i'Tec_P3
November 2016

Keywords: Dosage, Additive, Physical properties

Flow patterns of additives used in animal feed manufacture during blade extractor dosage

Additives can be fed (dosed) into feed mixes using screw conveyors or blade extractors. Blade extractors have a simple operating principle: the unit's flat base is fitted with a combination of fixed and mobile blades (**Figure 1**). The motion of these blades directs the product flow, and can be adjusted to various extractor index settings that control the size of the displacement and, therefore, the size of the aperture. The literature provides few insights into how a product's physical properties affect the output parameters of this type of extractor (flow rate, flow control).

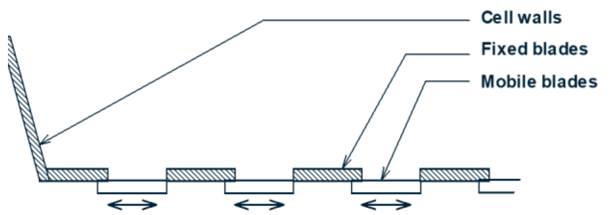

Figure 1: Diagram of a blade extractor

1. Industrial trials

1.1. Focus and Principle

The aim is to study how a product's physical properties affect extraction indices in terms of flow rate and regularity.

The studies' main focus concerns 5 reference additives for 20 to 30 product flow quantity measurements taken over a given time period at three different extraction indices.

Other flow rate measurements are taken on 7 additional products with a larger number of extraction indices, varying the number of measurements according to the extraction index used.

1.2. Equipment and apparatus

The study looks at five reference products. These are the same that are used for the screw conveyor dosage tests (i'Tec_P2). In this case though, the tests are supplemented by tests on 7 other products.

The tests use stainless steel rectangular units with a maximum capacity of 5 m^3, and cross-section 750 x 750 mm. The units' bottom section comprises a 1.5 m^3 dual-cone. The units are all located above the same weighing bin.

Each weighing bin has a maximum permissible load of 400 kg, and is accurate to +/- 50 g (100 g scale). This is a satisfactory level of accuracy, which is checked on a regular basis across the whole measurement range.

Extraction indices can be set on 15 fixed scales. Flow rate increases as the index rises; the open cross-section is not, however, proportional to the index value with the relationship being described as:

$$\sqrt{\text{Flow rate}} = a \cdot \text{Index} + b$$

The use of blade extractors in this study is not directly related to their conventional operating principle, as the test focuses on the behaviour of the products rather than that of the equipment. Standard practice involves programming the PLC with a threshold designed to reduce the extraction index according to the quantity of product remaining to be dosed. This technique makes it possible to obtain the expected accuracy.

1.3. Method

An average extraction index I2 capable of extracting 50% of the initial filling operation over 15 minutes is determined for the measurement of the 5 reference additives (A to E). This index automatically sets the lower-bound (I1) and upper-bound (I3) indexes by going up or down a given scale.

3 filling and 3 emptying operations are planned on the unit in order to take all the measurements. Each time the unit is filled, 10 measurements are made at each index value. This makes it possible to ensure that the unit is emptied in an identical manner at the end of each test. The successive indices tested are changed after each filling operation:

- Series 1: 10 x I1, 10 x I2, 10 x I3
- Series 2: 10 x I2, 10 x I3, 10 x I1
- Series 3: 10 x I3, 10 x I1, 10 x I2

Due to the difficulties encountered during Series 1, it was not possible to analyse the results of this series for the first 3 products (A to C). Only 20 measurements were validated for these 3 products.

For the seven additional products, 1 to 7 measurements were taken at each extraction index; the tested index range spans 3 to 15. It should also be noted that there was no control over pre- and post-test unit filling levels. Therefore, measurement accuracy for these 7 products was less.

1.4. Results

Due to the impossibility of using the same extraction indices for all the products the results had to be compared based on equations that describe changes in flow according to extraction index and, in particular, on the slope of this equation (a) and the coefficient of determination (R^2), which illustrates its accuracy.

