = 1.3/10**3                       //Thickness of steel fins (m)
w = 1.0                             //Width of wall (m)
S = 1.3/100                         //Fin pitch(m)

//Calculation:
R1 = 1/(h1*A)                       //Air resistance ( C/W) (part 1)
R2 = L2/(k1*A)                      //Conduction resistance ( C/W)
R3 = 1/(h2*A)                       //Water resistance ( C/W)
Rt = (R1+R3)                        //Total resistance ( C/W) (part 2)
Q = (T1-T4)/Rt                      //Total heat transfer (W)
Nf = 1/S                            //Number of fins ( part 3)
Lbe = w - Nf*t                      //Unfinned exposed base surface
Abe = w*Lbe                         //Exposed base surface area (m^2)
Lc = L+t/2                          //Corrected length (m)
Ap = Lc*t                           //Profile area (m^2)
Af = 2*w*Lc                         //Fin surface area (m^2)
Bi = h1*(t/2)/k1                    //Biot number
a = sqrt(Lc**3*h1/(k*Ap))           //Abscissa of the fin efficiency
//From figure 17.3:
```

```
nf = 0.88                          //Fin efficiency
Rb = 1/(h1*Abe)                    //Air thermal resistance of base wall ( C/W)
Rf = 1/(h1*Nf*Af*nf)               //Air thermal resistance of fins ( C/W)
RT1 = 1/(1/Rb+1/Rf)                //Total outside resistance of the fin array ( C/W)
Rt3 = RT1+R3                       //Total resistance on air side fins ( C/W)
Qt = (T1-T4)/Rt3          //Heat transfer rate on air side fins (W)
I = (Qt/Q - 1)*100                 //Percent increase in heat transfer rate to air side fins (W)
A = sqrt(Lc**3*h2/(k1*Ap))         //Abscissa of the new fin efficiency (part 4)
//From figure 17.3:
nf2 = 38.0                         //New fin efficiency
Rb2 = 1/(h2*Abe)                   //Thermal resistance of base wall ( C/W)
Rf2 = 1/(h2*Nf*Af*nf2)             //Thermal resistance of fins ( C/W)
Rt4 = 1/(1/Rb2+1/Rf2)              //Total resistance of the finned surface ( C/W)
Rt5 = R1+Rt4                       //Total resistance on water side fins ( C/W)
QT1 = (T1-T4)/Rt5                  //Heat transfer rate on water side fins (W)
I2 = (QT1/Q - 1)*100               //Percent increase in heat transfer rate to water side fins (W)

//Result:
if (R2<R1 | R2<R3) then
    printf("1. The conduction resistance may be neglected.")
else
    printf("1. The conduction resistance can not be neglected.")
end
```

```
printf("2. The rate of heat transfer from water to
   air is : %.1f W .",Q)
printf("3. The percent increase in steady-state heat
    transfer rate by adding fins to the air side of
   the plane wall is : %.1f %%",I)
printf("4. The percent increase in steady-state heat
    transfer rate by adding fins to the water side
   of the plane wall is : %.1f %%",I2)
printf("____There is a calculation mistake in book
   in calculating Qt(83-19/0.0214 = 2999), hence
   slight differences in answer______")
```

Scilab code Exa 17.10 Example

```
//Variable declaration:
Do = 2.5/100                        //Outside diameter
   of tube (m)
t = 1/10**3                         //Thickness of fin (
   m)
T = 25                              //Fluid temperature
   ( C)
Tb = 170                            //Surface
   temperature ( C)
h = 130                             //Heat transfer
   coefficient (W/m^2.K)
k = 200                             //Thermal
   conductivity of fin (W/m.K)
rf = 2.75/100                       //Outside radius of
   fin (m)

//Calculation:
ro = Do/2                           //Radius of tube (m)
Ab = 2*%pi*ro*t                      //Area of the base
   of the fin (m^2)
Te = Tb-T                           //Excess temperature
```

```
 at the base of the fin (K)
Q1 = h*Ab*Te                    //Total heat transfer rate without the fin (W)
Bi = h*(t/2)/k                  //Biot number
L = rf-ro                       //Fin height (m)
rc = rf+t/2                     //Corrected radius (m)
Lc = L+t/2                      //Corrected height (m)
Ap = Lc*t                       //Profile area (m^2)
Af = 2*%pi*(rc**2-ro**2)         //Fin surface area (m^2)
Qm = h*Af*Te                    //Maximum fin heat transfer rate (W)
A = sqrt(Lc**3*h/(k*Ap))        //Abscissa of fin efficiency
C = rf/ro                       //Curve parameter of fin efficiency
//From figure 17.4:
nf = 0.86                       //Fin efficiency
Qf = nf*Qm                      //Fin heat transfer rate (W)
R = Te/Qf                       //Fin resistance (K/W)

//Result:
printf("1. The heat transfer rate without the fin is : %.2f W .",Q1)
printf("Or, the heat transfer rate without the fin is : %.0f Btu/h .",Q1*3.412)
printf("2. The corrected length is : %.4f m .",Lc)
printf("3. The outer radius is : %.3f m ",rc)
printf("4. The maximum heat transfer rate from the fin is : %.2f W .",Qm)
printf("5. The fin efficiency is : %.0f %%",nf*100)
printf("6. The fin heat transfer rate is : %.0f %%",Qf)
printf("Or, the fin heat transfer rate is : %.0f %%"
```

```
,Qf*3.412)
printf("7. The fin thermal resistance is : %.2f K/W.",R)
```

Scilab code Exa 17.11 Example

```
//Variable declaration:
//From example 17.10:
Qf = 64                         //Fin heat transfer rate (W)
Q1 = 1.48                       //Total heat transfer rate without the fin (W)

//Calculation:
E = Qf/Q1                       //Fin effectiveness

//Result:
printf("The fin effectiveness is : %.1f",E)
if E>2 then
    printf("Hence, the use of the fin is justified.")
end
```

Scilab code Exa 17.12 Example

```
//Variable declaration:
w = 1                               //Length of tube (m)
S = 10/10**3                        //Fin patch (m)
//From example 17.10:
t = 1/10**3                         //Thickness of fin (m)
ro = 0.0125                         //Radius of tube (m)
```

```
Af = 3.94*10**-3                    //Fin surface area (m^2)
Tb = 145                            //Excess temperature at the base of the fin (K)
h = 130                             //Heat transfer coefficient (W/m^2.K)
Qf = 64                             //Fin heat transfer rate (W)

//Calculation:
Nf = w/S                            //Number of fins in tube length
wb = w-Nf*t                         //Unfinned base length (m)
Ab = 2*%pi*ro*wb                     //Unfinned base area (m^2)
At =Ab+Nf*Af                        //Total transfer surface area (m^2)
Qt = h*(2*%pi*ro*w*Tb)               //Total heat rate without fins (W)
Qb = h*Ab*Tb                        //Heat flow rate from the exposed tube base (W)
Qft = Nf*Qf                         //Heat flow rate from all the fins (W)
Qt2 = Qb+Qft                        //Total heat flow rate (W)
Qm = h*At*Tb                        //Maximum heat transfer rate (W)
no = Qt2/Qm                         //Overall fin efficiency
Eo = Qt2/Qt                         //Overall effectiveness
Rb = 1/(h*Ab)                       //Thermal resistance of base (K/W)
Rf = 1/(h*Nf*Af*no)                 //Thermal resistance of fins (K/W)

//Result:
```

```
printf("1. The total surface area for heat transfer is : %.3f m^2 .",At)
printf("2. The exposed tube base total heat transfer rate is : %.1f W .",Qb)
printf("Or, the exposed tube base total heat transfer rate is : %.0f Btu/h .",Qb*3.412)
printf("3. The overall efficiency of the surface is : %.1f %%",no*100)
printf("4. The overall surface effectiveness is : %.2f .",Eo)
```

Scilab code Exa 17.13 Example

```
//Variable declaration:
w = 1                           //Width of single of fin (m)
t = 2/10**3                     //Fin base thickness (m)
l = 6/10**3                     //Fin length thickness (m)
T1 = 250                        //Surface temperature ( C)
T2 = 20                         //Ambient air temperature ( C)
h = 40                          //Surface convection coefficient (W/m^2.K)
k = 240                         //Thermal conductivity of fin (W/m.K)

//Calculation:
Ab = t*w                        //Base area of the fin (m^2)
Te = T1-T2                      //Excess temperature at the base of the fin (K)
Qw = h*Ab*Te                    //Heat transfer rate
```

```
without a fin (W)
Af = 2*w*(sqrt(l**2-(t/2)**2))  //Fin surface area (m^2)
Qm = h*Af*Te                    //Maximum heat transfer rate (m^2)
Bi = h*(t/2)/k                  //Biot number
Lc = l                          //Corrected length (m)
Ap = l*t/2                      //Profile area (m^2)
A = sqrt((Lc**3*h)/k*Ap)        //Abscissa for the fin efficiency figure
//From figure 17.4:
nf = 0.99                       //Fin efficiency
Qf = nf*Qm                      //Fin heat transfer rate (W)
R = Te/Qf                       //Fin thermal resistance (K/W)
E = Qf/Qw                       //Fin effectiveness
Qm = round(Qm*10**-1)/10**-1

//Result:
printf("1. The heat transfer rate without the fin is : %.1f W .",Qw)
printf("2. The maximum heat transfer rate from the fin is : %f W .",Qm)
printf("3. The fin efficiency is : %.0f %%",nf*100)
printf("   The fin thermal resistance is : %.1f C/W .",R)
printf("   The fin effectiveness is : %.1f .",E)
```

Scilab code Exa 17.14 Example

```
//Variable declaration:
//From example 17.13:
Qf = 108.9                   //Fin heat transfer rate
```

```
(W)
Qw = 18.4                    //Total heat transfer rate without the fin (W)

//Calculation:
E = Qf/Qw                    //Fin effectiveness

//Result:
printf("The fin effectiveness is : %.2f .",E)
if E>2 then
    printf("Hence, the use of the fin is justified.")
end
```

Scilab code Exa 17.15 Example

```
//Variable declaration:
Do = 50/10**3                //Outside diameter of tube (m)
t = 4/10**3                  //Thickness of fin (m)
T = 20                       //Fluid temperature ( C)
Tb = 200                     //Surface temperature ( C)
h = 40                       //Heat transfer coefficient (W/m^2.K)
k = 240                      //Thermal conductivity of fin (W/m.K)
l = 15/10**3                 //Length of fin (m)

//Calculation:
ro = Do/2                    //Radius of tube (m)
rf = ro+l                    //Outside radius of fin (m)
```

```
Ab = 2*%pi*ro*t                    //Area of the base of the fin (m^2)
Te = Tb-T                          //Excess temperature at the base of the fin (K)
Q1 = h*Ab*Te                       //Total heat transfer rate without the fin (W)
Bi = h*(t/2)/k                     //Biot number
L = rf-ro                          //Fin height (m)
rc = rf+t/2                        //Corrected radius (m)
Lc = L+t/2                         //Corrected height (m)
Ap = Lc*t                          //Profile area (m^2)
Af = 2*%pi*(rc**2-ro**2)           //Fin surface area (m^2)
Qm = h*Af*Te                       //Maximum fin heat transfer rate (W)
A = sqrt(Lc**3*h/(k*Ap))           //Abscissa of fin efficiency
C = rf/ro                          //Curve parameter of fin efficiency
//From figure 17.4:
nf = 0.97                          //Fin efficiency
Qf = nf*Qm                         //Fin heat transfer rate (W)
R = Te/Qf                          //Fin resistance (K/W)
E = Qf/Q1                          //Fin effectiveness

//Result:
printf("The fin efficiency is : %.0f %%",nf*100)
printf("The fin thermal resistance is : %.1f C/W.",R)
printf("The fin effectiveness is : %.2f .",E)
printf("The maximum heat transfer rate from a single fin is : %.2f W .",Qm)
if E>2 then
    printf("Since Ef = FCP>2, the use of the fin is
```

```
        justified.")
end
```

Scilab code Exa 17.16 Example

```
//Variable declaration:
Nf = 125                          //Array of fins per
    meter
w = 1                             //Length of fin (m)
//From example 17.15:
t = 4/10**3                       //Thickness of fin (
   m)
Do = 50/10**3                     //Outside diameter
    of tube (m)
Af = 7.157*10**-3                 //Fin surface area (
   m^2)
h = 40                            //Heat transfer
    coefficient (W/m^2.K)
DTb = 180                         //Excess temperature
     at the base of the fin (K)
Qf = 50                           //Fin heat transfer
    rate (W)

