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Monitoring of pilot-scale induction processes for dairy powders using inline and offline approaches

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ABSTRACT

The induction of two dairy powders, skim milk powder (SMP; low-protein content), and milk protein isolate (MPI, high-protein content), was studied. The powder induction approaches investigated were (1) eductor alone, (2) eductor with a static mixer, and (3) eductor with high shear inline mixing. Measurement of pressure drop, from which viscosity was determined inline using the Hagen-Poiseuille equation, offline viscometry and particle size analyses were performed. High shear inline mixing provided the most efficient induction of powders. In addition, more rapid powder induction, as observed from particle size analysis, was achieved for SMP in comparison to MPI, owing to its better rehydration properties. Inline pressure drop data demonstrated that dissolution of MPI had two distinct phases: (i) powder introduction, and (ii) powder breakdown, irrespective of configuration and concentration employed.

1. Introduction

In the food industry, supply chains from primary production to finished product often require several transformations of physical state. In the case of dairy ingredients, the raw material is milk, with the derived ingredients often dried to a powder state to increase shelf-life, reduce bulk and facilitate use as food ingredients (O'Connell and Flynn, 2007; O'Sullivan & O'Mahony, 2016). For utilisation of these ingredients in food formulations, it is normally a prerequisite that the powder is completely rehydrated. Dairy ingredients that possess a high protein content and have a casein-dominant protein profile are challenging to reconstitute quickly and completely, and thus processors of these ingredients and end-users often employ a range of approaches to achieve homogeneous solutions, such as in-tank agitation, high shear mixing, ultrasonic processing, or hydrodynamic cavitation (Crowley et al., 2015; McCarthy et al., 2014; Schuck et al., 2007; Vos et al., 2016).

Powder induction is typically achieved through a two-step approach, although, for powders demonstrating good dissolution behaviour, the first step is adequate: (1) initial mixing of the powder with the solvent, using a powder inductor (also known as eductors), and (2) a means for achieving a uniform dispersion, through shear-induced disruption of powder agglomerates (Bete Fog Nozzle Inc., 1999; Forny et al., 2011; Venegas et al., 2014). Eductor technologies are widely used in industrial applications, such as lean phase pneumatic conveying, powder induction and liquid blending. Eductors usually consist of two inlets and a single outlet (Fig. 1d). One of the inlets narrows to a constricted point, referred to as a nozzle, while the second inlet is typically perpendicular to the exit of the first inlet, where at this point both streams intersect at a locus point, converge, and exit through a single outlet. At the locus point, the contents of the perpendicular inlet are drawn into contact with the tangentially flowing fluid from the nozzle by means of the venturi effect (Douglas et al., 2005; Gogate and Kabadi, 2009; Venegas et al., 2014). Powder induction can be achieved in either a batch (*e.g.*, batch stirred tank), continuous (*e.g.*, powder eductor) or semi-continuous configuration (*e.g.*, eductor with a recirculation loop).

Static mixers are devices that are readily used in continuous processing for mixing operations. Static mixers are motionless inserts, also known as elements, within a pipeline, which redirect fluid flow in directions transverse to the main direction of flow

