Asphaltene Damage Modeling: Simulation Report

R. Hosseinzadeh · E. Meghrazi · S. Aghaei

Adv. Formation Damage: Project #1

Under Supervision of Dr. Mohammad Hossein Ghazanfari

Department of Chemical & Petroleum Engineering
Sharif University of Technology

April, 2020

Contents

- Introduction
  - Asphaltene Definition and Damage Mechanisms
  - Asphaltene-induced Formation Damage
- Methodology
  - Formulation and Code Development
- Results and Discussion
  - Generated Plots
  - Sensitivity Analysis
- Summary and Conclusion

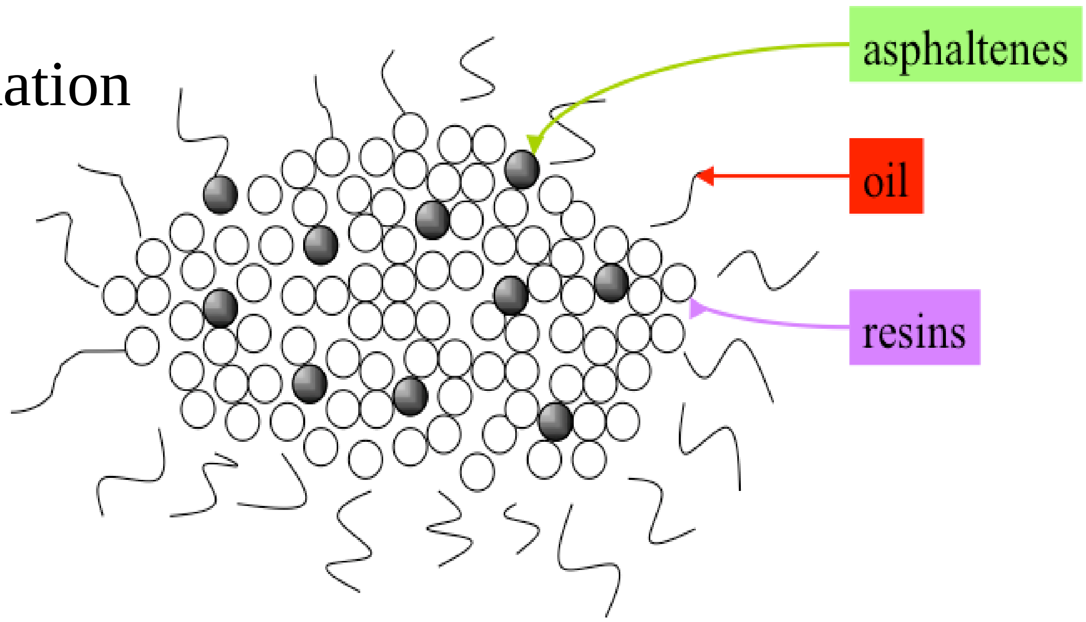
Introduction

An Introduction to Near-Wellbore Asphaltene Damage Modeling.

Asphaltene: Definition and Damage Mechanisms

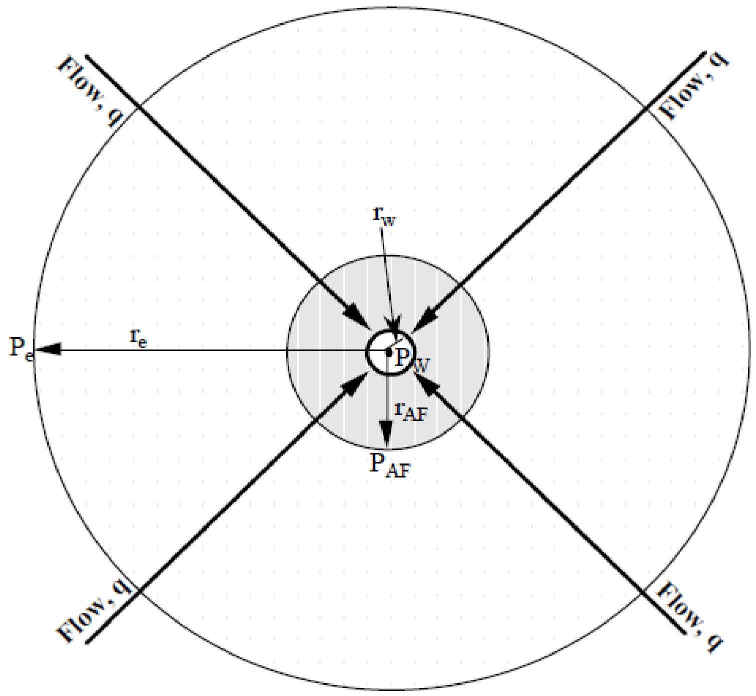
- Three possible mechanisms of asphaltene-induced formation damage:
  - Physical Blockage or Permeability Impairment
  - Wettability Alterations
  - Viscosity Increase or Emulsion Formation

- $$\lambda_o = \frac{k_o}{\mu_o} = \frac{k\,k_{ro}}{\mu_o}$$



Asphaltene-induced Formation Damage

- Radial flow of reservoir fluid from reservoir to the wellbore.
- Near-well asphaltene precipitation.
- In the Figure Pw is lower than P_{AF}
  - P_{AF}: Asphaltene Formation Pressure
  - r_{AF}: Asphaltene Damage Radius



Methodology

A step-by-step overview of the formulation used for re-generating the paper’s results.

Initial Values

- Initial parameters defined by the paper are:

```
Pe = 10579.5; % psia
P_AF = 8856.2;
Pw = 7998.9;
r_AF = 5.9; % ft
re = 626.1;
Tr = 250; % degrees F
rw = 0.583;
phi = .3;
k = .25; % darcy
PI = 3.1; % bbl/psi
q = 8000; % bbl/day
```

- There are also parameters defined based on the initial pressure profile:

```
h = 55; % reservoir thickness, ft; 55
mu = 1.3; % reservoir fluid viscosity, cp; 1.3
```

Hydraulic Radius Calc.

1. Calculate r_H and then d_H using d_g
2. Calculate d_{AP} using α

- The value for d_g used was equal to 6.5 microns.

$$r_H = \frac{\phi}{(1-\phi)} \frac{d_g}{6}$$

$$d_{AP} = \alpha d_H$$

```
dg = 6.5; % micron
rH = dg/6*(phi/(1-phi));
dH = 2*rH; % micron

dAP = alpha*dH; % micron
```

No-Damage Pressure Profile

- Calculating pressure drop using the following equation:

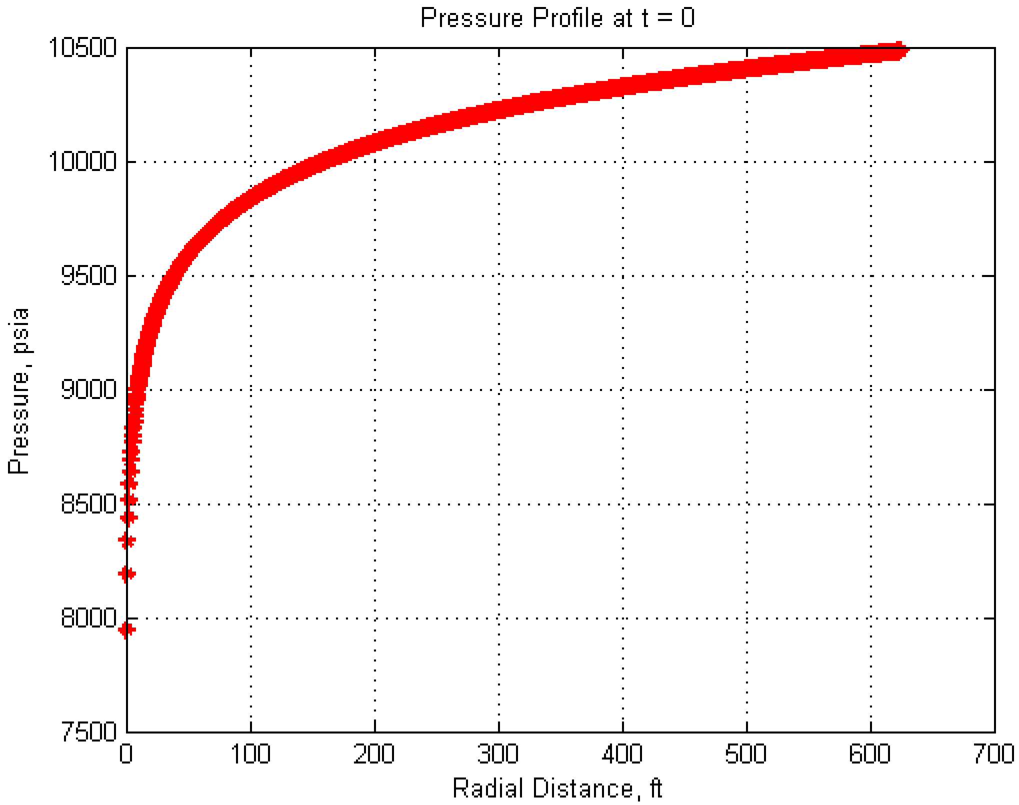
$$P = P_w + \frac{q\mu}{7.08\ k\ \varphi} ln\left(\frac{r}{r_w}\right)$$

