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Optimizing Injection Rate Through Ratio Data Method for Improved Oil Recovery Processes of Oil Rim Reservoirs

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Abstract: *A decrease in the volume of the reservoir`s original oil in place has been occasioned by long periods of hydrocarbon withdrawals; the oil and gas industry is bent on economic withdrawal to recoup investments and thus is engrossed in producing more of the trapped oil in the reservoir. The employment of water flooding and polymer flooding to recover most of the residual oil is associated with water production. This study investigates among other things the effect of placing the injection well close to a high permeable layer in a heterogeneous mature field during flooding processes. The study was performed with the aid of Eclipse 100 Reservoir software. A synthetic heterogeneous reservoir model characterized by (28 x 28 x 1) grid cells with dimensions 300 x 300 x 60ft in the X, Y, and Z coordinates. The reservoir permeability ranges from 2804 mD to 3136 mD. The datum depth of the reservoir is 8000 ft and pressure at the datum depth is 4000 psi, to depict a mature reservoir, the reservoir has an oil column thickness of 60ft, the Gas-Oil contact, and Water-Oil contact are at the datum depth of 8000ft and 8060 ft respectively. The injection rates for both water and polymer flooding were 1000, 4000, 7000, 10000, 13000, and 16000 STB/day. The simulation results for water flooding and polymer flooding were obtained and analyzed. The study applied the ratio data method to analyze the simulation result for optimum injection rate. The outcome indicated that the ratio of oil to water produced is higher at the injection rate of 1000Stb/d for both water and polymer flooding scenario. Conclusively, optimum injection rates are ideal during improved oil recovery processes. However, an infinitesimal increment of optimum injection rate will recover more oil without upsetting the water-cut ratio marginally considering the adverse effect of produced water such as the disposal cost, and equipment degradation. Furthermore, the simulation revealed that Injection wells closer to high permeable layers in a heterogeneous reservoir aid sweep efficiency of displacing fluid but also account for higher water production due to early breakthrough of water, and at higher injection rates, less oil was produced due to the unfavorable mobility ratio.*

Key Word: Mature Wells; Injection Rate; Water Flooding; Polymer Flooding; Water Production; Oil Production; Injection well

INTRODUCTION

Water flooding is a widely used enhanced oil recovery method that involves injecting water into an oil reservoir to displace oil and increase recovery. Latuan, D. R et al (2021). Waterflooding in top structure of oil rim to enhance the recovery of oil from such field can have diverse results. Adil Makanov 2022). Polymer flooding is an enhanced hydrocarbon recovery method that employs water-soluble polymer chemicals to improve the recovery of hydrocarbons by upgrading the viscosity of the displacing water to depreciate the mobility ratio of water/oil. The addition of a water-soluble polymer to the water permits the water to permeate through the porous media, giving rise to improved oil recovery. Polymer gel can be used as a sealant to shut off leakages through high-permeable zones thereby increasing the macroscopic displacement efficiency and more oil is produced. The fundamental mechanism of polymer flooding is the increase of displacing fluid viscosity and improvement of mobility ratios Claride E.L (1978). Oil- rim reservoirs are unconventional reservoirs characterized by strong aquifer, and a huge gas-cap with the oil width less than 100 feet. Davarpanah and Mirshekari (2018). oil recovery from oil-rim reservoirs poses some hurdles such as gas breakthrough, viscous fingering, and might result to low productivity. (Jaoua and Rafiee 2019: Hoftmann, M et al 2022)

LITERATURE

Davarpanah and Mirshekari (2018), stimulated six different injection rate for an iranian oilfield to determine an optimum rate of injection for higher oil production. Hydrocarbon withdrawal in the Niger Delta fields commenced in 1958, and cumulative withdrawal from most of the Niger Delta oil fields to date has exceeded a whopping 80% of oil originally in place (OOIP) Onwukwe S.I et al., (2019). Hu Jie (2018) investigated the influence of reservoir heterogeneity on physical processes and production performance of air injection in light oil reservoirs through a mathematical simulation approach. Zhao Yu et al., (2022) proved that the physical inter-layer arrangement of the reservoir formation bears an influence on the change of oil saturation in near layers. The group established this fact by applying the use of a rock structure model in studying the changes occurring in residual oil on a millimeter level in various layers during the different water flooding production techniques. An experimental trial was performed by Prem Bikkina et al., (2016) to appraise the influence of reservoir wettability and permeability heterogeneity on the effectiveness of miscible CO_2 injection as an enhanced oil recovery mechanism. Using n-hexadecane, the wettability of core samples with strong water affinity was modified, core sample permeability was achieved by merging two halves of water-wet core samples divided lengthwise, flooding tests were done for n-hexadecane core, synthetic brine core sample and CO_2 core at a minimum miscibility pressure of 1400 psig. The result proved that wettability affects CO_2-enhanced oil recovery.

