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Effect of pilot level pelleting conditions on pellet quality

This study was designed to investigate, at pilot level, how variations in compression rates and conditioning temperatures affect both the pelleting process and pellet quality.

The study also compares 3 pellet hardness testing techniques on a collection of broiler feeds produced using a variety of pelleting methods:

- Schleuniger (Now Sotax) hardness tester with a pointed or triangular head
- Schleuniger hardness tester with a 3-mm flat head
- Instron hardness tester

On the second aspect, this study supplements the findings presented in I'Tec G 8:

- Broader feed collection: 9 manufacturing procedures
- Comparison of differing methodologies: flat or V-shaped compression head, or plate-induced compression.

1. Apparatus and methods

1.1. Feedstuffs

The broiler chicken feed used in this study is mainly formulated as follows: 40% wheat, 30% soybean meal and 20% corn.

Its physical characteristics are as follows:

- Bulk density: 618 g/l
- Median diameter: 630 µm
- Geometric standard deviation: 1.7
- Angle of repose (flow): 61.8°

1.2. Pelleting

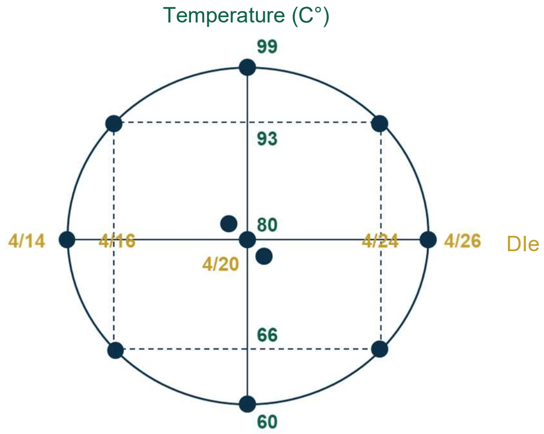
The pelleting line consists in an initial meal feed processed via a twin-screw system, a conditioner (INRA, Nantes) where steam is injected into the feed, and a Kalh brand fixed disc die press. The Kahl press is type 14-175, with a 3-kW drive motor.

The line is instrumented to record the following:

- initial temperature
- conditioning temperature (control setpoint)
- temperature in one of the die channels
- power demand of the main press drive motor
- steam pressure and flow rate

The production rate is set at 30 kg/h.

Eleven feeds were produced according to 9 different conditions based on a CDC experimental design aimed at covering a wide area of conditions:



The central point was repeated 3 times to test repeatability.

All the dies have a diameter of 4 mm, with thicknesses ranging from 14 to 26 mm. The study area concerning the effect of conditioning temperature ranges from 60 to 99°C.

A 10-kg sample was taken after each pelleting operation and cooled on separate coolers. This quantity was sufficient to take all the necessary measurements. The initial samples were then split successively, to obtain the test specimens.

1.3. Durability

Durability was measured using Eurotest equipment on test specimens containing 500g of pellets. Mechanical loads were 20 s. with a 3.2-mm mesh sifter.

1.4. Hardness

Hardness measurements using the **Schleuniger hardness tester**, with whatever head, were taken on a population of 36 pellets per test to take account of the variability of test results. The measurements were taken using the 3-mm flat head (photo - right) followed by the triangular head (photo - bottom).

The tester displays the force exerted on the pellet at its breaking point (value expressed in Newtons). The megapascal (MPa), which takes account of head geometry and pellet diameter, was used to enable comparisons between Schleuniger and Instron equipment. The force (in Newtons) is converted into a stress when using flat heads. In this case, pellet diameter and crushing length must be taken into account. The reference unit used is therefore the megapascal.

$$\text{Hardness (MPa)} = \frac{F \times 2}{\pi \times d \times L}$$

Hardness expressed in MPa

F = Pellet breaking force in N

d = pellet diameter (mm)

L = Length in mm of the force exerted on the pellet

Note that the reference unit for the triangular head remains the Newton, due to the impossibility of determining the surface area of the head's tip.

The **Instron** tester (see photo below) tracks changes in the force exerted on the pellet according to both piston displacement and breaking force.