- and then initial area open to flow (A_{init}) is calculated:

$$A_{initial}(r) = 2\pi r h \phi_{initial}$$

```
for i = 1:M1
    r(i) = dr*i;
    A_init(i) = 2*pi*r(i)*phi*h; % sqft
    P(i) = Pw + q*mu/(1.127*k*2*pi*phi*h)*log(r(i)/rw);
end
```

No-Damage Pressure Profile

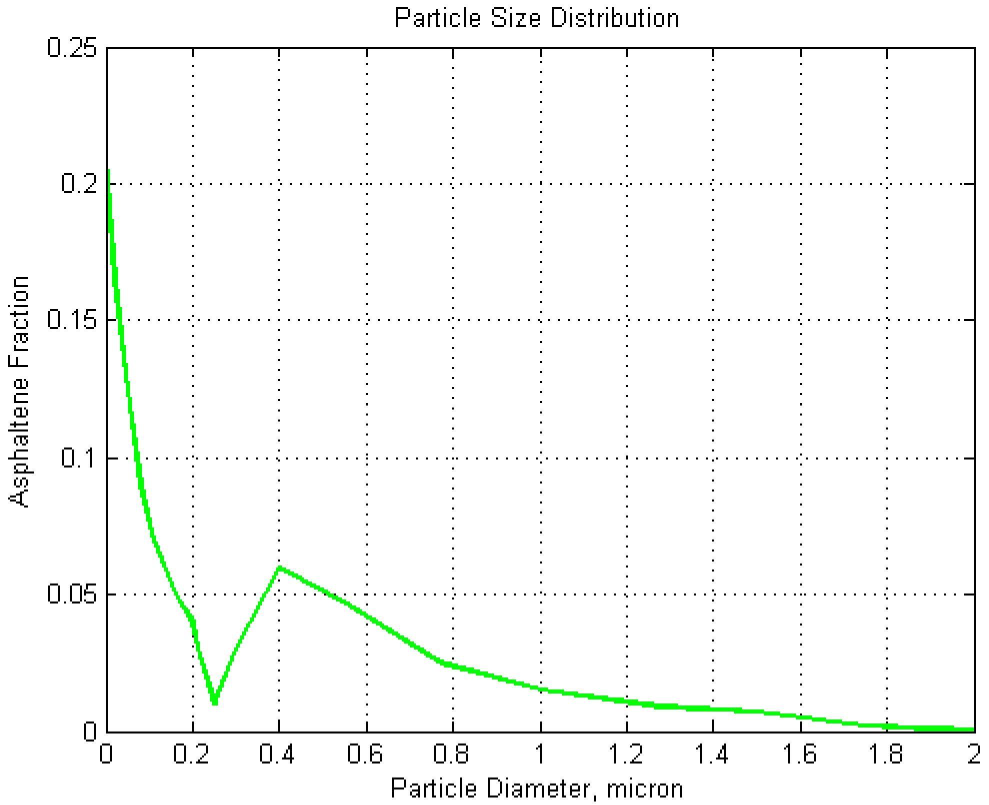


- Viscosity = 1.3 cp
- Thickness = 55 ft

$$P = P_w + \frac{q\mu}{7.08\ k\ \varphi} ln\left(\frac{r}{r_w}\right)$$

Particle Size Distribution: f_{trap}

```
for o = 
1:length(ParticleDiameter)
    if ParticleDiameter(o) >= dAP
        PD(o) = 
ParticleDiameter(o);
    end
end
PD1 = nonzeros(PD)';
nn = length(PD) - length(PD1) + 
1;
f_trap = trapz(PD1, 
AsphalteneFraction(nn:length(Asph
alteneFraction)));
```



- Based on Fig. 4 of the reference paper.
- Have been integrated from d_{AP} through the end to obtain f_{trap}.

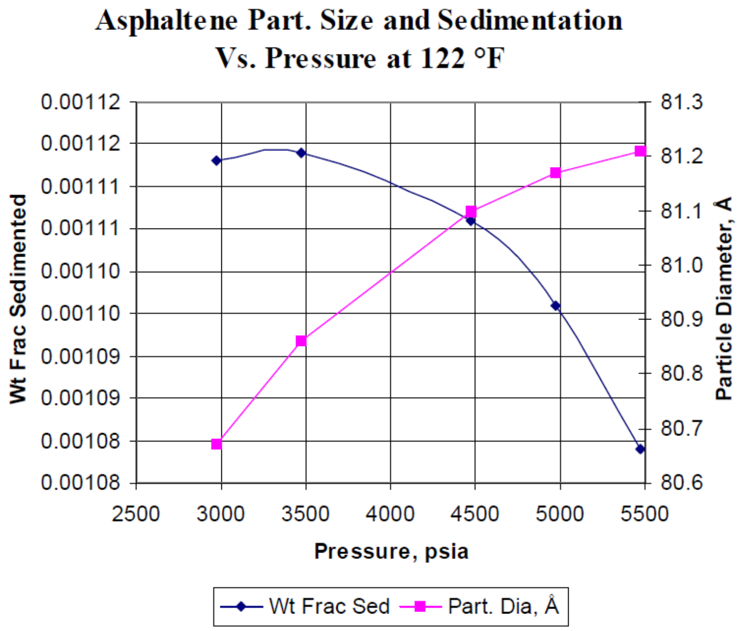
Mole Fraction Calc.

- Calculating MW_{RF} to obtain molar fraction instead of weight fraction.

```
component_MoleFraction = [0.013887 0.533045 0.047187 0.039397 0.024263
0.036136 0.058189 0.062541 0.071256 0.021870 0.057985 0.007795 0.001417
0.019344 0.005688];
component_MolecularWeight = [42.117 16 30 44 74.839 119.657 133.514
170.318 257.588 265.684 330 453.624 466.771 380.000 475.000];

MW_RF = sum(component_MoleFraction.*component_MolecularWeight); %
reservoir fluid mean molecular volume, gr/mol
MW_Asphaltene = 475; % gr/mole
% ref: Table 4-Reservoir Oil Characterization, SPE 37252
% also: Table-2 of the paper

wt_fraction = [.001118 .001119 .0011115 .001101 0.0010845];
mole_fraction = wt_fraction.*MW_RF/MW_Asphaltene;
```



Based on Slide 23 of the presentation

Molecular Weight Data

Table 4-Reservoir Oil Characterization							
Component	MW	Tc, °K	Pc, bar	Omega	Mole Fr.	Weight	Weight Fract.
N2-CO2	42.117	283.142	68.280	0.203	0.019976	0.841327	0.008853
Methane	16.043	190.550	45.990	0.011	0.559635	8.978227	0.094474
Ethane	30.070	305.330	48.710	0.099	0.023515	0.707082	0.007440
Propane	44.097	369.850	42.470	0.152	0.028547	1.258849	0.013246
C4-C6	74.839	431.745	36.109	0.209	0.041010	3.069130	0.032295
C7-C8	119.657	523.817	28.470	0.318	0.028591	3.421104	0.035999
C9-C10	133.514	554.773	25.616	0.363	0.028844	3.851084	0.040523
C11-C14	170.318	622.846	20.173	0.485	0.039207	6.677571	0.070265
OC15-C29	257.588	751.063	11.504	0.760	0.079677	20.523791	0.215964
NC15-C29	265.684	752.046	11.631	0.806	0.063602	16.897999	0.177811
Aromatics	330.000	805.000	9.500	0.900	0.052586	17.353349	0.182602
Resins	380.000	814.000	8.000	1.060	0.019584	7.441814	0.078307
OC30+	453.624	861.338	4.687	1.059	0.003871	1.755980	0.018477
NC30+	466.771	862.452	4.902	1.224	0.004834	2.256276	0.023742
Asphaltenes	475.000	880.000	4.000	1.300	0.006523	3.098203	0.032601
					1.000000	95.033583	1.000000

Based on (Leontaritis, 1997)

Mole Fraction Calc.

