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Enhancement and Utilization of Abu-Attifel Produced Water in Enhanced Oil Recovery

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Abstract

One of the main concerns of oil producing countries is to protect oil wells in order to increase their lifetime as well as their daily crude oil production. Abu-Attifel field produces large quantities of aquifer water and produced water daily. In this study, Abu-Attifel field is used as a model to assess the reinjection of aquifer and produced water and to study the effect of displacing residual crude oil in the field. In particular, an estimate of injection rates and pressures is needed during the planning stage of a water flood for the purpose of sizing injection equipment and for the purpose of predicting oil recovery rates. The main objective of this study is to develop of Abu-Attifel field with the object of enhancing hydrocarbons recovery. To evaluate the enhancement of crude oil production in Abu-Attifel field, the fluid flow in the reservoir (The rate of flow of crude oil and combined aquifer water and produced water at any radius r+dr in Q barrels per day) have been studied. The effect of permeability on fluid displacement is greatly strong dependent, high permeability is a major factor in the high recovery of oil by increasing the pressure and/or decreasing the pressure drop in the wellbore region. When the mobility is less than unity, oil flows better than water and it is easy for water to displace oil; however, this condition generally results in high sweep efficiencies and good oil recovery. The mobility of the injected fluid (water) during water flooding affects the stability of the displacement front; mobility control can lead to greater reservoir pore volume being contacted during flooding. Contacting more upswept zone of the reservoir will lead to greater recovery efficiency. In this study mathematical model is utilized where partial differential equation model is solved to estimate the pressure drop in different location of the field to locate the optimum operating condition of the EOR project.

Keywords: EOR; water injection; reservoir modelling; permeability; water flooding

1. Introduction

In oil reservoirs, drop in some environmental factors, e.g. pressure, decreases oil recovery. Hence, one of the main concerns of oil producing countries is to protect their oil wells in order to increase their lifetime. The methods called enhanced oil recovery (EOR) are used to increase the production of oil reservoirs. Usually, 30% of oil is recovered naturally, and about 70% need to use the other enhanced recovery methods [1].

Most of the current world oil production comes from mature fields. Increasing oil recovery from the aging resources is a major concern for oil companies and it is believed that EOR technologies will play a key role to meet the energy demand in years to come. In addition, the rate of replacement of the produced reserves by new discoveries has been declining steadily in the last decades [2]. Therefore, the increase of the recovery factors from mature fields under primary and secondary production will be critical to meet the growing energy demand in the coming years.

Water flooding also referred as an EOR technology method where water injection are carried out in a reservoir for a period of time in order to provide both microscopic and macroscopic sweep efficiencies and for pressure maintenance when the expansion of the aquifer or gas cap is insufficient for the purpose [3]. It is most often used as secondary recovery method of increasing oil recovery in reservoir since the begging practice of reinjection the produced water into porous and permeable subsurface formations in 1920s where primary depletion energy has been exhausted.

The yearly amount of produced water generated from onshore oil and gas activities in the U.S. from 1988 to 2007 varied between 14 and 21 billion barrels [4]. More than 98% of produced water from onshore wells was injected underground in 2007. Approximately 59% was injected into producing formations to maintain reservoir pressure and for enhanced recovery. In 2001, a total of 276.4 million cubic meters of water was injected for EOR operations in Alberta. Approximately 83 percent (228.9 million cubic meters) of this water was produced water, recovered together with oil from oil reservoirs and more than 50 percent of Alberta's production of conventional light oil each year is now supplied by EOR projects [5].

There are thousands of other fields throughout the world such as Parentis field in France and Zelten field in Libya employ water injection for increasing oil recovery [6]. In this study, Abu Attifel field in Libya has a decline in crude oil production from the current nominal 100,000 bopd to about 20,000 bopd in 2032 [7]. However, Abu Attifel field produces large quantities of aquifer water (a-water) and produced water (p-water) daily. So, in this study the main objective is to develop of Abu Attifel field by injection this water (i-water) with the object of enhancing hydrocarbons recovery. The fluid flow in the reservoir have been studied where partial differential equation model is solved to estimate the pressure drop in different location of the field to locate the optimum operating condition of the EOR project. The effect of permeability on fluid displacement is greatly strong dependent, high permeability is a major factor in the high recovery of oil by increasing the pressure and/or decreasing the pressure drop in the wellbore region.