Brownfield are characterized by undesirable water production, especially in heavy oil fields which adversely impact the production economics, power utilization, and consequently on recovery efficiency, Andres Pinilla et al; (2021). The recovery of residual oil from oil-rim fields needs an improved method of production, the introduction of water flooding serves as both a secondary and enhanced oil recovery method. The knowledge of the fluid and rock properties is necessary for selecting the appropriate enhanced oil recovery method. The implication of water-flooding in enhancing oil recovery from petroleum reservoirs in the Niger Delta to a profitable degree remains emphatically useful. The process pumps water through an injector well into the reservoir to obtain or maintain the reservoir pressure and displace oil towards the producer well. Water-flooding commences when a hydrocarbon reservoir has attained its economic withdrawal limit through all primary drive mechanisms. This process of water Flooding has been adjudged relevant for the secondary withdrawal stage in the Niger Delta offshore reservoirs today. Patrick Godwin Oyindobra Ossai et al; (2018).

Jaoua and Rafiee (2019) optimized oil recovery from a thin oil reservoir through numerical simulation by applying (waterflooding, gas flooding, and surfactant flooding) recovery techniques using inverted five spot horizontal space pattern to a selected zone of the oil-rim field. Optimization of the vertical/horizontal injection well length, lateral well length, pattern design was accomplished using the differential algorithm. The results indicated that waterflooding the oil rim selected zone with five spot horizontal well pattern increased in oil recovery, though it recorded low displacement efficiency. Because of viscous fingering into the aquifer and the gas zone. Furthermore surfactant flooding revealed a higher sweep efficiency than waterflooding.Taber et al., (1997) maintained that polymer flooding is only attractive for medium viscous oils. However, due to the demand for oil globally, polymer flooding is now attractive for heavy oil associated with higher viscosity Wassmuth et al; (2007). Polymer flooding is frequently employed in boosting the sweep efficiency through three mechanisms: improvement of the viscosity of the displacing fluid; reduction of the permeability of swept zones; increasing of the reservoir macroscopic displacing efficiency. In some of the oil fields, the stability of the polymer was improved by the addition of Nano-particles which imparts on the viscosity of the polymer solution Goshtasp Cheraghian et al., (2015).

Produced water" is an accepted expression in describing water produced in the process of hydrocarbon withdrawal from a petroleum formation. Atoufi H.D and Lampert D.J (2020). The major challenge encountered during the withdrawal of hydrocarbon from reservoirs is the "produced water". Parameters of some petroleum formations such as heterogeneity are customarily supportive of water production, for instance, formation produced through active aquifer drive may witness water coning due to the upward movement of the oil-water contact (OWC) leading to encroachment and elevated water production Azza Hashim Abbas et al; (2017).

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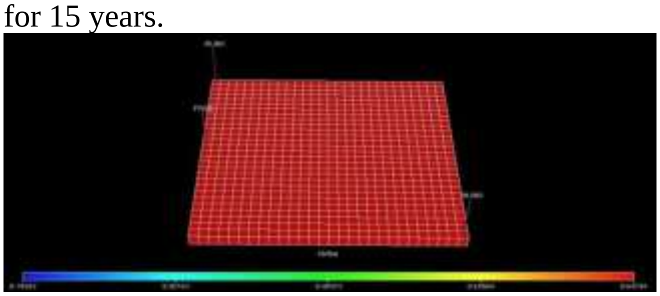
The explanation for the considerable water production dilemma can be itemized into; Technique of Water Management and Technique for Water Disposal; there have been facts that oil reservoirs produced water are contaminants and injurious to health due infectious potable water as a consequence of crude sewage in most of the world`s developing nations. Therefore it calls for the application of standard ecological rules and regulations for the disposal of produced water from mature oil fields Y. Du (2005). Oil field operators grouped water production challenges in terms of complications. These challenges range from simple ones such as tubing or casing leaks and movement of oil-water contact to complex ones such as coning J. Elphick and A. R. S. Seright, (1997). The constituents of produced water are at variance, some contain heavy metals and traces of uranium, thorium, and potassium which lead to scaling in the wellbore casings Igunu E. T. and Chen G. Z (2014).

METHODOLOGY

This study was performed with the aid of Eclipse 100 Reservoir software. A synthetic heterogeneous reservoir model characterized by 28 x 28 x 1 grid cells with dimensions 300 x 300 x 60ft in the x, y, and z coordinates correspondingly was applied in this study. The datum depth of the reservoir is 8000 ft and the pressure at the datum depth is 4000 psi, to depict a depleted mature reservoir, the reservoir has an oil column thickness of 60ft, the Gas-Oil contact, and Water-Oil contact are at the datum depth of 8000ft and 8060 ft respectively. The injection wells were strategically placed at different permeability layers of the reservoir (2804md, 2871md, 2937md, 3004md, 2070 md). The simulation results showed field oil production, water production, and gas production. The determination of optimum injection rate for the two recovery scenarios, analysis of the data result was carried out by applying ratio data method. The goal is to find the injection rate that yields the highest oil-to-water ratio.

