

INVESTIGATION AND OPTIMISATION OF COMMERCIAL REFRIGERATION CYCLES USING THE NATURAL REFRIGERANT CO₂

A thesis submitted for the degree of Doctor of Engineering

By

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APPENDIX B

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Appendix B

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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]

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

"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])

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

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

$P[14]=P[13]-\Delta P_HPDischarge$
 $T[14]=\text{Temperature}(R\$,H=H[14],P=P[14])$
 $\Delta T_MTSuction=T[14]-T[13]"$

"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])
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)

$\Delta P_{\text{CommonLiquid}} = BL[24] * (L_{\text{CommonLiquid}} / \text{Pipe}_{\text{CommonLiquid}}) * \rho[24] * (\text{Vel}_{\text{CommonLiquid}}^2 / 2)$
 $P[26] = P[24] - \Delta P_{\text{commonliquid}}$
 $T[26] = \text{Temperature}(R\$, H=H[26], P=P[26])$
 $X[26] = \text{quality}(R\$, P=P[26], H=H[26])$

$H[26] = H[24]$

"Pressure drop to MT Evaporator"

$T[26] = T[27]$

$P[26] = P[27]$

$H[27] = H[26]$

$L_{\text{MTLiquid}} = 25$

$\text{Pipe}_{\text{MTLiquid}} = 0.0099$

$\rho[26] = \text{Density}(R\$, H=H[26], P=P[26])$

$\text{Vel}_{\text{MTLiquid}} = M_{\text{dot}}_4 / ((\text{Pipe}_{\text{MTLiquid}}_{\text{CS}}) * \rho[26])$

$D_i[4] = \text{Pipe}_{\text{MTLiquid}}$

$\text{Pipe}_{\text{MTLiquid}}_{\text{CS}} = \pi * (\text{Pipe}_{\text{MTLiquid}} / 2)^2$

$M_{\text{flux}}[4] = M_{\text{dot}}_4 / (\text{Pipe}_{\text{MTLiquid}}_{\text{CS}})$

Call $\text{deltaPAB}(m_{\text{flux}}[4], d_i[4], \rho_{\text{f}}[26], \rho_{\text{g}}[26], f_{\text{f}}[26], f_{\text{g}}[26]: a[27], b[27])$

Call $\text{deltaPG}(a[27], b[27], x[26]: G[27])$

Call $\text{deltaP}(G[27], X[26], b[27]: dPdz_{\text{frict}}[27])$

$\Delta P_{\text{MTLiquid}} = (L_{\text{MTLiquid}} * dPdz_{\text{frict}}[27])$

$P[27] = P[26] - \Delta P_{\text{MTLiquid}}$

$T[27] = \text{Temperature}(R\$, H=H[27], P=P[27])$

$X[27] = \text{Quality}(R\$, H=H[27], T=T[27])$

$\Delta T_{\text{MTLiquid}} = T[26] - T[27]$

"MT Expansion"

$T[28] = \text{MT}$

$H[28] = H[26]$

$P[28] = \text{Pressure}(R\$, T=T[28], H=H[28])$

$X[29] = 0.99$

$P[29] = P[28] - \Delta P_{\text{MTEVAP}}$

$T[29] = \text{Temperature}(R\$, P=P[29], X=X[29])$

$H[29] = \text{Enthalpy}(R\$, P=P[28], X=X[29])$

"MT Evaporator pressure drop"

$X[28] = X[27]$

$L_{\text{MTEvap}} = 12$

$\text{Pipe}_{\text{MTEvap}} = 0.0107$

$\text{Pipe}_{\text{MTEvap}}_{\text{CS}} = \pi * (\text{Pipe}_{\text{MTEvap}} / 2)^2$

$M_{\text{flux}}_{\text{MTEvap}} = M_{\text{dot}}_4 / (\text{Pipe}_{\text{MTEvap}}_{\text{CS}})$

