i'Tec_G15
June 2023

Keywords: Pelleting – Milling – Energy

Effect of particle size on the energy efficiency of the Milling-Pelleting Pair

In bibliographical terms, Seeling and Wulff (1946), and Kumar (1973) describe 3 fundamental mechanisms of compression control:

- Slippage directly related to settling
- Elastic or plastic deformation
- Fragmentation

This third point suggests that a product that is "too coarse" would be likely to increase the press power demand during its agglomeration. While several authors (Smith, 1962, Lefumeux, 1979, Wellin, 1976, Payne, 1978) report that milled products with a finer particle size show better particle agglomeration, they do not necessarily mention overall energy consumption. Vercauteren (1982) believes that particle size plays an important role the agglomeration of mixtures; his experiments show that the coarser the product, the greater the friability (100 - durability) and the higher the fines content. According to a study by Pedamond (1977) on the agglomeration of particle size fractions of a maize meal (the fractions may have differing compositions) the power demand is lower when agglomerating fine particles. In theory, as particle size decreases the developed surface area increases, thus enabling a greater amount of steam to adhere. An increase in the lubricating ability of this steam would promote the formation of solid bridges, thus facilitating particle agglomeration. Other studies, however, have provided more nuanced findings, notably by Kansas State University, the most significant of which is a study by Stevens (1987 - Table below).

	D50	SEC $_{Milling}$ (KWh/t)	SEC $_{Pelleting}$ (KWh/t)	SEC $_{Total}$ (KWh/t)	Durability PDI (%)
Maize	**1023**	3.6	8.8	12.4	89.9
	794	4.7	7.7	12.4	88.8
	551	9.1	7.6	16.7	90.3
Wheat	**1710**	2.3	11.0	13.3	92.4
	802	3.9	9.9	13.8	96.7
	365	7.2	9.7	16.9	97.4

The study was performed on maize and wheat-based feed formulas pelleted at a setpoint temperature of 75°C (conditioner output), at pelleting rates of 1.7 to 2 t/h (3 repetitions for each feed formula).

For both types of formula, as particle size increased the results indicated:

- A decrease in Specific Energy Consumption during milling: SEC $_{milling}$
- Increase in SEC $_{pelleting}$
- Decrease in SEC $_{total}$
- A decrease in durability (PDI); particularly evident with the wheat formula.

A review of the bibliographic literature indicates that most components would be expected to result in lower energy consumption with decreasing meal particle size; a point of view shared by many, despite the conflicting results of the Stevens study. Should the energy saving actually exist, it would be useful to know whether the increased energy consumption during milling required to obtain a finer meal could be expected to generate a significant energy saving in terms of pelleting. Lastly, the rarity of this type of study, the age of the references and the use of an outdated, and less discriminating, method of measuring durability should also be noted.

Furthermore, this technical data sheet describes the results of an industrial-scale study of this type carried out in 1990 by Tecaliman, but which had never been transcribed into data sheet format.

1. Equipment and apparatus

1.1. Feedstuff

Feed for turkeys over the age of 4 weeks comprising mainly cereals (wheat 35% and maize 8%), soybean meal 48 (16%) and extruded soybeans (15%).

Each test was performed on a 10-tonne batch.

1.2. Hammer mill

Two hammer mills were used to obtain a sufficiently broad range of particle sizes:

- Buhler horizontal hammer mill (235 kW) with 1.7, 2.5 and 3.0-mm screens
- PSI vertical hammer mill (200 kW) with 20-mm screen; 5-mm screen at the end of the batch. The mill operates with a sifter and a recycling system. The sifter is fitted with 1.6, 2.2 and 3.2-mm screens.

1.3. Pelleting press

A 250 kW PSI press with 2 rollers was used under the following conditions:

- Output rate: 14.7 t/h
- Setpoint temperature: 67°C
- Die: Thickness 70 x Diameter 3.5, i.e. a compression rate of 20
- Measurement time in steady state regime: 20 minutes

2. Method

Six milling modes were tested, with each mode being repeated 3 times. Test repetitions were never consecutive. All 18 results were processed. Mode results were not averaged.

2.1. Milling

Mixer capacity being 5 tonnes, the 10-tonne batch was split into 2 sub-batches. Only 73.5% of the formula was milled, i.e. in sub-batches of 3.67 t. The milling time was counted from the moment the mill started to ramp up speed up to the end of the second sub-batch, subtracting idle time between the 2 sub-batches.

A sample of each sub-batch was taken at the mixer output to measure the moisture content. No liquid was added between mixing and pelleting.

