Modification of silica nanoparticles by dichlorodimethylsilane for foam stability and decontamination efficiency

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1. Introduction

Decontamination foam comprises a surfactant to generate the foam, a co-surfactant in the form of a long-chain alcohol to reduce the total number of surfactants, and chemical reactants to dissolve the contaminants on a solid surface. To increase the decontamination efficiency of this process, the contact time of the chemical reactants to the contaminated surface should be increased. Therefore, the present research is focused on increasing the contact time by adding a viscosifier, which is a biopolymer, or inorganic materials such as silica nanoparticles (NPs) to the decontamination foam solution [1].

Silica NPs increase the foam stability in the foam formulation. These particles can be specifically hydrophobized for optimal adsorption at the liquid/gas interface, which creates armor for the bubbles and prevents coalescence by reducing the internal gas transfer [2-4]. Conversely, hydrophilic particles remain confined in the liquid phase, and to enhance the foam stability. Kruglyakov and Taube [5] studied the drainage of foams generated from a non-ionic surfactant suspension of pyrogenic silica. Their results showed that the loss of liquid is slightly slowed down when particles are present because of the steric hindrance to the liquid flow.

In this study, we aimed to modify the surface of silica nanoparticles with dichlorodimethylsilane (DCDMS) reagents using methods proposed in previous studies. We also investigated the foam stability and decontamination efficiency with surface-modified silica nanoparticles to develop a new formulation of decontamination foam (Fig.1).

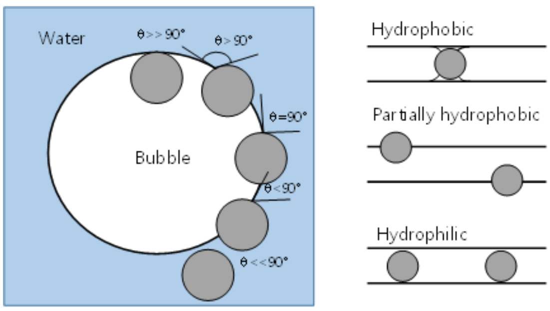

Fig. 1. Position of silica nanoparticles with different contact angle in the foam film.

2. Methods

Fumed silica (M-5) was purchased from Cabosil, and selected owing to its stability and in an acid medium and low cost. Various degrees of hydrophobicity were obtained through silanization of the silica particle surface with DCDMS (+99.5%, Sigma-aldrich). In the surface modification, 1.0 g fumed silica nanoparticles were modified using DCDMS/Si with a mole ratio of 0, 0.5 and 5% in toluene for 20 hrs and continuously injected by nitrogen gas. The samples were then dried in a furnace at 110 °C for 3 hrs.

Hydrophilic silica (M-5) was silylated through a reaction with DCDMS. The silylation was performed with variable amounts of silane in order to control the DCDMS group. The content of silanol groups was determined through titration with aqueous sodium hydroxide [6]. 1 g silica NPs modified with DCDMS/Si at a mole ratio of 0, 0.5 and 5% were added to a 1% v/v Elotant^{TM} Milcoside 100 (EM 100) surfactant solution to investigate the foam stability.

In all tests on the foam stability and structure, the foam height and liquid volume in the foam were measured using a Dynamic Foam Analyzer (DFA-100, KRŰSS, Germany). During foaming, compressed air was passed through a sintered glass frit at the bottom of a cylindrical glass vessel (40 mm inner diameter) containing the solutions and the decontamination foam. The initial liquid volume was 60 ml; the gas flow was 0.2 l/min, and was stopped after 60 s of foaming.

Decontamination foams were prepared using 100 ml of diluted nitric acid in a 1.0% v/v EM100 surfactant solution containing varying amounts of added 1 g silica NPs modified with DCDMS/Si at a mole ratio of 0, 0.5 and 5%. Approximately 250 ml of each decontamination foam formulation was generated from a 50 ml solution by shaking for 10 s in a 250 ml container, with a gas to liquid ratio of 4:1. An oxide film of nickel ferrite, prepared using electrodeposition, was placed in the middle of the bottles and left to react with the decontamination foam for 1 h at room temperature. The dissolved Fe and Ni were analyzed using atomic absorption spectroscopy after the foam decontamination test.

