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TESTING PROCEDURE OF PELLETABILITY OF INGREDIENTS AND COMPOUND FEEDS

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A b s t r a c t. An extrusion device with hydraulic press and a single hole die has been adapted from previous experiments, in order to test the pelleting ability of compound feeds. The analysis of the curve leads to the calculation of several criteria which could be used to characterize the behaviour of the material according to the processing variables, in order to predict full-scale pelleting.

K e y w o r d s: ingredients, compound feeds, pelletability, extrusion

INTRODUCTION

Feed pelleting concerns a large portion of compound feeds in Europe, mainly with a view to lower the costs of long distance transportation of these commodities and to facilitate their delivery to the farms.

Pelleting often involves the use of very high pressures (some hundreds of MPa) which bind particles strongly through various mechanisms [19,20]. This technology is therefore an energy consuming process: it accounts for 67 % of the total energy consumed in production of a pelleted feed [1,2]. Control of this operation depends on improved understanding of the behaviour of meal during compaction and of the mechanisms of cohesion which give the product the required mechanical strength.

Therefore it seems advisable to desire to quantify the many variable factors [7] which influence the manufacture of pellets in order to increase the efficiency of the process. The purpose in the present work is to look for a method which will enable us to foresee the process of transformation by a material in the course of pelleting. This testing procedure has been studied and used both in INRA in Nantes (France) and in the University of Agriculture in Lublin (Poland).

MATERIAL AND METHODS

Mechanisms of the pelleting process used in the feed industry has been mainly studied by Wittmann [23], Locussol [11], Friedrich [4], Podkolzine [16], Drzymała [3], Klassien and Griszajew [5]. In the analyses of agglomeration, two stages have been described: the first stage (compression stage) is a packing of the meal first by sliding and rearrangement of the particles, then by plastic deformation of the particles and their fragmentation, the second stage (extrusion stage) is the flow of the agglomerated material through a die.

Testing device

An extrusion device with hydraulic press and a single hole die, has been derived from previous experiments on fats [17,21] and adapted to the study of the agglomeration of the feed materials [12]. Between the two plates of laboratory hydraulic press (Perrier 133/146 or ZD 40), an extrusion device has been installed (Fig. 1). It is made of a cylinder which has been pierced at its

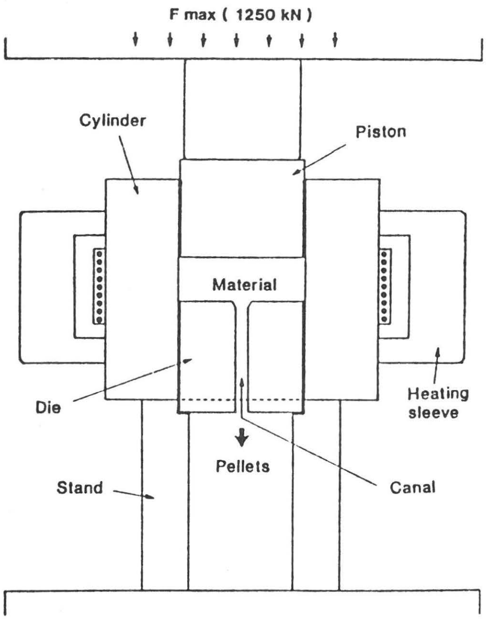

Fig. 1. Testing device for agglomeration studies with single-hole die.

bottom part by a hole of a given dimension: through this hole there runs the powder compressed by the piston which moves within the cylinder. A heating sleeve can bring and maintain the cylinder at any given temperature. The motion of the piston as well as the applied force are measured and registered by means of a pressure and displacement recorder.

The force necessary to extrude is not constant (Fig. 2) and leads to define the two stages mentioned above. The compression stage takes place before a first threshold in which the matter begins to get out of the canal (F_M). Then takes place the extrusion stage and a second threshold (F_E) when the minimum extrusion force is applied shortly before the end of the course of the piston. Agglomeration work (Wt) calculated from the total area under the curve has been divided conventionally into three parts in order to define a compression work (Wc), a friction work (Wf) and an extrusion work (We). The crushing resistance of the compacted products was evaluated afterwards.

Process description

The present work proposes a more accurate description of the curve. Thus, from experiments using ground wheat, soybean meal and rapeseed mixtures, the two stages mentioned above could be extended to four (Fig. 3).

