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Original Research

Experimental and simulation investigation of enhanced oil recovery and asphaltene deposition using gas injection technology

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ABSTRACT:

The most important issue is the right management of hydrocarbon reservoirs, and knowing the effects of different factors related to the amount of oil recovery. The formation of asphaltene deposition in oil reservoirs has been always a big problem. The studies showed that the causes of lack of permeability in the reservoirs, closing shaft, main pipes, line pipes, and refinery's equipment, permeability and wettability alteration of reservoirs rock which lead to reduction of oil products, are related to some factors such as: asphaltene precipitation in reservoirs, wells and wellhead equipment's because of low pressure and injection of light hydrocarbon liquids. It is necessary to measure the effective parameters in the formation of asphaltene precipitation in order to prevent the sedimentation of asphaltene. The effects of injection of carbon dioxide on the formation of asphaltene have been studied in this research. At the first step, PVT model is prepared by Windrop and PVTI. Then, the dynamic model of the reservoir was made by GEM and Eclipse 300 simulators. The sensitivity analysis on the asphaltene deposition and permeability was also analyzed. It is concluded that the most important factor in the modeling of permeability was the level of gas injection. Furthermore, the effects of production rate have been investigated. Findings illustrated that in the 23000 flow rate, the amount of deposition was 0.008 and in the 5000 flow rate it was 0.001. All these findings happened 14 years after production. The process of asphaltene deposition on the reservoir was better after some promotion in flow rate production.

Keywords:

Asphaltene deposition, Permeability reduction, Gas injection, Simulation.

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INTRODUCTION

Oil is one of the components of asphaltene. It has a complicated structure having aromatic chains (C_6H_6) in the core and also oil ingredients (CNH_2N_2) around the core. According to these factors, the molecules of asphaltene break down with changing in molecular weight distribution and also change in thermodynamic factors via different mechanisms. The formation of heavy organic and creation of deposition in oil products and also the pipelines of crude oil transmission are the most highlighted problems in oil industrials on the basis of operation, extraction, oil storage in hydrocarbon reservoirs and crude oil transmission pipelines. Most of the asphaltene deposition in oil reservoirs is at the primary stage and also during the different methods in the process of oil extraction.

The asphaltene deposition is via two ways: after the first oil recovery and also could be under deposition according to gas injection process in order to increase the removal factor in the porous media. The causes of asphaltene precipitation are influenced by too many factors such as: temperature, pressure, oil components and electrosynitic effects which the temperature factor can be avoided during a production lifetime. The above factors will change the chemical balance in the reservoir and lead to asphaltene deposition. Actually, the solid phase deposit around the well. The decrease of absolute permeability, a decrease of effective permeability of the oil, changeable wetting in porosity and finally reduction of oil production and visbreaking are influenced by asphaltene deposition in oil reservoirs (Leontaritis, 1998). The above phenomena have been observed in the natural depletion or in the miscible/immiscible injection of hydrocarbon and also CO_2 gas (Wang and Civan, 2001). Asphaltene deposition is according to both natural depletion or/and gas injection into reservoirs, or it will flow in the suspended solid mood (Nghiem *et al*., 1998). Finally the asphaltene deposition is followed by many factors such as the pressure and permeability of reservoirs, the rate of production in the well, the amount of asphaltene concentration in the oil, oil properties and the amount of gas injection rate (Ali and Islam, 1998). The most important factor in the process of asphaltene deposition is pressure drop. The solid particle in the asphaltene are formed when the pressure of reservoir become less than the pressure of asphaltene formation threshold. By reduction of the pressure, the more these particles will form and the more the asphaltene deposition. The solubility of asphaltene in the oil will increase by releasing the gas from the oil, so the amount of asphaltene deposition decline (Kalantari-Dahaghi *et al*., 2008).

It is important to find out the asphaltene deposition mechanisms and their effective parameters in order to have a reasonable strategy. Chemical, mechanical and heat methods are some ways to bring about the reduction of asphaltene deposition. All these techniques are so expensive and nonproductive, so the effective way is to prevent from forming the asphaltene precipitation.

The investigation into the effect of concentrative injection of CO_2 on asphaltene precipitation

Although CO_2 gas injection is one of the common ways of oil recovery, it may cause some changes in the properties of fluid reservoirs and also asphaltene deposition. When the regions around the well