Figure 2 shows the relationships describing the reference products. The intervals correspond +/- to a standard deviation.

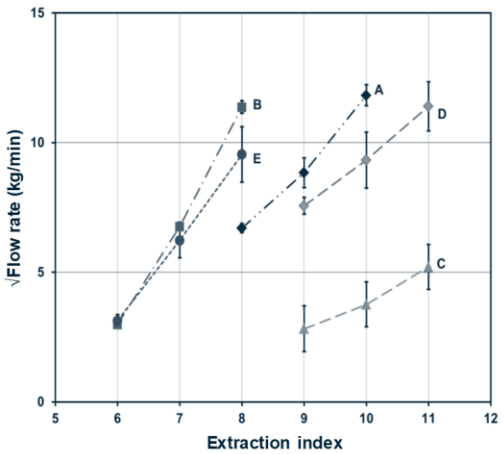

Figure 2: Change in flow according to extraction index for the 5 reference products

Coefficient **b** (Table 1) corresponds to the root of the flow value with a zeroed index. As the products stop flowing before the 0 value, this coefficient is always negative. Coefficient **a** corresponds to the slope of the straight line. An interesting parameter can be calculated by the ratio - a/b, which corresponds to the value of the extraction index for a full-off flow rate. This index is written as I_0.

Table 1 gives the values for each coefficient and for the coefficient of determination for each of the 5 products.

Products	b	a	I_0	R^2
A	- 13.92	2.56	5.4	95.5
B	- 22.28	4.19	5.3	99.5
C	- 8.02	1.19	6.7	56.4
D	- 9.78	1.92	5.1	77.8
E	- 16.14	3.21	5.0	92.7

Table 1: Flow model coefficients according to extraction indices and coefficients of determination for the reference products

Table 2 lists the same parameters for the 7 additional products.

Products	b	a	I_0	R^2
F	- 7.07	1.35	5.2	95.2
G	- 3.18	1.17	2.7	87.6
H	- 16.19	3.30	4.9	97.6
I	- 20.21	4.54	4.5	95.5
J	- 4.89	1.32	3.7	94.0
K	- 7.09	1.63	4.3	93.1
L	- 20.36	2.61	7.8	95.6

Table 2: Flow model coefficients according to extraction indices and coefficients of determination for the 7 additional products

With the exception of product A, flow rate standard deviations increase in tandem with increasing extraction levels. Once the flow rates have been converted into their root values, the standard deviations are not so closely linked to index increases; expressing these values as coefficients of variation gives fairly uniform results for each product whatever the extraction index. Product ranking in terms of increasing coefficient of variation:

B ≤ A < D ≤ E < C

With the exception of the plots for products E and D, this ranking very nearly defines the increase in coefficients of determination (Table 1):

B > A > E > D > C

The coefficient of determination would therefore seem to provide a good yardstick for describing product flow patterns. The coefficient of determination corresponds to the ratio of the percentage variation explained by the model against the total observed variation. The coefficient approaches 100% when the plots are practically on a straight line. This provides a snapshot of the scatterplot around the straight line and illustrates the probability of obtaining the desired flow rate for a given index. The **slope of equation a** is another parameter that indicates how flow rate increases in relation to the extraction index. This gives a different product ranking:

B > E > A > D > C

Lastly, the **value of index I_0** is another, apparently different, flow parameter as the product ranking changes to:

C > A > B > D > E

These 3 parameters have been compared against the physical properties of powders, taking the reference products as a basis. The additional products were added later.

2. Relationship with the physical characteristics of additives

A study of how industrial parameters correlate to the characteristics of the lab-tested products (over 40 products tested) revealed links with densities and, above all, with flow characteristics.

