



Stability of Foaming Agent for Foam Decontamination†

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This study conducted experiments to evaluate the stability of nano foaming agents by adding various types of surfactants, silica nanoparticles and viscosifiers with the aim of enhancing the stability of foaming agents containing nanoparticles. Nonionic surfactants such as EM100 showed higher stability as compared to the sodium dodecyl sulfate anionic surfactant. The cosurfactant addition did not significantly affect the foam stability. When silica nanoparticles were added to the surfactant EM100, the foam stability improved further. In particular, the foam stability of the nano foaming agent was observed to be the maximum when a partially hydrophobic nanoporous silica nanoparticles such as KAERI 1 was added, as compared to the addition of a hydrophilic dry silica such as M5. This is because the partially hydrophobic particles were distributed over the liquid film between the foams, thereby preventing drainage and increasing the stability of the foaming agent fluid.

Keywords: Decontamination, Foam, Stability, Nanoparticles.

INTRODUCTION

The facilities which handle radioactive materials become aged after a long period of operation. Hence, the maintenance, repair and decommissioning of the facilities are periodically required. Consequently, decontamination technology has been developed to prevent the proliferation of radioactive materials and to reduce the radiation exposure of operators during work^{1,2}.

Currently, chemical solution decontamination technology is being widely used as it exhibits a high decontamination effect achieved through chemical dissolution as well as oxidation and reduction reactions. However, this technology has a drawback in that a large amount of radioactive liquid waste is produced, which means that the amount of liquid waste produced by the application of decontamination technology needs to be reduced.

Foam decontamination technology can significantly reduce the radioactive waste produced after decontamination, since more than 90 % of the decontaminating materials used in this technology consist of gases. It can also be used in the decontamination of large-sized equipment or large facilities where application of decontamination technology is difficult. It also allows for remote decontamination³⁻⁵.

Decontamination efficiency generally increases with an increase in the contact time between the contaminated surface and the chemical decontaminant. Therefore, maintaining without breaking the foam for a certain time period is required for increasing the decontamination efficiency of the decontaminant. To improve the stability of the foam, surfactants and polymers or inorganic materials such as nanoparticles can be added^{6,7}.

The present study evaluated the stability of a foaming agent containing nanoparticles by using various types of surfactants and silica nanoparticles. This evaluation will contribute to an increase in the stability of the foam decontaminant as part of the development of an efficient foam decontaminant that can replace chemical solution decontaminant.

EXPERIMENTAL

The present study used nonionic surfactants such as Elotant™ Milcoside 440N (EM 440N, LG Household & Health Care) and Elotant™ Milcoside 100 (EM100, LG Household & Health Care) and an anionic surfactant such as sodium dodecyl sulfate (SDS, Sigma-Aldrich), which are widely used for commercial purposes, as surfactants consisting of foaming agents⁸.

Hydrophilic dry silica (fumed silica, M-5, Cabosil) and hydrophobic silica nanoparticles (K-P20, OCI Co.) were used

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as commercially available nanoparticles. Spherical mesoporous silica nanoparticles (KAERI 1), which are partially hydrophobic and less than 200 nm in size, are manufactured synthetically using M-5 silica nanoparticles with ethanol and tetraethyl orthosilicate (TEOS, Sigma-Aldrich). The effect of cosurfactant type on foam stability was investigated by adding 0.05 wt % each of dodecanol and decanol, separately to 1 wt % EM100.

A glass was filled with 60 mL of the manufactured liquid foaming agent and subsequently filled with nitrogen gas to produce approximately 200 mL of foam. The foamability and foam stability were measured over 3,600 s using FoamScan® (TECLIS, France) *via* image analysis and electrical conductivity measurements.

The change in foam volume, or the fraction of liquid remaining within the foam (liquid fraction) and the volume flowing into liquid as the foam collapsed over time (foam drainage), were analyzed to study the foam stability in real time.

RESULTS AND DISCUSSION

To study the foam stability with respect to surfactant types, 1 wt % EM100, EM440N and sodium dodecyl sulfate were used. Fig. 1 shows the results of the foam stability experiment over time. The foam volume decreased by 60 mL and 50 mL when using the sodium dodecyl sulfate anionic surfactant and the nonionic surfactants (such as EM100 or EM440N), respectively.

