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Short communication

Foam preparation at high-throughput using a novel packed bed system

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ABSTRACT

We investigated the formation of food foams using a novel packed bed system at different operating pressures. The foaming process was based on simultaneous injection of continuous (whey protein solution) and dispersed (nitrogen gas) phases into a column containing a packed bed of glass beads. Bubbles were produced by entrapment of nitrogen by thin films of continuous phase inside the porous medium. Initial results show a proof of principle that the proposed system can be an effective method for the controlled production of foams at overruns of up to 600%. The entire window of operation regarding all process and formulation possibilities is expected to be much wider but needs to be established in future research.

Keywords: Foam; Emulsion; Glass beads; Packed bed; Foam stability; Overrun

1. Introduction

Foams are dispersions of gas bubbles in a continuous liquid, semi-solid or solid phase (Eisner et al., 2007). Foams are widely used in food industry, e.g., in the preparation of ice-cream, mousse, meringues, soufflés, angel-food cakes, dessert toppings, cappuccino, etc. Foams are important for the structural stability, texture and mouth feel of the aerated food products, also after a follow-up treatment (freezing, baking, etc.). Thermodynamically foams are unstable resulting in changes in the distribution of gas and liquid within the foam (Eisner et al., 2007). This instability can be attributed to three physical processes namely drainage of liquid in films, coalescence and disproportionation of bubbles (Bisperink et al., 1992; Garrett, 1993).

On industrial scale, foams are mainly produced by rotor–stator mixing, turbulent mixing or by steam injection (Goh et al., 2009). These conventional foaming techniques are energy inefficient, i.e., a very small portion of energy is actually utilized in the dispersing zone and the rest is dissipated as heat, which may lead to heat damage of the product and its ingredients (McClements, 2005). Furthermore, they give wide distributions in bubble sizes resulting in foams that are not very stable due to disproportionation (Ostwald ripening). Foaming by membranes (Bals and Kulozik, 2003b) and other microstructured systems like microchannels (Yasuno et al., 2004) and EDGE (Edge-based Droplet GEneration) (van Dijke et al., 2010) are examples of cold aeration that are highly energy efficient and are able to produce small and uniform bubbles. In these devices, foams are produced by incorporating to-be-dispersed phase (air) into the continuous phase through pores or microchannels. The newly formed bubbles are then rapidly stabilized by the surfactant molecules present in the continuous phase.

A quantitative comparison of these systems is not so easy to do. Mostly, in microfluidics the production rates are

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reported in frequency unit, i.e., bubbles per second (van Dijke et al., 2010), and depending on applied pressure and dimensions of the microfluidic device, bubbles of a specific size can be made. In general, the applied pressure in microfluidic systems (typically below 250 mbar) is much lower as in membrane applications; therefore it is safe to say that the membrane systems have a higher productivity than the microfluidic systems. However, membranes tend to foul rather easily, and that is expected to be mitigated by the use of the packed bed that can be cleaned very easily by disintegrating the glass bead bed.

In the present work, we introduce a novel microstructured packed bed system in which foams are produced by mixing of air/gas with the continuous phase before entering a porous media, which is somewhat similar to the working of premix emulsification using packed beds (Nazir et al., 2013a, 2014). This is a start-up investigation showing a proof of the principle; further research will provide a more fundamental understanding of the system, which is expected to be quite relevant for industrial applications that require control of bubble size, distribution, and reproducibility.

2. Experimental

2.1. Packed bed system

The proposed system is shown in Fig. 1 and consists of a Plexiglas column (1.43 cm^2 inner surface area) having a top (0.5 mm diameter) and a side (0.2 mm diameter) nozzle for dispersed and continuous phases, respectively. At the bottom junction of the column a packed bed (2.5 mm thick) of hydrophilic glass beads (100HFL, Pneumix SMG-AF, 65 μm diameter) was held in place by a nickel support sieve (Stork Veco BV, the Netherlands) having long rectangular pores (pore dimension 11.6 μm × 331 μm, porosity 4%) (Nazir et al., 2013b). The sieve was thick enough (350 μm) to provide a good support to the bed and to withstand the applied pressure. The settling of the glass beads was carried out by introducing a small amount of water in the column, with the added benefit of properly wetting the system before starting an experiment.