Stage a₁

At the onset of compression, the particles will rearrange at a very low pressure without excessive deformation, and the

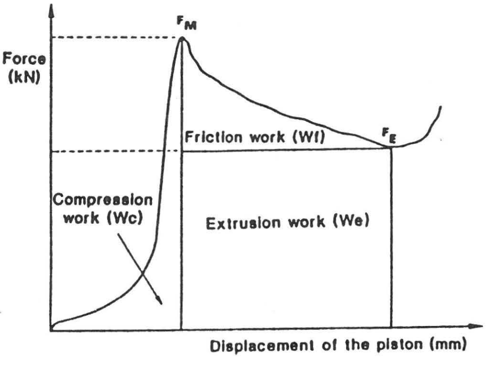

Fig. 2. F(D) plotted curve during compression and extrusion of the material.

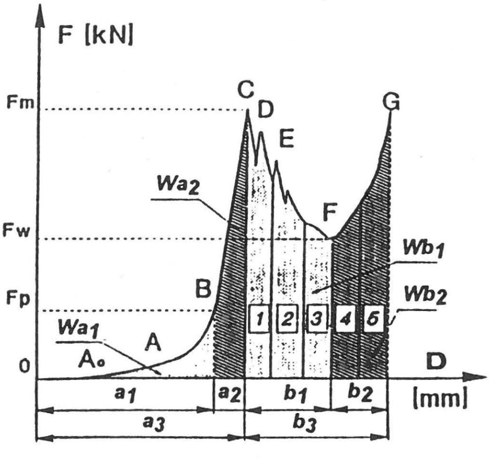

Fig. 3. Description of the different agglomeration stages.

voids of the same order of size as the original particles are filled owing to the elimination of air. The low strength provided by the air flow through the material and the low magnitude of friction need only a small increase in pressure (segment OA_0). A certain voidage between the particles remains and the mass shows no mutual coherence [8]. Further increase of pressure causes collapse and increase of particles sliding past one another. The displacement of the piston reduces the distance between particles and gradually the remaining voids disappear, according to the increased resistance to the air flow (segment A_0AB). The required energy increases with the higher friction and densification. The voids which are substantially smaller are filled by plastic flow of particles or by fragmentation. At the point B, air is practically eliminated. It was assumed that the rate of change of the compression force with respect to the relative displacement of the piston could be described by a power-type law.

Stage a_2

The material behaviour can be assimilated to an elastic behaviour. The increase of the compaction force is proportional to the displacement of the piston. The point B can be defined as a plasticity threshold after which the material is subjected to elastic deformation. The increase of density is low: it could be assumed that the energy required during the stage a_2 is not used for densification, but mainly against friction forces. At the point C, a maximum in force will be attained leading to a maximum in compact density, in which the matter begins to flow. The magnitude of the force (F_M) at the point C is generally 3-4 fold higher than at point B. The force is higher than the tensile strength calculated from the Coulomb's equation. The compression stage $a_3 = a_1 + a_2$ represents 6 to 12 % of the total agglomeration work according to the materials. Of course, there will be overlap of these stages to a certain degree and the steps will not occur completely separated, one following the other.

Stage b_1

The aspect of the curve (segment BF) and the magnitude of the force during the flow depend on the friction properties of the material against the die wall (external friction), and within the material itself (internal friction). The force decreases according to the fragmentation effect on the die inlet and the reduction of the volume of material within the cylinder, the ratio energy required/amount of material within the cylinder has practically a constant value according to time (Table 1). The force has been experimentally demonstrated to be minimum at point F when the piston reaches the top of a 'dead zone' xyz (Fig. 4), which can be delimited by the residual flow angle of the material [8]. The solid may inflate after ejection from the die; it recovers a certain volume under the effect of delayed reactive deformation.