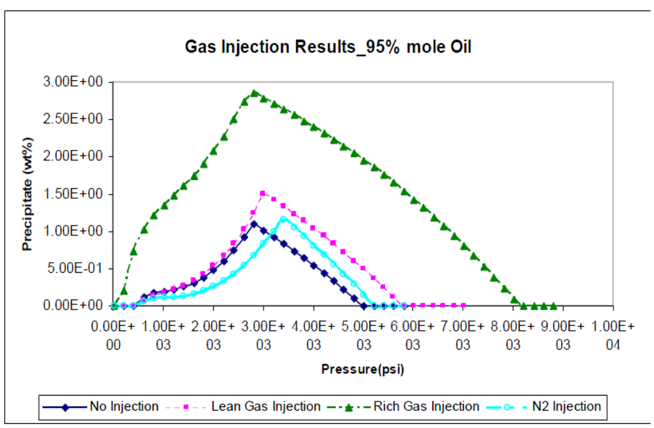


Figure 1. The effect of different gas injection on asphaltene precipitation

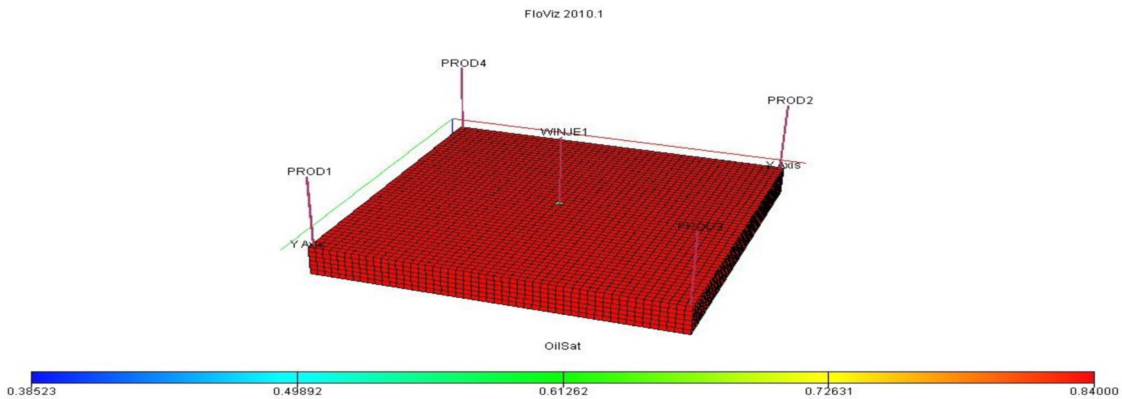
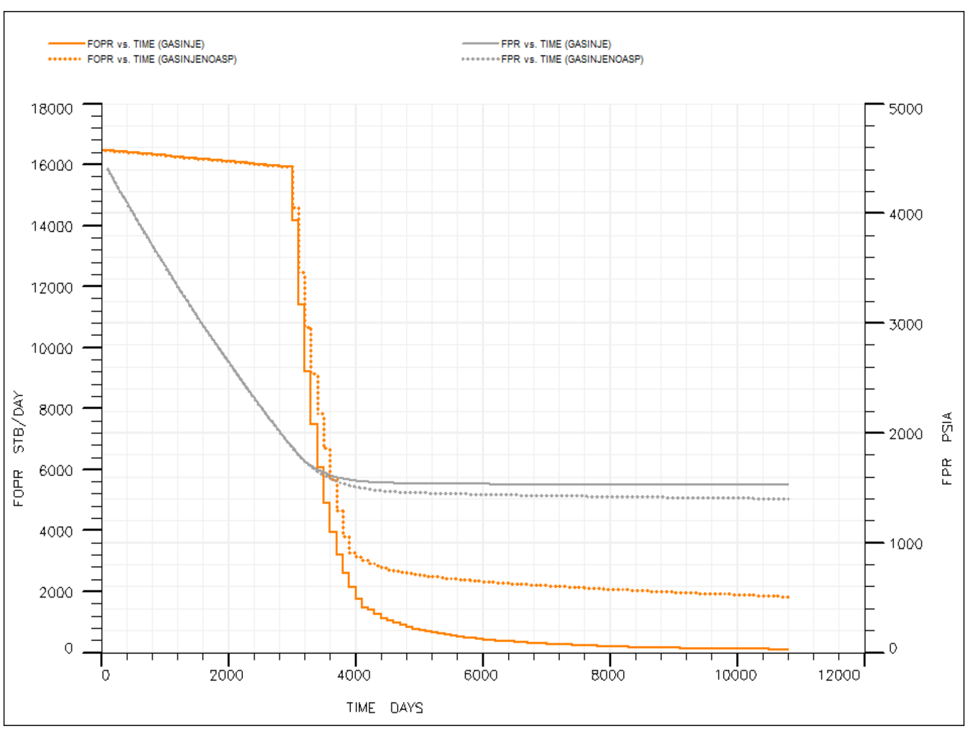


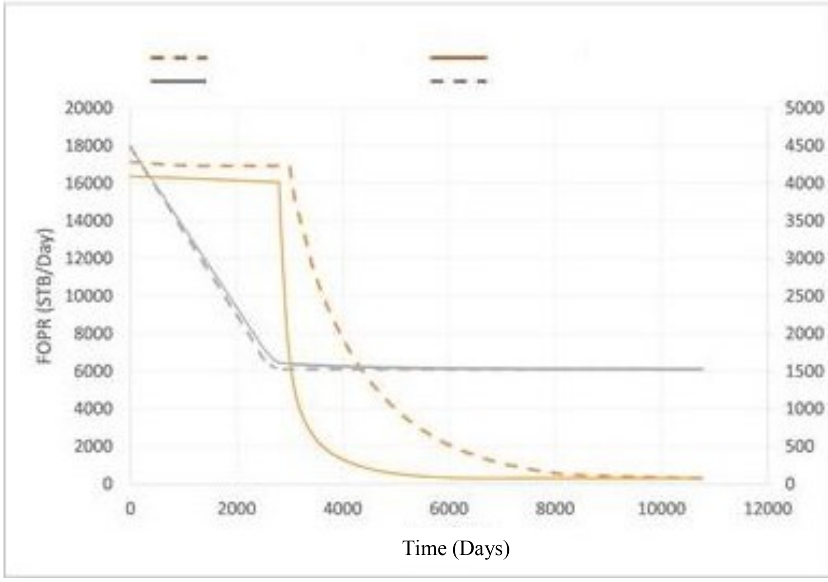
Figure 2. Static simulation model

and also wellhead facilities become closed, the asphaltene precipitation is formed and it lead to reduction of injection and formation of oil wells. The formation of surface precipitation starts when flocculated particles come close to the surface of the stone. Then these precipitations cause the pores to close. Formation of damage was also influenced by other factors such as: reduction of permeability and changing the wetting from water wet into oil wet. It is necessary to consider that during the gas injection or natural depletion process, many reservoirs with a little amount of asphaltene are able to form the asphaltene precipitation. For instance, in Venezuela there wasn't any problem with 7 % weight asphaltene in the Boskan oil field. While there were many problems in the Messaud-Hassi oil field with %.1 weight of CO_2. There



