Archives of Petroleum & Environmental Biotechnology

Research Article

Serhat Canbolat, et al. Petro and Envi Biotech, APEB-103.
DOI: 10.29011/2574-7614. 100103

Analysis of Water-Oil-Ratio Performance in Fractured Medium

Serhat Canbolat*

Near East University, Nicosia, Cypruss

***Corresponding author:** Serhat Canbolat, Near East University, Nicosia, Cypruss, Email: serhat.canbolat@neu.edu.tr

Citaion: Serhat Canbolat (2016) Analysis of Water-Oil-Ratio Performance in Fractured Medium. Petro Envi Biotec APEB-103. DOI: 10.29011/2574-7614. 100103

Received Date: 29th October, 2016; **Accepted Date:** 25th November 2016; **Published Date:** 30th November, 2016

Abstaract

Natural water drive is the most common mechanisms in oil reservoirs. High water production in oil fields is one of the major difficulties for the petroleum industry, while more reservoirs become mature. Costs of lifting, handling, separation and disposal of large amounts of produced water; environmental concerns about this water; coning due to bottom water drive; large amounts of produced water from high permeability layers; increased corrosion rates; higher tendency for emulsion; and, scale formation are among the main problems due to water production which often decrease the economic life of a well. Therefore, there is a need to reduce excessive water production and take precaution if the production life of the well has not been finalized before ultimate recovery.

The objective of this paper is proposing a new approach using a plot of the logarithm of the water-oil ratio (WOR) versus cumulative production (Np) for the evaluation and prediction of water in flux performance for identifying the dominant reservoir performance mechanism (uniform displacement, water coning, or water channeling).

WOR performance analysis indicates that Z-4, Z-8, Z-10, Z-16, Z-18, Z-19 and Z-21 currently are not assumed as the potential candidate wells for water treatment application.However, Z-1, Z-6, Z-7, Z-9, Z-11, Z-12, Z-13, Z-14, Z-15 and Z-20 wells show strong potential for being the candidates for water treatment operation.

Introductions

Sources of Excessive Water Production

Water production is one of the major technical, environmental and economic problems associated with oil production. Water production limits the productive life of the oil reservoir and causes severe problems including corrosion of tubular, fines migration, hydrostatic loading. Produced water represents the largest waste stream associated with oil production. The environmental impact of handling, treating and disposing of the produced water can seriously affect the profitability of oil production.

The sources of water include formation water, aquifer and injected water. The formation water can be originated from a water saturated zone within the reservoir or zones above or below the pay zone. Many reservoirs are adjacent to an active aquifer and are subject to bottom or edge water drive. Water is often injected oil reservoirs for pressure maintenance or secondary recovery purposes. Seright has remarked that, the injected water is one source of water production problem [1].

Reynolds has suggested that, the water usually flows to the wellbore during production, and this can occur through two types of paths. First, it flows to the wellbore through a separate path from that of the hydrocarbons. This type of water production directly competes with hydrocarbon production. Reducing water production in this case often leads to increased hydrocarbon production rates and higher recovery efficiencies. This type of water production should be the primary candidate of control treatments. The second type of water production is the water that is co-produced with oil usually later in the life of a waterflood. Reducing production of this type of water will result in corresponding reduction in oil production [2].

Moreover, Thomas et al. have also proposed that, layering and associated permeability variations are major channeling in the reservoir. As the water sweeps the high permeability intervals, permeability to subsequent flow of the water becomes even higher in those intervals and lower permeability intervals remain unswept. This leads to premature water breakthrough. Channeling can be further exacerbated by lower water viscosity as compared to oil particularly during waterflooding [3].

Strong Aquifer

Several authors have mentioned that the drive energy is provided by an aquifer that interfaces with the oil in the reservoir at the oil-water contact (OWC). As production continues, and oil is extracted from the reservoir, the aquifer expands into the reservoir displacing the oil. Clearly, for most reservoirs, solution gas drive will also be taking place, and there may also be a gas cap contributing to the primary recovery [2,3,4]. Two types of water drive are commonly recognized:

1. Bottom water drive
2. Edge water drive

The pressure history of a water driven reservoir depends critically upon:

1. The size of the aquifer,
2. The permeability of the aquifer,
3. The reservoir production rate.

If the production rate is low, and the size and permeability of the aquifer is high, then the reservoir pressure will remain high because all produced oil is replaced efficiently with water [2,3,4].

