Mapping the rate-limiting regimes of food powder reconstitution in a standard mixing vessel

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ABSTRACT

Poor reconstitution of food powders is a defect that hampers the development of novel dehydrated food products. In order to improve the quality of a powdered food during the development stages, a better understanding of how the powder behaves upon rehydration is vital. However, common methods to follow powder reconstitution, e.g. conductimetry, can yield uninterpretable results, especially if a powder does not completely wet, sink, disperse and dissolve.

To circumvent this problem, a mapping approach was developed to describe the powder behavior depending on the combinations of variables. To construct such a map, powders are reconstituted using a transparent vessel, and an optical recording of each trial is utilized to describe if the process was 'normal', i.e. if wetting/sinking, dispersing, and dissolving of the particles occur readily and more or less sequentially, or if it was limited by poor powder sinking, by sedimentation, slow material dissolution, or lump formation. By mapping the behaviors at different combinations of temperatures and agitation speeds, various regimes of limiting reconstitution behavior can be identified.

In the current study, rate-limiting regime maps of four types of maltodextrin (Glucidex DE21, IT21, DE6, and IT6) are constructed and compared in order to investigate the influence of molecular weight, particle size, water temperature, and agitation speed on the rehydration of a water-soluble amorphous food powder. Such a study would not have been possible using conventional techniques, as powder reconstitution is not always complete.

1. Introduction

Food products are often prepared in powdered form for a number of reasons, including prolonged shelf-stability, ease of transport, and convenience for the consumer [1]. Unfortunately however, problems related to the physical quality of the powders often arise, most notably lump formation upon reconstitution. This can cause problems at a consumer level, such the acceptability of a product, as well as at an industrial level, due to pipe blockage, fouling, and incomplete mixing.

The rehydration of water-soluble powder is often described as occurring in four separate but overlapping steps [2–5]: (i) Wetting: the solid–vapor interface is displaced by a solid–liquid interface as the powder comes into contact with the liquid. Due to the presence of intraand interparticle voids, the liquid may penetrate into the powder bed due to the action of capillary forces. (ii) Submerging: following or during wetting, the powder sinks below the liquid surface. Poor wetting and/or sinking may result in the powder remaining on the surface of the liquid. (iii) Dispersing: once submerged, the particle agglomerates and aggregates disperse into smaller units. Poor dispersion may lead to the presence of undesirable lumps in the final product. (iv) Dissolving: if the particles are thermodynamically compatible with the liquid medium, they will dissolve into individual molecules or ions. If the particles are not soluble they will remain dispersed in the liquid and complete dissolution will not take place.

The final aim for many food manufacturers is to produce a powder that will instantaneously pass through these steps, i.e. to produce an 'instant' powder. While the four steps mentioned above do overlap quite considerably, according to Hogekamp and Schubert [6] they should be addressed individually as the phenomena are governed by different sets of physical laws.

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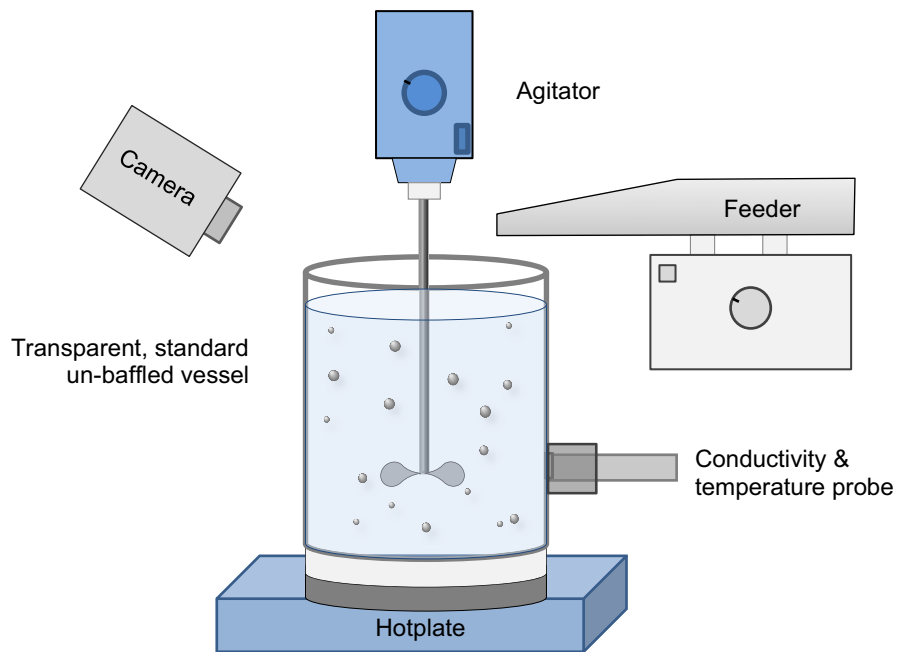E-mail address: a.d.salman@sheffield.ac.uk (A.D. Salman).

