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Original Research

Modeling and simulation examining of the asphaltene deposition in field scales during natural depletion

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ABSTRACT:

Asphaltene deposition is one of the most important and complicated problems in the process of oil production. Asphaltene deposition on the source rock is considered as a formation damage that can cause a problem for production. The asphaltene deposition can take place in the down and up well equipment, reservoir formation, and even transmission lines. One of the most important mechanisms of asphaltene deposition is the pressure drop. In this analysis, the expected PVT model of oil was prepared by Wiprop and PVTi. After that, the dynamic model of the storage was created in the simulation of GEM and ECLIPSE 300 combination. Dynamic compositional simulator of asphaltene deposition in porous medium consists of the flow of suspended solid particles in the oil phase. Deposition of asphaltene particles is the result of the process of absorption, detachment and trapping of asphaltene in holes. Sensitivity was conducted in the parameter of asphaltene deposition and permeability damage. It was shown that the rate of deposition will increase following the increase of adsorption and plugging coefficient. The production rate was examined in addition to the above cases. The result showed that increase of production rate provides the condition for faster asphaltene deposition on the reservoir rock. Permeability damage was examined as a result of asphaltene deposition on the reservoir rock and the effect of production rate. The results showed that the rate of permeability damage in different operations will increase.

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Asphaltene, Natural depletion, Simulation.

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INTRODUCTION

Asphaltene which is known as the heaviest and most polar in the oil composition is an aromatic complex molecule that is unsolvable in the light alkanes and solvable in toluene and benzene. The asphaltene deposition in oil reservoirs is a complex issue at the stage of primary production and using the methods of excess extracting of the oil that most of the oil areas face (Wang and Civan, 2001). Asphaltene deposition can lead to obstruction of the gap in the formation around the well and well equipment. This phenomenon in oil reservoirs decreases the permeability, changes the wettability of porous medium, and decreases oil production from oil well (Leontaritis, 1998). The first condition of reservoir changed during the natural depletion. Asphaltene may be created during the life of reservoir based on the condition of reservoir in term of composition, production mechanism, temperature, and etc. (Nghiem and Coombe, 1997). Formation and deposition of asphaltene is dependent on the pressure, permeability of reservoir, production rate of well, density of asphaltene in oil, properties of oil, and gas injection rate (Ali and Islam, 1998).

The main factor of the formation of solid asphaltene is the drop pressure. Solid particles of asphaltene in oil are formed when the pressure of reservoir reaches to a lesser extent of forming (over the bubble pressure). Decrease in pressure will increase the rate of formation of these particles. We have the maximum extend of the formed asphaltene at the pressure close to the bubble pressure. Below the saturated pressure, more decrease of the pressure and approaching the solubility of asphaltene and oil will increase the solubility in oil and also decreases the asphaltene formation (Nghiem *et al*., 1998).

The formation of asphaltene deposition is mainly dependent on the amount of compatibility of light and heavy parts (such as resins, asphaltene, and unsaturated oils). The existence of paraffin hydrocarbons with low molecular mass in oil will increase the formation of asphaltene. This issue is because of the full dissolution of some of the resins and saturated compounds (that are stabilizer factors) in the existence of hydrocarbons. It is expected that the release of light parts from oil (when pressure is less than bubble point pressure) decreases the tendency of asphaltene to agglomeration. In other word, the formation of asphaltene takes place generally in single-phase oil and over the bubble point. The volume fraction of light parts in supersaturated oils will increase by approaching the pressure to the bubble point. Increasing hydrocarbons with low molecular mass will form asphaltene in oil. System's pressure is decreased to isothermal, partial molar volume and compressibility of molecules (like methane). It changes significantly as compared to Pentane, while this change is less for C_7-C_{12}. It is expected that heavier oil part (resins and asphaltene) has less molar volume change with a decrease of pressure in that temperature. It was determined that the maximum amount of asphaltene formation takes place close to the bubble point of crude supersaturated oils. Light hydrocarbons exit in the form of gas below the bubble point. This process will increase the density of liquid phase (formation of the liquid phase is also changed). Light remaining components will cause better solubility of asphaltene in crude oil (Kabir and Jamaluddin, 2002).

The traditional method for removing asphaltene deposition consists of chemical, mechanical, and thermal methods that are too expensive and without efficiency; therefore preventing asphaltene deposition formation is the best way for confronting this problem. The mechanism of asphaltene deposition and its effective parameters need to be revealed in order to achieve an acceptable prevention strategy. Thus, doing various simulations of natural depletion are essential. These stimulations will provide the ways for preventing, delaying, and better perception about the asphaltene deposition in a porous medium. This survey examines

the modeling and simulation examining of the asphaltene deposition in the field scale during natural depletion (Peramanu *et al*., 1999).

Models of asphaltene depositions

Minssieux was the first person who performed the asphaltene deposition experiment on the porous medium. He used some natural cores with different permeability and passed some dead oil with various amounts of asphaltene from them. Results of his research are still used in testing the various modeling results (Minssieux, 1997). Experiments on asphaltene have been concerned for a long time, but modeling this deposit in a porous medium is concerned recently (Minssieux, 1997). Civan was the first person who modeled the simultaneous deposit of asphaltene and paraffin in the porous medium by the advanced formula of the parallel path (Civan and Knapp, 1987).

