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Evaluation of Matured Oil Field Rim through Fluid Contacts Movement

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Abstract
Most reservoir in mature oil fields are vulnerable to challenges of water and/or gas coning as the size of their oil column reduces due to extensive period of oil production. These often result to low oil production and excessive water and/or gas production. This study therefore seeks to evaluate the occurrence of coning through the movement of fluid contacts in mature oil field reservoir. MBAL petroleum software was used to study the tendency of coning in mature oil field in the Niger delta. Using reservoir production history; fluid saturation, initial pressure, initial fluid contacts and depth data, a simulation was run to predict the future movement of oil-water contact and gas-oil contact with declining pressure. Using the interception on a plot of oil-water contact and gas-oil contact against time, a point where both water and gas are likely to cone was identified. Sensitivity study was also carried out to evaluate the trend of the critical rate with the reduction in oil-column due to the shrinking fluid contact. It was observed that the critical rate reduces with declining oil rim fluid contacts. Therefore to avoid coning in mature oilfield rim, the critical rate of the respective decline in oil column thickness is determined to maximize oil production.

Keyword: Coning, critical rate, fluid contact movement, mature oil field.

1. Introduction

Mature oil fields refer to the fields that have past the peak of their production and are in a declining stage. Production from such reservoirs often perturbs the fluid contacts in a reservoir. Fluid contact is the interface that separates fluids of different densities in a reservoir. Horizontal fluid contacts are usually assumed, although tilted contacts occur in some reservoirs. Fluid contact monitoring is very essential especially in a reservoir with strong aquifer drive and overlying gas cap. As production commences, the oil water contact (OWC) moves upwards as the influx of water below the oil zone providing the drive force to replace the void space created as a result of the withdrawal of oil. The gas oil contact (GOC) also moves downwards as a result of the overlying gas cap. Overtime, this movement if not properly controlled can lead to water and/or gas coning, which may reduce the production of substantial quantity of oil and hence reduces the economic benefit derived from the reservoir, as it is been observed in some mature fields in the Niger Delta oil province. Most formation in the Niger Delta is friable and unconsolidated. The net to gross sand thickness varies across the delta. Porosity varies from 15 to 38 percent while permeability varies from less than 10 millidarcies to several darcies (Poston, Aruna & Thakur, 1982).

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Oil has been continuously produced from the Niger Delta oil field since its discovery in 1958. Cumulative production of many of the reservoirs in the Niger Delta field to date is over 80% of recoverable oil in place. This indicates that the field is at its mature stage of its productive life (Figure 1). Excessive water and/or gas production is a complex problem facing many matured fields, and has serious economic and environmental impact. Therefore, it is important to effectively evaluate the fluid contact movement, to determining the point of commencement of water and/or gas coning in the reservoir, in order to prevent the production of excessive water and/or gas, thereby optimizing oil production. This paper therefore seeks to evaluate fluid contact movement in a mature reservoir and determination of critical production rate to control the occurrence of coning in mature fields.

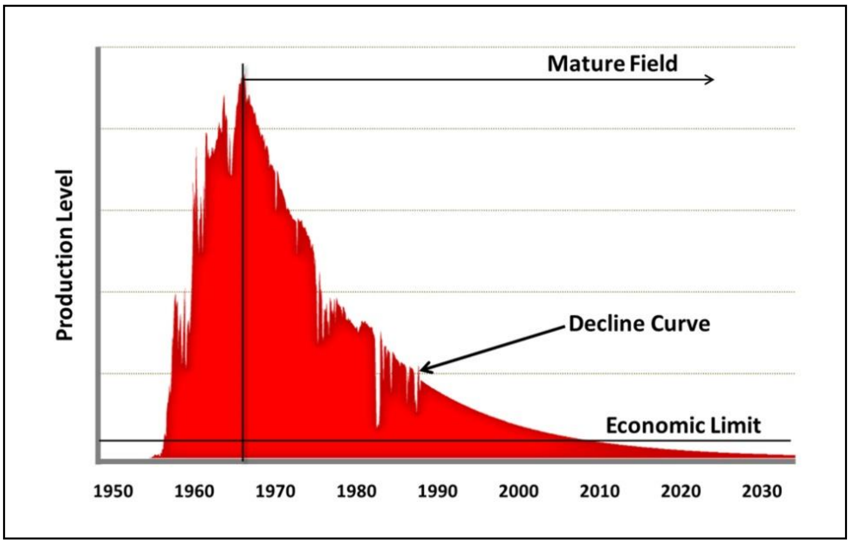

Figure 1: Sequence of Oil Production of Niger Delta Mature Field (Rob Hull, 2012)

