Journal of Alloys and Compounds 685 (2016) 97–106

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: http://www.elsevier.com/locate/jalcom

Salt-out in porosity medium: Mitigating gas channeling using alcohol-induced salt precipitation

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ARTICLE INFO

Article history:
Received 22 January 2015
Received in revised form
16 May 2016
Accepted 22 May 2016
Available online 24 May 2016

Keywords:
Alcohol-induced salt precipitation
Drying-out mechanism
Gas coning
Gas condensate field exploitation
Porosity medium

ABSTRACT

To eliminate the adverse effects of gas coning occurring during the condensate filed exploitation, alcohol-induced salt precipitation was used as the method to mitigate gas channeling. The predecessor's researches only focused on the ordinary mechanism which is the salt precipitation caused by ethanol inducing, but it was not able to explain a marked decrease in permeability after a long term gas injection. In this paper, a novel theory is presented, the permeability change is the result of two mechanism act synergistically, first is the salt precipitation caused by ethanol inducing, another mechanism also takes an important role in mitigating gas coning which is drying-out mechanism. For lager Peclet, the salt deposition was non homogeneous and accumulated near the surface, the salts distribution in the porosity medium was measured by experiment testing and a simple model calculation.

In this paper, the microscopic structure of NaCl crystal grain, distribution of grain size were analyzed by means of SEM, grain size analysis units analyzed by laser particle analyzer. Compared water-gas alternation injection (WGA) and foam injection, the alcohol-induced salt precipitation has some advantages with mitigating gas channeling in gas condensate field which more economic, more efficient and persistence.

1. Introduction

Gas recycling injection has been extensively implemented in condensate fields to enhance condensate gas recovery. However, early gas breakthrough frequently occurred in gas injection process due to the existence of natural fractures, hydraulic/acid fractures or faults, and high-permeability zones. Early gas breakthrough could lead to low sweep efficiency, disappointing condensate yield and high compression costs [1–3]. Various techniques have been studied to alleviate this problem and maintain the reservoir pressure, such as optimization of perforating way, injection method, injection well spacing and injection patterns [4–7]. These processes are limited as they only delay the occurrence of gas channeling, but not eliminate it. Many chemical blocking techniques have been developed and applied to reduce gas channeling, such as gel and foams. Each of these methods has some inherent problems, for example, the foam could only provide a limited blocking ability because it decays too rapidly. The stability of the polymer gels can be influenced by reservoir conditions (such as temperature and pH), flow rate and concentration of injected solutions [8,9],furthermore, many studies have shown that the polymer solution injection can lead to crossflow into less permeables strata and block migration pathway for oil and gas [10–12]. The conventional chemical methods to enhance the oil or gas recovery is proved uneconomical and non-environmentally friendly.

Considering all above problems being faced, it becomes necessary to develop an effective blocking technique to mitigate gas channeling. Alcohol-induced salt precipitation, has been proved to be a feasible technique. The alcohol-induced salt precipitation was based on the theory non-electrolyte reduce the solubility of electrolyte in brine [13]. Zhu published the results about alcohol-induced salt precipitation which was used for improved weep efficiency [14]. Sodium chloride-saturated brine was injected into the layer from gas-cut well, followed by water-soluble alcohol

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http://dx.doi.org/10.1016/j.jallcom.2016.05.251
0925-8388/

injection. The injected liquid mainly flows into the high permeable zones, and the solid salt crystals precipitate and piled up in the pores at formation temperature after intensive mixing. Consequently, a "permeability barrier" was formed in high permeability zones. Hence, the potential for fluid flow through these regions is limited and the fluids injected thereafter for improved oil recovery are forced to go into oil containing regions [15]. Similar the profile modication can be applied to eliminate gas coning on the same principle. Furthermore, gas is not able to dissolve the salt crystals as oil does because of no mobile water in gas formation, thus the "permeability barrier" in the gas flow zone remains and becomes more effective [16].

In this paper, we do research about the profile modication applied to eliminate gas coning in condensate fields. The predecessor focused on the mechanism which is the salt precipitation caused by ethanol inducing, but it was not able to explain a significant decrease in permeability after a long term gas injection, in this paper another mechanism was presented to explain this phenomenon which is drying-out mechanism, the effect on permeability change was measured through core experiment and it play an important role in the profile modication. The distribution of precipitation salt in the porosity medium was accurately measured by experiment testing and a simple model calculation, the experiment testing verify the validity of the sample model, so we can use models to predict the distribution. The plug ability of alcohol-induced salt precipitation was measured through a series of physical simulation experiments, and the results were compared with WGA and foam.