The following measurements were taken:

- Quantity (t)
- Total power capacity of the hammer mills and related suction systems (kW)
- Milling time (s)
- Meal particle size at mixer output (µm)
- Meal moisture content at mixer output (%)

2.2. Pelleting

The 2 sub-batches were collected in a silo bin upstream of the press. After switching the machine on, the controls were set to reach the target operating point, which was maintained for at least 20 minutes. Pelletising was deemed complete approximately one minute prior to the press power drop at the end of the batch.

The following measurements were taken:

- Flow rate (t/h)
- Press motor power (kW)
- Steam flow rate in the press conditioner (kg/h)
- Temperature of the meal before and after steam injection (°C)
- Pellet temperature at the die output (C°)
- Moisture content of the meal before and after steam injection (°C)
- Pellet durability (%) measured using the Tumbler method (PDI)

3. Results

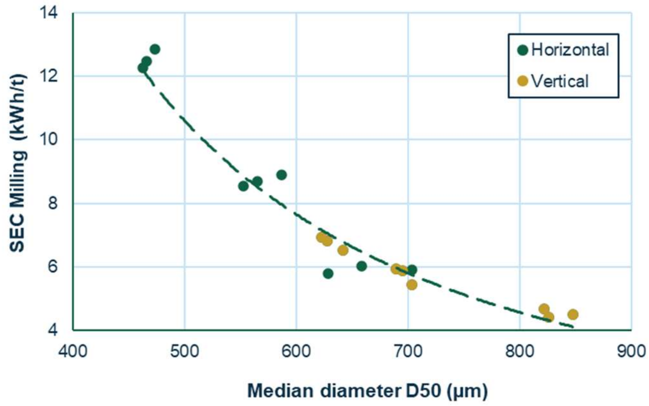
3.1. Milling conditions

The particle size ranges obtained (median diameters of the milled particles) were:

- 450 to 700 µm – horizontal hammer mill
- 600 to 800 µm – vertical hammer mill

The 600 to 700 µm range was common to both mills.

Specific energy consumption (SEC) at this station (all motors combined) decreased with increasing particle size irrespective of which mill was used (Figure below).



In this case, the change in the curve does not appear to be related to the change of mill.

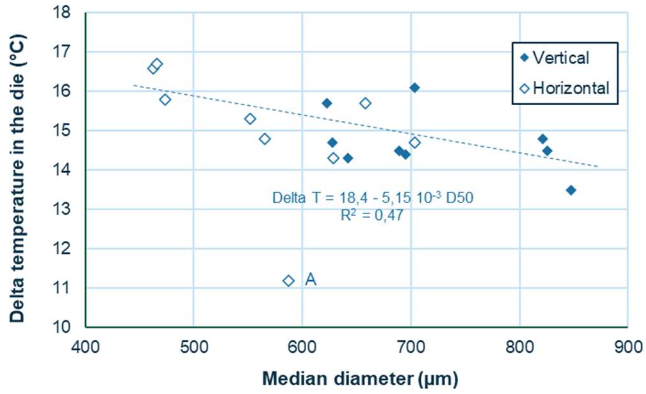
A Turkey feed with a particle size of approx. 800 µm will require around 5 kWh/t, while the same feed at 500 µm will require 11 kWh/t, i.e. 2.2 times more energy. This prompts questions concerning the zootechnical and nutritional benefits of using **2.2 times more energy** on milling in order to **go from 800 to 500 µm**.

3.2. Pelleting conditions

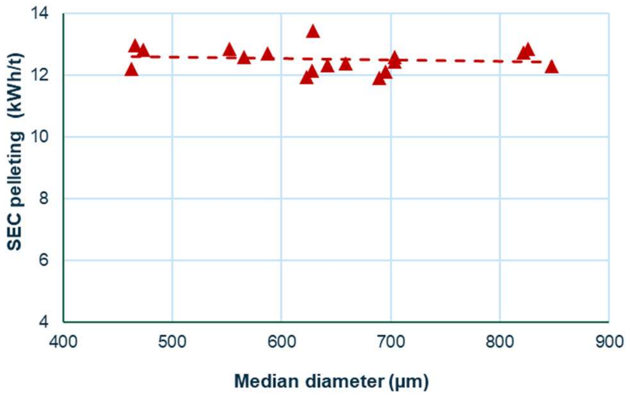
Generally speaking,

- The average temperature of the meal was 31.5°C, indicating that the feed is relatively hot after milling.
- An increase of + 2.6% water was observed during conditioning (+/- 0.46%) for an average temperature rise of 35.9°C (+/- 1.95°C), **i.e. +1% water for +13.8°C**.
- An increase of **+14.9°C during press throughput** with minimal variation between the tests (+/- 2.8°C between the extremes).

