Jurnal Petro 2022
https://trijurnal.lemlit.trisakti.ac.id/index.php/petro
VOLUME XI No. 2, September 2022
P-ISSN : 1907-0438
E-ISSN : 2614-7297

EFFECT OF SMART WATER ION CONCENTRATION ON OIL RECOVERY BY SPONTANEOUS IMBIBITION TEST

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ABSTRACT

Smart waterflooding has proven successfully improving oil recovery in numbers of laboratory and field scale applications. The phenomenon behind the positive outcome is concluded to be wettability alteration. The smart water composition changes the wettability of the rock surface into partially water-wet, thus promoting a spontaneous imbibition of the aqueous phase in displacing the oil. However, there are some mechanisms causing the wettability alteration that have been proposed by researchers. The present study examines the oil recovery from spontaneous imbibition tests by modifying certain ion composition of the smart water. Prepared core samples with initial water and oil saturation were immersed in spontaneous imbibition cells filled with smart water. The oil recovery was monitored subsequently for some period of time. The predesigned smart water compositions consist of different ions concentration; they are Na^+, Ca^{2+}, and Mg^{2+}; while maintaining total dissolved solid (TDS). The experimental results found that the ion composition of smart water affects the oil recovery regardless of the TDS, and at low Ca^{2+} and Mg^{2+} concentrations shows the highest recovery factor.

Keywords: Spontaneous imbibition; smart water ion concentration; TDS; recovery factor

INTRODUCTION

Modified ionic composition of water by adding or removing ions regardless value of salinity, can be defined as smart water (Al-Saedi et al., 2020). Different salt concentrations in smart water interrupt the equilibrium state in a reservoir when being injected in, either secondary or tertiary recovery stage (Maghsoudian et al., 2020). Smart waterflooding is a favored enhanced oil recovery method due to the high performance, relatively low cost, and environmentally friendlier compared to chemical EOR methods (Ding et al., 2019).

Smart waterflooding is mentioned interchangeably with low salinity waterflooding (LSWF) in the case of sandstone (Afekare & Radonjic, 2017; Bartels et al., 2019; Sohal et al., 2016). LSWF means decreasing the salinity of injected water. Whereas in carbonate, smart waterflooding is performed by injecting water with altered ion content of previous water injection, hence the well producing additional oil (Hao et al., 2019). Meanwhile, adjustment of particular salt content i.e., magnesium, calcium, sulfate, and other ions are possible (Hao et al., 2019).

The clay mineral content in sandstone acts as cation exchange material, which is the key factor in the proposed smart water flooding EOR mechanism (RezaeiDoust et al., 2011). Moreover, the common understanding of LSWF positive effect is caused by the interaction between injected brine and clay minerals (Bernard, 1967). During the displacement of formation water with smart water, divalent ions will be desorbed from the clay surface as a result of ion exchange occurred between H^+ and divalent ion, thus the organic materials will be then desorbed from the clay (Al-Saedi et al., 2020).

Meanwhile, the clay content in carbonate rocks is very low or even zero (Lager et al., 2008), thus the mechanism of LSWF in sandstone will not occur in the same way as in carbonate. The wettability of sandstone reservoirs tends to be strongly water-wet or mixed-wet compared to either completely oil-wet or mixed-wet for carbonate reservoirs (Chilingar & Yen, 1983; Treiber & Owens, 1972). Smart waterflooding affects the interaction between rock and fluids in oil reservoirs to alter the wettability towards more water-wet and optimize the oil recovery

(Maghsoudian et al., 2020). Understanding of the mechanisms have to clearly explain the reason behind the positive outcome of the smart waterflooding on the oil production, such as the multicomponent ionic exchange, double layer expansion, and the interfacial tension reduction.

The current study highlights the effect of ion concentration on oil recovery; particularly Na^+, Ca^{2+}, and Mg^{2+}; while maintaining identical total dissolved solid (TDS) in spontaneous imbibition test.

METHODOLOGY

A block of Berea sandstone with the dimension of 30 x 30 x 30 cm is drilled into 1 inch diameter and 30 cm long. The cores are then cut into shorter lengths of 4.5 cm and dried in the oven. The dry core weight is measured by using weighing balance. The bulk volume is calculated from the length and diameter of the core. These values will be used to calculate the porosity of the cores. In order to fully saturate the core with formation water, the cores are immersed in the formation water and placed in the vacuum vessel which is connected to the cooler and vacuum pump. The cooler and vacuum pump are operated for 12 hours until no more air bubbles are observed. This condition indicates the air in the pores has been evacuated and replaced by the formation water.