If the production rate is too high then the extracted oil may not be able to be replaced by water in the same time scale, especially if the aquifer is small or low permeability. In this case the reservoir pressure will fall [2,3,4].

Azari et al. have mentioned that the gas-oil ratio (GOR) remains very constant in a strongly water driven reservoir, as the decrease in pressure is small and constant, whereas if the pressure decrease is higher (weakly water driven reservoir) the GOR increases due to evolution of gas from the oil and water in the reservoir. Likewise the oil production from a strongly water driven reservoir remains fairly constant until water breakthrough occurs [5]. A natural water drive occurs when the oil reservoir overlays, or is flanked by, a water aquifer Figure 1.

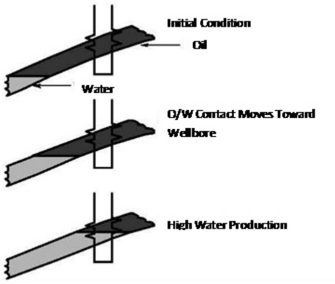

Figure1: Behavior of Strong Aquifer [20].

Al-Afaleg and Ershagi, Fernand and Van Golf-Racht have remarked that, as the pressure in the oil reservoir decreases due to fluid production, the aquifer water expands, leading to water influx from the aquifer into the oil reservoir [6,7].

For a given pressure drop at the boundary between the oil reservoir and the water aquifer, the influx of large volumes of water into the oil reservoir is necessary in order to provide adequate pressure support. This is due to the much smaller water compressibility compared to that of the reservoir fluids.

Consequently, like Cholet, all researchers have agreed that active aquifer support requires relatively large aquifer sizes. When active aquifer support is present, relatively high pressures can be sustained in the oil reservoir, thus leading to improved oil recovery [5,6,7,8].

However, Hardy and Van Batenburg have told that, the influx of water into a reservoir from an underlying aquifer is often a dilemma. Existence of the water often provides a strong energy support mechanism, which enhances production; however, it does so at a cost. That's why, determining the optimum production rate of oil that will minimize water coning while at the same time optimize the economics is an important consideration throughout the production life of a well[9].

Water Channeling

Another source of excessive water production is channeling. In many cases, the source of water is a water injection well in a water-flooded reservoir.

In Azari et al.'s work, it has been reported that a connection such as this between an injector and a producer reduces the amount of available water to push oil to the producer, decreases sweep efficiency, and increases the volume of produced water requiring disposal [5].

Water channeling occurs when a very high effective permeability connection between a source of water and the production well exists as shown in Figure 2.

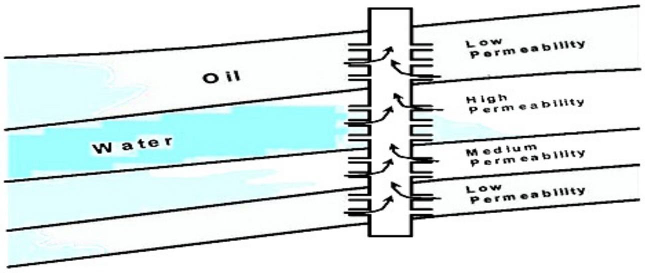

Figure 2: Schematic Configuration for Water Channeling [5].

Seright et al. have proposed that water channeling is caused by reservoir heterogeneities that lead to presence of high permeability streaks. In carbonates, fractures or fracture-like features are the most common cause of channeling. Water production could emanate via natural fractures from underlying aquifers. Fractured reservoirs can exhibit high productivity coupled with serious technical challenges. The major challenge is due to the fact that the permeability through the fractures is orders of magnitude larger than the permeability through the matrix. Once the hydrocarbons have been recovered from the fracture then the remaining target for recovery is in the tighter matrix. Induced or natural fractures can cause channeling between wells [1].

