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A COMPUTER PROGRAM TO EVALUATE ASPHALTENE-INDUCED FORMATION DAMAGE AROUND THE NEAR WELLBORE REGION

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ABSTRACT

Asphaltene are organic deposits which are originally in solution or colloidal suspension in the crude oil. Due to changes in the crude oil composition, temperature and pressure, asphaltene precipitates into distinctive solid phase after which it flocculates and deposit on rock surfaces and pores. Asphaltene deposition in the porous media causes damage to the formation. To evaluate formation damage due to asphaltene deposition, a computer program was developed to evaluate parameters such as permeability, porosity, skin factor and pressure within the damage region. Results from the evaluation indicate that asphaltene-induced formation damage is severe at the wellbore and less severe away from the wellbore. Analyzing the profiles generated from computer program for three scenarios; at the wellbore (0.29ft), near the wellbore (1ft) and away from the wellbore (10ft). Results showed that the effect of asphaltene deposition is less severe as the radial distance approaches the radius of asphaltene flocculation. It was observed that for an increasing flow rates asphaltene-induced formation, damage is severe at the wellbore but at reducing flow rates the severity of the damage is low thereby prolonging the production time prior to severe formation damage.

Keywords: asphaltene, formation damage, asphaltene precipitation, asphaltene deposition, excel VBA.

INTRODUCTION

Asphaltene is a complex molecule, polar and non-volatile substance defined to be insoluble in n-alkanes (n-pentane and n-heptane) and soluble in benzene and toluene. Asphaltene are viewed as the highest molecular weight fraction of asphalt. Asphaltene do not crystallize, hence it cannot be separated into individual components. The determination of the molecular weight of asphaltene is difficult to ascertain because of its low solubility in liquid. The molecular weight of petroleum asphaltene ranges from several hundred to several thousand grams per mol.

Factors such as changes in temperature, pressure and composition causes asphaltene to precipitate (Hirshberg *et al*., 1982). The precipitate aggregates or flocculates to form large size asphaltene particles. As a result of the large size, crude oil can no longer support it and thus the asphaltene particles settle out and deposit on solid surfaces (Leontaritis, 1998; Garrouch *et al*., 2005). The deposition of asphaltene particles causes problems such as wellbore plugging, restrictions of flow in tubings, flowlines and production facilities.

PROCESS OF ASPHALTENE PRECIPITATION, FLOCCULATION AND DEPOSITION

The precipitation and deposition of asphaltene is described in three stages:

a) Asphaltene precipitation occurs when the solid particles forms a distinctive phase as they come out of solution. The particles of asphaltene coming out of solution at this stage are small in size.
b) The small particles of asphaltene aggregates or clumps together to form larger size solid particles. This stage is known as the flocculation stage.
c) Due to the large size of the asphaltene particles, the crude oil can no longer support it and thus the particles settle out on solid surfaces. This stage is known as deposition.

Gruesbeck and Collins (1982) divided the porous medium into pluggable and non-pluggable pathways. In their work they presented the porous medium by two continuous branches, of which one branch consists of small pores that have a significant variation in diameter. These pores make up a network of tortuous flow paths that are susceptible to complete plugging. The other branch consists of large pores that make the non-pluggable pathways. These smooth and large diameter flow paths involve surface deposition and considered non-pluggable. Deposition of particles occurs by mechanical entrapment in the pluggable pathways and therefore blocking pore throats when several particles approach narrow flow constrictions. The conductivity of the flow path can diminish, therefore resulting to net permeability reduction. Dead oil is usually used in modeling asphaltene deposition porous media. Ali and Islam (1997) extended the work of Gruesbeck and Collins by incorporating asphaltene and wellbore plugging.