Nghiem *et al*. (2000), following the work of Ali and Islam (1998) in used adsorption formation and mechanical entrapment for modeling asphaltene deposition in a porous medium. They said that adsorption of asphaltene on the surface of rock is the first step in asphaltene deposition. They model the asphaltene adsorption to an isotherm Langmuir adsorption based on the experimental works of Collins (1942), Dubey and Waxman (1991), Gonzalez and Travalloni-Louvisse, (1993) and Nghiem *et al.* (2000) used simplified equation related to Gruesbeck and Collins (1982) for the expression of mechanical entrapment.

The effective damages on the formation depend on the common reaction between the particles, liquid storage, and porous medium. Formation of damage in the oil reservoirs takes place in the compound as a result of a series of complex processes. Most models consider one-phase flow. These models assume the mechanisms of damage formation such as the mobility, particles migration and remaining of the particles in a porous medium. Based on the laboratory results, three mechanisms can take place during the flow in the porous

Table 1. Fluid compounds on storage

Components	Residual oil	Gas	Recombined oil
	(Moll %)	(Moll %)	(Moll %)
H_2S	0.00	0.00	0.00
N_2	0.00	0.91	0.39
CO_2	0.00	4.10	1.74
C_1	0.00	48.38	20.55
C_2	0.00	17.22	7.31
C_3	0.10	12.43	5.34
iC_4	0.13	2.17	1.00
nC_4	1.67	6.34	3.65
iC_5	3.85	2.10	3.10
nC_5	6.44	2.45	4.75
C_6	7.73	2.44	5.48
C_7	4.82	1.07	3.23
C_8	2.03	0.36	1.32
C_9	3.93	0.03	2.27
C_{10}	3.80	0.00	2.19
C_{11}	3.15	0.00	1.81
$C_{12}+$	62.35	0.00	35.87
Total	100.00	100.00	100.00
Molecular weight of the residual oil			269
Molecular weight of C_{12}^+ fraction			370
Molecular weight of the reservoir oil			169
Sp.Gr. of C_{12}^+ fraction @ 60/60 ^oF			0.9769

Table 2. Fluid compound used in simulation

S. No	Component	Molecular weight	Mole fraction
1	CO_2	44.01	1.74
2	N_2 to CH_4	16.26	20.94
3	C_2H to C_3H	35.99	12.65
4	IC_4 to NC_5	66.93	12.50
5	C_6 to C_8	91.98	10.03
6	C_9 to C_{11}	133.04	6.27
7	C_{12} to C_{31}	285.01	28.64
8	C_{36}^+	706.62	4.20
9	Asph	706.62	3.03

medium: Surface adsorption, plugging coefficient, entrainment coefficient (Roque *et al*., 1995).

MATERIALS AND METHODS

This study concerns the determination of important parameters in simulation. Eclipse and CMG were used to achieve this aim. The process of simulation is performed by the compositional method.

PVTi and Winprop were used to simulate the behavior of the combined oil. Characteristics of reservoir fluid of a well bottom hole sample were used for building the fluid model. The data of the reservoir fluids obtained from differential liberation expansion, constant composition expansion and separation. The expected data consist of asphaltene. The solid model was used for deposition modeling. Peng and Robinson equation of the state were used to create PVT model. The data of the fluid component can be seen in Table 2.

RESULTS

We expand the oil compound up to C_{36}^+ in order to simplify the model and simulate the asphaltene part in PVT model. For doing this, the C_{12}^+ is divided into two parts that one of these parts which is the heaviest part of (C_{36}^+) is considered as a part in which the asphaltene exists. Some of the light parts are placed in a group in order to reduce the time of simulation in a dynamic model. The results of the group are mentioned in Table 1.

Results showed that the model has a good conformity with the PVT data of reservoir fluid. State equation of PR was adjusted with a proper accuracy for simulating the fluid storage. Its output is usable in simulating the dynamic storage (Table 3).

Asphaltene behaviour simulation by the Winprop Software

As Nghiem *et al.* (2000) reported, asphaltene precipitation is considered to be a pure solid. In the liquid model, the heaviest composition is divided into two precipitating (Asph) and none precipitating (C_{36}^+)[9] compositions. These compositions have the acentric factor properties and identical critical properties, but they

Table 3. The summary of modeling and the results of PVT experiment

S. No	Specification	QTY
1	Solution GOR(SCF/STB)	361.7
2	Reservoir Pressure (Psi)	4757
3	reservoir temperature (°F)	205
4	Saturation Pressureat 205°F (Psia)	1500
5	Oil Gravity of Residual Oil (°API)	20.37
6	Oil viscosity (cp)	1.689845
7	Oil Density @ Saturation pressure (g/cc)	0.7955
8	Density of Total Gas evolved (g/lit)	1.5136
9	Formation Volume Factor @ Sat. Pressure (Bbl/Bbl)	1.2927
10	Asphaltene content (wt%)	12.9
11	Oil in place	$1.11842^{9+}10$