Table 1. Evolution of extrusion work according to time during stages b_1 and b_2 for 3 different pure raw materials

Raw materials	Stages	b_1	b_1	b_1	b_1	b_2
	Sub-stages*	1	2	3	4	5
Wheat	Total work (J)	938.0	687.0	439.0	488.0	416.0
	Specific work (Jg^{-1})	21.9	21.9	21.3	46.1	84.1
Soybean meal	Total work (J)	741.0	581.0	391.0	302.0	313.0
	Specific work (Jg^{-1})	17.4	18.4	19.2	31.9	87.6
Whole rapeseeds	Total work (J)	31.0	32.6	30.7	19.9	14.3
	Specific work (Jg^{-1})	0.7	1.0	1.5	2.7	4.8

*sub-stages are 15, 16 and 20 seconds for wheat, soybean meal and rapeseeds, respectively.

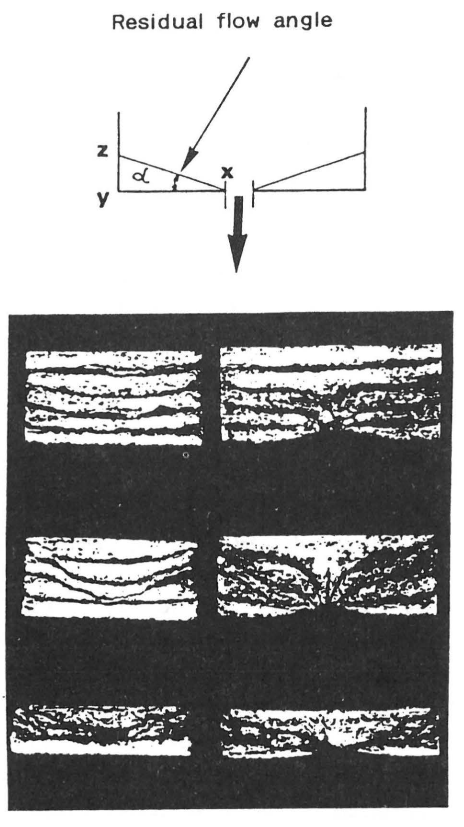

Fig. 4. Flow of the material through the die.

Stage b_2

The material included in the 'dead zone' participate to the flow. It needs an increase of the extrusion force. The density of the extruded material is 1.04 to 1.08-fold higher according to the materials during stage b_2 than during stage b_1. Extrusion stage $b_3 = b_1 + b_2$ represents 89 to 95 % of the total work.

Measuring forces and densities at the points B, C and F, and calculating plastic (Wa_1: stage a_1) and elastic (Wa_2: stage a_2) deformation works (or energies), extrusion work (Wb_1: stage b_1 :Wb_2 : stage b_2) appear as a further means of behaviour characterization at a given step of the process. The yield point of plasticity, which refers to the theoretical force required at point B in order to change from a discontinuous divided state into a semi-continuous coherent state, is determined graphically on the point of intersection of slopes formed by the two tangents at the curve. Specific works are calculated by comparing these energies to the mass of material into the cylinder or the mass of pelleted product.

RESULTS AND APPLICATIONS

The results of the test through a one-hole die depends on various factors, some of which have been systematically optimized: amount of powder under test (50 g), speed of the piston (0.13 mm s^{-1}). Other factors were considered as operating variables according to the usual pelleting conditions: dimensions of the hole of the die, steam addition, sleeve temperature set-point [15].

Simulation studies

This method could be of interest for evaluating the influence of the nature and the physical properties of the material such as particle size distribution and for predicting the effect of different raw materials mixtures, of liquids or binders addition [13]. A similar device has been developed to test pelleting ability regarding to moisture and steam addition to the meal by Vercauteren [22].

As an example, the respective influence of sugars and water levels in sugar cane molasse has been studied after addition to a feed by Nivet-Denois *et al.* [14]. Water added to molasse dry matter had a clear lubricating effect (Table 2) which appeared to be more important on the compression work (Wc). A slight decrease of the pellet hardness was observed. Molasse dry matter addition has practically no general lubricating effect notwithstanding a relative increase of friction work (Wf). The pellet hardness was greatly improved. These results lead to indications of practical interest: thus, molasse could be considered as a lubricant and/or as a binder according to its water and/or dry matter level.

Table 2a. Effect of an increase of molasse dry matter on agglomeration data*

Dry matter (% v/v)	0	3	6	9
Water level (% v/v)	3	3	3	3
Agglomeration work (Wt) (MJ/50 g)	3.65a	2.97b	2.76b	3.07b
Friction work Wf (% Wt)	23.6	34.0	33.0	38.8
Compression work Wc (% Wt)	15.1	11.1	9.8	9.4
Pellet hardness (DaN/cm)	2.9a	4.9b	6.9c	6.7c

*means within groups not followed by the same letter are significantly different (P>0.05).

