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Evaluating the stability of colloidal gas aphrons in the presence of montmorillonite nanoparticles

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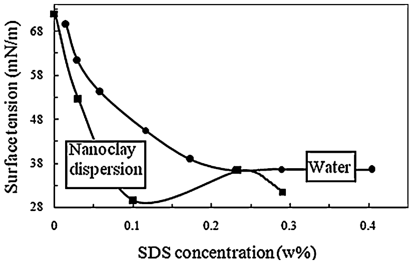
HIGHLIGHTS

- For pores blocking of the rock in aphron drilling operation, stability of colloidal gas aphrons is a key factor.
- Stability of CGAs has been investigated in the presence of nanoparticles.
- A novel interpretation of drainage curve is introduced for deducing the synergetic effect of nanoclay on CGA stability.
- The presence of nanoclay has particular effect on behavior of surface tension of aqueous nanofluid.

GRAPHICAL ABSTRACT



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ABSTRACT

To block rock pores in aphron drilling operation, colloidal gas aphrons (CGAs) stability is a key factor to minimize formation damage. Although the synergistic stabilization of aqueous foam by solid particles and surfactants has been extensively studied, there are few references for synergistic stabilization of CGAs. In this experimental study, stability of CGAs has been investigated in the presence of nanoparticles. CGAs dispersion were generated by stirring at 7000 rpm for 4 min in the presence of the nanoclay (Na-Montmorillonite). An anionic surfactant, sodium dodecyl sulfate (SDS), and also a non-ionic surfactant, nonyl phenol ethoxylate (NPE20) were used. The experimental macroscopic findings from the drainage curve observations were correlated to the microscopic behavior of CGAs. A novel analysis of drainage curve was introduced to examine synergistic effect of nanoclay on the CGA dispersion stability. This work concludes that nanoparticles influence the stability of CGAs dispersion and also nanoclays reduce the critical micelle concentration (CMC) in a surfactant solution.

1. Introduction

1.1. Colloidal gas aphrons (CGAs)

Aphrons, surfactant stabilized microbubbles with thick soapy shells, appear to have an average diameter of about 50 μm. They are held together by surface forces which give the dispersion the appearance of a quasi-liquid phase [1]. Because the bubbles show some colloidal properties, they are called Colloidal Gas Aphrons, CGAs or Aphrons for short by Sebba (Fig. 1). An aphron comprises two fundamental elements; a spherical core that can be liquid or gas and a relatively thick aqueous protective shell. Based on the core type, aphrons can be categorized as colloidal gas aphrons (CGAs) and colloidal liquid aphrons (CLAs). CGAs consist of gas bubbles but CLAs are micron-sized solvent droplets [2].

Several applications of CGAs have been reported in the technical and scientific literatures including removal of fine particles from dispersion [3], removal of toxic wastes from soil [4–6] and

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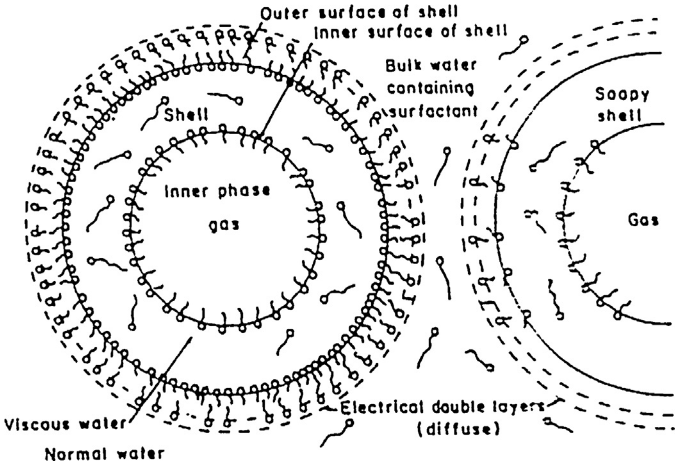

Fig. 1. Structure of aphrons proposed by Sebba [1].

recovery of a wide variety of valuable materials [7–11] among others [12–15].

Although the aphrons are stable in that their rate of coalescence is low, the CGA dispersion will cream and form a clear solution layer. As a result of creaming, the CGA dispersion is separated into a clear solution region and a sudsy media in which the aphrons are inevitably crowded together more closely than they were in the original dispersion. Both the movement of the clear solution interface and also the sudsy media surface depend on aphron size. Therefore, details of clear solution interface rise with time and also details of the fall of the upper surface of dispersion due to foam instability (gravity drainage, disproportionate, coalescence, and rupture of bubble film) with time, i.e. drainage curve, would provide a very useful insight into the structure of CGA dispersion. This is the basis of the method for the characterization of CGA dispersions that was developed by Amiri and Woodburn [16]. Moshkelani and Amiri have recently found that probing the electrical conductivity (EC) of clear solution (drained water) is a powerful method for the characterization of CGA dispersion [17].

