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Effectively optimizing production of horizontal wells in homogeneous oil reservoirs

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ABSTRACT

Horizontal well applications have been predominant since their conception, for reasons such as effective depletion of oil reservoirs and especially in water cresting, gas cresting or water and gas cresting applications due to the casings enhanced exposure to the reservoir. Cresting is hugely dependent on oil production rate, pressure drawdown and can negatively influence the degree of depletion as well as the overall recovery efficiency of oil reservoirs. This paper presents a novel procedure of mimicking horizontal wells aimed at investigating experimentally the effect of varying inclined sections (having different vertical and horizontal displacements) of horizontal wells at low angles of inclination (15°-30°) in a homogeneous reservoir underlain by a strong bottom aquifer and overlain by a considerable gas cap drive occurring simultaneously.

The results for the performance of the different horizontal well geometries in terms of cumulative oil recovery and Water-Oil-Ratio; over a fixed liquid production time were compared. From the results obtained, it was observed that the short radius well with 30° angle of inclination and ratio of vertical displacement of the inclined section to reservoir height of 0.07 resulted in the highest oil recovery of 38.73%. Using the presented procedure, 5.60% increment in oil was recovered with 11.40% reduction in cumulative produced water were observed between the best and worst cases from the same reservoir. At higher withdrawal rates and pressure drop, long radii wells are recommended due to cresting delay ability while improving oil recovery.

1. Introduction

Drilling of horizontal wells have been common practice (Permadi, 1996) for almost a century. The reason for this is their ability to access difficult to target oil pay zones and high productivity, by effectively delaying water and gas breakthrough times (Al zarafi, 1993; Chen, 1993; Coffin, 1993; Murphy, 1990; Sherrard et al., 1987). The productivity of horizontal wells depends to a large extent on the total length and distribution of the open intervals (Goode and Wilkinson, 1991). Horizontal wells are a preferred candidate to vertical wells due to more reservoir exposure of its laterals resulting in a lower pressure drop at the same withdrawal rate, which is important for minimizing cresting effect. At static condition, the reservoir gas, oil and water phases are separated by gravity, in order of their density differences (Balazs et al., 2009; Beveridge et al., 1970; Singhal, 1996). Moments after production starts, the original plane interfaces between bottom water and oil and the overlying gas and oil become distorted (Permadi and Jayadi, 2010) rapidly as a result of pressure drawdown being greater than the hydrostatic pressure that exist between the oil and gas (gas cresting), oil and water (water cresting) or water, oil and gas (water and gas cresting) occurring simultaneously.

Cresting in horizontal wells unlike coning in vertical wells is a well-known reservoir problem, often described as the protruded, crest-like movement of water and or gas in an oil reservoir towards the perforation of a horizontal well as a result of the imbalance of gravitational and viscous forces (Kromah and Dawe, 2008; Makinde et al., 2011; Permadi, 1996). The water and gas move up and down respectively towards the perforations of the well, while displacing the oil along its path and after the breakthrough time elapses, insurgence of water and or gas will be experienced. At this point, factors such as liquid production rate (Lozada et al., 2011) or withdrawal rate, ratio of water-to-oil mobility, ratio of vertical-to-horizontal permeability, distance from the wellbore to oil-water contact, productive length of the wellbore, and both the size and shape of drainage area will determine the water cut increment (Permadi and Jayadi, 2010; Yang and Wattenbarger, 1991). Water cresting is known to have an adverse effect in oil producing reservoirs (Weijun et al., 2014) and could lead to the early shutting-in of producing wells. Due to the increased volume of effluents (water and gas) produced over time, cresting is considered uneconomical because more money is spent in handling these effluents:

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the water is known to be corrosive in nature (Smith and Pirson, 1963) while the gas could damage surface facilities, both influencing the overall recovery efficiency of the oil reservoirs.

Most research on water and gas cresting have focused on critical rates, breakthrough times, its delay and prevention, but very few have considered the inclined section at low angles of inclination for optimization purposes for horizontal wells in oil reservoir faced with cresting problems. Benamara and Tiab (2001) investigated the effect of withdrawal rate, perforated thickness for vertical wells, horizontal well length and reservoir parameters in the Gas-Oil-Ratio (GOR) post breakthrough behavior. Balazs et al. (2009), investigated water and gas cresting in horizontal producing wells using an experimental model. The sole aim of their research was to provide fluid mechanics-based engineering guidelines for optimizing the productivity in horizontal wells. Makinde et al. (2011) numerically studied the performance of a horizontal well after breakthrough of water and further performed sensitivity analysis by setting a base case model and varying reservoir parameters (oil production rate, vertical and horizontal permeability, length of perforation, height above perforation, area extent of reservoir and the porosity of the formation) and production rate independently. Freeborn et al. (1990), undertook a case study of water cresting in South Jenner pool, a thin oil rim reservoir with thick bottom water. Medium and long radii wells of 420 m and 1042 m horizontal displacements respectively were drilled to determine their inflow performances compared to a vertical well in the presence of bottom water. When the production results were reviewed it was observed that the maximum production rate was highest for the long radius well however they indicated that the possible causes of poor performance of the short radius well was due to the cemented completion in the pay zone and the ineffectiveness of jet perforation in penetrating drilling damage. In addition, the water cut over time for each well was not reported. (Freeborn et al., 1990) numerically investigated different placement of the horizontal well from the top of the reservoir and observed that there was a decline in oil reserves produced when the well is closer to the OWC and water cresting is more likely to occur faster due to the upward water flood provided by the bottom water. A more comprehensive and general review on cresting can be found in (Makinde et al., 2011; Permadi and Jayadi, 2010).