1.1. Fluid Contact Movement

The location of the fluid contacts in the reservoir will change over time in the cause of oil production. The extent of the movement will depend on relative strength of the aquifer drive and gas cap drive. In reservoirs with strong aquifer drive it is more likely that the oil-water contact will move upwards. Figure 2 shows the possible movements of fluid contact in the course of oil production from an oil Reservoir.

The oil column will be displaced upward due to gas cap production under an active water drive. This will leave a zone of residual oil behind the advancing water and a zone of residual gas behind the advancing oil. Due to excessive gas cap production, a pressure gradient develops between the crest of the structure and the aquifer. As gas withdrawals continue and oil rim moves significantly, the oil column will gradually spread out through the gas cap. This leads to the loss of mobile oil and trapping of gas.

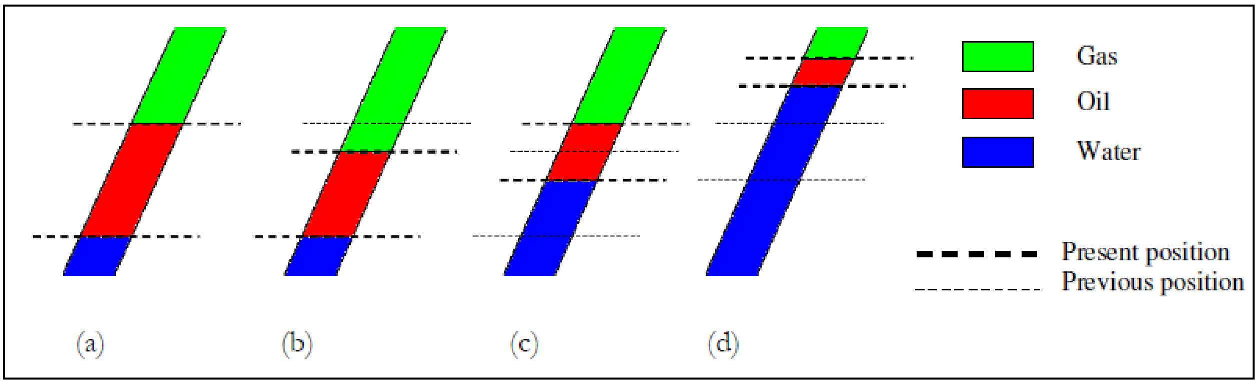

Figure 2: Movement of Fluid Contacts over Oil Reservoir life
(a) The oil reservoir at static conditions
(b) The GOC has moved downward due to expansion on oil production
(c) The oil column has moved upward due to displacement by the aquifer
(d) Loss of mobile oil due to strong aquifer displacing oil into gas cap

1.2. Coning Occurrence in Mature Field

Coning refers to the upward movement of water and/or the downward movement of gas in the reservoir, into the perforations of a producing well (Ahmed, 2006). These often result in a high water cut in case of water coning, and/or high GOR in case of gas coning (Figure 3). Coning are common occurrences in mature fields.

Mature fields represent the backbone of the Niger Delta oil production and produce about two thirds of the daily average oil production in the province and this percentage is increasing with time. Most of these mature fields were ones giant fields that have been produced over time, such that they are now acting like thin oil rim (see Figure 4). They are therefore prone to all the challenges facing any thin oil rim reservoirs. Understanding oil rim reservoir production dynamics is critical to successful development and management of these matured fields. Due to the thin oil column, the reservoirs are susceptible to water and/or gas coning, and this will influence production and economic feasibility of the project, especially when reservoir permeability is high as in Niger Delta oil fields. The interplay of subsurface factors and production constraints determine the dynamics of oil rim reservoir production. Oil recovery from a thin oil column under the influence of gas cap and water influx is strongly dependent on oil column thickness, formation permeability, gas cap size, aquifer strength, reservoir geometry, magnitude of bed dip, and oil viscosity (Vo *et al*, 2000).