In this case, the width of the jaw exceeds pellet length. The measurements were taken on a population of 100 pellets. The diameter was measured on 10 pellets, while the length was measured on all 100 pellets. INRA, Tours, provided Tecaliman with this hardness tester to perform the measurements.

These measurements were used to convert the breaking force (N) into a stress value (MPa). The equation is identical to the one above, except for the length L, which, in this case, is the full length of the pellets subjected to the piston's compressive force.

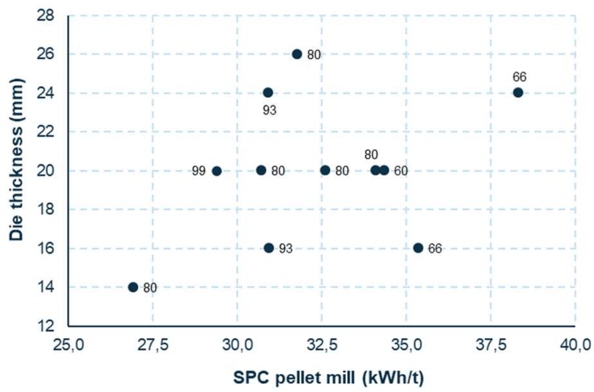
2. Results

2.1. Pelleting conditions

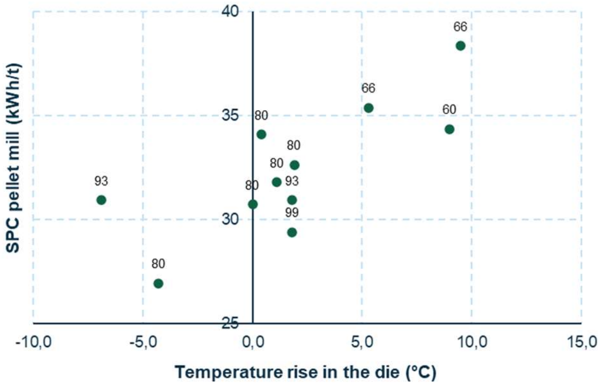
All the desired pelleting conditions were scrupulously applied. The conditioning temperature was controlled to within one degree.

This pilot line, which allows full control of all the parameters, enables observations, some of which would be difficult, or even impossible, to make in an industrial setting.

The figure below demonstrates that the increase in compression rate, in this case due to the increase in die thickness, is not necessarily correlated with an increase in specific power consumption (SPC). Conditioning (temperature labelled on each point) plays a role that is equally significant. For example, at 80°C, **increasing the die thickness** from 14 to 26 mm **increases SPC by 5 kWh/t** i.e. 5%, despite the variability recorded with the 20-mm die. At the same time, **increasing the conditioning temperature from 66 to 93 °C** for the 16 and 24-mm dies, or from 60°C to 99°C for the 20-mm die, systematically results in a **significant reduction in the manufacturing power demand at levels of 5 to 7.5 kWh/t**, i.e. a reduction of at least 15 to 23%.



Another observation concerns the **broadly linear relationship between specific power consumption (SPC) and the temperature rise during die throughput** (see figure below). This relationship is modified by changes in the conditioning temperature and die thickness. This temperature variation in the die vacillates around a conditioning temperature of 80 °C for this broiler feed. Therefore, the friction-induced temperature rise below this value, becomes a decrease when the compression rate is too low or the quantity of the value added is high.



2.2. Pellet quality

The pelleting conditions applied in this experimental design result in an extremely wide range of **durabilities** (see table below): 43.3 to 93.2%.

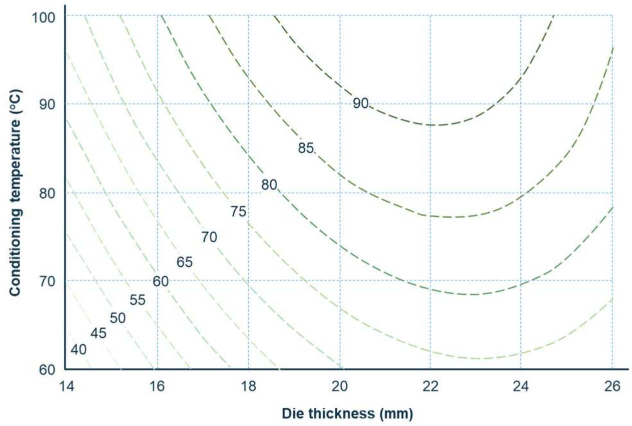
A multilinear regression analysis was carried out in an attempt to predict durability according to conditioning temperature (TC) and die thickness (F):

Durability (%) = -263.992 + 26.155. F + 1.132. TC – 0.523. F² - 0.033. F. TC

R^2 = 86.8%

This equation highlights the key role of die thickness on durability, as this parameter is cited 3 times in the equation with high coefficients.