De Pedrosa *et al*. (1995) examined the effect of asphaltene precipitation and deposition on rock properties, using fluids and cores from five different crude oil reservoirs having different asphaltene contents. Precipitation of asphaltene particle was induced by n-pentane injection. Permeability reduction measurement was evaluated by carrying out displacement tests before and after precipitation induction. The mean hydraulic radius of the pore was measured in the test which was used to infer permeability and porosity reduction. It was concluded that the degree of asphaltene deposition in the

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core will lead to the reduction of the core properties (i.e., permeability and porosity).

In the porous medium, it was considered that asphaltene deposition does not take place when the fluid was not flowing through the porous medium (Ring *et al*., 1992). Wang and Civan (2000) and Civan Faruk, (1995) modeled the deposition of paraffin and asphaltene in porous media by considering static and dynamic pore surface deposition and pore throat plugging. In this study, it was revealed that the static surface deposition may occur even without the fluid flowing and dynamic surface deposition is predominant during fluid flow.

Using a mass balance model, Garrouch and Al-Ruhaimani, (2005) formulated a mathematical model capable of predicting permeability reduction caused by asphaltene deposition for both homogenous and heterogeneous formation. Similar to the model developed by (Leontaritis, 1998), the model took into account the effects of rock permeability, fluid composition and pore size distribution (psd). Garrouch and Al-Ruhaimani, (2005) developed a relationship relating asphaltene deposition rate to the primary deposition processes earlier highlighted (pore throat plugging, adsorption and re-entrainment). In the implementation of the model, only the larger aggregated asphaltene particles are considered to deposit on the reservoir rock while the smaller asphaltene particles flows with the oil phase.

Kazeem *et al*. (2011) modeled permeability impairment under dynamic conditions in a porous media as a result of asphaltene deposition. The model which is based on the deep bed filtration theory, investigated the kinetics of asphaltene deposition in a flowing stream. The model is concerned with the pore volume occupied by the deposits, instead of the geometry of the deposit. In the pore a distinctive solid and liquid phase is said to exist which includes the deposited asphaltene, crude oil, asphaltene-free oil (maltenes).

kocabas *et al*. (2000) argued that the adsorption process of asphaltene deposition which led to trapping of asphaltene particles in the pores (pore plugging) is not a continuous process. In their model formulation, they separated the two deposition processes, and thus asphaltene adsorption process was modeled using surface excess theory while the mechanical trapping of asphaltene particles in the pores was modeled using Gruesbeck and Collins theory. The model evaluated the effect of asphaltene deposition in the near wellbore region in terms of permeability and porosity but also investigated the effect of flow rates which was found to greatly facilitate the extent of wellbore formation damage.

Almehaideb, (2004) modeled asphaltene precipitation, deposition and plugging of wellbore during primary production. In the formulation of the model, crude oil with solid asphaltene precipitate was considered, therefore, four phases was modeled (asphaltene-oil-gas-water). The model used a cylindrical form to simulate the direction of fluid flow around the wellbore. The solubility of the crude oil sample (asphaltic UAE crude oil) versus pressure is determined using a gravimetric method, which is used as input data in the simulation process. A typical production well was used for the simulation, results shows how asphaltene precipitation zone developed around the production well as the pressure at the wellbore region declines. A positive skin was reported in the near wellbore region

Near wellbore model formulation

To model asphaltene induced formation damage near the wellbore, it is necessary to know the amount of asphaltene and asphaltene particle size distribution (PSD) which flocculated as the reservoir fluid moves toward the wellbore. The model describes the retainment or filtration of asphaltene particles in the formation pore throat and considers a reservoir system above bubble point (under saturated) without water production.