2. Geological Characteristics of Abu-Attifel Field

2.1. Reservoir Characteristics

The Bu-Attifel field is one of the richest Libian oil field. It was discovered in the Sirte Basin, about 400 km South-East of Benghazi, in 1967 and oil production targeted in March 1972, approximately 17 km long and 2÷4 km wide, limited on alt Bides by faults and with a low dip of 5° to the North . Its OOIP is estimated at some 620 Mm^3 .The oil production comes from tbc Upper Nubian sandstones, a formation of a Lower Cretaceous age whose depth goes from 3886 to 4336 m s.s.l (subsea level) [8].

The oil bearing rock is a fine to coarse grained sandstone with interbedded shale and shaly-siltstones; fit ranges in net thickness from 75 -to 250 m. The porosity (8%-l6%) is inter-granular and was preserved at rather good value by a syntaxial siliceous cementation which reduced the effect the compaction after the deposition [8]. The horizontal permeability spans from a few mD to more than 1000 mD, and the anisotropy ratio (vertical permeability/horizontal permeability) ranges from 0.48 to 1.23. The initial water saturation, which correlates quite well with the local porosity, averages 16% [8].

At discovery, a bubble point variation with the depth was recognized, but the oil resulted under saturated at the initial pressure (47 .6 MPa) through all the field. The basic volumetric properties and an average composition are listed in table 2.1 and 2, respectively [8].

The crude has a 41 °API gravity; its base is paraffinic at high wax content (36 .7%) with an upper pour point of 39 °C [8].

2.2. Forecasting of Abu-Attifel Produced Water

Abu-Attifel field produces large quantities of aquifer and produced water every day table 2.2. The aquifer water is very clean with low particle counts and suspended solids were observed. It contains no oxygen and has a low corrosion rate. Since there are no reported problems with injection,

Table 2.1: Volumetric Characteristics of Nubian Oil Reservoir

Type Sampling	Subsurface
Reservoir Temperature	115.5°C
Reservoir Pressure	5305.6 PSIG
0. R.V.F. (Bo)	1.4104
Bubble Point Pressure	3440.6 PSIG
Stock Tank Oil Gravity	41 API
Data at Reservoir Pressure Solution Gas (Rs)	731.2 scf/bbl
Reservoir Oil Density	665 kg/m^3
Reservoir Oil Viscosity	0.85 mPa.s

this water requires no additional treatment, while the produced water needs treatment prior to injection to meet the water specification for EOR by removing the contaminants that could otherwise plug the reservoir and/or damage injection equipment. Therefore, in this study we deal with produced water as treated water.

A 15 year forecast is given in table 2.2 and figure 2.1. The rate of oilfield produced water production is expected to increase as oilfield ages [7]. This indicates a low of 74,652 bbl/d in 2015 increasing to a maximum of 101,000 bbl/d in 2028. Also, this forecasting indicates an injection demand declining from 207,391 bbl/d in 2015 down to 122,000 bbl/dd in 2030.

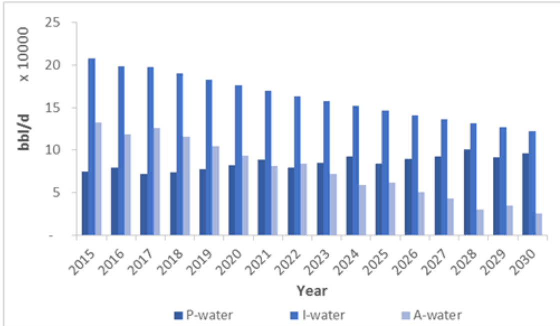

Figure 2.1: Water production and injection

Table 2.2: A/100 (Main and West) + NC125

Year	p-water (bbl/d)	i-water (bbl/d)	a-water req. (bbl/d)
2015	74,652	207,391	132,739
2016	79,623	198,454	118,831
2017	71,631	197,372	125,741
2018	74,084	189,886	115,802
2019	77,991	182,748	104,757
2020	82,281	175,936	93,655
2021	88,363	169,429	81,066
2022	79,021	163,209	84,188
2023	84,839	157,257	72,418
2024	92,772	151,559	58,787
2025	84,239	146,099	61,860
2026	90,013	140,865	50,852
2027	92,543	135,845	43,302
2028	101,163	131,026	29,863
2029	91,436	126,398	34,962
2030	96,517	121,952	25,435

The aquifer water requirement will be the difference between the injection requirement and the available produced water. On the basis of figures given in table 2.2 the aquifer water requirement will reduce from 132,739 bbl/d in 2015 down to 25,435 bbl/d 1n 2030.