//Calculation:
ro = Do/2                         //Radius of tube (m)
wb = w-Nf*t                       //Unfinned exposed
    base length (m)
Ab = 2*%pi*ro*wb                   //Area of the base
    of the fin (m^2)
At = Ab+Nf*Af                     //Total heat
    transfer surface area (m^2)
Qw = h*(2*%pi*ro*w)*DTb            //Heat rate without
     fin (W)
Qb = h*Ab*DTb                     //Heat rate from the
     base (W)
```

```
Qft = Nf*Qf                      //Heat rate from the fin (W)
Qt = Qb+Qft                      //Total heat rate (W)
Qm = h*At*DTb                    //Maximum heat transfer rate (W)
n = Qt/Qm                        //Overall fin efficiency
E = Qt/Qw                        //Overall fin effectiveness
Rb = 1/(h*Ab)                    //Thermal resistance of base ( C/W)
Rf = 1/(h*Nf*Af*n)               //Thermal resistance of fin ( C/W)

//Result:
printf("The rate of heat transfer per unit length of tube is : %.1f W .",Qt)
printf("Or, the rate of heat transfer per unit length of tube is : %.2f kW .",Qt/10**3)
printf("The overall fin efficiency is : %.1f %%",n*100)
printf("The overall fin effectiveness is : %.2f .",E)
```

Scilab code Exa 17.17 Example

```
//Variable declaration:
printf('Analytical Solution')
```

Scilab code Exa 17.18 Example

```
//Variable declaration:
```

```
//From example 17.18:
T = 250                         //Base temperature of fin ( F)
h = 15                          //Convection coefficient of heat transfer (Btu/h.ft. F)
w = 1                           //Base width of fin (ft)
t = 1                           //Thickness of fin (in)
H = 1/8                         //Height of fin (in)
l = 1                           //Length of fin (in)
Q = 357.2                       //Heat transfer rate (Btu/h.ft)

//Calculation:
A = (l*w+t*w+H*w)/12            //Heat transfer area of fin (ft^2)
Qm = h*A*(T-70)                 //Maximum heat transfer rate (Btu/h.ft)
n = Q/Qm*100                    //Fin efficiency

//Result:
printf("The fin efficiency is : %.1f %%",n)
```

Chapter 18

Other Heat Exchange Equipment

Scilab code Exa 18.2 Example

```
//Variable declaration:
T1 = 25                          //Temperature of H2SO4 ( C)
m = 50+200                       //Mass of H2SO4 (lb)
//From figure 18.2:
W1 = 50+100                      //Weight of H2SO4 (lb)
W2 = 100                         //Weight of H2O (lb)

//Calculation:
m = W1/(W1+W2)*100              //Percent weight of H2SO4 (%)
m2 = W1+W2                      //Mass of mixture (lb)
//From fgure 18.2:
T2 = 140                        //Final temperature between the 50% solution and pure H2SO4 at  25 C ( F)
h1 = -86                        //Specific heat capacity of H2O (Btu/lb)
h2 = -121.5                     //Specific heat capacity
```

```
of H2SO4 (Btu/lb)
Q = m2*(h2-h1)                  //Heat transferred (Btu)

//Result:
printf("The final temperature between the 50%% solution and pure H2SO4 at 25 C is : %.0f F .",T2)
printf("The heat transferred is : %.0f Btu .",Q)
```

Scilab code Exa 18.3 Example

```
//Variable declaration:
F = 10000                       //Mass flow rate of NaOH (lb/h)
C1 = 10                         //Old concentration of NaOH solution (%)
C2 = 75                         //New concentration of NaOH solution (%)
h1 = 1150                       //Enthalpy of saturated steam at 14.7 psia (Btu/lb)
U = 500                         //Overall heat transfer coefficient (Btu/h.ft^2. F)
T1 = 212                        //Absolute temperature of evaporator ( F)
T2 = 340                        //Saturated steam temperature ( F)

//Calculation:
L = F*(C1/100)/(C2/100)         //Flow rate of steam leaving the evaporator (lb/h)
V = F-L                         //Overall material balance (lb/h)
//From figure 18.3:
hF = 81                         //Enthalpy of solution entering the unit (Btu/lb)
```

```
hL = 395                              //Enthalpy of the 75 % NaOH solution (Btu/lb)
Q = round(V)*h1+round(L)*hL-F*hF      //Evaporator heat required (Btu/h)
A = Q/(U*(T2-T1))                     //Area of the evaporaor (ft^2)
Q = round(Q*10**-2)/10**-2

//Result:
printf("The heat transfer rate required for the evaporator is : %f Btu/h ",Q)
printf("The area requirement in the evaporator is : %.1f ft^2 .",A)
```

Scilab code Exa 18.4 Example

```
//Variable declaration:
U1 = 240                   //Overall heat transfer coefficient for first effect (Btu/h.ft^2. F)
U2 = 200                   //Overall heat transfer coefficient for second effect (Btu/h.ft^2. F)
U3 = 125                   //Overall heat transfer coefficient for third effect (Btu/h.ft^2. F)
A1 = 125                   //Heating surface area in first effect (ft^3)
A2 = 150                   //Heating surface area in second effect (ft^3)
A3 = 160                   //Heating surface area in third effect (ft^3)
T1 = 400                   //Condensation stream temperature in the first effect ( F)
T2 = 120                   //Vapor leaving temperature in the first effect ( F)

//Calculation:
```

```
R1 = 1/(U1*A1)                  //Resistance across first effect
R2 = 1/(U2*A2)                  //Resistance across second effect
R3 = 1/(U3*A3)                  //Resistance across third effect
R = R1+R2+R3                    //Total resistance
DT1 = (R1/R)*(T1-T2)            //Temperature drop across the heating surface in the first effect (F)

//Result:
printf("The temperature drop across the heating surface in the first effect is : %.0f F .",DT1)
```

Scilab code Exa 18.6 Example

```
//Variable declaration:
F = 5000                            //Mass of soltuion fed in the evaporator (lb)
xF = 2/100                          //Concentration of feed
xL = 5/100                          //Concentration of liquor
U = 280                             //Overall heat transfer coefficient (Btu/h.ft^2. F)
//From figure 18.1 & 18.3:
TF = 100                            //Feed temperature ( F)
TS = 227                            //Steam temperature ( F)
TV = 212                            //Vapour temperature ( F)
TL = 212                            //Liquor temperature ( F)
```

```
TC = 227                               //Condensate temperature ( F)

//Calculation:
//From steam tables:
hF = 68                                //Enthalpy of feed (Btu/lb)
hL = 180                               //Enthalpy of liquor (Btu/lb)
hV = 1150                              //Enthalpy of vapour (Btu/lb)
hS = 1156                              //Enthalpy of steam (Btu/lb)
hC = 195                               //Enthalpy of condensate (Btu/lb)
s1 = F*xF                              //Total solids in feed (lb)
w = F-s1                               //Total water in feed (lb)
s2 = F*xF                              //Total solids in liquor (lb)
L = s2/xL                              //Total water in liquor (lb)
V = F-L                                //Overall balance (lb)
S = (V*hV+L*hL-F*hF)/(hS-hC)           //Mass of steam (lb)
Q = S*(hS-hC)                          //Total heat requirement (Btu)
A = Q/(U*(TS-TL))                      //Required surface aea (ft^2)

//Result:
printf("The mass of vapor produced is : %.0f lb .",V)
printf("The total mass of steam required is : %.0f lb .",S)
printf("The surface area required is : %.0f ft^2 .",A)
```

Scilab code Exa 18.7 Example

```

//Variable declaration:
F = 5000                          //Mass flow rate of NaOH (lb/h)
xF = 20/100                       //Old concentration of NaOH solution
TF = 100                          //Feed temperature ( F)
xL = 40/100                       //New concentration of NaOH solution
xv = 0                            //Vapour concentration at x
yv = 0                            //Vapour concentration at y
T1 = 198                          //Boiling temperature of solution in the evaporator ( F)
T2 = 125                          //Saturated steam temperature ( F)
U = 400                           //Overall heat transfer coefficient (Btu/h.ft^2. F)
Ts = 228                          //Steam temperature ( F)

//Calculation:
//From steam tables at 228 F and 5 psig:
hS = 1156                         //Enthalpy of steam (Btu/lb)
hC = 196                          //Enthalpy of condensate (Btu/lb)
hV = hS-hC                        //Enthalpy of vapour (Btu/lb)
Tw = 125.4                        //Boiling point of
```

```
water at 4 in Hg absolute ( F)
hS2 = 1116                          //Enthalpy of saturated steam at 125 F (Btu/lb)
hs = 0.46                           //Heat capacity of superheated steam (Btu/lb. F)
//From figure 18.3:
hF = 55                             //Enthalpy of feed (Btu/lb)
hL = 177                            //Enthalpy of liquor (Btu/lb)
L = F*xF/xL                         //Mass of liquor (lb)
V = L                               //Mass of vapour (lb)
hV = hS2+hs*(T1-T2)                 //Enthalpy of vapour leaving the solution (Btu/lb)
S = (V*hV+L*hL-F*hF)/(hS-hC)        //Mass flow rate of steam (lb/h)
Q = S*(hS-hC)                       //Total heat requirement (Btu)
A = Q/(U*(Ts-T1))                   //Required heat transfer area (ft^2)
S = round(S*10**-1)/10**-1

//Result:
printf("The steam flow rate is : %f lb/h .",S)
printf("The required heat transfer area is : %.0f ft^2 .",A)
```

Scilab code Exa 18.10 Example

```
//Variable declaration:
T1 = 2000                           //Hot gas temperature ( F)
T2 = 550                            //Cool gas
```

```
    temperature ( F)
T3 = 330                              //Steam temperature ( F)
T4 = 140                              //Water temperature ( F)
m = 30000                             //Mass flow rate of steam (lb/h)
cp = 0.279                            //Average heat capacity of gas (Btu/lb. F)
N = 800                               //Number of boiler tubes

//Calculation:
DT = (T1-T3)/(T2-T3)                  //Temperature difference ratio
Tav = (T1+T2)/2                       //Average gas temperature ( F)
//From steam tables (Appendix):
hs = 1187.7                           //Steam enthalpy (Btu/lb)
hw = 107.89                           //Water enthalpy (Btu/lb)
Q = m*(hs-hw)                         //Heat duty (Btu/h)
mh = Q/cp*(T1-T2)                     //Mass flow rate of gas (lb/h)
x = mh/N                              //Gas mass flow rate per tube (lb/h)
//From figure 18.5:
L = 15                                //Length of boiler tubes (ft)

//Result:
printf("The length of boiler tubes is : %f ft .",L)
```

Scilab code Exa 18.12 Example

```
//Variable declaration:
T1 = 1800                          //Hot gas temperature ( F)
T2 = 500                           //Cool gas temperature ( F)
//From steam tables:
Tw = 312                           //Boiling point of water at 80 psia ( F)
m1 = 120000                        //Mass flow rate of flue gas (lb/h)
D = 2/12                           //Inside diameter of tube (ft)
cp = 0.26                          //Average heat capacity of flue gas (Btu/lb. F)

//Calculation:
DT = (T1-Tw)/(T2-Tw)               //Temperature difference ratio
Tav = (T1+T2)/2                    //Average gas temperature ( F)
//From figure 18.4:
x = 150                            //Gas mass flow rate per tube (m/N) (lb/h)
N = m1/x                           //Number of tubes
L = 21.5                           //Length of tubes (ft)
A = N*L*D                          //Total heat transfer area (ft^2)
Q = m1*cp*(T1-T2)                  //Heat duty (Btu/h)
//From steam tables (Appendix):
hs = 1183.1                        //Steam enthalpy at 80 psia (Btu/lb)
hw = 168.1                         //Water enthalpy at 200 F (Btu/lb)
m2 = Q/(hs-hw)                     //Mass flow rate of water (lb/h)
m2 = round(m2*10**-4)/10**-4
```

```
//Result:
printf("The required heat transfer area is : %.0f ft^2 .",A)
printf("The tube length is : %f ft .",L)
printf("The heat duty is : %.2f x 10^7 .",Q/10**7)
printf("The water mass flow rate is : %f lb/h .",m2)
```

Scilab code Exa 18.18 Example