As regards this last point, despite the minimal variation, it was possible to identify the beginning of a relationship between particle size and temperature variation (figure below). It would appear that it is the smallest particle sizes that generate higher temperatures when passing through the die (excluding point A, which corresponds to a measurement error). This variation was statistically validated despite the low R^2. The three fundamental compression control mechanisms (see above) suggest that slippage directly related to settlement plays an important role in the process. Conversely, fractionation during compression neither raises the temperature nor affects energy consumption during die throughput. The finest grained products, with larger developed surface areas, would have a greater contact surface area with the die channels, therefore generating greater friction despite the possibility of a greater quantity of steam collecting at particle surfaces. It would be useful to re-examine these findings, which contradict those of Stevens.

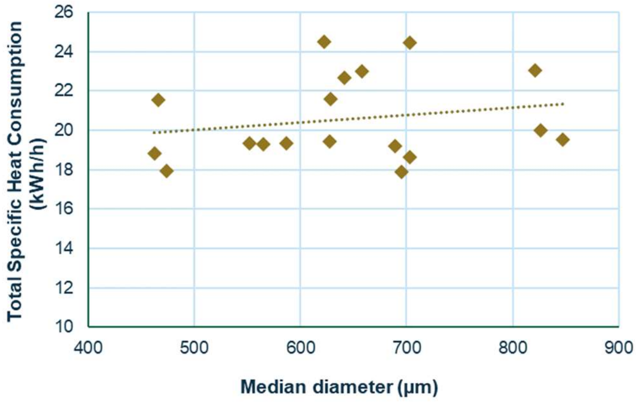


Another argument in favour of repeating this type of study is that this slight increase in temperature during pelleting does not cause a significant increase in SEC. Using the same scale as the previous figure for $SEC_{milling}$, the figure below shows an overall stability of press SEC as a function of meal particle size (CV = 3.2%).

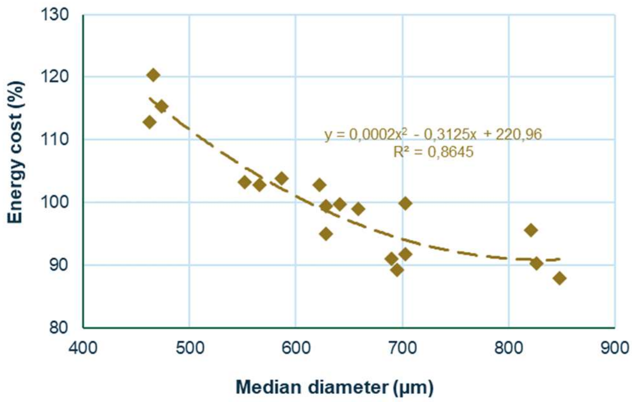


Despite changing on a fairly broad scale, particle size does **not** appear to **affect press power consumption**.

The following figure shows that the same applies to Specific Heat Consumption, which is not surprising, since this value is controlled not by the feed itself, but by the feed's initial temperature and the target temperature at the conditioner output. It therefore varies between 17.9 and 24.5 kWh/t.

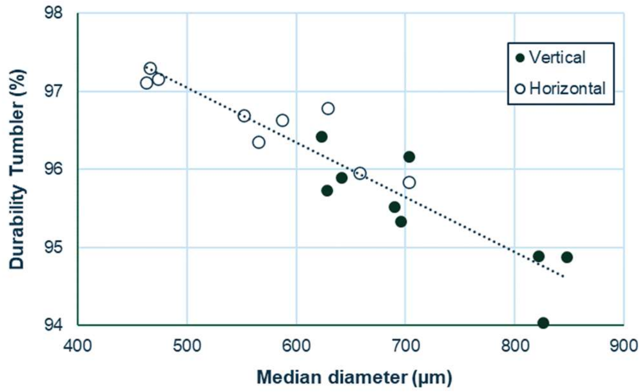


When translated into the energy cost for processing at these two main stations in terms of energy consumption (approx. 70% of a plant's electrical power and 100% of thermal energy), the total variation in costs (electrical and thermal power cost ratio - 2022 Baseline) would be around 30% (Figure below) across the entire study area. Going back to the comparison with the milling station, **increasing particle size from 500 to 800 µm** would generate a **reduction in the overall energy cost for these two stations of a little over 20%**.



