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FOAMING HONEY– PARTICLE OR MOLECULAR FOAMING AGENT?

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ABSTRACT

Honey foam was prepared using particle (precipitated CaCO_3) or molecular (sodium lauryl sulfate) foaming agent. We noted the foam volume and the time it took a foam sample to collapse completely so as to determine the best foaming agent. Foams were prepared by aerating honey in the presence of varying concentrations of the particles or sodium lauryl sulfate. Aqueous foams were similarly prepared for comparison. Sodium lauryl sulfate gave a higher volume of honey foam, which did not collapse completely for more than four months compared with precipitated CaCO_3 particles which gave a smaller foam volume that collapsed completely within four weeks. Aqueous foams prepared from the surfactant, by contrast, collapsed completely within three hours while those prepared from the particles did not collapse within the same timeframe. This shows that the surfactant is a better foaming agent in honey compared with the particles, while the particles are a better foaming agent in water compared with the surfactant.

Keywords: surfactant, small solid particle, **honey**, honey foam, foam stabilization, **liquid marbles**

INTRODUCTION

Applications of liquid foams are **ubiquitous**. In the food industry, liquid foams are used as food (*e.g.* whipped ice cream and beer foam) or **as** precursors of novel food products. In cosmetics, liquid foams are used for shaving and bathing. Liquid foams are also component of some fire extinguishers. However, these applications are greatly impeded by the physical separation of the gaseous and the liquid phases, driven by the relatively large liquid-air interfacial tension. In aqueous and non-aqueous liquids like oils, the physical separation of the gaseous and **the** liquid phases is commonly prevented using either a particle (so-called Pickering foams) or a molecular (proteins, polymers, surfactants) foaming agent. **Pickering**,^[1] **Ramsden**^[2] or **Ramsden-Pickering**^[3] **aqueous and oil foams are devoid of complete phase separation for several months or years**. The foams are so named after Ramsden ^[4] and Pickering ^[5] who first used small solid particles to stabilize foams and emulsions. By contrast, surfactant-stabilized aqueous and oil foams **typically** collapse completely within a few minutes to a few **days of their preparation**. The particles self-adsorb on the surfaces of the gas bubbles during foaming, preventing coalescence which ultimately leads to phase separation. Particle adsorption is dictated by the most favorable balance between the solid-air (also **known as** particle surface free energy), solid-liquid and liquid-air interfacial tensions, tuned

by wettability^[6]. Particle wettability is quantified by the three-phase contact angle θ . The balance between the three interfacial tensions is achieved with particles of relatively low surface free energy for which $\theta > 90^\circ$. Such particles are said to be hydrophobic or oleophobic when the liquid is water or oil, respectively. Once adsorbed, particle detachment is impossible due to the relatively large energy requirement (order of $10^3 k_B T$),^[6] where k_B is Boltzmann's constant and T is the absolute temperature. This can be compared to surfactants which are in dynamic equilibrium (adsorbing and desorbing from the surfaces of the gas bubbles). The dynamic equilibrium nature of surfactants makes their foams more prone to drainage, disproportionation, coalescence and ultimately phase separation compared to **foams of** small solid particles.

Various small solid particles have been used to stabilize liquid foams as summarized in the reviews of Hunter *et al.* ^[7] and Lam *et al.* ^[1]. Biomolecules like cellulose ^[8, 9] and inorganic particles like Al_2O_3 , ZrO_2 , $\text{Ca}_3(\text{PO}_4)_2$, SiO_2 ^[10, 11] and CaCO_3 ^[12] have been modified by suitable chemical agents and used for liquid foam preparation. Although significant success has been achieved with aqueous systems,^[9, 11-26] foam stabilization in non-aqueous systems is limited^[27-32] and foaming liquids of relatively low surface tension ($< 20 \text{ mN m}^{-1}$), *e.g.* C_8 -alkanes and perfluorohexane, still remains a major challenge. Compared with aqueous systems with relatively high surface or liquid-air interfacial tension (72 mN m^{-1}), liquids of relatively low surface tension (*e.g.* oils) require particles of lower surface free energy for foaming. This is often achieved by grafting fluoro-groups on the particles.^[28-30, 33]

Based on the foregoing, the conditions for obtaining stable aqueous and non-aqueous foams are well known including the choice of foaming agents. The question is do these conditions apply to a liquid like honey which is a complex mixture with less than 20% moisture? We ask this question because honey foam can be potentially applied in the food industry as bread, cracker or cake spread, but has never been investigated in terms of foaming to the best of our knowledge. The aim of this work is to foam honey using particle (**edible** calcium carbonate) or molecular (sodium lauryl sulfate) foaming agent and compare the volume of foam obtained as well as the time required for the foam to collapse completely so as to determine the best foaming agent in honey. Our finding will be important to the food, cosmetic and pharmaceutical industries where foams are often used for various applications as well as to colloid scientists for the advancement of novel products.

EXPERIMENTAL

Materials

Three precipitated calcium carbonate particles were used as received: Socal[®] R1E FG (Imerys Carbonates), Calofort[®] U and Calofort[®] SV (Specialty Mineral, UK). These particles are edible and either uncoated (Calofort[®] U,^[34, 35] Socal[®] R1E FG) or coated with 3% stearic acid (Calofort[®] SV).^[36] Sodium lauryl sulfate (99% pure) was from BDH Laboratory Supplies. **Sodium lauryl sulfate is** an edible surfactant and **is a** component of many food, cosmeceutical and pharmaceutical products. Natural honey (dark brown, Figure S1) was obtained from an apiarist in Kachia, Kaduna State, Nigeria. Although we did not determine the chemical composition of the honey sample, natural honey is reported^[37] to contain in varying proportions: sugars (fructose, glucose, sucrose, and disaccharides), minerals (K, S, Cl, P, Mg, Ca, Na, Fe, Cu, Mn), vitamins (riboflavin, niacin, thiamin, pantothenic acid, pyridoxin, and ascorbic acid), amino acids, enzymes (*e.g.* catalase and superoxide dismutase), flavonoids (*e.g.* apigenin, pinocembrin, kaempferol, and quercetin), phenolic acids, hydrogen peroxide, amino acids as well as water **give the typical % of water**.^[38] On this basis, honey can be considered as a concentrated complex aqueous solution. Water was ultrapure with pH \approx 6 and with resistivity \approx $18 \times 10^9 \Omega \text{ cm}$ at 30 °C.