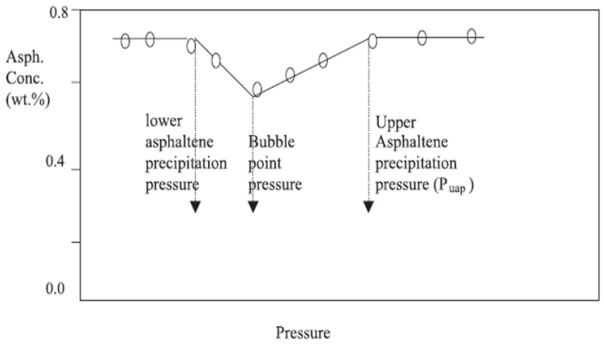

Figure 1. The scheme of changing the procedure of asphaltene deposition on the basis of pressure decrease of reservoir (14)

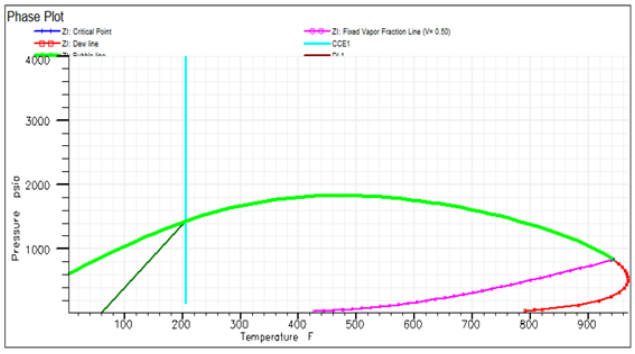

Figure 2. Determination of fluid phase behaviour

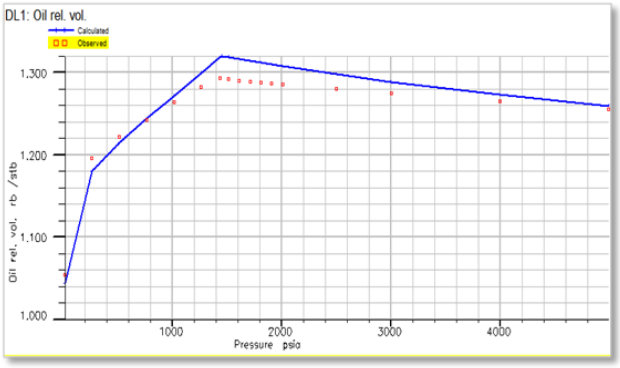

Figure 3. Volume factor of formation in PVTi expansion test

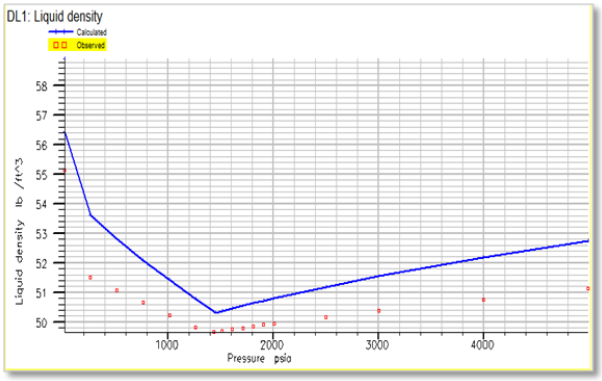

Figure 4. Determination of fluid density (PVTi)

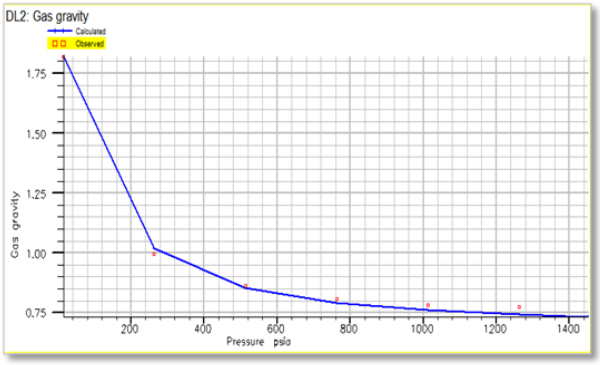

Figure 5. Determination of gas gravity (PVTi)

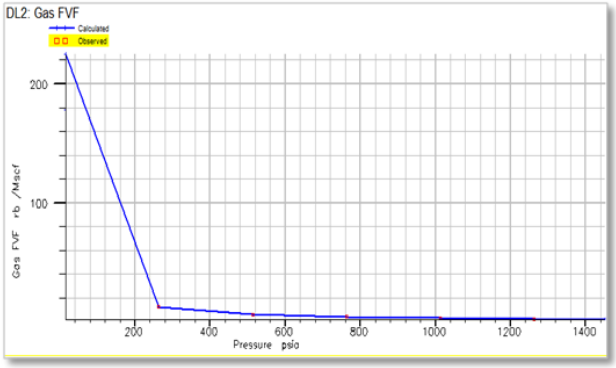

Figure 6. Determination of gas FVF (PVTi)

have different parameters of binary interaction coefficient.

