INVESTIGATION AND OPTIMISATION OF COMMERCIAL REFRIGERATION CYCLES USING THE NATURAL REFRIGERANT CO_2

A thesis submitted for the degree of Doctor of Engineering

By

Jason Alexander Shilliday

APPENDIX B

Supervised by Professor Savvas Tassou

School of Engineering and Design, Brunel University

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Appendix B

This section includes the EES simulation code developed for this Thesis

1. EES Code for Chapter 3 and 4 initial investigation simulation models

```
Procedure mincondtemp(T_amb:T[15])
If T_amb=5 then
T[15]=10
Else
If T_amb<5 then
T[15]=10
Else
T[15]=T_amb+5
Endif
Endif
End



Procedure subtrans(T[15]:P[15],H[15],mu[15])
If T[15]=31 then
P[15]=T[15]*287500-112000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
else
If T[15]<31 then
P[15]=Pressure(R744,T=T[15],X=0)
H[15]=Enthalpy(R744,T=T[15],X=0)
mu[15]=Viscosity(R744,T=T[15],X=0)
Else
If T[15]>31 then
P[15]=T[15]*287500-112000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])

Endif
Endif
Endif
End

Procedure deltaPAB(m_flux,d_i,Rho_f,Rho_g,f_f,f_g:a,b)
a=f_f*((2*m_flux^2)/(d_i*rho_F))
b=f_g*((2*m_flux^2)/(d_i*rho_g))
End

Procedure deltaPG(a,b,x:G)
G=a+(2*(b-a)*X)
End

Procedure deltaP(G,X,b:dPdz_frict)
dPdz_frict=G*(1-X)^(1/3)+b*x^3
End

Procedure EoutEin(X_out,X_in,Rho_g,Rho_f,M_flux,Sigma:E_out,E_in)
```

```
E_out=(X_out/Rho_g)/((1+0.12*(1-X_out))*((x_out/(Rho_g))+((1-x_out)/rho_f))+((1.18/m_flux)*(((g#*sigma*(rho_f-rho_g))/Rho_f^2)^0.25)*(1-x_out)))    " Void Fraction"
E_in=(X_in/Rho_g)/((1+0.12*(1-X_in))*((x_in/(Rho_g))+((1-x_in)/rho_f))+((1.18/m_flux)*(((g#*sigma*(rho_f-rho_g))/Rho_f^2)^0.25)*(1-x_in)))    " Void Fraction"
End

Procedure Momentum(X_out,X_in,Rho_g,Rho_f,M_flux,E_out,E_in:DeltaP_Momentum)
DeltaP_Momentum=m_flux^2*(((1-X_out)^2/((rho_f*(1-E_out)))+(x_out^2/rho_g^e_out))-((1-X_in)^2/((rho_f*(1-E_in)))+(x_in^2/rho_g^e_in)))
End

R$='R744'

"Inputs"

T_AMB=32
LT_CAPKW=5
MT_CAPKW=36


"LT Cabinets"
LT=-27                                  "LT Evap Temp"

LT_Cap=LT_CAPKW*1000                    "LT Evap Capacity"
LT_SH=7                                 "LT Superheat"
LTIS_EFF=0.63                           "LT Compressor Efficiency"
DeltaTLTEvap=1.5



"MT Cabinets"
MT=-8                                   "MT Evap Temp"
MP=Pressure(R$,T=MT,X=1)

MT_Cap=MT_CAPKW*1000                    "MT Evap Capacity"
MT_SH=7                                 "MT Superheat"
MTIS_EFF=0.55
DeltaTMTEvap=1.5


RP=3100000                              "Reciever Pressure"
RT=Temperature(R$,P=RP,X=1)             "Reciever Temperature"

SLHX2_eff=0.35
"Time=1"
X[1]=0.99


"Low Temp Evap Outlet Sat Vap"
T[1]=LT-DeltaTLTEvap
H[1]=enthalpy(R$,T=T[1],x=X[1])
P[1]=Pressure(R$,T=T[1],X=X[1])-DeltaP_LTEVAP
v[1]=Volume(R$,T=T[1],x=x[1])
S[1]=Entropy(R$,T=T[1],X=X[1])
rho[1]=Density(R$,T=T[1],x=x[1])
```

```
"Low Temp Evap Superheat"
T[2]=T[1]+LT_SH
P[2]=P[1]
H[2]=enthalpy(R$,T=T[2],P=P[2])

"Pressure drop to distance to compressor"

"T[2]=T[3]
P[3]=P[2]"
H[2]=H[3]
S[3]=Entropy(R$,T=T[3],P=P[3])
Rho[3]=density(R$,S=S[3],P=P[3])

L_LTSuction=25
Pipe_LTSuction=0.0129
Pipe_LTSuction_CS=pi*(Pipe_LTSuction/2)^2

Rho[2]=density(R$,T=T[2],P=P[2])
mu[2]=Viscosity(R$,H=H[2],P=P[2])
Re[2]=((M_dot_5/Pipe_LTSuction_CS)*Pipe_LTSuction)/mu[2]
BL[2]=0.316/(Re[2]^0.25)
DeltaP_LTSuction=BL[2]*(L_LTSuction/Pipe_LTSuction)*Rho[2]*(Vel_LTSuction^2/2)
Vel_LTSuction=M_dot_5/((Pipe_LTSuction_CS)*Rho[2])

P[3]=P[2]-DeltaP_LTSuction
T[3]=Temperature(R$,H=H[3],P=P[3])
DeltaT_LTSuction=T[2]-T[3]


"Time=0"


"LT Compression"
S[5]=S[3]
P[5]=P[31]                                  "No pressure drop in MT Evap"
P[4]=P[5]
H[5]=Enthalpy(R$,S=S[5],P=P[5])
T[5]=Temperature(R$,S=S[5],P=P[5])
LTIS_EFF=(H[3]-H[5])/(H[3]-H[4])
S[4]=Entropy(R$,H=H[4],P=P[4])
T[4]=Temperature(R$,H=H[4],P=P[4])
W_dot_LT=H[4]-H[3]
W_dot_LTKW=(W_dot_LT*M_dot_5)/1000

"SLHX 2"
"SLHX2"
"Qpotn1"


H[80]=enthalpy(R$,P=P[24],T=T[6]) "max"
H[81]=enthalpy(R$,P=P[6],T=T[24]) "min"
q_potn1=ABS(min((H[80]-H[24]),(H[6]-H[81])))

H[7]=H[6]-(SLHX2_eff*q_potn1)
T[7]=temperature(R744,H=H[7],P=P[7])
```

```
T[4]=T[6]
P[4]=P[6]
P[7]=P[6]


H[6]=Enthalpy(R$,P=P[6],T=T[6])

"MIXING PT OF LT MT"

H[8]=((M_dot_4*H[31])+(M_dot_5*H[7]))/M_dot_3
P[8]=P[7]
T[8]=Temperature(R$,P=P[8],H=H[8])

"MIXING PT OF FLASH VAPOUR AND COMMON SUCTION"
M_dot_1=M_dot_2+M_dot_3
V_dot_Swept_MTComp=M_dot_1/(Rho[11]*0.76)*3600
M_dot_1*H[9]=(M_dot_3*H[8])+(M_dot_2*H[25])
P[9]=P[8]
T[9]=Temperature(R$,P=P[9],H=H[9])

"INTERNAL HEAT EXCHANGER"

T[9]=T[10]
H[9]=H[10]
P[9]=P[10]

H[11]=H[10]

S[11]=Entropy(R$,P=P[11],H=H[11])
Rho[11]=Density(R744,T=T[11],S=S[11])



"Common Suction Line Pressure Drop"
L_CommonSuction=5
Pipe_CommonSuction=0.02
Pipe_CommonSuction_CS=pi*(Pipe_CommonSuction/2)^2
Rho[9]=Density(R$,H=H[9],P=P[9])
mu[9]=Viscosity(R$,H=H[9],P=P[9])
Re[9]=((M_dot_1/Pipe_CommonSuction_CS)*Pipe_CommonSuction)/mu[9]
BL[9]=0.316/(Re[9]^0.25)
DeltaP_CommonSuction=BL[9]*(L_CommonSuction/Pipe_CommonSuction)*Rho[9]*(Vel_CommonSuction^2/2)
Vel_CommonSuction=M_dot_1/((Pipe_CommonSuction_CS)*Rho[9])
P[11]=P[9]-DeltaP_CommonSuction
T[11]=Temperature(R$,H=H[11],P=P[11])
DeltaT_CommonSuction=T[9]-T[11]




"HIGH STAGE COMPRESSION"
S[13]=S[11]
P[13]=P[15]
P[12]=P[15]
```

```
H[13]=Enthalpy(R$,S=S[13],P=P[13])
T[13]=Temperature(R$,S=S[13],P=P[13])
MTIS_EFF=(H[11]-H[13])/(H[11]-H[12])
S[12]=Entropy(R$,H=H[12],P=P[12])
T[12]=Temperature(R$,H=H[12],P=P[12])