Methods

Morphology of particles

The morphology of the precipitated CaCO₃ particles was obtained from their scanning electron microscope (SEM) images. The dried powdered CaCO₃ particles were stuck to the stub of a Ziess EVO 60 SEM with the help of a self-adhesive. Low-pressured compressed air was blown over the stub to remove excess loosely held particles. A Polaron 7640 Sputter coater was used to coat the particles remaining on the stub with gold (~2 nm). The gold-coated particles were exposed to an electron beam of 20 kV and 100 pA under vacuum. SEM images (Figure 1) of the particles were edited using Corel[®] Paint Shop Pro[®] Photo X2 software. They were used to measure the size of the particles using Image J. The individual particles (0.1 – 0.2 μm) are non-spherical and fused together into polydisperse quasi-spherical agglomerates. An agglomerate size ranges from 4 – 34 μm (Calofort[®] U), 4 – 28 μm (Calofort[®] SV) and 1 – 4 μm (Socal[®] RE1 FG).

Density, refractive index and viscosity of honey

The honey sample was filtered with a sieve (pore size 0.1 mm \times 0.1 mm) to remove particulate impurities before use. After filtering, a portion of the honey was examined on a

dimple glass slide under an optical microscope (Olympus CX31) for the presence of particulate matter. Quasi-spherical (20 – 80 μm) yellow particles (Figure S2a), thought to be undissolved sugar crystals,^[39] pollen grains or wax particles were seen. As a result, a portion of the honey sample (5 g) was heated (20 min) on a water bath maintained at 100 °C and re-examined, with the hypothesis that the quasi-spherical particles would melt if sugar crystals or wax particles. **They did not melt following heating (Figure S2b); therefore, these particles are probably pollen grains.**

For density, a clean pycnometer bottle (50 cm^3) of known mass was filled with the honey sample at room temperature (30 ± 2 °C) and weighed. The difference between the mass of the pycnometer bottle when empty and when filled with the honey sample (50 cm^3) was obtained and divided by the volume of the honey to obtain the density. An average of three separate measurements and their standard deviation were taken.

The refractive index was measured using an Abbe 60/DR refractometer. Approximately 10 μL of honey (30 ± 2 °C) was placed on the glass prism of the refractometer. Light was channeled into the glass prism box using an illuminating mirror. An average of three separate measurements is reported with the standard deviation.

The viscosity of the honey sample was measured with a Brookfield viscometer DV-II+Pro. The honey sample (400 cm^3) was measured into a 600 cm^3 -Pyrex glass beaker. The appropriate spindle, model LV4 (S64), was attached to the viscometer and inserted into the honey sample along with the temperature probe. The viscosity was measured at a shear rate of 50 rpm at 30 ± 2 °C. An average of three separate measurements is reported with the standard deviation.

Moisture content of honey

Three clean Pyrex glass crucibles of known masses were filled with honey (2 g), weighed (W_1) and heated (105 °C) in a Genlab oven to a constant weight (W_2). For each crucible, the difference between W_1 and W_2 was obtained, added together, and divided by three to obtain the average moisture content which is reported with the standard deviation. The moisture content was also estimated from the refractive index value of honey using the Wedmore equation:^[40]

$$\% \text{moisture} = \frac{-0.2681 - \log(\text{refractive index} - 1)}{0.002243} \quad (1)$$

in accordance with Giulio and Lusco ^[41] who reported a strong correlation between the equation and experimental values obtained directly from oven drying.

Particle immersion test and liquid marble formation

1 g of a precipitated CaCO₃ particle sample was placed on the surface of honey samples (5 g) in screw cap transparent plastic vials (inner diameter ≈ 1.5 cm; height ≈ 5.5 cm) and observed if the particles became wetted and immersed in the honey or not. The mixture was further aerated at 13,000 rpm for three minutes using a T25 basic IKA Ultra Turrax high shear mixer with a steel head (diameter ≈ 8 mm) and observed whether a foam formed in the plastic vials or not. Approximately 40 μL of honey were released from a plastic syringe onto a bed of powdered CaCO₃ particles (100 mg) on a Teflon substrate (4 cm × 4 cm × 3 mm, Radio Spares, UK) and observed whether the honey wets the particles or not. The honey drop was further rolled back and forth on the particle bed to obtain a honey liquid marble.^[42] The experiment was repeated with ultrapure water for comparison. Photographs of honey marbles and others reported in this work were taken with a Canon digital camera (4.3 V Power Shot SX220 HS).

Preparation of honey foam

The required mass of the precipitated CaCO₃ particles (corresponding to 0 – 5 wt.%) or sodium lauryl sulfate (corresponding to 0 – 3 wt.%) was placed on the surface of honey samples (5 g) in screw cap transparent plastic vials (inner diameter ≈ 1.5 cm; height ≈ 5.5 cm). We could not reach 5 wt.% for the surfactant because the foam outflowed what do you mean? the plastic vials at concentrations above 3 wt.%. The mixture was aerated at 13,000 rpm for 3 min using a T25 basic IKA Ultra Turrax high shear mixer with a steel head (diameter ≈ 8 mm). The volume of foam and the residual volume of honey were estimated immediately after foaming by measuring the height of the foam layer and height of the residual honey and then multiplying them separately by πR_o^2 , where R_o is the radius of a screw cap plastic vial. Foam stability was studied by estimating the foam volume and residual volume of honey firstly after 24 h and then weekly for a period of 4 weeks. For comparison, the experiment was repeated separately with particles and sodium lauryl sulfate using water.

Optical microscopy of foams

An Olympus CX31 optical microscope fitted with a digital camera (Olympus E-330) was used to view the microstructure of the foams. A small foam sample was carefully smeared on a dimple glass slide (Fisher Scientific) and viewed with a 10× objective lens. The microscope

images were obtained from 30 min-old (aqueous) and 1 week-old (honey) foams directly into the memory card of the camera and transferred to a desktop and edited using Corel® Paint Shop Pro® Photo X2. The diameter of 100 gas bubbles on the microscope images was averaged using Image J software and reported with the standard deviation.

