

Rapid Communication

Removal of submicron particles from solid surfaces using surfactants

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ABSTRACT

The removal of nano- or submicron particles from solid substrates is of considerable interest in a range of existing industries including cleaning of surfaces inside a spacecraft after evaporation of nanofluids. A method of nanoparticle removal using aqueous surfactant solutions is proposed. The surfactants' cleaning efficiency is investigated for all four combinations of hydrophilic (HL) and hydrophobic (HB) nanoparticles and surfaces, in order to find the most successful cleaning method in each combination. Carbon and silica nanoparticles deposited onto Teflon and glass surfaces were used. Cationic, anionic and non-ionic surfactants with a range of CMCs and HLBs were used in order to identify the best surfactant in each scenario.

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The currently increasing focus on nanotechnology and the use of microstructures is beneficial to a number of industries, as well as to the ever improving quality of consumer products. However, nanoparticles have a tendency to bind to solid surfaces with incredible strength and can cause fouling to micro-structured devices [1]. This resilience is due to various intermolecular forces between the particles and the surface, such as Van der Waals, electrostatic forces and hydrogen bonding [2]. The effect of nanoparticle fouling on microstructures, however, is relatively unknown despite rising industrial interest in their uses [3].

There are a number of current methods to remove nanoparticles from solid surfaces such as those using nanobubbles [4], megasonics [5], lasers [6], aerosols [5] and chemical etching [7] among others. Although the previously mentioned techniques have shown to be effective at nanoparticle sizes as low as 10 nm, many have notable drawbacks. Examples of this include the required use of highly specialised equipment, which demand precise optimisation to be used effectively and sensitivity to fluctuations in parameters such as temperature [5]. Many of the methods, particularly those using lasers, operate on a very small area, making the cleaning of larger surfaces significantly more difficult.

The use of suitable selection of surfactants to remove two different types of nanoparticles from solid surfaces is proposed below in order to develop an easier and reliable procedure, which has the potential to be carried out without astronauts interference inside a spacecraft.

Below we investigate all possible scenarios with regard to the nature of the surface and particles and surfactants. The surfactants used were selected due to their range of properties, such as critical micelle concentration (CMC) and hydrophile–lipophile balance (HLB), and were used for all combinations of hydrophilic (HL) and hydrophobic (HB) nanoparticles and surfaces in order to investigate the most effective for each of four possible scenarios. Experiments of spreading or/and evaporation of nanosuspensions inside space crafts are supposed to be undertaken in the future. However, the residual nano-particles left on the solid surface after evaporation should be removed without the interference of astronauts, that is, the cleaning method should allow a complete automation. The method suggested below is capable of solving the mentioned problem.

In order to have a clean glass slides to use in the experiments, the slides were left for 45 min in a 1:1 volume solution of concentrated sulphuric acid (>95%) and hydrogen peroxide (35%) known as Piranha solution. After that, the slides were left in a beaker with reverse osmosis water (RO-water) and heated to 70 °C for a further 45 min before being used.

As a smooth surface was required the slides chosen were Corning 2947-75 × 25 mm Micro Slides (plain), with a thickness of 1 mm. The Teflon film was Goodfellow LS389078 PTFE Film with a thickness of 0.05 mm. The contact angles of pure water on both substrates (clean Glass and Teflon) were found to be 5.0 ± 1 deg. and 109.6 ± 0.2 deg., respectively.

The hydrophilic (HL) and hydrophobic (HB) particles, which were selected for experiments were silica (0.5–10 μm, approx. 80% between 1 and 5 μm; Sigma-Aldrich S5631) and carbon (<500 nm; Sigma-Aldrich 699632), respectively. Suspensions were made of each particle by adding the powders to RO-water, then agitated in an ultrasonic

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Table 1
The CMC, HLB, pH and conductivity values of the used surfactants.