W_dot_MT=H[12]-H[11]
W_dot_MTKW=(W_dot_MT*M_dot_1)/1000

"GAS COOLING/CONDENSATION"

"Pack to Gas Cooler / Condenser Pressure Drop"

H[14]=H[13]
P[14]=P[13]
T[14]=T[13]
Call mincondtemp(T_amb:T[15])
Call subtrans(T[15]:P[15],H[15],mu[15])



L_HPDischarge=25
Pipe_HPDischarge=0.0139
Pipe_HPDischarge_CS=pi*(Pipe_HPDischarge/2)^2

Rho[13]=Density(R$,H=H[13],P=P[13])
mu[13]=Viscosity(R$,H=H[13],P=P[13])
Re[13]=((M_dot_1/Pipe_HPDischarge_CS)*Pipe_HPDischarge)/mu[13]
BL[13]=0.316/(Re[13]^0.25)
DeltaP_HPDischarge=BL[13]*(L_HPDischarge/Pipe_HPDischarge)*Rho[13]*(Vel_HPDischa
rge^2/2)
Vel_HPDischarge=M_dot_1/((Pipe_HPDischarge_CS)*Rho[13])


"P[14]=P[13]-DeltaP_HPDischarge
T[14]=Temperature(R$,H=H[14],P=P[14])
DeltaT_MTSuction=T[14]-T[13]"



"INTERNAL HEAT EXCHANGER"

"Gas cooler / condenser to ICMT pressure drop"
T[15]=T[16]
P[15]=P[16]
H[15]=H[16]

"Internal Heat Exchanger"
T[17]=T[16]
P[17]=P[16]
H[17]=h[16]




"ICMT Valve"
T[17]=T[18]
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```
P[17]=P[18]
H[17]=H[18]

P[19]=RP
T[19]=RT
H[19]=H[18]

H[19]=H[20]
P[19]=P[20]
T[19]=T[20]

"RECIEVER"

T[21]=RT
P[21]=RP
H[21]=H[20]

H[21]=H[22]
P[21]=P[22]
T[21]=T[22]

"Liquid Refrigerant to Evaporators"

P[24]=RP
T[24]=RT
X[24]=0
H[24]=Enthalpy(R$,T=T[24],X=X[24])

M_dot_3=M_dot_4+M_dot_5



"Flash Vapour"
X[23]=1
P[23]=RP
H[23]=Enthalpy(R$,P=P[23],X=X[23])
M_dot_2=(M_dot_3*(H[24]-H[18]))/(H[18]-H[23])
T[23]=Temperature(R$,X=X[23],P=P[23])

"Flash Vapor Expansion"
T[25]=MT
H[25]=H[23]
P[25]=Pressure(R$,H=H[25],T=T[25])
X[25]=quality(R$,H=H[25],T=T[25])

"EVAPORATION"


"MT EVAPORATION"
L_CommonLiquid=10
Pipe_CommonLiquid=0.0139
Pipe_CommonLiquid_CS=pi*(Pipe_CommonLiquid/2)^2

Vel_Commonliquid=M_dot_3/((Pipe_CommonLiquid_CS)*Rho[24])
Rho[24]=Density(R744,T=T[24],H=H[24])
Re[24]=((M_dot_3/Pipe_CommonLiquid_CS)*Pipe_CommonLiquid)/mu[24]
mu[24]=Viscosity(R744,H=H[24],X=X[24])
BL[24]=0.316/(Re[24]^0.25)
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DeltaP_CommonLiquid=BL[24]*(L_CommonLiquid/Pipe_CommonLiquid)*Rho[24]*(Vel_Com
monliquid^2/2)
P[26]=P[24]-DeltaP_commonliquid
T[26]=Temperature(R$,H=H[26],P=P[26])
X[26]=quality(R$,P=P[26],H=H[26])


H[26]=H[24]



"Pressure drop to MT Evaporator"
"T[26]=T[27]"
"P[26]=P[27]"
H[27]=H[26]

L_MTLiquid=25
Pipe_MTLiquid=0.0099


Rho[26]=Density(R$,H=H[26],P=P[26])
Vel_MTliquid=M_dot_4/((Pipe_MTLiquid_CS)*Rho[26])
D_i[4]=Pipe_MTLiquid
Pipe_MTLiquid_CS=pi*(Pipe_MTLiquid/2)^2
M_flux[4]=M_dot_4/(Pipe_MTLiquid_CS)
Call deltaPAB(m_flux[4],d_i[4],Rho_f[26],Rho_g[26],f_f[26],f_g[26]:a[27],b[27])
Call deltaPG(a[27],b[27],x[26]:G[27])
Call deltaP(G[27],X[26],b[27]:dPdz_frict[27])
DeltaP_MTLiquid=(L_MTLiquid*dPdz_frict[27])
P[27]=P[26]-DeltaP_MTLiquid
T[27]=Temperature(R$,H=H[27],P=P[27])
X[27]=Quality(R$,H=H[27],T=T[27])
DeltaT_MTLiquid=T[26]-T[27]


"MT Expansion"
T[28]=MT
H[28]=H[26]
P[28]=Pressure(R$,T=T[28],H=H[28])
X[29]=0.99
P[29]=P[28]-DeltaP_MTEVAP
T[29]=Temperature(R$,P=P[29],X=X[29])
H[29]=Enthalpy(R$,P=P[28],X=X[29])


"MT Evaporator pressure drop"
X[28]=X[27]
L_MTEvap=12
Pipe_MTEvap=0.0107
Pipe_MTEvap_CS=pi*(Pipe_MTEvap/2)^2
M_flux_MTEvap=M_dot_4/(Pipe_MTEvap_CS)
mu_f[28]=Viscosity(R$,T=T[28],X=0)
mu_g[28]=Viscosity(R$,T=T[28],X=1)
rho_f[28]=Density(R$,T=T[28],X=0)
rho_g[28]=Density(R$,T=T[28],X=1)
Re_f[28]=(m_flux_MTEvap*Pipe_MTEvap)/mu_f[28]
Re_g[28]=(m_flux_MTEvap*Pipe_MTEvap)/mu_g[28]
f_f[28]=0.079/Re_f[28]^0.25
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```
f_g[28]=0.079/Re_g[28]^0.25
Sigma_MT=SurfaceTension(R$,T=T[28])
Rho[28]=Density(R$,H=H[28],P=P[28])
Vel_MTEvap=M_dot_4/((Pipe_MTEvap_CS)*Rho[28])
D_i[28]=Pipe_MTEvap

Call deltaPAB(m_flux_MTEvap,d_i[28],Rho_f[28],Rho_g[28],f_f[28],f_g[28]:a[28],b[28])
Call deltaPG(a[28],b[28],x[28]:G[28])
Call deltaP(G[28],X[28],b[28]:dPdz_frict[28])
Call
EoutEin(X[29],X[28],Rho_g[28],Rho_f[28],M_flux_MTEvap,Sigma_MT:E_out[28],E_in[28])

Call
Momentum(X[29],X[28],Rho_g[28],Rho_f[28],M_flux_MTEvap,E_out[28],E_in[28]:DeltaP_Mo
mentum[28])
DeltaP_Frict_MTEvap=INTEGRAL(dpdz_frict[28],X,X[28],X[29])*L_MTEvap
DeltaP_MTEVAP=DeltaP_momentum[28]+DeltaP_Frict_MTEvap



"MT Flow Rate"
M_dot_4=MT_Cap/(H[29]-H[28])
q_MT=H[29]-H[28]

COP_MT=MT_CAPKW/W_dot_MTKW
"MT Evap Superheat"
T[30]=T[29]+LT_SH
P[30]=P[29]
H[30]=enthalpy(R$,T=T[30],P=P[30])

"Pressure drop to distance to Pack (LTMT Mixing PT)"
"T[30]=T[31]
P[30]=P[31]"
H[30]=H[31]
L_MTSuction=25
Pipe_MTSuction=0.0129
Pipe_MTSuction_CS=pi*(Pipe_MTSuction/2)^2

Rho[30]=Density(R$,H=H[30],P=P[30])
mu[30]=Viscosity(R$,H=H[30],P=P[30])
Re[30]=((M_dot_4/Pipe_MTSuction_CS)*Pipe_MTSuction)/mu[30]
BL[30]=0.316/(Re[30]^0.25)
DeltaP_MTSuction=BL[30]*(L_MTSuction/Pipe_MTSuction)*Rho[30]*(Vel_MTSuction^2/2)
Vel_MTSuction=M_dot_4/((Pipe_MTSuction_CS)*Rho[30])


DeltaTINCREASE_MTSuction=3
P[31]=P[30]-DeltaP_MTSuction
T[31]=Temperature(R$,H=H[31],P=P[31])+DeltaTINCREASE_MTSuction
DeltaT_MTSuction=T[30]-T[31]

"LT EVAPORATION"

"Pressure drop to LT Evaporator"


"T[26]=T[32]"
```

```
"P[26]=P[32]"
H[26]=H[32]
L_LTLiquid=25
Pipe_LTLiquid=0.0099
Pipe_LTLiquid_CS=pi*(Pipe_LTLiquid/2)^2
Vel_LTliquid=M_dot_5/((Pipe_LTLiquid_CS)*Rho[26])
D_i[5]=Pipe_LTLiquid
M_flux[5]=M_dot_5/(pi*(Pipe_LTLiquid/2)^2)
mu_f[26]=Viscosity(R$,T=T[26],X=0)
mu_g[26]=Viscosity(R$,T=T[26],X=1)
rho_f[26]=Density(R$,T=T[26],X=0)
rho_g[26]=Density(R$,T=T[26],X=1)
Re_f[26]=(m_flux[5]*Pipe_LTLiquid)/mu_f[26]
Re_g[26]=(m_flux[5]*Pipe_LTLiquid)/mu_g[26]
f_f[26]=0.079/Re_f[26]^0.25
