Billet temperature simulation Codes (2D)

function

[Tbl, Tbhave, TaSh, FHub, FWNuub, FWSub, FWNub, FWSub, Fdwub, Fcuub, FHdb, FWNub, FWSdb, F
WN1db, FWSl1db, Fdw1db, Fcdub, FWNubuf, FWSubuf, Fbubdubuf, Ffubdubuf] = ip(i,t,tp,Tbl, WF, df,
dTaz, NN, Pt, P, Wb, Wbd, Wbdth, Wfd, Wfth, CL, dTaz, Lzc, Lz, Tw, zo, hgb,
Asx, cac, Acx, Sds, Sac, Sus, Asy, Scs, hbh, Th,
Shs, ac, Wu, cxp, cxm, cyp, cym, ae, zot, xo, yo, LB, St, Hu, Lu, Hc, Hb, LF, Hbw, Hfw, TaN, TaS, T
aM, CLm, TT, Ds, V, L, asa, asb, Emb, erbr, SBC)

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

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

%Atmosphere temperature which billet/bloom i experiences
Taxz=dTax(j)*((P(i,St(t))-Wbd(j)-L)/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);

%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);

qtrantotal=(qtrandst+qtranust+qtranuf+qtranhf);
qtrantotalcum=qtrantotalcum+qtrantotal;

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

%Incoming heat conduction
Tbxp=circshift(Tbl,[1 0 0]);
qucondxp=(Tbxp-
Tb1).*((aca*(Tbxp+Tb1)/2).^3+acb*((Tbxp+Tb1)/2).^2+acc*(Tbxp+Tb1)/2+acd)*Asx/
Wu.*cxp*10^(-3);
Tbxm=circshift(Tbl,[-1 0 0]);
qcondxm = (Tbxml - Tbl) .* (aca * ((Tbxml + Tbl) / 2) .* 3 + acb * ((Tbxml + Tbl) / 2) .* 2 + acc * (Tbxml + Tbl) / 2 + acd) * Asx / Wu .* cxm * 10^(-3);
Tbyp = circshift(Tbl, [0 1 0]);
qcondyp = (Tbyp - Tbl) .* (aca * ((Tbyp + Tbl) / 2) .* 3 + acb * ((Tbyp + Tbl) / 2) .* 2 + acc * (Tbyp + Tbl) / 2 + acd) * Asy / Hu .* cyp * 10^(-3);
Tbym = circshift(Tbl, [0 -1 0]);
qcondym = (Tbym - Tbl) .* (aca * ((Tbym + Tbl) / 2) .* 3 + acb * ((Tbym + Tbl) / 2) .* 2 + acc * (Tbym + Tbl) / 2 + acd) * Asy / Hu .* cym * 10^(-3);
qcondtotal = (qcondxp + qcondxm + qcondyp + qcondym);

% Emissivity of billet/bloom
aea = ae(i, 1);
aeb = ae(i, 2);
aec = ae(i, 3);
aed = ae(i, 4);
earb = 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)) -
(zo ./ (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)) -
(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) ./ zo) -
(zo ./ (Wbrd^2 + zo.^2).^0.5) * atan((Hb - yo) ./ zo); %

FWH = (Hu * Lu) / ((LB(i, St(t)) - Wb) * WF) * FubH;
FWWN = (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)) -
(zo ./ (Wbrd^2 + zo.^2).^0.5) * atan((Hc(j) - yo) ./ ((Wbrd^2 + zo.^2).^0.5));

FWNub = (Hu * Lu) / ((Wbrd * (Hc(j) - yo)) * FubWS;
FWNpl = (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)) +
(zo ./ (2 * 3.14159 * ((zo.^2 + (LB(i, St(t)) - Wb).^2).^0.5));

FWNub = (Hu * Lu) / ((Hb * (LB(i, St(t)) - Wb)) * FubWNL;
FWNsl = (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)) +
(zot ./ (2 * 3.14159 * ((zot.^2 + (LB(i, St(t)) - Wb).^2).^0.5));