The molar component of the asphaltene is calculated by the following formula:

1) $x_{Asph}Mw_{Asph} = Wt_{Asph}Mw_{Oil}$

where, x_{Asp}= Molar fraction of the asphaltene, Mw_{Asph} = Molecular weight of the asphaltene, W_{Asph} =Weight percent of the asphaltene, Mw_{Oil}= Molecular weight of the oil. Molar percent of the asephaltene is calculated with regard to the measurement of the rate of 12.8 % weight of the asepaltene within the oil and according to the equation (3-5) and equals to: 2.87%.

Participation of the asphaltene can be returned into the system and be solved into the oil by more drop pressure and under the pressure of bubbles by releasing gas from the oil. The parameters that control the behavior of asephaltene at the solid model are the solid

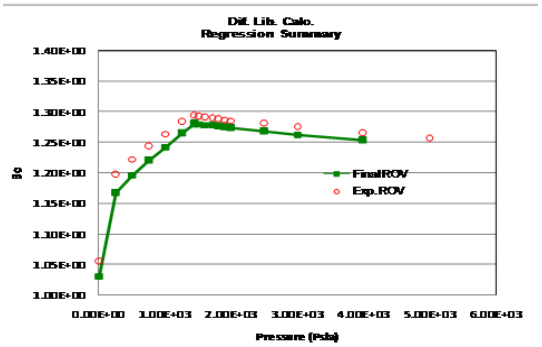

Figure 7. Determination of volume factor of the formation

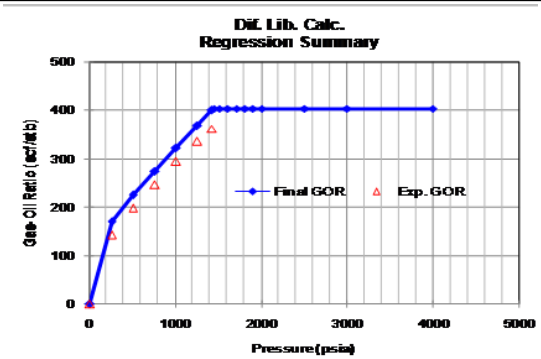

Figure 8. Determination of ratio of gas to oil

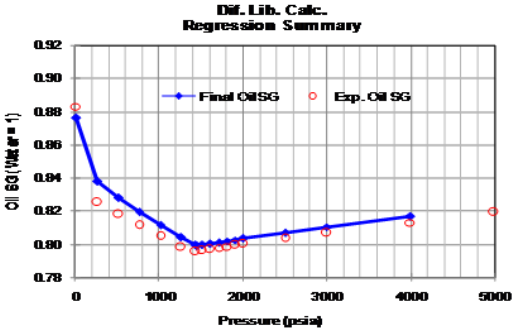

Figure 9. Determination of density of oil (Winprop)

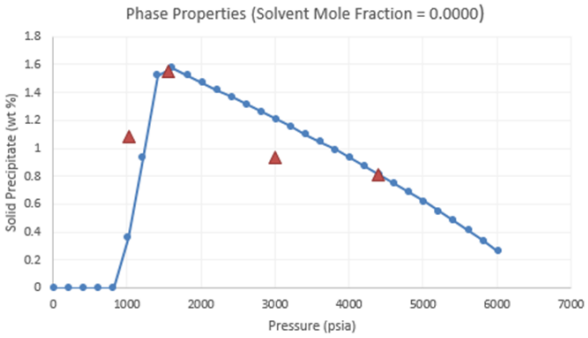

Figure 10. Asphaltene behaviour by pressure drop

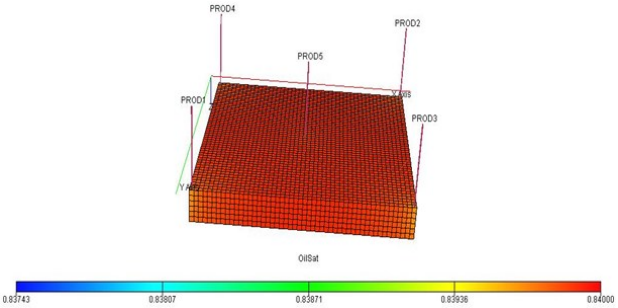

Figure 11. Three dimensional compositional model

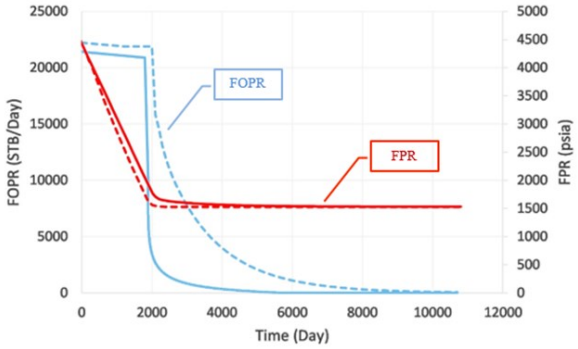

Figure 12. The flow rate of the produced oil, the process of pressure reduction and the effect of asphaltene precipitation on the flow rate of the production and drop of the pressure in the storage (CMG)

molar volume (V_s) [12] and parameters of the interactions among the precipitated compositions and the light compositions of oil, in a way that, increase in the solid molar volume leads to the increase in maximum precipitation rate in the saturated pressure. Increasing the interaction parameters with lighter compositions makes the asphaltene to return to the solution phase and it will be maintained to lower pressures.

