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COHESIVE PROPERTIES OF MODEL POWDERED FORMULAS FOR CHILDREN

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Key words: flow function, shearing test, agglomeration, powdered food products

In the reported study, analyses were carried out to determine the effect of agglomeration and raw material composition on cohesive properties of model powdered formulas for children. Measurements were carried out in a uniaxial shearing test according to a measuring procedure following Jenike's theory, at four levels of consolidating stress in the range of 4.6÷17.2 kPa. The examined powdered children formula were determined for the following parameters of plastic flow: cohesion, internal friction angle, resistance to uniaxial compression, maximum consolidating stress and flow index. Characteristics of flowability properties of the examined model powdered formula for children demonstrated various cohesive properties of those materials. The flow function described the model formula powders as poorly cohesive and soft flowing whereas agglomerates produced on their basis as cohesive powders, sparingly flowing.

INTRODUCTION

Powdered products exhibit a structure of dispersed systems with high practical value. Qualitative characteristics of powders usually focuses on aspects linked with their turnover as well as those linked with liquid reconstitution [Freitas--Eduardo & Silva-Lannes, 2007]. Extension of sizes of molecules through agglomeration is aimed at improving selected physical properties of a dispersed system. Such properties of molecules of solid bodies as: size and shape, porosity, bulk density, flow rate of powder, avoidance of compounds segregation or dust generation, are of key significance. In addition, food powders destined for dispersion in a liquid should be characterised by instant properties, namely by good wettability, settleability, dispersibility and solubility. Depending on the method of agglomeration, the above criteria are met to a various extent. The manner of agglomerates formation in a given process determines their properties [Turchiuli *et al.*, 2005].

In the technology of loose material, in most unitary operations, including sieving, mixing, and agglomeration, determination of the motion of loose medium is fundamental. Mechanical properties, including cohesive properties of food powders, play a significant role in elucidating and solving problems linked with their storage, transport and turnover [Al Mahdi *et al.*, 2006]. Consolidation, suspension and encrustation of loose material in a container as well as tunnel flow are examples of problems occurring during turnover of powdered materials [Domian *et al.*, 2004; Faqih *et al.*, 2007; Fitzpatrick *et al.*, 2007].

Determination of the flow capacity of powders requires simulation of conditions occurring in a container. In this case, the most useful method are assays of instantaneous shearing. According to powders flow theory by Jenike [Juliano *et al.*, 2006], values obtained from tests of instantaneous shearing enable determining parameters of plastic flow of loose materials with appropriate accuracy, to make them applicable in practice, and predicting the flow character of the examined loose material. Those parameters determine conditions in which loose material stops behaving as a solid body and becomes similar to liquid. The parameters of plastic flow include: angle of internal friction in the material, effective angle of friction (a measure of internal friction considering cohesion), powder resistance to deformations, cohesion, container walls friction angle, and bulk density. The above-mentioned parameters depend on the level of normal stress [Domian *et al.*, 2004; Fitzpatrick *et al.*, 2004].

This study was aimed at analysing the effect of agglomeration and raw material composition on cohesive properties of model powdered formulas for children, at four levels of consolidating stress in the range of 4.62÷17.24 kPa.

MATERIAL AND METHODS

The experimental material were the following commercial products: full-fat powdered milk (FPM), caster sugar (CS), rice semolina (RS), and strawberry powder (SP), that when mixed in appropriate ratios constituted the following model mixtures (contribution in percentage by weight): A (FPM 0%, CS 25%, RS 73%, SP 2%), B (FPM 40%, CS 25%, RS 33%, SP 2%), and C (FPM 73%, CS 25%, RS 0%, SP 2%).

The agglomeration process was carried out using a STREA 1 (Niro-Areomanic AG) device and the following parameters of the agglomeration processes: stock – 300 g of a mixture, moisturizing liquid – 48 g of water, temperature of inlet air 50±2°C, air flow rate through the bed – 50-80 m^3/h, pressure

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TABLE 1. Plastic flow parameters of model powdered formulas for children at four levels of consolidating stress.