RESULTS AND DISCUSSION

Refractive index, moisture content, density, and viscosity of honey

The refractive index of honey (30 ± 2 °C) was measured as 1.481 ± 0.002 compared to that for water (~ 1.342)^[43] at the same temperature. This value is in close agreement with 1.493 reported by Gómez-Díaz *et al.*^[44] for honey samples at 20 °C. The experimental moisture content (obtained from oven drying) was $18.8 \pm 0.3\%$ compared to the value of $22.2 \pm 0.2\%$ obtained from the Wedmore equation^[40] using the refractive index value of honey. The experimental moisture content (18.8%) agrees closely with values between 18.7 and 19.3% reported^[39] for some Australian honey samples as well as those (17-17.4%) reported by Gómez-Díaz *et al.*^[44] The density of honey was obtained as 1.496 ± 0.006 g cm⁻³ (at 30 ± 2 °C), ~ 1.5 times higher than the density (0.995 g cm⁻³)^[43] of water at the same temperature. The viscosity was measured as 7850 ± 7 cP (7.85 ± 0.01 Pa s) compared to values between 11.25 and 17.25 Pa s reported for some Australian honey samples at 20 °C.^[39]

Particle immersion test and liquid marble formation

The particle immersion test (placing particles on a liquid surface) gives a qualitative measure of the degree to which a given liquid wets powdered particles. For example, hydrophilic particles immerse easily in water while the hydrophobic ones do not and remain on the surface of water. This is also the case with oleophilic and oleophobic particles on oil surfaces, where the oleophilic ones immerse easily in oil while the oleophobic ones do not and remain on their surface.^[28, 29] When aerated, foams are obtained in liquids containing hydrophobic or oleophobic particles of suitable wettability, while particle dispersions result in those with hydrophilic or oleophilic particles.^[28, 29] Placing a liquid drop on a particle bed is the opposite of the particle immersion test and also gives a qualitative measure of the degree to which a liquid wets a given powdered particle. In this case, so-called liquid marbles are formed when the particles are poorly wetted (hydrophobic or oleophobic) by the liquid drop, but the liquid drop simply sinks into the particle bed if the liquid wets the particles (hydrophilic or oleophilic).^[28, 29]

We expected the same findings in honey, *i.e.* particles wetted by honey “*honephilic*” should form particle dispersions while those not wetted by honey “*honephobic*” should form foams and/or marbles. Consequently, in the particle immersion test, Calofort® U and Socal® RE1 FG which are uncoated, became immersed in honey within an hour while Calofort® SV (coated with 3% stearic acid) did not. Nonetheless, foams were obtained with all the particles when the mixture was aerated. Contrarily, when a drop of honey was placed on the bed of the particles and rolled back and forth, a honey marble was obtained with only the Calofort® SV particles (Figure 2a). Similarly, water wetted Calofort® U and Socal® RE1 FG but did not wet Calofort® SV, just like honey. When aerated, particle dispersions were obtained with Calofort® U and Socal® RE1 FG and a foam formed with Calofort® SV as expected, in line with existing literature.^[28-30] Calofort® SV also formed a **liquid** marble with water (Figure 2b). This indicates that the uncoated Calofort® U and Socal® RE1 FG particles are “*honephilic*” and hydrophilic, while the Calofort® SV particles coated with stearic acid are “*honephobic*” and hydrophobic. As reported elsewhere, particles completely wetted by a liquid (*e.g.* water or oils ^[28, 29]) rather form particle dispersions with them when aerated. This is also the case here where Calofort® U and Socal® RE1 FG are wetted completely by water and gave particle dispersions upon aeration. Contrarily, Calofort® U and Socal® RE1 FG were completely wetted by honey, but formed foams with the particles upon aeration. This may be due to *in-situ* honephobization^[45] of the particles by amphiphilic molecules in honey so that the particles are able to adsorb on the surfaces of gas bubbles and stabilize them.

Honey and aqueous foams stabilized by calcium carbonate particles

Following the formation of foams in the particle immersion test after aeration, honey foams were prepared at varying concentrations (0 – 5 wt.%) of the particles. The foams (Figures 3 and S3) were prepared by aerating honey (5 g) containing the required mass of particles at 13,000 rpm for 3 min. The volume of foam obtained and the residual volume of honey left immediately after foaming are plotted against particle concentration in a bar chart (Figure 4). The control experiment without CaCO₃ particles gave a small foam volume (~ 0.2 cm³) that collapsed completely within 1 week. Foaming here may be due to undissolved sugar crystals, pollen grains, wax particles or amphiphilic molecules in the honey, with the potential to adsorb on the surfaces of gas bubbles and temporarily stabilize them. Gas bubbles may also be trapped in honey due to its relatively high viscosity (7850 ± 7 cP). For systems containing CaCO₃ particles, foam volume increased initially with increasing particle concentration between 0 and 0.5 wt.%, similar to many particle-stabilized liquid foams,^[26, 29, 30, 46] but became independent of particle concentration above 0.5 wt.% giving ~1 cm³ of foam. A

relatively large volume of honey was left in all the systems after foaming (Figure 4), similar to many particle-stabilized liquid foams.^[26, 29, 30, 46] The volume of foam obtained immediately after aeration and the volume of residual honey remained unchanged for 1 week. Nonetheless, foams stabilized by Socal[®] R1E FG and Calofort[®] U (wetted by honey), collapsed completely within two weeks while those stabilized by Calofort[®] SV (not wetted by honey) did not collapse **until after** 4 weeks especially at relatively high particle concentrations (3–5 wt.%). This suggests that “*honeophobic*” particles are more suitable for obtaining relatively long-lived honey foams than the “*honephilic*” ones just like hydrophobic and oleophobic particles in aqueous^[26] and oil^[28-30] systems, respectively. The average diameter of 100 air bubbles in the foams, measured from their optical microscope images (Figures 3 and S4-S6), is plotted against particle concentration in Figure 5. The gas bubbles are spherical and polydisperse with large standard deviation (plotted as error bars). Although there is no clear relationship between the size of the air bubbles and particle concentration, their diameter appears to decrease with increasing particle concentration.