Simulation model for the asphaltene precipitation experiment during natural depletion

The reservoir is under saturated conditions and produced by rock and fluid expansion mechanisms.

Initial reservoir condition assuming the primary pressure 4757 psia, with 205 F temperature, 20.37 API and 19% initial water saturation.

In order to study the effect of asphaltene precipitation on the model, athree dimensional compositional model with the dimensions of 50×50×6 were built. The reservoir model in this study had some characteristics such as: DX=300, DY-300, DZ-30; there

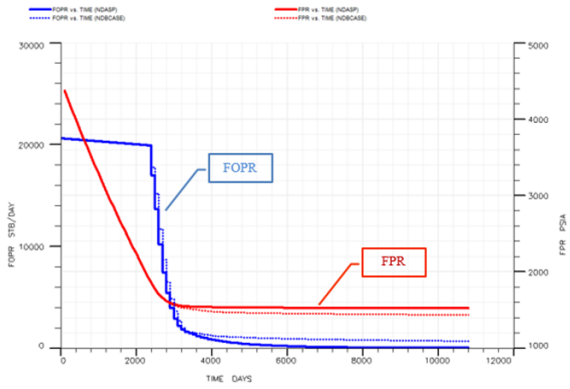

Figure 13. The flow rate of the produced oil, the process of pressure reduction and the effect of asphaltene precipitation on the flow rate of the production and pressure drop in the storage (E300)

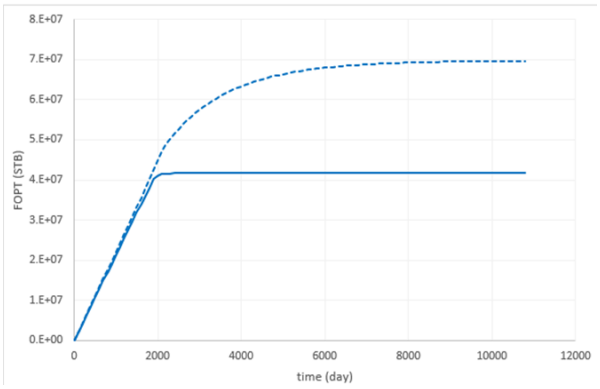

Figure 14. The cumulative production of the oil and the effect of the asphaltene precipitation on the cumulative production (CMG)

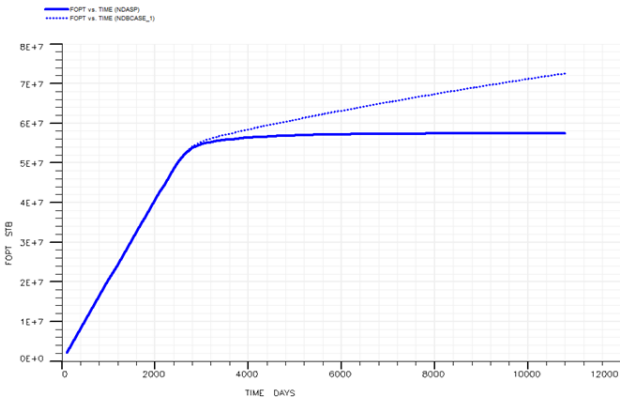

Figure 15. The cumulative production of the oil and the effect of asphaltene precipitation on the cumulative production (E300)

are 5 production wells in (1,1), (1,50), (25,25), (50,1), (50,50) grid blocks. All the five production wells are perforated with k=1 up to k=6.

In this research, the outflow of the oil production is considered to be 22000 barrel per dayand the maximum of the well pressure for the production is limited to be 1500 psia. In order to make a comparison, this sector of the field was investigated without considering the asphaltene. Daily oil production, storage pressure and storage of the produced oil are shown at Figures 12, 13, 14 and 15. All figures that are shown in the continuous lines are used to show the asphaltene presence in the experiment, and broken lines show other cases without the presence of asphaltene.