Formulation procedure

Asphaltene deposition is considered to occur within the near wellbore region, described as $r_w < r < r_{AF}$ where the pressure is below the asphaltene flocculation pressure P_{AF}, r_{AF} is the radius from the wellbore where asphaltene flocculation occurs. Again, within the region of $r_{AF} \leq r \geq r_e$ asphaltene deposition is not a problem. The radius r_{AF} is determined from:

$$r_{AF} = e^{\left[\frac{(P_{AF}-P_{wf})\ln r_e + (P_e-P_{AF})\ln r_w}{(P_e-P_{AF})+(P_{AF}-P_{wf})}\right]} \quad (1)$$

The near wellbore region is divided into radial segment Δr, the formation damage calculation is performed for all segments at each time increment Δt. When the asphaltene particles plugs the formation at a distance r from the centre of the wellbore, the area plugged by asphaltene particle at location r at time t is given as A(r,t). AP_{trap} is the number of moles of asphaltene particles trapped at location r at time t, given by AP_{trap} (r, t). To calculate A(r, t), AP_{trap} (r, t) is calculated first. Considering a section in the region $r_w < r < r_{AF}$ at a given time t and location r. ΔAP_{trap} is the incremental moles of asphaltene particles trapped at location r at time t within the time interval Δr and ΔA(r, t) is the incremental area plugged. Hence, the calculation is carried out over each Δr segment for a time increment of Δt, consecutively.

$$AP_{trap}(r, j) = S(r, j)\, f_{trap}(r, j)\, M_{RF}(r, j) \quad (2)$$

The total number of moles of asphaltene particles that has been trapped at location r at time t,

Where $t = j^*\Delta t$ and j is the jth time increment

$$AP_{trap}(r,t) = \sum_{j=1}^{N}[\Delta AP(r,j)] = \sum_{j=1}^{N}[S(r,j) f_{trap}(r,j) M_{RF}(r,j)] \quad (3)$$

Hydraulic diametre (d_H)

The mean hydraulic diametre is defined by the ratio of the total pore volume to total surface area of the flow channel. Hydraulic diametre can be represented in

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terms of hydraulic radius ($d_H = 2r_H$). According to the rule-of-thumb of filtration theory, a filter retains asphaltene particles with diametre 1/3 of the nominal rating of the filter.

$$d_{AP} = \frac{1}{3} d_H \quad (4)$$

The fraction of asphaltene particle deposited at the pore throat is given as:

$$f_{trap} = \int_{d_{AP}}^{\infty} f(d_{AP})\, dd_{AP} \quad (5)$$

Before any asphaltene plugging, the total area available to flow at a distance r from the centre of the wellbore is given by:

$$A_{initial}(r) = 2\pi r h \emptyset_i \quad (6)$$

The total area plugged at location r at time t

$$A(r,t) = \sum_{j=1}^{N} \left[S(r,j) Ftrap(r,j) M_{RF}(r,j) v_A(r,j) \frac{6}{d_H} \gamma \right] \quad (7)$$

Where β is the empirical factor accounting for the plugging by asphaltene particles, the value of β is between 0 and 1.0.

$$\gamma = \frac{6\beta}{\alpha}$$

The net area available to flow at location r, after asphaltene plugging for time t is given by:

$$A_{net}(r,t) = A_{initial}(r) - A(r,t) \quad (8)$$

Damage permeability

$$K_{dam}(r,t) = K_{initial} \left(1 - \frac{A(r,t)}{A_{initial}(r)} \right) \quad (9)$$

Damage porosity

$$\emptyset_{dam}(r,t) = \emptyset_i \left(1 - \frac{A(r,t)}{A_{initial}(r)} \right) \quad (10)$$

The pressure profile prior to damage from r_w to r_e is calculated by

$$P(r) = P_{wf} + \frac{qu}{7.08x10^{-3}} \frac{\ln r_e}{r_w} \quad (11)$$

The productivity index ratio is calculated by

$$\alpha = \frac{PI}{PI_o} \quad (12)$$

Using the area plugged by asphaltene deposition and the total area open to flow at given radius r, the productivity ratio is defined by

$$\alpha = \left(1 - \frac{A(r,t)}{A_{initial}(r)} \right)^2 \quad (13)$$

Flowing bottomhole pressure and pressure at radius, r

The flowing bottomhole pressure is determined at constant oil production

$$P_{wf}(t) = P_e - \frac{q}{PI} \quad (14)$$

Total local pressure loss by damage at constant oil production rate is given by

$$P_o = P_e - P(r) \quad (15)$$

$$\Delta P = \frac{\Delta P_o}{\alpha} \quad (16)$$

The instantaneous local pressure is calculated by

$$P = P_e - \Delta P \quad (17)$$

The instantaneous local pressure is used to determine pressure values beyond the wellbore and to create pressure profile for the region $r_w < r < r_{AF}$ affected by asphaltene deposition.