Thomas et al. have reported that also in unfractured reservoirs often stratification and associated permeability variations among various layers can result in channeling between an injector and a producer or from an edge water aquifer to the producers. Deviated and horizontal wells are prone to intersect faults or fractures. If these faults or fractures connect to an aquifer, water production can jeopardize the well [3].

Water Coning

Reynolds has defined that, water coning is caused by vertical pressure gradient near the well. The well is produced so rapidly that viscous forces overcome gravity forces and draw the water from a lower connected zone toward the wellbore. Eventually, the water can break through into the perforated or open-hole section, replacing all or part of the hydrocarbon production. Once breakthrough occurs, the problem tends to get worse as higher cuts of the water are produced. Although reduced production rates can curtail the problem, but they cannot cure it [2].

Cholet has showed this differential pressure deformation of oil/water interface into a cone shape as in Figure 3 [8].

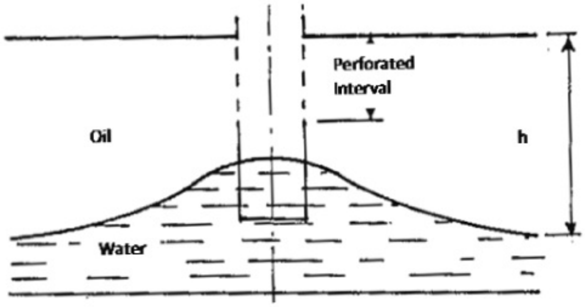

Figure 3: Schematic Configuration for Water Coning [8].

As production rate is increased, the cone height above the initial OWC also increases until water breaks through into the wellbore. The breakthrough occurs when the cone shaped profile becomes unstable due to the high-pressure drawdown around the wellbore [8].

Mathematical models have been developed to predict the performance of oil wells with water coning problems after water breakthrough. The equilibrium condition necessary to avoid water breakthrough requires that the vertical pressure gradient in the oil zone caused by viscous forces be balanced by the differential-gravity gradient in the underlying water zone [2,3,7,8,10].

Ahmed has used in all of vertical well coning calculations assuming the perforations are always located at the top of the oil zone, thereby maximizing the distance between the perforations and the oil-water contact.It is important to note that these correlations are valid for a continuous oil pay zone with oil-water contact [11].

Effect of Fractured Carbonate Reservoirs

Carbonates are sedimentary rocks deposited in marine environments with clear, shallow, warm waters and are mostly of biological origin. They are usually deposited very close to the place where they were created.

Moreover, this local deposition contributes significantly to the heterogeneity of carbonate grains. After carbonate rock is formed, a range of chemical and physical processes begins to alter the rock structure changing fundamental characteristics such as porosity and permeability, called diagenesis. Secondary porosity is one of the characteristic features of carbonate reservoirs. Due to variation in depositional environment and digenetic processes, several types of secondary porosity including vuggs, moulds, channels, and fractures may develop in carbonates. Secondary porosity may enhance permeability when it exceeds a certain value, subsequently increasing production [12].

Warren and Root have grouped the porosity of carbonate rocks into three types: connected porosity, existing between the carbonate grains; vuggs, which are unconnected pores resulting from the dissolution of calcite by water during diagenesis; and fracture porosity which is caused by stresses following deposition. Diagenesis can create stylolite structures which form horizontal flow barriers, sometimes extending over kilometers within the reservoir, having a dramatic effect on field performance. Fractures can be responsible for water breakthrough, gas coning and drilling problems such as heavy mud losses and stuck pipe [13]. All together, these three forms of porosity create a very complex path for fluids and directly affect well productivity.

In addition to the variations in porosity, Legens et al. have remarked that, wettability is a further heterogeneous characteristic in carbonates [14].