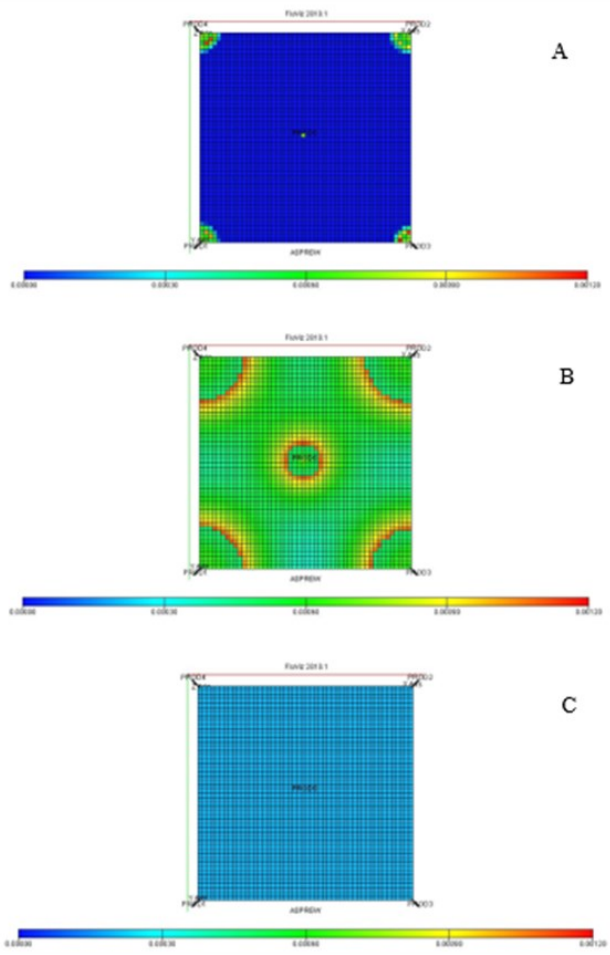

Figure 16. A) Distribution of the asphaltene precipitation in the model at early stages of the simulation B) Distribution of the asphaltene at the middle time steps C) Precipitation distribution at the end of the stages.

The charts shown in Figures 12, 13, 14, and 15 indicate that the maximum amount of production will

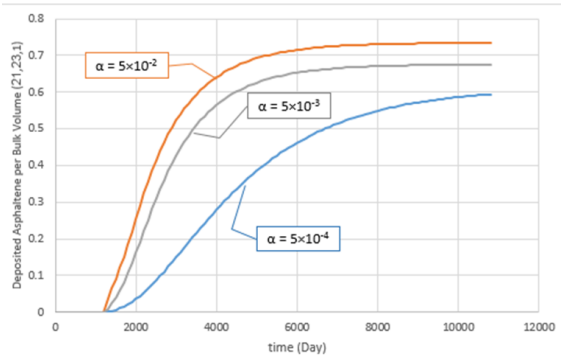

Figure 17. The effect of surface adsorption on the asphaltene deposition

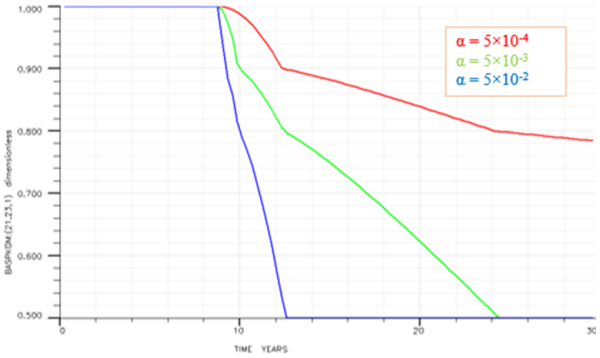

Figure 18. The effect of surface adsorption on the permeability damage.

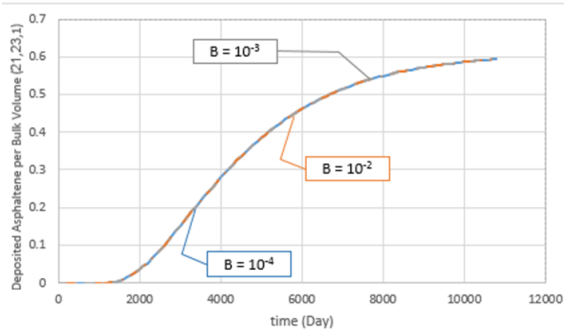

Figure 19. The effect of asphaltene plugging coefficient on the asphaltene deposition

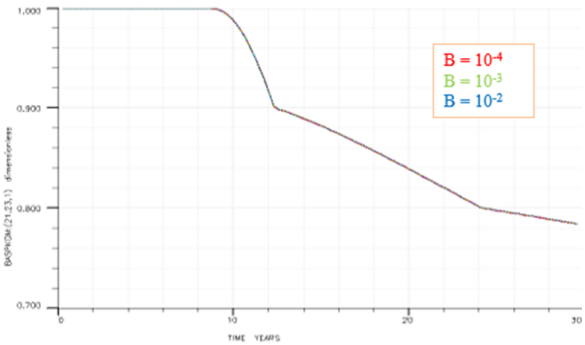

Figure 20. The effect of asphaltene plugging coefficient on the permeability damage

