Billet temperature simulation Codes (3D)

```
%Reading heated billets/blooms table
filename='Table for simulation.xlsx';
Sheet = 1;

IP= xlsread(filename, Sheet, 'B4:B143');  %Initial postion
Wt= xlsread(filename, Sheet, 'C4:C143'); %Weight
Ds= xlsread(filename, Sheet, 'D4:D143'); %Density
TT= xlsread(filename, Sheet, 'E4:E143'); %Transformation temperature
asb= xlsread(filename, Sheet, 'F4:I143'); %Parameters for specific
heat %Below and equal to TT
asa= xlsread(filename, Sheet, 'J4:M143'); %Parameters for specific
heat %Above TT
ac= xlsread(filename, Sheet, 'N4:Q143');  %Thermal conductivity
at= xlsread(filename, Sheet, 'P4:U143'); %Heat transfer coefficient
ae= xlsread(filename, Sheet, 'V4:Y143'); %Emissivity

%Reading operational condition

SK=400 ; %Stroke
Ih=45 ; %Time cycle of hearth when there is no extraction and no pose
[sec]
ps=25 ; %Pose of hearth to control furnace holding time [sec]
DWi=200 ; %Distance from a billet/bloom at initial postion to the wall at
inserting side [mm]
DWe=27800 ; %Distance from a billet/bloom at initial postion to the wall
at extracting side [mm]
Pe=27600 ; %Extracting position [mm]
v=0.0278 ; %Rolling velocity [ton/sec]
Iv=5 ; %Regular interval [sec]

%Reading event table (Stoppages schedule)
%SP=[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,300,0,0,900,0,0,0,0,0,0,0,0,0,0,180,0,0,0
,0,0,0,360,0,0,0,0,600,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1800,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,900,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,900,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0];
SP=zeros(1,140);

%Reading furnace structure
WF=13000 ; %Width of furnace [mm]
df=200 ; %Distance from wall to the front end of billets/blooms [mm]
PW1=7750 ; %Distance from wall to the wall between zone 1 and zone 2 [mm]
PW2=15750 ; %Distance from wall to the wall between zone 2 and zone 3 [mm]
PW3=21750 ; %Distance from wall to the wall between zone 3 and zone 4 [mm]
Wth1=100 ; %Thickness of the wall between zone 1 and zone 2 [mm]
Wth2=100 ; %Thickness of the wall between zone 2 and zone 3 [mm]
Wth3=100 ; %Thickness of the wall between zone 3 and zone 4 [mm]
Wbd=[-200,7800,15800,21800,0] ;%Dividing wall position in direction of
upstream
Wfd=[7800,15800,21800,27800,0]; %Dividing wall position in direction of
downstream
```

```
Lz=[7950,7900,5900,5950,0]; %Length of zones considering dividing wall
thickness 100 [mm]
Lzc=[8000,8000,6000,6000,0]; %Crude length of zones
Wbth=[0,Wth1,Wth2,Wth3,0]; %Dividing wall thickness in direction of
upstream
Wfth=[Wth1,Wth2,Wth3,0,0]; %Dividing wall thickness in direction of
downstream
CL=[1,1,1,1,0]; %Cancel matrix for zones
Hc=[1665,1665,1665,1665,0]; %Height of furnace ceiling from the hearth
Hbw=[1665,1000,1000,1000,0]; %Wall height in direction of upstream
Hfw=[1000,1000,1000,1665,0]; %Wall height in direction of downstream

  %Boundary of zones
  PWb1=PW1+Wth1/2;
  PWb2=PW2+Wth2/2;
  PWb3=PW3+Wth3/2;

%Reading portion map of billet/bloom
Rb=15 ; %Corner radius of billet/bloom [mm]
Hb=165 ; %Sectional hight of billet/bloom [mm]
Wb=165 ; %Sectional width of billet/bloom [mm]
Hu=55 ; %Unit length of mesh in hight of billet/bloom [mm]
Wu=55 ; %Unit length of mesh in width of billet/bloom [mm]
Lu=100 ; %Unit length of mesh in length of billet/bloom [mm]

  %Number of mesh
  SAb=Hb*Wb-(Rb^2*(4-3.141592)); %Sectional area of billets/blooms
  Lb=Wt./(SAb*Ds); %Length of each billet/bloom (depends on the weight and
the density)
  l=2+(Wb-2*Rb)/Wu; %Wu should be the value which can make l be integer
  m=2+(Hb-2*Rb)/Hu; %Hu should be the value which can make m be integer
  n=round(Lb/Lu); %Each billet/bloom might have different number

%Position and pitch
P(:,1)=IP'+400; %Input the initial positions of billets/blooms
N=140; %The number of strokes until the 70th billet is extracted
P=repmat(0:SK:SK*(N-1), [140 1])+repmat(IP+400, [1 N]); %Position matrix
from 1 to N-1 strokes

%Time schedule
Et=P;
Et(Et>Pe)=0;
Et(Et<Pe)=0;
Et=any(Et,3);
ET=1-any(Et);
 Rt=Wt/(1000*v); %rolling time when billet/bloom i is extracted
 IV=(Iv*ones(N,1)+Rt+SP')';
 TS=(IV*Et+(Ih+ps)*ET)'; %Time schedule

%Calculation of cumulative time
CTS=cumsum(TS);

%Distance to other billet/bloom or wall
D=P;
E=P;
```

```
E(E>=Pe)=0;
E(E<0)=0;

D(D>=Pe)=-1; %After extracting, value should be zero
D(D>=0)=1;
D(D<0)=0;

PN=circshift(P, [-1 0]);
PN(140,:)=zeros(1,N);
DN=circshift(D,[-1 0]);
DN(140,:)=zeros(1,N);
LB=(P-PN).*DN+((DWi+P).*(1-DN)).*D;
LB(140,:)=D(140,:).*(DWi+P(140,:));

LF=ones(140,N);
EB=circshift(E, [1 0]);
EB(1,:)=zeros(1,N);
DB=circshift(D,[1 0]);
DB(1,:)=zeros(1,N);
LF=((EB-E).*DB).*D+((DWe-E).*D).*(1-DB);
LF(1,:)=D(1,:).*(DWe-E(1,:));

%length of time period
 tp=30; %[sec]

%Time period and processed number of strokes
NN=fix(CTS(140)/tp);

CTSI=repmat(CTS', [NN 1]);
A=repmat(((tp:tp:NN*tp)'+CTS(1)), [1 N]);

K=A-CTSI;
K(K>=0)=1;
K(K<0)=0;
St=sum(K,2); %Inserting is counted as the first stroke

%Zone judgement during time period nn
AA=ones(140,1);
BB=ones(1,NN);
Pt=P(:,1)*BB+SK*AA*(St-1)';
Ett=Pt; %Preperation for finding extracting time period
Pt(Pt<0)=DWe+1;
Pt(Pt<=PWb1)=1;
Pt(DWe<Pt)=5;
Pt(PWb3<Pt)=4;
Pt(PWb2<Pt)=3;
Pt(PWb1<Pt)=2;%Zone where billet/bloom i at time period t. "5" means the
billets/bloom are outside of the furnace

%CLm
CLm=Pt;
CLm(CLm==5)=0;
CLm(CLm>0&CLm<5)=1;

%Spot finding matrix the element shows the spot where billet/bloom i is
```

```
%during t
PP=Ett;
PP=PP/400+1; %Be careful! position Pt=0 means the first spot SP=1
PP(PP<0 | PP>70)=0;

%Extracting time period of each billet/bloom
Ett(DWe>=Ett)=1;
Ett(Ett>1)=0;
ETT=sum(Ett,2);
ETT(ETT>=NN)=0; %0 means not extracted during the considered total time
periods
ETT(70)=NN;
ETT; %Indicating the time period when billet/bloom i is extracted

%Estimated holding time of each billet/bloom [min]
Ht=Pt;
Ht(Ht<=4)=1;
Ht(Ht>4)=0;
HT=sum(Ht,2)*tp/60;
HTT=HT.*any(ETT,2); %Still heated billets/blooms are removed from HTT. 0
means not extracted yet.

