

Effect of screen size and hammer speed on the particle size of three feed formulas produced on an industrial hammermill

While this grinding phase is energy-intensive (accounting for 20 - 25% of plant power consumption), it is a vital step in the subsequent production of high-quality pellets during the pelleting process. It is therefore useful to understand, know or even predict the particle size characteristics of ground products at the grinder output.

The purpose of this study is to analyse the performance of an industrial hammermill when grinding complete formulas (Pre-dosing) for various animals (Sow, Finishing pig and Poultry) and, in a preliminary phase, to attempt to model the effect of screen size or hammer speed on feedstuff particle size. A second phase involved running tests to validate the models.

1. Apparatus and methods

1.1. Feedstuffs

Table 1 gives the compositions of the 3 industrial formulas used to create the models (2-ton batches).

Feedstuff	Sow (%)	Finishing pig (%)	Poultry (%)
Wheat	20.0	38.9	57.5
Peas	15.0	25.0	
Barley	15.0	10.0	
Maize			5.0
Sunflower seed meal	8.8	3.1	
Fine bran	8.0		
Beet pulp	6.0		
Durum wheat middlings	4.8	2.0	
Soya meal	3.1	5.0	22.0
Cane molasses	2.7	3.2	
Rape seed		3.5	6.6
Rape seed meal		5.0	
Others	6.6	4.3	8.9

Table 1: Composition of the formulas used in the modelling phase

In the second step involving the model validation process, the compositions of the feed formulas used varied slightly due to the time lapse between the two test programmes (2 months) (Table 2).

Feedstuff	Sow (%)	Finishing pig (%)	Poultry (%)
Wheat	20.8	34.1	57.5
Peas	15.0	21.7	
Barley	25.0	14.9	
Maize			5.0
Triticale		5.0	
Sunflower seed meal	8.8	2.2	
Fine bran	8.0		
Beet pulp	6.0		
Durum wheat middlings	5.0	3.0	
Soya meal	3.0	5.0	22.0
Cane molasses	1.9	1.6	
Rape seed			6.6
Rape seed meal		5.0	
Rice cakes		3.4	
Others	6.5	4.1	8.9

Table 2: Composition of the formulas used in the model validation phase

1.2. Hammermills

The tests were performed on an industrial grinding line with two grinders fed with a mixture of raw materials. The first hammermill, B1, was a STOLZ brand grinder (RM 114) fitted with an ABB variable speed drive. The second hammermill, B2, was identical except for the engine speed, which was set at 3000 rpm. Table 3 gives the screen characteristics.

Perforation diameter (mm)	Thickness	% voids	Centre-to-centre perforation distance
2.0	2.0	40.0	3.0
2.5	2.5	46.0	3.5
3.0	3.0	51.0	4.0
3.5	3.0	54.0	4.5
4.0	3.0	48.0	5.5
5.0	3.0	53.0	6.5
6.0	3.0	55.0	8.0

Table 3: Description of the grinder screens

1.3. Testing

Eleven 2-ton batches were scheduled to be ground at varying speeds on the B1 hammermill for each type of formula. The batch throughput sequence was

set so as to keep the number of screen changes to the strict minimum. Testing began by flushing the line with the grinding of a first 2-ton batch. Next, the 11 tests were conducted according to the throughput sequence described in Table 4. Certain tests (shaded) were interrupted by industrial constraints (unscheduled stoppage, breakdown, etc.). Given the complexity of carrying out tests in an animal feed production plant, these results could not be repeated. They will not, therefore, be used for the rest of the study. A final test was carried out for each type of feed formula using the B2 hammermill at a fixed speed.

Tests	Screen (mm)	Sow	Finishing pig	Poultry
		Speed (rpm)	Speed (rpm)	Speed (rpm)
B1 1	2	2000	2000	1500
B1 2	3	2500	2500	1875
B1 3	3	1500	1500	1125
B1 4	4	3000	3000	2250
B1 5	4	2000	2000	1500
B1 6	4	2000	2000	1500
B1 7	4	2000	2000	1500
B1 8	4	1000	1000	750
B1 9	5	2500	2500	1875
B1 10	5	1500	1500	1125
B1 11	6	2000	2000	1500
B2	3.5	3000	3000	3000

Table 4: Batch throughput sequence during the modelling tests

Model validation tests were also run using the B1 hammermill. The only change made was to the hammermill's load setpoint, which resulted in higher flow rates. The line was flushed using 5-ton batches. Table 5 gives the batch throughput sequence.

