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Effect of powder densities, particle size and shape on mixture quality of binary food powder mixtures

Pooja Shenoy [a,b,1], Maxime Viau [c], Kristel Tammel [d], Fredrik Innings [e], John Fitzpatrick [b], Lilia Ahrné [a,*]

[a] SIK — The Swedish Institute for Food and Biotechnology, Gothenburg, Sweden
[b] Process and Chemical Engineering, School of Engineering, University College Cork, Ireland
[c] Tetra Pak-Guerin Systems, Powder Institute, France
[d] Santa Maria AB, Mölndal, Sweden
[e] Tetra Pak Processing Systems, Research Technology Lund, Sweden

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ABSTRACT

Particle size and density are two important parameters which affect the mixture homogeneity of powder mixtures. In this study several types of food powders with different particle sizes and poured bulk densities were chosen for the binary powder mixing trials. In each type of binary mixture salt was one of the main ingredients, hence conductivity analysis was performed on the mixtures and coefficient of variation was used to evaluate the mixture homogeneity. All binary powders were mixed at a ratio of 50:50 by weight in a 2 L prototype lab-scale paddle mixer. The experiments were conducted in such a way that the ingredients used either had a similar particle size and different bulk density or similar bulk density and different particle size. Different density and size ratios were investigated to observe the limit up to which good mixing takes place. Density differences between the binary powders were varied from 1.5 up to 16.4. The range of size ratio investigated was from 1.96 up to 15.73. Results indicate that powders mixed very well up to a particle size ratio of 4.45. For higher ratios mixture quality disimproved but no segregation was visually observed. The bulk density had a larger influence in affecting the mixture quality (MQ) as compared to particle size. At higher bulk density ratios almost complete segregation was observed and this was majorly influenced by the irregular shapes of thyme and oregano.

1. Introduction

Dry powder mixing is widely used across different types of industries and a key aim from the process is to produce a homogenous mixture [1–4]. It is crucial for the industries to maintain consistent homogeneity in their powder mixture since this helps them to manufacture products with consistent quality, taste, flavour, texture and other properties [5,2]. Another important step associated with mixing is the assessment of the mixture homogeneity or quality. The attainment and assessment of powder mixture homogeneity are extremely important in pharmaceutical industries to ensure that the dosage of the active ingredient is accurate in the dosage unit as costs associated with failure to meet the homogeneity standards are potentially large [6,4,7].

Powder mixing is influenced by mixing time, particle size, shape, density and types of powders as well as the design of the mixer used [2]. Most of the powder mixtures have ingredients with different sizes, shapes, textures and densities [8]. Bulk density and porosity are one of the important parameters which help to decide if the raw ingredients used can mix together or not [9]. During mixing, different particles can behave differently and the mixtures undergo mixing and demixing in successive stages during this process [8]. The physical properties of powders, especially particle size and density play a key role in determining their tendency to segregate or mix properly during and after a mixing operation [2,10]. If the powders mixed have a similar size, shape and density the tendency to segregate is reduced and they reach a state of equilibrium between the mixing and demixing stages thereby producing the final mix [2].

Though differences in density and shape of particles are known to cause segregation in mixtures, often difference in particle size has by far been considered as the most important parameter [2,11,12]. The particle size distribution of the ingredients used in a powder mixture is one of the key factors that determine the homogeneity of the mixture [13]. Small particles show a tendency to fall downwards leading to segregation [14,15]. A study by Drahun and Bridgwater [16] suggests that particle density ratio influences segregation and that free surface segregation can be minimised by maintaining an appropriate balance between the size and density ratios. Particle size distribution also affects other powder properties such as bulk density, flowability and compressibility [17,18]. Barbosa-Canovas et al. [19] reported that differences in particle size can cause segregation in a free flowing powder mixture.

* Corresponding author. Tel.: +46 704922723.
E-mail address: lilia.ahrne@sik.se (L. Ahrné).
[1] Tel: +46 704922723.

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Table 1
List of selected powders and their physical properties (Average values from six repeat trials).