Fig. 1. Mixing setup utilized in the current study.

In order to enhance the quality of powdered food products during the formulation and processing phases, an improved understanding of the powder's reconstitution behavior is required. However unfortunately, traditional approaches to describe the reconstitution of powders tend to report very little information about the process, for example, only reporting the overall reconstitution time or the 'dispersing rate' [7]. Reconstitution of food powders is often too complex to describe with numbers; upon reconstitution powders may remain at the liquid surface for extended periods of time, sediment to the bottom of the vessel, or form undesirable lumps. In the current study, a quantitative measurement technique is combined with qualitative descriptions of reconstitution in order to understand which aspect of reconstitution limited overall rehydration. A regime mapping strategy, analogous to those used for granulation processes [8,9] was developed for reconstitution—these maps describe the behavior as a function of water temperature and agitation speed for each type of powder tested.
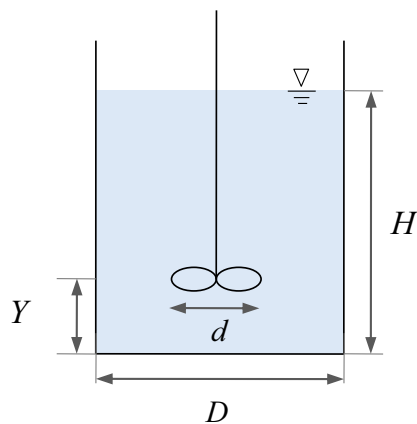
2. Experimental methods

2.1. Experimental setup

The reconstitution rig utilized (Fig. 1) consists of a vessel constructed with transparent PVC and with a camera (Canon PowerShot SD1100 IS, Japan) positioned to record both the liquid surface as well as the liquid bulk. The vessel is equipped with a marine-type impeller (Lightnin A100, USA, diameter 33 mm) for mixing, and the powder is added to water using a vibrating feeder from a fixed height and position (60 mm above the undisturbed liquid surface, half-way between the impeller shaft and the vessel wall). Feeding is calibrated for each powder to obtain a feeding rate of 3.8 g/s. A conductivity meter (Jenway 4510 model, k value 0.97 cm^{-1} at 25 °C, UK) measures the liquid conductivity, which is linearly correlated with dissolved concentration, over time. The amount of time required for the dissolved concentration to obtain 90% of the maximum value is taken as the dissolution time, and is referred to as the "t_{90}" [10], where t_0 is taken as the time when all powder has been added to the liquid.

Fig. 2. Standard mixing vessel ratios for experimental studies (Y: impeller off-bottom clearance, D: vessel inner diameter, d: impeller diameter, H: undisturbed liquid height). The ratio of d:Y:D:H is 1:1:3:3.

Table 1
Average number of glucose residues and average molecular mass, as well as true densities, of maltodextrins DE21/IT21 and DE6/IT6. N.B. maltodextrins with a DE value >20 are also called 'dehydrated glucose syrups'.

DE/IT	#Glucose residues	Molecular mass (g/mol)	True density (g/cm³)
6	~17	~2720	1.44
21	~5	~790	1.53

Table 2
Volume-based particle size distribution, determined by static light scattering.

Glucidex	$d_{10,3}$ [μm]	$d_{50,3}$ [μm]	$d_{90,3}$ [μm]
DE21	27	149	308
DE6	30	125	283
IT21	131	301	601
IT6	152	374	638