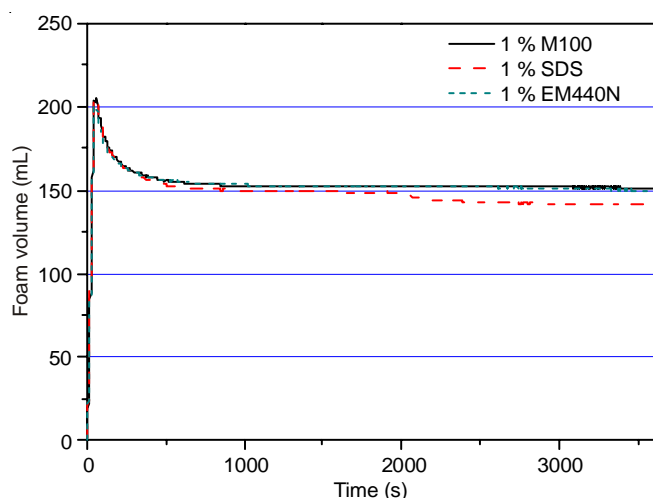


Fig. 1. Variation of foam volume in foam of 1 % EM100, sodium dodecyl sulfate, EM 440N

The foam volumes over time were compared according to the integration area of its curve, the use of nonionic surfactants such as EM100 and EM 440N provided 3.7 and 3.4 % higher foam stability, respectively, with respect to sodium dodecyl sulfate.

Thus, nonionic surfactants such as EM100 and EM 440N showed higher stability as compared to sodium dodecyl sulfate, whose foamability and stability are already known to be high⁸. However, EM 440N is sensitive to temperature and cannot be used over a wide temperature range, whereas EM100 is not sensitive to temperature and the foam produced can bestably maintained, making it an excellent principal surfactant for a nanofoaming agent.

To determine the effect of the cosurfactant on the foam stability, an experiment was conducted in which decanol and dodecanol of 0.05 wt % concentration were added to a nonionic surfactant such as 1 wt % EM100. As shown in Fig. 2, when the cosurfactant was not added, the foam volume decreased by 49 mL and after decanol was added, the volume decreased by 57 mL, indicating that the performance was worse with the cosurfactant than without it. The foam volume decreased by approximately 43 mL after dodecanol was added. Thus, it was observed that the cosurfactant did not significantly affect the increase in foam stability.

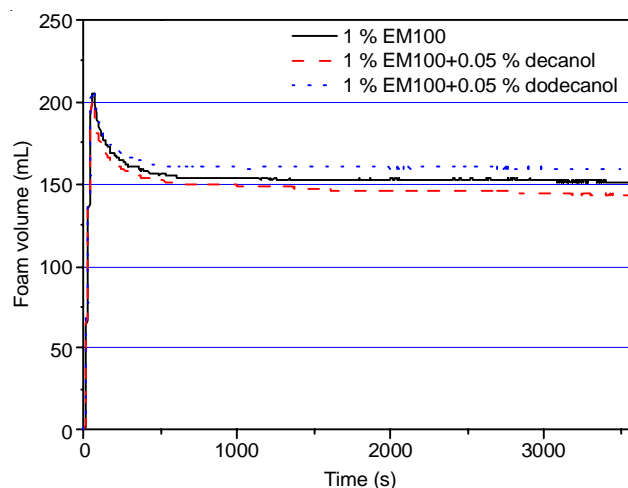


Fig. 2. Variation of foam volume of 1 % EM100 with 0.05 % decanol, dodecanol.

To determine the effect of silica nanoparticles on the foam stability, 1 wt % concentration of a hydrophilic dry silica such as M5, hydrophobic nanoparticles such as K-P20 and partially hydrophobic nanoporous silica such as KAERI 1 were added to 1 wt % EM100 to be used for evaluating the foam stability. The results of the foamability comparison in Fig. 3 showed that K-P20 = M5 > KAERI 1, in that order. The results of the liquid fraction in foam revealed that adding KAERI 1 to 1 wt % EM100 was the most effective, followed by K-P20, whereas M5 showed nearly the same result as the one without silica nanoparticles.