f_g[26]=0.079/Re_g[26]^0.25
Call deltaPAB(m_flux[5],d_i[5],Rho_f[26],Rho_g[26],f_f[26],f_g[26]:a[26],b[26])
Call deltaPG(a[26],b[26],x[26]:G[26])
Call deltaP(G[26],X[26],b[26]:dPdz_frict[26])
DeltaP_LTLiquid2=(L_LTLiquid*dPdz_frict[26])
P[32]=P[26]-DeltaP_LTLiquid2
T[32]=Temperature(R$,H=H[32],P=P[32])
X[32]=Quality(R$,H=H[32],P=P[32])
DeltaT_LTLiquid=T[26]-T[32]


"LT Expansion"
T[33]=LT
H[33]=H[32]
P[33]=Pressure(R$,T=T[33],H=H[33])

"LT Flow Rate"
M_dot_5=LT_Cap/(H[1]-H[33])
V_dot_Swept_LTComp=M_dot_5/(Rho[3]*0.76)*3600
q_LT=H[1]-H[33]
COP_LT=LT_CAPKW/W_dot_LTKW

"LT Evap Pressure Drop"
X[32]=X[33]
L_LTEvap=16
Pipe_LTEvap=0.0107
Pipe_LTEvap_CS=pi*(Pipe_LTEvap/2)^2
M_flux_LTEvap=M_dot_5/(Pipe_LTEvap_CS)
mu_f[33]=Viscosity(R$,T=T[33],X=0)
mu_g[33]=Viscosity(R$,T=T[33],X=1)
rho_f[33]=Density(R$,T=T[33],X=0)
rho_g[33]=Density(R$,T=T[28],X=1)
Re_f[33]=(m_flux_LTEvap*Pipe_LTEvap)/mu_f[33]
Re_g[33]=(m_flux_LTEvap*Pipe_LTEvap)/mu_g[33]
f_f[33]=0.079/Re_f[33]^0.25
f_g[33]=0.079/Re_g[33]^0.25
Sigma_LT=SurfaceTension(R$,T=T[33])
Rho[33]=Density(R$,H=H[33],P=P[33])
Vel_LTEvap=M_dot_5/((Pipe_LTEvap_CS)*Rho[33])
D_i[33]=Pipe_LTEvap

Call deltaPAB(m_flux_LTEvap,d_i[33],Rho_f[33],Rho_g[33],f_f[33],f_g[33]:a[33],b[33])
Call deltaPG(a[33],b[33],x[33]:G[33])
```

```
Call deltaP(G[33],X[33],b[33]:dPdz_frict[33])
Call EoutEin(X[1],X[33],Rho_g[33],Rho_f[33],M_flux_LTEvap,Sigma_LT:E_out[33],E_in[33])

Call
Momentum(X[1],X[33],Rho_g[33],Rho_f[33],M_flux_LTEvap,E_out[33],E_in[33]:DeltaP_Mom
entum[33])
DeltaP_Frict_LTEvap=INTEGRAL(dpdz_frict[33],X,X[33],X[1])*L_LTEvap
DeltaP_LTEVAP=DeltaP_momentum[33]+DeltaP_Frict_LTEvap



COP=(LT_CAPKW+MT_CAPKW)/(W_dot_LTKW+W_dot_MTKW)
```

2. EES Code for Chapter 6 Booster system verified model

```
Procedure mincondtemp(T_amb:T[15])
If T_amb<10 then
T[15]=12
Else
T[15]=T_amb+2
Endif
End


Procedure subtrans(T[15]:P[15],H[15],mu[15])
If T[15]<26 then
P[15]=Pressure(R744,T=T[15],X=0)
H[15]=Enthalpy(R744,T=T[15],X=0)
mu[15]=Viscosity(R744,T=T[15],X=0)
Else
If T[15]=26 then
P[15]=6600000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Endif
If T[15]>36 then
P[15]=9215000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Else
If T[15]>35.5 then
P[15]=9100000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Else
If T[15]>35 then
P[15]=8950000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Else
If T[15]>34.5 then
P[15]=8825000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Else
If T[15]>34 then
P[15]=8875000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Else
If T[15]>33.5 then
P[15]=8550000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Else
If T[15]>33 then
P[15]=8400000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Else
```

```
If T[15]>32.5 then
P[15]=8250000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Else
If T[15]>32 then
P[15]=8150000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Else
If T[15]>31.1 then
P[15]=8000000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Else
If T[15]>31 then
P[15]=7850000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Else
If T[15]>30.5 then
P[15]=7700000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Else
If T[15]>30 then
P[15]=7500000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Else
If T[15]>29.5 then
P[15]=7450000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Else
If T[15]>29 then
P[15]=7350000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Else
If T[15]>28.5 then
P[15]=7200000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Else
If T[15]>28 then
P[15]=7100000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Else
If T[15]>27.5 then
P[15]=6950000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Else
If T[15]>27 then
P[15]=6800000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
```

```
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Else
If T[15]>26.5 then
P[15]=6750000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Else
If T[15]>26 then
P[15]=6700000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Endif
If T[15]=26 then
P[15]=6600000
H[15]=Enthalpy(R744,T=T[15],P=P[15])
mu[15]=Viscosity(R744,T=T[15],P=P[15])
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
End

Procedure deltaPAB(m_flux,d_i,Rho_f,Rho_g,f_f,f_g:a,b)
a=f_f*((2*m_flux^2)/(d_i*rho_F))
b=f_g*((2*m_flux^2)/(d_i*rho_g))
End

Procedure deltaPG(a,b,x:G)
G=a+(2*(b-a)*X)
End

Procedure deltaP(G,X,b:dPdz_frict)
dPdz_frict=G*(1-X)^(1/3)+b*x^3
End

Procedure EoutEin(X_out,X_in,Rho_g,Rho_f,M_flux,Sigma:E_out,E_in)
E_out=(X_out/Rho_g)/((1+0.12*(1-X_out))*((x_out/(Rho_g))+((1-
x_out)/rho_f))+((1.18/m_flux)*(((g#*sigma*(rho_f-rho_g))/Rho_f^2)^0.25)*(1-x_out)))    " Void
Fraction"
```

```
E_in=(X_in/Rho_g)/((1+0.12*(1-X_in))*((x_in/(Rho_g))+((1-x_in)/rho_f))+((1.18/m_flux)*(((g#*sigma*(rho_f-rho_g))/Rho_f^2)^0.25)*(1-x_in)))     " Void Fraction"
End

Procedure Momentum(X_out,X_in,Rho_g,Rho_f,M_flux,E_out,E_in:DeltaP_Momentum)
DeltaP_Momentum=m_flux^2*(((1-X_out)^2/((rho_f*(1-E_out)))+(x_out^2/rho_g^e_out))-((1-X_in)^2/((rho_f*(1-E_in)))+(x_in^2/rho_g^e_in)))
End

R$='R744'

"Inputs"

"LT Cabinets"
LT=-32                              "LT Evap Temp"
LT_CAPKW=4
LT_Cap=LT_CAPKW*1000                "LT Evap Capacity"
LT_SH=7                             "LT Superheat"
LTIS_EFF=0.61                       "LT Compressor Efficiency"
DeltaTLTEvap=1.5



"MT Cabinets"
MT=-10                              "MT Evap Temp"
MP=Pressure(R$,T=MT,X=1)