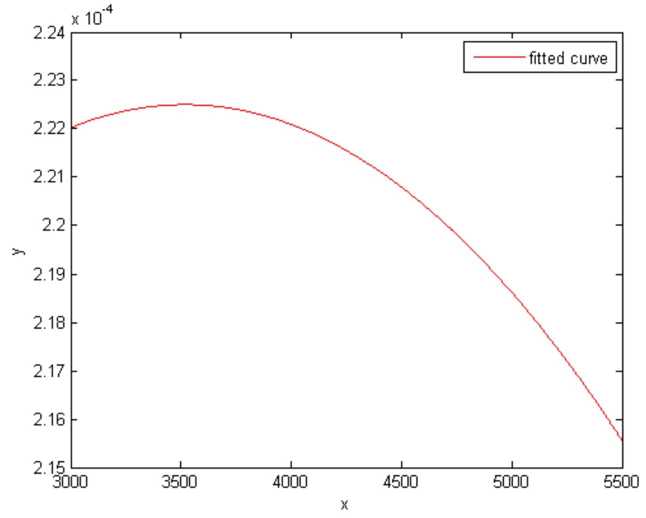
- To avoid over-fitting second degree polynomial is used to fit the S data
- The plot is Mole Fraction of Asphaltene vs. Pressure

```
Pressure = [3000 3500 4500 5000 5500];

% Fit:
[xData, yData] = prepareCurveData( Pressure, mole_fraction );

% Set up fittype and options.
ft = fittype( 'poly2' );

% Fit model to data.
S = fit( xData, yData, ft ); % weight fraction of asphaltene to
reservoir fluid
```



Equations Beyond the Source Paper

$M_{RF} = \frac{qt \times 0.159 \times 10^6}{24 v_{RF}}$ (**moles** of reservoir fluid) | $v_{RF} = \frac{MW_{RF} \times 1000}{\rho_{RF}}$ (**cc/mole** of reservoir fluid)

$v_A = \frac{MW_{Asph}}{\rho_{Asph}}$ (**cc/mole** of asphaltene particles) | $A_{AP} = S(P) f_{trap} M_{RF} v_A \frac{6\gamma}{d_H} \times 10.7639, \quad ft^2$

$\rho_{Asph} = 1.2\ gr/cc$

```
vA = MW_Asphaltene/1.2; % cc/mole, asphaltene density equal to 1.2 g/cc
v_RF = MW_RF*1000/rho_RF; % cc/mole
A_AP = zeros(M,N);
% calculating the main parameters
for j = 1:N
    M_RF(j) = q*(dt/24)*j/v_RF*0.158987294928*1e6; % mole of reservoir
fluid
%     Main Loop
    for i = M:-1:1
       A_AP(i,j) = S(P(i,j))*f_trap*M_RF(j)*vA*gamma*6/dH*10.7639; % sqft
       DOD(i,j) = 1/(1 - (A_AP(i,j)/A_init(i))); % (Step 7)
       k_dam(i,j) = k/DOD(i,j);                   % (Step 8)
       phi_dam(i,j) = phi/DOD(i,j);
    end
end
```

Pressure Profile/Skin Calc.

- Pressure profile is calculated for each time step and then using skin pressure drop the skin factor is estimated via the paper's formulation:

$$s(t) = \Delta P_s(t)\,\frac{7.08\,k_{initial}\,h}{q\mu}$$

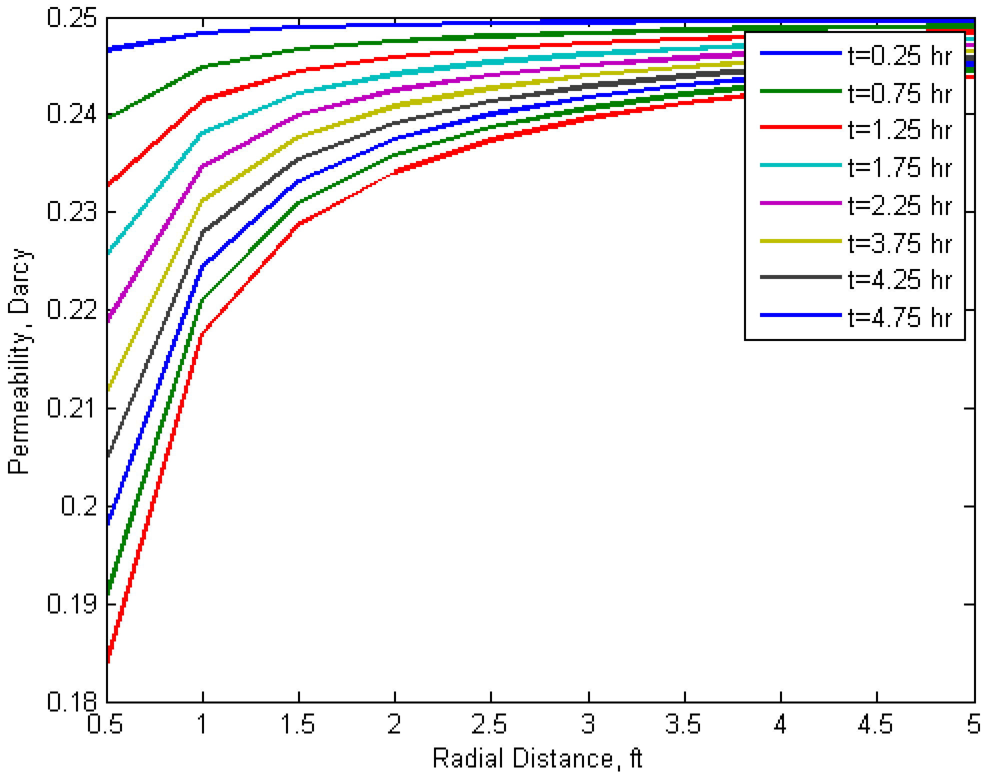
$$P_e - P_w(t) - \Delta P_s(t) = \frac{q\mu \ln\left(r_e/r_w\right)}{7.08\,k_{initial}\,h}$$

```
% calculating pressure profiles and relevant parameters
for j = 1:N
    for i = M:-1:1
        if j >= N
            break
        end
        P(i,j+1) = P(1,j) +
q*mu/(7.08*k_dam(i,j+1)*h*phi)*log(r(i)/rw);
        dPs(j+1) = Pe - P(1,j+1) - q*mu*log(re/rw)/7.08/k/h;
        skin(j+1) = dPs(j+1)*7.08*k*h/q/mu;
    end
end
```