Tests	Screen (mm)	Sow	Finishing pig	Poultry
		Speed (rpm)	Speed (rpm)	Speed (rpm)
1	4	1500	1500	1200
2	4	3000	3000	1300
3	4	-	-	1400

Table 5: Sequence of batch throughput and experimental parameters for the model validation tests

An energy analyser (HIOKI) was connected to the engines of each grinder line in order to compute the specific electrical energy required to grind each batch (grinder + suction system). The test results were used to define grinding line performance under standard production conditions: particle size, flow rate and energy.

Samples were taken at two points in the grinding line:

- Pre-grind - the samples were taken at the pre-mixer output. A sample was taken at 20-second intervals for each test. At the end of the sampling operation, a representative aggregate sample of 500 ml of feed formula was collected and packaged in an airtight container.
- Post-grinding - the meal samples were taken at the end of the extraction screw downstream of the hopper. For each test, three samples were

collected in 150-ml containers after 25%, 50% and 75% of grinding time had elapsed.

1.4. Analyses

D50 [Tecaliman, 1996]

Particle size distribution was analysed using a set of twelve standard Retsch sieves with sizes ranging from 80 to 2000 µm (80 µm, 125 µm, 160 µm, 200 µm, 250 µm, 315 µm, 425 µm, 630 µm, 800 µm, 1000 µm, 1250 µm and 2000 µm). The measurement was obtained from a 100-g sample and repeated three times. Each sample was sifted for 10 minutes. Each fraction was then weighed separately. The geometric mean diameter and the geometric deviation were then calculated [AFNOR, 1987].

Moisture content

The method for measuring moisture content follows NF V18-109 [NF V18-109 1982]. 5 g (± 0.05 g) of the feed formulas were first ground in a laboratory grinder cooled by a stream of cold water. They were then dried for at least 4 hours in an oven at 103°C.

Models and validation

StatGraph software was used to carry out a statistical survey that provided the basis for development of the predictive median diameter models. This involved a polynomial regression of the type: $D_{50} = \text{constant} + aX + bY + cX^2 + dY^2 + eXY$

Where X: screen perforation diameter (mm)

Y: rotational speed of the rotor (rpm)

2. Results

2.1. Development of the models

The raw data obtained during tests on the 3 feedstuffs are presented in Table to Table .

The mean pre-grind moisture contents of the raw materials for Sow, Finishing pig and Poultry feeds were 12.2% ± 0.2, 12.0% ± 0.1, and 11.2% ± 0.2 respectively.

The standard geometric deviations (GD) revealed that while particle size distributions are similar for Sow and Poultry feeds (GD between 2.0 and 2.1), they show greater variability, and occasionally a far greater spread, for Finishing pig feed (GD between 2.0 and 2.5). This can probably be explained by the composition of the feed formulas and, in particular, the greater proportion of feed peas in Finishing pig feed.

Typically, the specific electrical energy of all feedstuffs is inversely proportional to the particle size of the ground products, despite the observation of a certain dispersion for Poultry feed. At comparable particle size, lower energy yields are observed when combining low rotation speeds with screens with small perforations (Figure 1).

Code	Screen (mm)	Speed (rpm)	Flow (t/h)	Specific energy value (kWh/t)	D ₅₀ (µm)	GD
B1 2	3	2500	30.1	7.7	618	2.09
B1 5	4	2000	44.8	4.9	1045	2.10
B1 6	4	2000	49.4	4.8	1034	2.11
B1 7	4	2000	47.3	4.8	1049	2.08
B1 8	4	1000	27.8	8.6	1671	2.05
B1 9	5	2500	48.4	4.5	977	2.05
B1 10	5	1500	61.1	3.5	1607	2.09
B1 11	6	2000	71.5	2.9	1380	2.05
B2	3.5	3000	41.2	6.4	660	2.13

Table 6: Findings of the Sow feed modelling tests

Code	Screen (mm)	Speed (rpm)	Flow (t/h)	Specific energy value (kWh/t)	D ₅₀ (µm)	GD
B1 1	2	2000	21.4	10.8	474	2.03
B1 2	3	2500	40.7	5.7	676	2.17
B1 3	3	1500	32.2	7.5	930	2.19
B1 4	4	3000	34.9	6.8	597	2.19
B1 5	4	2000	44.7	5.2	889	2.19
B1 6	4	2000	44.2	5.3	851	2.21
B1 7	4	2000	44.7	5.5	851	2.20
B1 9	5	2500	55.2	4.2	980	2.19
B1 10	5	1500	70.4	3.1	1728	2.06
B1 11	6	2000	80.5	2.7	1440	2.16
B2	3.5	3000	41.9	6.3	473	2.53