Design of experiment

A horizontal producer well (PROD) was placed in the center of the reservoir and injectors' wells were placed at various permeability layers. Two recovery scenarios were investigated: water flooding and polymer flooding. Injection rates of 1000, 4000, 7000, 10000, 13000, and 16000 STB/day were designed for both water flooding and polymer flooding. A polymer concentration of 50 was applied for the polymer flooding process and a simulation of the reservoir was conducted for 15 years.



RESULTS

Table 1: Oil Production, and Water Production for Waterflooding at different water injection rates

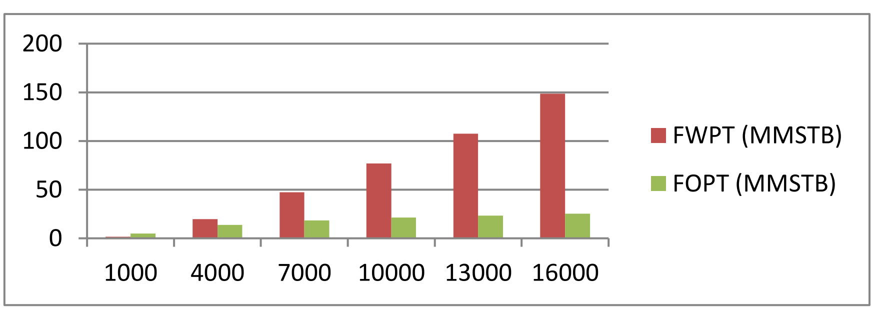
Injection Rate (STB/day)	**FOPT (MMSTB)**	**FWPT (MMSTB)**
1000	4.914	1.485
4000	13.878	19.684
7000	18.270	47.393
10000	21.224	76.957
13000	23.328	107.342
16000	25.315	148.527

Table 2: ratio data analysis for oil and water Production of Waterflooding at different water injection rates

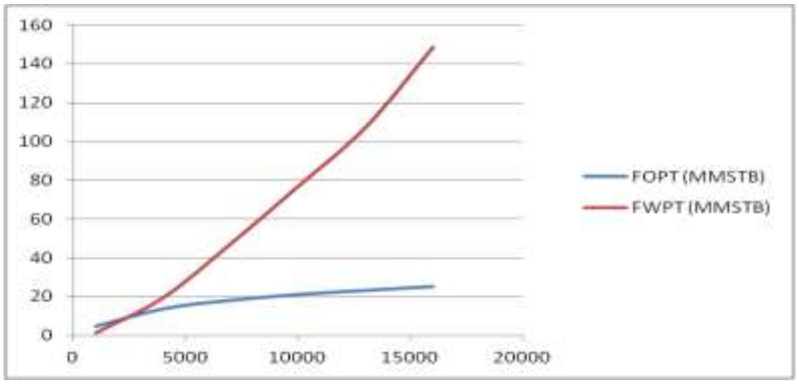
Injection Rate (STB/day)	**FOPT (MMSTB)**	**FWPT (MMSTB)**	**Data Analysis**
1000	4.914	1.485	3.31 : 1
4000	13.878	19.684	0.705 : 1
7000	18.270	47.393	0.386 : 1
10000	21.224	76.957	0.276 : 1
13000	23.328	107.342	0.217 : 1
16000	25.315	148.527	0.170 :1

Table 3. Ratio Analysis of optimum injection rate for Water flooding at different injection rate

Injection rate stb/day	1000	4000	7000	10000	13000	16000
Oil Ratio	3.31	0.705	0.386	0.276	0.217	0.170



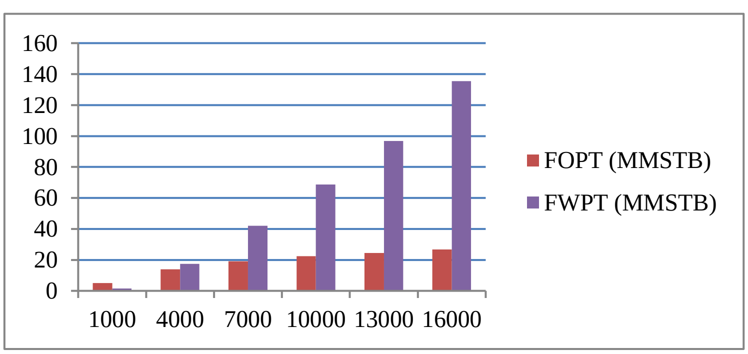
Graph 1a: Oil Production, and Water Production for different water injection rates



