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Premix membrane emulsification with microporous dynamic membranes to produce single and multiple emulsions stabilized with insect proteins

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Abstract

Premix membrane emulsification offers distinct advantages over conventional homogenization methods, such as low energy requirements, better control of the droplet size distribution, and reduced mechanical stress, particularly beneficial for applications involving shear-sensitive stabilizers such as proteins. However, depending on the membrane type and the emulsion formulation, e.g. when proteins are present, low productivity and membrane fouling may pose significant challenges for industrial application. Dynamic membranes of tunable pore size (DMTS), consisting of a bed of silica microbeads supported by a nickel microporous membrane (Figure 1), exhibit higher productivity (throughput) than other membrane emulsification processes [1-2] whilst maintaining the specific features of membrane emulsification, even in protein-stabilized emulsions [3-4].

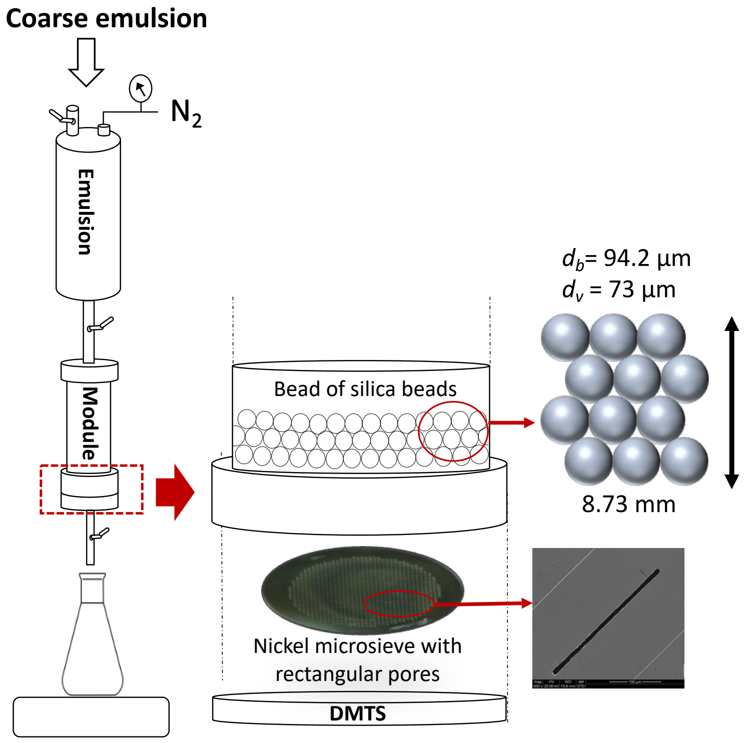

Figure 1. Schematic representation of the emulsification module using dynamic membranes of tunable pore size.

This research assesses the advantages and constrains of employing DMTS to produce single and double emulsions stabilized with proteins derived from sustainable sources, such as insects. A comparative analysis is conducted with a widely employed dairy protein, such as whey protein isolate (WPI). The DMTS system consists of a nickel microporous membrane of rectangular pores with a thickness of 120 μm with an upper layer of silica microbeads (Figure 1). To produce the silica microbeads layer, a weighed mass of the microbeads is placed on top of the nickel membrane and a few drops of water are added then vacuumed slowly several times to pack the microbeads and make sure the surface is flat. The bed porosity (ε), tortuosity (τ), interstitial void diameter (d_v), and height of the beads layer (H), directly related with the weight of silica micro-beads, are calculated using equations (1-4).

$$\epsilon = 1 - \frac{\rho_b}{\rho_p} \tag{1}$$

Where ρ_p and ρ_b are the particle and dry bulk densities, respectively.

$$\tau = 1 + 0.41 \ln\left(\frac{1}{\epsilon}\right) \tag{2}$$

$$d_v = \frac{4\,\epsilon}{A_v\,(1-\epsilon)} \tag{3}$$

Where A_v is the specific surface area calculated as $A_v=6/d_b$; d_b: diameter of the beads

$$H = \frac{mass\ of\ beads}{\rho_p\, A_{column}\,(1-\epsilon)} \tag{4}$$

Where A_{column} is the area used, 177 mm^2 in our case.

A coarse emulsion, prepared with a rotor-stator homogenizer under mild operation conditions, is refined by passing it several times (3 to 5) through the DMTS system using N_2 pressure (300-500 kPa). After being used for emulsification the DMTS system can be dissembled, and the silica microbeads cleaned with soap and water and then dried overnight at 100 °C. As for the nickel membrane, it can be cleaned by immersing it in an ultrasonic bath for 5 minutes, initially with 4 M NaOH and subsequently with distilled water. Using the DMTS system single oil-in-water (O/W) emulsions with up to 40% oil fraction (sunflower or lemon oil) stabilized with black soldier fly (*Hermetia illucens*) protein concentrates, BSFPC, were successfully produced. For sunflower oil, the emulsions obtained with this low-energy high-throughput technology present droplet size distributions and productivities comparable to those achieved with WPI-stabilized emulsions. For lemon oil emulsions, since this essential oil is partially soluble in water and reduces the pH of the water phase, the use of BSFPC, with a lower isoelectric point than WPI, enables to better stabilize emulsions with 30 and 40% oil fractions.

The DMTS system has also been successfully used to produce stable flaxseed oil emulsions stabilized with lesser mealworm (*Alphitobius diaperinus*) protein concentrated, LMPC, conjugated with tannic or chlorogenic acid, as examples of innovative antioxidant emulsifiers [5]. Moreover, this emulsification system has proven successful for the refinement of water-in-oil-in water ($W_1/O/W_2$) emulsions loaded with polyphenols in the inner water phase (W_1) and stabilized with LMPC or LMPC conjugated with tannic acid.

Our results indicate that the ability of the DMTS system for emulsion refinement regarding productivity is influenced by the porosity of the nickel membrane, the thickness of the microporous layer, and the size of the silica beads that control the interstitial void diameter. As for the final droplet size distribution, the critical system variables are the number of emulsification cycles, the thickness of the microporous layer, and the interstitial void diameter [3]. The system has been proven to be very robust, easily assembled, cleaned, and tuned to produce stable emulsions with high-throughput, between 200-500 $m^3\ m^{-2}\ h^{-1}$, using novel protein sources such as insect proteins.

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