$\mu_{\text{f}}[28] = \text{Viscosity}(R\$, T=T[28], X=0)$

$\mu_{\text{g}}[28] = \text{Viscosity}(R\$, T=T[28], X=1)$

$\rho_{\text{f}}[28] = \text{Density}(R\$, T=T[28], X=0)$

$\rho_{\text{g}}[28] = \text{Density}(R\$, T=T[28], X=1)$

$\text{Re}_{\text{f}}[28] = (m_{\text{flux}}_{\text{MTEvap}} * \text{Pipe}_{\text{MTEvap}}) / \mu_{\text{f}}[28]$

$\text{Re}_{\text{g}}[28] = (m_{\text{flux}}_{\text{MTEvap}} * \text{Pipe}_{\text{MTEvap}}) / \mu_{\text{g}}[28]$

$f_{\text{f}}[28] = 0.079 / \text{Re}_{\text{f}}[28]^0.25$

```

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)

```

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])

```


$$E_{in} = (X_{in}/Rho_g) / ((1 + 0.12 * (1 - X_{in})) * ((x_{in}/(Rho_g)) + ((1 - x_{in})/rho_f)) + ((1.18/m_flux) * (((g\# * sigma * (rho_f - rho_g))/Rho_f^2)^{0.25}) * (1 - x_{in})))$$
 " Void Fraction"
 End

Procedure Momentum(X_out,X_in,Rho_g,Rho_f,M_flux,E_out,E_in:DeltaP_Momentum)

$$\Delta P_Momentum = m_flux^2 * (((1 - X_{out})^2 / ((rho_f * (1 - E_{out}))) + (x_{out}^2 / rho_g * e_{out})) - ((1 - X_{in})^2 / ((rho_f * (1 - E_{in}))) + (x_{in}^2 / rho_g * e_{in})))$$
 End

R\$='R744'

"Inputs"

"LT Cabinets"

LT=-32
 LT_CAPKW=4
 LT_Cap=LT_CAPKW*1000
 LT_SH=7
 LTIS_EFF=0.61
 DeltaLTLEvap=1.5

"LT Evap Temp"

"LT Evap Capacity"

"LT Superheat"

"LT Compressor Efficiency"

"MT Cabinets"

MT=-10
 MP=Pressure(R\$,T=MT,X=1)
 MT_CAPKW=6.6
 MT_Cap=MT_CAPKW*1000
 MT_SH=7
 MTIS_EFF=0.5
 DeltaTMTEvap=1.5

"MT Evap Temp"

"MT Evap Capacity"

"MT Superheat"

RP=3100000
 RT=Temperature(R\$,P=RP,X=1)

"Reciever Pressure"

"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"

$$T[1] = LT - \Delta TLEvap$$

$$H[1] = \text{enthalpy}(R$, T=T[1], x=X[1])$$

$$P[1] = \text{Pressure}(R$, T=T[1], X=X[1]) - \Delta P_LTEVAP$$

$$v[1] = \text{Volume}(R$, T=T[1], x=x[1])$$

$$S[1] = \text{Entropy}(R$, T=T[1], X=X[1])$$

$$\rho[1] = \text{Density}(R$, T=T[1], x=x[1])$$

"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_CommonSuction^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_Commonliquid^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_Momentum[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 CO₂ 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
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"
 $Re_H=(m_flux*d_i/\mu_g)*(X+((\rho_g/\rho_f)*(1-X)))$
 $We_g=(m_flux^2*D_i)/(\rho_g*\sigma)$
 $Fr_g=m_flux^2/(\rho_g*(\rho_f-\rho_g)*g*D_i)$
 $f_f=0.079/Re_f^{0.25}$ "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"
 $P_l=0.025$ "longitudinal 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
R_eq/r=1.28*(X_m/r)*((X_L/X_M)-0.2)^0.5

```

"Staggered Layout"

"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"

$j[i]=0.170 \cdot \text{Row_number}[i]^{-0.141} \cdot (S_fins/D_o)^{-0.384} \cdot (\text{Re_air_dh}[i])^{-0.349}$ "KIM
KIM CORRELATION 2005"