3. Results

3.1 Foam stability and contact angle

Figure 2 shows the foam performance index (FPI) as the foam stability had a higher value with surface-modified silica nanoparticles in DCDMS/Si at a mole ratio of 0.5% than that with other silica nanoparticles. However, FPI had the lowest value with surface-modified silica nanoparticles in DCDMS/Si with a mole ratio of 5% compared with the other silica nanoparticles, indicating that a high concentration of DCDMS can hamper the foam stability. This result showed that the optimum mole ratio of DCDMS/Si with 0.025. The contact angle was 50, 82, and 90° with surface-modified silica nanoparticles in DCDMS/Si with a mole ratio of 0, 0.5 and 5%. This result suggests a contact angle of 80-85° had a positive effect on the foam stability; however, a contact angle of over 90° was hydrophobic and decreased the foam stability. When partially hydrophobic silica nanoparticles and suitable surfactants are combined, synergistic effects can be found in terms of the foamability and foam stability of the corresponding dispersions [7].

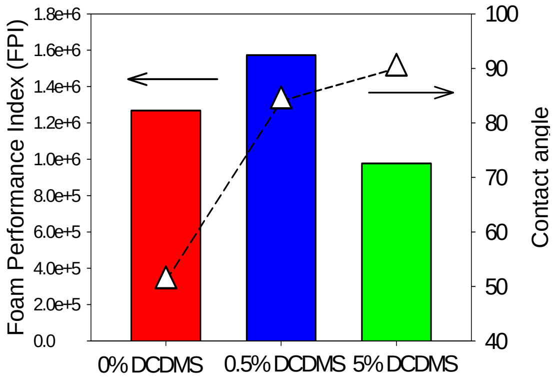

Fig. 2. Relationship between the foam performance index and contact angle.

3.2 Decontamination efficiency

To evaluate the decontamination performance of different foams with varying amounts of DCDMS, the dissolved Fe and Ni concentrations were measured. The dissolved Fe and Ni concentration was highest using decontamination foam with surface-modified silica nanoparticles in DCDMS/Si with a mole ratio of 0.5% as compared with decontamination foam with other silica nanoparticles. Faure's study [8] indicates that the rate of oxide dissolution is directly proportional to the foam stability. These results suggest that the use of surface-modified silica nanoparticles in decontamination foam increases the decontamination efficiency owing to the increased foam stability.

4. Conclusions

Modified silica nanoparticles are an effective stabilizer of decontamination foam by controlling their hydrophobicity, resulting in a foam stable against collapse. In future studies, decontamination tests will be conducted on a surface contaminated with radionuclides such as cesium and cobalt.

REFERENCES

1. C. Dame, C. Fritz, O. Pitois, S. Faure, Colloids Surf. A, 263, 210-218 (2005).
2. B.P. Binks, Curr. Opin. Colloid Interface Sci., 7, 21-741 (2002).
3. M. Abkarian, A.B. Subramaniam, S.H. Kim, R.J. Larsen, S.M. Yang, H.A. Stone, Phys. Rev. Lett., 99, 188301 (2007).
4. A.C. Martinez, E. Rio, G. Delon, A. Saint-Jalmes, D. Langevin, B.P. Binks, Soft Matter, 4, 1531-1535 (2008).
5. P.M. Kruglyakov, P.R. Taube, Coll. J.-USSR, 34, 194-196 (1972).
6. G.W. Sears, 28, Anal. Chem. 1981-1983 (1956).
7. U.T. Gonzenbach, A.R. Studart, E. Tervoort, L.J. Gauckler, Angew. Chem., Int. Ed. 45, 3526-3530 (2006).
8. S. Faure; B. Fournel; P, Fuentes. US patent US 7,662,754 B2 (2010).