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Influence of thermobaric conditions on size distribution of colloidal gas aphrons

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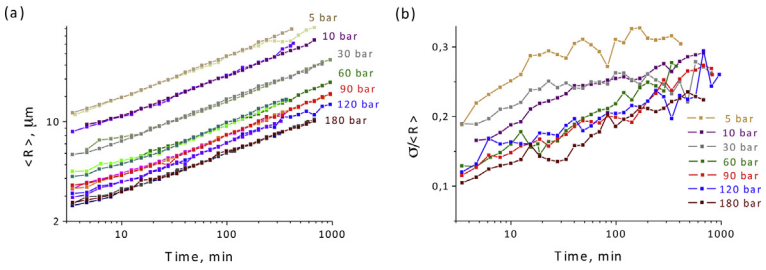
HIGHLIGHTS

- Preparation of monodisperse CGA stable at thermobaric conditions of a reservoir
- High-pressure instrumentation for CGA behavior monitoring at reservoir conditions
- Improved Circular Hough Transform for detection of >80% of bubbles present on image
- Key parameters affecting CGA size distribution during preparation and coarsening

GRAPHICAL ABSTRACT



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ABSTRACT

A new technique for the preparation of monodisperse colloidal gas aphrons (CGA) stable at reservoir conditions is developed. The behavior of such aphrons under compression–decompression protocols with pressure in the range 1–500 bar and pressure release rate in the range 50–3000 bar/min is studied with optical microscopy and densimetry. An image processing algorithm is developed for counting the aphrons and measuring the aphron size distribution. It is shown that the dispersity of the aphron system is independent of pressure. The dependence of the mean aphron size versus time follows Lifschitz–Slyozov law which is characteristic of wet foam coarsening. The monodisperse CGAs produced can be successfully used as pressure–temperature controlled systems for various oilfield applications

1. Introduction

Preparation of stable microbubble mixtures is of growing interest in various oilfield frontiers: drilling, completions, water flood monitoring, hydraulic fracturing etc. The main properties of bubble mixtures that attract much of the attention are their low density, effective gas encapsulation, and high yield stress, shear thinning rheology. The main complication in the development of the successful oilfield applications lies in the production of bubble mixtures able to survive reservoir conditions. The stability of micron-size bubbles comprises the problem that has been thoroughly studied in the field of medical ultrasound diagnostics where stabilized microbubbles are widely used as intravenously injected contrast agents [1]. The long life-time of such microbubbles is achieved as a result of four effects: the low diffusivity and the low solubility of the suitable gas in water solutions, the vanishing surface tension of the gas–liquid interface and the hardening (increase of elasticity) of the bubble shell. If one tries to transfer these sta-

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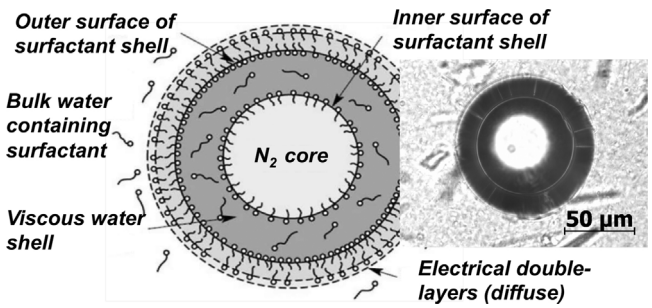

Fig. 1. CGA multilayer structure.

bilization techniques to reservoir conditions he would inevitably arrive at two possibilities: apply hard shell bubbles like hollow glass spheres [2] or generate soft shell bubbles like colloidal gas aphrons (CGA) which are capable of rearranging (reinforcing) their shells in response to pressure increase [3]. The former is obviously the most expensive case, moreover its disadvantage lies in the fact that the hard particles remaining intact during production operations can get accumulated, block pores and thus decrease permeability near injection wells. The latter is the more appropriate case for the oilfield applications as wellbore deblocking is easily achieved on pressure release [3].

2. CGA structure

At ambient conditions CGA based fluids consist of microbubbles (10–100 μm), the cores of which are composed of a gas surrounded by a thick multilayer shell [4]. The shell is formed of an inner surfactant film enveloped by a viscous water layer, which is in turn covered by a double layer of surfactants that provides rigidity and low permeability to the structure while imparting to it some hydrophilic character (see Fig. 1). The polar heads of the molecules that make up the outermost surfactant layer are oriented into the aqueous carrying fluid, thus making the structure hydrophilic and dispersible in it. This outermost surfactant layer also imparts an anionic charge to the aphron. Thus, aphrons tend to have little affinity for each other or for anionic mineral surfaces. These features ensure the successful use of CGA in drilling operations: by effective sealing of the wellbore CGAs prevent mud fluid losses and formation damage. In Fig. 1 you can see as well a microscope image of a gas aphron taken at ambient conditions. The noticeable eccentricity of the inner and the outer shell supports the outlined double-layer structure of the aphron as it can't be attributed to an optical artefact.