MT_CAPKW=6.6
MT_Cap=MT_CAPKW*1000                "MT Evap Capacity"
MT_SH=7                             "MT Superheat"
MTIS_EFF=0.5
DeltaTMTEvap=1.5


RP=3100000                          "Reciever Pressure"
RT=Temperature(R$,P=RP,X=1)         "Reciever Temperature"

SLHX2_eff=0.5

X[1]=0.99


"Set Suction Pressures"

P[11]=2450000

"T_AMB=25.8"

"Low Temp Evap Outlet Sat Vap"
T[1]=LT-DeltaTLTEvap
H[1]=enthalpy(R$,T=T[1],x=X[1])
P[1]=Pressure(R$,T=T[1],X=X[1])-DeltaP_LTEVAP
v[1]=Volume(R$,T=T[1],x=x[1])
S[1]=Entropy(R$,T=T[1],X=X[1])
rho[1]=Density(R$,T=T[1],x=x[1])


"Low Temp Evap Superheat"
```

```
T[2]=T[1]+LT_SH
P[2]=P[1]
H[2]=enthalpy(R$,T=T[2],P=P[2])

"Pressure drop to distance to compressor"

"T[2]=T[3]
P[3]=P[2]"
H[2]=H[3]
S[3]=Entropy(R$,T=T[3],P=P[3])
Rho[3]=density(R$,S=S[3],P=P[3])

L_LTSuction=25
Pipe_LTSuction=0.0129
Pipe_LTSuction_CS=pi*(Pipe_LTSuction/2)^2

Rho[2]=density(R$,T=T[2],P=P[2])
mu[2]=Viscosity(R$,H=H[2],P=P[2])
Re[2]=((M_dot_5/Pipe_LTSuction_CS)*Pipe_LTSuction)/mu[2]
BL[2]=0.316/(Re[2]^0.25)
DeltaP_LTSuction=BL[2]*(L_LTSuction/Pipe_LTSuction)*Rho[2]*(Vel_LTSuction^2/2)
Vel_LTSuction=M_dot_5/((Pipe_LTSuction_CS)*Rho[2])

P[3]=P[2]-DeltaP_LTSuction
T[3]=Temperature(R$,H=H[3],P=P[3])
DeltaT_LTSuction=T[2]-T[3]


"Time=0"


"LT Compression"
S[5]=S[3]
P[5]=P[11]                              "No pressure drop in MT Evap"
P[4]=P[11]
H[5]=Enthalpy(R$,S=S[5],P=P[5])
T[5]=Temperature(R$,S=S[5],P=P[5])
LTIS_EFF=(H[3]-H[5])/(H[3]-H[4])
S[4]=Entropy(R$,H=H[4],P=P[4])
T[4]=Temperature(R$,H=H[4],P=P[4])
W_dot_LT=H[4]-H[3]
W_dot_LTKW=(W_dot_LT*M_dot_5)/1000

"SLHX 1"
T[4]=T[6]
P[4]=P[6]
P[7]=P[6]
T[7]=T[6]-15
H[7]=Enthalpy(R$,P=P[7],T=T[7])

"MIXING PT OF LT MT"
H[8]=((M_dot_4*H[31])+(M_dot_5*H[7]))/M_dot_3
P[8]=P[7]
T[8]=Temperature(R$,P=P[8],H=H[8])

"MIXING PT OF FLASH VAPOUR AND COMMON SUCTION"
M_dot_1=M_dot_2+M_dot_3
V_dot_Swept_MTComp=M_dot_1/(Rho[11]*0.76)*3600
```

```
M_dot_1*H[9]=(M_dot_3*H[8])+(M_dot_2*H[25])
P[9]=P[8]
T[9]=Temperature(R$,P=P[9],H=H[9])

"INTERNAL HEAT EXCHANGER"

T[9]=T[10]
H[9]=H[10]
P[9]=P[10]
"P[10]=P[11]"
"P[11]=P[10]"
H[11]=H[10]
"T[11]=Temperature(R$,P=P[11],H=H[11])"
S[11]=Entropy(R$,P=P[11],H=H[11])
Rho[11]=Density(R744,T=T[11],S=S[11])

"Common Suction Line Pressure Drop"
L_CommonSuction=5
Pipe_CommonSuction=0.02
Pipe_CommonSuction_CS=pi*(Pipe_CommonSuction/2)^2
Rho[9]=Density(R$,H=H[9],P=P[9])
mu[9]=Viscosity(R$,H=H[9],P=P[9])
Re[9]=((M_dot_1/Pipe_CommonSuction_CS)*Pipe_CommonSuction)/mu[9]
BL[9]=0.316/(Re[9]^0.25)
DeltaP_CommonSuction=BL[9]*(L_CommonSuction/Pipe_CommonSuction)*Rho[9]*(Vel_Co
mmonSuction^2/2)
Vel_CommonSuction=M_dot_1/((Pipe_CommonSuction_CS)*Rho[9])

T[11]=Temperature(R$,H=H[11],P=P[11])
DeltaT_CommonSuction=T[9]-T[11]

"HIGH STAGE COMPRESSION"
S[13]=S[11]
P[13]=P[15]
P[12]=P[15]
H[13]=Enthalpy(R$,S=S[13],P=P[13])
T[13]=Temperature(R$,S=S[13],P=P[13])
MTIS_EFF=(H[11]-H[13])/(H[11]-H[12])
S[12]=Entropy(R$,H=H[12],P=P[12])
T[12]=Temperature(R$,H=H[12],P=P[12])
W_dot_MT=H[12]-H[11]
W_dot_MTKW=(W_dot_MT*M_dot_1)/1000

"GAS COOLING/CONDENSATION"
_
"Pack to Gas Cooler / Condenser Pressure Drop"

H[14]=H[13]
P[14]=P[13]
T[14]=T[13]
Call mincondtemp(T_amb:T[15])
Call subtrans(T[15]:P[15],H[15],mu[15])
```

```
L_HPDischarge=25
Pipe_HPDischarge=0.0139
Pipe_HPDischarge_CS=pi*(Pipe_HPDischarge/2)^2

Rho[13]=Density(R$,H=H[13],P=P[13])
mu[13]=Viscosity(R$,H=H[13],P=P[13])
Re[13]=((M_dot_1/Pipe_HPDischarge_CS)*Pipe_HPDischarge)/mu[13]
BL[13]=0.316/(Re[13]^0.25)
DeltaP_HPDischarge=BL[13]*(L_HPDischarge/Pipe_HPDischarge)*Rho[13]*(Vel_HPDischarge^2/2)
Vel_HPDischarge=M_dot_1/((Pipe_HPDischarge_CS)*Rho[13])


"P[14]=P[13]-DeltaP_HPDischarge
T[14]=Temperature(R$,H=H[14],P=P[14])
DeltaT_MTSuction=T[14]-T[13]"


"INTERNAL HEAT EXCHANGER"

"Gas cooler / condenser to ICMT pressure drop"
T[15]=T[16]
P[15]=P[16]
H[15]=H[16]

"Internal Heat Exchanger"
T[17]=T[16]
P[17]=P[16]
H[17]=h[16]


"ICMT Valve"
T[17]=T[18]
P[17]=P[18]
H[17]=H[18]

P[19]=RP
T[19]=RT
H[19]=H[18]

H[19]=H[20]
P[19]=P[20]
T[19]=T[20]

"RECIEVER"

T[21]=RT
P[21]=RP
H[21]=H[20]
```

```
H[21]=H[22]
P[21]=P[22]
T[21]=T[22]

"Liquid Refrigerant to Evaporators"

P[24]=RP
T[24]=RT
X[24]=0
H[24]=Enthalpy(R$,T=T[24],X=X[24])

M_dot_3=M_dot_4+M_dot_5



"Flash Vapour"
X[23]=1
P[23]=RP
H[23]=Enthalpy(R$,P=P[23],X=X[23])
M_dot_2=(M_dot_3*(H[24]-H[18]))/(H[18]-H[23])
T[23]=Temperature(R$,X=X[23],P=P[23])

"Flash Vapor Expansion"
T[25]=MT
H[25]=H[23]
P[25]=Pressure(R$,H=H[25],T=T[25])


"EVAPORATION"


"MT EVAPORATION"
L_CommonLiquid=10
Pipe_CommonLiquid=0.0139
Pipe_CommonLiquid_CS=pi*(Pipe_CommonLiquid/2)^2

Vel_Commonliquid=M_dot_3/((Pipe_CommonLiquid_CS)*Rho[24])
Rho[24]=Density(R744,T=T[24],H=H[24])
Re[24]=((M_dot_3/Pipe_CommonLiquid_CS)*Pipe_CommonLiquid)/mu[24]
mu[24]=Viscosity(R744,H=H[24],X=X[24])
BL[24]=0.316/(Re[24]^0.25)
DeltaP_CommonLiquid=BL[24]*(L_CommonLiquid/Pipe_CommonLiquid)*Rho[24]*(Vel_Com
monliquid^2/2)
P[26]=P[24]-DeltaP_commonliquid
T[26]=Temperature(R$,H=H[26],P=P[26])
X[26]=quality(R$,P=P[26],H=H[26])


H[26]=H[24]
_


"Pressure drop to MT Evaporator"
"T[26]=T[27]"
"P[26]=P[27]"
H[27]=H[26]
```

```
L_MTLiquid=25
Pipe_MTLiquid=0.0099

_
Rho[26]=Density(R$,H=H[26],P=P[26])
Vel_MTliquid=M_dot_4/((Pipe_MTLiquid_CS)*Rho[26])
D_i[4]=Pipe_MTLiquid
Pipe_MTLiquid_CS=pi*(Pipe_MTLiquid/2)^2
M_flux[4]=M_dot_4/(Pipe_MTLiquid_CS)
Call deltaPAB(m_flux[4],d_i[4],Rho_f[26],Rho_g[26],f_f[26],f_g[26]:a[27],b[27])