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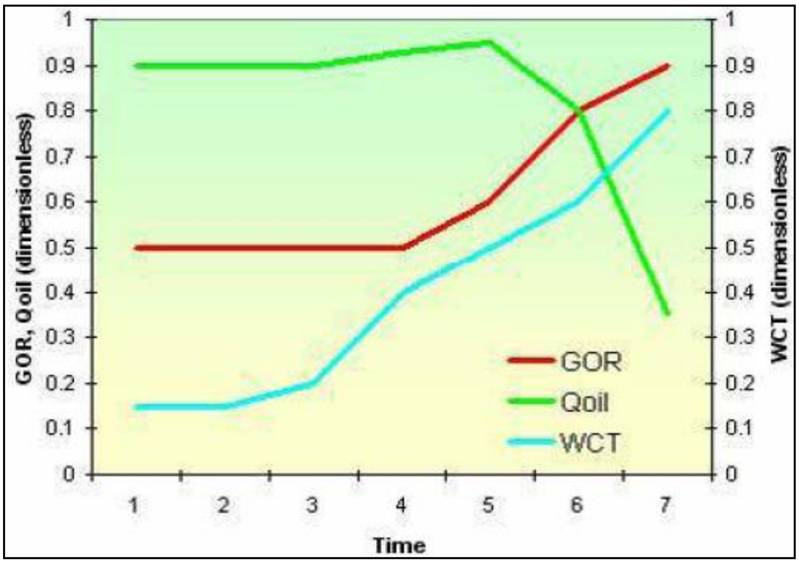

Figure 3: Typical Effect of Coning (Mogbo, 2010)

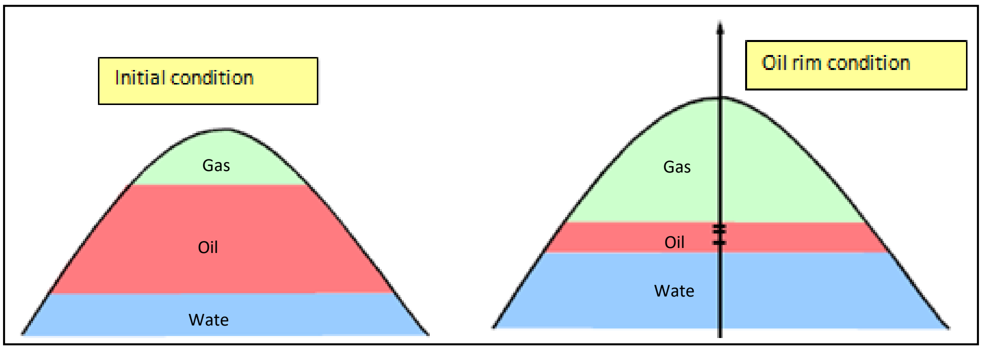

Figure 4: Mature field conditioned as thin oil rim

2. Review of Literature

In order to appropriately maximize oil production from the reservoir, many researchers has studied the impact of the reservoir fluid contacts movement.

Ariwodo, Kanfar, Al-Qatari, Saldungary & Rose, (2012) have shown that the Pulse Neutron Capture (PNC) Log is one of the most popular slim cased-hole formation evaluations logging tools, which allow running the survey without having to pull out the production string. The PNC Logs can be run periodically in the time-lapse mode to monitor changes in water saturation and movements in the oil-water contact and gas-oil contact.

Gil, Perez, Cuesta, Altamar & Sanabria, (2009) used an integrated interpretation of 3D seismic attributes, spectral decomposition and pseudo impedance for the identification of fluid contacts within heavy oil reservoirs in block II of the Uraco field, Eastern Venezuela. The combination of spectral decomposition data and pseudo impedances led to the identification of fluid contacts in the three phase reservoir. Log data was used to calibrate the attribute at well locations and to forecast lateral continuity.