Because Calofort[®] SV also formed aqueous foam, the effect of its concentration **in water** on foam volume was investigated. The volume of aqueous foam and the volume of residual water immediately after aeration are plotted in Figure S7 against the concentration of Calofort[®] SV (0.1 – 3 wt.%). A photograph of the foam is also shown in Figure S7 as an insert. The volume of aqueous foam increased as the concentration of Calofort[®] SV particles increases, with a corresponding decrease in the volume of residual water, plateauing at relatively high concentrations (> 1 wt.%). This trend has been reported previously in aqueous liquid foam.^[26] Although the foam volume remained unchanged for up to 4 weeks, optical microscopy (Figure S8) revealed that the foams contain very few quasi-spherical and non-spherical air bubbles (diameter $\leq 50 \mu\text{m}$) compared with the honey foams (Figures 3 and S4 – S6) with numerous large spherical air bubbles (Figure 5). This difference may be due to the water-air ($\sim 72 \text{ mN m}^{-1}$)^[29] and honey-air ($\sim 55 \text{ mN m}^{-1}$)^[47] **surface** tensions so that aerating at the same rate and time does not incorporate the same amount and size of air bubbles in the liquids. Non-spherical air bubbles in liquids have been reported previously^[29, 48] and were linked to a situation where the particles jam the surfaces of the air bubbles and prevent them from relaxing to a spherical geometry.

Honey and aqueous foams stabilized by sodium lauryl sulfate

Sodium lauryl sulfate was used to foam water and honey (Figure S9). The volume of foam and the residual volume of liquid immediately after aeration are plotted against the **surfactant**

concentration in Figure 6. The volume of foam generally increased as the concentration of the surfactant increases in both honey and water, with honey producing more foam than water, while the volume of residual liquid decreased as more air bubbles become incorporated, in line with previous reports^[49, 50]. Higher foam volumes were obtained in both water and honey with the surfactant (Figure 6) than with the CaCO₃ particles (Figure 4). In water, the foam collapsed completely within 3 hours, while those in honey underwent drainage but did not collapse completely within this timeframe. In fact, the surfactant-stabilized honey foam did not collapse completely for more than 4 months (Figure 7). Rather, the degree of drainage in the foams increases with time, with a corresponding increase in the volume of honey released (Figure S12).

Figures S10 and S11 show the optical microscope images of the aqueous and honey foams, respectively, at various concentrations of sodium lauryl sulfate. The aqueous foams were viewed 30 min after preparation because they collapsed **completely by 3 hours**, while the honey foams which did not collapse completely **within this timeframe** were viewed 1 week after preparation. **The air bubbles in both foams are spherical and their average diameter (from 100 bubbles, Figure S10 – S11) is plotted in Figure 8 as a function of the concentration of sodium lauryl sulfate.** Although the air bubbles in the foams are polydisperse as indicated by the large error bars, their size decrease with increasing surfactant concentration between 0.1 and 1 wt.%. However, above 1 wt.% their size is more or less independent of concentration. This is consistent with what is seen in the emulsifier-poor (decrease in size with emulsifier concentration) and emulsifier-rich (size independent of emulsifier concentration) regimes in emulsions^[51]. The air bubbles in water are larger than those in honey (Figure 8) as anticipated, given the difference in liquid-air surface tension.

From the foregoing, the surfactant is more suitable for foaming honey than precipitated CaCO₃ particles because the surfactant produces more foam. Additionally, the surfactant foam did not collapse completely for more than 4 months compared with the little foam produced by the precipitated CaCO₃ particles which collapsed completely within 4 weeks. This is in contrast to many aqueous^[10, 11, 26, 46, 52] and non-aqueous^[28-30] systems where particles give ultra-stable foams that do not collapse for many months. The outstanding stability of the surfactant-stabilized honey foam over the particle-stabilized ones may be due to the decrease in the honey-air **surface** tension accompanying surfactant adsorption, similar to aqueous systems,^[53] combined with the relatively high viscosity of honey. **This is in line with the Stokes equation,**

$$\text{Drainage rate} = \frac{2Dt \rho R^2}{9\eta} \quad (2)$$

which predicts a decrease in gravity-induced drainage of air bubbles (radius R) with increasing viscosity η of the liquid phase as well as the density difference $\Delta\rho$ between the liquid and air bubbles at constant gravitational acceleration g . Surfactants are therefore better foaming agents in honey producing relatively large volumes of stable foam compared with particles. In contrast, particles are better foaming agents in water, producing relatively small volumes of stable foams *cf.* surfactant molecules. The difference in stability of the particle-stabilized foams may be related to the difference in water-air and honey-air surface tension γ . The relatively high water-air tension ($\sim 72 \text{ mN m}^{-1}$)^[29] compared with the honey-air tension ($\sim 55 \text{ mN m}^{-1}$)^[47] means that the energy ΔG ^[6]

$$\Delta G = \pi r^2 \gamma (1 - |\cos \theta|)^2 \quad (3)$$

required to detach a spherical particle (radius r and contact angle θ) from an air bubble surface into water will be higher than that for detaching into honey. This implies that more particles will remain on air bubbles in water than air bubbles in honey. Consequently, coalescence and hence phase separation will be slower in an aqueous foam stabilized by particles than in a honey foam stabilized by the same particles. As a result, the particle-stabilized aqueous foam will survive longer than the honey-stabilized foam. Also, because the water-air tension is higher, a lower honey-air surface tension may result upon surfactant adsorption, as reported^[54] elsewhere for certain interfaces. This means the tendency of the air phase to separate from the liquid phase will be higher in water than in honey so that the surfactant-stabilized honey foam survives longer than the surfactant-stabilized aqueous foam. Furthermore, the much higher viscosity of honey ($7.85 \pm 0.01 \text{ Pa s}$) compared to that of water ($\sim 1 \text{ mPa s}$) means bubble drainage will be slower in honey than in water. Therefore, the synergistic effect of lower surface tension of honey and higher viscosity may be responsible for the outstanding stability of the surfactant-stabilized honey foam compared to that of the surfactant-stabilized aqueous foam.