No.	Name of powder	Bulk densities		Particle density (kg/L)	Particle size (μm)		
		Poured density (kg/L)	Tapped density (kg/L)		d (0.1)	d (0.5)	d (0.9)
1	Salt	1.283	1.403	2.165	231	436	718
2	Salt Extra Fine (Salt EF)	1.267	1.434	2.158	32	110	253
3	Salt Vacuum (Salt V)	1.182	1.262	2.155	367	692	1185
4	Salt Medel (Salt M)	1.085	1.151	2.132	1250	1460	1600
5	Salt Siede (Salt S)	1.061	1.141	2.134	538	993	1572
6	Sugar 500	0.857	0.947	1.589	236	542	1022
7	Potato starch	0.699	0.783	1.447	24	44	75
8	Onion granules	0.649	0.702	1.510	185	364	626
9	Paprika	0.454	0.517	1.364	67	223	485
10	Black pepper	0.371	0.438	1.343	72	345	706
11	Thyme	0.176	0.212	1.270	437	863	1488
12	Oregano	0.066	0.073	1.208	1250	1600	–

As the particle size decreases for a given powder, the degree of contact area between the particles increases thereby strengthening the intermolecular forces and reducing the ease of flow of the powder which can reduce segregation tendency [20].

In this study, physical properties, such as particle size and shape, bulk density and particle density were measured for different types of food powders that are used in the commercial manufacture of spice mixtures. Since differences in these properties are key parameters which affect mixing homogeneity, the objective of this study was to investigate the influence of differences in these properties on the mixing behaviour of binary food powder mixtures. Two sets of mixing trials were undertaken, one where powder densities were varied and another where particle size was varied. Images of particle shape of the powders were taken to investigate its influence.

2. Materials and methods

2.1. Powders

Several different food powders including dried herbs, sugars and salts of different shapes and sizes that are commonly used in the manufacture of different flavour seasonings were procured from Santa Maria AB, Paulig Group, Gothenburg, Sweden. The particle size and densities of the powders were measured. These data were used to select 12 powders that had suitable property values for this study. Five of the powders were different sized salts. The selected 12 powders along with their particle size and densities are presented in Table 1.

2.2. Particle size

The particle size distribution of all the powders was measured using a Malvern Mastersizer 2000. Due to the large particle size of oregano and Salt Medel, the particle size distribution of these powders was measured using sieve analysis.

Table 2
Powders used in the binary mixes for the density ratio and size ratio trials.

No.	Density ratio trials	No.	Size ratio trails
D1	Sugar 500–Salt	S1	Paprika–Salt
D2	Onion granules–Salt	S2	Paprika–Salt EF
D3	Black pepper–Salt	S3	Potato starch–Salt EF
D4	Thyme–Salt S	S4	Paprika–Salt V
D5	Thyme–Salt V	S5	Paprika–Salt S
D6	Oregano–Salt S	S6	Paprika–Salt M
D7	Oregano–Salt M	S7	Potato starch–Salt
		S8	Potato starch–Salt V

2.3. Density measurements

Particle density and poured and tapped bulk densities were measured. The poured and tapped bulk density of the powders was measured using a J. Engelsmann Jolting Volumeter type STAV II. A constant mass of powder was poured into the cylinder tube and the volume was measured to determine the poured bulk density. Subsequently, the cylinder was tapped 1250 times and the powder volume was measured again, from which the tapped bulk density was determined. The particle density of the powders was measured using the Micromeritics AccuPyc II 1340 gas pycnometer, using Nitrogen gas.

2.4. Mixing and sampling

The powders shown in Table 2 were selected for the binary mixing trials. Binary powder mixtures were produced by mixing the two ingredients, one being salt, in a 2 L prototype paddle mixer (Fig. 1). The two powders in all binary mixes were mixed in equal proportions by weight. The powders were placed side by side inside the mixer to start from a fully segregated medium. The mixing was carried out for up to 150 s and samples were withdrawn from predefined specific points across the mixer at fixed time intervals of 10s, 15 s, 30s, 90s and 150 s.

Salt being a good conductor of electricity was used as one of the ingredients during the mixing trials and electrical conductivity was used to measure the mixture homogeneity of the powder mixtures. The conductivity of each of the nine samples was measured using a SG78-SevenGo Duo Pro conductivity meter (Mettler Toledo). A standard salt calibration curve was prepared by measuring the conductivity

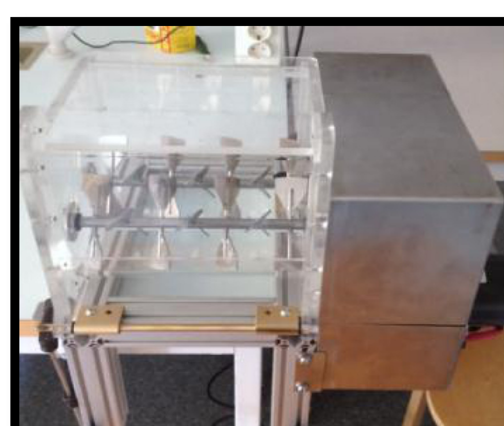

Fig. 1. Image of the 2 L paddle mixer.