%Area of each component
 %In direction of x [mm^2]
  Acx=(2*3.14159*Rb/4+(Hu-Rb))*Lu;
  Asx=Hu*Lu;
 %In direction of y [mm^2]
  Acy=(2*3.14159*Rb/4+(Wu-Rb))*Lu;
  Asy=Wu*Lu;
 %In direction of z [mm^2]
  Acz=3.14159*(Rb^2)/4+(Hu-Rb)*Wu+Rb*(Wu-Rb);
  Asz=Hu*Wu;

%Outside temperature
To=293;

%Initial set wall temperature
Tw=ones(4,NN);
Tw(1,:)=1273;
Tw(2,:)=1273;
Tw(3,:)=1373;
Tw(4,:)=1333;
Tw(5,:)=0;

%Initial temperature of hearth bricks
Th=vertcat(repmat(Tw(1,1), [20 1]),repmat(Tw(2,1), [20 1]),repmat(Tw(3,1),
[15 1]),repmat(Tw(4,1), [15 1]));

%Wall temperature for calculating hearth bricks temperature
Twh=Th;

%Spot positions of hearth where billets/blooms are mounted.
Sp=0:400:27600;
Spn=Sp/400+1;
```

```
%Initial temperature (Current temperature) of each component assuming the
temperature equals to outside temperature
%Tc(Current temperature should be always tracked and input)
%Tbi=To*ones(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu)); %Billets/blooms temperatures when
they are outside furnace before heating
%Tc=Tbi; %In this research, it was assumuted that all the billets/blooms
started to be heated from room temperature.
%Tb=Tc;
%Initial temperature of hearth bricks also has to be tracked or measured
Tbhave=To*ones(140,1); %Initial average temperature of billets/blooms at
y=1

%Property
    %Heat transfer coefficient between gas and billets/blooms
    ahgb=80;
    hgb=ahgb*1055.055853/0.3048/0.3048/3600/33.8; %[W/(m^2*K)]

    %Incoming heat by thermal radiation
    %Emissivity of bricks
    Embr=0.7;
    erbr=0; %error

    %Stefan Bolzmann Constant [W/(m^2*K^4)]
    SBC=5.670373*10^(-8);

    %Heat capacity of hearth bricks (Necessary to adjust using
experimental data)
    CH=3000; %[J/K]

    %Thermal contact condactance between billet/bloom and hearth
(Necessary to adjust using experimental data)
    hbh=6; %[W/(m^2*K)]

    %Thermal contact condactance between billet/bloom and feeding roller
    %hbr=200; %[W/(m^2*K)]

    %View factor of hearth spot (Necessary to adjust using experimental
data)
    Fbr=0.001;

%Parameters
    %Gradient of the atmosphere temperature
    dTax=[0,0,0,0,0]; %dTax=[0.0125,0.0125,0.0125,0.0125,0]; %Can change
depending on the furnace condition
    dTaz=[0,0,0,0,0]; %dTaz=[0.002,0.002,0.002,0.002,0]; %Can change
depending on the furnace condition

TaN=Tw;
TaNh=TaN+df/2*repmat(dTaz', [1 NN]);
TaM=TaN+(WF/2)*repmat(dTaz', [1 NN]);
TaS=TaN+WF*repmat(dTaz', [1 NN]); %TaSh is decided using the length of
billet/bloom i

i=1;
Tb1=To*ones(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu));
```

```
qcondz=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu));

qcondxt(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);
qcondyt(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);
qcondzt(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);

%qctrandstt(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);
%qctranustt(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);
%qctranuft(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);
%qctranfet(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);
%qctrantet(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);
%qtranhft(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);

%qraddstNt(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);
%qraddstSt(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);
%qraddstMt(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);
%qradustNt(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);
%qradustSt(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);
%qradustMt(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);
%qradufNt(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);
%qradufSt(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);
%qradufMt(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);
%qradfeNt(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);
%qradfeNht(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);
%qradteSt(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);
%qradteSht(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);