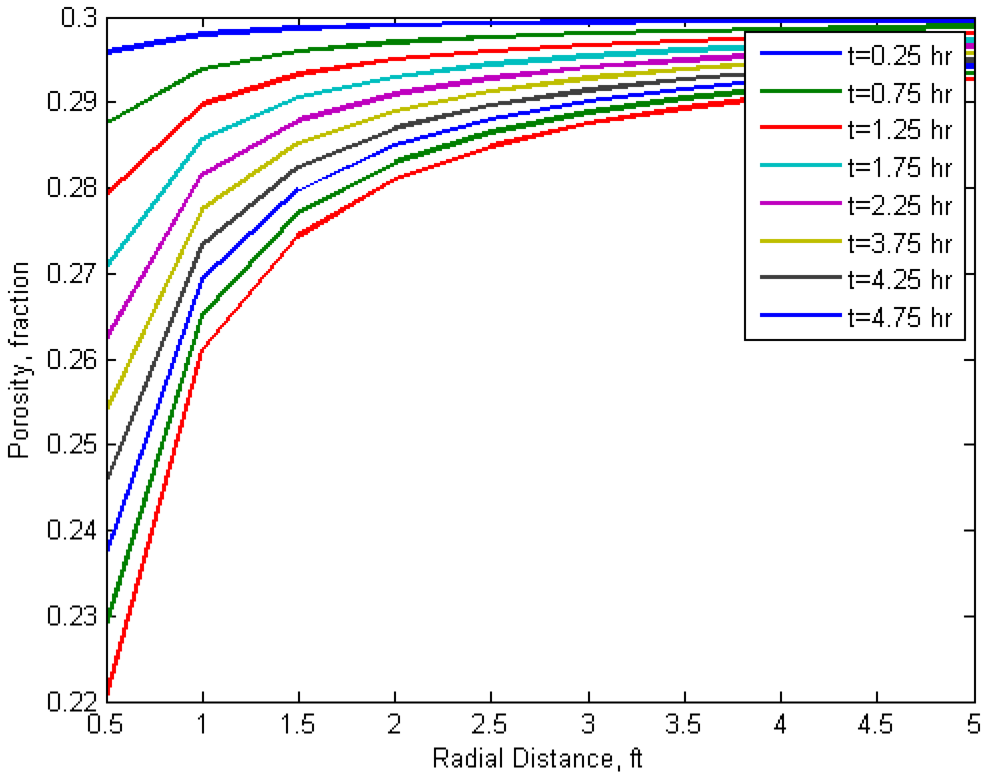
Results and Discussion

Demonstration and explanation of the generated plots by the application, and sensitivity analysis results.