Table 2b. Effect of an increase of molasse dilution on agglomeration data*

Dry matter (% v/v)	1	2	3	4
Water level (% v/v)	3	3	3	3
Agglomeration work (Wt) (MJ/50 g)	3.99a	3.62b	3.03c	2.82d
Friction work Wf (% of Wt)	28.8	26.8	27.4	27.3
Compression work Wc (% of Wt)	14.5	12.1	10.2	9.9
Pellet hardness (DaN/cm)	5.6a	5.9a	5.1a	4.4b

*means within groups not followed by the same letter are significantly different (P>0.05).

Prediction of pelleting process

Since full-scale trials are often hard to interpret owing to a number of uncontrolled variation sources, some of the criteria mentioned above can be used to characterize the behaviour of the materials according to the processing variables, in order to predict full-scale pelleting.

The maximum force (F_M) measured with the testing device has been shown [10] to be correlated without too many discrepancies (r=0.7) with the power required by a pellet mill in pilot scale experiments on 65 different feed mixtures (Fig. 5). In the same way, specific extrusion work (We) has been clearly related [18] to specific energy consumption by the pellet mill (Fig. 6a) using 20 different feeds containing 12 to 14 % liquids (molasses, fats and fermentation by-products). However, it appeared no relationship between friability of the pellets produced with the pellet mill and hardness of extruded products from the hydraulic press (Fig. 6b).

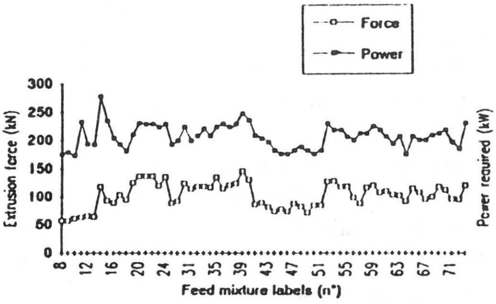

Fig. 5. Power required by the pellet mill versus maximum agglomeration force F_M.

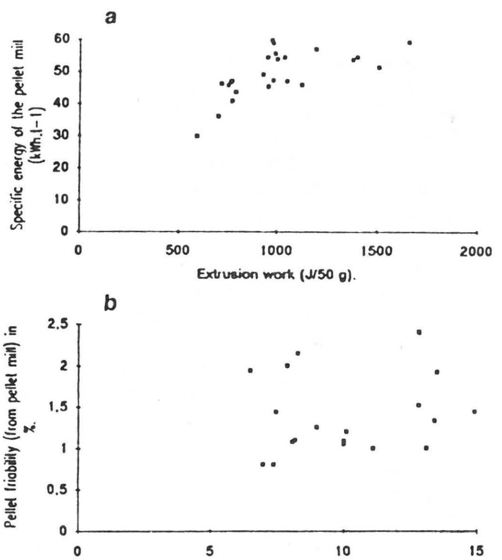

Fig. 6. Specific energy consumption (pellet mill) versus extrusion work W_E (extrusion device) (a) and pellet friability (from pellet mill) versus pellet hardness (from extrusion device) (b).

CONCLUSIONS

The tested procedure has been found to be sufficiently sensitive to discriminate raw materials, and to reveal the importance of their chemical composition, particle size of the flours, steam and/or binder additions. It could help to a more complete characterization of the materials and a better understanding of the agglomeration process, with respect to pelleting conditions.

However, the procedure appears to associate basically two different mechanisms which have to be studied separately. Indeed, inasmuch as the phenomena observed by simple compression were similar to those occurring in the die [6,9], further experiments are needed for a better knowledge of the flow behaviour of complex feed-type materials through a die. This would allow to simplify the procedure with respect to practical conditions and to avoid discrepancies between the results provided both by the test and full scale pelleting.