FWNsl = (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;
theta(theta>theta1)=10;
theta(theta<=theta1)=Hb(j);
theta(theta<11)=0;
Ewh=zeros(Wb/Wu,Hb/Hu,fix(L/Lu));
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)./((HF-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)./((Hc(j)-yo).^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)./(Hc(j)-yo-Ewh).^2+Wbrd^2).^0.5));
Ewh=zero=Wbrd*WF;
\begin{align*}
\text{FdbWN} &= \left(1/(3.14159*2)\right) \cdot \left(\arctan(yo./zo) + \arctan((Hb-yo)./zo)\right) - \\
&\left(\arctan((zo.^2+(LF(i,St(t))-Wb)^2).^0.5)\right) \cdot \text{atan}
\left(\left(\arctan((zo.^2+(LF(i,St(t))-Wb)^2).^0.5)\right) + \arctan((Hb-yo)./\left(\arctan((zo.^2+(LF(i,St(t))-Wb)^2).^0.5)\right)\right) \\
\text{FWNldb} &= (Hu*Lu) / \left(\arctan((zo.^2+(LF(i,St(t))-Wb)^2).^0.5)\right) \cdot \text{FdbWNl} \\
\text{FWSl} &= \left(1/(3.14159*2)\right) \cdot \left(\arctan(yo./zot) + \arctan((Hb-yo)./zot)\right) - \\
&\left(\arctan((zot.^2+(LF(i,St(t))-Wb)^2).^0.5)\right) \cdot \text{atan}
\left(\left(\arctan((zot.^2+(LF(i,St(t))-Wb)^2).^0.5)\right) + \arctan((Hb-yo)./\left(\arctan((zot.^2+(LF(i,St(t))-Wb)^2).^0.5)\right)\right) \\
\text{FWSLd} &= (Hu*Lu) / \left(\arctan((zo.^2+(LF(i,St(t))-Wb)^2).^0.5)\right) \cdot \text{FdbWSl} \\
\theta_3 &= \arctan((Hb-yo)/(LF(i,St(t))-Wb)) \\
\theta_4 &= \arctan(((Hc(j)-Hbw(j)-yo)/Wfrd) \\
\phi_3 &= \theta_3 \\
\phi_4 &= \theta_3 \\
\phi_3 &= \max(0, \min(1, \theta_3)) \\
\phi_3 &= (\arctan((Hc(j)-((Hb-yo)/(LF(i,St(t))-Wb))*Wfrd)-yo) \\
\theta_3 &= \max(10, \min(Hbw(j), 11)) \\
\text{Ewh2} &= \text{zeros}(Wb/Wu, Hb/Hu, fix(L/Lu)) \\
\text{CL2} &= \text{Ewh2} \\
\text{Fdbdw} &= \left(1/(3.14159*2)\right) \cdot \left(\arctan((Hc(j)-yo)/(Hc(j)-yo).^2+Wfrd^2).^0.5)\right) + \arctan((Hc(j)-yo)/(\arctan((Hc(j)-yo).^2+Wfrd^2).^0.5)) \\
\text{Fdbdw1} &= \left(1/(3.14159*2)\right) \cdot \left(\arctan((Hc(j)-yo)/(Hc(j)-yo).^2+Wfrd^2).^0.5)\right) + \arctan((Hc(j)-yo)/(\arctan((Hc(j)-yo).^2+Wfrd^2).^0.5)) \\
\text{Fdbdw2} &= \left(1/(3.14159*2)\right) \cdot \left(\arctan((Hc(j)-yo)/(Hc(j)-yo).^2+Wfrd^2).^0.5)\right) + \arctan((Hc(j)-yo)/(\arctan((Hc(j)-yo).^2+Wfrd^2).^0.5)) \\
\text{Fdbdw3} &= \left(1/(3.14159*2)\right) \cdot \left(\arctan((Hc(j)-yo-Ewh2)/(Hc(j)-yo-Ewh2).^2+Wfrd^2).^0.5)\right) + \arctan((Hc(j)-yo-Ewh2)/(\arctan((Hc(j)-yo-Ewh2).^2+Wfrd^2).^0.5)) \\
\text{Fdbdw4} &= \left(1/(3.14159*2)\right) \cdot \left(\arctan((Hc(j)-yo-Ewh2)/(Hc(j)-yo-Ewh2).^2+Wfrd^2).^0.5)\right) + \arctan((Hc(j)-yo-Ewh2)/(\arctan((Hc(j)-yo-Ewh2).^2+Wfrd^2).^0.5)) \\
\text{Fdbdw} &= \text{Fdbdw1} + \text{Fdbdw2} + \text{Fdbdw3} + \text{Fdbdw4} \\
\text{Fdwdb} &= (Hu*Lu) / (\arctan((Hc(j)-yo)/Wfrd) \\
\text{Fdwdb} &= \text{Fdbdw} \cdot \text{CL2} \\
\text{Fdwdb} &= \max(0, \min(Ewh2, \text{zer}(Wb/Wu, Hb/Hu, fix(L/Lu)))) \\
\text{Fdbdw} &= \left(1/(3.14159*2)\right) \cdot \left(\arctan((Hc(j)-yo)/(Hb-yo)/(LF(i,St(t))-Wb))^2.\cdot^0.5)\right) \cdot \text{atan}
\left(\left(\arctan((Hc(j)-yo)/(Hb-yo)/(LF(i,St(t))-Wb))^2.\cdot^0.5)\right) + \arctan((Hc(j)-yo)/(\arctan((Hc(j)-yo)/(Hb-yo)/(LF(i,St(t))-Wb))^2.\cdot^0.5))\right) \\
\text{Fdbcw} &= \left(1/(3.14159*2)\right) \cdot \left(\arctan((Hc(j)-yo)/(Hb-yo)/((Hc(j)-yo).^2+Wfrd^2).^0.5)\right) + \arctan((Hc(j)-yo)/(\arctan((Hc(j)-yo).^2+Wfrd^2).^0.5)) \\
\text{Fcdw} &= (Hu*Lu) / (\arctan((Hc(j)-yo)/Wfrd) \\
\text{Fcdw} &= \max(0, \min(Ewh2, \text{zer}(Wb/Wu, Hb/Hu, fix(L/Lu)))) \\
\text{FWdbAN} &= \text{FdbWN} + \text{FdbWNl} \cdot (Hu*Lu) \cdot (10^-6) \\
\end{align*}
FWdbAS = (FdbWS + FdbWSl) * (Hu*Lu) * (10^(-6));
FWdbAM = (FdbH + Fdbdw + Fdbc) * (Hu*Lu) * (10^(-6));