The figure illustrating the level curves expressed by this equation (see below) shows how **durability increases in relation to the two parameters**.



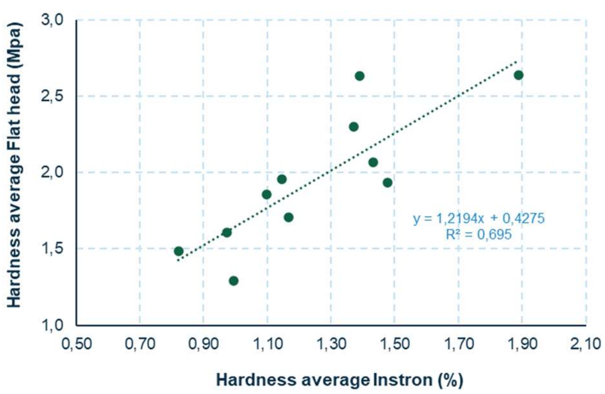
The assumption explaining the diminishing compressive effect observed at high values would represent the combined effect of increased steam incorporation at high conditioning temperatures and the difficulty of extracting moisture gained via the pilot coolers when pellets are more compacted. Pellet moisture content results, post cooling, effectively indicate that residual moisture is broadly related to conditioning temperature, a fact that is physically consistent.

It is likely that this effect is either absent or largely mitigated on industrial lines with coolers operating continuously, as demonstrated by certain programme tests conducted on the variation in die speeds (CINEP).

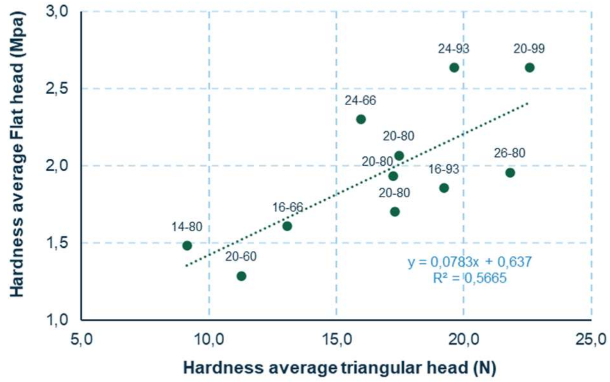
Die thickness (mm)	Conditioning temperature (°C)	Durability (%) *		Hardness 3-mm flat head (Mpa) *		Hardness Triangular head (N) *		Hardness Instron *	
14	**80**	43.3	k	1.48	i	9.1	h	0.82	k
16	**66**	68.6	j	1.61	j	13.1	i	0.97	j
16	**93**	83.9	h	1.86	g	19.2	d	1.10	h
20	**60**	73.3	i	1.29	k	11.3	j	0.99	i
20	**80**	85.6	f	1.94	f	17.2	g	1.48	b
20	**80**	86.3	e	1.70	h	17.3	f	1.17	f
20	**80**	87.9	c	2.07	d	17.5	e	1.43	c
20	**99**	93.2	a	2.64	a	22.6	a	1.89	a
24	**66**	83.7	g	2.30	c	16.0	h	1.37	e
24	**93**	91.0	b	2.64	b	19.6	c	1.39	d
26	**80**	86.6	d	1.96	e	21.8	d	1.15	g

* The ranking indicated by a letter is given for information only and is not validated by a statistical test

As regards **hardness** measurements, the above table gives the average values for the 3 techniques. The figure below illustrates that, overall, the 2 methods using surface crushing (flat head and **Instron**) give mutually consistent results with respect to breaking force. While the Instron method provides a larger dataset by recording a full curve for each crushing operation, this is not useful for obtaining data on average hardness. This is also a **costly piece of equipment**. Another cost item concerns the time taken to measure 100 pellets, including those that are +/- accurate in terms of their individual length.