The composition of produced and aquifer water is strongly field-dependent and includes a variety of inorganic and organic compounds. Results of Abu-Attifel field water analysis were obtained from Agip Oil Company in table 2.3 gives the concentration range of components in produced and aquifer water used in this study (All units as mg\l except PH (PH units), (*) calculated using pressurized PH value (figure in brackets assumes de pressurized PH)). Depending on the produced

water quality, current practice for produced water management of Abu-Attifel field includes reinjection into underground formations.

Table 2.3: Water Analysis

Parameter	p-water	a-water
Sodium	10,930	545
Potassium	105	39
Calcium	1830	220
Magnesium	160	130
Barium	5.2	< 0.1
Strontium	88	7.2
Total Iron	12	< 0.02
Dissolved Iron	12	< 0.02
Manganese	5.9	0.09
Zinc	0.17	< 0.05
Aluminum	< 0.5	< 0.2
Silicon	54	11
Phosphorus	< 0.15	< 0.06
Lithium	2.7	0.05
Boron	24	0.61
Chloride	20,280	950
Sulphate	475	755
Bicarbonate	87*(182)	42
Dissolved CO_2	187*(118)	17
H_2S	Nil	Nil
O_2	Nil	Nil
Temperature °C	71.5	32.5
PH	6.1	6.58

3. Mathematical Model

The descriptions of most scientific problems involve equations that relate the changes in some key variables to each other. Diffusivity equations are used to design the best well spacing in reservoirs and also are used to determine well shut down optimizations and can be written as follows [9][10]:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial p}{\partial r}\right) = \frac{1}{\eta}\frac{\partial p}{\partial r} \tag{3.1}$$

Where

$$\eta = \frac{K}{c_t \phi \mu} \tag{3.2}$$

For initial condition,

$$P(r,0) = P_i, For.all.r \tag{3.3}$$

For boundary condition,

$$P(\alpha,t) = P_i, For.all.t \tag{3.4}$$

$$r\frac{dp}{dr}(0,t) = \frac{Q\mu}{2\pi kh}, For.t > 0 \tag{3.5}$$

Where, Pw is bottom hole pressure, Psi; h is formation thickness, ft; r is radius, ft; rw is wellbore radius, ft; Q(t) is oil flow rate STB/d; Pi is initial formation pressure, psi;µ is fluid viscosity, cp; k is permeability, mD; Ct total compressibility psi^{-1}. For an infinite-acting reservoir, we also assume isotropic and homogeneous properties of the reservoir. The model, therefore, considers only 1-D radial flow of fluids in permeable rocks. Matthews and Russell (1967) proposed the following solution to the diffusivity equation,i.e., Equation 3.1:

$$P_{rwt} = P_w = P_i - \frac{Q\mu}{4\pi kh} ln\left(\frac{4kt}{\gamma\phi\mu c r^2 w}\right) \tag{3.6}$$

According to the Equation 3.6, actuate external boundary can be obtained, and the reservoir pressure distribution at any different location in the well can be obtained table 4.1 & figure.4.1.

4. Results and Discussion

In this study the graphical solution of mathematical model was applied for wells, and whole field. The maximum value of production rate of well-OO1 of Abu-Attifel field is predicted to reaches approximately 3980 bbl/day in year 2015. Therefore, the reservoir pressure distribution at any different location in the wellbore have been estimated based on equation 3.6 at three time periods after start of production table 4.1.