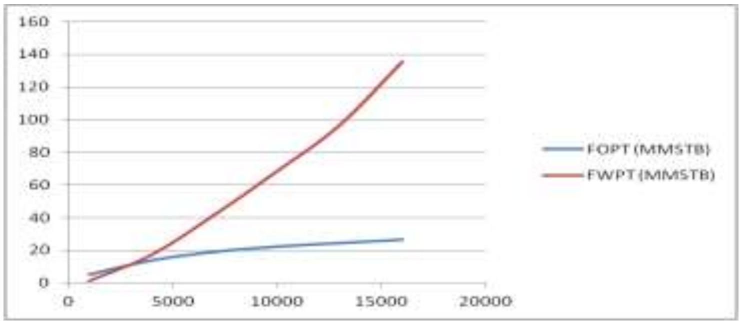
Graph 1b: Oil Production, and Water Production for different water injection rates

Table 4: Oil and water production of polymer flooding at different injection rates

Injection Rate (STB/day)	FOPT (MMSTB)	FWPT (MMSTB)
1000	4.949	1.498
4000	13.832	17.511
7000	19.076	41.978
10000	22.361	68.655
13000	24.561	96.858
16000	26.645	135.56



Graph 2a: Oil, and water production for different polymer flooding injection rates



Graph 2b: Oil and water production for polymer flooding at different injection rates

Table 5: Ratio data analysis for oil and water Production of Polymer flooding at different water injection rates

Injection Rate (STB/day)	FOPT (MMSTB)	FWPT (MMSTB)	Ratio Data analysis
1000	4.949	1.498	3.30: 1
4000	13.832	17.511	0.79 :1
7000	19.076	41.978	0.45 :1
10000	22.361	68.655	0.33 :1
13000	24.561	96.858	0.25 :1
16000	26.645	135.56	0.20 :1

Table 6. Ratio data analysis for oil recovery of polymer flooding at different injection rates

Injection rate STB/Day	1000	4000	7000	10000	13000	16000
Oil Ratio	3.30	0.79	0.45	0.33	0.25	0.20

Table 7: comparison of Oil and Water productions during water flooding and polymer flooding process at different injection rates

Injection Rate (STB/day)	FOPT (MMSTB) water Injection	FOPT (MMSTB) Polymer Injection	FWPT (MMSTB/Day) Water Injection	FWPT (MMMSTB/Day) Polymer Injection	Dif in FOPT Water & Polymer Injection	Dif in FWPT Water &Polymer Injection
1000	4.914	4.949	1.485	1.498	**0.035**	**0.013**

4000	13.878	13.832	19.684	17.511	**-0.046**	**-2.173**
7000	18.270	19.076	47.393	41.978	**0.806**	**-5.415**
10000	21.224	22.361	76.957	68.655	**1.137**	**-8.302**
13000	23.328	24.561	107.342	96.858	**1.233**	**-10.484**
16000	25.315	26.645	148.527	135.56	**1.330**	**-12.967**

DISCUSSION

The optimum injection rate is the rate gives the highest oil ratio which is observed at an injection rate of 1000 stb/day with an oil ratio of 3.31. this indicate that for every one stock tank barrel of water produced, approximately 3.31 units of oil are produced. The simulation study shows that an increase in injection rate is followed by increases in the production of oil, and water during water flooding, while during polymer flooding operation, more oil and less water are produced. During flooding in both scenarios, the 1000 STB/day injection rate shows that the ratio of produced oil to produced water is 3.3: 1 compared to higher injection rates, therefore injection rate increments require a very small margin to be able to achieve optimum recovery of oil and gas. The study also reveals that in a heterogeneous formation, if the well is close to a high permeable layer, water mobility will also be high and this is one of the reasons for the higher volume of water production. For polymer flooding, table shows that the oil-water ratio decreases as the injection rate increases, based on the trend, the highest oil-water ratio is at the lowest injection rate of 1000stb/day .

Implication to research and practice

The application of simplistic ratio data analysis is one of the best methods that can be used to compare oil recovery from different injection rate. It is a firsthand tool that field engineers can easily employ to guess correctly the injection rate that produces more oil.

CONCLUSION

Though a high injection rate can produce more oil, the water production is also high which attracts more cost implications during produced water disposal or change of equipment parts due to corrosion from produced water.
Injection wells closer to high permeable layers in a heterogeneous reservoir aid sweep efficiency of displacing fluid but also account for higher water production. The optimum injection rate is that rate that produces a higher volume of oil than water.

Future research

Further research is needed to develop predictive model that integrate ratio data analysis with other relevant parameters, such as reservoir properties, fluid characterization, and injection strategies.

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