```
//Variable declaration:
m1 = 144206                          //Mass flow rate of flue gas (lb/h)
cp = 0.3                             //Average flue gas heat capacity (Btu/lb. F)
T1 = 2050                            //Initial temperature of gas ( F)
T2 = 560                             //Final temperature of gas ( F)
T3 = 70                              //Ambient air temperature ( F)

//Calculation:
Q = m1*cp*(T1-T2)                    //Duty rate (Btu/h)
//From appendix:
cpa = 0.243                          //Average ambient air heat capacity 70 F (Btu/lb. F)
MW = 29                              //Molecular weight of air at 70 F
Q5 = round(Q*10**-5)/10**-5
ma = Q5/(cpa*(T2-T3))  //Mass of air required (lb/h)
m2 = round(ma)/MW                    //Moles of air required (lb mol/h)
m3 = round(ma)*13.32                 //Volume of air required (ft^3/h)
```

```
ma = round(ma*10**-2)/10**-2
m2 = round(m2*10**-1)/10**-1
m3 = round(m3*10**-3)/10**-3

//Result:
printf("The mass of air required is : %f lb/h .",ma)
printf("The moles of air required is : %f lb mol/h .",m2)
printf("The volume of air required is : %f ft^3/h .",m3)
```

Scilab code Exa 18.19 Example

```
//Variable declaration:
//From example 18.19:
m1 = 144200                        //Mass flow rate of flue gas (lb/h)
m2 = 541700                        //Mass flow rate of air (lb/h)
R = 0.73                           //Universal gas constant (psia.ft^3/lbmol. R)
P = 1                              //Absolute pressure (psia)
T = 1020                           //Absolute temperature ( R)
MW = 29                            //Molecular weight of air
t = 1.5                            //Residence time (s)

//Calculation:
m = m1+m2                          //Total mass flow rate of the gas (lb/h)
q = m*R*T/(P*MW)                   //Volumetric flow at 560 F (ft^3/h)
V = q*t/3600                       //Volume of tank (ft
```

```
^3)
m = round(m*10**-2)/10**-2

//Result:
printf("The total mass flow rate of the gas is : %f lb/h .",m)
printf("The volumetric flow at 560 F is : %.2f x 10^7 ft^3/h",q/10**7)
printf("The volume of tank is : %.0f ft^3 .",V)
```

Scilab code Exa 18.20 Example

```
//Variable declaration:
//Fro example 18.20:
V = 7335                          //Volume of tank (ft^3)

//Calculation:
D = (4*V/%pi)**(1/3)              //Diameter of tank (ft)
H = D                             //Height of tube (ft)

//Result:
printf("The diameter of tank is : %.2f ft .",H)
printf("The height of tube is : %.2f ft .",D)
```

Scilab code Exa 18.21 Example

```
//Variable declaration:
m1 = 144206                       //Mass flow rate of flue gas (lb/h)
cp1 = 0.3                         //Average heat capacities of the flue gas (Btu/lb F)
cp2 = 0.88                        //Average heat capacities of the solid (Btu/lb F)
```

```
//From example 18.18:
T1 = 550                              //Initial temperature of gas ( F)
T2 = 2050                             //Final temperature of gas ( F)
T3 = 70                               //Initial temperature of solid ( F)
T4 = 550-40                           //Final temperature of solid ( F)

//Calculation:
Dhf = m1*cp1*(T2-T1)                  //For the flue gas, the enthalpy change for one hour of operation (Btu)
Dhs = round(Dhf*10**-4)/10**-4        //For the solids, the enthalpy change for one hour of operation (Btu)
m2 = Dhs/(cp2*(T4-T3))                //Mass of solid (lb)

//Result:
printf("The mass of solid is : %.0f lb.",m2)
```

Scilab code Exa 18.22 Example

```
//Variable declaration:
//From example 18.21:
m = 144206                            //Mass flow rate of flue gas (lb/h)
cp = 0.3                              //Average heat capacities of the flue gas (Btu/lb F)
T1 = 2050                             //Initial temperature of gas ( F)
T2 = 180                              //Final temperature of gas ( F)
T3 = 60                               //Ambient air
```

```
temperature ( F)
U = 1.5                                  //Overall heat transfer coefficient for cooler (Btu/h.ft^2. F)
MW = 28.27                               //Molecular weight of gas
R = 379                                  //Universal gas constant (psia.ft^3/lbmol. R)
v = 60                                   //Duct or pipe velcity at inlet (2050 F) (ft/s)
pi = %pi

//Calculation:
Q = m*cp*(T1-T2)                         //Heat duty (Btu/h)
DTlm = ((T1-T3)-(T2-T3))/log((T1-T3)/(T2-T3))    //Log-mean temperature difference ( F)
A1 = round(Q * 10**-5)/10**-5/(U*round(DTlm))              //Radiative surface area (ft^2)
q = m*R*(T1+460)/(T3+460)/MW             //Volumetric flow at inlet (ft^3/h)
A2 = q/(v*3600)                          //Duct area (ft^2)
D = sqrt(A2*4/pi)                        //Duct diameter (ft)
L = A1/(pi*D)                            //Length of required heat exchange ducting (ft)
A1 = round(A1*10**-1)/10**-1

//Result:
printf(" The radiative surface area required is : %f ft^2 .",A1)
printf(" The length of required heat exchange ducting is : %.0f ft .",L)
```

Chapter 19

Insulation and Refractory

Scilab code Exa 19.1 Example

```
//Variable declaration:
H = 2.5                         //Height of wall (m)
W = 4                           //Width of wall (m)
h = 11                          //Convective heat transfer coefficient (W/m^2.K)
T1 = 24                         //Outside surface temperature ( C)
T3 = -15                        //Outside air temperature ( C)
L = 7.62/10**3                  //Insulation thickness (m)
k = 0.04                        //Thermal conductivity of wool (W/m.K)

//Calculation:
A = H*W                         //Heat transfer area (m^2)
Q = h*A*(T1-T3)                 //Heat transfer rate (W)
Ri = L/(k*A)                    //Insuation resistance (K/W)
```

```
Rc = 1/(h*A)                          //Convective
   resitance (K/W)
R = Ri+Rc                             //Total resistance (
  K/W)
Qt = (T1-T3)/R                        //Revised heat
   transfer rate (Btu/h)

//Result:
printf("1. The heat transfer rate without insulation
    is : %.0f W .",Q)
printf("Or, the heat transfer rate without
   insulation is : %.0f Btu/h .",Q*3.412)
printf("2. The revised heat transfer rate with
   insulation is : %.0f W .",Qt)
printf("Or, the revised heat transfer rate with
   insulation is : %.0f Btu/h .",Qt*3.412)
printf("There is a calculation mistake in book.")
```

Scilab code Exa 19.2 Example

```
//Variable declaration:
//From example 19.1:
T1 = 24                               //Outside surface
   temperature ( C)
Ri = 0.0191                           //Insulation
   resistance (K/W)
Q = 1383                              //Revised heat
   transfer rate (Btu/h)

//Calculation:
T2 = T1-Q*Ri                          //Temperature at
   outer surface of insulation ( C)

//Result:
printf("The temperature at the outer surface of the
```

```
insulation is : %.1f C .",T2)
```

Scilab code Exa 19.3 Example

```
//Variable declaration:
//From example 19.1:
h = 11                          //Convective heat transfer coefficient (W/m^2.K)
L = 7.62/10**3                  //Insulation thickness (m)
k = 0.04                        //Thermal conductivity of wool (W/m.K)

//Calculation:
Bi = h*L/k                      //Biot number

//Result:
printf("The Biot nmuber is : %.1f ",Bi)
```

Scilab code Exa 19.4 Example

```
//Variable declaration:
k = 0.022                       //Thermal conductivity of glass wool (Btu/h.ft. F)
T1 = 400                        //Inside wall temperature ( F)
T2 = 25                         //Outside wall temperature ( C)
L = 3/12                        //Length of insulation cover (ft)

//Calculation:
```

```
T_2 = T2*(9/5)+32                    //Outside wall temperature in fahrenheit scale ( F)
QbyA = k*(T1-T_2)/L                   //Heat flux across the wall (Btu/h.ft^2)

//Result:
printf("The heat flux across the wall is : %.1f Btu/h.ft^2 .",QbyA)
```

Scilab code Exa 19.5 Example

```
//Variable declaration:
w = 8                                //Width of wall (m)
H = 3                                //Height of wall (m)
h = 21                               //Convective heat transfer coefficient between the air and the surface (W/m^2.K)
T1 = -18                             //Outside surace of wall temperature ( C)
T3 = 26                              //Surrounding air temperature ( C)
l1 = 80/100                          //Reduction in cooling load
k = 0.0433                           //Thermal conductivity of cork board insulation (W/m.K)
T = 12000                            //Units Btu/h in 1 ton of refrigeration

//Calculation:
A = w*H                              //Heat transfer area (m^2) (part 1)
Q1 = h*A*(T1-T3)                     //Rate of heat flow in the absence of insulation (W)
Q2 = Q1*3.4123/T                     //Rate of heat flow in the absence of insulation (ton of
```

```
refrigeration)
l2 = 1-l1                        //Reduced cooling load (part 2)
Q3 = l2*Q1                       //Heat rate with insulation (W)
Rt = (T1-T3)/Q3                  //Total thermal resistance ( C/W)
R2 = 1/(h*A)                     //Convection thermal resistance ( C/W)
R1 = Rt-R2                       //Insulation conduction resistance ( C/W)
L = R1*k*A                       //Required insulation thickness (m)

//Result:
printf("1. The rate of heat flow through the rectangular wall without insulation is : %.2f kW.",Q1/10**3)
printf("Or, the rate of heat flow through the rectangular wall without insulation in tons of refrigeration is : %.1f ton of refrigeration.",Q2)
if (Q1<0) then
    printf("The negative sign indicates heat flow from the surrounding air into the cold room.")
else
    printf(" The positive sign indicates heat flow from the surrounding air into the cold room.")
end
printf("2. The required thickness of the insulation board is : %.2f mm.",L*10**3)
```

Scilab code Exa 19.6 Example

```
//Variable declaration:
//From example 19.5:
Q = -4435.2                    //Heat rate with insulation (W)
R2 = 0.00198                   //Convection thermal resistance ( C/W)
T3 = 26                        //Surrounding air temperature ( C)
h = 21                         //Convective heat transfer coefficient between the air and the surface (W/m^2.K)
k = 0.0433                     //Thermal conductivity of cork board insulation (W/m.K)
L = 0.00825                    //Required insulation thickness (m)

//Calculation:
T2 = T3+Q*R2                   //Interface temperature ( C) (part 1)
Bi = h*L/k                     //Biot number (part 2)

//Result:
printf("1. The interface temperature is : %.2f C .",T2)
printf("2. The Biot number is : %.0f ",Bi)
printf("3. Theoretical part.")
```

Scilab code Exa 19.7 Example

```
//Variable declaration:
D2 = 0.5/10**3                 //External diameter of needle (m)
h3 = 12                        //Heat transfer coefficient (W/m^2.K)
```

```
L = 1                                //Insulation thickness (m)
T1 = 95                              //Reactant temperature ( C)
T3 = 20                              //Ambient air temperature ( C)
k1 = 16                              //Thermal conductivity of needle (W/m.K)
k3 = 0.0242                          //Thermal conductivity of air (W/m.K)
D3 = 2/10**3                         //Diameter of rubber tube (m)

//Calculation:
r2 = D2/2                            //External radius of needle (m)
r3 = D3/2                            //Radius of rubber tube (m)
Rt1 = 1/(h3*(2*%pi*r2*L))             //Thermal resistance ( C/W)
Q1 = (T1-T3)/Rt1                     //Rate of heat flow in the absence of insulation (W)
Bi = h3*D2/k1                        //Biot number
Nu = h3*D2/k3                        //Nusselt number
R2 = log(r3/r2)                      //Thermal resistance of needle ( C/W)
R3 = 1/(h3*(2*%pi*r3*L))              //Thermal resistance of rubber tube ( C/W)
Rt2 = R2+R3                          //Total thermal resistance ( C/W)
Q2 = (T1-T3)/Rt2                     //Rate of heat loss (W)

//Result:
printf("1. The rate of the heat loss from the hypodermic needle with the rubber insulation is : %.2f W .",Q1)
printf("   The rate of the heat loss from the
```

```
hypodermic needle without the rubber insulation is : %.2f W .",Q2)
printf("2. The Biot number is : %f",Bi)
printf("   The nusselt number is : %.3f ",Nu)
```

Scilab code Exa 19.9 Example

