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Research paper

Insight into the behavior of colloidal gas aphron (CGA) fluids at elevated pressures: An experimental study

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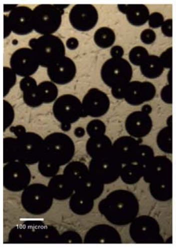
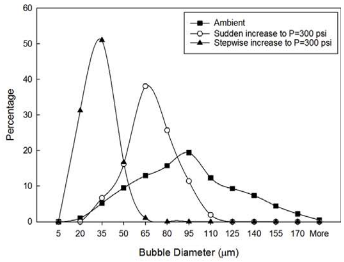
GRAPHICAL ABSTRACT



CGAs at ambient condition

CGAs after sudden increase to 300 psi

CGAs after slow and stepwise pressure increase to 300 psi



CGAs bubble size distribution dependence on path of pressurization

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ABSTRACT

Recently, colloidal gas aphron (CGA) fluids technology has been employed to drill depleted oil and gas reservoirs. Almost all reported experience on CGA fluids were conducted at ambient conditions, and little attention has been paid on the behavior of CGAs at high pressures which is more close to real conditions. In this study, high pressure experiments were conducted by using High Pressure Microscope cell to visualize/monitor the behavior of CGAs at elevated pressures. Single bubble behavior and bubble size distribution (BSD) of CGAs were investigated under different scenarios of pressure change. Results of experiments revealed that BSD of CGAs is controlled by the path of pressure changes, and sudden pressure change affects BSD less than stepwise changes in pressure. The pressure-volume product of bubbles, as a new criterion for analysis of single bubble behavior was introduced. The behavior of pressure-volume product for a single bubble shows significant loss of air via diffusion through tri-layer film into the bulk phase during compression as well as a hysteretic behavior during compression and decompression processes. Monitoring single bubble behavior at elevated pressures revealed that CGAs meet three distinct regions with time: first, they exhibited a sharp reduction in bubble size (region I), then became stable with minimum change in bubble diameter (region II), and finally, the size of bubbles decreased suddenly and after a short time they were collapsed (region III). Observations which showed aphrons were survived at pressures as high as 2000 psig may support the idea for field applications of CGAs as drilling fluids. Results of this work may provide thorough insight into behavior of CGA fluids at elevated pressures.

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1. Introduction

Colloidal Gas Aphron (CGA) based drilling fluids were successfully used in petroleum industry to drill through depleted reservoirs and low pressure formations [1–5]. This fluid system has been proven to have many advantages such as minimal fluid invasion, eliminating intermediate casing, reducing rig days, and rapid cleanup during production phase without the need for costly stimulation.

CGA based drilling fluids differ from foam and aerated drilling fluids in structural, stability and rheological properties [6]. The schematic of a micro-bubble (aphron) proposed by Sebba, is shown in Fig. 1 [7]. Aphrons are comprised of a spherical core of air and a protective tri-layer film. This tri-layer film is composed of an inner surfactant film enveloped by a viscous water lamella, which is overlaid with a surfactant bilayer that provides rigidity and low permeability to the whole structure. This shell enables aphrons to make difficult leakage of air from the gaseous core into the bulk fluid and allows them to survive severe conditions of pressure and temperature.

A polymer is used in the formulation of CGAs to viscosify the water “lamella” that surrounds the aphron core and strengthens the bubble film so that the aphrons can survive for a long period of time. If the base fluid viscosity is too low, the film between the inner surfactant layer and the outer surfactant bi-layer becomes too thin and the bi-layer won’t be stabilized. One should note if the film becomes very thin, polar head groups from the inner surfactant layer and the outer surfactant bi-layer will face to each other. This situation cannot exist for long times, because the polar groups repel each other. In CGA based-drilling fluids, the polymer viscosifies the water lamella and provides stability to the aphron structure. Brookey mentioned that a high yield stress, shear thinning (HYSST) polymer should be used in the formulation of base fluid [1]. In this case a xanthan gum biopolymer was found to enhance CGAs stabilization and increase the low shear rate viscosity (LSRV) which provided good hole cleaning, cuttings transport and invasion control. Growcock introduced the blend of a clay/polymer to act as a viscosifier in based fluid [8]. In this system, polymer/surfactant blends were added to act as aphron stabilizers.

CGAs are stable in drilling fluids at low pressures. The main concern associated with the application of CGA-based fluids in drilling operations lies in generating bubble mixtures able to withstand severe reservoir conditions. There exists a lot of theoretical and experimental studies on the stability and properties of CGAs at ambient conditions ([9–14]). However, there are a few studies in the literature addressing CGAs behavior at elevated pressures at downhole conditions.