CONCLUSION

We have shown that honey foam can be prepared using particle (precipitated CaCO_3) or molecular (sodium lauryl sulfate) foaming agents just like in aqueous and non-aqueous

systems. However, a **larger** foam volume is obtained with sodium lauryl sulfate than with CaCO₃ particles. Additionally, foams obtained with precipitated CaCO₃ particles collapsed completely within 4 weeks while those obtained with sodium lauryl sulfate did not collapse completely for more than 4 months. By contrast, aqueous foams stabilized by sodium lauryl sulfate collapsed completely within 3 hours, indicating that surfactants are better foaming agents in honey than particles. We hope to investigate the effect of surfactant type (anionic, cationic, nonionic) on the stability of honey foam in the future. This finding will be important to the food, cosmetic and pharmaceutical industries where foams are used for various applications. It will also be important to colloid scientists for the creation of novel honey foam-based products.

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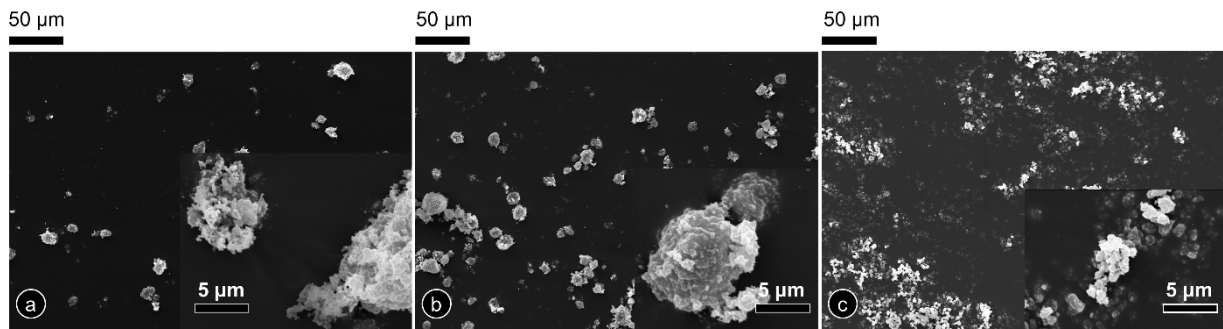


Figure 1. SEM images of precipitated CaCO_3 particles: (a) Calofort[®] SV, (b) Calofort[®] U and (c) Socal[®] R1E FG.

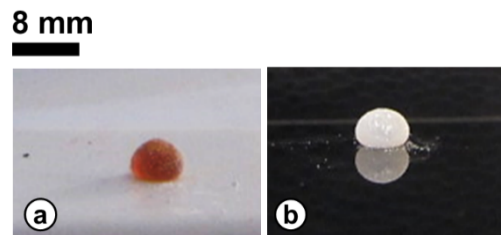


Figure 2. Photograph (soon after preparation) of a 40 μL : (a) honey marble (resting on a Teflon substrate) and (b) water marble (resting on a glass slide), both stabilized by Calofort[®] SV particles.

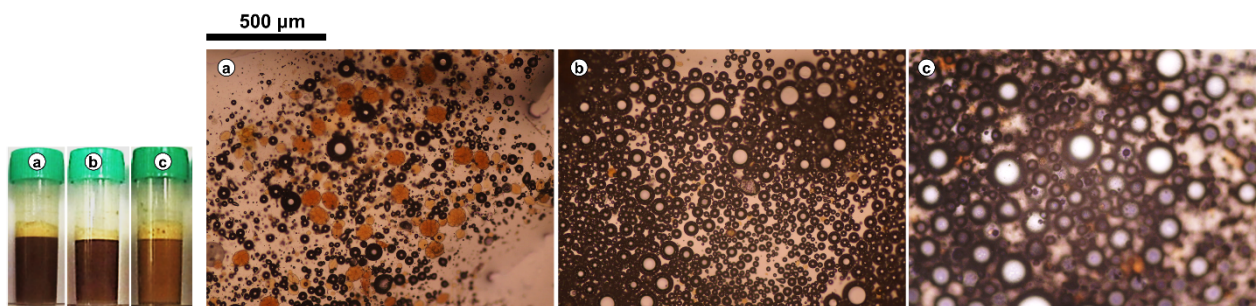


Figure 3. (left) Photographs (one week after preparation) of plastic vials containing honey foams stabilized by 1 wt.% of: (a) Socal[®] RE1 FG, (b) Calofort[®] U or (c) Calofort[®] SV particles. (right) Corresponding optical microscope images of honey foams stabilized by 1 wt.% of: (a) Socal[®] RE1 FG, (b) Calofort[®] U or (c) Calofort[®] SV particles.

