**i'Tec_B11**
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# Effect of airflow and feed rate on the milling station and product quality on a pilot line

The material's residence time in the grinding chamber can theoretically affect both the milled particles produced (particle size, generation of fine particles, heating, variation in moisture content, etc.) and the plant's output at this station (production rate, specific power consumption, etc.). For instance, the longer the particles' residence time in the grinding chamber, the finer the grind. Conversely, coarser particles are obtained with a shorter residence time.

This pilot study aims to identify how the mill loading rate and airflow rate affect particle residence times. Should changes in airflow be shown to have an effect, this parameter could possibly be boosted to improve energy performance. This could support the relevance of installing a variable speed drive on fan motors at the milling station, which would be adjusted in relation to the airflow rate and desired product quality.

To recap, the milling station accounts for 20 to 25% of a plant's electricity consumption. The fan motor represents around 15% of this electricity consumption.

## 1. Equipment and methods

### 1.1. Raw material

For these tests, wheat kernels were sampled at the plant. Fine particles (<1 mm) were removed. The raw material characteristics are shown below:

| Analyses | Methods | Results |
|---|---|---|
| **Bulk density** | Nilema Litre – 1 repeat | 774.5 g/L |
| **Hardness** | SOTAX MT50 - V-shaped jaw – 10 repeats | 58.6 N |
| **Weight 1000 g** | Counting and weighing – 1 repeat | 40 g |
| **Moisture content** | Whole grains dried in a Chopin oven at 104°C until reaching a stable weight | 13.2% |

**Table 1:** Characteristics of milled wheat kernels

### 1.2. Milling line

Tests were carried out on an instrumented pilot milling line comprising a Retsch SR 300 rotor beater mill and a Nilfisk VP 930 industrial vacuum cleaner. The latter mimics an industrial fan by creating a known airflow in the circuit. A cyclone system separates the milled particles from the air. Table 2 compares the characteristics of the pilot line with an average industrial line (data taken from the survey presented in i'tec_B9 and B10 and from internal data).

| Characteristics | Milling line | |
|---|---|---|
| | Pilot | Industrial |
| Mill motor rated power | 2.2 kW | Avg. 193 kW<br>(15 to 355 kW) |
| Motor rotation speed | 3 000 to 10 000 rpm | 500 to 3 000 rpm |
| Peripheral rotation speed | 26 to 72 m/s | 53 to 106 m/s |
| Screen perforation diameter | 2 / 4 / 5 / 8 mm | Avg. 3.5 mm<br>(0.5 to 15 mm) |
| Screen thickness | 1.5 mm | 1.5 to 3.0 mm |
| Perforation shape | Round | Round<br>(in 96% of cases) |
| Open surface in screens | For a 4 mm screen: 37% | 27 to 50%<br>Optimum - 40 to 50% |
| Total screen surface | 111 cm²/kW | 87 to 105 cm²/kW |
| Airflow | 2 to 120 $m^3/h$ | 2 000 to 30 000 $m^3/h$ |
| Milling throughput | 8 to 300 kg/h** | 1 to 104 t/h |

**Table 2**: Comparison between the Tecaliman pilot milling line and an industrial mill

*** Max. test throughput rate (this throughput rate could be increased under other experimental conditions)*

We can logically ascertain that the pilot mill motor has a lower power rating and rotation speed than those of an industrial mill. However, the peripheral rotation speed of the hammers, which is directly linked to the material's milling mechanism, lies within ranges that are common to a pilot and an industrial mill.

The characteristics of the screens used are fairly similar. Screen thicknesses in the pilot are slightly below the industrial average. Tests carried out at Tecaliman in 1986, using screens with a thickness of 1.5 to 3 mm, revealed that thickness had no significant effect on particle size (internal data). Lastly, the feed and airflow rates also differ between the two scales.

It would be useful to calculate airflow rate in relation to mill screen surface area, as this indicator could allow more effective scaling. However, this would require additional data on screen surface areas and industrial airflow rates.

### 1.3. Test method

Motor rotation speed was set at 10,000 rpm, i.e. **a peripheral hammer speed of 72 m/s**. A **4-mm** screen was selected. These choices cover the full range of mill power ratings under load and industrial particle sizes. The two variable parameters in this study were airflow rate and mill filling rate.

The rate was controlled to obtain rates of between **25 and 70 m$^3$/h**. This was achieved either by:

- modifying the vacuum power: speed 0 = 0 W, speed 1 = 430 W, speed 2 = 863 W
- or generating load losses by opening holes in the aeraulic circuit (0 to 5 open holes)

The mill's load rate was boosted by varying the feed rate. This can be controlled by the height of the hopper arriving at the conveyor, and by the vibration of the conveyor. For these tests, the hopper was fixed 2 cm above the conveyor; only the vibration of the conveyor was modified. The feed rate for these tests varied from **10** to **273 kg/h**.