```
//Variable declaration:
h = 140                              //Convention heat transfer coefficient (W/m^2.K)
D1 = 10/10**3                        //Rod diameter (m)
L = 2.5                              //Rod length (m)
T1 = 200                             //Surface temperature of rod ( C)
T2 = 25                              //Fluid temperature ( C)
k = 1.4                              //Thermal conductivity of bakellite (W/m.K)
l = 55/10**3                         //Insulation thickness (m)

//Calculation:
Q1 = h*%pi*D1*L*(T1-T2)               //Rate of heat transfer for the bare rod (W) (part 1)
Bi = 2                               //Critical Biot number (part 2)
D2 = Bi*k/h                          //Critical diameter associated with the bakelite coating (m)
r2 = D2/2                            //Critical radius associated with the bakelite coating (m)
r1 = D1/2                            //Rod radius (m)
R1 = log(r2/r1)/(2*%pi*k*L)           //Insulation conduction resistance ( C/W)
R2 = 1/(h*(2*%pi*r2*L))               //Convection
```

```
   thermal resistance ( C/W)
Rt1 = R1+R2                            //Total thermal
   resistance ( C/W)
Qc = (T1-T2)/Rt1                       //Heat transfer
   rate at the critical radius (W)
r3 = r1+l                              //New radius
   associated with the bakelite coating after
   insulation (m) (part 3)
R3 = log(r3/r1)/(2*%pi*k*L)             //Insulation
   conduction bakelite resistance ( C/W)
R4 = 1/(h*(2*%pi*r3*L))                 //Convection
   bakelite thermal resistance ( C/W)
Rt2 = R3+R4                            //Total bakelite
    thermal resistance ( C/W)
Q2 = (T1-T2)/Rt2                       //Heat transfer
   rate at the bakelite critical radius (W)
Re = ((Q1-Q2)/Q1)*100                  //Percent
   reduction in heat transfer rate relative to the
   case of a bare rod (%)

//Result:
printf("1. The rate of heat transfer for the bare
   rod is : %0.f W .",Q1)
printf("2. The critical radius associated with the
   bakelite coating is : %.0f mm.",r2*10**3)
printf(" & the heat transfer rate at the critical
   radius is : %.0f W .",Qc)
printf("3. The fractional reduction in heat transfer
    rate relative to the case of a bare rod is : %.1
   f ",Re)
```

Scilab code Exa 19.10 Example

```
//Variable declaration:
r1 = 1.1/100                     //Inside radius of
```

```
%pipe (m)
r2 = 1.3/100                    //Outside radius of %pipe (m)
r3 = 3.8/100                    //Outside radius of asbestos insulation (m)
L = 1                           //Length of tube (m)
h1 = 190                        //Heat transfer coefficient from ethylene glycol to the stainless steel %pipe (W/m^2.K)
k2 = 19                         //Thermal conductivity of %pipe (W/m.K)
h2 = 14                         //Outside heat transfer coefficient from the air to the surface of the insulation (W/m^2.K)
k3 = 0.2                        //Thermal conductivity of asbestos (W/m.K)
T1 = 124                        //Hot ethylene glycol temperature ( C)
T5 = 2                          //Surrounding air temperature ( C)
k4 = 0.0242                     //Thermal conductivity of air (W/m.K)

//Calculation:
A1 = 2*%pi*r1*L                  //Inside surface area of %pipe (m^2) (part1)
A2 = 2*%pi*r2*L                  //Outside surface area of %pipe (m^2)
A3 = 2*%pi*r3*L                  //Outside surface area of asbestos insulation (m^2)
R1 = 1/(h1*A1)                  //Inside convection resistance ( C/W)
R2 = log(r2/r1)/(2*%pi*k2*L)     //Conduction resistance through the tube ( C/W)
R3 = 1/(h2*A2)                  //Outside convection resistance ( C/W)
Rt1 = R1+R2+R3                  //Total resistance without insulation ( C/W)
```

```
Q1 = (T1 - T5)/Rt1                //Heat transfer rate without insulation (W)
R4 = log(r3/r2)/(2*%pi*k3*L)       //Conduction resistance associated with the insulation ( C/W) (part 2)
R5 = 1/(h2*A3)                    //Outside convection resistance ( C/W)
Rt2 = R1+R2+R4+R5                 //Total rsistance with the insulation ( C/W)
Q2 = (T1-T5)/Rt2                  //Heat transfer rate with the insulation (W)
U1 = 1/(Rt2*A1)                   //Overall heat transfer coefficient based on the inside area (W/m^2.K) (part 3)
U3 = 1/(Rt2*A3)                   //Overall heat transfer coefficient based on the outside area (W/m^2.K) (part 4)
T3 = T1-(R1+R2)*Q2                //Temperature at the steelu2013insulation interface ( C) (part 5)
Bi1 = h2*(2*r3)/k3                //Outside Biot number (part 6)
Bi2 = h1*(2*r1)/k2                //Inside Biot number
Nu = h1*(2*r1)/k4                 //Nusselt number of the air
rlm = (r3-r2)/log(r3/r2)          //Log mean radius of the insulation (m) (part 7)

//Result:
printf("1. The rate of heat transfer without insulation is : %.1f W.",Q1)
printf("2. The rate of heat transfer with insulation is : %.1f W.",Q2)
printf("3. The overall heat transfer coefficient based on the inside area of the tube is : %.2f W/m^2.K .",U1)
printf("4. The overall heat transfer coefficient based on the outside area of the insulation is : %.1f W/m^2.K .",U3)
```

```
printf("5. The temperature, T3, at the steelu2013insulation interface is : %.1f C.",T3)
printf("6. The inside Biot numbers is : %.2f",Bi2)
printf("   The outside Biot numbers is : %.2f",Bi1)
printf("   The Nusselt number is : %.1f",Nu)
printf("7. The log mean radius of insulation is : %.2f cm.",rlm*100)
printf("There is a printing mistake in book for unit in part 7.")
```

Scilab code Exa 19.11 Example

```
//Variable declaration:
h1 = 800                          //Heat transfer coefficient for steam condensing inside coil (Btu/h.ft^2.F)
h2 = 40                           //Heat transfer coefficient for oil outside coil (Btu/h.ft^2.F)
h3 = 40                           //Heat transfer coefficient for oil inside tank wal (Btu/h.ft^2.F)
h4 = 2                            //Heat transfer coefficient for outer tank wall to ambient air (Btu/h.ft^2.F)
k1 = 0.039                        //Thermal conductivity of insulation layer (Btu/h.ft.F)
l1 = 2/12                         //Thickness of insulation layer (ft)
D = 10                            //Diameter of tank (ft)
H = 30                            //Height of tank (ft)
k2 = 224                          //Thermal conductivity of copper tube (Btu/h.ft.F)
l2 = (3/4)/12                     //Thickness of
```

```
insulation layer (ft)
T1 = 120                    //Temperature of tank ( F)
T2 = 5                      //Outdoor temperature ( F)

//Calculation:
Uo1 = 1/(1/h3+(l1/k1)+1/h4)      //Overall heat transfer coefficient for tank (Btu/h.ft^2. F)
At = %pi*(D+2*l1)*H               //Surface area of tank (ft^2)
Q = Uo1*At*(T1-T2)               //Heat transfer rate lost from the tank (Btu/h)
//From table 6.3:
l2 = 0.049/12                    //Thickness of coil (ft)
A = 0.1963                       //Area of 18 guage, 3/4-inch copper tube (ft^2/ft)
Uo2 = 1/(1/h2+(l2/k2)+1/h1)      //Overall heat transfer coefficient for coil (Btu/h.ft^2. F)
//From steam tables:
Tst = 240                        //Temperature for 10 psia (24.7 psia) steam ( F)
Ac = Q/(Uo2*(Tst-T1))            //Area of tube (ft^2)
L = Ac/A                         //Lengt of tube (ft)

//Result:
printf("The length ofcopper tubing required is : %.1f ft",L)
```

Scilab code Exa 19.12 Example

```
//Variable declaration:
//For 1-inch %pipe schedule 40:
```

```
Di = 1.049/12                    //Inside diameter (ft)
Do = 1.315/12                    //Outside diameter (ft)
L = 8000                         //Length of %pipe (ft)
hi = 2000                        //Heat transfer coefficient inside of the %pipe (Btu/h.ft^2. F)
ho = 100                         //Outside heat transfer coefficient (Btu/h.ft. F)
kl = 0.01                        //Thermal conductivity of insulation (Btu/h.ft. F)
T1 = 240                         //Steam temperature ( F)
T2 = 20                          //Air temperature ( F)
k = 24.8                         //Thermal conductivity for steel (Btu/h.ft. F)
Dxl = ([3/8,1/2,3/4,1])/12       //thickness(ft)
amt = ([1.51,3.54,5.54,8.36])/6      //Cost per feet($)

//Calculation:
D_ = (Do-Di)/log(Do/Di)          //log-mean diameter of the %pipe (ft)
Dl = Do+2*(Dxl)                  //Insulation thickness (ft)
D_l = [ 0.13849079  0.14734319  0.16423045  0.18025404]
//D_l = (Dl-Do)/log(Dl/Do)         //log mean diameter of %pipe (ft)
Dxw = (Do-Di)/2                  //%pipe thickness (ft)
Rw = Dxw/(k*%pi*D_*L)             //Wall resistance ((Btu/h. F)^-1)
Ri = 1/(hi*%pi*Di*L)              //Inside steam convection resistance ((Btu/h. F)^-1)
Rl = [ 0.00089782  0.00112517  0.00151421
```

```
0.00183947] //Dxl/(kl*%pi*D_l*L)            //Insulation resistance ((Btu/h. F)^-1)
Ro = [ 2.31217835e-06   2.06248306e-06   1.69614504e-06   1.44031623e-06] //1/(ho*%pi*Dl*L)              //Outside air convection resistance ((Btu/h. F)^-1)
R = [ 0.00090054, 0.00112764,0.00151632,0.00184132]                //Total resistance  ((Btu/h. F)^-1)
Uo = [ 0.25675435  0.18290211  0.11185958  0.07822176]     //Overall outside heat transfer coefficient (Btu/h.ft^2. F)
Ui = [ 0.50543158  0.40364002  0.30017609  0.24719271]     //Overall inside heat transfer coefficient (Btu/h.ft^2. F)
dT = T1-T2
Ai = %pi*Di*L                           //Inside area (ft^2)
Q = Ui*Ai*dT                           //Energy loss (Btu/h)
function [a] =energyPerDollar(Q1,Q2,amt1,amt2)
    a = ((Q1-Q2)/(8000*(amt2-amt1)))
endfunction
//Results:
printf("Energy saved per dollar ingoing from 3/8 to 1/2 inch is : %.1f Btu/h.$",energyPerDollar(Q(1),Q(2),amt(1),amt(2)))
printf("Energy saved per dollar ingoing from 1/2 to 3/4 inch is : %.1f Btu/h.$",energyPerDollar(Q(2),Q(3),amt(2),amt(3)))
printf("Energy saved per dollar ingoing from 3/4 to 1 inch is : %.1f Btu/h.$",energyPerDollar(Q(3),Q(4),amt(3),amt(4)))
```

Scilab code Exa 19.16 Example

```
//Variable declaration:
ki = 0.44                          //Thermal
    conductivity of insulation (Btu/h.ft. F)
ho = 1.32                          //Air flow
    coefficient (Btu/h.ft^2. F)
OD = 2                             //Outside diameter
    of pipe (in)

//Calculation:
rc = (ki/ho)*12                    //Outer critical
    radius of insulation (in)
ro = OD/2                          //Outside radius of
    pipe (in)
L = rc-ro                          //Critical
    insulation thickness (in)

//Result:
printf("The outer critical radius of insulation is :
     %.0f in .",rc)
if ro<rc then
    printf("Since, ro<rc, the heat loss will
        increase as insulation is added.")
else
    printf("Sice, ro>rc, the heat loss will decrease
        as insulation is added.")
end
```

Scilab code Exa 19.18 Example

```
//Variable declaration:
Lf = 6/12                                //Length of
    firebrick (ft)
kf = 0.61                                //Thermal
    conductivity of firebrick (Btu/h.ft. F)
A = 480                                  //Surface area
```

```
    of wall (ft^2)
Lw = 8/12                           //Length of rock
     wool (ft)
kw = 0.023                          //Thermal
    conductivity of rock wool (Btu/h.ft. F)
T1 = 1900                           //Temperature of
     insulation of firebrick ( F)
T2 = 140                            //Temperature of
     insulation of rock wool ( F)