Call deltaPG(a[27],b[27],x[26]:G[27])
Call deltaP(G[27],X[26],b[27]:dPdz_frict[27])
DeltaP_MTLiquid=(L_MTLiquid*dPdz_frict[27])
P[27]=P[26]-DeltaP_MTLiquid
T[27]=Temperature(R$,H=H[27],P=P[27])
X[27]=Quality(R$,H=H[27],T=T[27])
DeltaT_MTLiquid=T[26]-T[27]


"MT Expansion"
T[28]=MT
H[28]=H[26]
P[28]=Pressure(R$,T=T[28],H=H[28])
X[29]=0.99
P[29]=P[28]-DeltaP_MTEVAP
T[29]=Temperature(R$,P=P[29],X=X[29])
H[29]=Enthalpy(R$,P=P[28],X=X[29])


"MT Evaporator pressure drop"
X[28]=X[27]
L_MTEvap=12
Pipe_MTEvap=0.0107
Pipe_MTEvap_CS=pi*(Pipe_MTEvap/2)^2
M_flux_MTEvap=M_dot_4/(Pipe_MTEvap_CS)
mu_f[28]=Viscosity(R$,T=T[28],X=0)
mu_g[28]=Viscosity(R$,T=T[28],X=1)
rho_f[28]=Density(R$,T=T[28],X=0)
rho_g[28]=Density(R$,T=T[28],X=1)
Re_f[28]=(m_flux_MTEvap*Pipe_MTEvap)/mu_f[28]
Re_g[28]=(m_flux_MTEvap*Pipe_MTEvap)/mu_g[28]
f_f[28]=0.079/Re_f[28]^0.25
f_g[28]=0.079/Re_g[28]^0.25
Sigma_MT=SurfaceTension(R$,T=T[28])
Rho[28]=Density(R$,H=H[28],P=P[28])
Vel_MTEvap=M_dot_4/((Pipe_MTEvap_CS)*Rho[28])
D_i[28]=Pipe_MTEvap

Call deltaPAB(m_flux_MTEvap,d_i[28],Rho_f[28],Rho_g[28],f_f[28],f_g[28]:a[28],b[28])
Call deltaPG(a[28],b[28],x[28]:G[28])
Call deltaP(G[28],X[28],b[28]:dPdz_frict[28])
Call
EoutEin(X[29],X[28],Rho_g[28],Rho_f[28],M_flux_MTEvap,Sigma_MT:E_out[28],E_in[28])

Call
Momentum(X[29],X[28],Rho_g[28],Rho_f[28],M_flux_MTEvap,E_out[28],E_in[28]:DeltaP_Mo
mentum[28])
DeltaP_Frict_MTEvap=INTEGRAL(dpdz_frict[28],X,X[28],X[29])*L_MTEvap
```

```
DeltaP_MTEVAP=DeltaP_momentum[28]+DeltaP_Frict_MTEvap



"MT Flow Rate"
M_dot_4=MT_Cap/(H[29]-H[28])
q_MT=H[29]-H[28]
_
COP_MT=MT_CAPKW/W_dot_MTKW
"MT Evap Superheat"
T[30]=T[29]+LT_SH
P[30]=P[29]
H[30]=enthalpy(R$,T=T[30],P=P[30])

"Pressure drop to distance to Pack (LTMT Mixing PT)"
"T[30]=T[31]
P[30]=P[31]"
H[30]=H[31]
L_MTSuction=25
Pipe_MTSuction=0.0129
Pipe_MTSuction_CS=pi*(Pipe_MTSuction/2)^2

Rho[30]=Density(R$,H=H[30],P=P[30])
mu[30]=Viscosity(R$,H=H[30],P=P[30])
Re[30]=((M_dot_4/Pipe_MTSuction_CS)*Pipe_MTSuction)/mu[30]
BL[30]=0.316/(Re[30]^0.25)
DeltaP_MTSuction=BL[30]*(L_MTSuction/Pipe_MTSuction)*Rho[30]*(Vel_MTSuction^2/2)
Vel_MTSuction=M_dot_4/((Pipe_MTSuction_CS)*Rho[30])


DeltaTINCREASE_MTSuction=3
P[31]=P[30]-DeltaP_MTSuction
T[31]=Temperature(R$,H=H[31],P=P[31])+DeltaTINCREASE_MTSuction
DeltaT_MTSuction=T[30]-T[31]

"LT EVAPORATION"

"Pressure drop to LT Evaporator"


"T[26]=T[32]"
"P[26]=P[32]"
H[26]=H[32]
L_LTLiquid=25
Pipe_LTLiquid=0.0099
Pipe_LTLiquid_CS=pi*(Pipe_LTLiquid/2)^2
Vel_LTliquid=M_dot_5/((Pipe_LTLiquid_CS)*Rho[26])
D_i[5]=Pipe_LTLiquid
M_flux[5]=M_dot_5/(pi*(Pipe_LTLiquid/2)^2)
mu_f[26]=Viscosity(R$,T=T[26],X=0)
mu_g[26]=Viscosity(R$,T=T[26],X=1)
rho_f[26]=Density(R$,T=T[26],X=0)
rho_g[26]=Density(R$,T=T[26],X=1)
Re_f[26]=(m_flux[5]*Pipe_LTLiquid)/mu_f[26]
Re_g[26]=(m_flux[5]*Pipe_LTLiquid)/mu_g[26]
f_f[26]=0.079/Re_f[26]^0.25
f_g[26]=0.079/Re_g[26]^0.25
```

```
Call deltaPAB(m_flux[5],d_i[5],Rho_f[26],Rho_g[26],f_f[26],f_g[26]:a[26],b[26])
Call deltaPG(a[26],b[26],x[26]:G[26])
Call deltaP(G[26],X[26],b[26]:dPdz_frict[26])
DeltaP_LTLiquid2=(L_LTLiquid*dPdz_frict[26])
P[32]=P[26]-DeltaP_LTLiquid2
T[32]=Temperature(R$,H=H[32],P=P[32])
X[32]=Quality(R$,H=H[32],P=P[32])
DeltaT_LTLiquid=T[26]-T[32]


"LT Expansion"
T[33]=LT
H[33]=H[32]
P[33]=Pressure(R$,T=T[33],H=H[33])

"LT Flow Rate"
M_dot_5=LT_Cap/(H[1]-H[33])
V_dot_Swept_LTComp=M_dot_5/(Rho[3]*0.76)*3600
q_LT=H[1]-H[33]
COP_LT=LT_CAPKW/W_dot_LTKW

"LT Evap Pressure Drop"
X[32]=X[33]
L_LTEvap=16
Pipe_LTEvap=0.0107
Pipe_LTEvap_CS=pi*(Pipe_LTEvap/2)^2
M_flux_LTEvap=M_dot_5/(Pipe_LTEvap_CS)
mu_f[33]=Viscosity(R$,T=T[33],X=0)
mu_g[33]=Viscosity(R$,T=T[33],X=1)
rho_f[33]=Density(R$,T=T[33],X=0)
rho_g[33]=Density(R$,T=T[28],X=1)
Re_f[33]=(m_flux_LTEvap*Pipe_LTEvap)/mu_f[33]
Re_g[33]=(m_flux_LTEvap*Pipe_LTEvap)/mu_g[33]
f_f[33]=0.079/Re_f[33]^0.25
f_g[33]=0.079/Re_g[33]^0.25
Sigma_LT=SurfaceTension(R$,T=T[33])
Rho[33]=Density(R$,H=H[33],P=P[33])
Vel_LTEvap=M_dot_5/((Pipe_LTEvap_CS)*Rho[33])
D_i[33]=Pipe_LTEvap

Call deltaPAB(m_flux_LTEvap,d_i[33],Rho_f[33],Rho_g[33],f_f[33],f_g[33]:a[33],b[33])
Call deltaPG(a[33],b[33],x[33]:G[33])
Call deltaP(G[33],X[33],b[33]:dPdz_frict[33])
Call EoutEin(X[1],X[33],Rho_g[33],Rho_f[33],M_flux_LTEvap,Sigma_LT:E_out[33],E_in[33])

Call
Momentum(X[1],X[33],Rho_g[33],Rho_f[33],M_flux_LTEvap,E_out[33],E_in[33]:DeltaP_Mom
entum[33])
DeltaP_Frict_LTEvap=INTEGRAL(dpdz_frict[33],X,X[33],X[1])*L_LTEvap
DeltaP_LTEVAP=DeltaP_momentum[33]+DeltaP_Frict_LTEvap



COP=(LT_CAPKW+MT_CAPKW)/(W_dot_LTKW+W_dot_MTKW)
```

3. EES Code for Chapter 3 and 4 CO_2 evaporator simulation model

```
Procedure
rowjfactor(L_ev_t,W_evap,T_airflow:Row_number,Column_number,Tube_number,T_air_in)
If L_ev_t<W_evap then
Row_number=1
Column_number=1
Tube_number=1
T_air_in=T_airflow
Else
If L_ev_t<2*W_evap then
Row_number=1
Column_number=2
Tube_number=2
T_air_in=T_airflow
Else
If L_ev_t<3*W_evap then
Row_number=1
Column_number=3
Tube_number=3
T_air_in=T_airflow
Else
If L_ev_t<4*W_evap then
Row_number=2
Column_number=3
Tube_number=4
T_air_in=-20.53
Else
If L_ev_t<5*W_evap then
Row_number=2
Column_number=2
Tube_number=5
T_air_in=-20.53
Else
If L_ev_t<6*W_evap then
Row_number=2
Column_number=1
Tube_number=1
T_air_in=-20.53
Else
If L_ev_t<7*W_evap then
Row_number=3
Column_number=1
Tube_number=7
T_air_in=-20.98
Else
If L_ev_t<8*W_evap then
Row_number=3
Column_number=2
Tube_number=8
T_air_in=-20.98
Else
If L_ev_t<9*W_evap then
Row_number=3
Column_number=3
```

```
