Tecaliman
Center of expertise for a sustainable feed business

**i'Tec_P2**
November 2016

**Keywords: Dosage, Additive, Physical properties**

# Flow patterns of additives used in animal feed manufacture during screw extractor feeding

Whether for additives or raw materials, operators may wish to predict flow rate and regulation according to screw speed in order to control dosing operations. These parameters depend on screw geometry and the linkage between the cell and the screw, and also on the physical properties of the dosed products. This research seeks to further insight into how the product factor impacts on dosing flow rates and regulation. A test was therefore carried out at an industrial site equipped with identical cell/screw systems leading to the same weighing bin. These tests used 5 reference additives whose physical properties were representative of all the additives generally used in the animal feed sector. The detailed physical properties of these products were determined and compared against industrial measurements.

## 1. Industrial trials

### 1.1. Focus and Principle

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

The dosage accuracy for each additive was assessed by weighing the quantity of product that flowed during a given time unit 30 times.

### 1.2. Equipment and apparatus

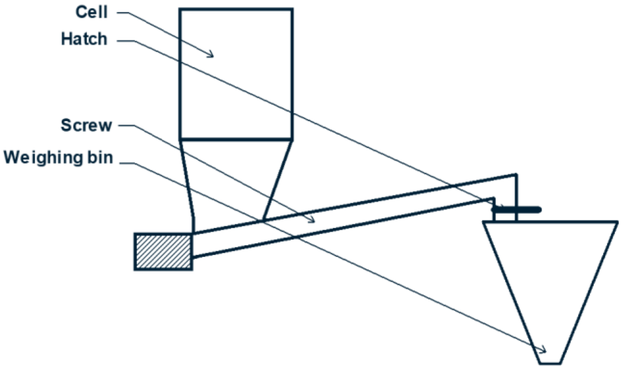

**Figure 1: Industrial facility**

This comprised five tubular cells with a conical base 1.2 m in diameter (Figure 1). Their maximum capacity was 2 $m^3$. The volume above the cone represented 68% of the total volume.

The extraction screws had a diameter of 150 mm. While their total length varied, the open length in the cells was constant. At the screw tip, a hatch stopped the flow as soon as the screw stopped rotating. A frequency controller was used to adjust screw rotation speed. A time delay mechanism was used to operate the extractor during a preset time period.

The weighing bin had a maximum capacity of 600 kg, accurate to +/- 50 g (100-g scale). Weighing bin accuracy was satisfactory for weights over 2 kilograms.

### 1.3. Method

The 5 products (A to E) were processed at 3 extraction speeds (V1, V2, V3). The tests were organised so as to minimise the effect of fill rate on product flow behaviour. The average speed (V2) was set so that applying a speed 3 times greater 90 times during 30 seconds would empty the cell by no more than 50%. The lower speed (V1) was set at 50% of the average speed. The higher speed (V1) was set at 150% of the average speed.

The speed succession tested after a single fill operation consisted in three repetitions of the cycle: 10 x V1, 10 x V2, 10 x V3 which were run at three successive fill levels.

The cells were filled the evening before the tests. At the start of the tests, the products had spent at least 11 hours in the cells.

### 1.4. Results

| Products | | A | B | C | D | E |
|---|---|---|---|---|---|---|
| **V1** | Flow kg/min | 6.3 | 7.2 | 4.1 | 11.6 | 11.2 |
| | AND | 0.29 | 0.34 | 0.21 | 1.49 | 0.50 |
| **V2** | Flow kg/min | 12.0 | 14.1 | 7.8 | 23.5 | 23.0 |
| | AND | 0.20 | 0.51 | 0.21 | 1.71 | 1.05 |
| **V3** | Flow kg/min | 17.8 | 18.3 | 11.6 | 33.2 | 34.2 |
| | AND | 0.29 | 0.27 | 0.30 | 2.14 | 1.17 |
| Slope (MP) | | 5.96 | 6.45 | 3.89 | 11.30 | 11.40 |
| $R^2$ (MR2) | | 99.5 | 94.4 | 99.2 | 95.5 | 99.0 |

**Table 1: Average flow rate and flow rate regularity according to product**

The average flow rate its related standard deviation were determined for each speed and each product (Table 1).