REFERENCES

1. **Tecaliman A.F.M.E.**: L'alimentation animale. Techniques pour matriser l'nergié. Agence Francaise pour la Matrise de l'Energie ed, Paris, 62, 1991.
2. **Beumer H.**: Consommation et possibilité d'économie d'énergie dans l'industrie de l'alimentation animale: une orientation. Ins. Graan Meel en Brod. TNO Wageningen. Report 80-145, 1980. In: Delort-Laval J. Industries des Céréales, 11, 25-29, 1981.
3. **Drzymała Z.**: Bases du génie des procédés de compactage et de pressage des matériaux (in Polish). PWN, Warszawa, 1988.
4. **Friedrich W.**: Das Pelletieren von Mischfutter - Grundlagen und Einflussgrössen des Pressprozesses und Wirkung auf die Nährostoffe. Aufbereitungs-Technik, 19, 401-406, 1978.
5. **Klassien P.W., Griszajew I.G.**: Fundammental of Pelleting Technique (in Polish). WNT, Warszawa, 1989.
6. **Kumar M.**: Compaction behaviour of ground corn. J. Food Sci., 38, 877-878, 1973.
7. **Laskowski J.**: Study on feed pelleting process (in Polish). Seria Wydawnicza, Rozprawy Naukowe 113, Wyd. Akademii Rolniczej, Lublin, 75, 1989.
8. **Laskowski J.**: Etude du processus d'agglomération des matiéres premiéres biologiques. Int. Rep. I.N.R.A., Nantes, 46, 1989.
9. **Le Deschault de Monredon F.**: Axial compression as a model for studying the granulation of feed powders. 1-Methodology. Sci. Aliments, 10, 189-202, 1990.
10. **Le Marchand P., Riou Y., Abdallah A., Ilari J.L., Melcion J.P.**: Agglomération des aliments composés destinés à l'alimentation du bétail. Etude du comportement au pressage selon la nature du mlange et la conduite de la presse. Final Report Programme R 82-85, D. I. A. A.-Tecaliman, 63, 1985.
11. **Locussol L.**: Contribution a l'tude des presses a extrusion utilises dans l'alimentation animale. Bull. Anciens Eleves Ecole Frse de Meunerie, 206, 71-75, 1965.
12. **Melcion J.P.**: Nouvelle technique d'étude de l'agglomération des aliments des animaux. Prix Protector Inter., 34, 1974.
13. **Melcion J.P., Delort-Laval J.**: Effet des liants sur la production, les caractristiques physiques et la valeur nutritive des aliments agglomérés. Bull. Anc. Eleves de l'ENSMIC, 279, 148-164, 1977.
14. **Nivet-Denois H., Riou Y., Melcion J.P.**: L'agglomération des aliments. Etude paramétrique. C.R.A. - Tecaliman report, part 5, 51, 1982.
15. **Pedamond M.**: Aptitude à l'agglomération des aliments des animaux; application ě l'étude de l'influence de la granulomtrie et de la nature des matiéres premiéres. Eng. thesis ENITIAA Nantes, 83, 1977.
16. **Podkolzine Y.V.**: Détermination analytique de la longueur du trou d'une matrice servant à la production d'aliments comprimés pour le bétail (in Russian). Traktory i sel'chozmasziny, 10, 19-20, 1972.
17. **Prentice J.H.**: An instrument of estimating the spreadability of butter. Lab. Practice, 3, 186-189, 1954.
18. **Riou Y., Picoche B., de Monredon F.**: Etude de l'influence de la duré de conditionnement et d'incorporation d'additifs sur le comportement au pressage des aliments à teneur élevée en matiéres premiéres liquides. Final Report Programme 85-16 FRT 85, A.C.T.I.A. - Tecaliman, 49, 1986.
19. **Rumpf H., Hermenn W.**: Eigenschaften, Bindungs -Mechanismen und Festigkeit von Agglomeraten. Aufbereitungs-Technik, 3, 117-127, 1970.
20. **Schubert H.**: Principles of agglomeration. Int. Chem. Eng., 21, 363-377, 1981.
21. **Vasic I., de Man J.**: Measurement of some rheological properties of plastic fats with an extrusion modification of the shear press. J. Am. Oil Chem. Soc., 44, 225-228, 1967.
22. **Vercauteren W. C. P.**: Future developments in feed production technology. Holmen Feed Prod. Symp., Holmed ed. London, (UK), C1-C22, 1982.
23. **Wittmann A.**: Strangpressen in der Ring-und Scheibenmatrize. Aufbereitungs-Technik, 3(7), 287-293, 1962.