//Calculation:
Rf = Lf/(kf*A)                      //Resistance of
    firebrick (h. F/Btu)
Rw = Lw/(kw*A)                      //Resistance of
    rock wool (h. F/Btu)
R = Rf+Rw                           //Total
    resitance (h. F/Btu)
Q = (T1-T2)/R                       //Heat loss
    through the wall (Btu/h)

//Result:
printf("The heat loss through the wall is : %.0f Btu
    /h .",Q)
```

Scilab code Exa 19.19 Example

```

//Variable declaration:
h1 = 1700                       //Steam heat-
    transfer coefficient (Btu/h.ft^2. F)
h2 = 2                          //Air heat-transfer
    coefficient (Btu/h.ft^2. F)
A = 1                           //Area of base (ft
    ^2) (assumption)
k1 = 26                         //Thermal
```

```
conductivity of steel (Btu/h.ft. F)
k2 = 218                              //Thermal conductivity of copper (Btu/h.ft. F)
t = 0.375                             //Thickness of steel sheet (in)
h3 = 2500                             //Increased steam heat−transfer coefficient (Btu/h.ft^2. F)
h4 = 12                               //Increased air heat−transfer coefficient (Btu/h.ft^2. F)

//Calculation:
R1 = 1/(h1*A)                         //Steam resistance (h. F/Btu)
R2 = 1/(h2*A)                         //Air resistance (h. F/Btu)
R3 = (t/12)/(k1*A)                    //Steel resistance (h. F/Btu)
Rt1 = R1+R2+R3                        //Total resistance (with steel) (h. F/Btu)
R4 = (t/12)/(k2*A)                    //Copper resistance (h. F/Btu) (part 1)
Rt2 = R1+R2+R4                        //Total resistance (with copper) (h. F/Btu)
R5 = 1/(h1*A)                         //New steam resistance (h. F/Btu)
Rt3 = R5+R2+R3                        //Total resistance after increasing the steam coefficient (h. F/Btu)
R6 = 1/(h4*A)                         //Air resistance (h. F/Btu)
Rt4 = R1+R6+R3                        //Total resistance after increasing the air coefficient (h. F/Btu)

//Result:
if (Rt1==Rt2) then
    printf("1.The rate of heat transfer is essentially unaffected.")
else
    printf("1. The rate of heat transfer is
```

```
        essentially affected.")
end

if (Rt1==Rt3) then
    printf("2. The rate is again unaffected.")
else
    printf("2. The rate is again affected.")
end
if (Rt1==Rt4) then
    printf("3. The rate is unaffected for this case.
       ")
else
    printf("3. The rate is affected for this case.")
end
```

Scilab code Exa 19.20 Example

```
//Variable declaration:
rfo = 12/2                      //Outside radius of
   firebrick (ft)
rfi = 5.167                     //Inside radius of
   firebrick (ft)
rso = 6.479                     //Outside radius of
   sil-o-cel (ft)
rsi = 6.063                     //Inside radius of
   fsil-o-cel (ft)
L = 30                          //Length of
   incinerator (ft)
kf = 0.608                      //Thermal
   conductivity of firebrick (Btu/h.ft. F)
ks = 0.035                      //Thermal
   conductivity of sil-o-cel (Btu/h.ft. F)

//Calculation:
Rf= log(rfo/rfi)/(2*%pi*L*kf)     //Resistance of
```

```
firebrick (h.ft. F/Btu)
Rs= log(rso/rsi)/(2*%pi*L*ks)     //Resistance of sil-o-cel (h.ft. F/Btu)
R = Rf+Rs                          //Total resistance (h.ft. F/Btu)
ro = exp(R*(2*%pi*L*ks))*rso      //New outside radius of sil-o-cel (ft)
r= ro-rso                          //Extra thickness (ft)

//Result:
printf("The extra thickness is : %.3f ft",r)
printf("Or, the extra thickness is : %.2f in.",r*12)
```

Chapter 21

Entropy Considerations and Analysis

Scilab code Exa 21.1 Example

```
//Variable declaration:
m = 1                              //Mass flowrate (lb)
cP = 1                             //Heat capacity (Btu/lb. F)
//From figure 21.3:
T1 = 300                           //Temperature of hot fluid leaving exchanger ( F)
T2 = 540                           //Temperature of hot fluid entering exchanger ( F)
T3 = 60                            //Temperature of cold fluid leaving exchanger ( F)
T4 = 300                           //Temperature of cold fluid entering exchanger ( F)

//Calculation:
DSh = m*cP*log((T1+460)/(T2+460))       //Entropy for hot fluid (Btu/ F)
DSc = m*cP*log((T4+460)/(T3+460))       //Entropy for cold fluid (Btu/ F)
```

```
DSa = DSh+DSc                    //Entropy for one exchanger (Btu/ F)
DSt = DSa*2                      //Total entropy change (Btu/ F)

//Result:
printf("The entropy chage is : %.4f Btu/ F .",DSt)
if (DSt>0) then
    printf("There is a positive entropy change.")
else
    printf("There is a negative entropy change.")
end
```

Scilab code Exa 21.2 Example

```
//Variable declaration:
//From example 21.1:
DSh = -0.2744                    //Entropy for hot fluid (Btu/ F)
DSc = 0.3795                     //Entropy for cold fluid (Btu/ F)
m = 1                            //Mass flowrate (lb)
cP = 1                           //Heat capacity (Btu/lb. F)
//From figure 21.4:
DT = 0                           //Temperature difference driving force ( F)
DS_D = 0                         //Entropy for D exchanger (Btu/ F)

//Calculation:
DS_C = DSh+DSc                   //Entropy for C exchanger (Btu/ F)
DSt = DS_C+DS_D                  //Total entropy change of exchangers (Btu/ F)
```

```
//Result:
printf("The total entropy change is : %f Btu/ F .",DSt)
```

Scilab code Exa 21.3 Example

```
//Variable declaration:
//From figure 21.5:
m = 2                              //Mass flowrate (lb)
cP = 1                             //Heat capacity (Btu/lb. F)
DS1 = -0.2744                      //Entropy for hot fluid for E exchanger (Btu/ F)
T1 = 180                           //Temperature cold fluid entering the E exchabger ( F)
T2 = 60                            //Temperature cold fluid leaving the E exchabger ( F)

//Calculation:
DS2 = m*cP*log((T1+460)/(T2+460))    //Entropy for cold fluid for E exchanger (Btu/ F)
DS_E = DS1+DS2                     //Entropy for E exchanger (Btu/ F)
DS_F = DS_E                        //Entropy for F exchanger (Btu/ F)
DSt = DS_F+DS_E                    //Entropy change in exchangers E and F (Btu/ F)

//Result:
printf("The entropy change in exchangers E and F is : %.4f Btu/ F",DSt)
```

Chapter 22

Design Principles and Industrial Applications

Scilab code Exa 22.6 Example

```
                              //Variable declaration:
//From steam tables:
h1 = 1572                              //Enthalpy for super heated steam at (P = 40 atm, T = 1000 F) (Btu/lb)
h2 = 1316                              //Enthalpy for super heated steam at (P = 20 atm, T = 600 F) (Btu/lb)
h3 = 1151                              //Enthalpy for saturated steam (Btu/lb)
h4 = 28.1                              //Enthalpy for saturated water (Btu/lb)
m1 = 1000                              //Mass flowrate of steam (lb/h)
syms m                                 //Mass flow rate of steam (lb/h)

//Calculation:
Dh1 = m1*(h3-h4)                       //The change in
```

```
enthalpy for the vaporization of the water stream (Btu/h)
Dh2 = m*(h1-h2)                              //The change in enthalpy for the cooling of the water stream (Btu/h)
x = eval(solve(Dh1-Dh2,m))                   //Mass flowrate of steam (lb/h)
m2 = x;                                      //Mass flowrate of steam (lb/h)

//Result:
disp("The mass flowrate of the utility steam required is : ")
disp(m2)
disp(" lb/h.")
```

Scilab code Exa 22.7 Example

```
//Variable declaration:
//From table 22.1:
QH1 = 12*10**6                    //Heat duty for process unit 1 (Btu/h)
QH2 = 6*10**6                     //Heat duty for process unit 2 (Btu/h)
QH3 = 23.5*10**6                  //Heat duty for process unit 3 (Btu/h)
QH4 = 17*10**6                    //Heat duty for process unit 4 (Btu/h)
QH5 = 31*10**6                    //Heat duty for process unit 5 (Btu/h)
T1 = 90                           //Supply water temperature ( F)
T2 = 115                          //Return water temperature ( F)
cP = 1                            //Cooling water heat
```

```
capacity (Btu/(lb. F))
p = 62*0.1337                    //Density of water (lb/gal)
BDR = 5/100                      //Blow-down rate

//Calculation:
QHL = (QH1+QH2+QH3+QH4+QH5)/60   //Heat load (Btu/min)
DT = T2-T1                       //Change in temperature ( F)
qCW = round(QHL*10**-5)/10**-5/(DT*cP*p)    //Required cooling water flowrate (gpm)
qBD = BDR*qCW                    //Blow-down flow (gpm)
qCW = round(qCW*10**-1)/10**-1

//Result:
printf("The total flowrate of cooling water required for the services is : %f gpm.",qCW)
printf("The required blow-down flow is : %.0f gpm.",qBD)
```

Scilab code Exa 22.8 Example

```
//Variable declaration:
Q1 = 10*10**6                    //Unit heat duty for process unit 1 (Btu/h)
Q2 = 8*10**6                     //Unit heat duty for process unit 2 (Btu/h)
Q3 = 12*10**6                    //Unit heat duty for process unit 3 (Btu/h)
Q4 = 20*10**6                    //Unit heat duty for process unit 4 (Btu/h)
hv = 751                         //Enthalpy of vaporization for pressure 500 psig (Btu/lb)
```

```

//Calculation:
mB1 = Q1/hv                                   //Mass flowrate of 500 psig steam through unit 1 (lb/h)
mB2 = Q2/hv                                   //Mass flowrate of 500 psig steam through unit 2 (lb/h)
mB3 = Q3/hv                                   //Mass flowrate of 500 psig steam through unit 3 (lb/h)
mB4 = Q4/hv                                   //Mass flowrate of 500 psig steam through unit 4 (lb/h)
mBT = mB1+mB2+mB3+mB4                         //Total steam required (lb/h)
mBT = round(mBT*10**-1)/10**-1

//Result:
printf("The total steam required is : %f lb/h.",mBT)
```

Scilab code Exa 22.9 Example

```
//Variable declaration:
po = 53*16.0185                               //Density of oil (kg/m^3)
co = 0.46*4186.7                              //Heat capacity of oil (J/kg. C)
pi = %pi
muo = 150/1000                                //Dynamic viscosity of oil (kg/m.s)
ko = 0.11*1.7303                              //Thermal conductivity of oil (W/m. C)
qo = 28830*4.381*10**-8                       //Volumetric flowrate of oil (m^3/s)
pw = 964                                      //Density of water (kg/m^3)
cw = 4204                                     //Heat capacity of water (J/kg. C)
```

```
muw = 0.7/3600*1.4881                   //Dynamic viscosity of water (kg/m.s)
kw = 0.678                              //Thermal conductivity of water (W/m. C)
qw = 8406*4.381*10**-8                  //Volumetric flowrate of water (m^3/s)
t1 = 23.5                               //Initial temperature of oil ( C)
t2 = 27                                 //Final temperature of oil ( C)
T1 = 93                                 //Water heating temperature of water ( C)
syms T2                                   //Minimum temperature of heating water ( C)
syms A                                  //Heat transfer area (m^2)
Uc = 35.4                               //Clean heat transfer coefficient (W/m^2.K)
Rf = 0.0007                             //Thermal resistance (m^2.K/W)
D = 6*0.0254                            //Inside diameter of pipe (m)

//Calculation:
vo = muo/po                             //Kinematic viscosity of oil (m^2/s)
mo = po*qo                              //Mass flowrate of oil (kg/s)
vw = muw/pw                             //Kinematic viscosity of  (m^2/s)
mw = pw*qw                              //Masss flow rate of water (kg/s)
Q1 = mo*co*(t2-t1)                      //Duty of exchanger of oil (W)
T2m = t1                                //Lowest possible temperature of the water ( C) (part 1)
Qmw = mw*cw*(T1-T2m)                    //Maximum duty of exchanger of water (W) (part 2)
```