Qv(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);
Qzz(:,:,:,1)=zeros(Hb/Hu,Wb/Wu,fix(Lb(i)/Lu),1);


for t=1:4920/tp %NN

i=1;

TaSh=TaS-((WF-df-Lb(i))/2)*repmat(dTaz', [1 NN]);

%Cancel matrices
 %x=1
 cxp=ones(Wb/Wu,Hb/Hu,fix(Lb(i)/Lu));
 cxp(1,:,:)=zeros;
 %x=Wb/Wu
 cxm=ones(Wb/Wu,Hb/Hu,fix(Lb(i)/Lu));
 cxm(Wb/Wu,:,:)=zeros;
 %y=1
 cyp=ones(Wb/Wu,Hb/Hu,fix(Lb(i)/Lu));
 cyp(:,1,:)=zeros;
 %y=Hb/Hu
 cym=ones(Wb/Wu,Hb/Hu,fix(Lb(i)/Lu));
 cym(:,Hb/Hu,:)=zeros;
 %z=1
 czp=ones(Wb/Wu,Hb/Hu,fix(Lb(i)/Lu));
 czp(:,:,1)=zeros;
 %z=Lb(i)/Lu
 czm=ones(Wb/Wu,Hb/Hu,fix(Lb(i)/Lu));
 czm(:,:,fix(Lb(i)/Lu))=zeros;
```

```
 %All corners
 cac=ones(Wb/Wu,Hb/Hu,fix(Lb(i)/Lu));
 cac(1,1,:)=zeros;
 cac(1,Hb/Hu,:)=zeros;
 cac(Wb/Wu,1,:)=zeros;
 cac(Wb/Wu,Hb/Hu,:)=zeros;

%Target matrices
 %Surface at downstream side
 Sds=zeros(Wb/Wu,Hb/Hu,fix(Lb(i)/Lu));
 Sds(1,:,:)=ones;
 %Surface at upstream side
 Sus=zeros(Wb/Wu,Hb/Hu,fix(Lb(i)/Lu));
 Sus(Wb/Wu,:,:)=ones;
 %Surace at front end
 Sfe=zeros(Wb/Wu,Hb/Hu,fix(Lb(i)/Lu));
 Sfe(:,:,1)=ones;
 %Surface at tail end
 Ste=zeros(Wb/Wu,Hb/Hu,fix(Lb(i)/Lu));
 Ste(:,:,fix(Lb(i)/Lu))=ones;
 %Surface at hearth side
 Shs=zeros(Wb/Wu,Hb/Hu,fix(Lb(i)/Lu));
 Shs(:,1,:)=ones;
 %Surface at ceiling side
 Scs=zeros(Wb/Wu,Hb/Hu,fix(Lb(i)/Lu));
 Scs(:,Hb/Hu,:)=ones;
 %All corners
 Sac=zeros(Wb/Wu,Hb/Hu,fix(Lb(i)/Lu));
 Sac(1,1,:)=ones;
 Sac(1,Hb/Hu,:)=ones;
 Sac(Wb/Wu,1,:)=ones;
 Sac(Wb/Wu,Hb/Hu,:)=ones;

%Mesh position map matrices
x=repmat(repmat([1:Wb/Wu]', [1 Hb/Hu]), [1 1 fix(Lb(i)/Lu)]);
y=repmat(repmat([1:Hb/Hu], [Wb/Wu 1]),[1 1 fix(Lb(i)/Lu)]);
z=permute(repmat([1:fix(Lb(i)/Lu)], [Hb/Hu 1 Wb/Wu]), [3 1 2]);

%Unit position
xo=(x-1/2)*Wu;
yo=(y-1/2)*Hu;
zo=df+(z-1/2)*Lu;
zot=WF-zo;

%The zone where billet/bloom i is during t
j=Pt(i,t);

%Distance from the nearest wall in direction of upstream to billet surface
Wbrd=(P(i,St(t))-Wb/2)*CL(j)-Wbd(j)-Wbth(j)/2;
%Distance from the nearest wall in direction of downstream to billet
surface
Wfrd=Wfd(j)-Wfth(j)/2-(P(i,St(t))+Wb/2)*CL(j);

%Atmoshpere temperature which billet/bloom i experiences
Taxz=dTax(j)*(P(i,St(t))-Wbd(j)-Lzc(j)/2)+Tw(j,t)+dTaz(j).*zo;
```

```
%Transmitted heat through heat transfer from gas to billets/blooms

qtrandst=hgb*(Taxz-Tb1).*(Asx*Sds.*cac+Acx*Sds.*Sac)*10^(-6);
qtranust=hgb*(Taxz-Tb1).*(Asx*Sus.*cac+Acx*Sus.*Sac)*10^(-6);
qtranuf=hgb*(Taxz-Tb1).*(Asy*Scs.*cac)*10^(-6);
qtranfe=hgb*(Taxz-Tb1).*(Asz*Sfe.*cac+Acz*Sfe.*Sac)*10^(-6);
qtrante=hgb*(Taxz-Tb1).*(Asz*Ste.*cac+Acz*Ste.*Sac)*10^(-6);

%qctrandstt(:,:,:,t+1)=qctrandstt(:,:,:,t)+qtrandst;
%qctranustt(:,:,:,t+1)=qctranustt(:,:,:,t)+qtranust;
%qctranuft(:,:,:,t+1)=qctranuft(:,:,:,t)+qtranuf;
%qctranfet(:,:,:,t+1)=qctranfet(:,:,:,t)+qtranfe;
%qctrantet(:,:,:,t+1)=qctrantet(:,:,:,t)+qtrante;

%Finding spot where billet/bloom i is on right now
besp=P(i,St(t))/400+1;
besp(besp>=70)=70;
besp(besp<1)=1;

%Transmitted heat by contact heat transfer through hearth
qtranhf=hbh*(Th(besp)-Tb1).*(Asy*Shs.*cac)*10^(-6);

%qtranhft(:,:,:,t+1)=qtranhft(:,:,:,t)+qtranhf;


qtrantotal=(qtrandst+qtranust+qtranuf+qtranfe+qtrante+qtranhf);

%Thermal conductivity
aca=ac(i,1);
acb=ac(i,2);
acc=ac(i,3);
acd=ac(i,4);

%Incoming heat conduction
Tbxp=circshift(Tb1,[1 0 0]);
qcondxp=(Tbxp-
Tb1).*(aca*((Tbxp+Tb1)/2).^3+acb*((Tbxp+Tb1)/2).^2+acc*(Tbxp+Tb1)/2+acd)*A
sx/Wu.*cxp*10^(-3);
Tbxm=circshift(Tb1,[-1 0 0]);
qcondxm=(Tbxm-
Tb1).*(aca*((Tbxm+Tb1)/2).^3+acb*((Tbxm+Tb1)/2).^2+acc*(Tbxm+Tb1)/2+acd)*A
sx/Wu.*cxm*10^(-3);
Tbyp=circshift(Tb1,[0 1 0]);
qcondyp=(Tbyp-
Tb1).*(aca*((Tbyp+Tb1)/2).^3+acb*((Tbyp+Tb1)/2).^2+acc*(Tbyp+Tb1)/2+acd)*A
sy/Hu.*cyp*10^(-3);
Tbym=circshift(Tb1,[0 -1 0]);
qcondym=(Tbym-
Tb1).*(aca*((Tbym+Tb1)/2).^3+acb*((Tbym+Tb1)/2).^2+acc*(Tbym+Tb1)/2+acd)*A
sy/Hu.*cym*10^(-3);
Tbzp=circshift(Tb1,[0 0 1]);
qcondzp=(Tbzp-
Tb1).*(aca*((Tbzp+Tb1)/2).^3+acb*((Tbzp+Tb1)/2).^2+acc*(Tbzp+Tb1)/2+acd)*A
sz/Lu.*czp*10^(-3);
```

```
Tbzm=circshift(Tb1,[0 0 -1]);
qcondzm=(Tbzm-
Tb1).*(aca*((Tbzm+Tb1)/2).^3+acb*((Tbzm+Tb1)/2).^2+acc*(Tbzm+Tb1)/2+acd)*A
sz/Lu.*czm*10^(-3);

qcondtotal=(qcondxp+qcondxm+qcondyp+qcondym+qcondzp+qcondzm);