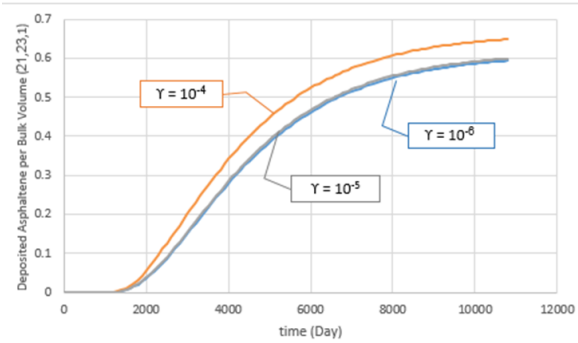

Figure 21. The effect of entrainment coefficient effect on asphaltene deposition

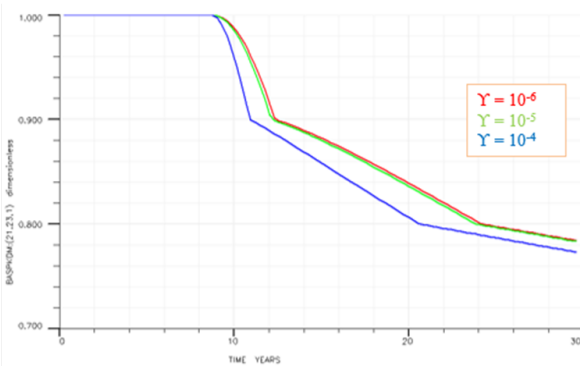

Figure 22. The effect of entrainment coefficient on permeability damage

decrease within seven years and the sector production will be stopped less than eight years. The main reason for ending the production is the pressure drop at the oil field. The pressure of the field will be less than 1500 pam after eight years; therefore, the production will not be possible any longer. It can be observed that when the asphaltene precipitation is formed, the flow rate of the oil is less than the time when no asphaltene is formed, so the accumulation of oil is decreased. This is due to the destruction that asphaltene precipitation mechanism sustains to the structure.

We used both E300 and CMG softwares in order to draw the daily oil production charts, reservoir pressure and cumulative oil production. Both soft wares present the processes. This is due to the differences between the two softwares at the various stages of simulation including data preparation, setting the parameters and

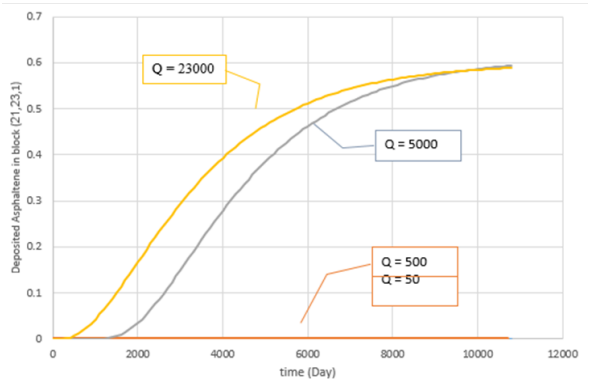

Figure 23. The effect of the different flow rates on asphaltene deposition

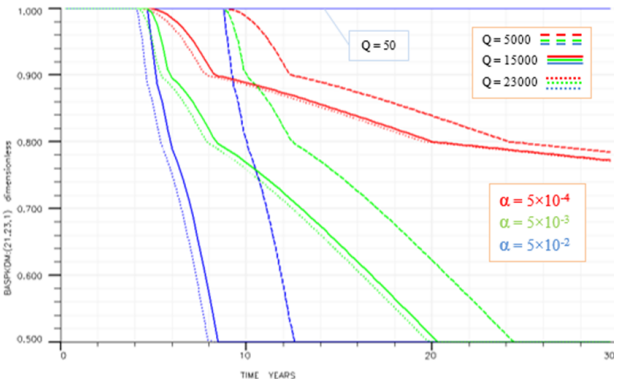

Figure 24. The effect of flow rate on the surface adsorption coefficient and permeability damage

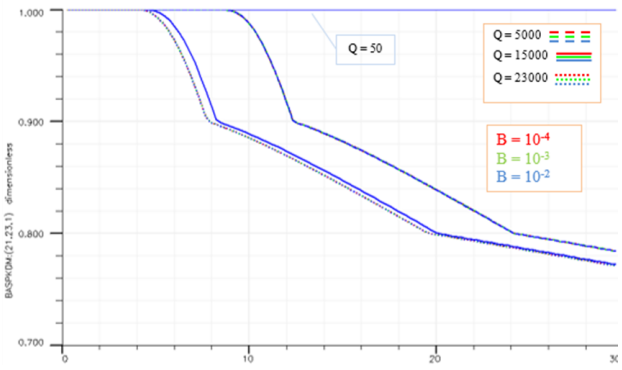

Figure 25. The effect of flow rate on the plugging coefficient and permeability damage

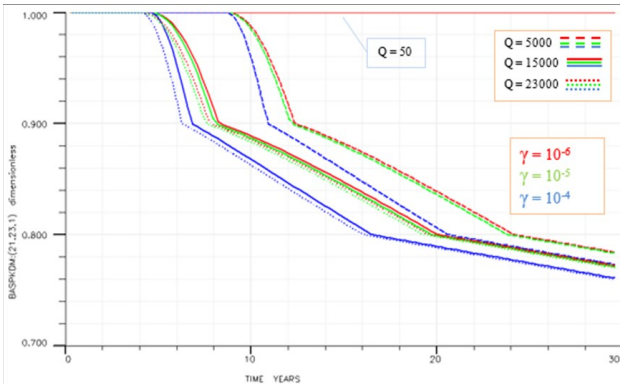

Figure 26. The effect of flow rate on entrainment coefficient and permeability damage

setting various operational conditions on each one of them.