A centred composite design was produced based on these two parameters. A total of 11 methods were tested, with 3 repeats of the central point.

| Methods | Feed rate (kg/h) | Airflow (m$^3$/h) |
|---|---|---|
| **A** | 273.0 | 70.0 |
| **B** | 273.0 | 25.0 |
| **C** | 10.0 | 25.0 |
| **D** | 10.0 | 70.0 |
| **E** | 234.5 | 47.5 |
| **F** | 141.5 | 31.6 |
| **G** | 48.5 | 47.5 |
| **H** | 141.5 | 63.4 |
| **I (x3)** | 141.5 | 47.5 |

**Table 3:** Theoretical parameters to be achieved during milling

All the tests were carried out over a single day. The mill was cleaned beforehand, the vacuum bag changed and the various probes cleaned. Before starting the tests, the mill was run for 30 minutes with no load. The methods were conducted in random order and at a steady feed rate (the start and end of the batch was not milled.

### 1.4. Recorded parameters

**The airflow rate** in the milling station was acquired using a VA 570 thermal mass flow meter.

**The feed rate** was determined prior to conducting the tests. A quantity of material was sampled during 30 seconds and then weighed. The measurement was repeated twice.

**Mill power** was acquired using a single-phase transmitter.

**Ambient temperature and moisture content** were measured using a portable HD 110 Kimo thermohygrometer at the start of each test.

**Grain temperature** was measured using a probe placed directly in the wheat kernels.

**The temperature of the milled particles** was measured on completion of the milling process. The milled particles were rapidly placed in an isothermal bowl with a temperature probe. The temperature was recorded once stabilised.

### 1.5. Analyses

**The particle size distribution** was established on previously divided samples with a weight of between 50 and 100 g. Each sample was sieved for 10 minutes at a vibration amplitude of 1.22 using eleven Retsch sieves (mesh sizes: 80 µm, 125 µm, 160 µm, 200 µm, 315 µm, 500 µm, 800µm, 1000µm, 1250 µm and 2000 µm, 3150 µm). Each fraction was weighed separately. The geometric mean diameter was then calculated. The measurement was repeated twice.

**The moisture content of the milled particles** was measured a few days after the tests. As soon as one milling method was completed, the milled particles were quickly inserted into a double-sealed bottle, then placed in a cold room. Moisture content was measured on a 5g sample using a Chopin oven at 104°C for 4 hours. The percentage moisture content was obtained by recording the difference in the sample's weight pre- and post-oven treatment.

## 2. Results

The central tests (points I1, I2, I3) indicated good repeatability of the protocol used.

### 2.1. Residence times

The residence time of the wheat kernels in the grinding chamber was determined by increasing, and then decreasing, the power of the acquired mill motor. Residence time is directly linked to feed rate by a power equation. The lower the feed rate, the longer the residence time in the grinding chamber. No link was found between airflow and residence time however.

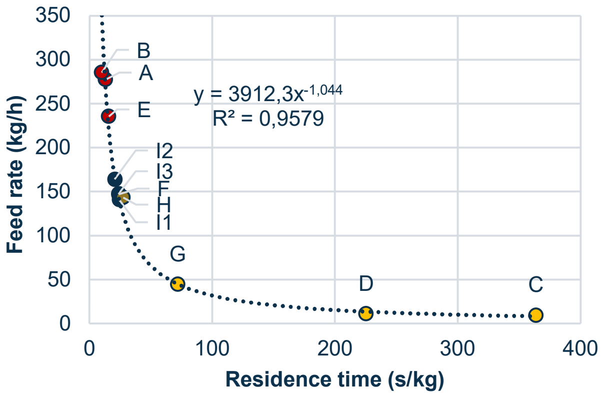

**Figure 1:** Relationship between residence time in the grinding chamber and feed rate

## 2.2. Net specific consumption

The electrical power of the vacuum cleaner could not be measured separately for each test. Therefore, it has not been taken into account in the calculation of the mill's net specific consumption.

| Methods | Airflow (m³/h) | Feed rate (kg/h) | Avg. net power (W) | Net specific consumption (kWh/t) |
|---|---|---|---|---|
| **A** | 72 | 278 | 1474 | 5.3 |
| **B** | 26 | 286 | 1749 | 4.9 |
| **C** | 24 | 9 | 58 | 5.9 |
| **D** | 70 | 11 | 97 | 6.1 |
| **E** | 49 | 236 | 1185 | 5.2 |
| **F** | 38 | 147 | 799 | 5.3 |
| **G** | 49 | 45 | 291 | 5.8 |
| **H** | 61 | 144 | 758 | 5.8 |
| **I1** | 47 | 141 | 761 | 5.1 |
| **I2** | 47 | 164 | 906 | 5.2 |
| **I3** | 48 | 148 | 803 | 5.3 |

**Table 4:** Results of tests on airflow, feed rate, power rating and specific consumption

Varying the airflow rate appears to have a minimal effect on the mill's specific consumption, which appears to improve at lower airflow rates. At similar feed rates, specific consumption is lowest at point B at 26 m³/h, followed by point E at 49 m³/h and finally point A at 72 m³/h. This observation only applies to high feed rates.