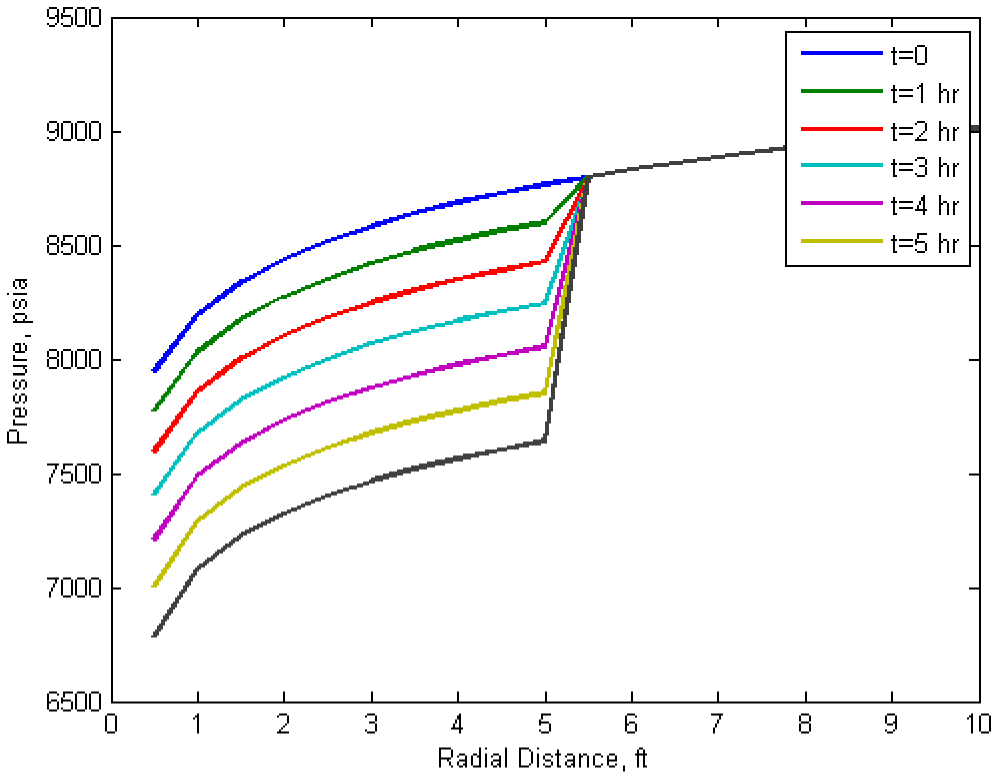
Permeability Reduction



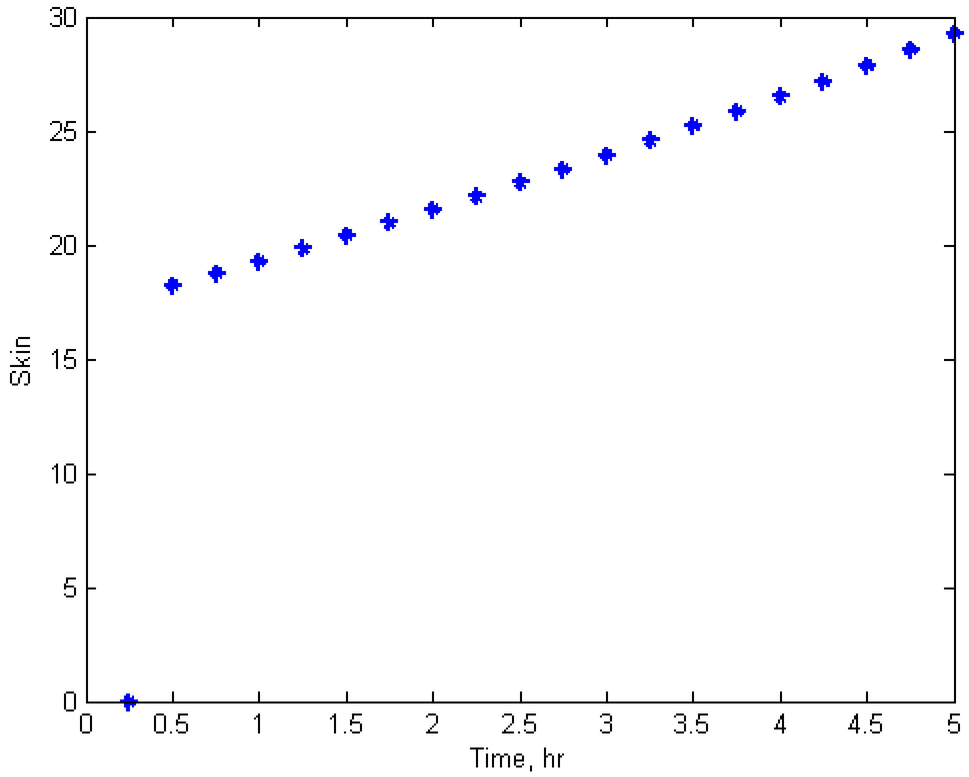
Porosity Reduction



Pressure Profile

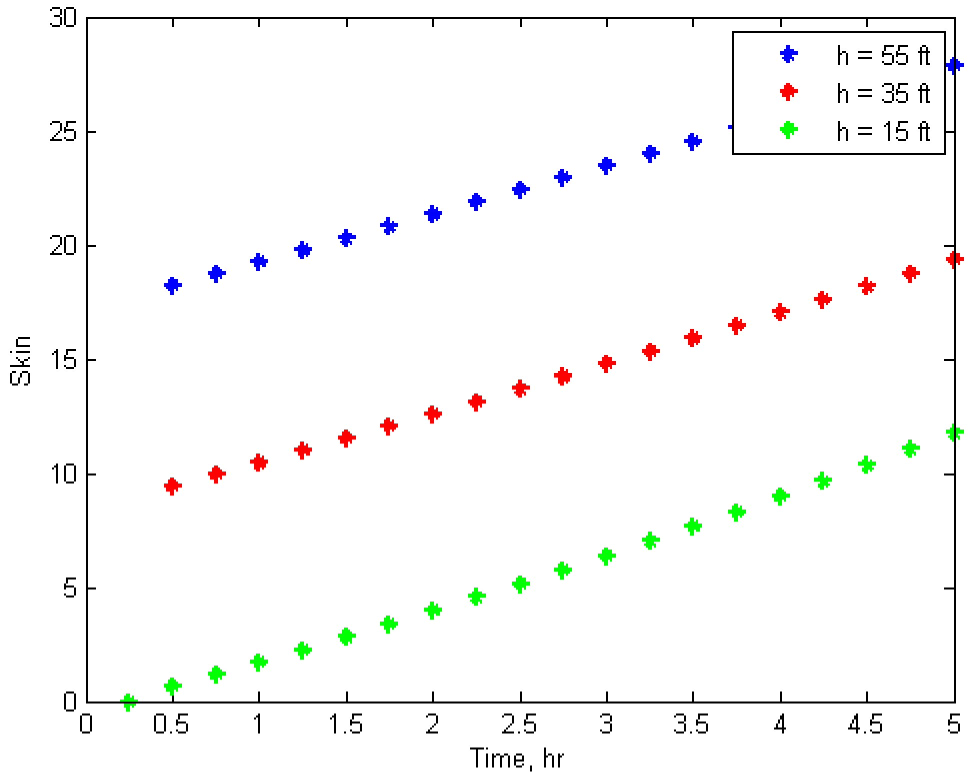


Skin Variation vs. Time



Sensitivity Analysis

Pay Zone Thickness

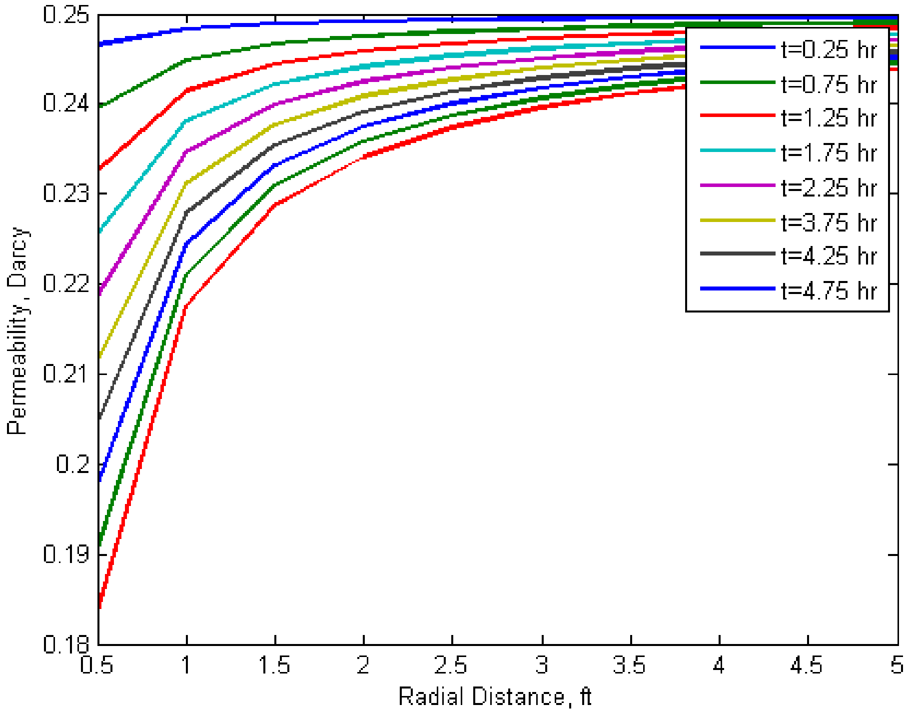


$$s(t) = \Delta P_s(t)\,\frac{7.08\,k_{initial}\,h}{q\mu}$$

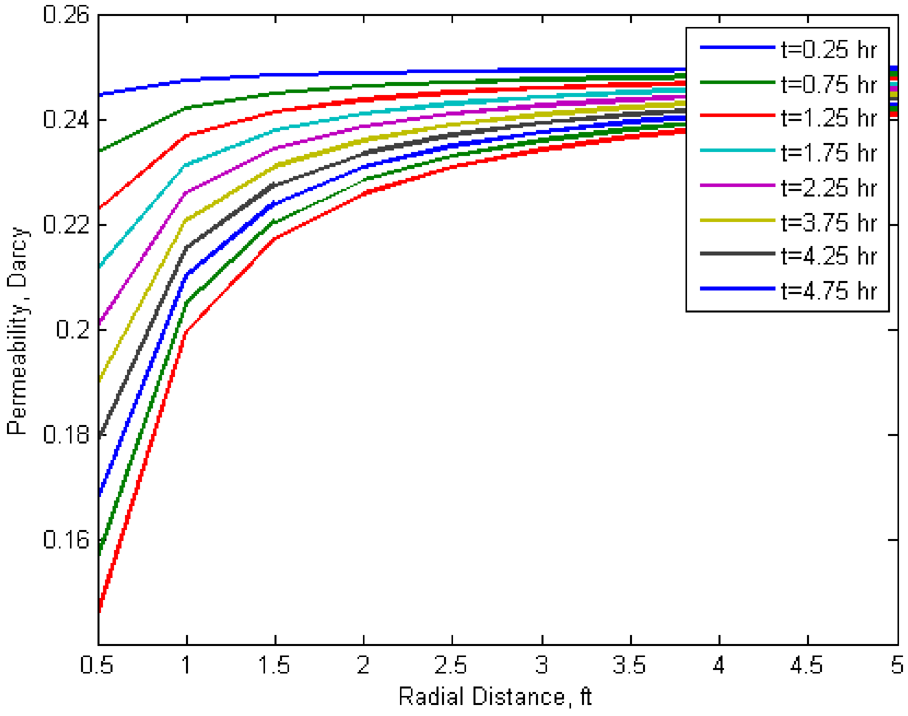
Sensitivity Analysis

Pay Zone Thickness

Thickness = 55 ft



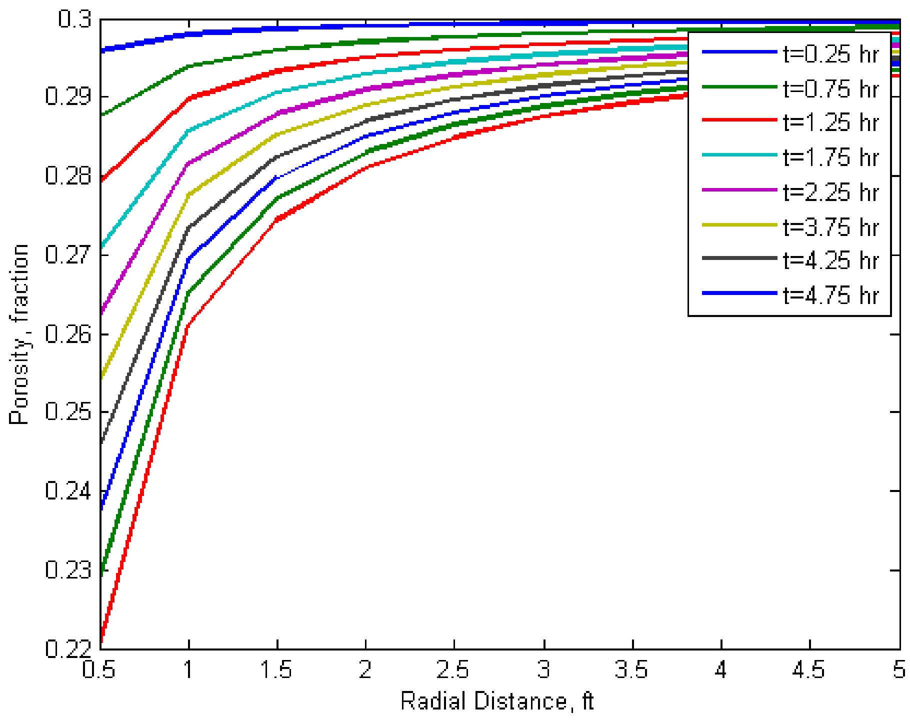
Thickness = 35 ft



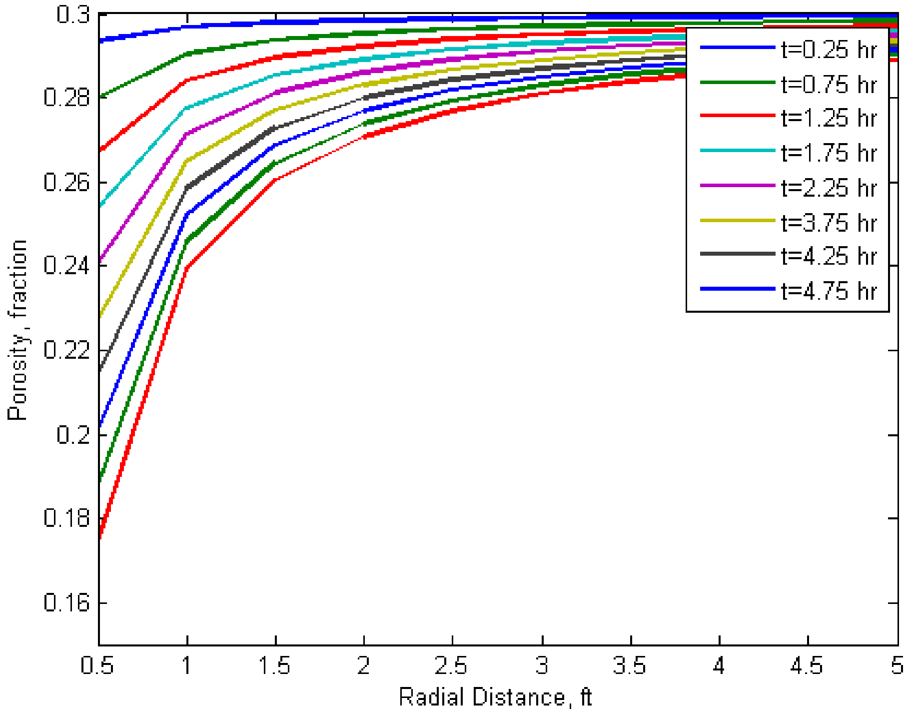
Sensitivity Analysis

Pay Zone Thickness

Thickness = 55 ft

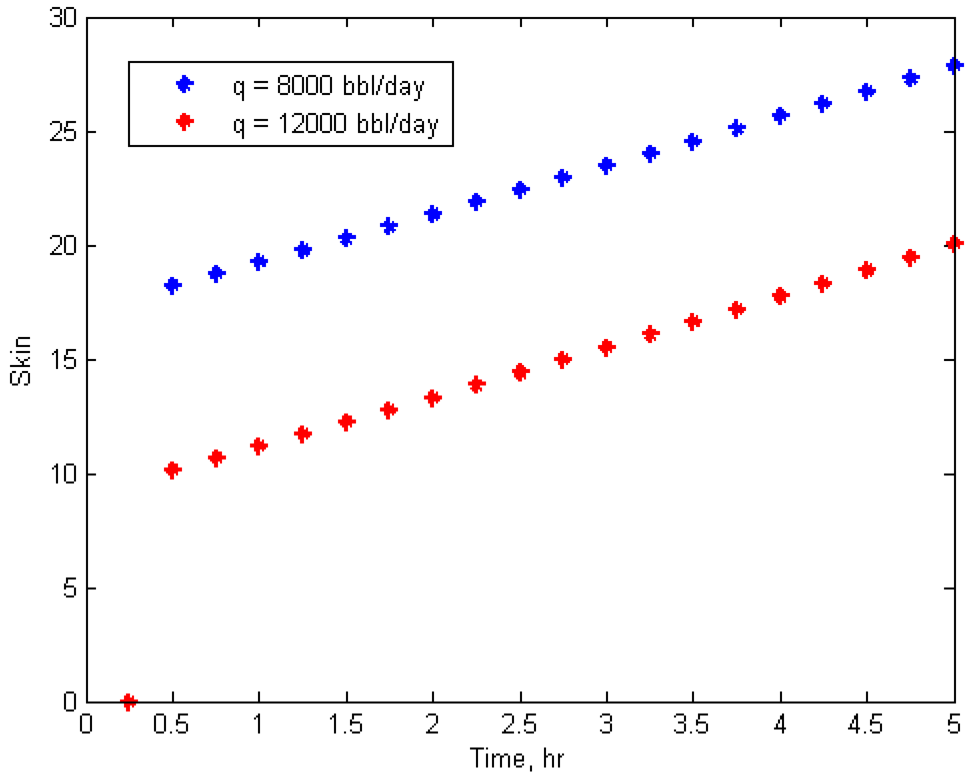