Akbar et al. have repeated that, most carbonate reservoirs are naturally fractured. The fractures exist at all scales, from microscopic fissures to kilometer sized structures called fracture swarms or corridors, creating complex flow networks in the reservoir. That's why, the movement of hydrocarbons and other fluid is often not as expected or predicted. Just a few very large fracture corridors can be highways for fluids in the middle of a carbonate reservoir; therefore, knowing their exact position is critical for planning new wells and for simulating and forecasting reservoir production [10].

Ghafoori et al. have proposed that, a fractured reservoir is a dual porosity system consisting of primary intergranular matrix interlaced by a network of channels comprising the fracture network. Usually the fracture system is extensive, and has considerable surface area contact with matrix, oil is easily transferred into the fracture system where it is delivered to the producing wells with very little loss of pressure. Thus a fractured reservoir is capable of surprising performance compared with a conventional reservoir of similar matrix porosity and permeability [11].

Van Golf-Racht and Fernand, have implemented, the properties and mechanical behavior of a fractured reservoir depend on the matrix and fracture characteristics. Particularly important properties are the capability of the matrix and fractures to store (porosity) and transport (permeability) fluids. A commonly used classification subdivides fractured reservoirs into types based on the matrix and fracture contribution to porosity and permeability [7]. The simplest conventional and fractured reservoir representations are given in Figure 4.

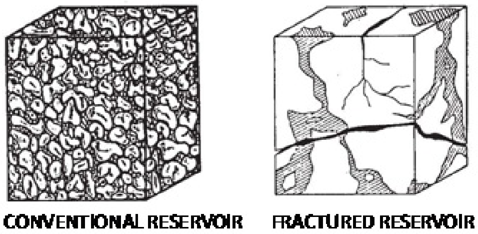

Figure 4: Conventional and Fractured Reservoirs [15].

Several authors have remarked, the essential characteristics of a fractured reservoir is a network of fractures oriented in both horizontal and vertical directions extending throughout the reservoir. This assures tremendous contact area of the fracture channels with the matrix and almost unrestricted movement of fluids in any direction shown in Figure 5 [13,15].

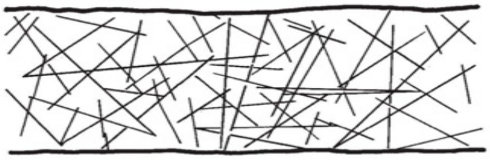

Figure 5: Fractures Oriented in Intersecting Planes in the Reservoirs [15].

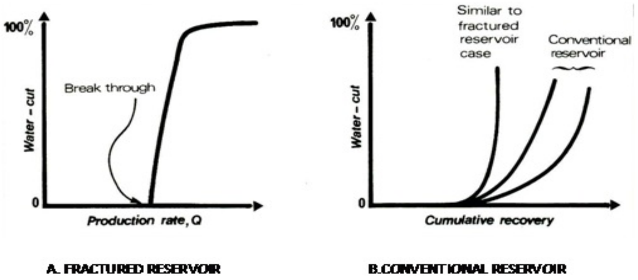

Figure 6: Water-Cut in the Fractured and Conventional Reservoirs [15].

Water cut in the fractured reservoir is essentially a function of production rate while in the conventional reservoir it depends on the conditions causing the beakthrough, both cases coning and displacement processes.

In a fractured reservoir the water-cut increases suddenly from 0 to 100 % if a well rate is higher than critical rate Figure 6. In conventional reservoir the water-cut increases slowly 0 to 100 % due to condition of displacement-uniformity of permeability distribution, viscosity ratio etc [15].

Due to the heterogeneous characteristics of fractured carbonates water cut in the reservoir increases unexpectedly.

Production Analysis of Field

Field Z has been on production with a mechanism which is described as strong natural water drive reservoir where oil production and fluid flow is controlled by fractures connected to vuggs.

Figure 7: Z Field Structural Contour Map Top B Formation.

Estimating the petrophysical properties and understanding the fluid flow mechanisms of carbonate reservoirs are more challenging, as well as production performance. Production mechanisms in fractured reservoirs differ strongly from those in (conventional) non-fractured reservoirs. The fracture network delineates matrix, in which most of the oil is contained. The fracture system, however, will contribute most to the fluid flow conductivity. During the initial period of pressure depletion, oil will be expelled from the matrix into the fracture system by expansion and solution gas drive [16].