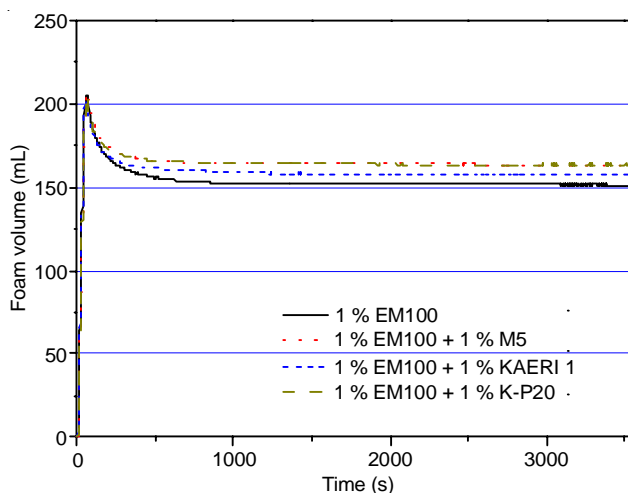


Fig. 3. Variation of foam volume of 1 % EM100 with M5, KAERI 1 and K-P20

The effects of the formulation on the liquid fraction have been investigated by determining the time for the initial liquid fraction (ϵ_0) to halved ($\tau(\epsilon_{1/2})$) and for the initial liquid fraction (ϵ_0) to become 1/10th ($\tau(\epsilon_{1/10})$). As shown in Table-1, $\tau(\epsilon_{1/2})$ is almost same, regardless of nanoparticles type, as compared to the case using only EM100, while $\tau(\epsilon_{1/10})$ is improved by a factor of 3.2 with KAERI 1, by a factor of 1.3 with K-P20, than for solely EM100.

TABLE-1
CHARACTERISTIC FOAM DRAINAGE
DATA: ϵ_0 , $\tau(\epsilon_{1/2})$ AND $\tau(\epsilon_{1/10})$

| | Initial liquid fraction and its time parameters | | |
|------------------------|---|----------------------------|-----------------------------|
| | ϵ_0 (%) | $\tau(\epsilon_{1/2})$ (s) | $\tau(\epsilon_{1/10})$ (s) |
| 1 % M100 | 22.8 | 119.3 | 409.2 |
| 1 % M100 + 1 % M-5 | 16.5 | 116.3 | 396.2 |
| 1 % M100 + 1 % KAERI-1 | 18.0 | 120.3 | 1,310.0 |
| 1 % M100 + 1 % K-P20 | 17.2 | 117.3 | 547.2 |

Thus, it was shown that the hydrophobicity of the nanoparticles affected the foam stability. In particular, it was shown that nano foaming agents that added partially hydrophobic nanoporous silica such as KAERI 1 had the highest foam stability. This is because hydrophobic silica is aligned with the lamellar side and hydrophilic silica is distributed over the Plateau border, whereas partially hydrophobic nanoparticles are dispersed over the entire liquid film between the foams, preventing drainage and thereby increasing the stability of the nano foaming agent⁹. It was observed that adding partially hydrophobic KAERI 1 to 1 wt % EM100 increased the foam stability more than any other silica particle.

Conclusion

The present study conducted experiments on nano foaming agents for evaluating their stability by adding various types of surfactants, silica nanoparticles and viscosifiers to increase the stability of the foaming agents containing nano-

particles. The results showed that nonionic surfactants such as EM100 showed higher stability as compared to the commercial sodium dodecyl sulfate, whose foamability and stability are known to be high. The addition of cosurfactants and viscosifiers in the foaming agent compositions showed that the cosurfactant addition did not significantly affect the foam stability. In addition, the foam stability of the nano foaming agent was observed to be at maximum when a partially hydrophobic nanoporous silica such as KAERI 1 was added, as compared to the addition of a hydrophilic dry silica such as M5. This is because the partially hydrophobic particles were distributed over the liquid film between the foams, thereby preventing drainage and increasing the stability of the foaming agent fluid. Thus, the foaming agent, manufactured using a solution in which 1 wt % of KAERI 1 nanoparticles was added to 1 wt % EM100 showed the effective foam stability.

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