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Effect of composition and storage conditions on the flowability of dairy powders

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Abstract

This work investigated the influence of composition (moisture, fat, lactose and protein content) and storage conditions (temperature, time and moisture sorption from air) on the flowability of dairy powders. This was undertaken by measuring the flow properties of eight different commercial dairy powders using shear testing techniques and by measuring how temperature and exposure to moisture in air affected their flowability. Differential scanning calorimetry was used to measure phase and state transitions. The dominant compositional factors affecting the cohesiveness of dairy powders were moisture, amorphous lactose and fat content. All powders had a tendency to absorb moisture from air when in intimate contact with air, however the powders with greater amounts of amorphous lactose were more sensitive to absorbing moisture, giving rise to lumping and caking problems. Fat content had a major influence on powder cohesiveness, with greater particle surface fat content resulting in greater cohesiveness.

Keywords: Dairy powders; Powder flowability; Shear testing; Storage and handling

1. Introduction

There is a large quantity and variety of dairy ingredients produced industrially in powder form, and there is a need for information about their handling and processing characteristics. Powder flow properties are important in handling and processing operations (de Silva, 2000; Knowlton, Carson, Klinzing, & Yang, 1994; Ortega-Rivas, 2003; Peleg, 1978). Flow problems in hoppers and silos are commonplace problems for engineers and process operatives (McGee, 2004). Many flow problems are caused by a funnel flow pattern and can be cured by altering the pattern to mass flow (Johanson, 2002; Purutyan, Pittenger, & Carson, 1998). Measurement of powder flow properties is necessary for the design of mass flow hoppers. Jenike (1964) pioneered the application of shear cell techniques for measuring powder flow properties. Hopper wall friction is a critical parameter in the design and operation of hoppers and silos for reliable discharge of bulk solids (Prescott, Ploof, & Carson, 1999).

Many dairy powders are cohesive and many industrial silos storing them have mechanical and pneumatic discharge aids to help prevent arching and ratholing in an effort to maintain consistent reliable flow. There are not many reports in the literature on the flowability of dairy powders and how it is influenced by powder properties and storage conditions. The first major work was reported over 30 years ago by Buma (1971), who investigated the effect of particle size, free-fat content, temperature and moisture content on the cohesion of whole-milk powder (WMP). Cohesion was measured using an unconfined yield test, whereby a powder plug was first created by compacting a sample of powder, and the pressure required to cause collapse of the unsupported plug was measured. Small particle sizes in the range of 20–40 μm were examined and it was found that there was a significant increase in cohesion at the smaller size. Cohesion is also expected to increase with increased free-fat content, especially at higher temperatures with greater fat liquefaction and liquid bridge formation. Buma (1971) determined free-fat content by

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solvent extraction, but found no correlation between free-fat content and the cohesion of powders with similar particle size. Experiments were performed to investigate the effect of temperature (5, 20 and 40 °C) on the cohesion of four different WMPs. The results showed a significant increase in cohesion between 5 and 20 °C, but not at 40 °C, except for one WMP that had the highest free-fat content. The increase in cohesion was attributed to fat liquefaction resulting in the formation of liquid bridges between the particles. Experiments were also conducted to investigate the effect of moisture content on cohesion. The results showed a gradual reduction in cohesion from 2% to 5.5% moisture content followed by a sharp increase in cohesion above 6%.

Rennie, Chen, Hargreaves, and Mackereth (1999) reported on the effect of composition, particle size, moisture and temperature on the cohesion of milk powders using an unconfined yield test similar to Buma (1971). Their results showed that the cohesion of WMP is much greater than skim-milk powder (SMP), and that reducing particle size from 200 to 80 μm produced a significant increase in cohesion for both powders. They showed that moisture content affects cohesion, with a sharp increase in cohesion of WMP above 6% moisture, similar to Buma's (1971) results. Temperature also affects the cohesion of WMP; however, its influence depends on the moisture content of the powder. WMP with 2.8% moisture showed a sharp increase in cohesion at around 45 °C, whereas WMP with 1.8% moisture showed a sharp increase in cohesion at around 55 °C.

Many food powders containing lactose in its amorphous state may crystallise, producing a discontinuous solid lactose phase within the particles. Crystallisation will only take place if the powder temperature is greater than its glass transition temperature (T_g), whereby the molecules have sufficient mobility to initiate crystallisation (Jouppila, Kansikas, & Roos, 1997; Jouppila & Roos, 1994; Roos, 1995, 2002, 2003). T_g is usually well above the storage temperature for most dry powders. However, lactose in its amorphous state is very hygroscopic and will readily absorb moisture from ambient air, and this increase in moisture will cause a significant plasticisation and reduction in T_g. Crystallisation will occur if T_g is reduced to below the powder temperature. Crystallisation is preceded by the formation of liquid bridges between powder particles, which leads to an increase in the cohesiveness and caking ability of the powder. For this reason, exposure of powders to higher temperatures and humidities, such as in tropical countries, can lead to the glass transition temperature of amorphous components being exceeded, leading to powder handling and caking problems.

The objective of this work was to investigate the influence of composition (moisture, fat, lactose and protein content) and storage conditions (temperature, time and moisture sorption from air) on the flowability of dairy powders. This was undertaken by measuring the flow properties of eight different commercial dairy powders using shear testing techniques and by measuring how temperature, exposure to moisture in air and time affected their flowability.

2. Materials and methods

2.1. Milk powders

Commercial SMP with 1% fat and 56% lactose, WMP with 26% fat and 38% lactose, whey protein concentrate powder with 35% whey protein and 55% lactose (WPCP) and a crystalline α-lactose monohydrate powder (LP) were donated by Dairygold, Mitchelstown, Ireland. A high fat powder (HFP) with 73% milk fat content, whey permeate powder (WPP) with 86% lactose, rennet casein powder (RCP) and sodium caseinate powder (SCP) were donated by Kerry Ltd., Listowel, Ireland. Typical component concentrations in each of these powders in addition to the measured moisture contents are provided in Table 1.

2.2. Particle size and moisture content

Particle size distribution was measured by laser diffraction using a Mastersizer MSS with powder feeder unit (Malvern, Worcestershire, UK). Each test was carried out in duplicate and the average median particle size was recorded. The difference in median particle size of the duplicates was less than 5% of the average particle size. Moisture content (wet basis) was measured by weighing 3 g of a sample before and after drying in an oven (Sanyo-Gallenkamp, Loughborough, UK) at 105°C for 3 d. Each test was carried out in triplicate. The difference in moisture content between the triplicates was within 0.6%. If two of the moisture contents were close to each other, then the average of these two was recorded, otherwise the average of the three was recorded.

Table 1
Typical composition of powders (%, w/w), including measured moisture contents

Powder[a]	Moisture (%)	Fat (%)	Protein (%)	Lactose (%)	Ash (%)
SMP	4.7	0.9	35	51	7
WMP	3.3	26	27	38	6
HFP	2	73	9	13	3
LP	—	—	—	95	—
WPP	3.8	—	—	85	9
WPCP	8.6	3	35	49	6
RCP	10.1	1.5	86	—	1.5
SCP	7.1	1.5	87	1.5	4

[a]SMP: skim-milk powder; WMP: whole-milk powder; HFP: 73% milk fat powder; LP: lactose powder; WPP: whey permeate powder; WPCP: whey protein concentrate powder; RCP: rennet casein powder; and SCP: sodium caseinate powder.