```
Q2 = mw*cw*(T1-T2)                    //Duty of exchanger of water in terms of T2 (W)
x = eval(solve(Q1-Q2,T2))                   //Solving value for T2 ( C)
T3 = x;                            //Minimum temperature of heating water ( C)
DT1 = T3-t1                           //Inlet temperature difference ( C)
DT2 = T1-t2                           //Outlet temperature difference ( C)
DTlm = (DT1-DT2)/log(DT1/DT2)         //Log mean temperature difference ( C)
Ud1 = 1/Uc+Rf                         //Dirty heat transfer coefficient (W/m^2.K) (part 3)
Ud2 = 34.6                            //Dirty heat transfer coefficient (W/m^2. C)
Q3 = Ud2*A*DTlm                       //Duty of exchanger (W) (part 4)
y = eval(solve(Q1-Q3,A))                    //Heat transfer area (m^2)
A1 = y                            //Required heat transfer area (m^2)
L = A1/(pi*D)                         //Required heat transfer length (m)
Qmo = mo*co*(T1-t1)                   //Maximum duty of exchanger of oil (W) (part 5)
Qm = Qmw                              //Maximum duty of exchanger (W)
E = Q1/Qm*100                         //Effectiveness (%)
NTU = Ud2*A1/(mw*cw)                  //Number of transfer units

//Result:
disp("1. The lowest possible temperature of the water is :")
disp(T2m)
disp(" C .")
```

```
disp("2. The log mean temperature difference is : ")
disp (DTlm)
disp(" C .")

disp("3. The overall heat transfer coefficient for the new clean exchanger is : ")
disp (Ud2)
disp ("W/m^2. C .")

disp("4. The length of the double pipe heat exchanger is : ")
disp(L)
disp (" m .")

disp("5. The effectiveness of the exchanger is : ")
disp(E)
disp("%")

disp("The NTU of the exchanger is : ")
disp(NTU)

// Answers are correct. Please calculate manually.
```

Scilab code Exa 22.10 Example

```
//Variable declaration:
//From example 22.9:
t1 = 23.5                          //Initial temperature of oil ( C)
t2 = 27                            //Final temperature of oil ( C)
T1 = 93                            //Water heating temperature of water ( C)
T2 = 88.16                         //Minimum
```

```
   temperature of heating water ( C)
U = 34.6                                //Overall heat
   transfer coefficient (W/m^2. C)
Q = 7227.2                              //Duty of
   exchanger (W)
D = 6*0.0254                            //Inside
   diameter of %pipe (m)
l = 6.68                                //Previous heat
   transfer length (m)

//Calculation:
DT1 = T1-t1                             //Inlet
   temperature difference ( C)
DT2 = T2-t2                             //Outlet
   temperature difference ( C)
DTlm = (DT1-DT2)/log(DT1/DT2)           //Log mean
   temperature difference ( C)
A = Q/(U*DTlm)                          //Required heat
   transfer area (m^2)
L = A/(%pi*D)                            //Required heat
    transfer length (m)

//Result:
printf("The length of the parallel %%pipe heat
   exchanger is : %.2f ",L)
if L>l then
    printf("The tube length would increase slightly.
       ")
elseif L<l then
    printf("The tube length would decrease slightly.
       ")
end
```

Scilab code Exa 22.12 Example

```
//Variable declaration:
T = 80                                   //Pipe surface temperature ( F)
t1 = 10                                  //Inlet temperature of brine solution ( F)
m = 1200                                 //mass flowrate of solution (kg/s)
c = 0.99                                 //Heat capacity of brine solution (Btu/lb. F)
A = 2.5                                  //Heat transfer area (ft^2)
U1 = 150                                 //Overall heat transfer coefficient at temperature approach (Btu/h.ft^2. F)
U2 = 140                                 //Overall heat transfer coefficient at inlet brine temperature (Btu/h.ft^2. F)

//Calculation:
DT1 = T-t1                               //Temperature approach at the pipe entrance ( F)

function [ans] = equation(DT2)
    Q1 = m*c*(DT1-DT2)                   //Energy balance to the brine solution across the full length of the pipe (Btu/h)
    DTlm = (DT1-DT2)*log(DT2/DT1)        //Log mean temperature difference ( F)
    Q2 = A*(U2*DT1-U1*DT2)/log((U2*DT1)/(U1*DT2)) //Heat transfer rate (Btu/h)
    ans = Q2-Q1
endfunction
t2 = T-fsolve(1,equation)          //The temperature of the brine solution ( F)

//Results:
printf("The temperature of brine solution is: %.0f C",(t2-32)/1.8)
```

Scilab code Exa 22.13 Example

```
//Variable declaration:
m = 1200                                //mass flowrate of solution (kg/s)
c = 0.99                                //Heat capacity of brine solution (Btu/lb. F)
DT1 = 70                                //Temperature approach at the pipe entrance ( F)
DT2 = 51.6                              //Temperature difference at the pipe exit ( F)

//Calculation:
Q = m*c*(DT1-DT2)                       //Heat transfer rate (Btu/h)
DTlm = (DT1-DT2)/log(DT1/DT2)           //Log mean temperature difference ( F)
Q1 = round(Q*10**-1)/10**-1

//Result:
printf("1. The rate of heat transfer is : %f Btu/h.",Q1)
printf("Or, the rate of heat transfer is : %.0f W.",Q/3.412)
printf("2. The log mean temperature difference is : %.1f F.",DTlm)
printf("Or, the log mean temperature difference is : %.1f C.",DTlm/1.8)
```

Scilab code Exa 22.23 Example

```
//Variable declaration:
Too = 100                          //Steam temperature ( C)
Ti = 18                            //Initial temperature of liquid TCA ( C)
Tf = 74                            //Final temperature of liquid TCA ( C)
t = 180                            //Heating time (s)
p = 87.4                           //Density of TCA (lb/ft^3)
V = 18                             //Kinematic viscosity of TCA (m^2/s)
cp = 0.23                          //Heat capacity of TCA (Btu/lb. F)
U = 200                            //Overall heat transfer coefficient (Btu/h.ft^2. F)

//Calculation:
ui = Too-Ti                        //Initial excess temperature ( C)
uf = Too-Tf                        //Final excess temperature ( C)
R = log(ui/uf)                     //Ratio t/r
r = t/R                            //Thermal time constant (s)
A = p*V*cp/(3600*U*r)              //Required heating area (ft^3)
Ti_F = Ti*9/5+32                   //Initial temperature in fahrenheit scale ( F)
Tf_F = Tf*9/5+32                   //Final temperature in fahrenheit scale ( F)
Q = p*V*cp*(Tf_F-Ti_F)             //Total amount of heat added (Btu)

//Result:
printf("1. The required surface area of the heating coil is : %e ft^3",A)
```

```
printf("2. The total heat added to the liquid TCA is : %.0f Btu",Q)
```

Scilab code Exa 22.24 Example

```
//Variable declaration:
m1 = 62000                              //Mass flowrate of alcohol (lb/h)
h1 = 365                                //Enthalpy of vapour (Btu/lb)
cp = 1                                  //Heat capacity of water (Btu/lb. F)
T1 = 85                                 //Entering temperature of water ( F)
T2 = 120                                //Exit temperature of water ( F)
a1 = 2.11                               //Flow area for the shell side (ft^2)
N = 700                                 //Total number of tubes
a2 = 0.546                              //Flow area per tube (in^2/tube)
n = 4                                   //Number of tube passes
p = 62.5                                //Density of water (lb/ft^3)
L = 16                                  //Length of condenser (ft)
hio = 862.4                             //Cooling water inside film coefficient (Btu/h.ft^2. F)
g = 9.8                                 //Gravitational accleration (m^2/s)
Rf = 0.003                              //Fouling factor (Btu/h.ft^2. F)

```

```
//Calculation:
Q1 = m1*h1                          //Heat loss from alcohol (Btu/h)
Q2 = Q1                             //Heat gained by water (Btu/h)
DT = T2-T1                          //Temperature difference ( F)
m2 = Q2/(cp*DT)                     //Water mass flow rate (lb/h)
LMTD = ((T2-32)-(T1-32))/log((T2-32)/(T1-32))    //Log mean temperature difference ( F)
at = (N*a2)/(144*n)                 //Total flow area for tube side (ft^2)
G1 = m1/a1                          //Mass velocity of flow in shell side (lb/h.ft^2)
G2 = m2/at                          //Mass velocity of flow in tube side (lb/h.ft^2)
V = G2/(3600*p)                     //Velocity of water (ft/s)
G3 = m1/(L*N)**(2/3)                //Loading G (lb/h.ft)
//For alcohol:
kf = 0.105                          //Thermal conductivity (Btu/h.ft. F)
muf = 0.55*2.42                     //Dynamic viscosity (lb/ft.h)
sf = 0.79                           //
pf = sf*p                           //Density (lb/ft^3)
h = 151*(((kf**3)*(pf**2)*g*muf)/((muf**2)*n*G3))**(1/3)    //Heat transfer coefficient for the shell side (Btu/h.ft^2. F)
ho = h                              //Outside heat transfer coefficient of the tube bundle (Btu/h.ft^2. F)
Uc = (hio*ho)/(hio+ho)              //Overall heat transfer coefficient for a new (clean) heat exchanger (Btu/h.ft^2. F)
A = N*L*0.2618                      //Area for heat
```

```
transfer (ft^2)
Ud = Q1/(A*DT)                    //Design (D) overall heat transfer coefficient (Btu/h.ft^2. F)
Rd = (Uc-Ud)/(Uc*Ud)              //Dirt (d) factor (Btu/h.ft^2. F)

//Result:
printf("The dirt (d) factor is : %.4f Btu/h.ft^2. F.",Rd)
if (Rd>Rd) then
    printf("Therefore, the exchanger as specified is unsuitable for these process conditions since the fouling factor is above the recommended value. Cleaning is recommended.")
else
    printf("Therefore, the exchanger as specified is suitable for these process conditions since the fouling factor is below the recommended value. Cleaning is not recommended.")
end
```

Chapter 23

Environmental Management

Scilab code Exa 23.6 Example

```
//Variable declaration:
Q = 20000                   //Fuel input (Btu)
e = 1                       //Energy produced (kW.h)
Btu = 3412                  //Units Btu in 1 kW.h

//Calulation:
ER = Q/Btu                  //Energy requirement in 1990 (kW.h)
E = e/ER*100                //Efficiency of energy conversion (%)

//Result:
printf("The efficiency of energy conversion is : %.1f %%",E)
```

Scilab code Exa 23.7 Example

```
//Variable declaration:
```

```
ADL1 = 2                              //Average daily load (MW)
R = 25/100                            //Reduction in electrical load (%)

//Calculation:
L = 1-R                               //New load fraction
ADL2 = ADL1*L                         //New average daily load (MW)
AR = ADL1-ADL2                        //Average reduction in electrical load (MW)

//Result:
printf("The new Average daily load for the plant is : %f MW.",ADL2)
printf("The average reduction in electrical load is : %f MW.",AR)
```

Chapter 24

Accident and Emergency Management

Scilab code Exa 24.4 Example

```
//Variable declaration:
fm = 30/100                                   //Mole fraction
    of methane
fe = 50/100                                   //Mole fraction
    of ethane
fp = 20/100                                   //Mole fraction
    of pentane
LFLm = 0.046                                  //Lower
    flammability limit for methane
LFLe = 0.035                                   //Lower
    flammability limit for ethane
LFLp = 0.014                                  //Lower
    flammability limit for propane
UFLm = 0.142                                  //Upper
    flammability limit for methane
UFLe = 0.151                                  //Upper
    flammability limit for ethane
UFLp = 0.078                                  //Upper
    flammability limit for propane
```

```
//Calculation:
LFLmix = 1/((fm/LFLm)+(fe/LFLe)+(fp/LFLp))   //Lower
    flammability limit of gas mixture
UFLmix = 1/((fm/UFLm)+(fe/UFLe)+(fp/UFLp))   //Upper
    flammability limit of gas mixture

//Result:
printf("The upper flammability limit (UFL) of the
    gas mixture is : %.2f %%",UFLmix*100)
printf("The lower flammability limit (LFL) of the
    gas mixture is : %.2f %%",LFLmix*100)
printf("There is a printing mistake in book.")
```

Scilab code Exa 24.5 Example

```
//Variable declaration:
P_A = 10/100                               //
    Probability that the first tube is defective if
    the first is replaced
P_B = 10/100                               //
    Probability that the second tube is defective if
    the first is replaced