%qcondz=qcondz+qcondzp+qcondzm

%qcondxt(:,:,:,t+1)=qcondxt(:,:,:,t)+qcondxp+qcondxm;
%qcondyt(:,:,:,t+1)=qcondyt(:,:,:,t)+qcondyp+qcondym;
%qcondzt(:,:,:,t+1)=qcondzt(:,:,:,t)+qcondzp+qcondzm;

 %Emissivity of billet/bloom
 aea=ae(i,1);
 aeb=ae(i,2);
 aec=ae(i,3);
 aed=ae(i,4);
 erb=0;


%View factor
%View factor between billet/bloom surface at upstream side and furnace
FubH=(1/(3.14159*2))*(atan(zot./yo)+atan(zo./yo))-
(yo./(2*3.14159*(yo.^2+(LB(i,St(t))-
Wb)^2).^0.5)).*(atan(zot./(yo.^2+(LB(i,St(t))-
Wb)^2).^0.5)+atan(zo./(yo.^2+(LB(i,St(t))-Wb)^2).^0.5));
FHub=(Hu*Lu)/((LB(i,St(t))-Wb)*WF)*FubH;
 FubWN=(1/(3.14159*2))*(atan((Hc(j)-yo)./zo)-
(zo./(Wbrd^2+zo.^2).^0.5).*atan((Hc(j)-yo)./((Wbrd^2+zo.^2).^0.5))-
(atan((Hb-yo)./zo)-(zo./(Wbrd^2+zo.^2).^0.5).*atan((Hb-
yo)./((Wbrd^2+zo.^2).^0.5))));
 FWNub=(Hu*Lu)/(Wbrd*(Hc(j)-yo)).*FubWN;
  FubWS=(1/(3.14159*2))*(atan((Hc(j)-yo)./zot)-
(zot./(Wbrd^2+zot.^2).^0.5).*atan((Hc(j)-yo)./((Wbrd^2+zot.^2).^0.5))-
(atan((Hb-yo)./zot)-(zot./(Wbrd^2+zot.^2).^0.5).*atan((Hb-
yo)./((Wbrd^2+zot.^2).^0.5))));
  FWSub=(Hu*Lu)/(Wbrd*(Hc(j)-yo)).*FubWS;
   FubWNl=(1/(3.14159*2))*(atan(yo./zo)+atan((Hb-yo)./zo))-
(zo./(2*3.14159*((zo.^2+(LB(i,St(t))-
Wb)^2).^0.5))).*(atan(yo./((zo.^2+(LB(i,St(t))-Wb)^2).^0.5))+atan((Hb-
yo)./((zo.^2+(LB(i,St(t))-Wb)^2).^0.5)));
   FWNlub=(Hu*Lu)/(Hb*(LB(i,St(t))-Wb))*FubWNl;
    FubWSl=(1/(3.14159*2))*(atan(yo./zot)+atan((Hb-yo)./zot))-
(zot./(2*3.14159*((zot.^2+(LB(i,St(t))-
Wb)^2).^0.5))).*(atan(yo./((zot.^2+(LB(i,St(t))-Wb)^2).^0.5))+atan((Hb-
yo)./((zot.^2+(LB(i,St(t))-Wb)^2).^0.5)));
    FWSlub=(Hu*Lu)/(Hb*(LB(i,St(t))-Wb))*FubWSl;
     theta=atan((Hb-yo)/(LB(i,St(t))-Wb));
     theta1=atan(((Hc(j)-Hbw(j))-yo)/Wbrd);
     theta2=atan((Hc(j)-yo)/Wbrd);
     phi=theta;
     phi2=theta;
     phi(phi<theta1)=0;
     phi(phi>theta2)=0;
     phi(theta1<=phi & phi<=theta2)=1;
```

```
     phi=phi.*((Hc(j)-((Hb-yo)/(LB(i,St(t))-Wb))*Wbrd)-yo);
     theta(theta>theta1)=10;
     theta(theta<=theta1)=Hbw(j);
     theta(theta<11)=0;
     zero=zeros(Wb/Wu,Hb/Hu,fix(Lb(i)/Lu));
     Ewh=zero+phi+theta;
     Fubdw1=(1/(3.14159*2))*(((Hc(j)-yo)./(((Hc(j)-
yo).^2+Wbrd^2).^0.5)).*atan(zo./(((Hc(j)-
yo).^2+Wbrd^2).^0.5))+(zo./((zo.^2+Wbrd^2).^0.5)).*atan((Hc(j)-
yo)./((zo.^2+Wbrd^2).^0.5)));
     Fubdw2=(1/(3.14159*2))*(((Hc(j)-yo)./(((Hc(j)-
yo).^2+Wbrd^2).^0.5)).*atan((WF-zo)./(((Hc(j)-yo).^2+Wbrd^2).^0.5))+((WF-
zo)./(((WF-zo).^2+Wbrd^2).^0.5)).*atan((Hc(j)-yo)./(((WF-
zo).^2+Wbrd^2).^0.5)));
     Fubdw3=(1/(3.14159*2))*(((Hc(j)-yo-Ewh)./(((Hc(j)-yo-
Ewh).^2+Wbrd^2).^0.5)).*atan((WF-zo)./(((Hc(j)-yo-
Ewh).^2+Wbrd^2).^0.5))+((WF-zo)./(((WF-zo).^2+Wbrd^2).^0.5)).*atan((Hc(j)-
yo-Ewh)./(((WF-zo).^2+Wbrd^2).^0.5)));
     Fubdw4=(1/(3.14159*2))*(((Hc(j)-yo-Ewh)./(((Hc(j)-yo-
Ewh).^2+Wbrd^2).^0.5)).*atan(zo./(((Hc(j)-yo-
Ewh).^2+Wbrd^2).^0.5))+(zo./((zo.^2+Wbrd^2).^0.5)).*atan((Hc(j)-yo-
Ewh)./((zo.^2+Wbrd^2).^0.5)));
     Fubdw=Fubdw1+Fubdw2-Fubdw3-Fubdw4;
     Fdwub=(Hu*Lu)/(Ewh*WF).*Fubdw;
      phi2(phi2<=theta2)=0;
      phi2(phi2>theta2)=1;
      phi2=phi2.*(((Hc(j)-yo)./(Hb-yo))*(LB(i,St(t))-Wb));
      phi2(phi2<=0)=Wbrd;
      Fubc=(1/(3.14159*2))*(atan((WF-zo)./(Hc(j)-yo))+atan(zo./(Hc(j)-
yo)))-((Hc(j)-yo)./(2*3.14159*(((Hc(j)-yo).^2+phi2.^2).^0.5))).*(atan((WF-
zo)./(((Hc(j)-yo).^2+phi2.^2).^0.5))+atan(zo./(((Hc(j)-
yo).^2+phi2.^2).^0.5)));
      Fcub=(Hu*Lu)/(Wbrd*WF)*Fubc;

FWubAN=(FubWN+FubWNl)*(Hu*Lu)*(10^(-6));
FWubAS=(FubWS+FubWSl)*(Hu*Lu)*(10^(-6));
FWubAM=(FubH+Fubdw+Fubc)*(Hu*Lu)*(10^(-6));

%View factor between billet/bloom surface at downstream side and furnace
FdbH=(1/(3.14159*2))*(atan((WF-zo)./yo)+atan(zo./yo))-
(yo./(2*3.14159*((yo.^2+(LF(i,St(t))-Wb)^2).^0.5))).*(atan((WF-
zo)./((yo.^2+(LF(i,St(t))-Wb)^2).^0.5))+atan(zo./((yo.^2+(LF(i,St(t))-
Wb)^2).^0.5)));
FHdb=(Hu*Lu)/((LF(i,St(t))-Wb)*WF)*FdbH;
 FdbWN=(1/(3.14159*2))*(atan((Hc(j)-yo)./zo)-
(zo./(Wfrd^2+zo.^2).^0.5).*atan((Hc(j)-yo)./((Wfrd^2+zo.^2).^0.5))-
(atan((Hb-yo)./zo)-(zo./(Wfrd^2+zo.^2).^0.5).*atan((Hb-
yo)./((Wfrd^2+zo.^2).^0.5))));
  FWNdb=(Hu*Lu)/(Wfrd*(Hc(j)-yo)).*FdbWN;
  FdbWS=(1/(3.14159*2))*(atan((Hc(j)-yo)./zot)-