Owing to the fact that cresting is a natural phenomenon which will occur at some point in the production life of a horizontal well despite producing at a water and gas-free oil rate 'critical rate' (Leemhuis et al., 2007), there is a need to determine an optimum well geometry for better oil recovery in reservoirs with cresting problems. Previous researchers have investigated the use of horizontal wells in reducing cresting effects but have only considered the effect of varying the lateral lengths and measured depths of inclined or deviated wells without considering the effect of the steepness of such wells on its performance such as in the works of Balazs et al. (2009). In this regard, a novel procedure for mimicking inclined or deviated wells was developed for the purpose of this research. This procedure involved varying the inclined section of the horizontal well without altering the lengths of the laterals (having same completion mechanism) and vertical (main bore) sections of the horizontal well unlike in the works of Freeborn et al. (1990). This was possible using compression and pneumatic fittings. Using these fittings, the modeled inclined sections can be fitted to the lateral and main bore sections with ease. This instigates a change in the measured depths (MD), true vertical depth (TVD), horizontal and vertical displacements of horizontal wells, vertical and horizontal displacements of the inclined sections at any preferred angle of inclination.

2. Experiment description and procedure

The facility used in this investigation is illustrated in Fig. 1. The water and gas-cresting rig consists of a reservoir, 0.45 m long, 0.10 m wide and 0.43 m high. The reservoir was made of clear acrylic [Poly (methyl methacrylate)] for visibility of the water and gas cresting process and had a free surface for easy filling of the polymer pellets (porous media). The water inlet points 1 and 2 were for the water feed to the reservoir, which was taken from a water storage tank. In this study, the horizontal wells were considered to have configurations as described in Tables 1 and 2. The horizontal wells had an internal diameter of 0.006 m and external diameter, 0.008 m and a fixed lateral section of 0.305 m, exposed to the reservoir. These wells were constructed and coupled to the reservoir. The constructed inclined sections of 15°-30° angles were fitted to the vertical and lateral sections of the horizontal well using compression fittings. Production was instigated and stopped using a ball valve. A comprehensive summary of the dimensions for the different geometries of the horizontal well models used in this investigation, such as the Measured Depth (MD), True Vertical Depth (TVD), Horizontal displacement (H_d) of the inclined section as well as the ratio of the Vertical Displacement of the inclined section to reservoir height (V_d/H_r), are illustrated in Tables 1 and 2. For the case of this investigation, Cases-1A, 1B and 2A were considered long radii, Cases-3A, 2B and 1C, medium radii wells, while Cases 3C, 3B and 2C were short radii wells. The radius of arc r, for each inclined section was calculated using Eq. (1).

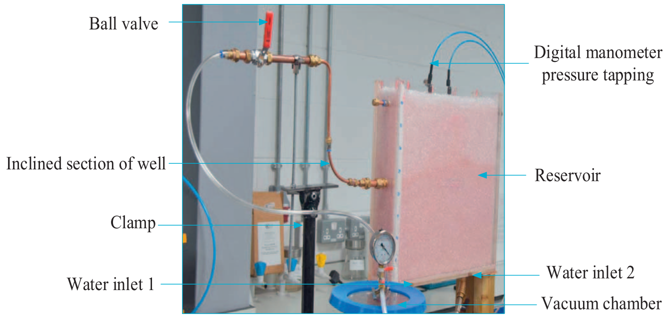

Fig. 1. Water and gas cresting facility.

$$l = \frac{n^o}{360^o} x 2\pi r \tag{1}$$

Where l is the length of arc in meters, n^o is the angle of inclination in degrees, r is the radius of arc in meters and π=3.142.

The influx of fluid into the fixed perforated lateral section of the horizontal was radial in nature, having four shots per cross-section. The lateral distance between perforations was 0.05 m, with hole-sizes of 0.002 m. The reservoir type being modeled in this investigation was an oil reservoir; with the oil sandwiched between strong water bottom aquifer and a considerable gas cap drive. A strong bottom water drive was achieved with a total bottom water flow rate of 0.03 kg/s through two inlet points located at the bottom of the reservoir to enable uniform water distribution. The bottom water was considered strong since the mass flow rate of the injected bottom water was greater than the overall approximate liquid mass flow rate (0.01 kg/s) for all cases while the considerable gas cap drive was modeled at atmospheric pressure. Silicone oil [Poly (dimethylsiloxane)] was the oil used in this investigation due to its non-stain, non-sticky nature and most importantly it is insoluble in water at low and intermediate pressures.

For effective visualization of the water and gas cresting process, the water used was colored with fluorescein Sodium Dye-Fluorescent tracer, while clear-shiny plastic pellets were used as the porous media to distinguish the gas zone from the oil zone. Polymer pellets were first inserted to the required level (0.43 m from the base of the reservoir). Colored water was then pumped through the bottom inlets to the required WOC level (0.03 m from the base of the reservoir). Silicone oil was introduced into the reservoir from the top of the reservoir to achieve a uniform WOC interface and until a GOC level of 0.37 m was attained prior to the start of production. The water was supplied at