Table 7: Findings of the Finishing pig feed modelling tests

Code	Screen (mm)	Speed (rpm)	Flow (t/h)	Specific energy value (kWh/t)	D ₅₀ (µm)	GD
B1 2	3	1875	37.6	6.1	800	2.02
B1 3	3	1125	24.7	9.6	1078	2.13
B1 4	4	2250	55.5	4.3	931	2.07
B1 5	4	1500	53.1	4.3	1274	2.05
B1 6	4	1500	54.2	4.3	1251	2.08
B1 7	4	1500	54.0	4.3	1232	2.08
B1 8	4	750	21.0	8.7	1875	1.98
B1 9	5	1875	59.8	3.2	1225	2.06
B1 10	5	1125	70.4	2.6	1931	1.92
B1 11	6	1500	98.4	2.0	1598	2.01
B2	3.5	1500	68.2	3.1	1490	2.01

Table 8: Findings of the Poultry feed modelling tests

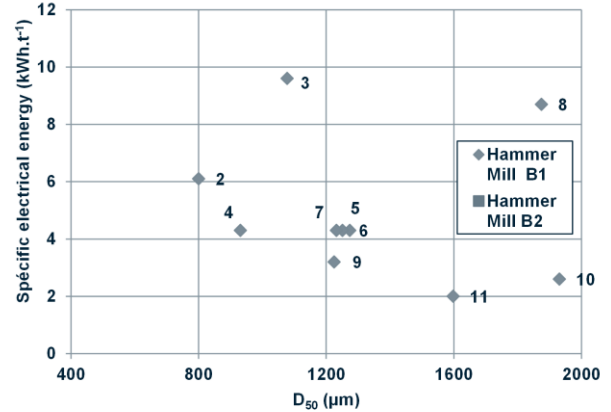
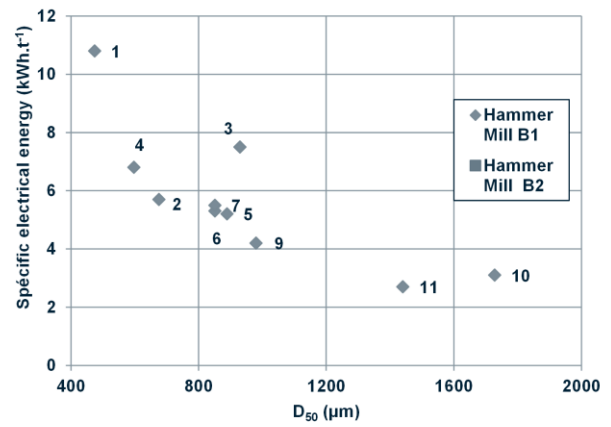
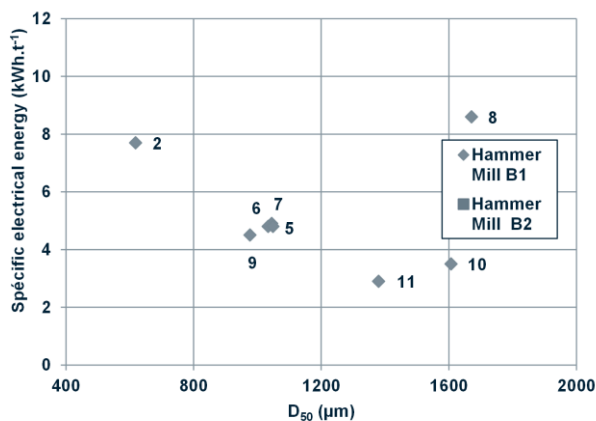


Figure 1: Specific electrical energy vs D₅₀ for Sow, Finishing pig and Poultry feeds (top to bottom)

The polynomial regression equations used to predict median sifter diameter (D₅₀) according to the screen/speed pair are listed in Table .

For all 3 feedstuffs, the primary effects of screens and speeds are antagonistic: increasing the screen perforation diameter increases D₅₀, while increasing the speed tends to reduce it. The D₅₀ models reveal 1st order interactions between "Screen" and "Speed" factors in addition to quadratic effects (X² and Y²), and a simple XY interaction.

For "Poultry" feed, the main effects of screen and speed on D₅₀ are significantly higher and more antagonistic than the results observed with the other feedstuffs.

Feedstuff	Model equation	Adjusted R ²
Sow	$D_{50}(\mu\text{m}) = 678.031.X - 0.1446.Y - 7.931.X^2 + 0.000111776.Y^2 - 0.199.XY - 132.228$	95%
Finishing pig	$D_{50}(\mu\text{m}) = 591.754.X - 0.067.Y + 19.385.X^2 + 0.000150039.Y^2 - 0.247.XY - 239.509$	92%
Poultry	$D_{50}(\mu\text{m}) = 1051.890.X - 0.294082.Y - 43.1316.X^2 + 0.000265731.Y^2 - 0.2853.XY - 705.105$	99%

Where X: screen perforation diameter (mm)
Y: rotational speed of the rotor (rpm)

Table 9: Model equations obtained for each feedstuff

2.2. Validating the models

A comparison of the raw data obtained during the modelling and validation test programme on Sow and Finishing pig feedstuffs (B1 grinder, 3000 rpm, 4-mm screens) reveals that it is the increase in the grinder's motor load and the change in feed formula that causes an increase in flow rate, particle size and lower specific electrical energy (Table). This naturally increases the D_{50} meal diameter, thus increasing the constant for both models (Sow feed: + 145 μm , Finishing pig feed: + 211 μm), which correlates to a probable decrease in product residence times in the grinder.