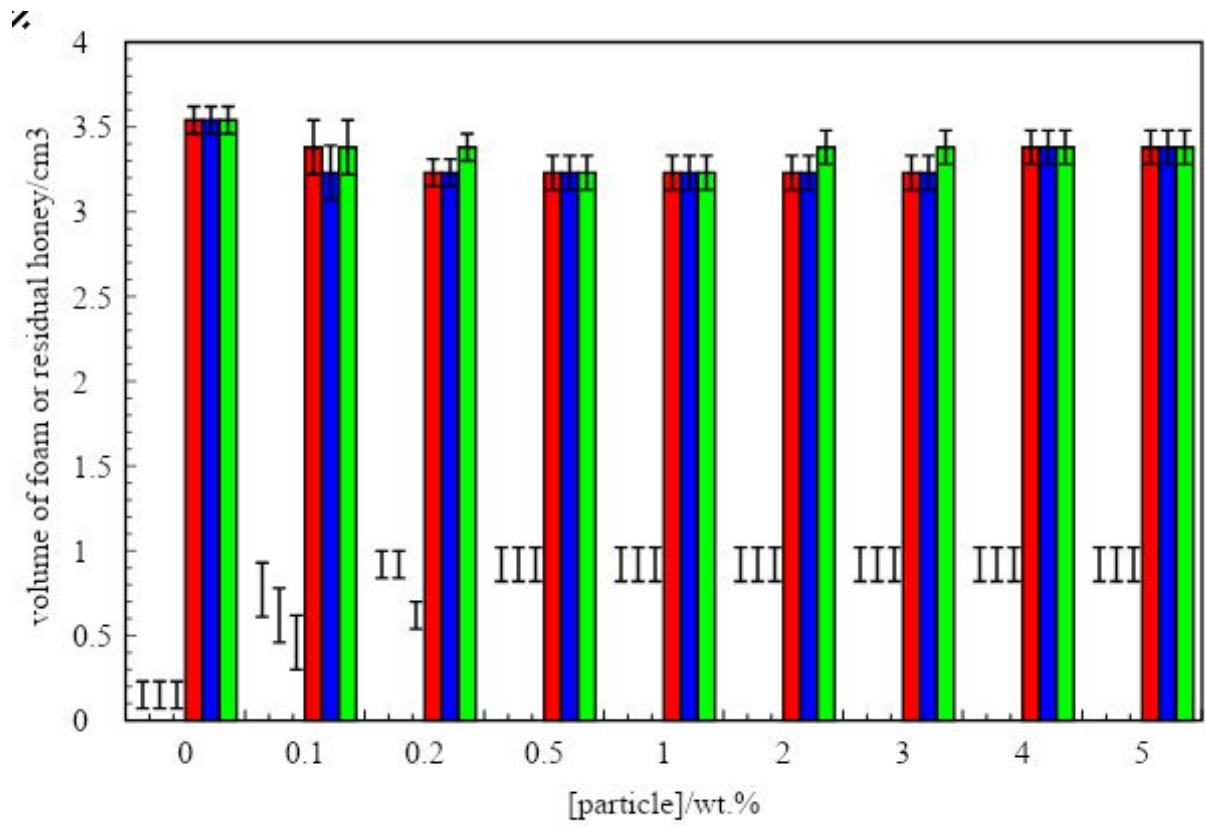








Figure 4. Volume of foam or residual honey immediately after preparation *versus* concentration of particles for Socal[®] RE1 FG (foam , residual honey , Calofort[®] U (foam , residual honey ) or Calofort[®] SV (foam , residual honey .

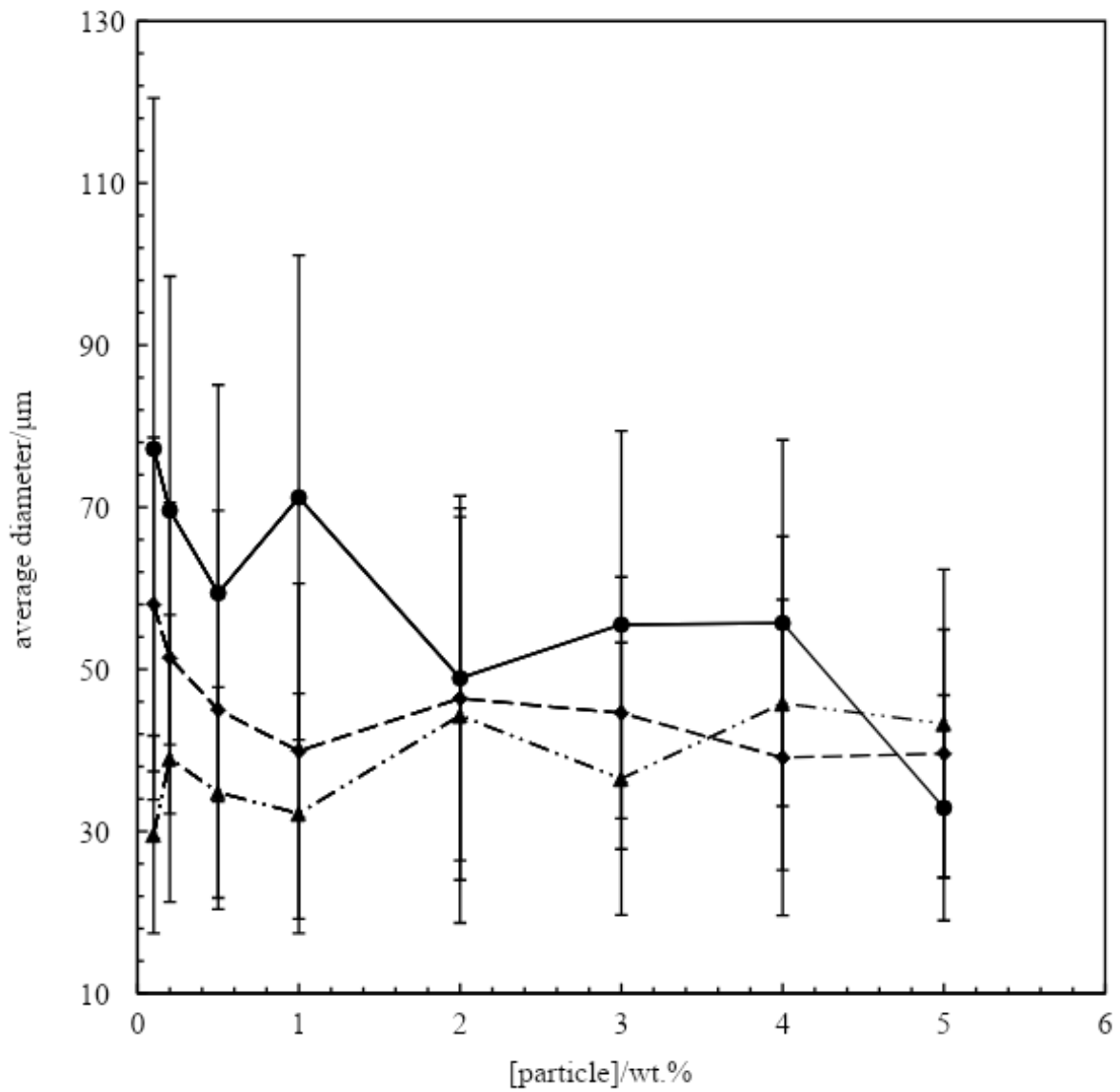


Figure 5. Plot of average diameter of one hundred air bubbles in honey foams (1 week old) stabilized by: Calofort[®] SV (●), Calofort[®] U (◆) or Socal[®] RE1 FG (▲) particles obtained from their microscope images *versus* particle concentration (wt.%). The error bars are standard deviation of 100 measurements.

