


CARLSON M. SAGD and Geomechanics. JCPT v. 42, n. 6, Jun. 2003


COLLINS P.M. The False Lucre of Low-Pressure SAGD. JCPT. Pre-print. 2004
COLLINS P.M., CARLSON M.R., WALTERS D.A., SETTARI A. Geomechanical and Thermal Reservoir Simulation Demonstrates SAGD Enhancement Due to Shear Dilation. SPE/ISMR Paper 78237. 2002

DUSSEAULT M. B. Production Technologies for Development of Heavy Oil. Aversion1. 2006

EASTWOOD J. Temperature-Dependent Propagation of P- and S-waves in the Cold Lake Oil Sands: Comparison of Theory and Experiment. v. 58, n. 6, p. 863-872. 1993


FIORILLO G. Exploration and Evaluation of the Orinoco Belt. PDVSA. 1983


GUTIERREZ M. e LEWIS R.W. The Role of Geomechanics in Reservoir Simulation. SPE Paper 47392. 1996

FUNG L.S.-K., BUCHANAN L., WAN R.G. Coupled Geomechanical-Thermal Simulation for Deforming Heavy-Oil Reservoirs. JCPT v. 33, n. 4, April 1994

HATCHELL P.J., KAWAR R.S., SAVITSKI A.A. Integrating 4D Seismic, Geomechanics and Reservoir Simulation in the Valhall Oil Field. EAGE 67th Conference & Exhibition – Madrid, Spain, 13 - 16 June 2005

IBAÑEZ J.P. Modelagem Constitutiva para Solos com Ênfase em Solos Não Saturados. Dissertação de mestrado. Departamento de Engenharia Civil -


ITO Y. e SUZUKI S. Numerical Simulation of the SAGD Process in the Hangistone Oil Sands Reservoir. JCPT. v.38, n. 9, September 1996


LI P. e CHALATURNYK R.J. Discussion on SAGD and Geomechanics. JCPT. v. 42. n.9. September 2003


LI P. e CHALATURNYK R.J. Permeability Variations Associated with Shearing and Isotropic Unloading During SAGD Process. JCPT. n. 45 n. 1, January 2006

LI P. e CHALATURNYK R.J. When Is It Important to Consider Geomechanics in SAGD Operations?. JCPT. v. 43, n. 4. April 2004


LI P., CHALATURNYK R.J., TAN T.B. Coupled Reservoir Geomechanical Simulations for the SAGD Process. JCPT v.45, n. 1, January 2006


SAMIER P. E de Gennaro S. A Practical Iterative Scheme for Coupling Geomechanics with Reservoir Simulation. SPE paper 107077. 2007


TORTIKE, W.S. e FAROUQ ALI S.M. Reservoir Simulation Integrated with Geomechanics. JCPT. v. 32, n. 5, May 1993
TRAN D., NGHIEM L., BUCHANAN L. An Overview of Iterative Coupling Between Geomechanical Deformation and Reservoir Flow. SPE/PS-CIM/CHOA Paper 97879. 2005

TRAN D., SETTARI A., NGHIEM L. New Iterative Coupling Between a Reservoir Simulator and Geomechanics Module. SPE paper 88989. 2004


VINSOME P.K.W. e WESTERVELD J. A Simple Method for Predicting Cap and Base Rock Losses in Thermal Reservoir Simulators. JCPT, July-September 1980, 87-90


WANG Z. e NUR AMOS. Effect of Temperature on Wave Velocities in Sands and Sandstone with heavy hydrocarbons. Rock physics Project, Stanford University. 1986

Apêndice A
Arquivo de entrada para o cálculo da substituição de fluidos

Adaptado do código desenvolvido por Kummar (2006)

% Dados de entrada:
% rho_o = densidade do óleo (API)
% rho_g = densidade específica do gás (API)
% T = Temperatura (oC)
% P = Pressão (psi)
% phi = porosidade (fração)
% VSH = volume de folhelho (fração)
% isw = SWT: saturação inicial de água (fração)
% tsw = saturação final de água
% vp = velocidade de onda P apartir de perfil (ft/s)
% vs = velocidade de onda S apartir de perfil (ft/s)
% rho = densidade total apartir de perfil (gm/cc)

