3D wormhole visualization after carbonate matrix acidizing with EDTA

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This paper was prepared for presentation during the 13th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, August 26-29, 2013.

Abstract

Ethylenediaminetetraacetic acid can be used as an alternative fluid to acidize carbonate formations. Acid stimulation is challenging due to the instability of the dissolution pattern mainly in a carbonate matrix. The goal of this work is to study the 3D geometry of the wormholes formed in carbonate core samples in various experimental stimulation strategies. High energy x-ray microtomography was used and the results show that amount and injection rate affect the geometry of the channels.

Introduction

The use of acids to stimulate or to improve oil production from reservoir formations creates wormhole designs [1]. Hydrochloric (HCl), acetic (CH_3COOH) and emulsified acids are the main acids used in this procedure [2].

HCl is most commonly used in acidizing treatments, because it is cheap and leaves no insoluble reaction product. CH_3COOH is weakly ionized and it is used much less frequently than HCl, being suitable primarily for wells with high bottom-hole temperatures or where prolonged reaction times are desired. Ethylenediaminetetraacetic (EDTA) is an alternative fluid, which has been shown to stimulate carbonate formations at lower injection rates [3].

Many models of wormholing process have been studied in order to describe them. Wormhole characteristics (size, length, and distribution) can be controlled by acid-injection, diffusion, and fluid-loss rates. Thus, the knowledge of their physical and chemical designs is very important [4].

X-ray microtomography (microCT) is a non-destructive imaging technique, which enables to examine rocks' internal structure with micron resolution. The great advantage of microCT is that allows obtaining direct three-dimensional parameters and consequently characterizing morphological and topological structures [5,6].

Matrix acidizing experiments combined with a non-destructive technique, such as, microCT can be used to study details of wormhole network. In this context, the goal of his study was to investigate the acidizing procedure when using EDTA acid in different experimental conditionals. For that purpose, high energy microCT system was used.

Methodology

The acidizing procedure was conducted on four Indiana carbonate core samples named #21, #27, #28 and #29, with 37.70 ± 0.25 mm of diameter and 70.4 ± 0.4 mm of height (figure 1). In Figure 1 it is possible to note the inlet faces, which are illustrated with a black arrow.

Figure 1: Indiana carbonate core samples used in the acidizing procedure performed with EDTA.

Table 1 shows the experimental acidizing setups. EDTA acid was injected through the cores and the pressure was monitored to end the injection when significant changes occurred in the cores as indicated by the differential pressure transducer.

Table 1: Experimental acidizing conditions

Samples	Injection rate (cc/min)	Acid system
21	5	0.25 M EDTA
27	5	0.10 M EDTA
28	0.05	0.25 M EDTA
29	5	0.10 M EDTA

MicroCT images were obtained in a high energy microtomography system - Skyscan/Bruker, model 1173. The sample was placed in the experimental equipment inside a polystyrene support. The system was calibrated to operate in an energy and current of 130 kV and 61 μA respectively. In order to reduce the contribution of low energy photons (beam hardening effect), a combination of two filters was used: copper (0.10 mm of thickness) and aluminum (1.0 mm of thickness). The pixel size was 20 µm and a flat panel detector was used (2240 x 2240 pixels) to register the cone X-ray beam transmission. The projection images were taken over 360º at each step of 0.50º rotation.

After the acquisition procedure the images were reconstructed by using Nrecon® (v.1.6.8.0) [7] and InstaRecon® (v.1.3.9.2) [8] softwares, with algorithm based on Feldkamp work [9]. It is possible to adjust some reconstruction parameters in order to obtain better image quality. In this work, ring artifact (7), beam hardening (14%) and smoothing filters (Gaussian kernel) fine-tuning were used. CTAn® (v1.11.8.0) and CTVox® [10] were used in order to analyze and visualized the 3D data.

Results

Figure 2 shows the 3D MicroCT visualizations of EDTA acidizing dissolution patterns, where wormhole formation in different experimental acid injection conditionals can be noticed. EDTA amount and injection rate affect the geometry of the channels.

The key reaction between EDTA solution and calcite includes H+ attack, ligand attack and water attack depending on the pH of the solution (Li et al 2008). No single dominant wormhole channel can be observed in figure 2a-c. At high injection rate (5 $cc.min^{-1}$) and moderate concentration (0.25 M) acid is consumed on the inlet flow face of the core and a conic geometry is obtained (figure 2a). However, with the same acid amount (0.25 M) but with a different injection rate (0.05 $cc.min^{-1}$)) the acid penetrates into more pores and enlarges flow channels. Figure 1b shows limited acid penetration as well as figure 1d, although in this last figure an increase in the surface channel area can be observed. EDTA reacts while slow moving, which can cause more homogeneous dissolution pattern and deep penetration can be achieved. However due to EDTA chemical characteristic reaction with carbonate materials, figure 2 shows that at the same injection rate and acid amount (Figure 2b and 2d), heterogeneous radial formation is obtained.

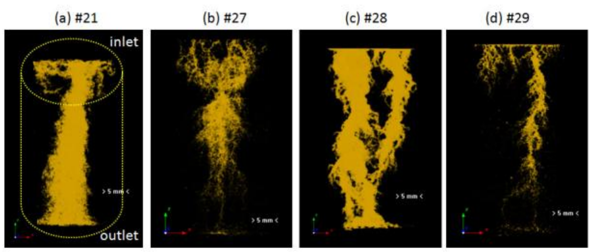

Figure 2: 3D MicroCT visualizations of EDTA acidizing dissolution patterns: (a) 5cc/min (0.25 M), (b) 5cc/min (0.10 M), (c) 0.05cc/min (0.25 M), (d) 5cc/min (0.10 M).

Conclusions

In this work we illustrated the capabilities of x-ray microCT approach to characterize wormhole formation induced by EDTA acidizing. We showed that changes in pore-grain and the wormhole geometry can be described from microCT images as well as typical dissolution structures formed during the stimulation of carbonate by EDTA.

Acknowledgments

This work was partially supported by Conselho Nacional de Desenvolvimento (CNPq), Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (ANP) and Centro de Pesquisas Leopoldo Américo Miguez de Mello (CENPES).

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