In the work the notion of the CGA behavior at reservoir conditions is acquired through the monitoring of the aphron density and the bubble size distribution (BSD) under variable pressure protocols.

3. CGA preparation procedure

The CGA based fluids used for the studies are prepared with the anionic surfactant sodium dodecyl sulfate (SDS) as an aphronizer. As a component of CGA, it is used to reduce the surface tension in order to preserve the gas aphron as it is formed and build the multilayer bubble wall. A polymer component of CGA acts as a viscosifier as well as a stabilizer. It improves the bubble stability by decreasing both the fluid drainage rate and the gas diffusion through the bubble interface. A set of test experiments is performed in order to find out what biopolymer among those actively used in oilfield applications is the best candidate for the preparation of the gas aphrons stable at reservoir conditions (to be published separately). Among the tested biopolymers are such polysaccharides as potassium alginate, guar, and xanthane. The tests show that xanthane is

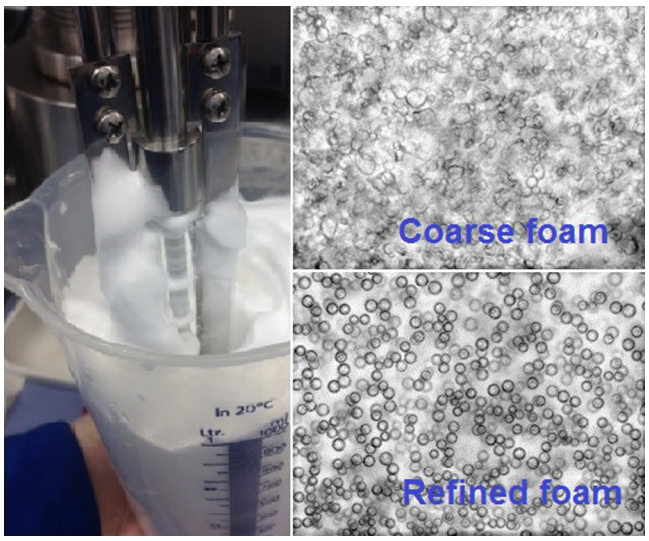

Fig. 2. CGA foam generation

the best choice in this respect. Moreover xanthane is the low shear rate viscosifier, which is used to control invasion of drilling fluid and to clean borehole from cutting suspension. As CGA based drilling fluid reduces deep fluid invasion both rheologically and mechanically it displays more attractive behavior in comparison with pure xanthane solution. Our rheological experiments show that the gas aphrons increase the viscosity by 5–6 times and such parameters of Bingham model as yield stress and flow behavior index by 1.5–2.5 times.

Usually CGAs are generated in a viscous polymer/surfactant solution with a high-speed blade mixer. Decompression voids emerging in such turbulent rotational flow give rise to the formation of bubbles of various sizes and as a result the final BSD of the produced CGA is broad. Broad BSD is obviously a drawback if one attempts to produce CGA based fluid with pressure-controllable mean size. Indeed, the aphron colloid with broad BSD is vastly subjected to inter-bubble gas diffusion as it contains a lot of bubbles that eventually become subcritical and dissolve. To produce narrow bubble SDs mechanical homogenization is used as a first step needed to quickly entrap gas into the base polymer/surfactant solution, then the decompression approach is applied, i.e. on the second step the aphron foam is squeezed till all the amount of the entrapped gas get dissolved in the solution, and finally the gas-saturated solution is exposed to the abrupt pressure release with controllable pressure release rate. It results in gas nucleation and in the formation of the monodisperse CGA based fluid. Further the preparation procedure for the most stable CGA based on xanthane gum is presented in detail.

At first stock aqueous solutions of 15 g/L xanthane, 200 g/L SDS and 15 g/L sodium stearate (NaSt) are prepared. The first two solutions are obtained under stirring at room temperature until the complete dissolution of the chemicals. Sodium stearate 15 g/L solution is made by mixing stearic acid and 2 wt.% NaOH solution in a heated environment (85 °C) for 2 h under slow stirring. At the end of heating NaSt solution is quickly added to xanthane-SDS solution which is formed by mixing the desired ratio (2:1) of xanthane and SDS stock solutions. Then the mixture is vigorously homogenized for 7 minutes at 12,000 rpm with a mixer specially constructed in the house for the aphron preparation. The main element of the mixer is an abrasive disk Ø30 × 1 mm. The mixer and the vessel containing the solution are enclosed within a thin transparent plastic shell which is connected to a gas line providing nitrogen at the rate of 250 cm^3/min. The shell is used to maintain single gas atmo-