Naturally fractured reservoirs are usually anisotropic and heterogeneous having different horizontal to vertical permeability ratios. Productivity of naturally fractured reservoirs depends on the permeability, size, distribution and extension of fractures throughout the matrix in each direction [16].

In oil-wet rock the capillary forces will try to retain the oil in the matrix, and displacement from the matrix will be by gravity forces only. In order to do this when the water cut reaches higher values, higher drawdown rates are necessary to realize oil flow from matrix to fracture [16].

At the start of the production life of Z field wells, the fractures are filled with an oil, and they allow flow rates water free, however, as the mobile oil is withdrawn from the fractures, due to the fracture intensity distribution and the vertical fractures [16], it is quickly replaced with water that is pushing up from the aquifer.

As a result, water production rates increase rapidly and producing fluid level rise, which leads to rapidly declining oil rate. The ability to recover oil from lower permeability matrix rock becomes increasingly difficult as more and more water is produced. Oil stored in lower permeability matrix is slowly recovered over many years, as it moves into the large water saturated spaces [16].

The wells having low cumulative oil recovery and producing with high water cut is the clue for direct communication of well with aquifer. Water channeling/intrusion is caused by fractures or fracture-like features in carbonate reservoirs. The matrix oil cannot be able to flow to the wellbore due to high relative permeability of water coming from the aquifer. This is caused by strong natural aquifer that expands, due to the fluid production. Field wells cumulative oil production and water cut values are given in the Table.1including abandoned ones and producing with water-cuts of 98% or greater, at or near their economic limit [16].

Well Name	Cumulative Oil Prod.	Cumulative Water Prod.	Water Cut	Status
	bbls	bbls	%	
Z-1	43,638	575,483	100	Abandoned Producer
Z-2	--	--	100	Disposal Well
Z-3	89,969	26,285	100	Disposal Well
Z-4	121,542	337,625	83	Producer
Z-5	232,204	73,558	100	Abandoned Producer
Z-6	77,100	359,941	99	Shut-in
Z-7	293,169	646,026	98	Producer
Z-8	97,720	114,597	62	Producer
Z-9	342,865	1,221,396	99	Producer
Z-10	150,954	16,498	24	Producer
Z-11	73,556	828,079	99	Shut-in
Z-12	70,076	192,413	98	Producer
Z-13	100,652	340,332	99	Shut-in
Z-14	99,415	1,319,946	98	Producer
Z-15	167,890	1,326,665	98	Producer
Z-16	44,479	1,984	4	Producer
Z-17	--	--	--	Dry Well
Z-18	12,690	49,088	86	Producer
Z-19	13,412	115,925	98	Producer
Z-20	21,881	746,050	99	Producer
Z-21	19,064	49,156	86	Producer
	2,072,276	8,341,047		
* All numbers updated in JUNE 2011				

Table 1: Z Field Wells Cumulative Oil & Water Production, Water Cut and Status.

Fanlysis of Water Oil Ratio Performance

Natural water drive is the most common mechanisms in oil reservoirs. A plot of the logarithm of the water-oil ratio (WOR) versus cumulative production (Np) is the technique used for the evaluation and prediction of water in flux performance. Besides, the WOR data can be plotted versus Np issued as a diagnostic tool to identify the dominant reservoir performance mechanism (uniform displacement, water coning, or water channeling) [17].

The intention is to develop a methodology and use this technique for selecting right well candidates for water treatment operation with proposed model for the analysis of oil and water production data (WOR, Cumulative production). The qualitative analysis of (WOR) performance data would be significantly improve our evaluation and selection criteria for wells [16].

In Figure 8 the first analysis of WOR performance is seen for Z-1 well. The sharp and almost vertical increase is observed in WOR data means that the well production highly affected by the fractures. The well has a very high fracture intensity that the water hasinvaded to the well very quickly and continuously that the cumulative production cannot be reached its desired value. Water invasion is very dramatic for this well with respect to the analysis.