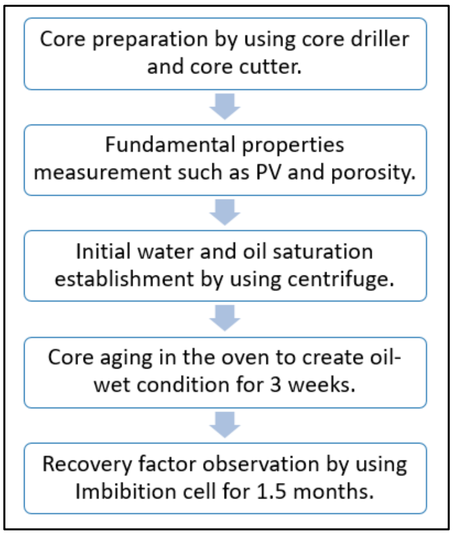

Figure 1. Workflow spontaneous imbibition test

The wet core is placed in the specially designed cell to be centrifuged. The centrifugation process expels water from the pores by high rotation speed which then accumulate at the bottom part of the cell. The core is directly submerged in a beaker glass full of oil to displace the empty pores with the oil after centrifugation. The volume of the expelled water will determine the initial oil saturation of the core. It is assumed that the empty pore where the expelled water was resided is fully occupied by the oil. Subsequently, the beaker glass is placed in the oven for aging with the temperature maintained at 80°C for three weeks.

The spontaneous imbibition experiment is conducted in a specially designed imbibition cell. First, the predesigned smart water is poured into the glass. The composition of smart water can be found in Table 1. Then, the core is put into the glass. The cap is installed and tightened. The smart water is again added to fill the cap by using a long syringe needle. Finally, the imbibition cell is placed in the oven at 60°C. The produced oil is monitored with time over one and a half months. The brief workflow is summarized in Figure 1.

Table 1. Smart water composition

Smart water	**Na^+ (ppm)**	**Ca^{2+} (ppm)**	**Mg^{2+} (ppm)**
SW x	1980	1000	20
SW y	1980	20	1000
SW z	2960	20	20

RESULT AND DISCUSSION

The effect of each ion on oil recovery was investigated through spontaneous imbibition experiment. The oil accumulation in one of the spontaneous imbibition cells can be seen in Figure 2. The results from the spontaneous imbibition experiment showed an increasing oil recovery trend with lowering Ca^{2+} concentration. The recovery factor reached the highest value when the Ca^{2+} and Mg^{2+} concentrations were as low as 20 ppm.

The analyses of the results are divided into three points of view; they are of Ca^{2+}, Mg^{2+}, and Na^+ concentrations, respectively. By plotting the recovery factor versus predesigned smart water with different ion concentrations, decreasing trend of recovery factor was observed with increasing Ca^{2+} concentration, from SW z to SW y to SW x, as we can see in Figure. 3. Whereas, the addition of Na^+ concentration raised the recovery factor as illustrated from SW x to SW y to SW z. Na^+ acts as a buffer to maintain the same total ion concentration in the water. Therefore, when the concentration of Na^+ is high, the other ion concentration will be low. Meanwhile, the highest recovery factor was found when the concentration of Mg^{2+} was 20 ppm in SW z. However unlike Ca^{2+}, low concentration of Mg^{2+} did not always proportional with good oil recovery. In this study, 20 ppm Mg^{2+} in the SW x resulted in the lowest recovery factor compared to SW y and z.

Figure 2. Oil accumulation in spontaneous imbibition cell

The results showed that low concentration of divalent ions, i.e., Ca^{2+} and Mg^{2+} in SW z produced the highest oil recovery of 45.71%. When the concentration of divalent ions was increased to 1000 ppm, Ca^{2+} in SW x and Mg^{2+} in SW y, the recovery factor was consequently decreased compared to SW x, where both concentrations were at the lowest. The effect of low Ca^{2+} concentration on oil recovery corresponded to relatively high oil gain among three cases. On the contrary, low Mg^{2+} concentration did not always correspond to high oil recovery. This might be caused by a stronger bond of Ca^{2+} compared to Mg^{2+} and Na^{+} (Lager et al., 2008).

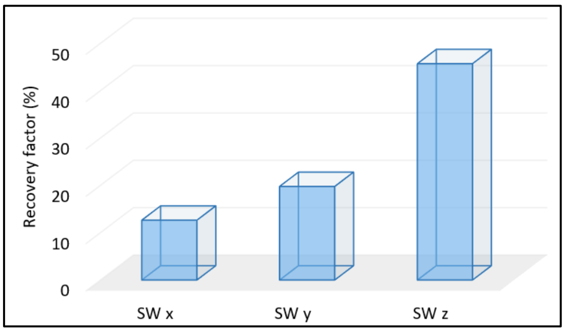

Figure 3. Recovery factor for spontaneous imbibition of SW x, y, and z

CONCLUSIONS

Several important conclusions can be drawn from this study. The water ion composition was proven to affect the oil recovery regardless of the TDS. The most effective smart water in producing oil consists of low Ca^{2+} and Mg^{2+} concentrations. According to the experiment, decreasing Ca^{2+} and adding Na^{+} concentrations at the same time in the smart water increased the oil recovery. The low concentration of Mg^{2+} produced high recovery only if the Ca^{2+} concentration in the smart water was also low.

ACKNOWLEDGEMENTS

This work is supported by the Smart Waterflooding Project grant fund and fully facilitated by the Laboratory of Petroleum Engineering, Sejong University, Republic of Korea.

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