Ogbunude, Egelle & Afoama (2014) presented a methodology for fluid contact monitoring using calibrated material balance models. To perform this calibration, pulsed neutron generated fluid contact was required. With the fluid contact determined by the pulsed neutron logs, the tuning of the model's sweep efficiency was done until a good match is obtained. The match obtained at a given sweep efficiency was described as calibrated model which can be used to predict future fluid contacts. A case study was used to validate the theory proposed and a good match was obtained showing that a calibrated material balance can be used to predict fluid contacts to reasonable accuracy.

Delauretis,Yarranton & Baker (2008) developed a methodology to estimate current oil-water-contact (OWC) and gas-oil-contact (GOC) in the field from initial fluid in place, production and, rock and fluid properties. The methodology was based on the volume of remaining fluid in the reservoir using material balance techniques and calculation of the fluid contacts assuming the whole reservoir as a single tank, and with best estimate of initial contacts and residual saturations. The result showed that in order to increase oil production from the current wells, gas injection could be increased in a way that takes into account the effect of fluid movement and the wells need, to be operated as much as possible at low gas oil ratio that is possible due to strong water drive.

2.1. Application of Horizontal Well Technology

Several researchers have recommended horizontal well technology as a solution for the development of reservoirs with water coning problems (Vijay *et al*, 1998; Al Kaioumi *et al*, 1996). While vertical wells act like point source concentrating all the pressure drawdown around the bottom of the wellbore, horizontal wells act more like a line sink and so distribute the pressure drawdown over the entire length of the wellbore. Therefore horizontal wells are generally accepted as a better way to control coning and improve recovery (Okwananke & Isehunwa, 2008). Research efforts have led to the development of mathematical equations for the evaluation of the performance of horizontal wells in coning control. Onwukwe (2012) presented a proxy models representing a graphical semi-analytical approach of estimating critical rate in oil rim reservoir using horizontal production in the Niger Delta given as:

$$q_{oc} = 6.7*10^{-4}\frac{k_h^{0.69}h_o^{1.47}L^{0.68}r_w^{\ 0.21}}{\mu_o^{0.98}B_o^{1.21}A^{0.12}(\rho_o-\rho_g)^{0.1}(\rho_w-\rho_o)^{0.4}}$$

3. Methodology

A reservoir simulator (MBAL) version 7.5 was used for modeling a mature oil reservoir. MBAL is a reservoir modeling tool belonging to the Integrated Petroleum Modeling (IPM) suite. It utilizes Material balance concept based on the principle of conservation of mass:

The Material balance program was used to model a mature oil reservoir to predict the reservoir behaviour from the effects of reservoir fluids production data given in Table 1. Figure 5 shows the procedural steps used in modeling the mature oil reservoir using MBAL

Table 1: Reservoir input parameters

Reservoir Parameters	Input Values
Reservoir type	Oil
Temperature	250 deg F
Initial Pressure	4000 psig
Porosity	0.23
Connate Water Saturation	0.15
Water Compressibility	Use Correlation 1/psi
Original Oil In Place	210.607 MMSTB
Start of Production	01-01-2001
Formation GOR	500
Oil gravity	39
Gas gravity	0.798
Water salinity	0
H_2S, CO_2, and N_2	None