Flow rate of reservoir with asphaltene — Flow rate of reservoir without asphaltene - - - - - -
Reservoir pressure with asphaltene — Reservoir pressure without asphaltene - - - - -

Figure 3.The flow rate of oil production and the drop in reservoir pressure in gas injection mode, with and without asphaltene



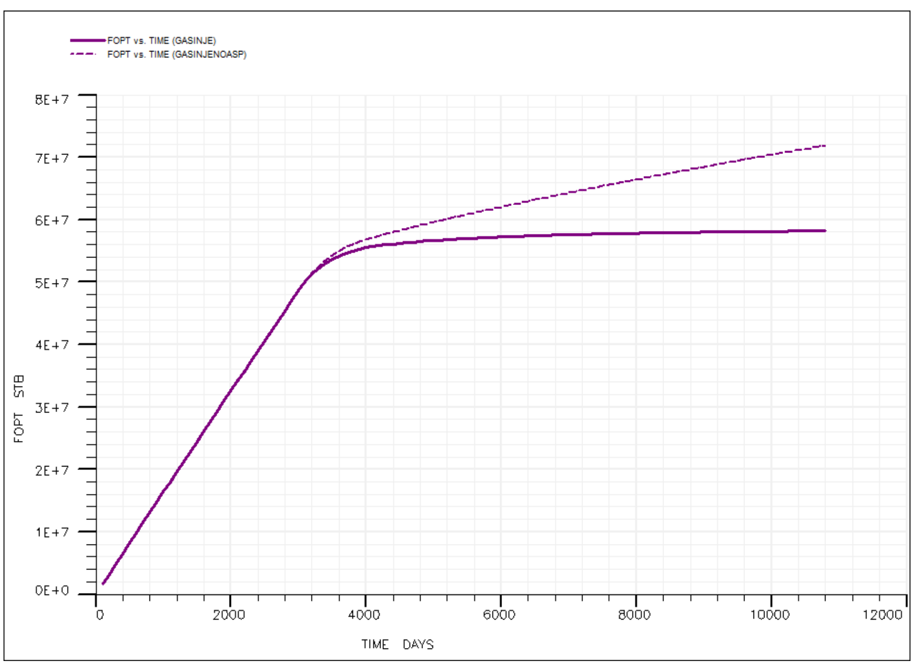
Flow rate of reservoir with asphaltene ______ Flow rate reservoir without asphaltene - - - -
Reservoir pressure with asphaltene ______ Reservoir pressure without asphaltene - - - - -

Figure 4. The out flow of oil production and the pressure drop of reservoir in gas injection mood, with asphaltene and without it in CMG

was a study about investigation into the effect of gas injection on the amount of damage formation by Hon *et al*. (2007). The concentration of CO_2 gas injection is also studied in this research.

The effects of different gas injection on asphaltene deposition formation

Asphaltene deposition and wax precipitation caused serious problems in many oil reservoirs of Iran.



Cumulative production (with asphaltene) ______
Cumulative production (without asphaltene) ---------

Figure 5. The cooperative production of gas injection digram, with and asphaltene without in E 300

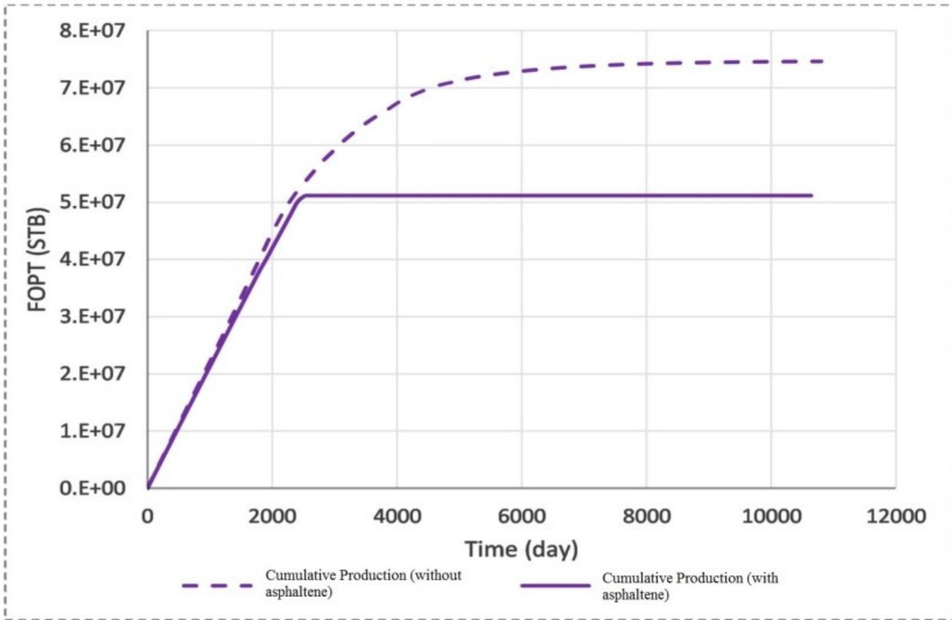


Figure 6. The cooperative production with gas injection diagram, with and without asphaltene in CMG

A short note on the effects of dry gas, rich gas and nitrogen on asphaltene deposition can be known by the study of Hajizadeh *et al.* (2009).