Product behaviour within the tested speed range can be globally assessed using curves that plot the change in flow rate against screw speed.

It appeared that the best approach was to apply a straight line model (e.g. Y = a X) to these flow variations. Table 1 gives the slopes (a) (in kg/min/speed) and the coefficients of determination ($R^2$) deriving from the application of these models. These two criteria provide insight into how the products behave in general (slope) and the reliability of this behaviour ($R^2$).

Significant differences in the flow rate measured at the same screw speed, as seen in products A, B and E, indicates that flow rates are often slower at the start of the emptying cycle (level 1) than at subsequent levels. Product D marks a singularity with flow rates that vary significantly depending on the levels of the three speeds. For product D, flow rates decreased in tandem with the decrease in the quantity of product in the cell. This behaviour explains the large overall variation observed with this product. The absence of similar differences with the other products is what makes product D so singular.

In four out of the five products, the flow rate changed in a linear fashion according to screw speed. For product B, the switch from V2 to V3 generated a clear change in the slope giving a lower than expected average flow rate in relation to the V1/V2 adjustment. It therefore appears that increasing the speed decreases the screw fill rate.

Major differences between the flow rates of all five products were observed at every speed level, with the exception of V3, where two products recorded practically identical flow rates: A and B. Overall, the product order in decreasing order of flow rate was as follows:

**D > E > B ≥ A > C**

It is difficult to identify a general trend for these variations in flow rate (ET): while the flow rates for product D appear to vary widely at all times, mainly due to a difference in the way it responded to emptying rates, the other four products occupy the next four positions indiscriminately depending on the speed level.

The coefficients of determination globalise this change in flow rate to a certain extent. However, for product B, the poor coefficient seems to relate to how the plots are scattered around the straight line, and also to the absence of linearity.

The linear line slopes are more marked and relatively close for products D and E. Those for products A and B are close, mainly due to the change of slope for the change in product B. Product C has a shallower slope.

## 2. Relationship with the physical properties of the additives

Industrial measurements were used to identify which parameters to compare against the additives' physical properties:

- MP or VP: Mass flow and volume flow slopes according to screw speed that illustrate the change in the mass or volume collected during a given time period according to screw speed
- MR2: Coefficient of determination for mass flow linear regression lines according to screw speed that illustrate the scatterplot around the straight line and correspond to the probability (as a percentage) of obtaining a specified flow rate with a chosen screw speed.
- MDn or VDn: Mass or volume flow at the extraction speed Vn (n from 1 to 3).
- METn or VETn: Standard deviation for the mass or volume flow at extraction speed Vn.
- MCVn or VCVn: Coefficient of variation for the mass or volume flow at extraction speed Vn.

Volume data were collected by dividing the mass data by the tap density. The comparisons appear to reveal several influences, i.e. densities, particle size, flow characteristics.

### 2.1. Densities

**The increase in tap density increases the flow rate irrespective of screw speed** (Figure 2). The relationship tends to strengthen at higher speeds (better coefficient of determination). Bulk density had the same effect, but to a lesser degree.

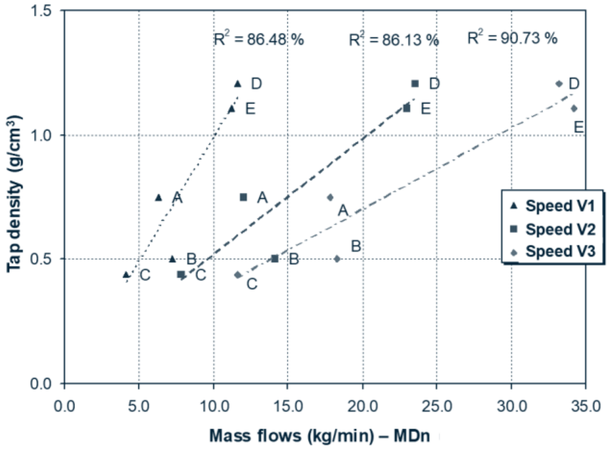

**Figure 2: Effect of tap density on mass flows**

These observations confirm the straight line relationship known to exist between a product's density and the change in its flow rate. This is why these flow rates should be expressed as a volume rather than a mass, in order to spotlight the effects of other characteristics.