API_o = 10;
 rhoi_g = 1.2;
 Ti = xlsread('tempi_3D.xls');
 Ti = (5/9)*(Ti-32);
 Pi = xlsread('pressi_3D.xls');
 T = xlsread('CASE1_DIR1_42_STEP108_T.xls');
 T = (5/9)*(T-32);
 P = xlsread('CASE1_DIR1_42_STEP108_P.xls');
 S = 0.0
 phi = 0.32;
 vsh = 0.03632;
 isg = 0.088;
 isw = 0.164;
 tsw = xlsread('CASE1_DIR1_42_STEP108_Sw.xls');
 tsg = xlsread('CASE1_DIR1_42_STEP108_Sg.xls');
 ifluid = 1;
 fluid = 2;
 vp = 8397.0;
 vs = 3759.0;
 rho = 2.065;

% Parâmetros fixos (e.g., Mavko et al., 1998)


\[
k_{\text{clay}} = 20.9; \\
k_{\text{qtz}} = 36.6; \\
rho_{\text{clay}} = 2.58; \\
rho_{\text{qtz}} = 2.65; \\
\%
\% Conversões
\%
\text{div}_\text{mill} = 1/1000000; \\
\text{fs2kms} = 0.000305; \\
k_{\text{clay}} = 3280.84; \\
v_{\text{clay}} = v_{\text{sh}}*0.70; \\
v_{\text{qtz}} = 1-v_{\text{clay}}; \\
is_{\text{sh}} = 1-isw-isg; \\
t_{\text{sh}} = 1-tsw-tsg; \\
rho_{\text{o}}_{\text{matrix}} = 141.5/(\text{API}_o+131.5); \\
P_i = Pi*0.006894757*0.001; \\
P = P*6.894757*0.001; \\
S = S*\text{div}_\text{mill}; \\
v_p = v_p*\text{fs2kms}; \\
v_s = v_s*\text{fs2kms}; \\
\%
\% GOR_{\text{i}} = 2.03*rho_{\text{g}}*(0.006894757*Pi.*\exp(0.02878*\text{API}_o-0.00377*Ti)).^{1.205}; \\
GOR = 2.03*rho_{\text{g}}*(0.006894757*P.*\exp(0.02878*\text{API}_o-0.00377*T)).^{1.205}; \\
\%
\% Passo 1: Propriedades da matriz \\
\%
\text{k}_{\text{voigt}} = v_{\text{clay}}k_{\text{clay}} + v_{\text{qtz}}k_{\text{qtz}}; \\
k_{\text{reuss}} = 1/(v_{\text{clay}}k_{\text{clay}} + v_{\text{qtz}}k_{\text{qtz}}); \\
k_{\text{matrix}} = 0.5*(k_{\text{voigt}} + k_{\text{reuss}}); \\
rho_{\text{matrix}} = v_{\text{clay}}\rho_{\text{clay}} + v_{\text{qtz}}\rho_{\text{qtz}}; \\
\%
\% Passo 2: Propriedades da salmoura \\
\%
\text{w}(1,1) = 1402.85; \text{w}(1,3) = 3.437*10^{\text{-3}}; \\
\text{w}(2,1) = 4.871; \text{w}(2,3) = 1.739*10^{\text{-4}}; \\
\text{w}(3,1) = -0.04783; \text{w}(3,3) = -2.135*10^{\text{-6}}; \\
\text{w}(4,1) = 1.487*10^{\text{-4}}; \text{w}(4,3) = -1.455*10^{\text{-8}}; \\
\text{w}(5,1) = -2.197*10^{\text{-7}}; \text{w}(5,3) = 5.230*10^{\text{-11}}; \\
\text{w}(1,2) = 1.524; \text{w}(1,4) = -1.197*10^{\text{-5}}; \\
\text{w}(2,2) = -0.0111; \text{w}(2,4) = -1.628*10^{\text{-6}}; \\
\text{w}(3,2) = 2.747*10^{\text{-4}}; \text{w}(3,4) = 1.237*10^{\text{-8}}; \\
\text{w}(4,2) = -6.503*10^{\text{-7}}; \text{w}(4,4) = 1.327*10^{\text{-10}}; \\
\text{w}(5,2) = 7.987*10^{\text{-10}}; \text{w}(5,4) = -4.614*10^{\text{-13}}; \\
sumi = 0; \\
\text{for } i=1:5 \\
\quad \text{for } j=1:4 \\
\quad \quad \text{sumi} = \text{sumi}+\text{w}(i,j).*Ti.^(i-1).*Pi.^(j-1); \\
\quad \text{end} \\
\text{end} \\
v_i_{\text{water}} = \text{sumi}; \\
\text{sum} = 0; \\
\text{for } i=1:5 \\
\quad \text{for } j=1:4 