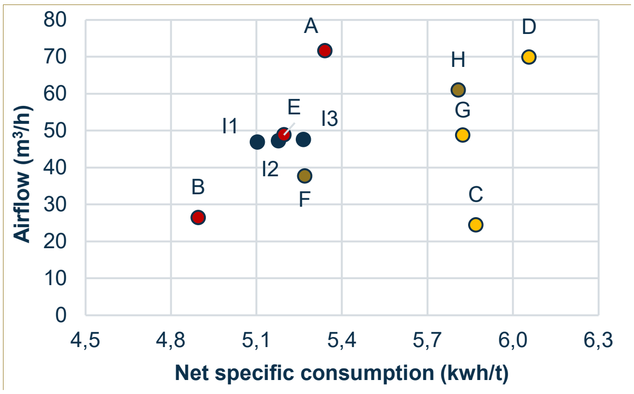

**Figure 2 :** Relationship between net specific consumption and airflow

Conversely, feed rate has a direct impact on the mill's specific consumption, which decreases with increasing feed rate.

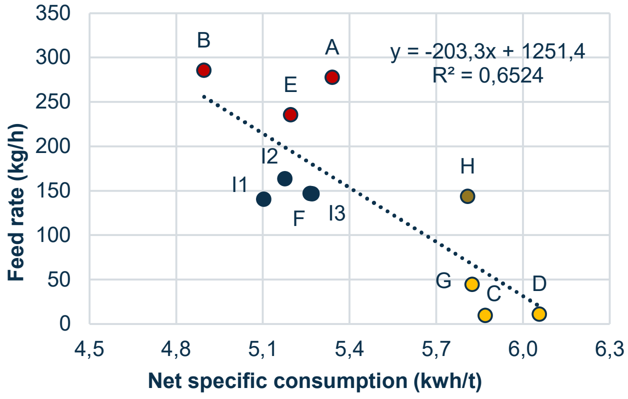

**Figure 3:** Relationship between net specific consumption and feed rate

## 2.3. Particle size distribution

Median particle size diameters obtained ranged from 483 to 632 µm. The study observed a visual variation in fine particles. The proportion of particles with diameter below <200 µm was therefore investigated and observed to range from 13.4 to 21.8%.

| Methods | D50 (µm) | Proportion (%) particles smaller than | |
|---|---|---|---|
| | | < 200 µm | <80 µm |
| **A** | 632 | 13.4 | 4.8 |
| **B** | 591 | 15.8 | 6.4 |
| **C** | 501 | 20.2 | 7.5 |
| **D** | 483 | 21.8 | 9.4 |
| **E** | 593 | 15.8 | 6.1 |
| **F** | 569 | 16.7 | 6.4 |
| **G** | 502 | 20.1 | 7.5 |
| **H** | 537 | 18.5 | 7.6 |
| **I1** | 542 | 18.2 | 7.6 |
| **I2** | 551 | 17.2 | 6.8 |
| **I3** | 546 | 17.6 | 7.1 |

**Table 5:** Results of tests on the particle size distribution of the milled particles

While no link was found between the median diameter and the variation in airflow, median particle size is strongly linked to the feed rate. The lower the feed rate, the lower the particle $D_{50}$.

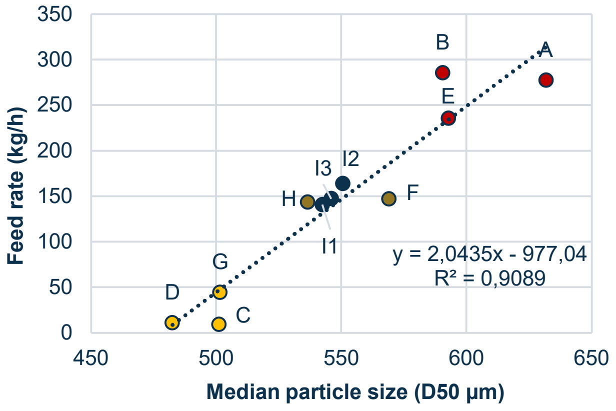

**Figure 4 :** Relationship between $D_{50}$ and feed rate

The reduction in particle size is directly linked to the generation of the finest particles. Decreasing the feed rate therefore increases the fraction of particles with diameter under 80 µm. In industrial terms, this can cause more rapid clogging of the filtration system. Longer residence times would therefore result in greater particle attrition, generating a larger fine fraction.