Density also effects the variation in mass flow assessed by the standard deviations (METn).

The principal effect therefore appears to involve particulate density.

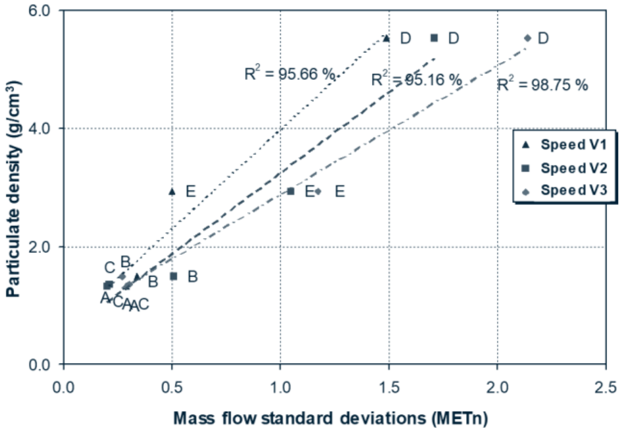

**Figure 3: Effect of particulate density on mass flows standard deviations**

The relationships follow a straight line overall, but are generally influenced by the presence of products D and E, which are set apart from the product group A, B and C (Figure 3). This suggests that the heavier the product, in particulate terms, the greater the probability that the resulting flow rate or mass will be distant from the desired rate or mass. In practice, this can be explained by the **increase in the standard deviation between the desired quantity and the actual quantity in proportion to particulate density**. A single, additional rotation of the screw has a greater impact on the resulting mass where a heavy product is concerned.

## 2.2. Particle size

Particle size only impacts on the diameters calculated by image analysis (Figure 4).

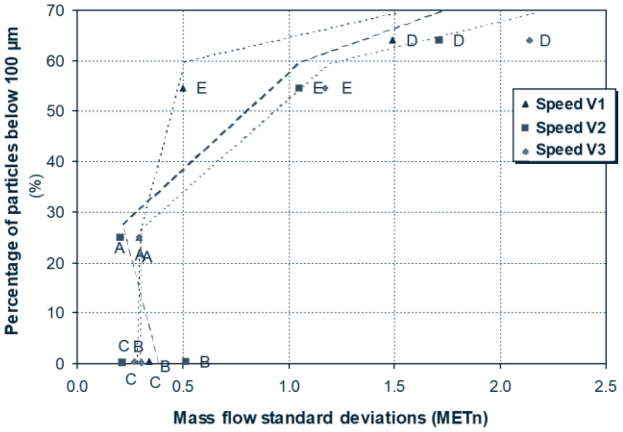

**Figure 4: Effect of the percentage of particles smaller than 100µm on mass flow standard deviations**

While particle size does seem to affect the mass flow curve (MP), the relationship appears fairly tenuous. In practice, this observation would mean that below approx. 100 to 200 µm, mass flow increases with increasing screw speed. This might be explained by the fact that screw fill capacity rises with finer-grained products, but this assumption would have to be confirmed by other tests on low-density, fine-grained products.

Increasing the percentage of particles smaller than 100µm appears to have a stronger impact on mass flow standard deviations (Figure 5). It would appear that the standard deviation increases above 50% of particles. This relationship would be attractive, as it would support trends found in the literature that point to poorer flow performance with particles smaller than 100 µm. However, as in the previous case, this relationship disappears when the flow rate is expressed as a volume, which suggests that the **density of the finest-grained products has a greater effect than their particle size**.

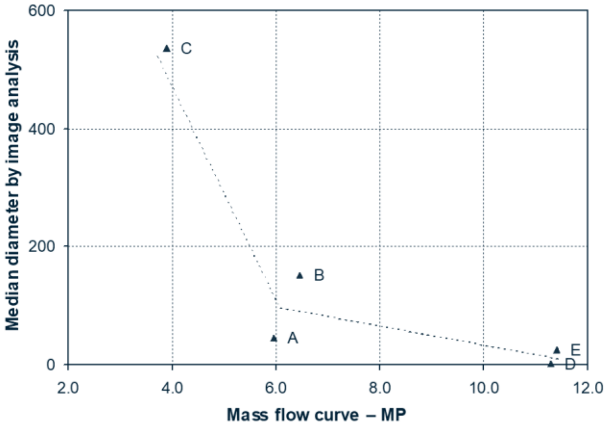

**Figure 5: Effect of particle diameter (image analysis) on the mass flow slope**

## 2.3. Flow properties

The effect of flow properties is illustrated by expressing the data as a volume flow. The smallest flow diameter (i'Tec_Q4) would be related to volume flow (Figure 6) with:

- maximum flow rate when this index is low.
- minimum flow rate when the index approaches 30.
- higher flow rate when the smallest flow diameter increases above 30.