Material	Consolidating stress σ_E (kPa)	Bulk density of consolidated material ρ (kg/m^3)	Kinetic angle of internal friction φ(°)	Effective angle of internal friction δ(°)	Cohesion C (kPa)	Resistance to uniaxial compression σ_c (kPa)	Maximum consolidating stress σ_1 (kPa)	Flowability index ff_c (-)
Mixture A	17.24	313	15	21	2.68	4.5	26.0	5.8
	13.03	306	16	23	2.49	4.2	20.1	4.8
	8.83	306	18	24	2.00	3.4	14.5	4.3
	4.62	304	21	29	1.10	1.8	8.1	4.5
Mixture B	17.24	648	22	31	2.61	5.4	33.7	6.2
	13.03	645	16	29	2.51	4.7	22.3	4.7
	8.83	641	25	30	1.68	3.3	17.1	5.2
	4.62	631	25	30	0.88	1.5	8.8	5.9
Mixture C	17.24	693	28	33	2.53	5.3	34.7	6.5
	13.03	691	30	34	1.68	3.7	27.6	7.5
	8.83	690	28	33	1.20	2.5	18.1	7.2
	4.62	680	22	32	0.79	1.4	9.0	6.4
Agglomerate A	17.24	218	21	31	4.40	10.2	31.9	3.1
	13.03	217	21	31	3.71	8.9	25.0	2.8
	8.83	216	24	35	2.76	6.8	18.4	2.7
	4.62	209	28	39	1.67	4.4	11.1	2.5
Agglomerate B	17.24	388	22	31	4.23	10.3	32.8	3.2
	13.03	388	24	32	3.26	8.2	25.6	3.1
	8.83	387	26	34	2.22	5.6	18.5	3.3
	4.62	383	26	37	1.41	3.4	10.1	3.0
Agglomerate C	17.24	366	22	31	3.75	9.1	32.7	3.6
	13.03	355	21	32	3.79	8.9	24.7	2.8
	8.83	333	21	32	2.53	5.8	16.8	2.9
	4.62	320	24	36	1.57	4.0	9.6	2.4

of air compressed in a spray nozzle – 1 bar, moistening with breaks in the period of up to 10 min, agglomerate drying for 12 min at the inlet air temperature of 50±2°C.

Analyses of cohesive properties were carried out with instantaneous shear tests in an apparatus adjusted to a measuring procedure according to Jenike's theory (a measuring chamber 95 mm in diameter and 50 mm in height) [Jenike & Carson, 1985]. The samples – powdered formulas for children – were consolidated with consolidating stress in the range of 4.62÷17.24 kPa.

The model powdered formulas for children and agglomerates produced on their basis were determined for the following parameters of plastic flow [Domian *et al.*, 2004; Juliano *et al.*, 2006]: φ – kinetic angle of internal friction, δ – effective angle of internal friction, C – cohesion, σ_E – consolidating stress, σ_1 – maximum consolidating stress, σ_c – resistance to uniaxial compression, ff_c – flowability index. The formula powders examined were characterized by means of flow function (FF) and bulk density of the consolidated material ρ.

The mean diameter (median) of the model powdered formulas for children and their agglomerates was determined with the use of particle size analyzer in air AWK – V 97 (Kamika Warsaw, Poland).

RESULTS AND DISCUSSION

The model children powdered formulas examined were characterized by various flow capacity of the material. In general, values of plastic flow parameters are determined by raw material composition and agglomeration as well as by the adopted level of consolidating stresses (Table 1). An increase in the consolidating stress is accompanied by an increase in density of consolidated material, the angle of internal friction, cohesion, resistance to uniaxial compression and the maximum consolidating stress.

The value of consolidating stress and extent of agglomeration of powdered formula for children affect both the kinetic and effective angle of internal friction. The latter includes an increase of cohesion in loose material during consolidation. Its values are higher than those of the kinetic angle of internal friction, irrespective of the level of consolidating stress applied.

The more loose the bed's structure, *i.e.* the lower its density, the higher the cohesion forces occur, and consequently the worse the powder's capacity for free flow. Simultaneously, an increase in cohesion forces results in increased resistance of the powdered formula examined to uniaxial compression,

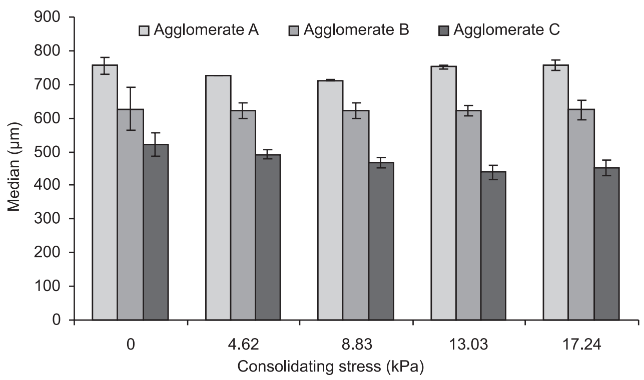

FIGURE 1. Mean diameter (median) of model powdered formulas for children at 4 levels of consolidating stress.

