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Optimization of acid injection rate in high rate acidizing to enhance the production rate: An experimental study in Abteymour oil field, Iran

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ABSTRACT

Matrix acidizing in which the injection pressure is maintained lower than fracturing limits of the formation, has long been known as a remedial stimulation technique to restore the well productivity. It is a must to determine the acidizing parameters such as injection rate and volume in a systematic way in order to achieve an optimum-efficient condition. Also, it is well known that low injection rates result in surface dissolution whereas high rates will create ramified wormholes. A single, dominant wormhole will be formed at an optimum intermediate rate.

In this study, a series of low to high rate acid injection tests have been conducted on Abteymour oil field core samples at reservoir conditions. The experimental data was used to construct the acid efficiency curve from which the optimum injection rate can be determined. Then, the optimum injection rate up scaled from the core-scale to the field condition. Experimental data and CT scanning analysis show that the best wormholing efficiency was obtained at relatively high injection rates compared to other Iranian oil and gas fields. Also, the relationship between pore volumes to breakthrough and injection rate was found to be a polynomial function of order three rather than two.

1. Introduction

The main function of the acidizing fluid is to bypass the near wellbore damage and connect the undamaged part of the reservoir to the wellbore. During acidizing, wormholes are propagated through carbonate/dolomite reservoir rock and the most important factors that can affect wormhole propagation such as acid concentration, injection rate and volume, heterogeneity, … have been addressed by many authors (Mostofizadeh and Economies, 1994). The acid injection rate is a determining factor that can create different reaction patterns including face (compact) dissolution, dominant and highly ramified wormhole (Williams et al., 1979). There is an optimum injection rate in which the lowest acid volume is required to create a uniform wormhole with fewer branches. The injection rate should be decreased when its value exceeds the optimum and vice versa (Mostofizadeh and Economies, 1994).

A number of experimental and theoretical studies have been carried out to model and understand the wormhole growth mechanism in both carbonate and dolomite reservoirs so far. To prevent face dissolution near the wellbore area, the acid must be injected at highest possible rates without fracturing the formation (Williams et al., 1979). Daccord et al. (1993) recommended in order to achieve the optimal condition, minimum amount of acid should be injected into the formation and they confirmed it by injecting water into plaster. The patterns which are formed during water injection were similar to those formed during acid injection into the reservoir rock.

An interesting work was done by Hoefner and Fogler, (1989) where they injected the melting metal into the wormhole and formed a metal cast by dissolving the rock. This study led to the introduction of Damkohler number but the different dissolution patterns were not considered in the model. Wang et al. (1993) studied the effects of different parameters such as acid concentration, mineralogy and temperature on the optimum injection rate and they found that there is an optimum injection rate which will result in formation of an optimum wormhole. Bazin et al. (1995) and Bazin (2001) conducted experiments similar to Wang et al. (1993) to study the effects of length, permeability, acid concentration and temperature on optimal conditions in limestone core samples. Ziauddin and Bize (2007) conducted coreflood experiments similar to the ones conducted by Bazin et al. (1995) on different types of carbonates.

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Table 1
Petrophysical properties of the core samples used for acidizing experiments.

Core No.	Weight (g)	Length (cm)	Diameter (cm)	Porosity (%)	Permeability (md)	Density (g/ cm^3)
1	628.54	9.97	6.28	18.95	5.052	2.664
2	658	9.905	6.53	21.78	7.429	2.665
3	654.09	9.93	6.36	20.26	11.606	2.680
4	642.01	9.72	6.4	20.43	9.466	2.669
5	632.75	9.77	6.285	21.26	4.212	2.653
6	633.86	10.03	6.275	16.34	4.227	2.657
7	685.95	9.94	6.41	14.5	5.344	2.659
8	650.17	9.98	6.34	19.72	12.263	2.658

Cohen et al. (2008) and Kalia and Balakotaiah (2009) studied the effects of domain size (length or height) on the optimum injection rate and volume and they found that the optimum parameters will not be affected by changing the domain size. As the domain size increased (greater than 1 in * 6 in), the optimum rate and corresponding breakthrough volume seem to decrease. These results were in complete agreement with those observed by Bazin (2001).