(zot./(Wfrd^2+zot.^2).^0.5).*atan((Hc(j)-yo)./((Wfrd^2+zot.^2).^0.5))-
(atan((Hb-yo)./zot)-(zot./(Wfrd^2+zot.^2).^0.5).*atan((Hb-
yo)./((Wfrd^2+zot.^2).^0.5))));
  FWSdb=(Hu*Lu)/(Wfrd*(Hc(j)-yo)).*FdbWS;
   FdbWNl=(1/(3.14159*2))*(atan(yo./zo)+atan((Hb-yo)./zo))-
(zo./(2*3.14159*((zo.^2+(LF(i,St(t))-
```

```
Wb)^2).^0.5))).*(atan(yo./((zo.^2+(LF(i,St(t))-Wb)^2).^0.5))+atan((Hb-
yo)./((zo.^2+(LF(i,St(t))-Wb)^2).^0.5)));
   FWNldb=(Hu*Lu)/(Hb*(LF(i,St(t))-Wb))*FdbWNl;
    FdbWSl=(1/(3.14159*2))*(atan(yo./zot)+atan((Hb-yo)./zot))-
(zot./(2*3.14159*((zot.^2+(LF(i,St(t))-
Wb)^2).^0.5))).*(atan(yo./((zot.^2+(LF(i,St(t))-Wb)^2).^0.5))+atan((Hb-
yo)./((zot.^2+(LF(i,St(t))-Wb)^2).^0.5)));
    FWSldb=(Hu*Lu)/(Hb*(LF(i,St(t))-Wb))*FdbWSl;
     theta3=atan((Hb-yo)/(LF(i,St(t))-Wb));
     theta4=atan(((Hc(j)-Hbw(j))-yo)/Wfrd);
     theta5=atan((Hc(j)-yo)/Wfrd);
     phi3=theta3;
     phi4=theta3;
     phi3(phi3<theta4)=0;
     phi3(phi3>theta5)=0;
     phi3(theta4<=phi3 & phi3<=theta5)=1;
     phi3=phi3.*((Hc(j)-((Hb-yo)/(LF(i,St(t))-Wb))*Wfrd)-yo);
     theta3(theta3>theta4)=10;
     theta3(theta3<=theta4)=Hbw(j);
     theta3(theta3<11)=0;
     zero2=zeros(Wb/Wu,Hb/Hu,fix(Lb(i)/Lu));
     Ewh2=zero2+phi3+theta3;
     CL2=Ewh2;
     CL2(CL2>0)=1;
     Fdbdw1=(1/(3.14159*2))*(((Hc(j)-yo)./(((Hc(j)-
yo).^2+Wfrd^2).^0.5)).*atan(zo./(((Hc(j)-
yo).^2+Wfrd^2).^0.5))+(zo./((zo.^2+Wfrd^2).^0.5)).*atan((Hc(j)-
yo)./((zo.^2+Wfrd^2).^0.5)));
     Fdbdw2=(1/(3.14159*2))*(((Hc(j)-yo)./(((Hc(j)-
yo).^2+Wfrd^2).^0.5)).*atan((WF-zo)./(((Hc(j)-yo).^2+Wfrd^2).^0.5))+((WF-
zo)./(((WF-zo).^2+Wfrd^2).^0.5)).*atan((Hc(j)-yo)./(((WF-
zo).^2+Wfrd^2).^0.5)));
     Fdbdw3=(1/(3.14159*2))*(((Hc(j)-yo-Ewh2)./(((Hc(j)-yo-
Ewh2).^2+Wfrd^2).^0.5)).*atan((WF-zo)./(((Hc(j)-yo-
Ewh2).^2+Wfrd^2).^0.5))+((WF-zo)./(((WF-
zo).^2+Wfrd^2).^0.5)).*atan((Hc(j)-yo-Ewh2)./(((WF-zo).^2+Wfrd^2).^0.5)));
     Fdbdw4=(1/(3.14159*2))*(((Hc(j)-yo-Ewh2)./(((Hc(j)-yo-
Ewh2).^2+Wfrd^2).^0.5)).*atan(zo./(((Hc(j)-yo-
Ewh2).^2+Wfrd^2).^0.5))+(zo./((zo.^2+Wfrd^2).^0.5)).*atan((Hc(j)-yo-
Ewh2)./((zo.^2+Wfrd^2).^0.5)));
     Fdbdw=Fdbdw1+Fdbdw2-Fdbdw3-Fdbdw4;
     Fdwdb=(Hu*Lu)/(Ewh2*WF).*Fdbdw;
     Fdwdb=CL2.*Fdwdb;
     Fdwdb(isnan(Fdwdb))=0;
      phi4(phi4<=theta4)=0;
      phi4(phi4>theta5)=1;
      phi4=phi4.*(((Hc(j)-yo)./(Hb-yo))*(LF(i,St(t))-Wb));
      phi4(phi4<=0)=Wfrd;
      Fdbc=(1/(3.14159*2))*(atan((WF-zo)./(Hc(j)-yo))+atan(zo./(Hc(j)-
yo)))-((Hc(j)-yo)./(2*3.14159*(((Hc(j)-yo).^2+phi4.^2).^0.5))).*(atan((WF-
zo)./(((Hc(j)-yo).^2+phi4.^2).^0.5))+atan(zo./(((Hc(j)-
yo).^2+phi4.^2).^0.5)));
      Fcdb=(Hu*Lu)/(Wfrd*WF)*Fdbc;

FWdbAN=(FdbWN+FdbWNl)*(Hu*Lu)*(10^(-6));
FWdbAS=(FdbWS+FdbWSl)*(Hu*Lu)*(10^(-6));
FWdbAM=(FdbH+Fdbdw+Fdbc)*(Hu*Lu)*(10^(-6));
```

```
%View factor of between billet/bloom surface at front end and furnace
FbfeH=(1/(3.14159*2))*(atan((Lz(j)-(Wbrd+Wb+Wbd(j)/2-
xo))./yo)+atan((Wbrd+Wb+Wbd(j)/2-xo)./yo))-
(yo./(2*3.14159*((yo.^2+df^2).^0.5))).*(atan((Lz(j)-(Wbrd+Wb+Wbd(j)/2-
xo))./((yo.^2+df^2).^0.5))+atan((Wbrd+Wb+Wbd(j)/2-
xo)./((yo.^2+df^2).^0.5)));
FHbfe=(Wu*Hu)/(Lz(j)*df)*FbfeH;
 Fbfec=(1/(3.14159*2))*(atan((Lz(j)-(Wbrd+Wb+Wbd(j)/2-xo))./(Hc(j)-
yo))+atan((Wbrd+Wb+Wbd(j)/2-xo)./(Hc(j)-yo)))-((Hc(j)-
yo)./(2*3.14159*(((Hc(j)-yo).^2+df^2).^0.5))).*(atan((Lz(j)-
(Wbrd+Wb+Wbd(j)/2-xo))./(((Hc(j)-
yo).^2+df^2).^0.5))+atan((Wbrd+Wb+Wbd(j)/2-xo)./(((Hc(j)-
yo).^2+df^2).^0.5)));
 Fcbfe=(Wu*Hu)/(Lz(j)*df)*Fbfec;
  Fbfebdw1=(1/(3.14159*2))*(atan((Hc(j)-yo)./(Wbrd+Wb-xo))-(Wbrd+Wb-
xo)./((df^2+(Wbrd+Wb-xo).^2).^0.5).*atan((Hc(j)-yo)./((df^2+(Wbrd+Wb-
xo).^2).^0.5)));
  Fbfebdw2=(1/(3.14159*2))*(atan((Hc(j)-yo-Hbw(j))./(Wbrd+Wb-xo))-
(Wbrd+Wb-xo)./((df^2+(Wbrd+Wb-xo).^2).^0.5).*atan((Hc(j)-yo-
Hbw(j))./((df^2+(Wbrd+Wb-xo).^2).^0.5)));
  Fbfebdw=Fbfebdw1-Fbfebdw2;
  Fbdwbfe=(Wu*Hu)/(df*Hbw(j))*Fbfebdw;
   Fbfefdw1=(1/(3.14159*2))*(atan((Hc(j)-yo)./(Wfrd+xo))-
(Wfrd+xo)./((df^2+(Wfrd+xo).^2).^0.5).*atan((Hc(j)-
yo)./((df^2+(Wfrd+xo).^2).^0.5)));
   Fbfefdw2=(1/(3.14159*2))*(atan((Hc(j)-yo-Hfw(j))./(Wfrd+xo))-
(Wfrd+xo)./((df^2+(Wfrd+xo).^2).^0.5).*atan((Hc(j)-yo-