Belkin et al. conducted a study under the auspices of the U.S. Department of Energy to gain some knowledge of the mechanisms of CGA fluids by which they control fluid invasion in permeable formations [15]. During the study, they discovered that aphrons can survive compression to at least 4000 psig for a significant period of time. They pointed out when fluids containing bubbles are subjected to pressure increase, the bubble diameter changes in accordance to Boyle’s Law. In this case, conventional bubbles lose their entrained air rapidly via diffusion mechanism while aphrons lose air much more slowly due to much less permeable membrane, and hence retain their air for hours. They reported when aphrons diameter reach a critical size (50–100 microns), they become unstable and suffer from catastrophic loss of air.

Bjorndalen and Kuru conducted experiments to investigate CGAs behavior at elevated pressures [16]. They performed high pressure experiments by pressurizing a Jerguson cell with a view window and capturing digital images of the fluid in the cell. The cell was pressurized at 50 psig intervals up to 500 psig and then was depressurized to the atmosphere. They studied single bubble behavior and observed that the bubble size decreased at a faster rate with increasing pressure at higher polymer and lower surfactant concentrations. Bubble size distribution (BSD) variation with pressure change, which is of great importance, was not addressed in their work.

Zozulya and Pletneva developed a new technique for the preparation of stable colloidal gas aphrons (CGAs) [17]. CGA fluid was prepared in three stages, including stirring the solution at ambient conditions, squeezing quickly the obtained foam to the nitrogen-saturated solution at 350–450 bar and finally, the solution was decompressed at a fixed pressure release rate to the prescribed pressure value below the gas nucleation threshold. They studied the behavior of aphrons under compression/decompression protocols in the range of 1–500 bar and pressure release rates in the range of 50–3000 bar/min with optical microscopy. Zozulya and Pletneva concluded that the released gas content is almost independent of pressure release rate. They

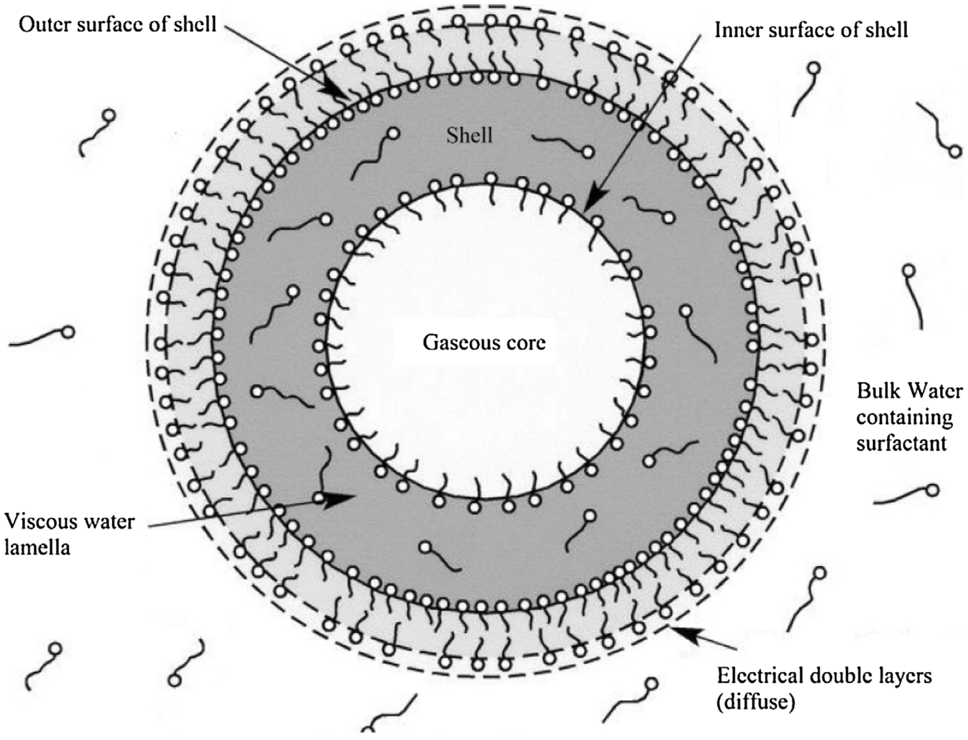

Fig. 1. Structure of a CGA proposed by Sebba [7].