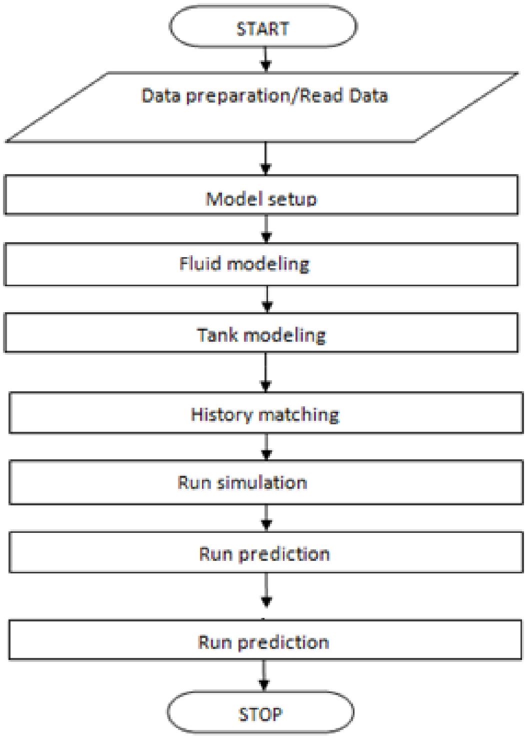

Figure 5: Schematic of MBAL Simulator Procedural Steps

3.1. Fluid Contact Prediction

The movement of the fluid contact is always monitored as production proceeds in order to avoid excessive production of gas or water from the reservoir. For the reservoir under study, a prediction is run to determine the position of the fluid contacts every six months as the GOC increased while the OWC decreased with production as shown in Table 2.

Onwukwe *et al* (2012) was also used to evaluate the decline trend in the critical production rate as the reservoir oil column declines, occasioned by the fluid contact movement.

Table 2: Field Data of GOC, OWC and Pressure Decline

Date	GOC (ft)	OWC (ft)	Pressure Decline (psi)
01/01/2001	8671 (initial)	8737 (initial)	4000 (initial)
01/04/2006	8671	8733.73	2426.37
30/10/2006	8671	8733.41	2293.39
30/04/2007	8671.13	8733.15	2196.58
29/10/2007	8672.1	8732.97	2171.36
28/04/2008	8673.28	8732.85	2141.02
27/10/2008	8674.58	8732.77	2108.05
27/04/2009	8675.78	8732.7	2065.94
26/10/2009	8677.03	8732.65	2009.11
26/04/2010	8678.39	8732.58	1937.66
25/10/2010	8679.85	8732.5	1851.76
25/04/2011	8681.37	8732.4	1751.76
24/10/2011	8682.94	8732.28	1638.25
23/04/2012	8684.53	8732.13	1512.26
22/10/2012	8686.12	8731.97	1375.39
22/04/2013	8687.68	8731.79	1229.96
21/10/2013	8689.21	8731.6	1079.11
21/04/2014	8690.67	8731.4	926.784
20/10/2014	8692.05	8731.22	777.559
20/04/2015	8693.35	8731.05	636.202
19/10/2015	8694.58	8730.91	507.076
18/04/2016	8695.74	8730.81	393.508
17/10/2016	8696.85	8730.75	297.347
17/04/2017	8697.95	8730.75	218.848
16/10/2017	8699.03	8730.8	156.897

4. Result and Discussion

The resultant modeling using MBAL gave a plot of GOC & OWC vs. time as shown in the Figure 6. The prediction made for the given set of reservoir fluid properties and fluid contact movement show that the point of interception of the GOC and OWC is sometime in 2011. This is the point at which water and gas would cone simultaneous into the production wellbore. Oil production beyond this point will result to coning of both gas and water, resulting to high GOR, increased Water-cut and declining oil production.

Figure 7 show a summary of a sensitivity study carried out to evaluate the trend of the critical rate with reduction in oil-column due shrinking fluid contact. This shows that, the critical rate is proportional to the oil column thickness. As the fluid contacts close-in on the oil column, the critical production rate continue to reduced until the economic limit is attained. Therefore to avoid coning tendencies as the oil column is reduced, the critical production rate of respective oil column thickness should be maintained. That is, there is no constant critical rate for reservoirs with Dynamic Oil Rim Fluid Contacts.