These relationships are fairly clear and remain similar, whatever the screw speed. In addition, products D and E, which had the smallest particle size and the highest density, are not close, which supports the assumption that this effect is not linked to the previous 2 effects.

The effect of the Hausner Index (see i'Tec_Q9-2004) on flow rate standard deviations is less visible (Figure 7), as it is not uniform with that of the smallest flow diameter and is mainly based on the position of point D. However, the data appears to indicate that the variation in poured volumes increases at higher Hausner indices. This effect, which is attractive due to its agreement with the expectations, will have to be confirmed by other tests on products with intermediate indices between 1.2 and 1.45.

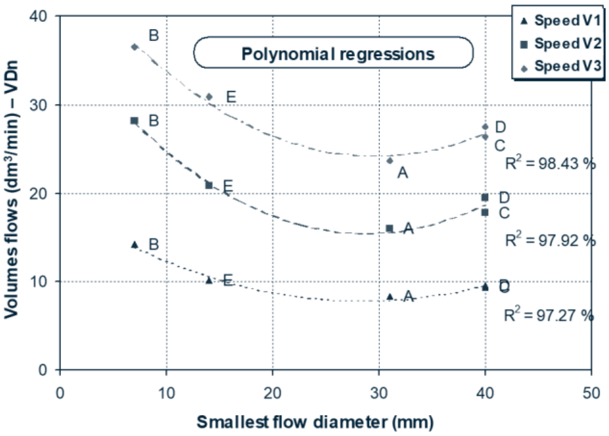

Figure 6: Effect of smallest flow diameter on volume flows

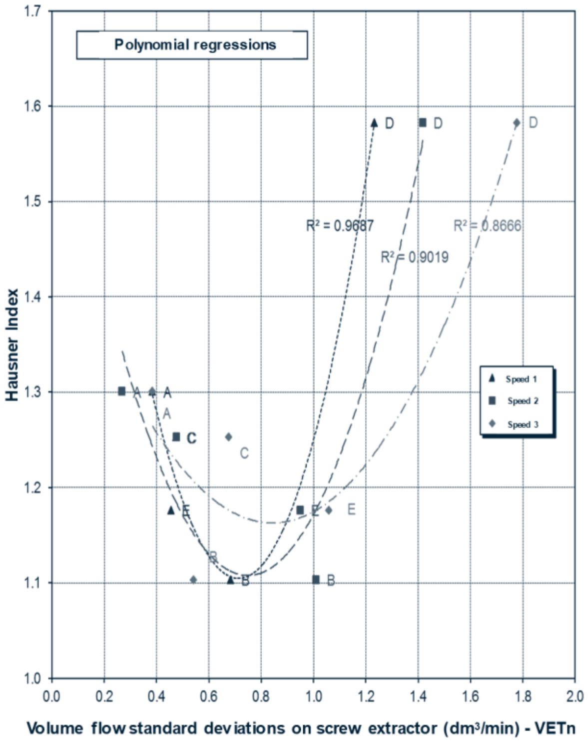

Figure 7: Effect of the Hausner Index on volume flow standard deviations

## 3. Conclusion

The impact of certain physical product properties established in the laboratory seems fairly clear-cut and logical meaning that they can already be judged as good predictors of how a product will behave as it flows through screw extractors.

**Tap density gives a fairly good prediction of product flow rates according to screw volume. The increase in particulate density appears to generate weighing errors.** The poor flow indices clearly disadvantage volume flows and their regularity and indicate the possible presence of thresholds.

Conversely, the impact of particle size has not been clearly demonstrated; additional tests will be required on less dense, finer-grained products.

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