%View factor of between billet/bloom upper surface and furnace
FbufWN = (1/(3.14159*2)) * (atan((Wbrd+Wb-xo)/zo) + atan((Wfrd+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((Wfrd+xo)/(zo.^2+(Hc(j)-Hb).^2).^0.5)));

FbufWS = (Lu*Wu)/((Hc(j)-Hb)*Lz(j))*FbufWN;

FbufsW = (Lu*Wu)/((Hc(j)-Hb)*Lz(j))*FbufWS;

%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;
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;
gradustN = SBC * (Embr + erbr) * FWubAN * (aea * Tbl.3 + aeb * Tbl.2 + aec * Tbl + aed + erb) * (TaN(j,t)^4 - Tbl.4) * Sus;
gradustS = SBC * (Embr + erbr) * FWubAS * (aea * Tbl.3 + aeb * Tbl.2 + aec * Tbl + aed + erb) * (TaS(j,t)^4 - Tbl.4) * Sus;
gradustM = SBC * (Embr + erbr) * FWubAM * (aea * Tbl.3 + aeb * Tbl.2 + aec * Tbl + aed + erb) * (TaM(j,t)^4 - Tbl.4) * Sus;

gradufN = SBC * (Embr + erbr) * FWbufAN * (aea * Tbl.3 + aeb * Tbl.2 + aec * Tbl + aed + erb) * (TaN(j,t)^4 - Tbl.4) * Scs;
gradufS = SBC * (Embr + erbr) * FWbufAS * (aea * Tbl.3 + aeb * Tbl.2 + aec * Tbl + aed + erb) * (TaS(j,t)^4 - Tbl.4) * Scs;
gradufM = SBC * (Embr + erbr) * FWbufAM * (aea * Tbl.3 + aeb * Tbl.2 + aec * Tbl + aed + erb) * (TaM(j,t)^4 - Tbl.4) * Scs;

gradtotal = gradustN + gradustS + gradustM + gradufN + gradufS + gradufM;
%gradtotalcum = gradtotalcum + gradtotal;

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

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

% Temperature changes [K]
dTb = Qoverall ./ (Ds(i) * spch.*V);
Tbl = Tbl + dTb;
end