The most important characteristic of CGAs is their high stability compared to conventional foams [18]. This unique feature makes them a powerful tool for particular applications such as aphron drilling operation to minimize formation damage. CGAs can be used to block the pores of the rock which can later be easily removed when the well is open for production. In this case, the aphrons are able to penetrate within the pore spaces and plug the borehole. CGAs behave in this operation like tough, yet flexible seal and bridging materials [19].

Effect of small particles on foam stabilization has been well examined in scientific sources [20–36]. The interaction of surfactant and solid particle is a complex phenomenon. Previous works of surfactant adsorption at the solid surface have demonstrated that the sensitivity of adsorption is related to the properties of solid particles, concentration of electrolytes, temperature, pH, and surfactant properties (such as the structure, adsorption mechanism, and concentration).

Presence of particles can provide three effects in the system: depletion of surfactant concentration by adsorption loss, increase in viscosity, and stabilization of thin liquid films by the particles.

It has been generally accepted that stable foams are difficult to form when the particles are hydrophilic, when the contact angle is less than 90° [21]. Therefore, only hydrophobic or at least partially hydrophobic particles can be used to stabilize foams [22].

A typical contact angle modification route is via surface coating with a suitable kind and amount of surfactant on the particle surface. For example, hydrophilic SiO_2 nanoparticles can be modified by surface silylation to obtain various wettability [22,23].

Binks and Horozov [22] and Kostakis and co-workers [24] studied foams stabilized by partly hydrophobic fumed silica particles. They also investigated the influence of particle hydrophobicity [22] and salt concentration [24] on foam stability. Studart and co-workers [26,27] accomplished in situ hydrophobization of particles using short-chain amphiphiles.

Particle wettability can also be modified by the adsorption of long-chain surfactants on the particle surfaces [28].

There are reports that addition of surfactant to particle dispersions does not always promote foam stability and may lead to act as a defoamer. Alargova et al. [29] found that the stability of foams prepared by mixtures of hydrophobic rod-shaped particles and sodium dodecyl sulfate (SDS) was decreased compared with that by the particles alone. Because the adsorption of SDS onto the particles renders them more hydrophilic and then the particles lost their affinity for the solution/air interface.

Surface active nanoparticles similar to surfactant molecules, i.e. asymmetry with tail and head group, can be obtained by preparing “Janus” particles [30–32].

In situ surface activation is another method for changing wettability of particles and making them as surface active nanoparticles in aqueous media via interaction with amphiphilic compounds [33–36].

1.2. Montmorillonite nanoclay and its modification

Clays are hydrophilic in nature because of the presence of inorganic cations on the basal planar of Montmorillite [37]. Due to their natural availability and the capacity for the chemical and physical modifications, clays are used in many scientific applications. A general method for modification of clay is to use a suitable surfactant and make them as organo-montmorillonite (organo-MMT).

Organo-MMTs are synthesized by grafting surfactants such as including anionic, cationic, and nonionic into the interlayer space [38,39]. It was reported [40–42] that replacement of the exchange ions in MMT by surfactants can create a fresh surface with a certain degree of hydrophobicity. These clays are referred to as organoclays or organophilic clays.

The present research is an attempt to study modifications of Na-MMT by NPE20 and SDS to achieve greater hydrophobicity as a result of interaction between surfactant and nanoclay.

Fig. 2 depicts schematically how Na-MMT is modified from hydrophilic to hydrophobic surface by surfactant molecules. It can be seen that intercalation of organic surfactants between layers of clays provide this modification [43].

Although the synergistic stabilization of foam by solids and surfactants has been widely investigated, studies on CGAs dispersions prepared from mixtures of surfactants and nanoparticles have been limited. However, some microbubbles described in foam literature are exactly similar to CGAs [19].

The main objective of this work is to fill this knowledge gap by studying CGAs dispersion stability under the conditions of two types of surfactants and a nanoclay.

2. Experimental design

2.1. Materials

Pure deionized water with a specific electrical resistance of 18 MΩ cm at 25 °C was used.

Na^+-montmorillonite clay of the smectite group was purchased locally (NANOSANY CO., Meshhed, Iran) and used without further