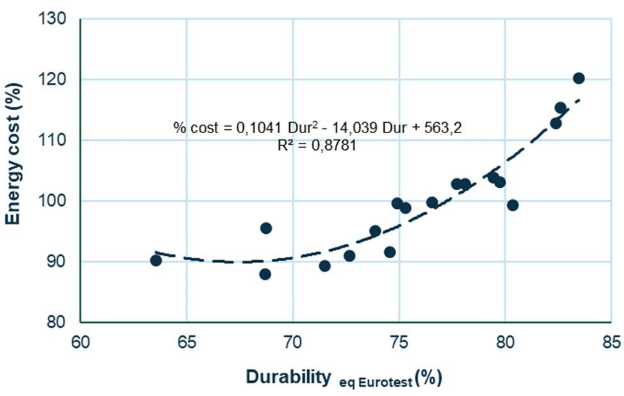
3.3. Durability

However, this reduction in overall energy consumption results in what might constitute lower pellet quality. Durability decreases as pellet size increases.



While this appears a minimal decrease in terms of value, it is important to remember that the measurement was made using the Tumbler method.

Note that, based on the equation specified in i'Tec G6 between Tumbler and Eurotest durability (R = 0.95 with $Dura_{Tumbler} = 0.1637\ Dura_{Eurotest} + 83.64$), the overall change in the durability curve, if it had been measured according to the Eurotest, would have been between 65 and 85%, as shown on the figure below, which illustrates the durability/ energy cost ratio (%).



This curve shows that, below the 70/75% durability area, the energy cost (for this feed) remains stable. From 75% durability up to about 84%, **each additional durability point would increase the total energy cost by over 3%** (this is an estimated value based on the relationship between the 2 durability methods).

This relationship illustrates the necessity of **defining a durability threshold** that could be justified on zootechnical grounds, to determine the technological production criteria that would make it possible to reach this threshold, with the clear aim of maximizing energy consumption efficiency. It would appear that, beyond a certain threshold, the quest for extra durability points generates a rapid increase in energy costs.

4. Conclusions

These industrial trials carried out with 2 hammer mills on a Turkey feed with particle sizes ranging from 450 to 800 µm showed that, where pelleting is concerned, reducing the median meal diameter makes it possible to achieve:

- A statistically significant increase, amounting to a few degrees, in the temperature at the die output
- Improved durability
- Stability of press SEC

In terms of the energy balance, these trials indicated:

- No effect on steam consumption and specific heat consumption
- A significant 220% reduction in SEC at the milling stage when particle size goes from 500 to 800 µm
- An estimated increase of over 3% in the overall energy cost for every durability point above 75% (Eurotest Equivalent)

The findings of these trials are, to a certain degree, consistent with Stevens' findings, in terms of milling and durability, but not in terms of energy consumption during the pelleting process. This variance might be explained by the use of a rather fatty Turkey feed in these trials.

These trials therefore confirm the effect of feed grain size both on the overall energy consumption of the milling/pelleting pair and on pellet quality.

These findings should encourage industry to repeat this type of study on other feeds, testing other parameters such as conditioning temperature and compression rates, in order to specify all cost components in terms of durability.

Tests should also be carried out on a range of particle size distributions for a given median diameter, to enable a more accurate assessment of the impact of fine particle fractions in feeds.

Bibliography

Kumar M., 1973. Compaction behavior of ground corn. J. of Food Sci. 38, 877-878.

Lefumeux J., 1979. Etude de la fabrication des pellets. Publication NRA – Fats in pellets handling equipment, 314, 4-11.

Payne J.D., 1978. Improving quality of pellet feeds. Milling feed and fertilizer, 5, 34-41.

Pedamond M., 1977. Aptitude à l'agglomération des aliments des animaux : mise au point méthodologique ; application à l'étude de l'influence de la granulométrie et de la nature des matières premières. Thèse ENITIAA, Nantes, 79 p.

Seeling R.R.P., Wulff J. 1946. Trans. Aime, 106 : 492. Cité par Pedamond, 1977.

Smith G.M., 1962. The effect of particle size. Feed production school, 47-50.

Stevens C.A., 1987. Effect of particle size on pelleting efficiency and pellet quality. Kansas State University.

Vercauteren W.C.P. 1982. Future development in feed production technology. Holmen Feed production symposium.

Wellin F., 1976. Pelleting equipment operations. Feed Manufacturing Technology. AFMA, 329-332.