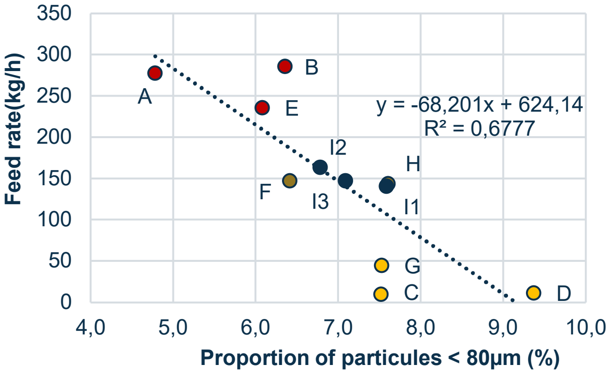

**Figure 5 :** Proportion of particles smaller than 80 µm as a function of feed rate

## 2.4. Temperature and moisture content of milled particles

The pre- and post-grinding temperature delta ranged from +5.3°C to +8.0°C.

| Methods | Temperature delta output – input (°C) | Moisture content (%) |
|---|---|---|
| **A** | 5.3 | 12.2 |
| **B** | 8.0 | 12.1 |
| **C** | 6.6 | 11.4 |
| **D** | 6.2 | 12.0 |
| **E** | 6.9 | 11.8 |
| **F** | 7.1 | 12.0 |
| **G** | 6.6 | 11.9 |
| **H** | 6.1 | 11.7 |
| **I1** | 6.2 | 12.1 |
| **I2** | 7.0 | 11.7 |
| **I3** | 6.8 | 11.7 |

**Table 6:** Results of tests on variations in temperature and moisture content in milled particles

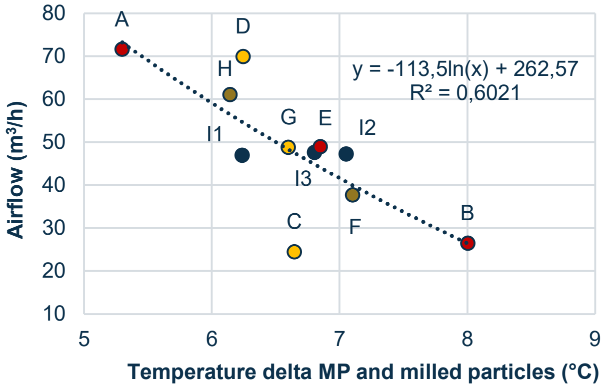

**Figure 6:** Relationship between the temperature delta of milled material and airflow rate

Decreasing the airflow rate increases the temperature of the milled particles. It is important to note that although the tests used a fairly short grinding time, this still resulted in an 8°C increase in product temperature (in under 1 min of grinding).
Conversely, no link was found between the heating of the milled particles and the feed rate. This appears surprising as the feed rate is directly linked to particle residence time in the grinding chamber. It was expected to see a rise in the temperature of the milled particles. This could possibly be explained by a threshold effect limiting this temperature rise.

Given the difficulty in obtaining reliable particle moisture content measurements, the moisture content of the milled particles was only compared between the different methods. A variation is considered significant when a deviation of 0.2% is observed. Nevertheless, the variations remain small (from 11.4% to 12.2%) with no clear trend. Note that while test C recorded the highest moisture loss it had the lowest feed and airflow rates in the study.

# 3. Conclusion

Feed rate (and therefore mill load rate) has a direct affect both on the milled particles and on milling station throughput. It can be beneficial to increase the feed rate as this decreases particle residence time in the grinding chamber, thereby limiting the generation of fine particles. This also improves the mill's net specific consumption.

While airflow rates have little effect on the above-mentioned parameters, it is interesting to note that a lower airflow raises the temperature of the milled particles, but with no apparent effect on their moisture content and, therefore, the wet waste at this station.

It therefore seems that boosting the airflow would not have any major adverse effect on the quality of the milled particles or on station throughput. For example, this adjustment would make it possible to reduce the power consumption of the milling station fan, to compensate for the load loss linked to the clogging of filter bags, etc.

However, to confirm these findings, it is essential to conduct further industrial trials. To assess the effect of airflow alone, these tests will have to be carried out at a constant, high feed rate, given the latter's strong impact on all performance parameters.