2.1. Densities

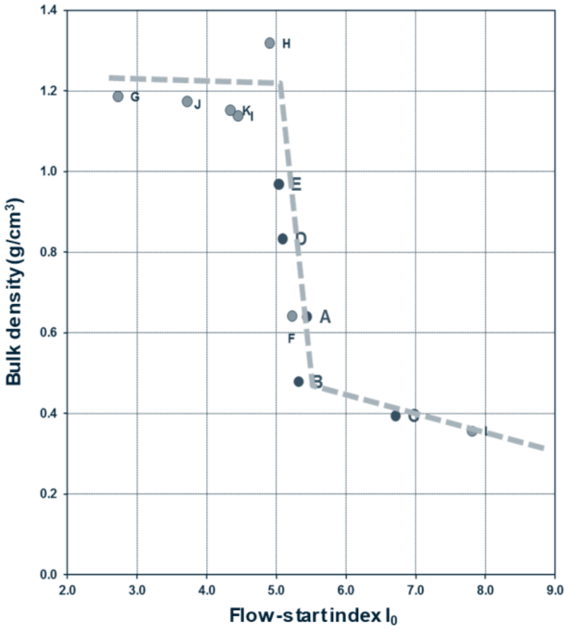

Figure 3: Effect of bulk density on the flow-start index I_0

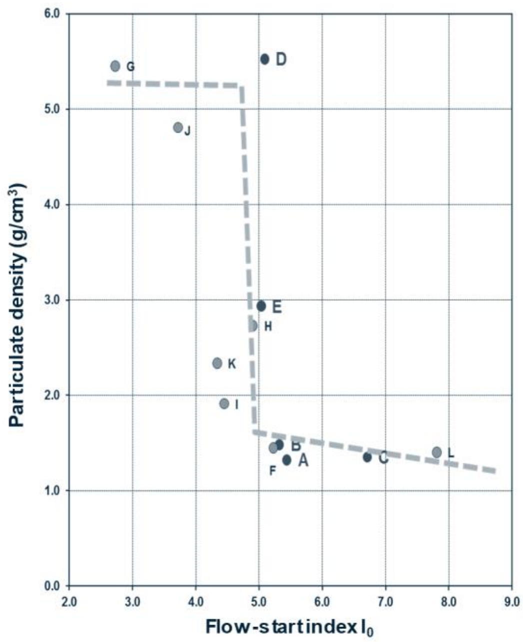

Figure 4: Effect of bead density on the flow-start index I_0

It is the flow-start index (I_0) that appears to be influenced by densities – the charts reveal an evident threshold effect.

This effect is more pronounced with bulk density (Figure 3 – i'Tec_Q9) than with bead density (Figure 4 – i'Doc_Q5). This is mainly due to the plots of the additional products.

For bulk density, at approx. 1.2 g/cm^3, the index varies but always remains below 5. Between 1.2 and 0.5 g/cm^3, the index is always close to 5. Above 0.5 g/cm^3, the indices increase rapidly above 5.

This effect appears to be that of the ratio between the force of gravity and the particle tension forces that limit product flow.

2.2. Flow indices

The flow a profile links two flow indices.

With the reference products, the angle of repose (flow) appears to be a robust flow profile predictor (its square root) according to index. The plots here show a good spatial distribution and a fairly satisfactory coefficient of determination (95.07%). The measurements taken on the 7 additional products tend to confirm this assumption. The relationship is not as clear, but the equation that describes the relationship is hardly changed.

In practice, this means that the smaller a product's angle of repose (flow), the quicker its flow rate accelerates when extraction indices intersect.

When programming the PLC, a product with a high angle of repose would require stronger progressions in the extraction index. Conversely, the flow rate of a product with a low angle of repose would be likely to change rapidly depending on the extraction indices. This would require tighter index changes when switching from one threshold to another.

A similar relationship exists with the smallest flow diameter (i'Tec_Q9), but with a lower coefficient of determination based on the five reference products. The introduction of additional products scatters the relationship by creating another equation and reducing the coefficient of determination.

This parameter is still interesting though, as physically, its measurement is based on a phenomenon similar to that observed in blade extractors: the opening of a surface below a product batch.