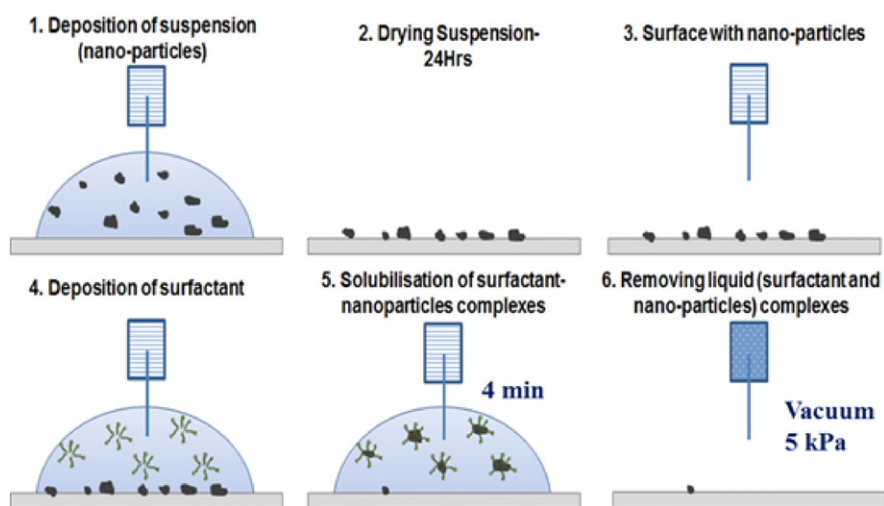
Type	Surfactant	CMC mM	HLB ^a	pH	Cond. $\mu\text{s}/\text{cm}$
Anionic	Sodium dodecyl sulphate (SDS)	8.2 ^A	40.0	7	702
	Sodium 1-octanesulfonate monohydrate (1-SOS)	155 ^B	41.9	5.5	8529
	Sodium 1-dodecanesulfonate (1-SDDS)	7 ^E	9.7	6.3	446
Non-ionic	Triton X-100 (T-X-100)	0.24 ^F	13.5	6.2	180
	Tween 20 (T-20)	0.05 ^G	16.7	5.9	370
	Novac TM FC-4430	0.17 ^A	–	6	18
	Novac TM FC-4432	0.5 ^A	–	4.6	28
Cationic	Dodecyltrimethylammonium bromide (DoTAB)	11 ^C	12	6.7	1070
	Myristyltrimethylammonium bromide (MTAB)	4 ^D	14	5.7	387

A: From experimental data; B: [8]; C: [9]; D: Sigma-Aldrich, 2015; E: [10]; F: [11]; G: [11].

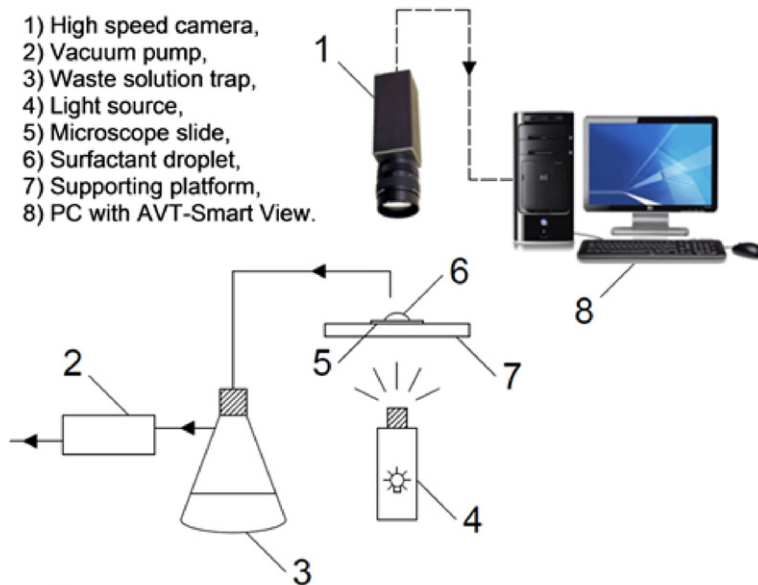
^a All HLB values were calculated using the Davies method [12].

bath for an hour to have a homogeneous suspension. The first half of the experiments (HB particles on HB substrate and HB particles on HL substrate) were conducted using the carbon suspensions and the latter half (HL particles on HL substrates and HL particles on HB substrates) using silica suspensions. The HL and HB surfaces where the particles were deposited onto were glass slides (HL) and Teflon film (HB), respectively. These materials were chosen due to the variety of industrial applications in which they are used, such as windows and containers for glass and a range of aerospace components made of Teflon. After the slides had been cleaned, as discussed above, a 5 μL droplet of a suspension was deposited onto the centre of each solid substrate using a micropipette. The slides were then covered in order to protect the droplets from contamination and left for 24 h to dry.

Table 1 shows the chosen surfactants and their properties including critical micelle concentration (CMC), hydrophilic–lipophilic balance (HLB), pH and conductivity values (at 1 CMC). This selection of surfactants provided a suitable variety of CMCs and other properties required.



a



b

Fig. 1. a—Schematic presentation of the methodology steps; b—diagram of the experimental apparatus.

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