Prediction of the preposition distribution and asphaltene deposition during the processes are shown in Figure 16 by the simulator. The more we approach to the location of wells we see that the number of the above mentioned cases increases and permeability destruction and obstruction rate increase as well. That's because, the pressure drop around the production wells are drastically felt.

Sensitivity analysis

Deposition of the asphaltene in the porous material is mainly based on the researches carried out by Wang and Civan, (2001) in which three major phenomena of the depositions, namely, surface adsorption, trapping and plugging and entrainment of the asphaltene particles explain the rate of the deposited asphalteene in the porous and fractured space. These three processes control the amount of precipitated asphaltene by the three parameters of α, β and γ.

In this section, we will discuss the effect of the asphaltene parameters on the asphaltene deposition and permeability damage. The effect of the production rate along with the above-mentioned cases will be discussed (Table 4).

The effect of the surface adsorption (α^{13})

The results obtained from performing three simulators with different alpha on the asphaltene deposition and permeability damage are shown in Figures 18 and 19. Increasing the alpha rate will lead to the increase in precipitation. Alpha is defined as a criterion for the surface adsorption of asphaltene on the reservoir rocks, so the higher rate of alpha makes the asphaltene go out of the deposition phase and then be deposited, so the rate of deposition is increased. According to the said argument, when the rate of alpha

Table 4. The effect of asphaltene parameters

Surface adsorption coefficient (α)	Plugging coefficient (ϒ)	Entrainment coefficient (B)	Critical velocity of the asphaltene entrainment (U_{cr})
2500	10^{-4}	$^{-}10^{-6}$	5×10^{-4}

increases, the rate of deposition will be also increased (Figure 18).

The increase in the deposition rate leads to the reduction in permeability. Asphaltene deposition will fully block some of the voids and limit others. So the available space decreases, and the permeability damage increases.

The effect of plugging coefficient of the asphaltene (β)

The plugging coefficient of the asphaltene can be effective, only when the speed is equal to the critical speed and the materials can be carried along. So, when β increases, more asphaltene is plugged from the storage and is suspended within the system. Then it will decrease the deposition and permeability damage. In this case, the reduction of the production flow rates will have no remarkable effect on the damage sustained by the permeability reduction and asphaltene deposition. That's because beta doesn't have tangible effect and the speed of the process is less than critical speed and materials are not carried along in a remarkable extent. These results are shown in the Figures 20 and 21.

The effect of entrainment effect (γ)

Following the increase of Gamma, deposition and precipitation rate also increase. Gamma is a criterion for entrainment potential of the asphaltene particles. The increase in the deposition leads to the increase in permeability damage and decrease in permeability. Asphaltene deposition fully blocks some of the voids and cavities and limits some others, so, the available space decreases.

The effect of the flow rate

As Figure 23 shows, when the production of flow rate increases, it prepares the conditions for asphaltene deposition on the reservoir rock earlier.

In the following figures, Figures 24 and 25 show the proportion of changes of α, β and γ to the permeability damage at different flow rates. Generally, when α, β and γ changes, the permeability damage increases, but changes at the β will not have remarkable effect on the permeability damage. When we compare three charts, we come to this conclusion that the increase in flow rate leads to the increase in permeability damage which is caused by asphaltene deposition on the reservoir rocks.

CONCLUSION

Simulation of the asphaltene deposition is so complicated. Although the presented theory of this field is applied by the commercial software, due to the high number of the parameters and deposition mechanisms, we should take utmost care on predicting a conclusion about the location of deposition and the amount of sustained losses. Simulation is carried out based on pre-suppositions about the validity of the deposition coefficient and by changing the permeability reduction coefficient and viscosity. Pressure drop of the simulation and experiment is within an acceptable limit.

By reviewing the research, we come to the following conclusion:

1. The precipitation triangle of the asphaltene is highly sensitive to two parameters of molar volume and binary interaction coefficient among the light compositions which are above C_6 and heavy compositions.
2. The prediction of the precipitation distribution during the simulation period shows that when we approach to the location of wells, the amount of the asphaltene precipitation increases that is due to higher pressure drop around the production wells.

3. Natural depletion simulations which were done show that surface adsorption and entrainment mechanisms were active at the same time.

4. In the surface adsorption mechanism, when alpha increases, the deposition increases too, accordingly, the damage sustained by the permeability damage reduction increases.

5. At the entrainment mechanism, when gamma increases, it causes the deposition arte to increase and then when deposition increases, permeability decreases and permeability damage increases.

6. With regard to natural depletion simulations which were carried out, surface adsorption has more effect on the permeability damage than entrainment.

7. At the process of natural depletion, when the rate of well production increases, the damages incurred to the formation by adsorption mechanisms, entrainment and deposition and as a whole the amount of formation damage increase.

8. After comparing the results obtained from the two soft - wares of CMG and ECIPSE 300, we found that CMG is a better software for the simulation of asphaltene deposition. This is due to the differences of the two soft wares at the various stages of simulation including data preparation, parameter regulation and setting various operational conditions.

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