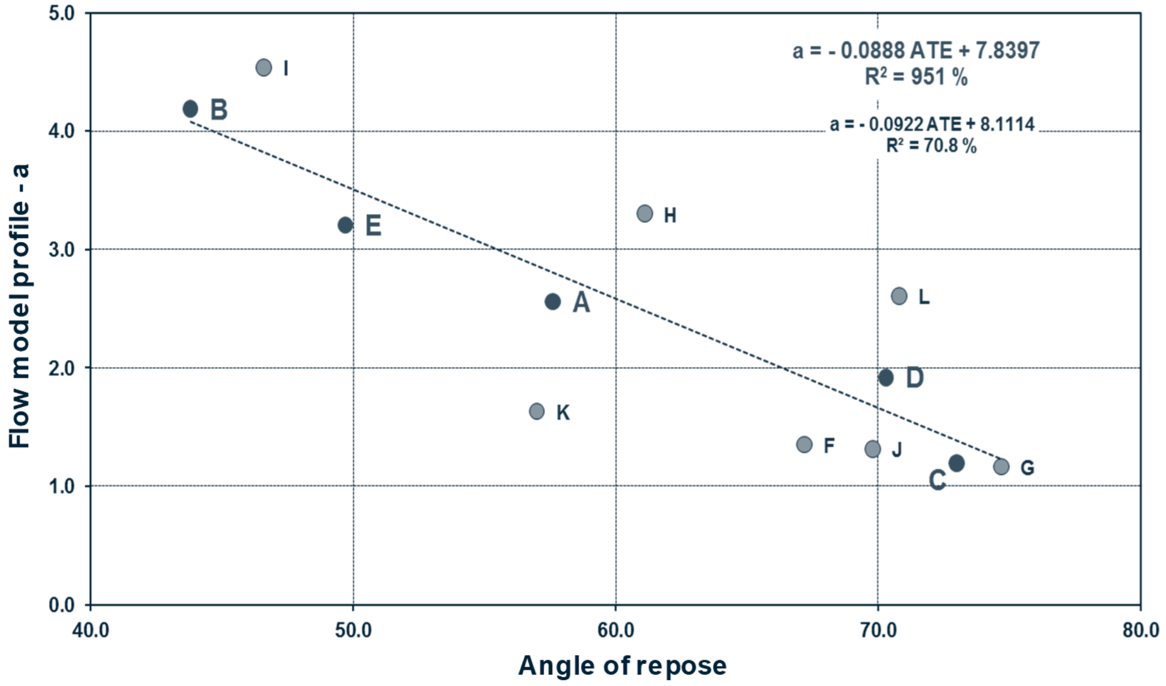

Figure 5: Effect of the angle of repose (flow) on the flow model profile - a

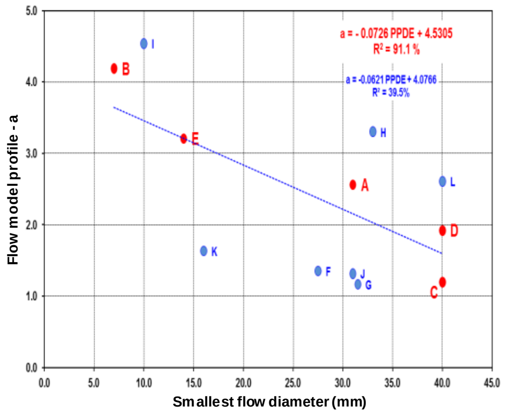

Figure 6: Effect of the smallest flow diameter on the flow model profile - a

3. Conclusion

Contrary to expectations, none of the powders' physical characteristic could explain the fluctuation in flow rate measured using the coefficients of determination.

This industrial data cannot therefore be predicted at present.

However, there are several laboratory characteristics that appear to accurately predict the behaviours observed at industrial sites:

- Bulk density contributes to the flow-start
- Flow indices, primarily the angle of repose (flow), can be used to predict the progression in the flow rate according to the increase in extraction indices.

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