Thickness = 35 ft



Sensitivity Analysis

Production Flow-Rate: Skin Sensitivity

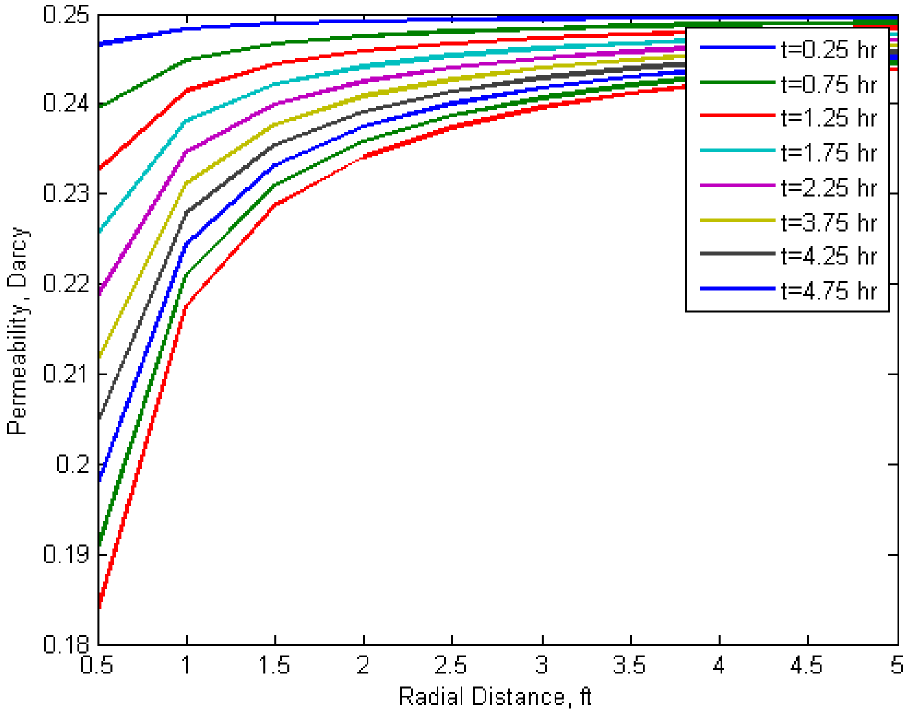


$$s(t) = \Delta P_s(t)\,\frac{7.08\,k_{initial}\,h}{q\mu}$$

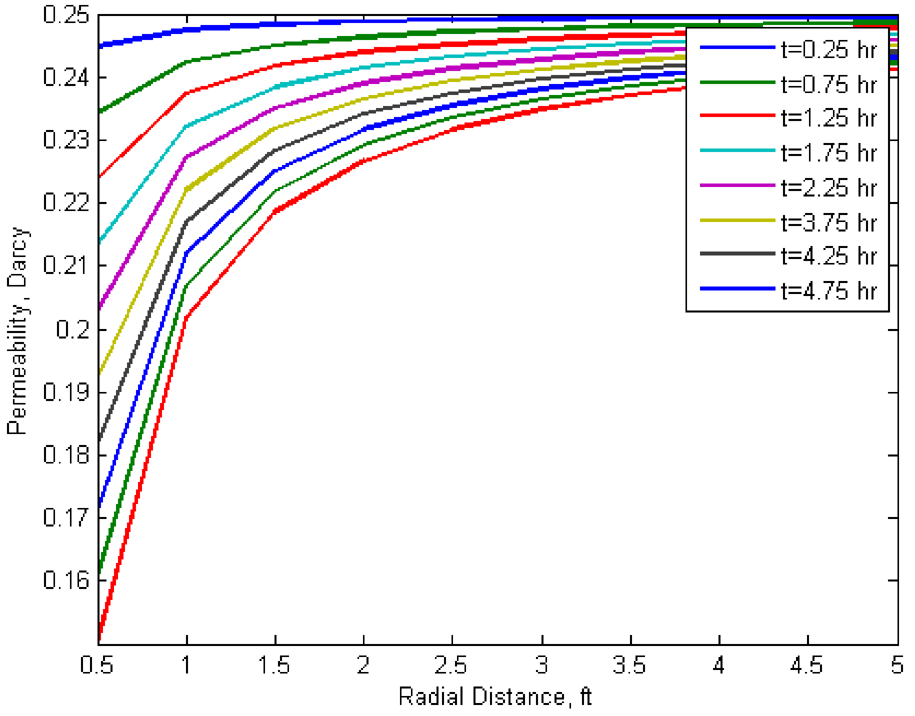
Sensitivity Analysis

Production Flow-Rate

Flow-Rate = 8000 bbl/day



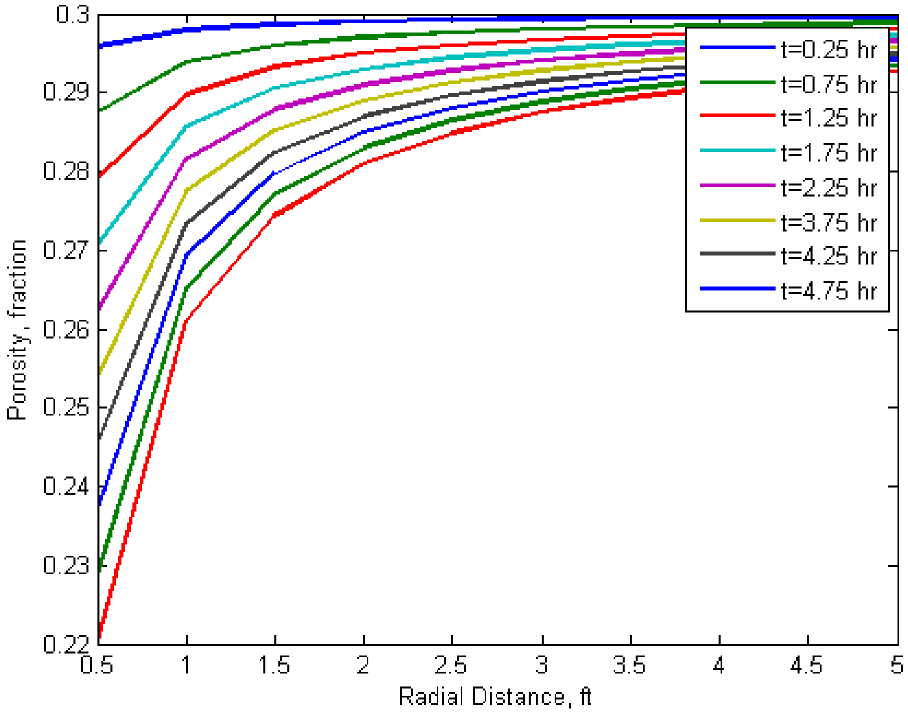
Flow-Rate = 12000 bbl/day



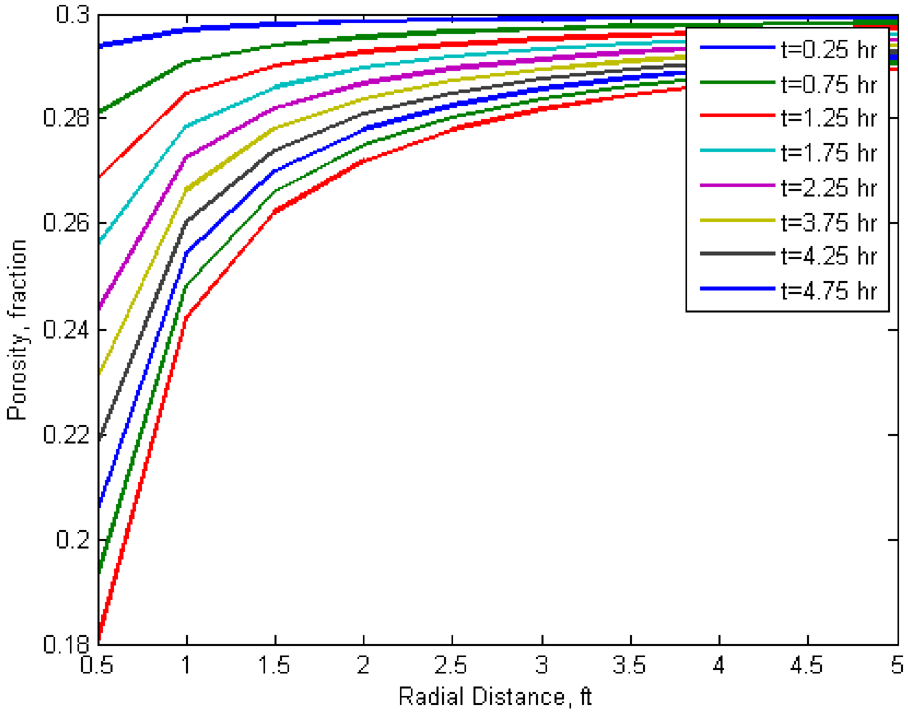
Sensitivity Analysis

Production Flow-Rate

Flow-Rate = 8000 bbl/day

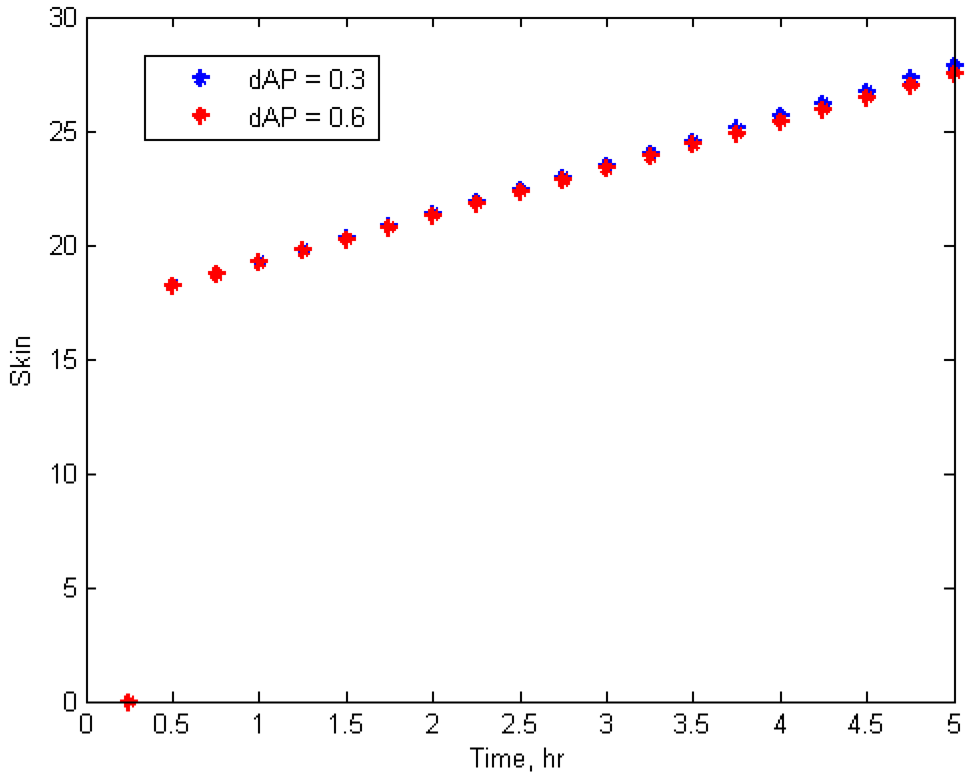


Flow-Rate = 12000 bbl/day



Sensitivity Analysis

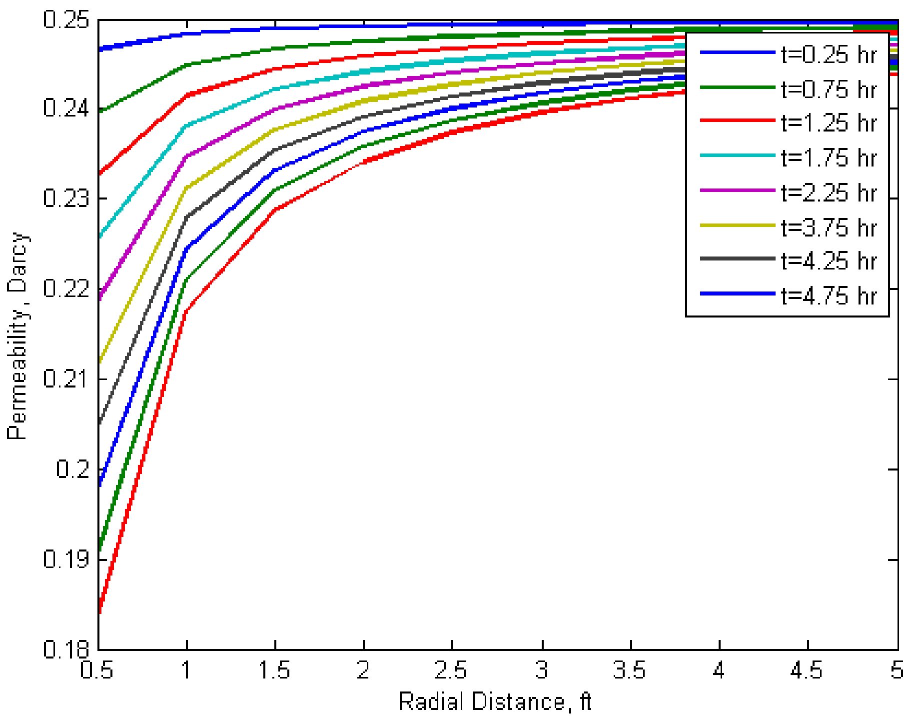
Critical Asphaltene Particle Diameter



