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A visualized investigation on the mechanisms of anti-water coning process using nitrogen injection in horizontal wells

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ABSTRACT

Horizontal wells have been widely used in oil reservoirs with bottom aquifer. As bottom water coning occurs, water cut of the production well rises sharply and the output declines rapidly. In this paper, an experimental study on the mechanism of anti-water coning and oil production increment by injecting nitrogen in horizontal wells was carried out. A theory of bubbling behaviors induced by gas permeating through a porous medium is skillfully applied to analyze the mechanisms of anti-water coning by injecting nitrogen. A series of visual experiments and a one-dimensional displacement experiment are conducted to intuitively study bubble characteristics and blocking mechanisms in porous media, as well as the microscopic mechanisms of the improvement of well performance by injecting nitrogen. The results show that there are three forms of nitrogen in the water channeling path: tiny bubble, elongated bubble, and gas channeling, which are related to water saturation and gas injection volume in the water channel. Elongated bubble, the main mechanism of anti-water coning by injecting nitrogen, can block high-permeable water channeling path to a certain extent. As the viscosity of crude oil increases, the negative effect of anti-water coning and the increment of bottom water sweeping range show up. It is suitable for non-homogeneous reservoirs, which is conducive to the exploitation of oil on the top layer in low permeability oil region. It can also largely increase the sweeping area of bottom water in low permeability reservoirs. But for high permeability formation, water suppression effect is poor. The earlier the injection of nitrogen gas, the better the effect of inhibiting water encroachment which can even reduce the water cut to zero. However, the effect of oil production increment will be not that good. This paper provides reference for the study in anti-water coning and increasing oil production by injecting nitrogen through the horizontal wells.

1. Introduction

Bottom water reservoir is widely distributed in the various fields all over the world and oil production in reservoirs with active bottom water is one of he most challenging problems in petroleum engineering. In most cases of such reservoirs, there is a serious water coning phenomenon, which happens very quickly and then the influx of water restricts oil production and limits recovery, leading to a significient decrease in well productivity (Deng and Liu, 2017; Siemek and Stopa, 2002; Perez et al., 2012). However, if the coning is suppressed reasonably and strategically, the active bottom water can again become a positive energy for improving development efficiency (X Tu et al., 2007). Horizontal well has been widely used in oil reservoirs with active bottom aquifer, which can effectively increase oil production and restrain the bottom water coning (Florez Anaya et al., 2012; Zhou et al., 2004; Bie et al. 2007). Some on-site implementation has shown that horizontal well technology has been proven to reduce coning problems and improve well performance of bottom water reservoirs (Peng and Yeh, 1995; Permadi, 1996). Particularly, compared with the straight well, the horizontal well can effectively delay the emergence of the water (gas) cone (Zhou and Deng, 2004; Hadia et al., 2007), however, it is still a major problem for bottom water reservoirs that the bottom water invades the oil zone and finally moves towards the well (Alblooshi and Wojtanowicz, 2014; Wibowo et al., 2004). Although the bottom aquifer can complement part of formation energy to ensure the continuity of the development process, once water appears in the well, causing that the bottom water breakthrough in advance and bottom water intrusion pattern changes from “coning” into “cresting” as a result of the imbalance of gravitational and viscous forces (Makinde et al., 2011). The formation of water crestiong greatly reduces the scope of

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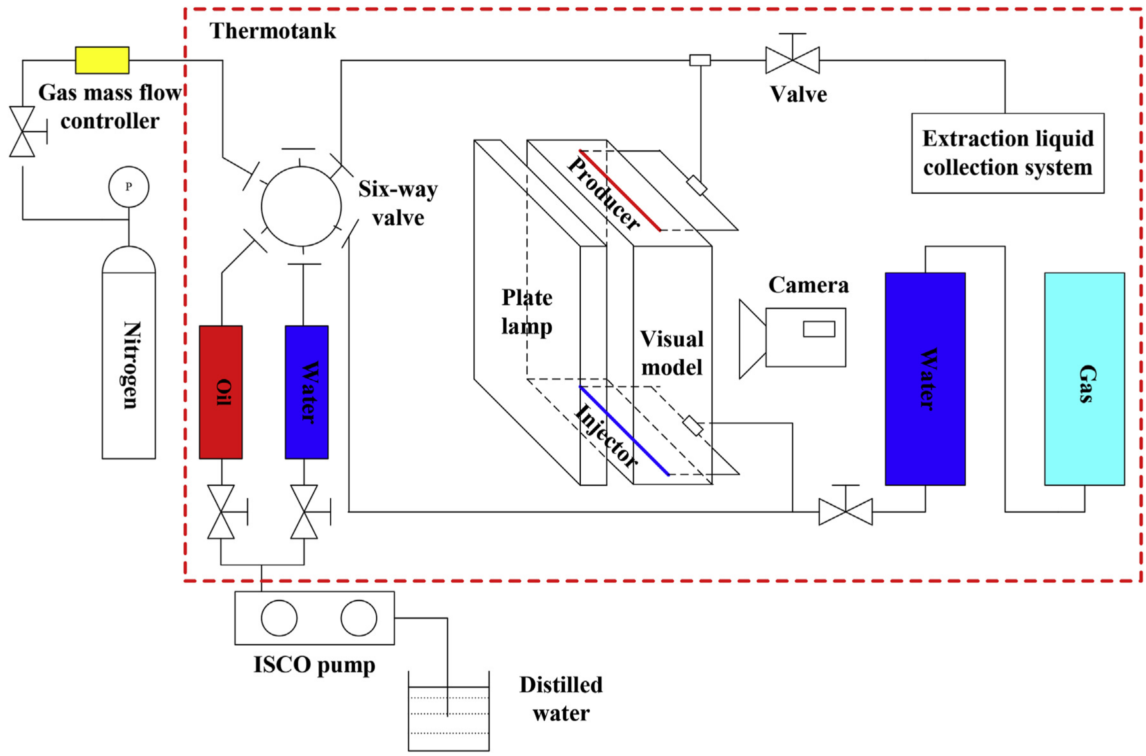