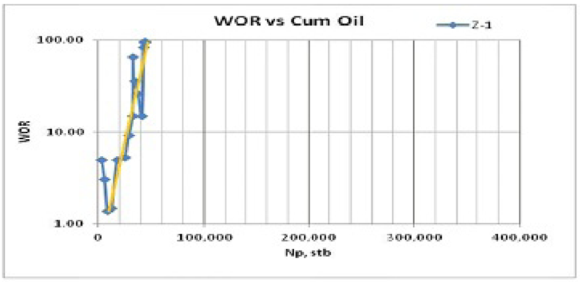

Figure 8: WOR Performance Analysis for Z-1.

In Figure 9 the WOR performance of Z-4 well is shown. The sharp increase in WOR is followed by sharp decrease due to water injection from neighboring well Z-6. The fracture network has developed well enough that oil in the fractures produced quickly and aquifer invasion has delayed with controlled production.

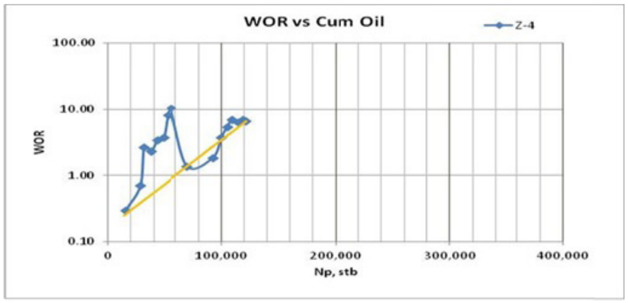

Figure 9: WOR Performance Analysis for Z-4.

In Figure 10log WOR vs. cumulative oil production of Z-6 well is shown. Due to its location and fracture development in the well the WOR has increased very sharply. The water has invaded to the well very quickly and continuously that the ultimate cumulative production cannot be reached. Water invasion is very intense for this well with respect to the analysis.

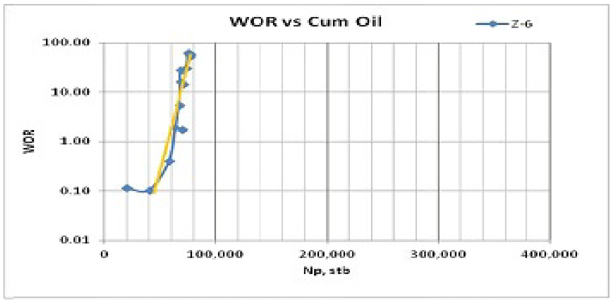

Figure 10: WOR Performance Analysis for Z-6.

In Figure 11the WOR performance of Z-7 well is shown. The sharp increase in WOR is followed by sharp decrease due to perforation done in the upper zone. During the production period, controlled rate and good developed fracture network let the well produce second highest cumulative oil in the field with a delayed aquifer invasion.

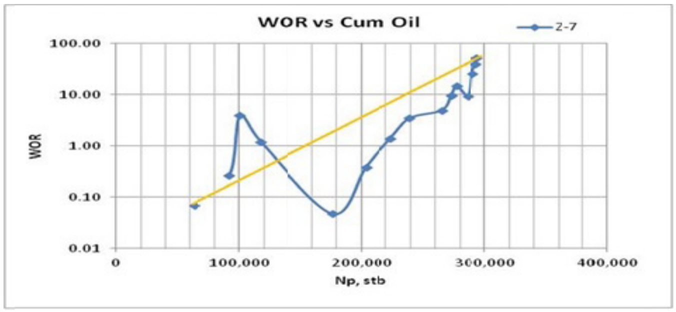

Figure 11: WOR Performance Analysis for Z-7.

Z-8 analysis is shown in Figure 12, that a gradual increase in WOR shows a declining trend due to the neighboring water injection/disposal operations. The well has not been involved with a serious water encroachment problem during production and is not a candidate for water treatment operation currently.