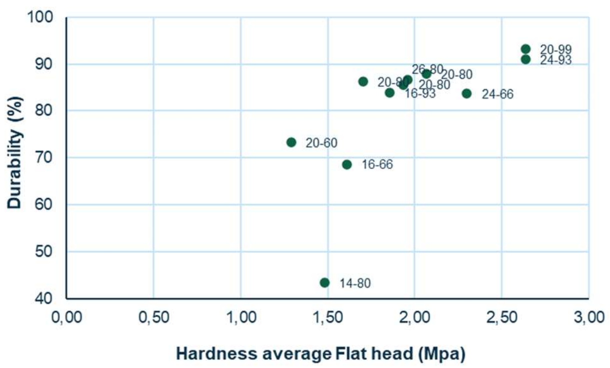
As regards the comparison of the **two hardness tester heads**, the figure below shows that while increases in hardness generally follow the same trend, there may be a **strong distribution** around the general trend that leads to a poor quality R^2.

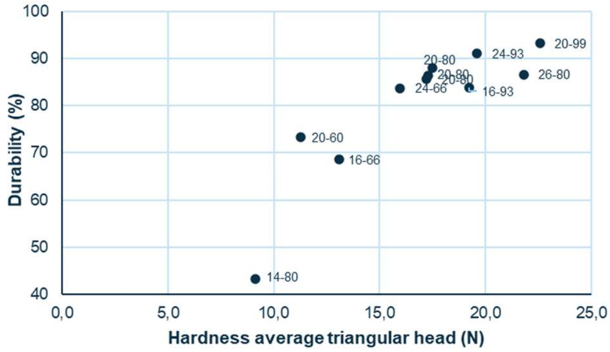


This **disparity between the two hardness testing methods** is also observed in the relationship with durability. The 2 figures below illustrate that the relationship between durability and hardness measured using the triangular head appears more consistent and less scattered.

This indicates that durability increases along with hardness, until reaching the asymptote near the highest possible value for this measurement. This progression is less noticeable when using the flat head, mainly due to the position of the 14-80 test.

Another consequence is that **hardness-based feed rankings differ** according to use of a flat or triangular head. The following figures that label dies and conditioning temperature, or the table above that lists values and ranking (letters), illustrate the **disparity in ranking**: e.g. test 16-93, ranked 4th by the triangular head and 7th by the flat head, or test 24-66, ranked 8th by the triangular head and 3rd by the flat head. This suggests the importance of correctly identifying which ranking is the most relevant. A V-shaped triangular head may be more useful for animals that use incisors or beaks, while a flat head might be more relevant for an animal that predominantly uses its molar teeth.





3. Conclusions

These tests were carried out on broiler feed as this type of feed is often the focus of pellet quality indexes – hardness in particular. The applied test plan and the use of an instrumented pilot line enables the application of extremely precise, **targeted pelleting setpoints and instructions**, which provide data on specific observations.

Increasing die thickness from 14 to 26 mm, i.e. equivalent to 14 to 26 in terms of compression rate (pilot/industrial multiplier factor estimated at 4) results in a 5% increase in power consumption for an identical output rate. Conversely, **increasing the conditioning temperature** from 66 to 93°C results in a **5% reduction in power consumption**. These effects are known, but not always factored in. It has also been demonstrated that a **linear relationship exists between specific power consumption and increasing die temperature***.

Over the very broad study area, **durability** varies between 43 to 93% and is **strongly impacted by the compression rate**. It is important to note that the drying issues encountered with the pilot coolers, that operate by load, result in test plan outliers being less impacted by compression rate and conditioning temperature, especially in relation to high pellet moisture contents.

As regards hardness tests, while the **Instron** system appears **too cost-intensive**, use of a Schleuniger (Sotax) type hardness tester could be justified both to eliminate the operator effect and to test a panel of pellets that is sufficiently large (> 30) to provide a reliable average.

The **disparity in feed rankings according to the choice of test head** (triangular or flat) requires a new approach, in order to **test animal behaviour** to validate the most relevant head and, thereby, to predict the hardness requirements for a given animal feed and its manufacturing conditions.