Problems influenced by asphaltene deposition

- There are many problems influenced by asphaltene deposition such as: reduction permeability: asphaltene causes the treat of holes and cavities in the porous media. So the amount of permeability and production leads to declination. The effect of asphaltene deposition on permeability is related to these factors:
- Distribution of asphaltene particles ratio on the distribution size of cavities
- The amount of asphaltene deposition
- The amount of adsorption of asphaltene in both small and big cavities

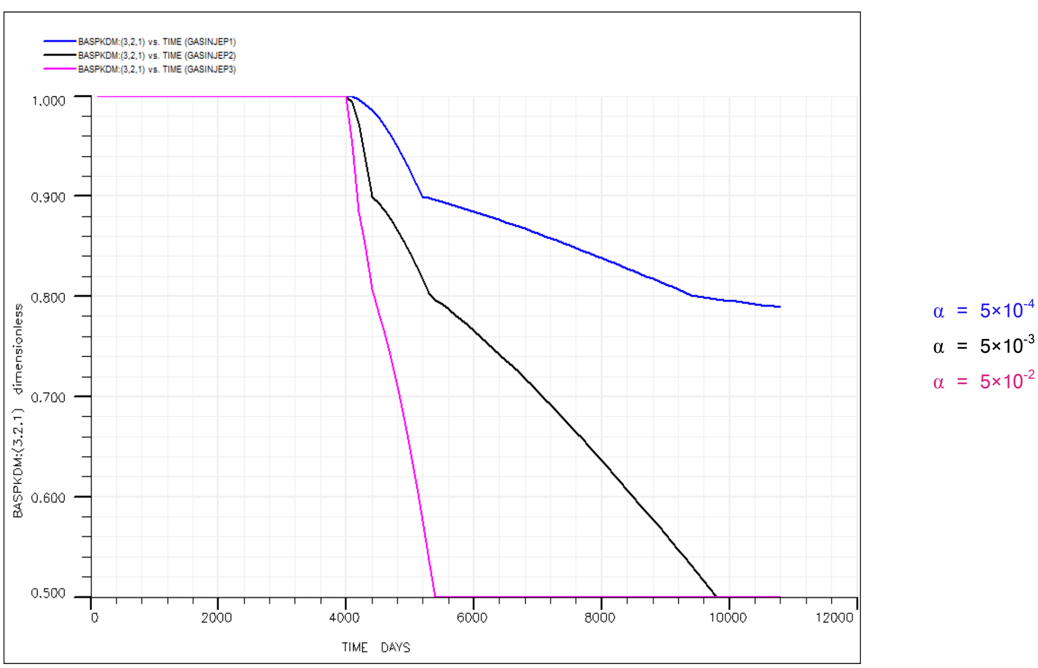


Figure 7. The effect of surface adsorption coefficient on permeability damage in E300

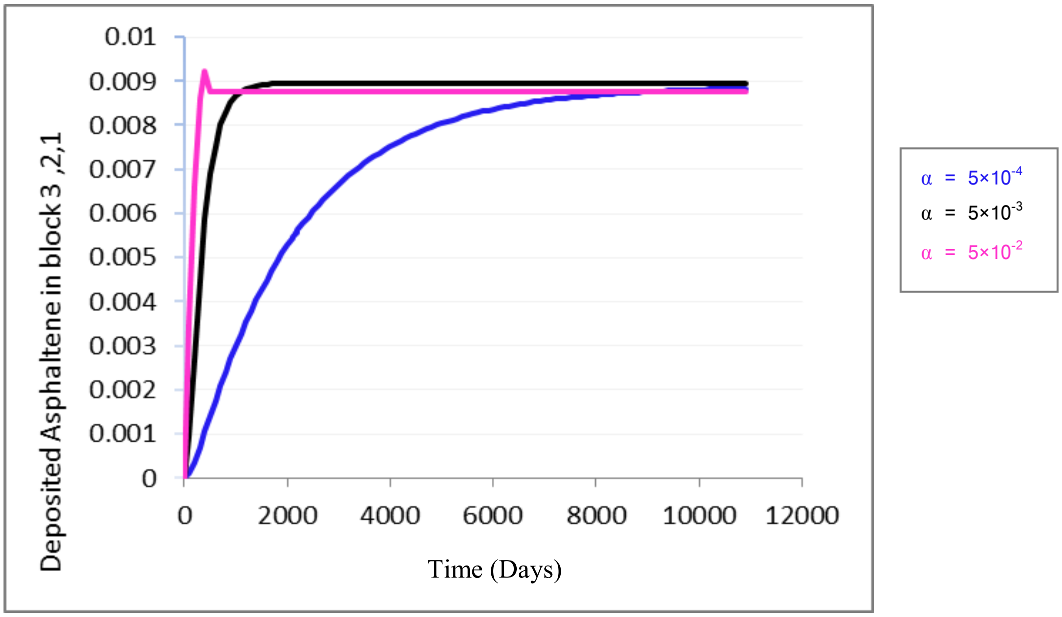


Figure 8. The effect of surface adsorption coefficient on deposition in CMG

- The amount of solubility of asphaltene during fluid flow from the holes

Wettability alteration

The asphaltene deposition adsorbs on the rock reservoirs, so it can change the properties of wettability from water wet to oil wet. Wettability is a kind of feature which controls the fluid stone in relative permeability curves and the end spot saturation. It also affects the fluid distribution during the movement processes. However it changes the stone's wettability by changing the surface tension between oil and water. Asphaltene increased the viscosity of hydrocarbon compounds by sticking the water emulsions in the oil.