2. Materials and methods

Many experiments were designed in this paper to study the phase behavior, mechanisms of salt out in porous medium and plugging ability of alcohol-induced salt precipitation, the whole experiments were shown in Fig. 1.

2.1. Phase behavior experiment

Phase equilibrium experiments were performed to determine the quantity of salt precipitation with using ethanol and sodium chloride brine and find the optimum proportion of ethanol and sodium chloride.

2.1.1. Materials

Ethanol used in studies was supplied by Kelong Chemical Corporation, and anhydrous ethanol contains less than 0.5 ppm benzene. The high temperature and high pressure vessel, 5 μm filter, electronic scale (the metering accuracy is 0.1 mg) were prepared.

2.1.2. Methodology

2.1.2.1. The optimum proportion calculation. Precipitation experiments were conducted by mixing ethanol and brine saturated sodium chloride brine (300 g/L). The volume ratios of brine and ethanol are 5:45, 10:40, 15:35, 20:30, 25:25, 30:20, 35:15, 40:10, 45:5 (ml/ml) respectively. Solutions were agitated for one week for complete phase equilibration. The solution was then filtered through a 5 μm filter, and the filter was evaporated to measure the quantity of dissolved salt. The quantity of salt precipitation was calculated by measuring the difference between the salt in the initial brine and the salt remaining in solution. The optimum proportion was determined by crystallization rate and unit crystallization rate. We define the crystallization rate and the unit crystallization rate as the evaluation index of precipitation experiment. The crystallization rate is described as the percentage of the weight of the salt precipitation at the total salt weight in the solution (Eq. (1)); The unit crystallization rate is used to evaluate the induce capacity (availability factor), and it is described as the weight of the precipitation for per 1 mL inducer (Eq. (2)).

$$\text{crystallization rate} = \frac{\text{weight of the salt precipitation}}{\text{total salt weight in the solution}} \times 100\% \tag{1}$$

$$\text{unit crystallization rate} = \frac{\text{weight of the salt precipitation}}{\text{volume of the inducer}} \tag{2}$$

2.1.2.2. Effect of temperature and pressure on precipitation rate. The effect of temperature and pressure on precipitation rate was tested in the pressure vessel. The quantity of salt precipitation was calculated as the procedure in 2.1.2.1.

2.1.2.3. Particle size and spatial distribution. In this section, the particle size of salt precipitated was measured by laser particle analyzer (Mastersizer 2000), the particles spatial distribution were observed by scanning electron microscope (SEM) and the mixture volume ratio (ethanol and NaCl brine) is 1:1(ml/ml).

2.2. Mechanisms of the salt precipitation test experiment

In this section, the experiments were conducted to test the influence of precipitation mechanism on permeability reduction of porous media.

2.2.1. Materials

The sandstone cores used in this experiment were artificial cores with 16–20% porosity and permeability of about 100mD. The rock properties are summarized in Table 1. The non-wetting fluid used in this study is nitrogen because the hydrocarbon gas might cause ancillary geochemical reactions and adsorption on the surface of rock. The single brine solution was prepared for the experiment. The mixture of aqueous sodium chloride (300 g/L) solutions was used and ethanol was added as the inducer.

2.2.2. Methodology

The experiment used cylindrical core (7 cm long and 3.8 cm in diameter) in a horizontal core holder and the set up was shown in Fig. 2. The inlet of the core holder is connected to the high pressure gas pump and the injection pressure controller and the back pressure was set as 0.5 MPa at outlet. The Outlet gas flow was measured with a gas flow meter and the water outlet volume had been recorded by using burette. The pressure drop across the sample was also recorded. The whole experiment procedure was set at constant temperature environment and the temperature was 90 °C. The sandstone sample cores were initially dried in an oven at 90 °C for 24 h. All initial gas permeability were determined before the experiment starting by measuring the flow rate and the pressure difference between inlet and outlet.

2.3. Permeability modification using alcohol-induced salt precipitation

In this section, three sets of experiment was presented, the first one was used to measure the plugging capacity, the second one is used to evaluate the plugging capacities of these different blocking means, the blocking acting time was evaluated through abrasion resistance experiment.