Numerical solution approach is used to solve the formation damage model, the most important step is to solve equation (7) numerically by dividing the region $r_w < r < r_{AF}$ into equal segments and calculating the area plugged by asphaltene deposition numerically over time increment Δt.

Skin factor

Skin is defined as the additional resistance to flow that reduces the capacity of the production in oil wells (Van Everdingen, 1953). The additional pressure drop due to skin (ΔP_{skin}) is the difference between the actual pressure in the well when it is flowing and the ideal pressure. The term skin factor (S) is used to quantify the magnitude of skin effect.

$$\Delta P_{skin} = \left(\frac{q\mu}{2\pi kh} \right) S \quad (20)$$

$$\Delta P_{skin} = P_{wf}(t) - P_{wf}(t=0) \quad (21)$$

Excel visual basic for application (Excel VBA)

Visual Basic for Application (VBA) uses the same syntax as Microsoft Visual Basic Programming Language. VBA has the features that allow programmer and user to work with familiar Microsoft Excel environment such as workbook, worksheet, cells and charts (Bernard, 2009; Joseph Billo, 2007). VBA is used

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to develop the program which solves the numerical equation for evaluating the formation damage as a result of asphaltene deposition in the near wellbore region.

Input data

Table-1. Well and formation data used for simulation.

Well/Formation data	
Reservoir Pressure, psia	8500
Reservoir Temperature, °F	220
Production rate, reservoir bpd	3000
Flowing Bottomhole Pressure, psia	7105
Asphaltene Onset Pressure, psia	7786
Well Productivity index, res bbl/day/psi	2.15
Formation Permeability, md	100
Porosity, fraction	0.25
Asphaltene particle diametre retained, μm	0.26

Table-2. Well and fluid data used for simulation.

Well/fluid data	
Well drainage radius, ft	1044
Wellbore radius, ft	0.29
Thickness, ft	50
Fluid density, lb/cuft	50
Viscosity, cp	2.0105
Molecular weight, lb/lb.mol	500

RESULTS AND DISCUSSIONS

To evaluate the severity of formation damage at the wellbore and away from the wellbore, the reduction in permeability, porosity and increase in skin factor as a result of asphaltene deposition is presented in Figures 1, 2, 3 and 4. The profiles are evaluated for production time 0, 24, 120, 720 and 1200 hours at constant production rate of 3000 barrel per day. The results shows that at the wellbore (r = 0.29ft) severe asphaltene deposition occurs and the reduction in permeability, porosity and the wellbore pressure are significantly reduced. At a radius (r = 1ft) near the wellbore region, formation damage occurs as a result of asphaltene deposition and at a radius of (r = 10ft) the formation damage is less severe and close to the initial conditions of rock properties.

To study the effect of flow rate on asphaltene deposition, a case study of three scenarios consisting of varying constant production flow rate 4000 bpd, 3000 bpd and 2000 bpd (Figures 5, 6 and 7). When asphaltene particles drop out of solution, it flocculates into large size which are carried along with crude oil and deposited in the pore spaces, the continues deposition causes the pores to become plugged. Hence, the rate of deposition of asphaltene particles is depended on the flow rate at which the asphaltene particles are transported. The higher the flow rate, the faster the rate of deposition of asphaltene in the pore spaces and the faster the plugging of the pore spaces. In contrast, the lower the flow rate, the lower the rate of deposition of asphaltene in the pore spaces which leads to low plugging of formation pores.