Tube_number=9
T_air_in=-20.98
Else
If L_ev_t<10*W_evap then
Row_number=4
Column_number=3
Tube_number=10
T_air_in=-21.37
Else
If L_ev_t<11*W_evap then
Row_number=4
Column_number=2
Tube_number=11
T_air_in=-21.37
Else
If L_ev_t<12*W_evap then
Row_number=4
Column_number=1
Tube_number=12
T_air_in=-21.37
Else
If L_ev_t<13*W_evap then
Row_number=5
Column_number=1
Tube_number=13
T_air_in=-21.72
Else
If L_ev_t<14*W_evap then
Row_number=5
Column_number=2
Tube_number=14
T_air_in=-21.72
Else
If L_ev_t<15*W_evap then
Row_number=5
Column_number=3
Tube_number=15
T_air_in=-21.72
Else
If L_ev_t<16*W_evap then
Row_number=6
Column_number=3
Tube_number=16
T_air_in=-22.02
Else
If L_ev_t<17*W_evap then
Row_number=6
Column_number=2
Tube_number=17
T_air_in=-22.02
Else
If L_ev_t<18*W_evap then
Row_number=6
Column_number=1
Tube_number=18
T_air_in=-22.02
Else
If L_ev_t<19*W_evap then
```

```
Row_number=7
Column_number=1
Tube_number=19
T_air_in=-22.33
Else
If L_ev_t<20*W_evap then
Row_number=7
Column_number=2
Tube_number=20
T_air_in=-22.33
Else
If L_ev_t<21*W_evap then
Row_number=7
Column_number=3
Tube_number=21
T_air_in=-22.33
Else
If L_ev_t<22*W_evap then
Row_number=8
Column_number=3
Tube_number=22
T_air_in=-22.6
Else
If L_ev_t<23*W_evap then
Row_number=8
Column_number=2
Tube_number=23
T_air_in=-22.6
Else
If L_ev_t<24*W_evap then
Row_number=8
Column_number=1
Tube_number=24
T_air_in=-22.6
Else
If L_ev_t<25*W_evap then
Row_number=9
Column_number=1
Tube_number=22
T_air_in=-22.19
Else
If L_ev_t<26*W_evap then
Row_number=9
Column_number=2
Tube_number=23
T_air_in=-20.48
Else
If L_ev_t<27*W_evap then
Row_number=9
Column_number=3
Tube_number=24
T_air_in=-20.48
Else
If L_ev_t<28*W_evap then
Row_number=10
Column_number=3
Tube_number=28
T_air_in=-20.48
```

```
Else
If L_ev_t<29*W_evap then
Row_number=10
Column_number=2
Tube_number=29
T_air_in=-20.48
Else
If L_ev_t<30*W_evap then
Row_number=10
Column_number=1
Tube_number=30
T_air_in=-20.48
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
Endif
End


Procedure Overall(X,X_di,X_de,Alpha_mist,Alpha_tp,Alpha_dryout:Alpha_total)
If X<X_DI then
Alpha_total=Alpha_tp
Else
If X=X_DI then
Alpha_total=Alpha_dryout
Else
If X<X_de then
Alpha_total=Alpha_dryout
Else
If X=X_de then
Alpha_total=Alpha_mist
```

```
Else
Alpha_total=Alpha_mist
Endif
Endif
Endif
Endif
End

Procedure Capacity1(Row_number,DeltaH,UA:UA1,DeltaH1)
If Row_number=1 then
DeltaH1=DeltaH
UA1=UA
Else
UA1=0
DeltaH1=0
Endif
End

Procedure Capacity2(Row_number,DeltaH,UA:UA2,DeltaH2)
If Row_number=2 then
DeltaH2=DeltaH
UA2=UA
Else
UA2=0
DeltaH2=0
Endif
End

Procedure Capacity3(Row_number,DeltaH,UA:UA3,DeltaH3)
If Row_number=3 then
DeltaH3=DeltaH
UA3=UA
Else
UA3=0
DeltaH3=0
Endif
End

Procedure Capacity4(Row_number,DeltaH,UA:UA4,DeltaH4)
If Row_number=4 then
DeltaH4=DeltaH
UA4=UA
Else
UA4=0
DeltaH4=0
Endif
End

Procedure Capacity5(Row_number,DeltaH,UA:UA5,deltaH5)
If Row_number=5 then
DeltaH5=DeltaH
UA5=UA
Else
UA5=0
DeltaH5=0
Endif
End
```

```
Procedure Capacity6(Row_number,DeltaH,UA:UA6,DeltaH6)
If Row_number=6 then
DeltaH6=DeltaH
UA6=UA
Else
UA6=0
DeltaH6=0
Endif
End

Procedure Capacity7(Row_number,DeltaH,UA:UA7,deltaH7)
If Row_number=7 then
DeltaH7=DeltaH
UA7=UA
Else
UA7=0
DeltaH7=0
Endif
End

Procedure Capacity8(Row_number,DeltaH,UA:UA8,deltaH8)
If Row_number=8 then
DeltaH8=DeltaH
UA8=UA
Else
UA8=0
DeltaH8=0
Endif
End


R$='R744'

"INPUTS"

"Air Properties"
T_ambient=25
V_air=2
T_airflow=-20
H_air_in=enthalpy(air,T=T_airflow)
mu_air=Viscosity(air,T=T_airflow)
Rho_air=Density(Air,T=T_airflow,P=Po#)
Pr_air=Prandtl(Air,T=T_airflow)
k_fin=k_(Aluminum, T=T_airflow)



"Refrigerant Properties"
T_r_evap=-30
X_r_in=0.01
x=0.1
P_r_evap=Pressure(R$,T=T_r_evap,X=X_r_in)
H_r_evap=enthalpy(R$,T=T_r_evap,X=X_r_in)
M_dot_r=0.0069
M_dot_th=2100/H_fg
m_flux=m_dot_r/(pi*(d_i/2)^2)
H_f=enthalpy(R$,T=T_r_evap,X=0)
H_g=enthalpy(R$,T=T_r_evap,X=1)
```

```
H_fg=H_g-H_f
rho=Density(R$,T=T_r_evap,X=X)
rho_f=Density(R$,T=T_r_evap,X=0)
rho_g=Density(R$,T=T_r_evap,X=1)
mu_f=Viscosity(R$,T=T_r_evap,X=0)
mu_g=Viscosity(R$,T=T_r_evap,X=1)
sigma=SurfaceTension(R$,T=T_r_evap)
Pr_f=Prandtl(R$,T=T_r_evap,x=0)
Pr_g=Prandtl(R$,T=T_r_evap,x=1)
k_f=Conductivity(R$,T=T_r_evap,X=0)
k_g=Conductivity(R$,T=T_r_evap,X=1)
cp_f=SpecHeat(R$,T=T_r_evap,X=0)
cp_g=SpecHeat(R$,T=T_r_evap,X=1)
Re_f=(m_flux*d_i)/mu_f                          "Reynolds Number Liquid"
Re_g=(m_flux*d_i)/mu_g                          "Reynolds Number Gas"
Re_H=(m_flux*d_i/mu_g)*(X+((Rho_g/Rho_f)*(1-X)))
We_g=(m_flux^2*D_i)/(rho*sigma)
Fr_g=m_flux^2/(rho_g*(rho_f-Rho_g)*g#*D_i)
f_f=0.079/Re_f^0.25                             "Friction Factor Liquid"
f_g=0.079/Re_g^0.25                             "Friction Factor Gas"

q_hf=243
q_crit=0.131*Rho_g^0.5*H_fg*((g#*sigma*(Rho_f-Rho_g))^0.25)
theta_dry=0                                     "annular flow"
P_crit=P_crit(R$)

"Evaporator geometry"
D_i=0.00801                                     "Tube internal Diameter"
Delta_tube=0.001                                "Tube Thickness"
D_o=D_i+(2*Delta_tube)                          "Tube External Diameter"
r=D_o/2                                         "Tube External Radius"
Delta_fin=0.001                                 "fin width"
FPI=3
N_fins=FPI*39.37*W_evap
S_fins=(W_evap-(Delta_fin*N_fins))/N_fins
P_t=0.025                                       "Traverse fin Pitch"
P_l=0.025                                       "longitudional fin pitch"