Hfw(j))./((df^2+(Wfrd+xo).^2).^0.5)));
   Fbfefdw=Fbfefdw1-Fbfefdw2;
   Ffdwbfe=(Wu*Hu)/(df*Hfw(j))*Fbfefdw;
    FbfeWN1=(1/(3.14159*2))*((Hc(j)-yo)./(((Hc(j)-
yo).^2+df^2).^0.5)).*(atan((Lz(j)-(Wbrd+Wb-xo))./(((Hc(j)-
yo).^2+df^2).^0.5))+atan((Wbrd+Wb-xo)./(((Hc(j)-yo).^2+df^2).^0.5)));
    FbfeWN2=(1/(3.14159*2))*((Lz(j)-(Wbrd+Wb-xo))./(((Lz(j)-(Wbrd+Wb-
xo)).^2+df^2).^0.5)).*(atan((Hc(j)-yo)./(((Lz(j)-(Wbrd+Wb-
xo)).^2+df^2).^0.5))+atan(yo./(((Lz(j)-(Wbrd+Wb-xo)).^2+df^2).^0.5)));
    FbfeWN3=(1/(3.14159*2))*(yo./((yo.^2+df^2).^0.5)).*(atan((Lz(j)-
(Wbrd+Wb-xo))./((yo.^2+df^2).^0.5))+atan((Wbrd+Wb-
xo)./((yo.^2+df^2).^0.5)));
    FbfeWN4=(1/(3.14159*2))*((Wbrd+Wb-xo)./(((Wbrd+Wb-
xo).^2+df^2).^0.5)).*(atan((Hc(j)-yo)./(((Wbrd+Wb-
xo).^2+df^2).^0.5))+atan(yo./(((Wbrd+Wb-xo).^2+df^2).^0.5)));
    FbfeWN=FbfeWN1+FbfeWN2+FbfeWN3+FbfeWN4;
    FWNbfe=(Hu*Wu)/(Hc(j)*Lz(j))*FbfeWN;

FWbfeAN=(FbfeWN)*(Wu*Hu)*(10^(-6));
FWbfeANh=(FbfeH+Fbfec+Fbfebdw+Fbfefdw)*(Wu*Hu)*(10^(-6));

%View factor of between billet/bloom surface at tale end and furnace
FbteH=(1/(3.14159*2))*(atan((Lz(j)-(Wbrd+Wb+Wbd(j)/2-
xo))./yo)+atan((Wbrd+Wb+Wbd(j)/2-xo)./yo))-(yo./(2*3.14159*((yo.^2+(WF-
Lb(i)-df)^2).^0.5))).*(atan((Lz(j)-(Wbrd+Wb+Wbd(j)/2-xo))./((yo.^2+(WF-
Lb(i)-df)^2).^0.5))+atan((Wbrd+Wb+Wbd(j)/2-xo)./((yo.^2+(WF-Lb(i)-
df)^2).^0.5)));
FHbte=(Wu*Hu)/(Lz(j)*(WF-Lb(i)-df))*FbteH;
```

```
 Fbtec=(1/(3.14159*2))*(atan((Lz(j)-(Wbrd+Wb+Wbd(j)/2-xo))./(Hc(j)-
yo))+atan((Wbrd+Wb+Wbd(j)/2-xo)./(Hc(j)-yo)))-((Hc(j)-
yo)./(2*3.14159*(((Hc(j)-yo).^2+(WF-Lb(i)-df)^2).^0.5))).*(atan((Lz(j)-
(Wbrd+Wb+Wbd(j)/2-xo))./(((Hc(j)-yo).^2+(WF-Lb(i)-
df)^2).^0.5))+atan((Wbrd+Wb+Wbd(j)/2-xo)./(((Hc(j)-yo).^2+(WF-Lb(i)-
df)^2).^0.5)));
 Fcbte=(Wu*Hu)/(Lz(j)*(WF-Lb(i)-df))*Fbtec;
  Fbdwbte1=(1/(3.14159*2))*(atan((Hc(j)-yo)./(Wbrd+Wb-xo))-(Wbrd+Wb-
xo)./(((WF-Lb(i)-df)^2+(Wbrd+Wb-xo).^2).^0.5).*atan((Hc(j)-yo)./(((WF-
Lb(i)-df)^2+(Wbrd+Wb-xo).^2).^0.5)));
  Fbdwbte2=(1/(3.14159*2))*(atan((Hc(j)-yo-Hbw(j))./(Wbrd+Wb-xo))-
(Wbrd+Wb-xo)./(((WF-Lb(i)-df)^2+(Wbrd+Wb-xo).^2).^0.5).*atan((Hc(j)-yo-
Hbw(j))./(((WF-Lb(i)-df)^2+(Wbrd+Wb-xo).^2).^0.5)));
   Fbdwbte=Fbdwbte1-Fbdwbte2;
   Fbtebdw=(Wu*Hu)/((WF-Lb(i)-df)*Hbw(j))*Fbdwbte;
    Fbtefdw1=(1/(3.14159*2))*(atan((Hc(j)-yo)./(Wfrd+xo))-
(Wfrd+xo)./(((WF-Lb(i)-df)^2+(Wfrd+xo).^2).^0.5).*atan((Hc(j)-yo)./(((WF-
Lb(i)-df)^2+(Wfrd+xo).^2).^0.5)));
    Fbtefdw2=(1/(3.14159*2))*(atan((Hc(j)-yo-Hfw(j))./(Wfrd+xo))-
(Wfrd+xo)./(((WF-Lb(i)-df)^2+(Wfrd+xo).^2).^0.5).*atan((Hc(j)-yo-
Hfw(j))./(((WF-Lb(i)-df)^2+(Wfrd+xo).^2).^0.5)));
    Fbtefdw=Fbtefdw1-Fbtefdw2;
    Ffdwbte=(Wu*Hu)/((WF-Lb(i)-df)*Hfw(j))*Fbtefdw;
     FbteWN1=(1/(3.14159*2))*((Hc(j)-yo)./(((Hc(j)-yo).^2+(WF-Lb(i)-
df)^2).^0.5)).*(atan((Lz(j)-(Wbrd+Wb-xo))./(((Hc(j)-yo).^2+(WF-Lb(i)-
df)^2).^0.5))+atan((Wbrd+Wb-xo)./(((Hc(j)-yo).^2+(WF-Lb(i)-df)^2).^0.5)));
     FbteWN2=(1/(3.14159*2))*((Lz(j)-(Wbrd+Wb-xo))./(((Lz(j)-(Wbrd+Wb-
xo)).^2+(WF-Lb(i)-df)^2).^0.5)).*(atan((Hc(j)-yo)./(((Lz(j)-(Wbrd+Wb-
xo)).^2+(WF-Lb(i)-df)^2).^0.5))+atan(yo./(((Lz(j)-(Wbrd+Wb-xo)).^2+(WF-
Lb(i)-df)^2).^0.5)));
     FbteWN3=(1/(3.14159*2))*(yo./((yo.^2+(WF-Lb(i)-
df)^2).^0.5)).*(atan((Lz(j)-(Wbrd+Wb-xo))./((yo.^2+(WF-Lb(i)-
df)^2).^0.5))+atan((Wbrd+Wb-xo)./((yo.^2+(WF-Lb(i)-df)^2).^0.5)));
     FbteWN4=(1/(3.14159*2))*((Wbrd+Wb-xo)./(((Wbrd+Wb-xo).^2+(WF-Lb(i)-
df)^2).^0.5)).*(atan((Hc(j)-yo)./(((Wbrd+Wb-xo).^2+(WF-Lb(i)-
df)^2).^0.5))+atan(yo./(((Wbrd+Wb-xo).^2+(WF-Lb(i)-df)^2).^0.5)));
     FbteWN=FbteWN1+FbteWN2+FbteWN3+FbteWN4;
     FWNbte=(Hu*Wu)/(Hc(j)*Lz(j))*FbteWN;

FWbteAS=(FbteWN)*(Wu*Hu)*(10^(-6));
FWbteASh=(FbteH+Fbtec+Fbdwbte+Fbtefdw)*(Wu*Hu)*(10^(-6));

%View factor of between billet/bloom upper surface and furnace
FbufWN=(1/(3.14159*2))*(atan((Wbrd+Wb-xo)./zo)+atan((Wbrd+xo)./zo))-
zo./(2*314159*((zo.^2+(Hc(j)-Hb)^2).^0.5)).*(atan((Wbrd+Wb-
xo)./((zo.^2+(Hc(j)-Hb)^2).^0.5))+atan((Wbrd+xo)./((zo.^2+(Hc(j)-
Hb)^2).^0.5)));
FWNbuf=(Lu*Wu)/((Hc(j)-Hb)*Lz(j))*FbufWN;
 FbufWS=(1/(3.14159*2))*(atan((Wbrd+Wb-xo)./(WF-zo))+atan((Wbrd+xo)./(WF-
zo)))-(WF-zo)./(2*314159*(((WF-zo).^2+(Hc(j)-
Hb)^2).^0.5)).*(atan((Wbrd+Wb-xo)./(((WF-zo).^2+(Hc(j)-