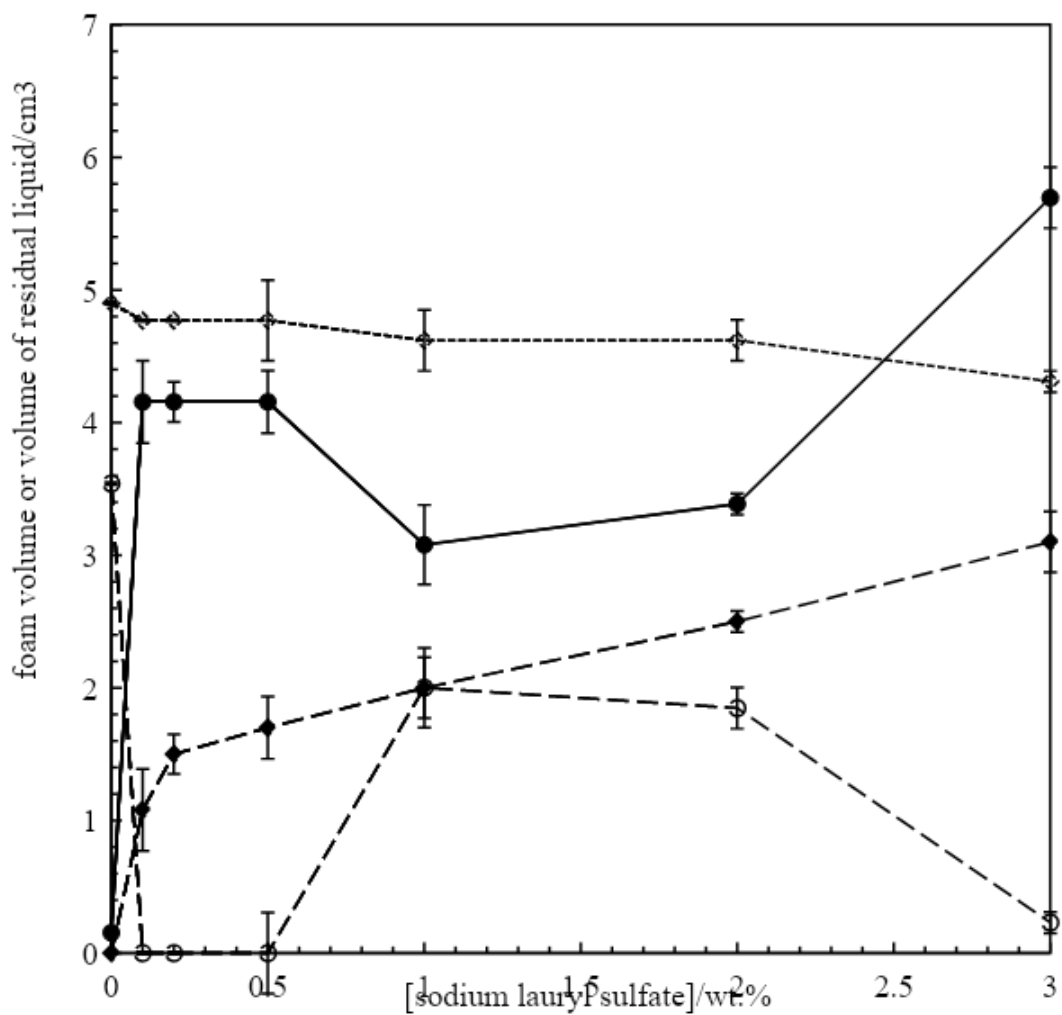


Figure 6. Plot of volume of foam or residual volume of liquid immediately after aerating honey or water against the concentration of sodium lauryl sulfate. The symbols are honey foam (●), residual honey (○), aqueous foam (◆) and residual water (◇). The error bars are standard deviations of 3 separate measurements.