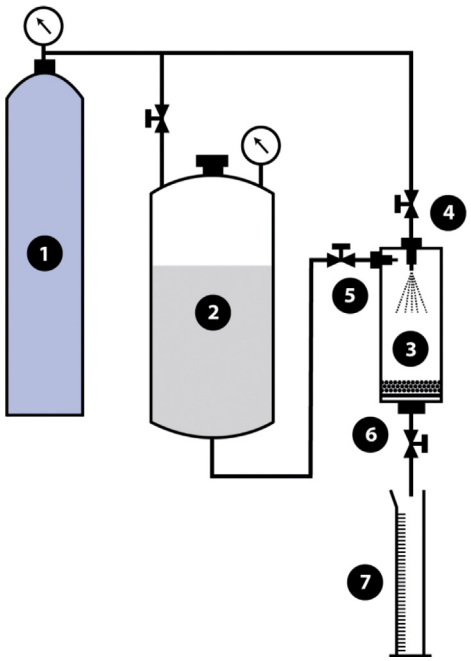

Fig. 1 – Schematic representation of the packed bed foaming system. (1) Pressurized nitrogen cylinder; (2) pressure vessel containing 10% whey protein aqueous solution; (3) Plexiglas column; (4) inlet for nitrogen (0.5 mm diameter nozzle); (5) inlet for whey protein solution (0.2 mm diameter nozzle); (6) outlet for foam; (7) receiving cylinder.

The side nozzle was connected to a pressure vessel containing 10% (w/v) whey protein isolate (FrieslandCampina, the Netherlands) aqueous solution as continuous phase. The vessel was pressurized with nitrogen keeping the valve connected to the column closed before starting an experiment. The top nozzle was also connected to the pressurized nitrogen supply. The applied pressure was similar on both nozzles, and experiments were carried out at 1–5 bar pressures.

2.2. Volumetric flux of foam

The foam was collected in a graduated cylinder (250 mL) placed on an electrical balance for digitally recording the increase in mass every second, and to record the volume. The volumetric flux of foam across the packed bed was calculated from the mass flow rate, $\dot{m}$, using the relation:

$$\text{volumetric flux} = \frac{\dot{m}}{\rho_f A}, \tag{1}$$

where ρ_f is the foam density, and A is the effective surface area of the packed bed. Foam density was calculated by dividing the mass with volume of the foam contained in the graduated cylinder.

2.3. Characterization of foam

2.3.1. Foam overrun

The gas holding capacity of the foam was assessed by overrun, which was calculated by weighing the mass of solution and foam as follows (Bals and Kulozik, 2003b):

$$\text{overrun} = \left(\frac{m_s - m_f}{m_f}\right) \times 100 \tag{2}$$

where m_s and m_f are masses of the same volume V of solution and foam, respectively.

2.3.2. Foam stability

The foam stability was tested by measuring the drainage after a period of 30 min, i.e., higher the drainage, lesser the foam stability. The drainage was calculated by measuring the weight of the drained liquid of foam, m_d, filled in a 250 mL cylinder as follows (Nicorescu et al., 2009):

$$\text{drainage} = \left(\frac{m_d}{m_f}\right) \times 100. \tag{3}$$

2.3.3. Bubble size analysis

The foam samples, collected from different locations of the cylinder, were immediately analyzed under a microscope (Axiovert 200 MAT, Carl Zeis B.V., Sliedrecht, The Netherlands) attached to a camera (MotionPro HS4, Redlake MASD Inc., San Diego, CA, USA). The microscopic images were then analyzed for droplet size using image analysis software (Image Pro plus 4.5). The average bubble diameter was calculated from the arithmetic mean of 300–500 bubbles.