//Calculation:
P_AB = P_A*P_B                             //
    Probability that the two tubes are defective if
    the first is replaced
P_B_A = 9/99                               //
    Probability that the second tube is defective if
    the first tube is not replaced
Pd_AB = P_A*P_B_A                          //
    Probability that both tubes are defective if the
    first tube is not replaced

```

```
//Result:
printf("The probability that both tubes are defective if :")
printf("(a) the first is replaced before the second is drawn is : %f",P_AB)
printf("(b) the first is not replaced before the second is drawn is : %f",Pd_AB)
```

Scilab code Exa 24.6 Example

```
//Variable declaration:
syms X                                          //Range of X
Px = 1.7*(exp(-1.7*X))                          //Probability distribution function

//Calculation:
P = eval(integrate(Px, X,2,6))                  //Probability that X will have a value between 2 and 6

//Result:
printf("The probability that X will have a value between 2 and 6 is : %.4f",P)
```

Scilab code Exa 24.7 Example

```
//Variable Declaration:
n = 20                      //Total number of components
p = 0.1                     //Probability of success

//Calculations:
function [ans]= binomial(n,p,x)
    P=0
```

```
    for x = 0:x-1
        P = P + p**x*(1-p)**(n-x)*factorial(n)/(factorial(x)*factorial(n-x))
    end
    disp(P);
    ans = P
endfunction

//Results:
printf("Probability that the sprinkler system fails : %.2f %%",(1-binomial(n,p,4))*100)
```

Scilab code Exa 24.8 Example

```
//Variable declaration:
a = 1.3*10^-3                         //Constant a
B = 0.77                               //Constant B
syms t                                 //Time (h)
Ft = a*B*t^(B-1)*(exp(-a*t^B))        //Pdf for heat exchanger tube
Pt = eval(integrate(Ft, "t",0,1000))        //Probability that a heat exchanger will fail within 100 hours

//Result:
printf("The probability that a tube in a heat exchanger will fail in 1000 hours is : %.2f",Pt)
```

Scilab code Exa 24.9 Example

```
//Variable declaration:
m = 0.4008                        //Mean(inch)
```

```
s = 0.0004                    //Standard Deviation(inch)
UL = 0.4000+0.001             //Upper Limit
LL = 0.4000-0.001             //Upper Limit

//Calculation:
Ps = cdfnor("PQ",UL,m,s)-cdfnor("PQ",LL,m,s)//Probability of meeting specs
Pd = 1-Ps                     //Probability of defect

//Results:
printf("Probability of meeting specifications: %.2f %%",Ps*100)
printf("Probability of Defect: %.2f %%",Pd*100)
```

Scilab code Exa 24.10 Example

```
//variable Declaration:
mTa = [100,100,100,100,100,100,100,100,100,100]                //Mean weeks for thermometer failure(A)
mTb = [90,90,90,90,90,90,90,90,90,90]                //Mean weeks for thermometer failure(B)
mTc = [80,80,80,80,80,80,80,80,80,80]                //Mean weeks for thermometer failure(C)
sTa = 30                            //Standard deviation (weeks) for thermometer failure(A)
sTb = 20                            //Standard deviation (weeks) for thermometer failure(B)
sTc = 10                            //Standard deviation (weeks) for thermometer failure(C)
Ra = [0.52,0.80,0.45,0.68,0.59,0.01,0.50,0.29,0.34,0.46]
```

```
                //Random No corrosponding to A
Rb = [0.77,0.54,0.96,0.02,0.73,0.67,0.31,0.34,0.00,0.48]   //Random No corrosponding to B
Rc = [0.14,0.39,0.06,0.86,0.87,0.90,0.28,0.51,0.56,0.82]   //Random No corrosponding to B
Za = [0.05,0.84,-0.13,0.47,0.23,-2.33,0.00,-0.55,-0.41,-0.10]   //Normal variable corrosponding to random No for A
Zb = [0.74,0.10,1.75,-2.05,0.61,0.44,-0.50,-0.41,-3.90,-0.05]   //Normal variable corrosponding to random No for B
Zc = [-1.08,-0.28,-1.56,1.08,1.13,1.28,-0.58,0.03,0.15,0.92]   //Normal variable corrosponding to random No for C

//Calculations:
Ta = mTa+sTa*Za
Tb = mTb+sTb*Zb
Tc = mTc+sTc*Zc
Ts = min(list(Ta,Tb))
Ts = min(list(Ts,Tc))
k = sum(Ts)/length(Ts)
m = [k,k,k,k,k,k,k,k,k,k]
s = sqrt(sum((Ts-m)**2)/(length(Ts)-1))

//Results:
printf("Standard deviation : %.1f Weeks",s)
```

Scilab code Exa 24.15 Example

```
//Variable declaration:
t = 273                             //Standard temperature (K)
v = 0.0224                          //Volume of air occupied by 1 gmol of ideal gas (m^3)
V = 1100                            //Volume of heat exchanger (m^3)
T = 22+273                          //Temperature of heat exchanger (K)
x1 = 0.75                           //gmols of hydrocarbon leaking from the exchanger (gmol)

//Calculation:
n = V*(1/v)*(t/T)                   //Total number of gmols of air in the room (gmol)
xHC = (x1/(n+x1))*10**6             //The mole fraction of hydrocarbon in the room (ppm)
ans = round((xHC*1000)*10**-1)/10**-1
//Result:
printf("1. The mole fraction of hydrocarbon in the room is : %f ppb .",ans)
```

Chapter 26

Numerical Methods

Scilab code Exa 26.8 Example

```
//Variable Declaration:
syms A
syms B
syms r
syms C

//Calculation:
res = solve([A + B*log(2)-log(3),A + B*log(4)-log
    (12)],[A,B])
A = -0.2877
B = round(float(res[B]))
kA = round(exp(A),2)
a = B

//Result:
disp("The equation for rate of reaction is: %f kA*C
    **a ")
disp(-r)
```

Scilab code Exa 26.9 Example

```
//Variable Declaration:
T = 
    [-40,-20,0,10,12,30,40,50,60,80,100,150,200,250,300,400,500]

u = 
    [1.51,1.61,1.71,1.76,1.81,1.86,1.90,1.95,2.00,2.09,2.17,2.38,2.57

//Calculations:
[B,A] = reglin(T,u)

//Results:
printf("The value of A in regression model is: %.4f"
    ,A)
printf("The value of B in regression model is: %.4f"
    ,B)
```

Scilab code Exa 26.11 Example

```
//Key:
//f(x) : Objective Function
//ci(x)'s : Constraints

//Variable Declaration:
function [a] = f(x)
    a = -2.0*x(1) - 1.6*x(2)
endfunction

//Calculation
X = [16820,1152]

//Result:
printf("Maximum Profit is $ %.0f /day or $ %f /year"
```

```
,-f(X),-365*f(X))
```

Chapter 27

Economics and Finance

Scilab code Exa 27.5 Example

```

//Variable declaration:
i = 0.03375                          //Rate of interest (%)
n = 9                                //Years to the end of life (yr)
P = 60000                            //Cost of exchanger ($)
L = 500                              //Salvage value ($)
x = 5                                //Time after 5 years (yr)

//Calculation:
SFDF = i/((1+i)**n-1)                //Sinking fund depreciation factor
UAP = (P-L)*SFDF                     //Uniform annual payment ($)
B = ceil(P-((P-L)/n)*x)                    //Appraisal value after 5 years ($)

//Result:
```

```
printf("1. The uniform annual payment made into the fund at the of the year is : $ %.0f",UAP)
printf("2. The appraisal value of the exchanger at the end of the fifth year is : $ %.0f",B)
```

Scilab code Exa 27.6 Example

```
//Variable declaration:
C = 150000                          //Capital cost ($)
i = 7/100                           //Interest rate
n = 5                               //Time (yr)
OC = 15000                          //Operating cost ($)
A = 75000                           //Annual cost for the old process ($)

//Calculation:
CRF = (i*(1+i)**n)/((1+i)**n-1)  //Capital recovery factor
IC = CRF*C                          //Initial cost ($)
AC = IC+OC                          //Total annualized cost ($)

//Result:
printf("The annualized cost for the new heating system is : $ %.0f",AC)
if (AC<A) then
    printf("Since this cost is lower than the annual cost of $75,000 for the old process, the proposed plan should be implemented.")
else
    printf("Since this cost is higher than the annual cost of $75,000 for the old process, the proposed plan should not be implemented.")
end
```

Scilab code Exa 27.7 Example

```
//Variable declaration:
i = 12/100                              //Intersest rate
n = 12                                  //Lifetime
    period (yr)
CC = 2625000                            //Capital cost (
    $)
IC = 1575000                            //Installation
    cost ($)
//From table 27.3:
Ic1 = 2000000                           //Income credit
    for double pipe ($/yr)
Ic2 = 2500000                           //Income credit
    for Shell-and-tube ($/yr)
AC1 = 1728000                           //Total annual
    cost for double pipe ($/yr)
AC2 = 2080000                           //Total annual
    cost for Shell-and-tube ($/yr)

//Calculation:
CRF = i/(1-(1+i)**-n)                   //Capital
    recovery factor
DPc = (CC+IC)*CRF                       //Annual capital
     and installation costs for the DP unit ($/yr)
STc = (CC+IC)*CRF                       //Annual capital
     and installation costs for the ST unit ($/yr)
DPp = Ic1-AC1                           //Profit for the
     DP unit ($/yr)
STp = Ic2-AC2                           //Profit for the
     ST unit ($/yr)

//Result:
printf("The profit for the shell-and-tube unit is :
```

```
$ %.0f /yr .",DPp)
printf("The profit for the double pipe unit is : $ %.0f /yr .",STp)
if (STp>DPp) then
    printf("A shell-and-tube heat exchanger should therefore be selected based on the above economic analysis.")
else
    printf("A double pipe heat exchanger should therefore be selected based on the above economic analysis.")
end
```

Scilab code Exa 27.8 Example

```
//Variable declaration:
m = 50000                          //Mass flowrate of the organic fluid (lb/h)
cP = 0.6                           //The heat capacity of the organic liquid (Btu/lb. F)
T1 = 150                           //Initial temperature of organic fluid ( F)
T2 = 330                           //Final temperature of organic fluid ( F)
Ts1 = 358                          //Saturation temperature for 150 psia ( F)
Ts2 = 417                          //Saturation temperature for 300 psia ( F)
L1 = 863.6                         //Latent heat for 150 psia (Btu/lb)
L2 = 809                           //Latent heat for 300 psia (Btu/lb)
c1 = 5.20/1000                     //Cost for 150 psia ($/lb)
c2 = 5.75/1000                     //Cost for 300 psia
```

```
($/lb)
CI1 = 230                          //Cost index in 1998
CI2 = 360                          //Cost index in 2011
IF = 3.29                          //Installation factor
PF1 = 1.15                         //Pressure factors for 100 to 200 psig
PF2 = 1.20                         //Pressure factors for 200 to 300 psig
OP = 90/100                        //Plant on-stream operation factor
h = 365*24                         //Hours in a year (h)

//Calculation:
Q = m*cP*(T2-T1)                   //Overall heta duty (Btu/h)
DT1 = Ts1-T1                       //Temperature driving force 1 for 150 psia ( F)
DT2 = Ts1-T2                       //Temperature driving force 2 for 150 psia ( F)
LMTD1 = (DT1-DT2)/log(DT1/DT2)     //Log-mean temperature difference for 150 psia ( F)
DT3 = Ts2-T1                       //Temperature driving force 1 for 300 psia ( F)
DT4 = Ts2-T2                       //Temperature driving force 2 for 300 psia ( F)
LMTD2 = (DT3-DT4)/log(DT3/DT4)     //Log-mean temperature difference for 1300 psia ( F)
A1 = Q/(138*LMTD1)                 //Required heat transfer area for 150 psia (ft^2)
A2 = Q/(138*LMTD2)                 //Required heat transfer area for 300 psia (ft^2)
BC1 = 117*A1**0.65                 //Base cost for 150 psia ($)
BC2 = 117*A2**0.65                 //Base cost for 13000 psia ($)
C1 = BC1*(CI2/CI1)*IF*PF1          //Capital cost for
```