Hb)^2).^0.5))+atan((Wbrd+xo)./(((WF-zo).^2+(Hc(j)-Hb)^2).^0.5)));
 FWSbuf=(Lu*Wu)/((Hc(j)-Hb)*Lz(j))*FbufWS;
  FbufbdW1=(1/(3.14159*2))*(atan(zo./(Wbrd+Wb-xo))-(Wbrd+Wb-xo)./(((Hc(j)-
Hb)^2+(Wbrd+Wb-xo).^2).^0.5).*atan(zo./(((Hc(j)-Hb)^2+(Wbrd+Wb-
xo).^2).^0.5)));
```

```
  FbufbdW2=(1/(3.14159*2))*(atan(zo./(Wbrd+Wb-xo))-(Wbrd+Wb-xo)./(((Hc(j)-
Hb-Hbw(j))^2+(Wbrd+Wb-xo).^2).^0.5).*atan(zo./(((Hc(j)-Hb-
Hbw(j))^2+(Wbrd+Wb-xo).^2).^0.5)));
  FbufbdW3=(1/(3.14159*2))*(atan((WF-zo)./(Wbrd+Wb-xo))-(Wbrd+Wb-
xo)./(((Hc(j)-Hb)^2+(Wbrd+Wb-xo).^2).^0.5).*atan((WF-zo)./(((Hc(j)-
Hb)^2+(Wbrd+Wb-xo).^2).^0.5)));
  FbufbdW4=(1/(3.14159*2))*(atan((WF-zo)./(Wbrd+Wb-xo))-(Wbrd+Wb-
xo)./(((Hc(j)-Hb-Hbw(j))^2+(Wbrd+Wb-xo).^2).^0.5).*atan((WF-zo)./(((Hc(j)-
Hb-Hbw(j))^2+(Wbrd+Wb-xo).^2).^0.5)));
  FbufbdW=FbufbdW1-FbufbdW2+FbufbdW3-FbufbdW4;
  FbdWbuf=(Lu*Wu)/(Hbw(j)*WF)*FbufbdW;
   FbuffdW1=(1/(3.14159*2))*(atan(zo./(Wbrd+xo))-(Wbrd+xo)./(((Hc(j)-
Hb)^2+(Wbrd+xo).^2).^0.5).*atan(zo./(((Hc(j)-Hb)^2+(Wbrd+xo).^2).^0.5)));
   FbuffdW2=(1/(3.14159*2))*(atan(zo./(Wbrd+xo))-(Wbrd+xo)./(((Hc(j)-Hb-
Hfw(j))^2+(Wbrd+xo).^2).^0.5).*atan(zo./(((Hc(j)-Hb-
Hfw(j))^2+(Wbrd+xo).^2).^0.5)));
   FbuffdW3=(1/(3.14159*2))*(atan((WF-zo)./(Wbrd+xo))-(Wbrd+xo)./(((Hc(j)-
Hb)^2+(Wbrd+xo).^2).^0.5).*atan((WF-zo)./(((Hc(j)-
Hb)^2+(Wbrd+xo).^2).^0.5)));
   FbuffdW4=(1/(3.14159*2))*(atan((WF-zo)./(Wbrd+xo))-(Wbrd+xo)./(((Hc(j)-
Hb-Hfw(j))^2+(Wbrd+xo).^2).^0.5).*atan((WF-zo)./(((Hc(j)-Hb-
Hfw(j))^2+(Wbrd+xo).^2).^0.5)));
   FbuffdW=FbuffdW1-FbuffdW2+FbuffdW3-FbuffdW4;
   FfdWbuf=(Lu*Wu)/(Hfw(j)*WF)*FbuffdW;

FWbufAN=(FbufWN)*(Lu*Wu)*(10^(-6));
FWbufAS=(FbufWS)*(Lu*Wu)*(10^(-6));
FWbufAM=(FbufbdW+FbuffdW)*(Lu*Wu)*(10^(-6));

%Transmitted heat by radiation [W/(K^4)] %F value includes area and view
factor
qraddstN=SBC*(Embr+erbr)*FWdbAN.*(aea*Tb1.^3+aeb*Tb1.^2+aec*Tb1+aed+erb).*
(TaN(j,t)^4-Tb1.^4).*Sds; %Assuming wall temperature is the same as the
atmosphere temperature at the same position
qraddstS=SBC*(Embr+erbr)*FWdbAS.*(aea*Tb1.^3+aeb*Tb1.^2+aec*Tb1+aed+erb).*
(TaS(j,t)^4-Tb1.^4).*Sds;
qraddstM=SBC*(Embr+erbr)*FWdbAM.*(aea*Tb1.^3+aeb*Tb1.^2+aec*Tb1+aed+erb).*
(TaM(j,t)^4-Tb1.^4).*Sds;

qradustN=SBC*(Embr+erbr)*FWubAN.*(aea*Tb1.^3+aeb*Tb1.^2+aec*Tb1+aed+erb).*
(TaN(j,t)^4-Tb1.^4).*Sus;
qradustS=SBC*(Embr+erbr)*FWubAS.*(aea*Tb1.^3+aeb*Tb1.^2+aec*Tb1+aed+erb).*
(TaS(j,t)^4-Tb1.^4).*Sus;
qradustM=SBC*(Embr+erbr)*FWubAM.*(aea*Tb1.^3+aeb*Tb1.^2+aec*Tb1+aed+erb).*
(TaM(j,t)^4-Tb1.^4).*Sus;

qradufN=SBC*(Embr+erbr)*FWbufAN.*(aea*Tb1.^3+aeb*Tb1.^2+aec*Tb1+aed+erb).*
(TaN(j,t)^4-Tb1.^4).*Scs;
qradufS=SBC*(Embr+erbr)*FWbufAS.*(aea*Tb1.^3+aeb*Tb1.^2+aec*Tb1+aed+erb).*
(TaS(j,t)^4-Tb1.^4).*Scs;
qradufM=SBC*(Embr+erbr)*FWbufAM.*(aea*Tb1.^3+aeb*Tb1.^2+aec*Tb1+aed+erb).*
(TaM(j,t)^4-Tb1.^4).*Scs;

qradfeN=SBC*(Embr+erbr)*FWbfeAN.*(aea*Tb1.^3+aeb*Tb1.^2+aec*Tb1+aed+erb).*
(TaN(j,t)^4-Tb1.^4).*Sfe;
```

```
qradfeNh=SBC*(Embr+erbr)*FWbfeANh.*(aea*Tb1.^3+aeb*Tb1.^2+aec*Tb1+aed+erb)
.*(TaNh(j,t)^4-Tb1.^4).*Sfe;

qradteS=SBC*(Embr+erbr)*FWbteAS.*(aea*Tb1.^3+aeb*Tb1.^2+aec*Tb1+aed+erb).*
(TaS(j,t)^4-Tb1.^4).*Ste;
qradteSh=SBC*(Embr+erbr)*FWbteASh.*(aea*Tb1.^3+aeb*Tb1.^2+aec*Tb1+aed+erb)
.*(TaSh(j,t)^4-Tb1.^4).*Ste;


qradtotal=qraddstN+qraddstS+qraddstM+qradustN+qradustS+qradustM+qradufN+qr
adufS+qradufM+qradfeN+qradfeNh+qradteS+qradteSh;

%qraddstNt(:,:,:,t+1)=qraddstNt(:,:,:,t)+qraddstN;
%qraddstSt(:,:,:,t+1)=qraddstSt(:,:,:,t)+qraddstS;
%qraddstMt(:,:,:,t+1)=qraddstMt(:,:,:,t)+qraddstM;
%qradustNt(:,:,:,t+1)=qradustNt(:,:,:,t)+qradustN;
%qradustSt(:,:,:,t+1)=qradustSt(:,:,:,t)+qradustS;
%qradustMt(:,:,:,t+1)=qradustMt(:,:,:,t)+qradustM;
%qradufNt(:,:,:,t+1)=qradufNt(:,:,:,t)+qradufN;
%qradufSt(:,:,:,t+1)=qradufSt(:,:,:,t)+qradufS;
%qradufMt(:,:,:,t+1)=qradufMt(:,:,:,t)+qradufM;
%qradfeNt(:,:,:,t+1)=qradfeNt(:,:,:,t)+qradfeN;
%qradfeNht(:,:,:,t+1)=qradfeNht(:,:,:,t)+qradfeNh;
%qradteSt(:,:,:,t+1)=qradteSt(:,:,:,t)+qradteS;
%qradteSht(:,:,:,t+1)=qradteSht(:,:,:,t)+qradteSh;

%Overall transmitted heat in direction z
Qz=(qtranfe+qtrante+qradfeN+qradfeNh+qradteS+qradteSh+qcondzp+qcondzm)*tp.