CONCLUSIONS

To evaluate formation damage in the wellbore as a result of asphaltene deposition, a computer program is developed using Excel Visual Basic for Application. The following conclusions can be made based on the result from the evaluation:

a) Parameters such as permeability, porosity and skin factor evaluated indicates that formation damage due to asphaltene deposition is severe at and around the wellbore.
b) Away from the wellbore, formation damage as a result of asphaltene deposition is less severe based on the result from computer program evaluation.
c) Reducing the flow rate results to reduction in the severity of the damage, this is due to low asphaltene deposition is the pore spaces at reduced flow rates.
d) Reducing flow rate results to extending the production life and reducing the pressure drop at the wellbore.

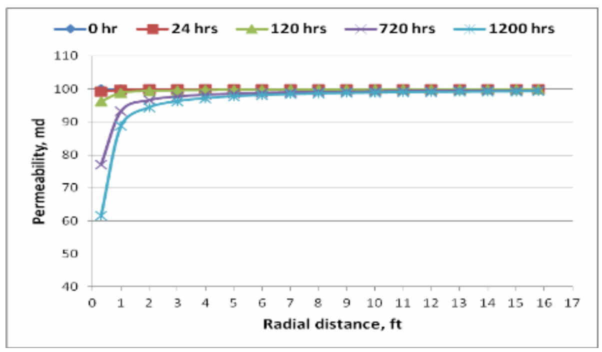

Figure-1. Permeability profile in the asphaltene damaged region.

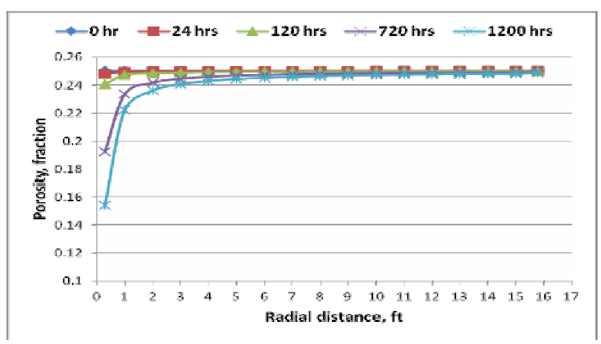

Figure-2. Porosity profile in the asphaltene damaged region.

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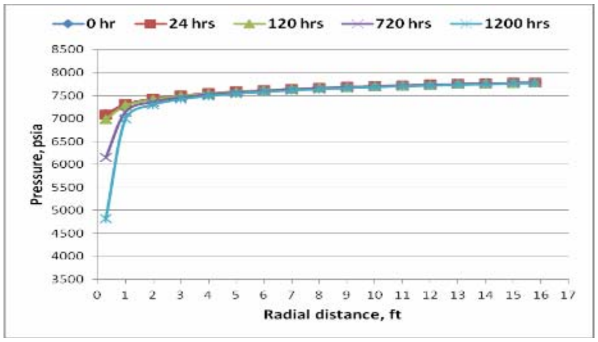

Figure-3. Pressure profile in the asphaltene damaged region.

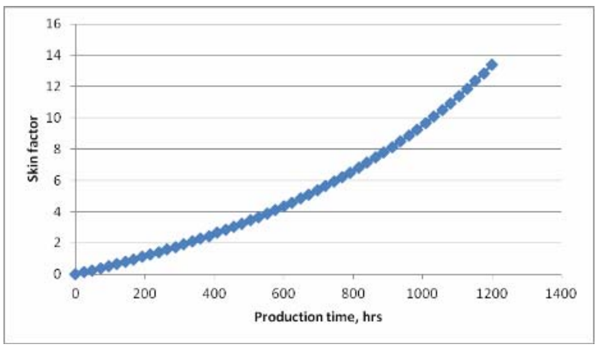

Figure-4. Skin factor for production from 0 to 1200 hrs at constant production rate.