Flow deviation

The congestion of wells and pipelines are influenced by asphaltene deposition and it lead to the

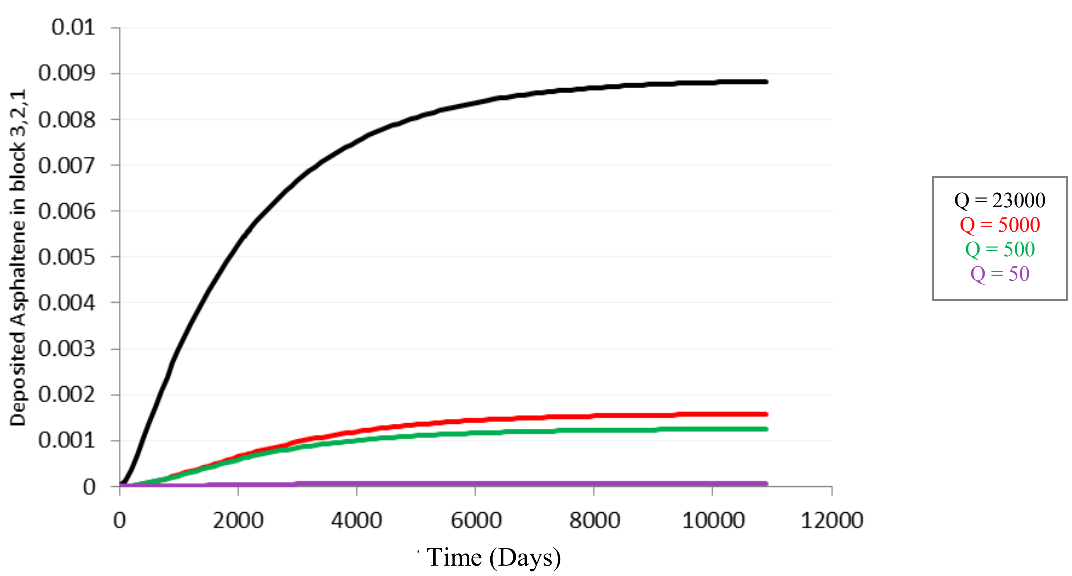


Figure 9. Effects of different flow rate on asphaltene deposition in CMG

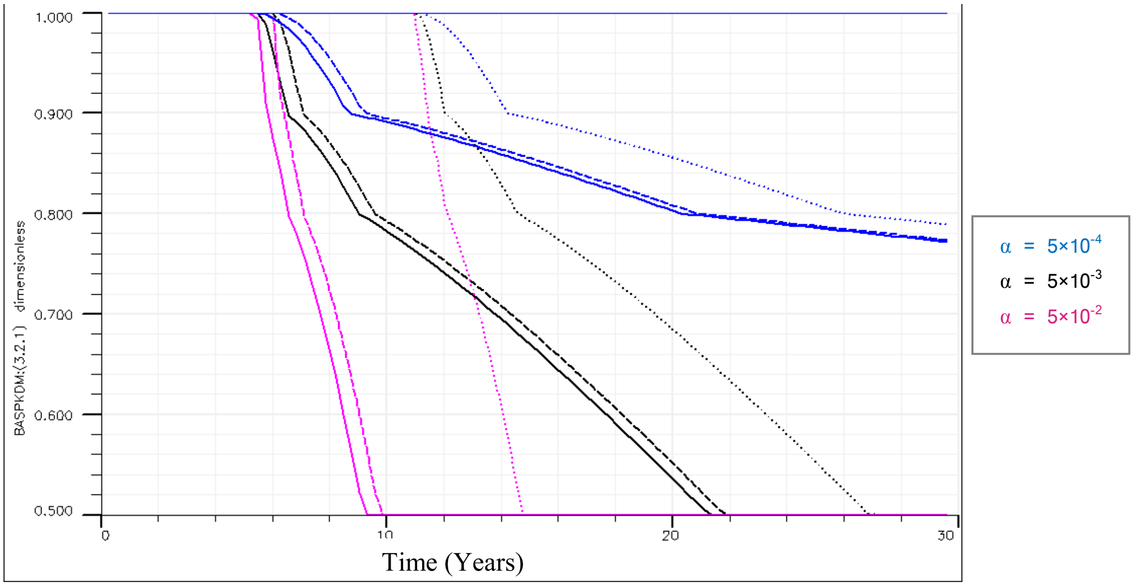


Figure 10. The effect of different flow rates on surface adsorption coefficient and permeability in E300

flow and canalization increases the pressure and reduces the product (Bagheri *et al.,* 2011).