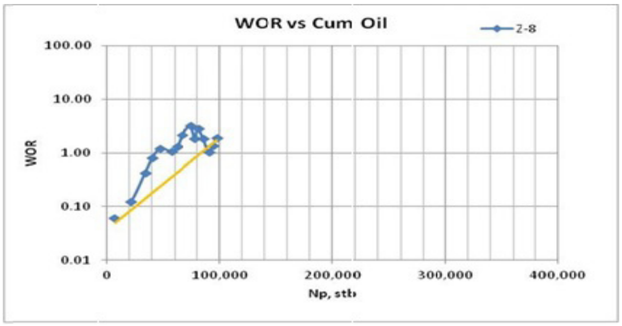

Figure 12: WOR Performance Analysis for Z-8.

Z-9 well has reached the highest cumulative production without reaching higher water cut till to the production of approximately 300,000 bbls of cumulative oil Figure 13. However, the well than has been invaded by the aquifer water sharply reaching 100% water cut. This shows the favorable development of the fracture network, porosity, permeability and drainage area of the well as a candidate.

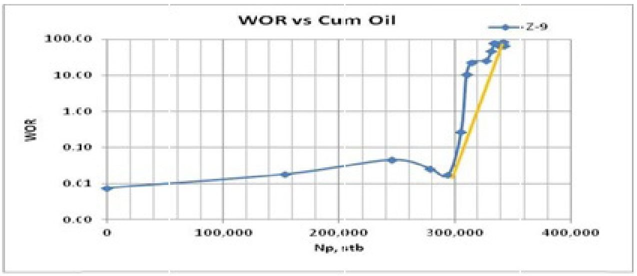

Figure 13: WOR Performance Analysis for Z-9.

Other wells WOR performances graphs are also given in respectively.

Z-10 well has produced 140,000 bbls of cumulative oil with a low WOR showing a good performance of productionFigure 14.

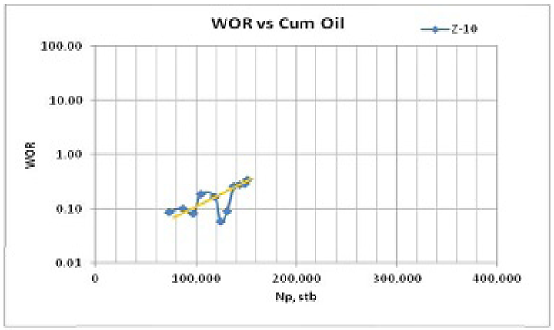

Figure 14: WOR Performance Analysis for Z-10.

In figure 15 wells Z-11, Z-12, Z-13, Z-14, Z-15 and Z-20 show very sharp increase with higher WOR value showing the capacity to produce more as a candidate potential for water treatment operation.

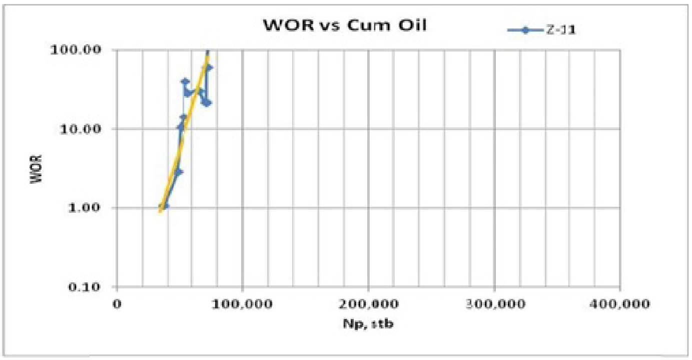

Figure 15: WOR Performance Analysis for Z-11.

Very low WOR and low cumulative oil recovery distinguish Z-16 form other wells and is confirming its potential not to be a candidate for water treatment operation due to low permeability and fracture potential.

With respect to analysis Z-18, Z-19and Z-21 show a sharp increase but the value of WOR is not high showing low permeability and low fracture intensity development around these wells.

Conclusions

Excessive water production can not only reduce the project economics by treatment and disposal cost but also can completely prevent the production from oil wells, from which the production has become uneconomic.