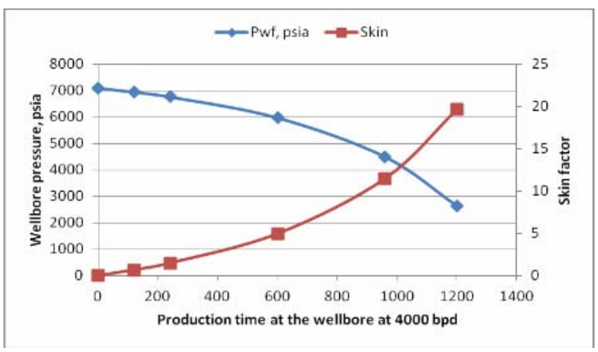

Figure-5. Wellbore and skin factor against production time at 4000 bpd.

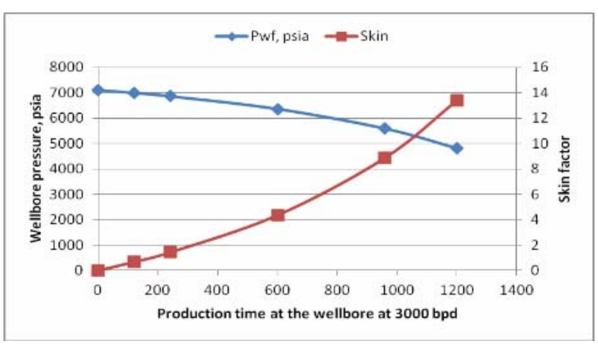

Figure-6. Wellbore and skin factor against production time at 3000 bpd.

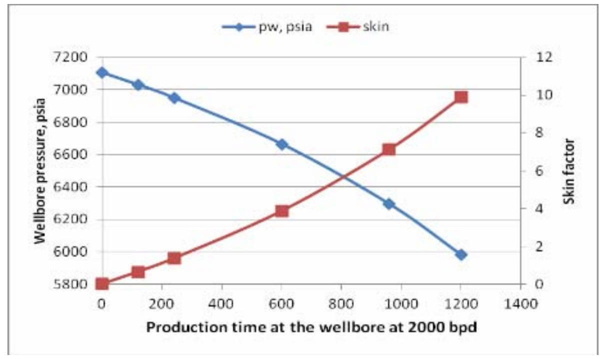

Figure-7. Wellbore and skin factor against production time at 2000 bpd.

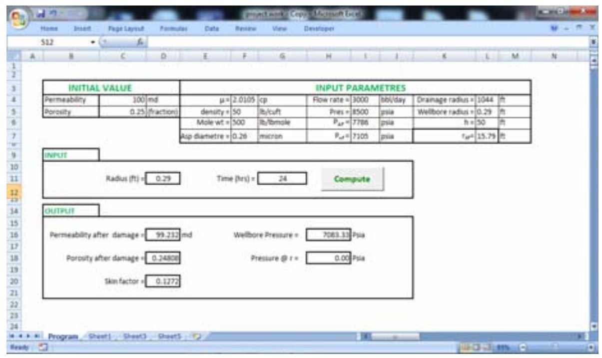

Figure-8. Program interface.

Nomenclature

r_e	reservoir external radius
r_w	wellbore radius
h	reservoir thickness
μ	viscosity
$K_{initial}$	initial permeability
K_{dam}	permeability in the damage zone
$Ø_i$	initial porosity
$Ø_{dam}$	porosity in the damage zone
MW_f	crude molecular weight
S_i	number of asphaltene particles per mole of reservoir fluid
A(r,t)	area of asphaltene plugged
d_{AP}	diameter of smallest asphaltene retained
d_H	hydraulic diametre
f_{trap}	fraction of asphaltene particles
v_a	molar volume
A_i	area open to flow
PI	productivity index
A	productivity index ratio
γ	plugging efficiency (from 0 to 1)
S	skin factor

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