MATERIALS AND METHODS

The oil field Iran is full of oil with 20.37 degree of API. It is a carbonate reservoir with heavy oil. The ratio of gas to oil is 361.69 SCF/STB and the volume modulus of oil is 1.26BBL/STB. The reservoir is isotropic, homogeneous and without any fracture. The heaviest components of the oil is divided into two parameters: deposition and non-deposition. The characteristics of both two parameters are the same. The amount of mass mole deposition can be calculated by using of some present data such as: Z_{Asph}, $Mw_{Asph,}$ $W_{Asph,}$ $Mw_{Oil.}$ The equation is illustrated as below:

$$Z_{Asp}*Mw_{Asp}=Wt_{Asp}*Mw_{Oil} \quad (1)$$

According to the above equation, the amount of asphaltene is 12.8 % of weight in the oil. According to the above equation, the amount of mole percent was 2.87. As per this model, the asphaltene process simulates with

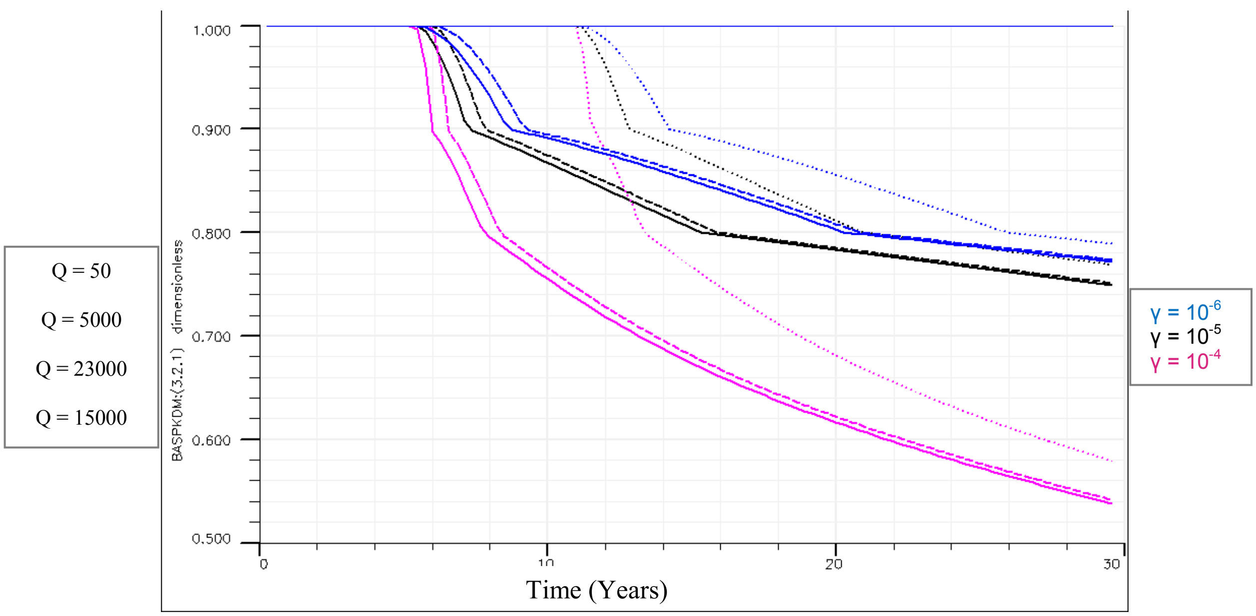


Figure 11. The effect of different flow rate on permeability damage and obstruction bottleneck coefficient in E300

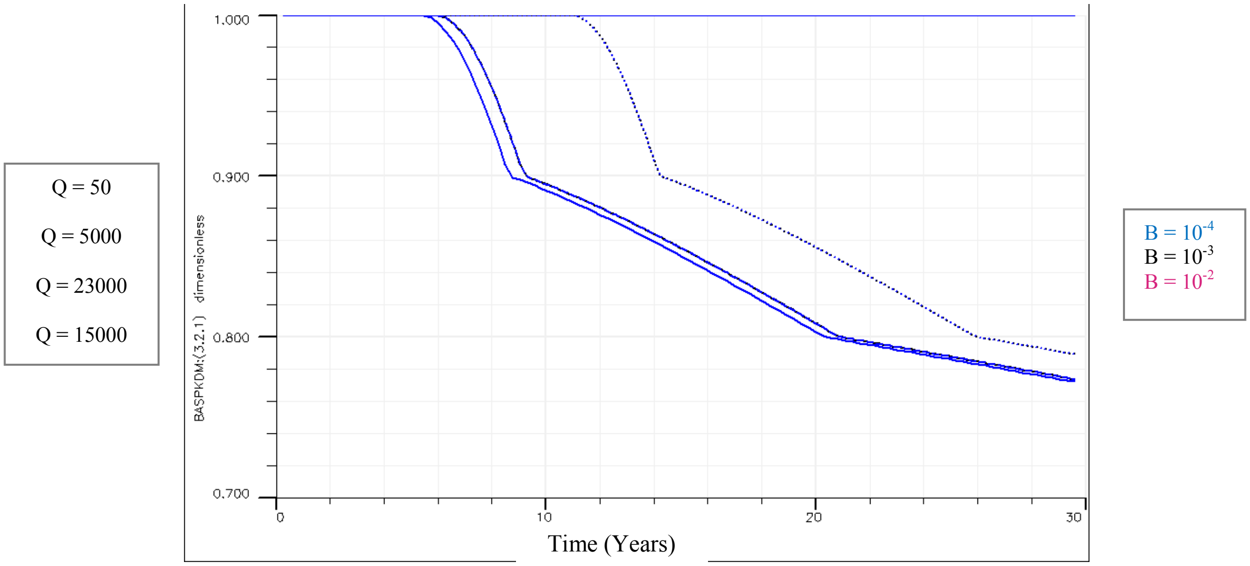


Figure 12. The effect of different flow rates on permeability damage and segregation coefficient