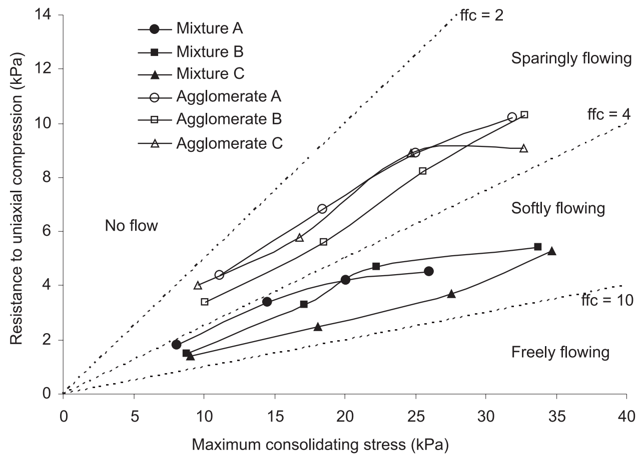

FIGURE 2. Flow function of model powdered formulas for children.

which is of special significance in the case of agglomeration of formulas. The application of consolidating stresses at a level of 4.62÷17.24 kPa does not evoke any significant damage to the structure of agglomerates formed (Figure 1).

Figure 2 presents flow functions of the model powdered formulas for children and depicts distribution of flow capacity of the material analysed through division of figure area into parts corresponding to boundary values of the flow index, according to Jenike's criterion [Jenike & Carson, 1985]. The flow functions of model powdered formula for children are located in the area of $4<ff_c<10$, which indicates that the powders are poorly cohesive, soft flowing. In turn, the flow functions of agglomerates produced based on children formula powders are observed entirely in the area of $2<ff_c<4$, which classifies the examined material as cohesive agglomerates, sparingly flowing.

CONCLUSIONS

1. Parameters of plastic flow, obtained from tests of instantaneous shearing and characterizing flowability properties of model powdered formula for children, are determined by raw material composition, agglomeration and the adopted level of consolidating stresses.

2. The uniaxial compression test enabled explicit characterization of the flow properties of the model powdered formulas for children and demonstrated various cohesive properties of those materials. The flow function describes the model formulas powders as poorly cohesive, soft flowing, whereas agglomerates produced on their basis – as cohesive, sparingly flowing.

3. Analyses of the model powdered formulas for children and agglomerates produced on their basis demonstrated that an increase in consolidating stress resulted in increasing resistance of the material, cohesion, density and flow index, as well as a decrease in the angle of internal friction.

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WŁAŚCIWOŚCI KOHEZYJNE MODELOWYCH SPROSZKOWANYCH ODŻYWEK DLA DZIECI

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W niniejszej pracy badano wpływ aglomeracji i składu surowcowego na właściwości kohezyjne modelowych sproszkowanych odżywek dla dzieci. Pomiary wykonywano w teście jednoosiowego ścinania według procedury pomiarowej zgodnej z teorią Jenike, przy czterech poziomach naprężenia konsolidującego z zakresu 4,6÷17,2 kPa. Dla badanych odżywek w proszku dla dzieci wyznaczono parametry plastycznego płynięcia takie, jak kohezja, kąt tarcia wewnętrznego, wytrzymałość na jednoosiowe ściskanie, największe naprężenie konsolidujące, indeks płynięcia. Charakterystyka właściwości płynięcia badanych modelowych sproszkowanych odżywek dla dzieci wykazała różne właściwości kohezyjne tych materiałów. Funkcja płynięcia określa modelowe odżywki sproszkowane jako słabo kohezyjne, łatwo płynące. Aglomeraty utworzone na podstawie modelowych odżywek dla dzieci pod względem zdolności do płynięcia, na podstawie funkcji płynięcia, są proszkami kohezyjnymi, trudno płynącymi.