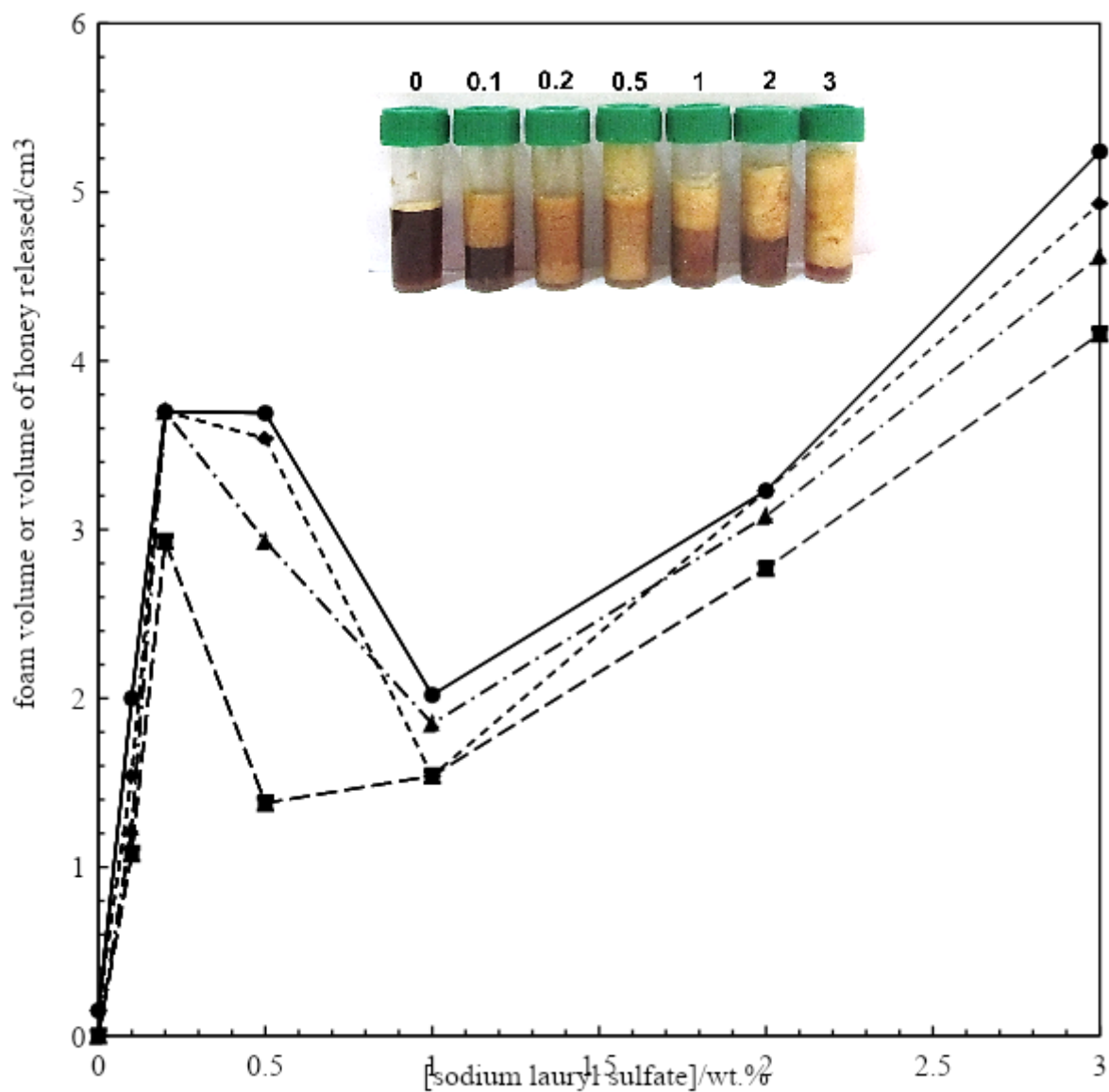


Figure 7. Volume of honey foam *versus* concentration of sodium lauryl sulfate for various time intervals: 24 h (●), 1 week (◆), 2 weeks (▲) and 3 weeks (■). The error which is the standard deviation of three separate measurements is between 0.01 and 0.24. Insert: Photograph of plastic vials containing honey foams (24 h after preparation) at various concentrations (wt.%, given) of sodium lauryl sulfate.

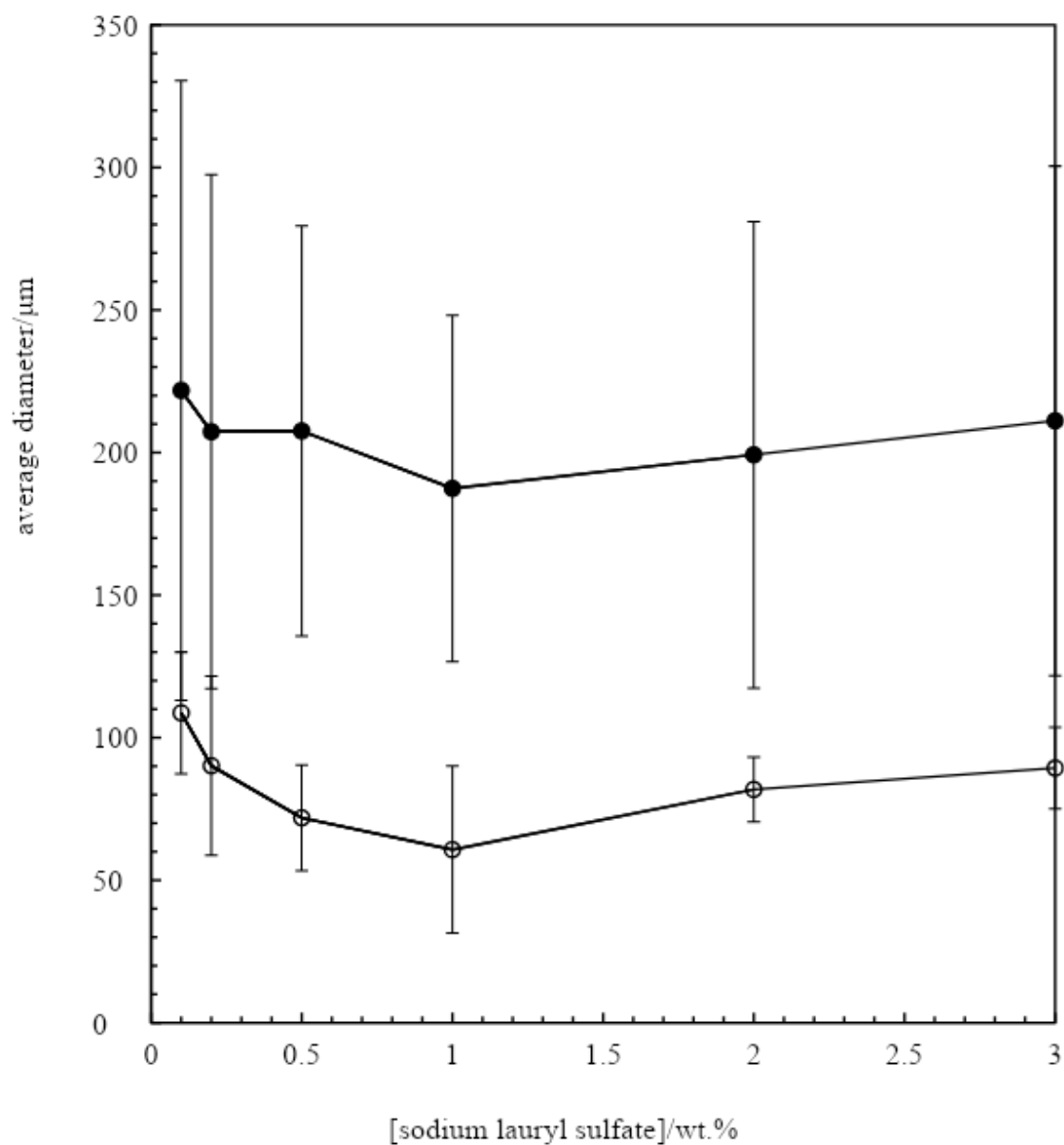


Figure 8. Average diameter of 100 air bubbles in aqueous (●) and honey (○) foams measured from their optical micrographs (Figures S10 – S11) *versus* concentration of sodium lauryl sulfate.