three parameters such as: surface adsorption, trapping plugging and entrainment (Wang and Civan, 2001). The parameters can be ascertained as per the following equation

$$\frac{\partial \varepsilon_i}{\partial t} = \alpha\varphi C_a + \gamma|F_{oi}|C_a - \beta(|U_{oi}| - U_{cr})^{+}\varepsilon_i \qquad (2)$$

where deposition volume fraction in I direct flow, 'α' is the adsorption coefficient (day^{-1}), 'ϕ' is the real-time porosity, 'C_a' is the volume concentration of slug in oil phase, 'F_{oi}' is oil dorcy fluxgate, 'γ' is the fractured coefficient of ft^{-1}, 'β' is the rate coefficient, 'U_{oi}' is speed of oil phase and 'U_{cr}' is critical speed. The meaning of the positive sign up to the parenthesis means that when 'U_{oi}' is less than 'U_{cr}', the result of the equation will be zero.

Simulation of reservoir's model

After making the flaw reservoir model and the adaptation of experimental data with the result of the equation of state in PVTI and Win Prop, data will enter to software in order to simulate the parameters. The Kartizon grade system was used in order to make a block grade system. The reservoir in this study had some characteristics such as: DX=300, DY-300 and DZ-30

All above the features were in the primary pressure which was 4757 in the reservoir, with 205 F, API was 20.37 and the water primary saturation was 16%. The static simulation model is illustrated in Figure 2. There are four production wells in the grades of: 1:50, 50:1, 50:50 and 1:1 and also one injection well in the grade of 25:25. All the four production wells and the injection well are perforated with k=1 up to k=6.

RESULTS

Investigation of the effect of asphaltene in gas injection process

The CO_2 gas injected into the reservoir was in the grade of 25:25 in this model. The amount of out flow was defined as 16500 barrels per day for each production well and the minimum of the sand face pressure was limited to 1500 PA. The plan of gas injection with asphaltene and without it was used in two soft wares in order to investigate the effect of asphaltene on the output of gas injection. The process of minimizing the pressure, cooperative production, the effect of asphaltene on the flow rate, the pressure drop of reservoir are shown in the flow rate of oil production diagram in two softwares called E300 and CMG. It was found out that the amount of flow rate and cooperative production was different in both asphaltene mode and without it. Comparison of these two manners, showed that the amount of flow rate in asphaltene is less than the flow rate in non asphaltene mode. So, the measure of cooperative production of oil becomes decreased. It is because of changing the composition of reservoir fluid under the gas injection. And also it is one of the reason of changing the balance mode in system, so it causes inconsistency in asphaltenes and the maximum deposition in them. It is also observed that the rate of maximum production become decreased in less than nine years and also the rate of sector production become decreased in less than 11 years. The pressure of oil field came to a decrease to 1500 PA and the production of oil continues with a little flow rate.

Results indicated that the flow rate and cumulative production are different according to the asphaltene or without it. At the time of asphaltene formation, the flow rate of oil is very little, so the cumulative production also reduced. When the flow combination of reservoir changes under the gas injection process, it leads to some events such as: the imbalance of the system, destroying the asphaltene stability and so the deposition of asphaltene, Also, it is observed that, the maximum range of production reduces, according to nine years and the sector production declines less than eleven years. The field pressure reduces to the minimum pressure which is 1500 pa in less than 11 years, so the production continues with a little flow rate. The high reduction of reservoir pressure leads to cumulative production and a little rate of production.

The effect of surface deposition rate coefficient

The surface deposition rate coefficient is investigated in Figure 7 and Figure 8 in three manners as following: (5×10^{-2}), (5×10^{-3}), (5×10^{-4})

All of these are with flow rates of 5000 barrels per day on permeability damage with E300 and asphaltene deposition in CMG. According to the enhancement of surface deposition coefficient, the measure of deposition in the reservoirs increase, so the pressure drops and the possibility of permeability reduction were more than other situations. The stages of asphaltene deposition and entrapping take place in the porosity. The enhancement of deposition leads to a reduction of permeability and porosity in the reservoir. So it decreases the flow and reduction of production.

As it can be seen, the amount of asphaltene deposition decreases by the enhancement of surface deposition. So, it leads to pressure reduction and also reduction of wettability in the reservoir. All the above events cause more deposition in the reservoir. The deposition of asphaltene occurs in the process of adsorption of asphaltene in pores. Enhancement of deposition reduces the penetration and porosity in the reservoir. So the amount of production and flow decreases.

Effects of flow rate

The basic model of the reservoir in the flow rate of 5000 barrels per day was investigated with the following equation:

$5*\ 4^{-10}\alpha$, $4_{-10}\ \beta$ and $6_{-10}\ \gamma$

The effect of different flow rates on asphaltene adsorption in CMG software was shown in Figure 9. The maximum rate of asphaltene deposition took place sooner with more flow rate and its measure is more than the other times. The best condition of asphaltene deposition on the reservoir rock is prepared. The asphaltene deposition destroys the permeability of rocks with high flow rate. The surface deposition causes lot of problems in the process of production. This leads to the high speed of formation damage, therefore the mobility of hydrocarbons decrease because of the reduction in permeability.