D_evap=(N_r*(D_o+P_L))+(P_L)                    "Evaporator Depth"
W_evap=2                                        "Evaporator Width"
H_evap=N_t*(D_o+(2*P_t))                        "Evaporator Height"
N_r=8                                           "Number of tube rows"
N_t=3                                           "Number of tubes per row"
N_tubes=N_r*N_t
k_tube=k_(Copper, T=T_r_evap)
A_face=W_evap*H_evap                            "Evaporator Face Area"
A_face_tubes=D_o*N_t*W_evap                     "Evaporator tube face area"
A_face_fins=H_evap*delta_fin*N_fins-(N_fins*D_o*Delta_fin*N_t)"Evaporator fin face Area"
A_min=A_face-A_face_tubes-A_face_fins           "Evaporator free flow Area"
Ao_fin_T=N_tubes*W_evap*(N_fins/W_evap)*(2*(((P_t*P_L))-((D_o/2)^2)))
Ao_tube_T=((N_tubes*W_evap)*(pi*D_o)-((N_fins/W_evap)*Delta_fin))
A_T=Ao_tube_T+Ao_fin_t

"Evaporator air flow properties"
d_h=(4*D_evap*A_min)/A_T                        "Hydraulic diameter"
v_airmax=v_air/(A_min/A_Face)                   "Max valocity based on free flow
area"
M_dot_air=v_airmax*A_min*Rho_air                "Air flow rate based on free flow
area"
```

```
m_flux_air=m_dot_air/A_min
X_L=p_l/2
X_M=(((P_t/2)^2+(P_l)^2))^0.5/2                              "Staggered Layout"
R_eq/r=1.28*(X_m/r)*((X_L/X_M)-0.2)^0.5


"ELEMENTAL HEAT TRANSFER"

"No of elemental volumes per tube"
N_ev_tube=99
M_dot_air_ev=M_dot_air/(N_ev_tube)
X_r_out=0.99

P[N_ev_tube]=P_r_evap
X_out[1]=0.99
X_in[N_ev_tube]=0.01

"INITIATION BY ELEMENT 1"

"Quality Distrubition"
Duplicate i=1,1
X_in[i]=X_out[1]-(i*((X_out[i]-X_in[N_ev_tube])/N_ev_tube))
H_in[i]=Enthalpy(R$,X=X_in[i],P=P[N_ev_tube])          "NO PRESSURE DROP
ACCOUNTED FOR"
DeltaX[i]=X_out[i]-X_in[i]
end

Duplicate i=1,1
X_out[i]=X_in[i-1]
H_out[i]=Enthalpy(R$,X=X_out[i],P=P[N_ev_tube])
DeltaH[i]=H_out[i]-H_in[i]
end

"Heat transfer coefficients"
Duplicate i=1,1
"Air Side"
j[i]=0.170*1^(-0.141)*(S_fins/D_o)^(-0.384)*(Re_air_dh[i])^(-0.349)          "KIM KIM
CORRELATION 2005"
Re_air_dh[i]=(v_air*d_h*Rho_air[i])/(mu_air[i])
Rho_air[i]=Density(Air,T=T_air_in[i],P=Po#)
mu_air[i]=Viscosity(air,T=T_air_in[i])
Alpha_o[i]=(j[i]*m_flux_air*cp_air[i])/Pr_air^(2/3)
cp_air[i]=Cp(Air,T=T_air_in[i])
Pr_air[i]=Prandtl(Air,T=T_air_in[i])
m[i]=SQRT((2*Alpha_o[i])/(k_fin*delta_fin))
phi[i]=((R_eq/r)-1)*(1+0.35*ln(R_eq/r))
Eta[i]=tanh(m[i]*r*phi[i])/(m[i]*r*phi[i])
Eta_o[i]=1-Ao_fin_ev[i]/Ao_T_ev[i]*(1-Eta[i])
end

"Capacity calculation using delta H"
Duplicate i=1,1
Q[i]=m_dot_r*(H_out[i]-H_in[i])                              "Refrigerant elememtal volume
Cooling capacity"
T_air_in[1]=T_airflow
M_dot_air_ev[i]=M_dot_air/(N_ev_tube)
Q[i]=M_dot_eachvol2[i]*cp_air[i]*(T_air_in[i]-T_air_out[i])
DeltaTA[i]=abs(T_r_evap-T_air_in[i])
```

```
DeltaTB[i]=abs(T_r_evap-T_air_out[i])
T_LMTD[i]=(T_air_in[i]-T_air_out[i])/(ln((DeltaTA[i])/(DeltaTB[i])))
Q[i]=UA[i]*T_LMTD[i]
End

"Elemental Volume Length Calculation"
Duplicate i=1,1
L_ev[i]=UA[i]*(((Eta_o[i]*Alpha_o[i]*(((N_fins/W_evap)*(2*(((P_t*P_L))-
((D_o/2)^2))))+(((d_o*pi)-(N_fins*Delta_fin*D_o*pi/W_evap)))))^(-
1))+((Alpha_total[i]*(pi*D_i))^(-1)))
Ao_fin_ev[i]=L_ev[i]*(N_fins/W_evap)*(2*(((P_t*P_L))-((D_o/2)^2)))
Ao_tube_ev[i]=L_ev[i]*((d_o*pi)-(N_fins*Delta_fin*D_o*pi/W_evap))
Ao_T_ev[i]=(L_ev[i]*(N_fins/W_evap)*(2*(((P_t*P_L))-((D_o/2)^2))))+(L_ev[i]*((d_o*pi)-
(N_fins*Delta_fin*D_o*pi/W_evap)))
Ai_T_ev[i]=L_ev[i]*pi*D_i
End

"Total Evaporator Length Calculation"
Duplicate j=1,1
L_ev_T[j+1]=L_ev_t[j]+L_ev[j]
end
L_ev_T[1]=L_ev[1]

"Pressure and temperature drop"
TotalP_out=sum(DeltaP_total[i],i=1,N_ev_tube)
Pout[1]=P_r_evap-TotalP_out
Tout[1]=Temperature(R$,P=Pout[1],X=X_out[1])
hout[1]=enthalpy(R$,P=Pout[1],X=X_out[1])
Pin[1]=Pout[1]+DeltaP_total[1]
Tin[1]=Temperature(R$,P=Pin[1],X=X_in[1])

"First Element Row Number Naming"
Row_number[1]=1
Column_number[1]=1
Tube_number[1]=1



"OTHER ELEMENTS"

"Quality Distrubition"
Duplicate i=2,(N_ev_tube-1)
X_in[i]=X_out[i]-(((X_out[1]-X_in[N_ev_tube])/N_ev_tube))
end

Duplicate i=2,(N_ev_tube)
X_out[i]=X_in[i-1]
H_in[i]=Enthalpy(R$,X=X_in[i],P=P[N_ev_tube])          "NO PRESSURE DROP
ACCOUNTED FOR"
H_out[i]=Enthalpy(R$,X=X_out[i],P=P[N_ev_tube])
DeltaX[i]=X_out[i]-X_in[i]
DeltaH[i]=H_out[i]-H_in[i]
end

"Heat transfer coefficients"
Duplicate i=2,(N_ev_tube)
"Air Side"
```

```
j[i]=0.170*Row_number[i]^(-0.141)*(S_fins/D_o)^(-0.384)*(Re_air_dh[i])^(-0.349)          "KIM
KIM CORRELATION 2005"
Re_air_dh[i]=(v_air*d_h*Rho_air[i])/(mu_air[i])
Rho_air[i]=Density(Air,T=T_air_in[i],P=Po#)
mu_air[i]=Viscosity(air,T=T_air_in[i])
Alpha_o[i]=(j[i]*m_flux_air*cp_air[i])/Pr_air^(2/3)
cp_air[i]=Cp(Air,T=T_air_in[i])
Pr_air[i]=Prandtl(Air,T=T_air_in[i])
m[i]=SQRT((2*Alpha_o[i])/(k_fin*delta_fin))
phi[i]=((R_eq/r)-1)*(1+0.35*ln(R_eq/r))
Eta[i]=tanh(m[i]*r*phi[i])/(m[i]*r*phi[i])
Eta_o[i]=1-Ao_fin_ev[i]/Ao_T_ev[i]*(1-Eta[i])
end

"Capacity calculation using delta H"
Duplicate i=2,(N_ev_tube)
Q[i]=m_dot_r*(H_out[i]-H_in[i])                         "Refrigerant elememtal volume
Cooling capacity"

M_dot_air_ev[i]=M_dot_air/(N_ev_tube)
Q[i]=M_dot_eachvol2[i]*cp_air[i]*(T_air_in[i]-T_air_out[i])
DeltaTA[i]=abs(T_r_evap-T_air_in[i])
DeltaTB[i]=abs(T_r_evap-T_air_out[i])
T_LMTD[i]=(T_air_in[i]-T_air_out[i])/(ln((DeltaTA[i])/(DeltaTB[i])))
Q[i]=UA[i]*T_LMTD[i]
End

"Elemental Volume Length Calculation"
Duplicate i=2,(N_ev_tube)
L_ev[i]=UA[i]*(((Eta_o[i]*Alpha_o[i]*(((N_fins/W_evap)*(2*(((P_t*P_L))-