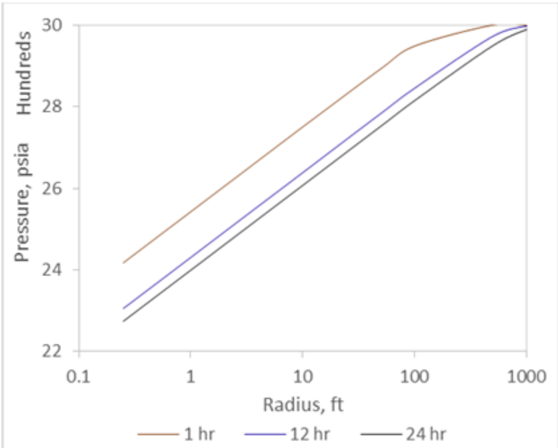

Figure 4.1: Pressure profiles as a function of time on a semi log scale

Table 4.1: Pressure distribution about Abu-Attifel well-OO1 at three time periods after start of production

r(ft)	P(r,1hr),psi	P(r,12hr),psi	P(r,24hr),psi
0.25	2417.48	2305.482	2274.241
5	2687.521	2575.524	2544.283
10	2750.003	2638.006	2606.765
50	2892.638	2783.084	2751.843
100	2947.605	2844.761	2814.325
500	2999.968	2971.957	2948.912
1000	3000	2997.179	2988.502
1500	3000	2999.851	2997.945
2000	3000	2999.995	2999.739
2500	3000	3000	2999.977

The results was drawn on a semi-log scale graph Figure 4.1. This figure shows clearly the pressure will be reach to maximum value after 1000 ft to reach 3000 psi.
Also this figure indicated that as the pressure disturbance moves radially away from the wellbore, the reservoir boundary and its configuration has no effect on the pressure behavior, and in this case the pressure gradient is positive.
If type of this graph is maintained for each injection well, the data can be easily manipulated to make a best prediction of production rate on a whole remaining oil wells to reach about 99,577 bbl/day in 2015. Furthermore; the oil production forecasting have been made in the years of 2015 to 2030 based on the amounts of water to be injection figure 4.2.

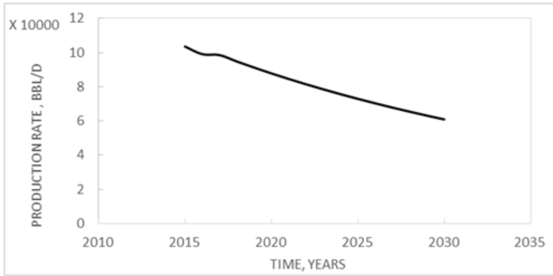

Figure 4.2: Forecasting of production rate after injection

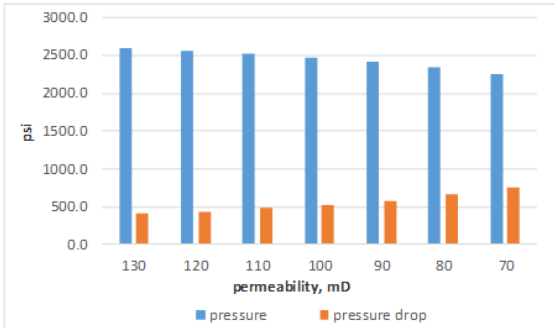

Figure 4.3: The effect of permeability on the pressure at the wellbore

The effect of permeability on fluid displacement have been investigated. Sensitivity analysis on well-OO1 have been made, as result we can conclude from figure 4.3 that high permeability is a major factor in the high recovery of oil by increasing the pressure and/or decreasing the pressure drop in the wellbore region.

5. Conclusion

High permeability is a major factor in the high recovery of oil, therefore, the primary recovery from highly permeable reservoirs is normally very high and such reservoirs are less viable option for EOR because most of the oil would have been produced already through primary drive. The expected maximum oil production of the field was in year 2015 about 103557 bbl/d rather than 80,000 bbl/d before injection. This value will be reduced to reach about 60890 bbl/d in year 2030 instead 20,000 bbl/d. Figure 5.1 represents the main conclusions drawn in this study.

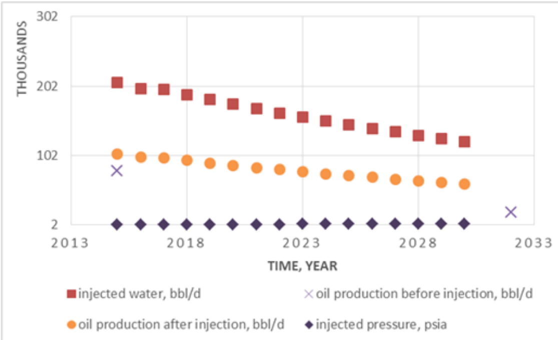

Figure 5.1: Overall conclusion

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