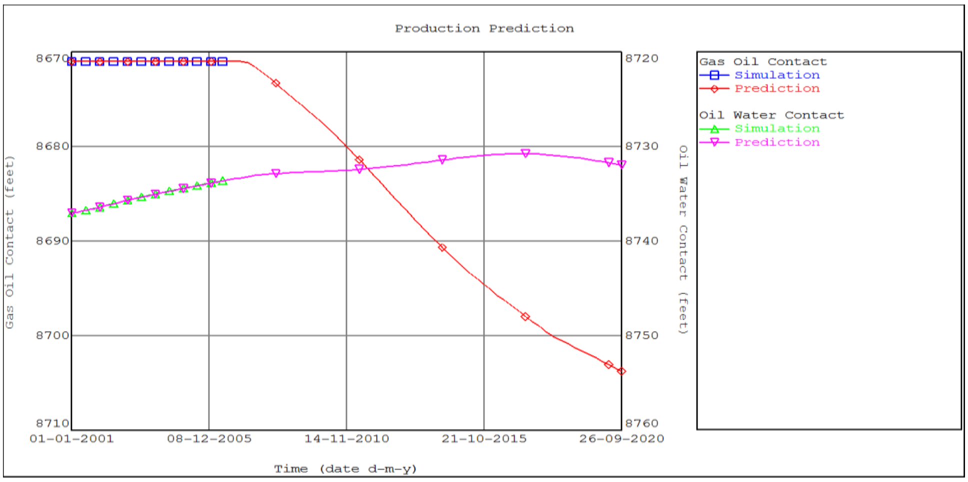

Figure 6: Plot of GOC & OWC vs. Time

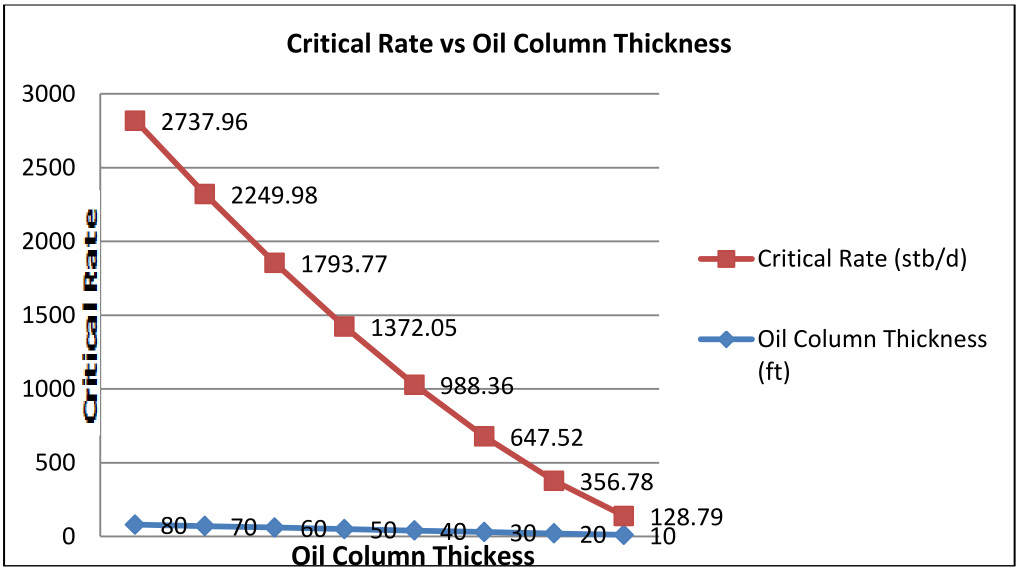

Figure 7: Sencitivity Study of Critical Rate and Oil Column thickness

5. Conclution and Recommendation

The knowledge of the analysis of the movement of fluid contacts in the reservoir is a pertinent aspect of reservoir studies which can go a long way in assisting in the effective management of the reservoir and to predict the future performance of the reservoir. The following conclusions can be drawn on the basis of this study:

i. Water and/or gas coning are common occurrence in mature oil fields, where the fluid contacts (OWC and GOC) moves up and/or down respectively into the oil column of the reservoir.

ii. Coning may result to significant increase in water and/ or gas production from oil reservoir, thereby significantly reducing reservoir energy.

iii. The critical rate reduces with declining oil rim fluid contacts

iv. To avoid coning tendencies in mature oilfield, the critical production rate of respective oil column thickness should be maintained.

To avoid coning in mature oilfield rim, it is therefore recommended that the critical production rate of the respective decline in oil column thickness is determined and used to maximize oil production.

NOMENCLATURE

A = Drainage area, acres
Bo = Oil formation volume factor, rb/stb
ho = Oil zone thickness, ft
kh = Horizontal permeability, md
ko = Oil permeability, md
L = Horizontal well length, ft
rw = Wellbore radius, ft
μo = Oil viscosity, cp
ρo = Oil density, lb/ft3
ρg = Water density, lb/ft3
ρw = Water density, lb/ft3

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