Feedstuff and tests	Observed D_{50} (μm)	E.G.	Flow (t/h)	Specific electrical energy (kWh/t)
Sow modelling	618	2.09	30.1	7.7
Sow validation	763	2.14	50.0	5.5
Finishing pig modelling	597	2.19	34.9	6.9
Finishing pig validation	808	2.11	50.4	5.2

Table 10: Influence of grinder operation and feed formula composition

To test the models, the D_{50} values predicted for the feed formulas (modified D_{50} s for Sow and Finishing pig feeds, and initial D_{50} s for Poultry feed) were compared against the D_{50} values obtained during the validation tests. The raw data of this comparison are presented in Figure 2. Despite the limited amount of data and the variety of grinding conditions (feedstuff composition and grinder operation), it was possible to establish a relationship between the predicted and observed values. Figure 2 shows a high correlation between these values ($R^2 = 0.91$), which tends to validate the models proposed for the three tested feedstuffs.

The observed values for the Sow and Finishing pig feeds exceed the predicted values, a phenomenon that appears to be influenced by rotor speed. The best results were obtained with the "Poultry" model

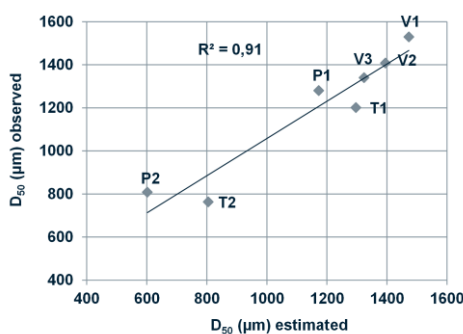


Figure 2: Ratio between estimated D50 and observed D50

The models were tested during the second test programme (Figure 3) in order to check the reliability of the data.

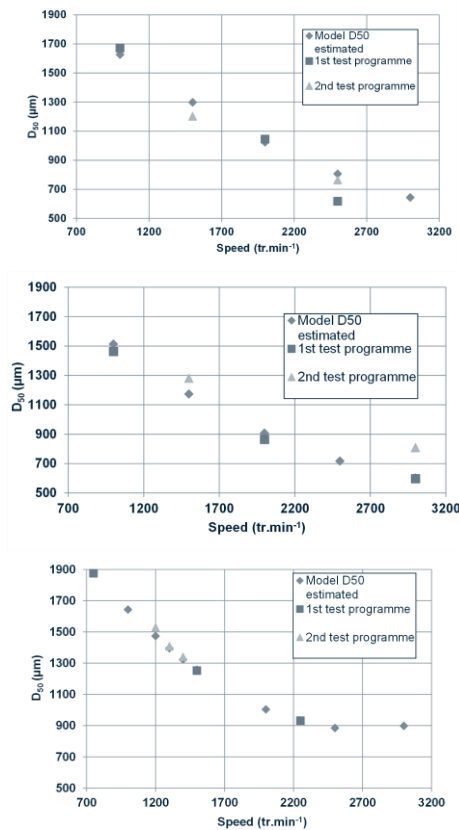


Figure 3: Ratio between estimated D_{50} and measured D_{50} for ground products during two test programmes on Sow, Finishing pig and Poultry feeds (top to bottom) using Screen 4 and various rotor speeds

Figure 3 illustrates that the models suggested for each feedstuff can be used to predict D_{50} values that are very close to the actual D_{50} values recorded during the two test series (D_{50} obtained and D_{50} measured against hammer rotation speed). It may therefore be concluded that the proposed models could help industrials forecast the results of their grinding operations.

3. Conclusion

Despite the challenging experimental conditions encountered in industrial environments, the results illustrate that:

- it is possible to predict the particle size of wholemeal animal feedstuffs fairly accurately if the rotor speed and screen perforation diameter are known
- the prediction error is probably of the same magnitude as the variability in the particle sizes obtained under standard conditions using a mill at 3000 rpm (fixed rotor speed and screen perforation defined according to the feed formula).

However, it would be useful to carry out additional tests in order to determine the influence of changes in the feed formula as the two successive test programmes on the "same" feed formulas have demonstrated the effect of changes in composition on authorized flow rates, and therefore, the influence of grinder operation on prediction quality