((D_o/2)^2))))+(((d_o*pi)-(N_fins*Delta_fin*D_o*pi/W_evap)))))^(-
1))+((Alpha_total[i]*(pi*D_i))^(-1)))
Ao_fin_ev[i]=L_ev[i]*(N_fins/W_evap)*(2*(((P_t*P_L))-((D_o/2)^2)))
Ao_tube_ev[i]=L_ev[i]*((d_o*pi)-(N_fins*Delta_fin*D_o*pi/W_evap))
Ao_T_ev[i]=(L_ev[i]*(N_fins/W_evap)*(2*(((P_t*P_L))-((D_o/2)^2))))+(L_ev[i]*((d_o*pi)-
(N_fins*Delta_fin*D_o*pi/W_evap)))
Ai_T_ev[i]=L_ev[i]*pi*D_i
End

"Total Evaporator Length Calculation"
Duplicate j=2,(N_ev_tube-1)
L_ev_T[j+1]=L_ev_t[j]+L_ev[j]
end

"For calculating row number and air out temperature"
Duplicate j=2,(N_ev_tube)
Call
rowjfactor(L_ev_t[j],W_evap,T_airflow:Row_number[j],Column_number[j],Tube_number[j],T_
air_in[j])
end

"Refrigerant Velocity"
Pipe_CS=3.14*(D_I/2)^2
Duplicate i=1,N_ev_tube
Rho_X[i]=Density(R$,T=Tout[i],X=X_out[i])
Velocity[i]=m_dot_r/(Rho_X[i]*Pipe_cs)
End
```

```
"Pressure Drop"
Duplicate i=1,(N_ev_tube)
x[i]=((x_in[i]+X_out[i])/2)
a[i]=f_f*((2*m_flux^2)/(d_i*rho_F))
b[i]=f_g*((2*m_flux^2)/(d_i*rho_g))
G[i]=a[i]+(2*(b[i]-a[i])*X[i])
dPdz_frict[i]=G[i]*(1-X[i])^(1/3)+b[i]*x[i]^3
E_out[i]=(X_out[i]/Rho_g)/((1+0.12*(1-X_out[i]))*((x_out[i]/(Rho_g))+((1-
x_out[i])/rho_f))+((1.18/m_flux)*(((g#*sigma*(rho_f-rho_g))/Rho_f^2)^0.25)*(1-x_out[i])))    "
Void Fraction"
E_in[i]=(X_in[i]/Rho_g)/((1+0.12*(1-X_in[i]))*((x_in[i]/(Rho_g))+((1-
x_in[i])/rho_f))+((1.18/m_flux)*(((g#*sigma*(rho_f-rho_g))/Rho_f^2)^0.25)*(1-x_in[i])))   " Void
Fraction"
DeltaP_Momentum[i]=m_flux^2*(((1-X_out[i])^2/((rho_f*(1-
E_out[i])))+(x_out[i]^2/(rho_g*e_out[i])))-((1-X_in[i])^2/((rho_f*(1-
E_in[i])))+(x_in[i]^2/(rho_g*e_in[i]))))
DeltaP_Friction[i]=dPdz_frict[i]*L_ev[i]
DeltaP_Total[i]=DeltaP_Momentum[i]+DeltaP_Friction[i]
P_out[i]=P_r_evap-DeltaP_total[i]
End

"Pressure Drop"
Duplicate i=2,(N_ev_tube)
Pout[i]=Pin[i-1]
Pin[i]=Pout[i]+DeltaP_total[i]
Tout[i]=Temperature(R$,P=Pout[i],X=X_out[i])
hout[i]=enthalpy(R$,P=Pout[i],X=X_out[i])
Tin[i]=Temperature(R$,P=Pin[i],X=X_in[i])
End

"Refrigerant Side Heat Transfer Coefficient"

Duplicate i=1,N_ev_tube
X_IA[i]=1/(1.8^(1/0.875)*(rho_g/Rho_f)^(-1/1.75)*(mu_f/mu_g)^(-1/7)+1)
X_di[i]=0.58*exp(0.52-
(0.236*We_g^0.17*Fr_g^0.17*(Rho_g/Rho_f)^0.25*(Q_hf/Q_crit)^0.25))
X_de[i]=0.61*exp(0.57-
(0.502*We_g^0.16*Fr_g^0.15*(Rho_g/Rho_f)^0.09*(Q_hf/Q_crit)^0.72))
delta[i]=(d_i/2)-((((d_i/2)^2)-((1-E[i])*pi*(d_i^2))/((2*(((2*pi))-theta_dry))))^0.5)
delta_IA[i]=(d_i/2)-((((d_i/2)^2)-((1-E_IA[i])*pi*(d_i^2))/((2*(((2*pi))-theta_dry))))^0.5)
E[i]=(X[i]/Rho_g)/((1+0.12*(1-X[i]))*((x[i]/(Rho_g))+((1-
x[i])/rho_f))+((1.18/m_flux)*(((g#*sigma*(rho_f-rho_g))/Rho_f^2)^0.25)*(1-x[i])))    " Void
Fraction"
E_IA[i]=(X_IA[i]/Rho_g)/((1+0.12*(1-X_IA[i]))*((X_IA[i]/(Rho_g))+((1-
X_IA[i])/rho_f))+((1.18/m_flux)*(((g#*sigma*(rho_f-rho_g))/Rho_f^2)^0.25)*(1-X_IA[i])))    "
Intermittant to annular Void Fraction"
Alpha_nb[i]=(131*p_r[i]^(-0.0063)*((-log10(P_r[i]))^(-0.55)*MolarMass(R$)^(-0.5))*q_hf^0.58)
P_r[i]=Pheat[i]/P_crit
Pheat[i]=pressure(R$,T=T_r_evap,X=X[i])
Alpha_cb[i]=0.0133*(((4*m_flux*(1-X[i])*delta[i])/((1-E[i])*mu_f))^0.69)*Pr_f^0.4*(k_f/delta[i])
alpha_wet[i]=((((alpha_nb[i])^3)+(alpha_cb[i]^3))^(1/3))
Alpha_g[i]=0.023*Re_g^0.8*Pr_g^0.4*(k_g/d_i)
Alpha_tp[i]=((theta_dry*Alpha_g[i])+(((pi*2)-theta_dry)*alpha_wet[i]))/(2*pi)
Alpha_dryout[i]=Alpha_tp[i]*X_di[i]-(((X[i]-X_di[i])/(X_de[i]-X_di[i]))*((alpha_tp[i]*X_di[i])-
(Alpha_mist[i]*X_de[i])))                                     "Dry out inception heat transfer
coefficient"
Alpha_mist[i]=0.00000002*Re_H[i]^1.97*Pr_g^1.06*Y[i]^(-1.83)*(K_g/d_i)
```

```
Re_H[i]=(m_flux*d_i/mu_g)*(X[i]+((Rho_g/Rho_f)*(1-X[i])))
Y[i]=1-0.1*((((Rho_f/Rho_g)-1)*(1-X[i]))^0.4)
Call Overall(X[i],X_di[i],X_de[i],Alpha_mist[i],Alpha_tp[i],Alpha_dryout[i]:Alpha_total[i])
end

"EVAPORATOR CAPACITY CALCULATION"
Duplicate i=1,N_ev_tube
Call Capacity1(Row_number[i],DeltaH[i],UA[i]:UA1[i],DeltaH1[i])
Call Capacity2(Row_number[i],DeltaH[i],UA[i]:UA2[i],DeltaH2[i])
Call Capacity3(Row_number[i],DeltaH[i],UA[i]:UA3[i],DeltaH3[i])
Call Capacity4(Row_number[i],DeltaH[i],UA[i]:UA4[i],DeltaH4[i])
Call Capacity5(Row_number[i],DeltaH[i],UA[i]:UA5[i],DeltaH5[i])
Call Capacity6(Row_number[i],DeltaH[i],UA[i]:UA6[i],DeltaH6[i])
Call Capacity7(Row_number[i],DeltaH[i],UA[i]:UA7[i],DeltaH7[i])
Call Capacity8(Row_number[i],DeltaH[i],UA[i]:UA8[i],DeltaH8[i])
End

Capacity1H=sum(DeltaH1[i], i=1,N_ev_tube)
UArow1=sum(UA1[i], i=1,N_ev_tube)
Qrow1=Capacity1H*M_dot_r
Capacity2H=sum(DeltaH2[i], i=1,N_ev_tube)
UArow2=sum(UA2[i], i=1,N_ev_tube)
Qrow2=Capacity2H*M_dot_r
Capacity3H=sum(DeltaH3[i], i=1,N_ev_tube)
UArow3=sum(UA3[i], i=1,N_ev_tube)
Qrow3=Capacity3H*M_dot_r
Capacity4H=sum(DeltaH4[i], i=1,N_ev_tube)
UArow4=sum(UA4[i], i=1,N_ev_tube)
Qrow4=Capacity4H*M_dot_r
Capacity5H=sum(DeltaH5[i], i=1,N_ev_tube)
UArow5=sum(UA5[i], i=1,N_ev_tube)
Qrow5=Capacity5H*M_dot_r
Capacity6H=sum(DeltaH6[i], i=1,N_ev_tube)
UArow6=sum(UA6[i], i=1,N_ev_tube)
Qrow6=Capacity6H*M_dot_r
Capacity7H=sum(DeltaH7[i], i=1,N_ev_tube)
UArow7=sum(UA7[i], i=1,N_ev_tube)
Qrow7=Capacity7H*M_dot_r
Capacity8H=sum(DeltaH8[i], i=1,N_ev_tube)
UArow8=sum(UA8[i], i=1,N_ev_tube)
Qrow8=Capacity8H*M_dot_r


Q_TOTAL=Qrow8+Qrow7+Qrow6+Qrow5+Qrow4+Qrow3+Qrow2+Qrow1

"Air temperature drop across tube using whole row Q and deltaX"
Total_Length=sum(L_ev[i], i=1,N_ev_tube)
Total_M_Dot_Air=sum(M_dot_eachvol[i], i=1,N_ev_tube)
Duplicate i=1,N_ev_tube
M_dot_eachvol[i]=(M_dot_air/8)*L_ev[i]
End


Duplicate i=1,N_ev_tube
Ug[i]=(UA[i])/Ao_T_ev[i]
End
```