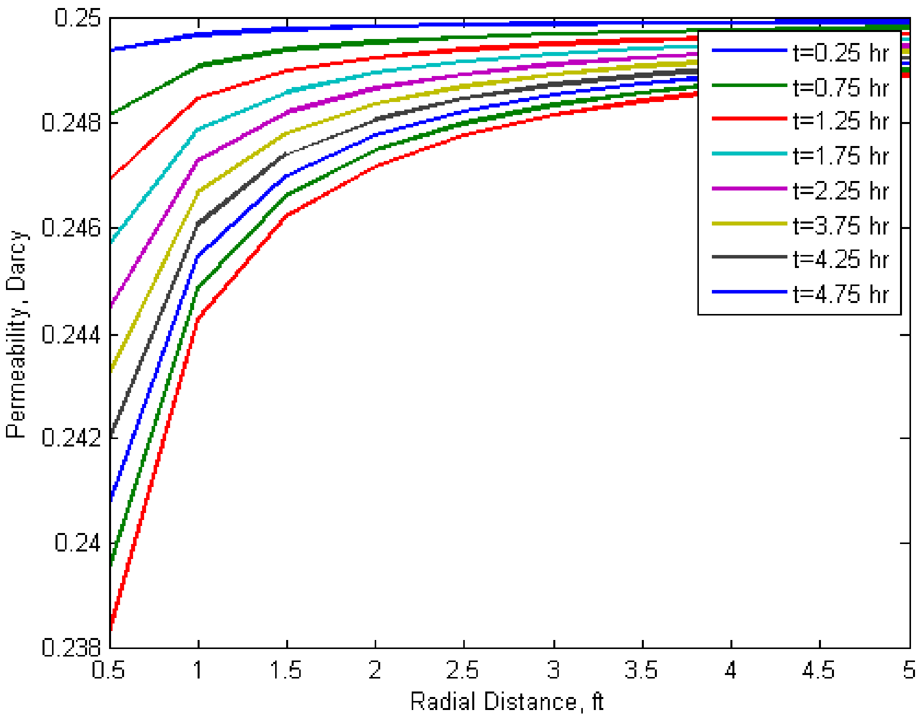
Sensitivity Analysis

Critical Asphaltene Particle Diameter

d_{AP} = 0.3 micron



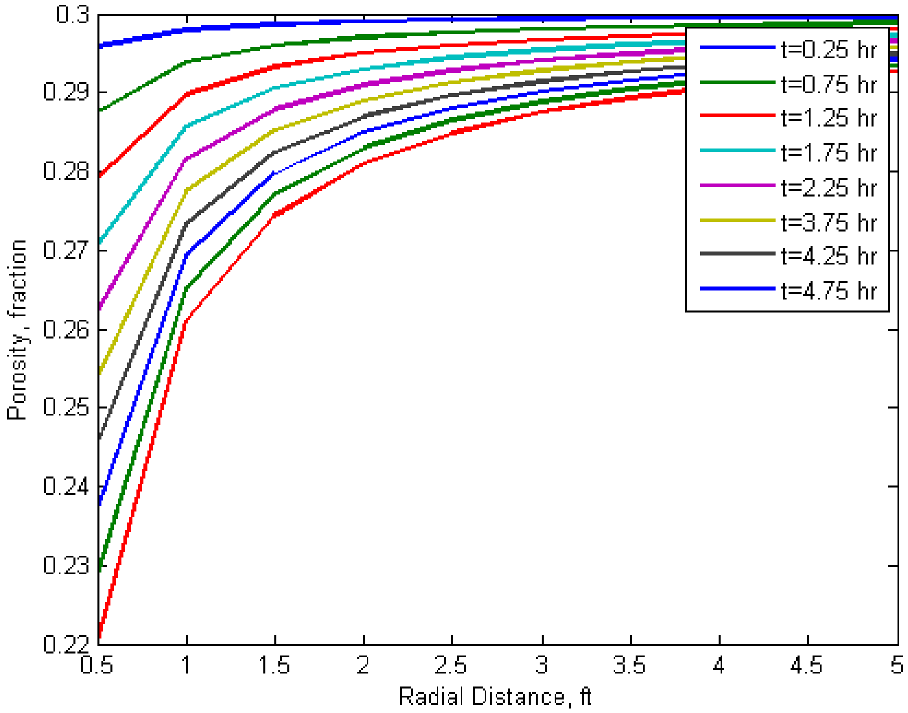
d_{AP} = 0.6 micron



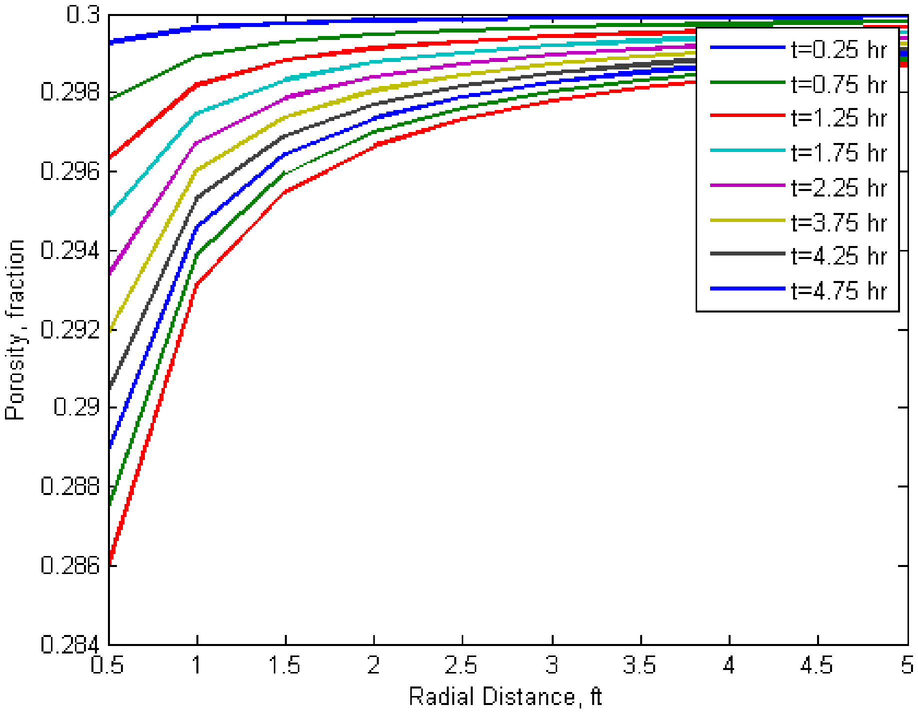
Sensitivity Analysis

Critical Asphaltene Particle Diameter

d_{AP} = 0.3 micron



d_{AP} = 0.6 micron



Summary and Conclusion

- A brief summary of asphaltenes and near-wellbore asphaltene damage phenomenon has been discussed
- The methodology to determine skin due to asphaltene precipitation according to the source paper is introduced. (Leontaritis, 1998)
- The output plots of the application to re-generate the source paper's results have been explained.
- Sensitivity analysis have been carried out on four parameters, the results have shown great sensitivity to formation thickness and production flow-rate, however, low sensitivity to viscosity.

References

- Leontaritis, K. (1997). PARA-Based (Paraffin-Aromatic-Resin-Asphaltene) Reservoir Oil Characterizations. doi:10.2118/37252-MS
- Leontaritis, K. J. (1998). *Asphaltene Near-wellbore Formation Damage Modeling*. Paper presented at the SPE Formation Damage Control Conference, Lafayette, Louisiana. https://doi.org/10.2118/39446-MS
- Leontaritis, K. J. *Asphaltene Near-Wellbore Formation Damage Modeling*. Presentation Slides for AsphWax, Inc