The process of changing α, γ and β in eclipse program was illustrated in Figures 10, 11 and 12 based on the permeability damage in 50, 5000, 15000 and 23000 flow rate. Generally, by changing the amount of 'α' and 'γ', the enhancement of permeability happens. But there is no effect on permeability damage by changing 'β' according to gas injection process. Actually it can be understood that there is a direct relationship between flow rate and permeability damage, which means that when one of them increase, the other one also increase and *vice versa*. Actually, the enhancement behavior of permeability is observed by changing 'α' and 'β'. But changing in 'β' has a little effect on permeability damage. Enhancement in flow rate causes an increase in permeability damage

DISCUSSION

Some experimental researches have been done in order to investigate the reduction of permeability which was influenced by asphaltene deposition during the gas injection (Sim *et al*., 2005). Permeability of primary cores, concentration of CO_2 and the amount of asphaltene particles in oil and CO_2 mixture, were the variables of this study. A substance injected with a 3.9 % asphaltene and by different out flow had a permeability between 9 and 105 and its porosity was between 15 and 28 %. It was observed that there is a rule for water injection which is from 1.3 to 1.7.

It means that if the size of particles were more than the average of 1.3 the diameter of cavities bottleneck in the porous media and a bridge will form on the surface of the core like a cake. On the other hand, there was no permeability reduction when the sizes of particles were less than 1.7 bottlenecks of cavities. It is also pointed that the features of asphaltene deposition change during the injection of solvent into the mixture. It may be causes sedimentation of the extra amount of crude oil resin with asphaltene (*Ibid*). In 2011, a study was done in order to measure the asphaltene deposition during the CO_2 injection. The injection of high amount of CO_2 concentration was related to more asphaltene deposition (Yee *et al*., 2007). Asphaltene deposition and asphaltene precipitation models were specified in 2004. In this model, asphaltene deposition was specified in two groups, called solid one and solid two. Solid 1 is thermodynamically reversible and is in a balanced mode with asphaltene components in the oil phase. During the chemical processes, solid 2 come from solid 1. It represents the compressive particles of asphaltene and completely or partly can be reversible or irreversible.

A relationship between deposition model and parameters such as: surface adsorption, entrainment and plugging were also made. Then the effects of deposition on porosity and reduction of permeability. This model is used in studies about the production of oil in a natural mode and also simulation of core flooding in order to inject the gas in lightweight oils (Kohse and Nghiem, 2004). In 2009, the asphaltene deposition simulated with Eclipse program in one of the fractured reservoirs of Iran (Mirzabozorg *et al*., 2009). At the first step, they defined some parameters of flow model in order to adapt with experimental data, after that the simulation was done in two manners based on the developed field map, with and without asphaltene deposition. The sensitivity analysis was determined with changing of fracture parameters and its effect on the field's efficiency and damage formation by the enhancement of the width of fractured out flow, the amount of production reduced, and the pressure drop increased. All the above reasons lead to more asphaltene deposition (*Ibid*). In 2011, a research was done about studying the effects of asphaltene deposition and controlling precipitation parameters on the reservoir's efficiency (Khanifar *et al*., 2011). There were many plans which was defined in order to specify the effects of main parameters on the efficiency of reservoirs after making the flow model, and controlling parameters which was related to asphaltene and putting the data in this combined model. The based plan defined as combined model without asphaltene in order to make comparison with the other plans. The results showed that nearly 4 % of oil recovery and almost 14 % of the average pressure of reservoirs lead to decline based on combined asphaltene model. The amount of oil recovery in the water injection mood is more than natural depletion mood (*Ibid*). The relationship between dynamic asphaltene deposition and its effects on the experimental parameters, the relationship between changing the volume of solvent, the effects of temperature on the injesction and permeability reduction, were investigated by Zahedi (2005).

CONCLUSION

We concluded some findings by the end of this study, as given below:

- The reduction of oil density and visbreaking influenced gas injection and asphaltene deposition.
- In the asphaltene deposition conditions, the amount of cumulative production and recovery from the reservoir decreases during the gas injection process than non asphaltene deposition situation.
- According to sensitivity analysis on the asphaltene parameters, the absorption coefficient has more effect on the measurement of damage formation modeling. The amount of asphaltene deposition will increase because of pressure alteration and change in reservoir fluid combination during a gas injection.
- Although enhancement of physical properties are influenced by asphaltene deposition, but asphaltene deposition causes reduction of permeability. In this study, the amount of recovery declined and the reduction of permeability factor was dominated.
- Asphaltene is influenced by the rate of production. Hence, controlling parameters of production can delay the asphaltene deposition problem.

Future studies and suggestions

- In order to have some comparisons between these three softwares for asphaltene deposition modeling. It is suggested to use PVT sim model. According to the effect of carbon dioxide on the asphaltene deposition, it is suggested to study the amount of permeability reduction based on the injection of CO_2 gas.
- It is suggested to have sufficient empirical studies on the effect of porous media parameters on asphaltene deposition like wetting and distribution of porosity, because these parameters have an effective role in the amount of asphaltene deposition.

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