sum = sum+w(i,j).*T.^(i-1).*P.^(j-1);
end
v_water = sum;

v1i = 1170-9.6*Ti+0.055*Ti.*Ti-8.5*10^(-5)*Ti.*Ti+2.6*Pi-0.0029*Ti....
    *Pi-0.0476*Pi.*Pi; 
vi_brine = vi_water+S*vi1i+S*1.5*(780-10*Pi+0.16*Pi.*Pi)-1820*S*S;

r1i = 489*Pi-2*Ti.*Pi+0.016*Ti.*Ti-1.3*10^(-5)*Ti.*Ti....
    *Pi-0.333*Pi.*Pi-0.002*Ti.*Pi.*Pi;

r2i = 300*Pi-2400*Pi.*S+Ti.*(80+3*Ti-3300*S-13*Pi+47*Pi.*S);

rhoi_water=1+10^(-6)*(-80*Ti-3.3*Ti.*Ti+0.00175*Ti.*Ti+Ti+r1i);

rhoi_brine = rhoi_water+0.668*S+0.44*S*S+10^(-6)*S*r2i;

ki_brine = rhoi_brine.*vi_brine.*vi_brine*div_mill;

% Passo 3: Propriedades iniciais do hidrocarboneto

if ifluid == 1
    Boi = 0.972+0.00038*(2.495*GORi*sqrt(rhoi_g/rhoi_o)+Ti+17.8).^1.175;
    rhoi_ps = rhoi_o./((1+0.001*GORi).*Boi);
    rhoi_s = (rhoi_o+0.0012*GORi*rhoi_g)./Boi;
    r1i = rhoi_s+(0.00277*Pi-1.71*0.0000001*Pi.*Pi.*Pi).*
        (rhoi_s-1.15).^2+3.49*0.0001*Pi;
    rhoi_hyc = r1i./((0.972+3.81.*0.0001(*(Ti+17.78).*1.175));
    vi = 2096*sqrt(rhoi_ps/(2.6-rhoi_ps))-3.7*Ti+4.64*Pi+0.0115*...
       (sqrt(18.33./rhoi_ps-16.97)-1).*Ti.*Pi;
    ki_hyc = rhoi_hyc.*vi.*vi*div_mill;

    R = 8.314;
    Tai = Ti+273.15;
    Ppri = Pi./((4.892-0.4048*rhoi_g);
    Tpri = Tai./((94.72+170.75*rhoi_g);
    Ek = exp(-Ppri.^2./Tpri.*((0.45+8*(0.56-1./Tpri).^2));
    Ei = 0.109*(3.85-Tpri).^2.*Ek;
    Z1i = 0.03+0.00527*(3.5-Tpri).^3;
    Zi = Z1i.*Ppri+0.642*Ppri-0.007*Ppri.^4-0.52+Ei;
    rho_hyc_g_i = (28.8*rhoi_g.*Ppri./Zi*R.*Tai);
    dz_dp_i=Z1i+0.109.*((3.85-Tpri).^2.*Ek.*(-1.2*Ppri.^2./Tpri.*...
        (0.45+8*(0.56-1./Tpri).^2));
    yoi = 0.85+5.6./(Ppri+2)+27.1./(Ppri+3.5).^2-8.7*exp(-0.65*(Ppri+1));
    k_hyg_i = Pi.*yoi./1000*1.0./(1-Ppri./Zi.*dz_dp_i);
end

% Passo 4: Propriedades do fluido

% ki_fl = 1./(isw/**ki_brine+ish/**ki_hyc+isg/**k_hyg_i);

rhoi_fl = isw.*rhoi_brine+ish.*rhoi_hyc+isg.*rho_hyc_g_i;