```
    150 psia ($)
C2 = BC2*(CI2/CI1)*IF*PF2        //Capital cost for 300 psia ($)
S1 = Q*(h*OP)/L1                 //Steam requirement for 150 psia (lb/yr)
S2 = Q*(h*OP)/L2                 //Steam requirement for 300 psia (lb/yr)
SC1 = S1*c1                      //Annual steam cost for 150 psia ($/yr)
SC2 = S2*c2                      //Annual steam cost for 300 psia ($/yr)
C1 = round(C1*10**-3)/10**-3
C2 = round(C2*10**-3)/10**-3
SC1 = round(SC1*10**-3)/10**-3
SC2 = round(SC2*10**-3)/10**-3

//Result:
printf("1. The capital cost for 150 psia is : $ %f",C1)
printf("   The capital cost for 300 psia is : $ %f",C2)
printf("2. The annual steam cost for 150 psia is : $ %f /yr .",SC1)
printf("   The annual steam cost for 300 psia is : $ %f /yr .",SC2)
if (C1<C2 & SC1>SC2) then
    printf("The 300-psia exchanger costs less to purchase and install, but it costs more to operate. Choosing the more expensive, 150-psia exchanger is the obvious choice.")
else if (C1>C2 & SC1<SC2) then
    printf("The 150-psia exchanger costs less to purchase and install, but it costs more to operate. Choosing the more expensive, 300-psia exchanger is the obvious choice.")
end
```

Scilab code Exa 27.9 Example

```
//Variable declaration:
TCC_TB = 2500000                              //Total capital cost ($)
R_TB = 3600000                                //R_TBevenue generated from the facility ($)
AOC_TB = 1200000                              //Annual operating costs ($)
TCC_FB = 3500000                              //Total capital cost ($)
R_FB = 5300000                                //R_TBevenue generated from the facility ($)
AOC_FB = 1400000                              //Annual operating costs ($)
n = 10                                         //Time of facility (yr)

//Calculation:
D = 0.1*TCC_TB                                //Depriciation ($)
WC = 0.1*TCC_TB                               //Working capital ($)
TI = R_TB-AOC_TB-D                            //Taxable income ($)
IT = 0.5*TI                                   //Income tax to be paid ($)
A = R_TB-AOC_TB-IT                            //After-tax cash flow ($)
function [ans] = eqTB(i)
    x = (((1+i)**n-1)/(i*(1+i)**n))*A + (1/(1+i)**n)*WC    //Equation for computing rate of return for TB unit
    y = WC + 0.5*TCC_TB + 0.5*TCC_TB*(1+i)**1
```

```
                        //Equation for computing rate of return for TB unit
    ans = x-y
endfunction
iTB = ceil(fsolve(0.8,eqTB)*100)    //Rate of return for TB unit (%)

D = 0.1*TCC_FB                      //Depriciation ($)
WC = 0.1*TCC_FB                     //Working capital ($)
TI = R_FB-AOC_FB-D                  //Taxable income ($)
IT = 0.5*TI                         //Income tax to be paid ($)
A = R_FB-AOC_FB-IT                  //After-tax cash flow ($)

function [ans] = eqFB(i)
    x = (((1+i)**n-1)/(i*(1+i)**n))*A + (1/(1+i)**n)*WC    //Equation for computing rate of return for FB unit
    y = WC + 0.5*TCC_FB + 0.5*TCC_FB*(1+i)**1
                        //Equation for computing rate of return for FB unit
    ans = x-y
endfunction
iFB = fsolve(0.8,eqFB)*100 //Rate of return for FB unit (%)

//Results:
printf("The rate of return for TB unit is: %.0f %%",iTB)
printf("The rate of return for FB unit is: %.1f %%",iFB)
```

Scilab code Exa 27.10 Example

```
//Variable declaration:
f = 100000                                    //Flow rate of
    flue gas (acfm)
i = 0.1                                       //Interest rate
//From table 27.4:
//For finned preheater:
ac1 = 3.1                                     //Equipment cost (
    $/acfm)
ac2 = 0.8                                     //Installation
    cost ($/acfm)
ac3 = 0.06                                    //Operating cost (
    $/acfm-yr)
ac4 = 14000                                   //Maintenance cost
     ($/yr)
an = 20                                       //Lifetime (yr)
//For 4-pass preheater:
bc1 = 1.9                                     //Equipment cost (
    $/acfm)
bc2 = 1.4                                     //Installation
    cost ($/acfm)
bc3 = 0.06                                    //Operating cost
    for ($/acfm-yr)
bc4 = 28000                                   //Maintenance cost
     ($/yr)
bn = 15                                       //Lifetime of (yr)
//For 2-pass preheater:
cc1 = 2.5                                     //Equipment cost (
    $/acfm)
cc2 = 1.0                                     //Installation
    cost ($/acfm)
cc3 = 0.095                                   //Operating cost
    for ($/acfm-yr)
```

```
cc4 = 9500                              //Maintenance cost for ($/yr)
cn = 20                                 //Lifetime of (yr)

//Calculation:
//For Finned preheater:
aEC = f*ac1                             //Total equipment cost ($)
aIC = f*ac2                             //Total installation cost ($)
aOC = f*ac3                             //Total operating cost ($)
aMC = f*ac4                             //Total maintenance cost ($)
aCRF = (i*(1+i)**an)/((1+i)**an-1)  //Capital recovery factor
aAEC = aEC*aCRF                         //Equipment annual cost ($/yr)
aAIC = aIC*aCRF                         //Installation annual cost($/yr)
aAOC = ac3*f                            //Annual operating cost ($)
aAMC = ac4                              //Annual maintenance cost ($)
aTAC = aAEC+aAIC+aAOC+aAMC              //Total annual cost ($)

//For 4-pass preheater:
bEC = f*bc1                             //Total equipment cost ($)
bIC = f*bc2                             //Total installation cost ($)
bOC = f*bc3                             //Total operating cost ($)
bMC = f*bc4                             //Total maintenance cost ($)
bCRF = (i*(1+i)**bn)/((1+i)**bn-1)  //Capital recovery factor
```

```
bAEC = bEC*bCRF                      //Equipment annual cost ($/yr)
bAIC = bIC*bCRF                      //Installation annual cost($/yr)
bAOC = bc3*f                         //Annual operating cost ($)
bAMC = bc4                           //Annual maintenance cost ($)
bTAC = bAEC+bAIC+bAOC+bAMC           //Total annual cost ($)
//For 2-pass preheater:
cEC = f*cc1                          //Total equipment cost ($)
cIC = f*cc2                          //Total installation cost ($)
cOC = f*cc3                          //Total operating cost ($)
cMC = f*cc4                          //Total maintenance cost ($)
cCRF = (i*(1+i)**cn)/((1+i)**cn-1)  //Capital recovery factor
cAEC = cEC*cCRF                      //Equipment annual cost ($/yr)
cAIC = cIC*cCRF                      //Installation annual cost($/yr)
cAOC = cc3*f                         //Annual operating cost ($)
cAMC = cc4                           //Annual maintenance cost ($)
cTAC = cAEC+cAIC+cAOC+cAMC           //Total annual cost ($)

//Result:
printf("Total annual cost for finned preheater is : $ %.0f",aTAC)
printf("Total annual cost for 4-pass preheater is : $ %.0f",bTAC)
printf("Total annual cost for 2-pass preheater is :
```

```
$ %.0f",cTAC)
if (cTAC<aTAC & cTAC<bTAC) then
    printf("According to the analysis, the 2-pass exchanger is the most economically attractive device since the annual cost is the lowest.")
elseif (bTAC<aTAC & bTAC<cTAC) then
    printf("According to the analysis, the 4-pass exchanger is the most economically attractive device since the annual cost is the lowest.")
elseif (aTAC<cTAC & aTAC<bTAC) then
    printf("According to the analysis, the finned exchanger is the most economically attractive device since the annual cost is the lowest.")
end
```

Scilab code Exa 27.12 Example

```
//Variable declaration:
TH = 500                                    //Hot stream temperature at exchanger 1 ( F)
tc = 100                                    //Cold stream temperature at exchanger 2 ( F)
A = 10                                      //Constant A
B1 = 100000                                 //Constant B1
B2 = 4000                                   //Constant B2
B3 = 400000                                 //Constant B3

//Calculations:
//It forms equation fo form t^2 - t(Th-tc) +tcTH +B/A
t1 = roots([1, -(TH+tc),(tc*TH + B1/A) ]); //Roots
tmax1 = TH - sqrt(B1/A)             //Upon maximising
```

```
profit
t2 = roots([1, -(TH+tc),(tc*TH + B2/A) ]); //Roots
tmax2 = TH - sqrt(B2/A)          //Upon maximising profit
t3 = roots([1, -(TH+tc),(tc*TH + B3/A) ]); //Roots
tmax3 = TH - sqrt(B3/A)          //Upon maximising profit

//Results:
printf("tBE for case 1: %.0f F %.0f F",t1(1),t1(2))
printf("tmax1: %.0f F",tmax1)
printf("tBE for case 2: %.0f F %.0f F",t2(1),t2(2))
printf("tmax1: %.0f F",tmax2)
printf("tBE for case 1: %.0f F %.0f F",t3(1),t3(2))
printf("tmax1 : %.0f F",tmax3)
```

Scilab code Exa 27.15 Example

```
//Key:
//f(x) : Objective Function
//ci(x)'s : Constraints

//Variable Declaration:
function [ans] = f(x)
    ans = -1.70*x(1) - 2*x(2)
endfunction

//Calculation
X = [7500,6000]

//Result:
printf("Maximum Profit is $ %.1f /day or $ %.1f /year",-f(X),-365*f(X))
```

Chapter 28

Open Ended Problems

Scilab code Exa 28.11 Example

```
//Variable declaration:
//From table 28.3:
//For stream 1 to be heated:
hm1 = 50000                          //Mass flowrate (lb/h)
hcP1 = 0.65                          //Heat capacity (Btu/lb. F)
hTi1 = 70                            //Inlet temperature ( F)
hTo1 = 300                           //Outlet temperature ( F)
//For stream 2 to be heated:
hm2 = 60000                          //Mass flowrate (lb/h)
hcP2 = 0.58                          //Heat capacity (Btu/lb. F)
hTi2 = 120                           //Inlet temperature ( F)
hTo2 = 310                           //Outlet temperature ( F)
//For stream 3 to be heated:
```

```
hm3 = 80000                           //Mass flowrate (lb/h)
hcP3 = 0.78                           //Heat capacity (Btu/lb. F)
hTi3 = 90                             //Inlet temperature ( F)
hTo3 = 250                            //Outlet temperature ( F)
//From table 28.4:
//For stream 1 to be cooled:
cm1 = 60000                           //Mass flowrate (lb/h)
ccP1 = 0.70                           //Heat capacity (Btu/lb. F)
cTi1 = 420                            //Inlet temperature ( F)
cTo1 = 120                            //Outlet temperature ( F)
//For stream 2 to be cooled:
cm2 = 40000                           //Mass flowrate (lb/h)
ccP2 = 0.52                           //Heat capacity (Btu/lb. F)
cTi2 = 300                            //Inlet temperature ( F)
cTo2 = 100                            //Outlet temperature ( F)
//For stream 3 to be cooled:
cm3 = 35000                           //Mass flowrate (lb/h)
ccP3 = 0.60                           //Heat capacity (Btu/lb. F)
cTi3 = 240                            //Inlet temperature ( F)
cTo3 = 90                             //Outlet temperature ( F)

//Calculation:
```

```
H1 = hm1*hcP1*(hTo1-hTi1)          //Heating duty for stream 1 (Btu/h)
H2 = hm2*hcP2*(hTo2-hTi2)          //Heating duty for stream 2 (Btu/h)
H3 = hm3*hcP3*(hTo3-hTi3)          //Heating duty for stream 1 (Btu/h)
H = H1+H2+H3                       //Total heating duty (Btu/h)
C1 = cm1*ccP1*(cTi1-cTo1)          //Cooling duty for stream 1 (Btu/h)
C2 = cm2*ccP2*(cTi2-cTo2)          //Cooling duty for stream 2 (Btu/h)
C3 = cm3*ccP3*(cTi3-cTo3)          //Cooling duty for stream 1 (Btu/h)
C = C1+C2+C3                       //Total Cooling duty (Btu/h)

//Result:
printf("Table: Duty Requirements.")
printf("Stream                          Duty, Btu/h")
printf("1                             %.0f",H1)
printf("2                             %.0f",H2)
printf("3                             %.0f",H3)
printf("4                             %.0f",C1)
printf("5                             %.0f",C2)
printf("6                             %.0f",C3)
```