Fig. 1. Schematic diagram of visual experiment.

water flooding and causes the water cut rising rapidly, making the overall recovery rate is less than 40%. Owing to the fact that water cresting is a normal phenomenon which will occur at some point in the production of a horizontal well despite producing at a critical rate (Akangbou et al., 2016), there is a need to determine several effective methods for more effective exploitation of oil in reservoirs with cresting problems. Moreover, It is often too costly and risky to solve this problem by controlling the production of oil well, optimizing perforation, adjusting well network system, and making artificial partitions, etc. Often the treatment of horizontal well with high water cut is to block the aquifer, and then perforate the upper straight section to further tap the potential, but this will lose the advantages of horizontal wells (Verre et al., 2007; Arangath and Mkpasi, 2002). Due to the high cost of horizontal wells, the closure of the operation is usually worth the candle. Many researchers have devoted themselves in the technology about how to delay the water coning by artificial methods. There are many experimental and theoretical analysis on the water plugging ability of various agents, including polymer, emulsion, silica gel and foam, available for improving waterflood performance on the development of bottom water reservoirs (Islam and Farouq, 1987; Elkaddifi et al., 2008). There are a number of factors that constrain the plugging effect of foam injection in horizontal wells: (1) Due to horizontal well has a large contact area, the injected gas is mixed with the foaming agent to form a foam, which is not fixed and migrates under pressure. The foam concentrates on the upper part, while the remaining foam on the lower part becomes an infiltration zone, which easily leads to intrusion of water from the bottom. (2) In the current foam blocking theory, it is more important to focus on the regenerative capacity of foam in porous media. Due to the horizontal section length of the horizontal well, the drainage area is large and the flow rate of the liquid relative to the vertical well is low, so the foam has poor regeneration ability. (3) By injecting a certain amount of foam into the horizontal well, the distribution will be more dispersed and the concentration scope is small, which affects the effect of the blocking effect. Many previous researches have proved that the injection of aforementioned agents have a positive influence on increasing the sweep efficiency and waterflood performance, and thus increase oil recovery (Ezeddin, 2000; Liu et al., 2008), however, disadvantages of these methods are the effect of stratigraphic adsorption and pollution to formation water and possible damages on the low permeability unswept oil zone (Taksaudom, 2014).

Injection of immiscible gas with associated additives into the production wells to achieve the purpose of inhibiting the flow of formation water into the wellbore, developed by Alberta Oil Sands Technology Research Authority (AOSTRA), was patented in 1985 by AOSTRA as the Anti-Water Coning Technology (AWACT) Process (Luhning et al., 1990). It has been applied commercially to mitigate water coning problems (Pang et al., 2008; Lai and Wardlaw, 1999). Aiming at the above problems, this paper puts forward the method of injecting gas injection to further excavate. It is found that N_2 has good expansibility and compressibility, which can effectively replenish the formation energy and have a strong compression effect. Compared with other measures to control the water intrusion, the nitrogen injection process is the most economical and reasonable, because nitrogen, as an inert gas, is an integral part of air, and its resources are abundant and relatively cheap. Moreover, the field application of this technique has a relatively small ratio of economic input to output, which reduces the water cut effectively and has obvious effect on oil increasement.

To explore the mechanisms of nitrogen injection to suppress water coning and increase oil production, a series of experiments are performed. In this paper, water flooding process is firstly carried out to display the macroscopic distribution of remaining oil in a visualized model filled with glass beads. Then, nitrogen is injected into this model through horizontal well. In this process, bubbles generation and migration in porous media are intuitively reproduced, which vividly reflects changes in bubble morphology at different stages. The theory of bubbling behaviors induced by gas permeating through a porous medium is skillfully applied to anylaze its blocking mechanism. The more important is to make a comparison of sweep efficiency and oil recovery prior and posterior nitrogen injection in the case of different reservoir properties and different nitrogen injection timing. On this basis, a one-dimensional displacement experiment was carried out to