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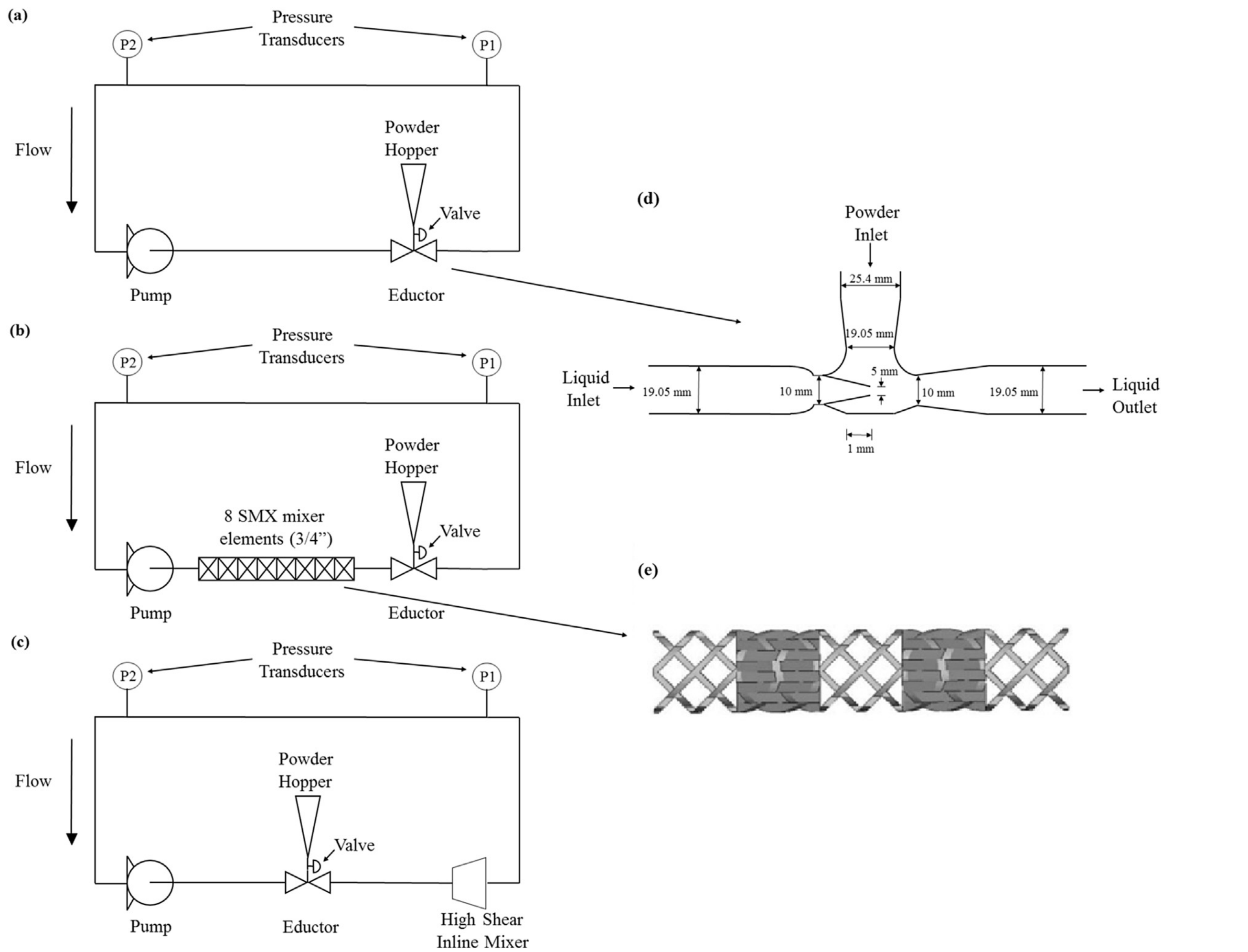

Fig. 1. Schematic representation of the experimental configurations employed: (a) eductor alone, (b) eductor and SMX static mixer, and (c) eductor and high shear inline mixer. All configurations show a pump and pressure transducers. Panel (d) shows a schematic of the eductor configuration and (e) is a CAD diagram of a five element section of a standard SMX static mixer, for which rights of use were acquired from O. Mihailova (Mihailova et al., 2015).

(Thakur et al., 2003). SMX static mixers (Sulzer Chemtech, Winterthur, Switzerland; Fig. 1e) disrupt bulk fluid flow through the development of striations due to their structure, and further disrupt flow by each consecutive element being oriented by 90° to the preceding one (Ghanem et al., 2014; Mihailova et al., 2015, 2016).

High shear mixing technologies are widely used for the disruption of powder aggregates to form homogeneous solutions and in emulsification applications (Hall et al., 2013). The configuration of these mixers is that of a rotor-stator, and they can be used as inline devices for either continuous processing (*i.e.*, single pass mode) or batch processing (*i.e.*, multiple pass mode) (Hall et al., 2011). The shear rate range for high shear mixers is typically within the range 20,000–100,000 s^{-1} (Pacek et al., 2007).

In this study, three powder induction approaches were investigated: (1) eductor alone, (2) eductor integrated with an SMX static mixer, and (3) eductor integrated with a high shear inline mixer. The powders examined were low (skim milk powder; SMP) and high (milk protein isolate; MPI) protein content dairy ingredients, in order to comparatively assess the processing performance and industrial relevance of these approaches for rehydration of dairy powders across a wide range of protein content. The objectives of this research were to discern differences in rehydration properties of the selected dairy powders, SMP and MPI, in terms of wettability, dispersibility and changes in particle size, and relate these differences to variations in the rate of powder induction, as monitored inline using a pressure drop approach to calculate viscosity, by applying the Hagen-Poiseuille equation. This approach could allow for the real-time monitoring of industrial dissolution processes for dairy ingredients, and allow manufacturers to optimise such processes for shear energy and time, with major energy-saving potential.

2. Materials and methods

2.1. Materials

Milk protein isolate (MPI) was kindly provided by Kerry Ingredients and Flavours (Listowel, Ireland). The skim milk powder (SMP) used in this study was sourced from a local commercial outlet. The composition of the SMP and MPI is presented in Table 1. The water used throughout this study was deionised water, unless stated otherwise.

2.2. Powder induction configuration

Powder induction was conducted at two protein concentrations, 3.6 and 7.2% (w/w), for both SMP and MPI. Three configurations