However, most of the investigations were conducted at relatively low injection rates and to date no experimental work have been reported on high injection rates as high as 50 cc/min (3000 cc/h) at reservoir condition. In the work published by Al-Ghamdi et al. (2014), the acid injection rate was increased to as high as 50 cc/min and the temperature limited to 77 °F. To the best of our knowledge, determination of the optimal parameters at high injection rates and temperatures have not been examined so far. A high precision injection pump (0.01 cc/min) and also data acquisition system was employed to track and record pressure data in every second and even hundredth of seconds. Only few experimental data are available at maximum injection rate of 30 cc/min which most of them simulated in a model to scale up and predict the skin factor and the amount of radial penetration at higher injection rates (Furui et al., 2012; Kumar et al., 2014) or reported as interstitial velocity in latest works (Safari et al., 2014; Dong et al., 2016).

In this study, a series of acidizing core flood test have been carried out on Abteymour oil field samples and the acid efficiency curve was generated. Then, the optimized injection rate was scaled up the field condition and the amount of wormhole propagation was determined as a function of injected volume. This is found that the relationship between the pore volumes to breakthrough and the injection rate is a polynomial function of three rather than two in order which can be attributed to the increase in the number of samples. In other words, the more the samples, the more polynomial order. The three dimensional CT scanning analysis confirms the results of laboratory tests and can be used as an efficient tool

2. Material and methods

2.1. Core samples

The core samples were taken from Ilam Formation of a well in Abteymour oil field located in south west of Iran. After core preparation process which is composed of cleaning by methanol, re-coring and cutting them into specified dimension (2.5 in × 4 in), properties such as permeability, porosity, and grain density were measured and then the core samples were saturated by formation water. The XRD data indicates that more than 95% carbonate and less than 3% dolomite with no clay content for the selected core samples. The specifications and petrophysical properties of the core samples have been listed in Table 1. The core samples were selected in a way to cover the most parts of the interval. Fig. 1 shows core No. 1 before preparation and cleaning.

2.2. Injection fluids

The injection fluids were formation water and 15 wt% hydrochloric acid. The formation water properties are brought in Table 2. The formation water passed through filter paper before use.

The viscosity of the injecting fluids was determined at reservoir temperature (T = 220 °F = 104 °C) and the data were used in Darcy linear equation to calculate the core permeability. The acidizing fluid was a mixture of deionized water, a corrosion inhibitor to protect lines and equipments from being corroded and pure hydrochloric acid. In order to prepare 15 wt% Hydrochloric acid, the pure concentration (37 wt% HCl) was diluted with deionized water and then the concentration of them was confirmed by hydrometer at room temperature and titration by 2N sodium hydroxide solution.

2.3. Experimental setup

The core flooding system used for this study is composed of a core holder, four fluid vessels which two of them are acid resistant (Hastelloy C276), a pressure transducer to measure the pressure drop along the core, a Gilson pump for fluid injection and annulus pneumatic pump to exert overburden pressure over the Viton rubber sleeve covering the core sample, back pressure regulator, fluid fraction collector and the data acquisition system to display and record the data (Fig. 2). In order to apply higher injection rates (more than 20 cc/min), a high pressure single pump with a maximum allowable working pressure of 10,000 psi was employed to apply injection rates up to 80 cc/min.

Fig. 1. Core No.1 before preparation.

Table 2
Formation water analysis of Ilam formation.

Total Salinity	Na^+ and K^+	Ca^{2+}	Mg^{2+}	Fe_2O_3	Cl^-	SO_4^{2-}	HCO_3^-
220,000	74,581	9600	729	357	133,504	575	610