% Passo 5: Módulo original in-situ (rocha saturada in-situ)

dens_poros = 0;
if dens_poros == 1
    rho = phi*rhoi_fl + (1-phi)*rho_matrix;
end

k_sat = rho*(vp*vp-vs*vs*4/3);

g = rho*vs*vs;
% Passo 6: Propriedades do arcabouço
% k1 = k_sat*(phi*k_matrix./ki_fl+1-phi)-k_matrix;
k2 = phi*k_matrix./ki_fl+k_sat/k_matrix-1-phi;
k_frame = k1./k2;
%
% Passo 7: Seleção do tipo de fluido de saída
%
if fluid == 1
    if fluid == 2

B0 = 0.972+0.00038*(2.495*GOR*sqrt(rhoi_g/rhoi_o)+T+17.8).^1.175;
rho_ps = rhoi_o./((1+0.001*GOR).*B0);
rho_s = (rhoi_o+0.0012*GOR*rhoi_g)./(1+0.001*GOR).*B0;
r1 = rho_s+(0.00277*P-1.71*0.0000001*P.*P).*((rho_s-1.15).^2+...% 3.49*0.0001*P;
rho_hyc = r1./((0.972+3.81*0.0001*(T+17.78).^1.175);
v = 2096*sqrt(rho_ps./((2.6-rho_ps)))-3.7*T+4.64*P+0.0115*...% (sqrt(18.33./rho_ps-16.97)-1).*T.*P;
k_hyc = rho_hyc.*v.*v*div_mill;
R = 8.314;
Ta = T+273.15;
Ppr = P./(4.892-0.4048* rhoi_g);
Tpr = Ta./(94.72+170.75* rhoi_g);
E1 = exp(-Ppr.^1.2./Tpr.*((0.45+8*(0.56-1./Tpr).^2));
E = 0.109*(3.85-Tpr).^2.*E1;
Z1 = 0.03+0.00527.*(3.5-Tpr).^3;
Z = Z1.*Ppr+0.642*Tpr-0.007*Tpr.^4-0.52+E;
rho_hyc_g = 28.8*rhoi_g.*Ppr./((Z*R.*Ta);
dz_dp=Z1+0.109.*(3.85-Tpr).^2.*E1.*(-1.2*Ppr.*0.2./Tpr.*((0.45+8*...%
(0.56-1./Tpr).^2));
yo = 0.85+5.6./(Ppr+2)+27.1./(Ppr+3.5).^2-8.7*exp(-0.65*(Ppr+1));
% Salmoura
v11 = 1170-9.6*T+0.055*T.*T-8.5*10^-5*T.^T.*T+2.6*P-0.0029*P.*...%
0.0476*P.*P;
v1_brine = v_water+S*v11+S^1.5*(780-10*P+0.16*P.*P)-1820*S*S;
r11 = 489*P-2*T.*P+0.016*T.*T.*T.*P-1.3*10^-5*T.*T.*P-0.333*P.*...%
0.002*T.*P.*P;
rho1_water=1+10^-6*(-80*T-3.3*T.*T+0.00175*T.*T.*T+11);
r21 = 300*P-2400*P.*S+T.*(80+3*T-3300*S-13*P+47*P.*S);
rho1_brine = rho1_water+0.668*S+0.44*S*S+10^-6*S*r21;
k_brine = rho1_brine.*v1_brine.*v1_brine*div_mill;
k_hyg = P.*yo./1000*1.0/(1-Ppr./Z.*dz_dp);
end
%
% Passo 8: Propriedades do fluido (saturação final) e densidade
% da rocha saturada
%
k_fl = 1./(tsw/k_brine + tsh/k_hyc + tsg/k_hyg);
rho_fl = tsw.*rho1_brine + tsh.*rho_hyc + tsg.*rho_hyc_g;
rho_sat = phi*rho_fl+(1-phi)*rho_matrix;
%
% Passo 9: Módulo total da rocha saturada
%
k1 = phi./k_fl+(1-phi)/k_matrix-k_frame/(k_matrix*k_matrix);
k_sat_new = k_frame + ((1-k_frame./k_matrix).^2)./k1;
%
% Passo 10: Velocidade sísmica depois da substituição de fluidos
%
vp_sat = sqrt((k_sat_new+g*4/3)./rho_sat)*1000;
vs_sat = sqrt(g./rho_sat)*1000;
Al = vp_sat.*rho_sat;