$\text{Re_air_dh}[i]=(v_air \cdot d_h \cdot \text{Rho_air}[i]) / (\mu_air[i])$
 $\text{Rho_air}[i]=\text{Density}(\text{Air}, T=T_air_in[i], P=Po\#)$
 $\mu_air[i]=\text{Viscosity}(\text{air}, T=T_air_in[i])$
 $\text{Alpha_o}[i]=(j[i] \cdot m_flux_air \cdot cp_air[i]) / Pr_air^{(2/3)}$
 $cp_air[i]=Cp(\text{Air}, T=T_air_in[i])$
 $Pr_air[i]=\text{Prandtl}(\text{Air}, T=T_air_in[i])$
 $m[i]=\text{SQRT}((2 \cdot \text{Alpha_o}[i]) / (k_fin \cdot \text{delta_fin}))$
 $\phi[i]=((R_eq/r)-1) \cdot (1+0.35 \cdot \ln(R_eq/r))$
 $\text{Eta}[i]=\tanh(m[i] \cdot r \cdot \phi[i]) / (m[i] \cdot r \cdot \phi[i])$
 $\text{Eta_o}[i]=1 - \text{Ao_fin_ev}[i] / \text{Ao_T_ev}[i] \cdot (1 - \text{Eta}[i])$
 end

"Capacity calculation using delta H"

Duplicate i=2,(N_ev_tube)
 $Q[i]=m_dot_r \cdot (H_out[i] - H_in[i])$ "Refrigerant elemental volume
Cooling capacity"

$M_dot_air_ev[i]=M_dot_air / (N_ev_tube)$
 $Q[i]=M_dot_eachvol2[i] \cdot cp_air[i] \cdot (T_air_in[i] - T_air_out[i])$
 $\text{DeltaTA}[i]=\text{abs}(T_r_evap - T_air_in[i])$
 $\text{DeltaTB}[i]=\text{abs}(T_r_evap - T_air_out[i])$
 $T_LMTD[i]=(T_air_in[i] - T_air_out[i]) / (\ln((\text{DeltaTA}[i]) / (\text{DeltaTB}[i])))$
 $Q[i]=UA[i] \cdot T_LMTD[i]$
 End

"Elemental Volume Length Calculation"

Duplicate i=2,(N_ev_tube)
 $L_ev[i]=UA[i] \cdot (((\text{Eta_o}[i] \cdot \text{Alpha_o}[i] \cdot ((N_fins/W_evap) \cdot (2 \cdot ((P_t \cdot P_L) - ((D_o/2)^2)))) + (((d_o \cdot \pi) - (N_fins \cdot \text{Delta_fin} \cdot D_o \cdot \pi / W_evap))))))^{-1}) + ((\text{Alpha_total}[i] \cdot (\pi \cdot D_i))^{-1})$
 $\text{Ao_fin_ev}[i]=L_ev[i] \cdot (N_fins/W_evap) \cdot (2 \cdot ((P_t \cdot P_L) - ((D_o/2)^2)))$
 $\text{Ao_tube_ev}[i]=L_ev[i] \cdot ((d_o \cdot \pi) - (N_fins \cdot \text{Delta_fin} \cdot D_o \cdot \pi / W_evap))$
 $\text{Ao_T_ev}[i]=(L_ev[i] \cdot (N_fins/W_evap) \cdot (2 \cdot ((P_t \cdot P_L) - ((D_o/2)^2)))) + (L_ev[i] \cdot ((d_o \cdot \pi) - (N_fins \cdot \text{Delta_fin} \cdot D_o \cdot \pi / W_evap)))$
 $\text{Ai_T_ev}[i]=L_ev[i] \cdot \pi \cdot D_i$
 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
 $\text{rowjfactor}(L_ev_t[j], W_evap, T_airflow: \text{Row_number}[j], \text{Column_number}[j], \text{Tube_number}[j], T_air_in[j])$
 end

"Refrigerant Velocity"

$\text{Pipe_CS}=3.14 \cdot (D_I/2)^2$
 Duplicate i=1,N_ev_tube
 $\text{Rho_X}[i]=\text{Density}(R\$, T=T_out[i], X=X_out[i])$
 $\text{Velocity}[i]=m_dot_r / (\text{Rho_X}[i] \cdot \text{Pipe_cs})$
 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))^0.1/3)
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]=0.0000002*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

```