Plotting the logarithm of WOR vs. Np graphs of each well in fractured carbonate reservoirs exposed a new technique for interpretation of the candidate wells for water treatment application. The sharp increase is observed in WOR shows that the fractures are very dominant on production performance and high fracture intensity around the well that the intrusion of the water is continuous means that the well is candidate.

WOR performance analysis indicates that Z-4, Z-8, Z-10, Z-16, Z-18, Z-19 and Z-21 currently are not assumed as the potential candidate wells for water treatment.

However, Z-1, Z-6, Z-7, Z-9, Z-11, Z-12, Z-13, Z-14, Z-15 and Z-20 wells show strong potential for being the candidates for water treatment operation.

Acknowledgement

The authors would like to appreciate SAYER Group of Companies for giving the permission of Z field data used in this study.

References

1. Seright RS, Lane RH, Sydansk RD (2003) A Strategy for Attacking Excess Water Production. SPE Production and Facilities.
2. Reynolds RR (2003) Produced Water and Associated Issues, Oklahoma Geological Survey Open-File.
3. Thomas FB and Bennion DB (1998) Anderson G. and Meldrum B, Water Shutoff Treatments – Reduce Water and Accelerate Oil Production, 49th Annual Technical Meeting of The Petroleum Society of CIM in Calgary, AB, Canada.
4. Di Lullo G and Rae P (2002) New Insight into Water Control- Review, Paper SPE 77963 presented at SPE Asia Pacific Oil and Gas Conference and Exhibition, Melbourne, Australia.
5. Azari M and Soliman M (1997) Reservoir Engineering Aspects of Excess Water and Gas Production, Paper SPE 37810, presented at the SPE Middle East Oil Show, Bahrain.
6. Al-Afaleg NI and Ershagi I (1993) Coning Phenomena in Naturally Fractured Reservoirs, Paper SPE 26083, Western Regional Meeting held in Anchorage Alaska, USA.
7. van Golf-Racht TD and Fernand S (1994) Water-Coning in a Fractured Reservoirs, Paper SPE 28572, Annual Technical Conference and Exhibition held in New Orleans, LA, USA.
8. Cholet H (2000) Well Production Practical Handbook, Editions TECHNIP27 rue Ginox, 75737 Paris Cedex 15 France.
9. Hardy M and van Batenburg D (1997) Near-Wellbore Temperature Simulations Assist Design of Water-Shutoff Treatments, Paper SPE 38196, presented at the SPE European Formation Damage Conference held in Den Haag, The Netherlands.
10. Akbar M, Nurmi R, Standen E, Sharma S, Pinwar P, et al. (1993) Middle East Well Evaluation Review, No:14 Schlumberger Oil Field Review.
11. Ahmed T (2006) Reservoir Engineering Handbook, Gulf Professional Publishing Elsevier Inc. Linacre House, Jordan Hill, Oxford OX2 8DP, UK.
12. Oil and Natural Gas Commission, Schlumberger, Carbonate Reservoirs, 2007.
13. Warren JE and Root PJ (1963) The Behavior of Naturally Fractured Reservoirs, SPE Journal, Volume 3.
14. Legens C, Toulhoat H, Cuiec L, Villieras F, Palermo T (1998) Wettability Change Related to the Adsorption of Organic Acids on Calcite: Experimental and Ab Initio Computational Studies, Paper SPE 49319, prepared for presentation at the SPE Annual Technical Conference and Exhibition, New Orleans.
15. Schlumberger (1980) Reservoir and Production Fundamentals Booklet.
16. Canbolat S and Parlaktuna M (2012) Well Selection Criteria for Water Shut-Off Polymer Gel Injection in Carbonates, SPE 158059, 12.SPE Abu Dhabi International Petroleum Exhibition & Conference held in Abu Dhabi, UAE.
17. Bondar VV and BlasingameTA (2002) Analysis and Interpretation of Water-Oil-Ratio Performance, Paper SPE 77569,SPE Annual Technical Conference and Exhibition held in San Antonio, Texas.