*CLm(i,t);

Qzz(:,:,:,t+1)=Qzz(:,:,:,t)+Qz;

%Overall transmitted heat
Qoverall=(qtrantotal+qcondtotal+qradtotal)*tp.*CLm(i,t);

Qv(:,:,:,t+1)=Qv(:,:,:,t)+Qoverall;

%Specific heat
cb=asb(i,1)*Tb1.^3+asb(i,2)*Tb1.^2+asb(i,3)*Tb1+asb(i,4);
ca=asa(i,1)*Tb1.^3+asa(i,2)*Tb1.^2+asa(i,3)*Tb1+asa(i,4);
spch=Tb1;
spch(spch<=TT(i))=1;
spch(spch>TT(i))=0;
spch1=ones(Wb/Wu,Hb/Hu,fix(Lb(i)/Lu))-spch;
spch=spch.*cb+spch1.*ca;

%Volume matrix
Vs=Wu*Hu*Lu*ones(Wb/Wu,Hb/Hu,fix(Lb(i)/Lu)).*cac;
Vc=Acz*Lu*ones(Wb/Wu,Hb/Hu,fix(Lb(i)/Lu)).*Sac;
V=Vs+Vc;

%Temperature changes [K]
dTb=Qoverall./(Ds(i)*spch.*V);
Tb1=Tb1+dTb;
 Tb11(t)=Tb1(1,1,1);
```

```
Tb12(t)=Tb1((Wb/Wu+1)/2,1,1);
Tb13(t)=Tb1(Wb/Wu,1,1);
Tb14(t)=Tb1(1,(Hb/Hu+1)/2,1);
Tb15(t)=Tb1((Wb/Wu+1)/2,(Hb/Hu+1)/2,1);
Tb16(t)=Tb1(Wb/Wu,(Hb/Hu+1)/2,1);
Tb17(t)=Tb1(1,Hb/Hu,1);
Tb18(t)=Tb1((Wb/Wu+1)/2,Hb/Hu,1);
Tb19(t)=Tb1(Wb/Wu,Hb/Hu,1);

Tb501(t)=Tb1(1,1,fix(Lb(i)/Lu)/2);
Tb502(t)=Tb1((Wb/Wu+1)/2,1,fix(Lb(i)/Lu)/2);
Tb503(t)=Tb1(Wb/Wu,1,fix(Lb(i)/Lu)/2);
Tb504(t)=Tb1(1,(Hb/Hu+1)/2,fix(Lb(i)/Lu)/2);
Tb505(t)=Tb1((Wb/Wu+1)/2,(Hb/Hu+1)/2,fix(Lb(i)/Lu)/2);
Tb506(t)=Tb1(Wb/Wu,(Hb/Hu+1)/2,fix(Lb(i)/Lu)/2);
Tb507(t)=Tb1(1,Hb/Hu,fix(Lb(i)/Lu)/2);
Tb508(t)=Tb1((Wb/Wu+1)/2,Hb/Hu,fix(Lb(i)/Lu)/2);
Tb509(t)=Tb1(Wb/Wu,Hb/Hu,fix(Lb(i)/Lu)/2);

%i=2-------------------------------------------------------------------------
-------------------------------------------------------------

%Obtaining the average billet/bloom temperature at y=1
Thep=(Tbhave'*(ones(140,70)-any((repmat(IP, [1 N/2])+400*St(t))-repmat(Sp,
[140 1]),3)))'; %Temperature which the spot SP of hearth experiences

%Twh matrix
Twh=vertcat(repmat(Tw(1,t), [20 1]),repmat(Tw(2,t), [20
1]),repmat(Tw(3,t), [15 1]),repmat(Tw(4,t), [15 1]));

%Temperature of hearth brick spots
Th=Th+(1/CH)*(SBC*Embr*Embr*Fbr*(Twh.^4-Th.^4).*(1-any(Thep,2))-hbh*(Th-
Thep).*(any(Thep,2)));

%Average billet/bloom temperatuer at y=1 for the next time period
Tbhave=(mean(mean(Tb1(:,1,:),1))*ones(1,140))';

end

%For checking
AAAA=Tb1;
AAAA=permute(AAAA, [3 2 1]);
K1=AAAA(:,1,1);
K2=AAAA(:,1,(Wb/Wu+1)/2);
K3=AAAA(:,1,Wb/Wu);
K4=AAAA(:,(Hb/Hu+1)/2,1);
K5=AAAA(:,(Hb/Hu+1)/2,(Wb/Wu+1)/2);
K6=AAAA(:,(Hb/Hu+1)/2,Wb/Wu);
K7=AAAA(:,Hb/Hu,1);
K8=AAAA(:,Hb/Hu,(Wb/Wu+1)/2);
K9=AAAA(:,Hb/Hu,Wb/Wu);

KA=[K1,K2,K3,K4,K5,K6,K7,K8,K9]
Tb1t=[Tb11',Tb12',Tb13',Tb14',Tb15',Tb16',Tb17',Tb18',Tb19']
Tb50t=[Tb501',Tb502',Tb503',Tb504',Tb505',Tb506',Tb507',Tb508',Tb509']
```

```
Qzzk=permute(Qzz, [3 1 2 4]);
Qvk=permute(Qv, [3 1 2 4]);
Qzzt=[Qzzk(:,:,1,4920/tp+1),Qzzk(:,:,2,4920/tp+1),Qzzk(:,:,3,4920/tp+1),];
Qvt=[Qvk(:,:,1,4920/tp+1),Qvk(:,:,2,4920/tp+1),Qvk(:,:,3,4920/tp+1),];


%Qraddst=qraddstNt+qraddstSt+qraddstMt;
%Qradust=qradustNt+qradustSt+qradustMt;
%Qraduf=qradufNt+qradufSt+qradufMt;
%Qradfe=qradfeNt+qradfeNht;
%Qradte=qradteSt+qradteSht;
```