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Energy efficiency of small hammermills when milling maize

A law passed in Brazil following the latest energy crisis forbids the use of machinery with poor energy efficiency. A Brazilian-German project investigated energy consumption and milling quality of hammermills processing maize. At the same time the validity of different energy calculation models was investigated. The influence of throughput, rpm and sieve mesh hole diameter on the specific energy consumption was confirmed.

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Literature

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In southern countries maize is an important food and feed. In Brazil more than a quarter of all arable land is used for growing maize with around 40 m tonnes of maize grain produced. A large proportion of this crop is grown on small and medium sized farms where the farmers mainly process the grain themselves through low-performance hammermills. These types of hammermill, which are not known in Europe, actually comprise a combination of hammermill, disc-chopper and mixer. These milling machines known as Desintegrador Picador Moedor (DPM) are used for the chopping of elephant grass and forage maize as well as rasping of cassava as well as milling and bruising maize and small grains. Thus, currently machines of between 1.5 and 10 kW are produced by almost 30 inland manufacturers.

Because of the large selection it is very difficult for the farmer to choose a suitable machine, especially with regard to energy requirements and milling performance. Energy consumption has become an important criterion in Brazil's rural areas not least since the latest energy crisis. The extreme distances involved mean that electricity cable cross sections are underdimesioned rather than overdimensioned. From the State's point of view and that of the energy supply companies, low consumption and efficient utilisation of electrical energy by the consumer is therefore of great importance [1, 2].

Materials and methods

The investigated DPM hammermills comprised a horizontal milling system with a disc and wingwheel aligned on the same axis, plus a cyclone. On the upper surface are fitted up to four hammer brackets and a closable opening for ejection of chopped material. The underside is fitted with an interchangeable, semi-circular sieve which is replaceable by a sheet metal plate during chopping operations. In milling, the bruised grain is sucked out from under the sieve and transported by a radial fan in the cyclone. For bruising, a steel slide is opened in the floor of the mill casing for outflow of treated grain. The most important technical data are presented in *table 1*.

The hammermills are driven by an induction motor (3.75 kW; 3515 min^{-1}) over an rpm-torque measurement shaft which is mounted on a separate bracket. Through exchanging the belt pulley on the drive input and output of the measurement shaft the hammermill rpm can be altered in five steps. The torque is measured by a factory calibrated torque measurement shaft (1000 Nm) and the rpm with an inductive impulse transmitter [3]. Both signals are converted into analogue currants and subsequently recorded and displayed through the associated measurement software.

Grain maize (*Zea mays L*) grown in Brazil was used in the investigation. Average moisture content was 11.5% and heap density

Table 1: Specification of the tested DPM hammermills

Parameter		Mill 1	2	3	4	5
Rated power	kW	3.75	5.63	3.75	3.75	3.75
Rated rpm	min^{-1}	4000	3800	3000	3500	3600
Own weight	kg	71	66	63	82	78
Diameter of hammer movement circle	mm	275	235	295	285	295
Number of hammer packets	-	4	2	2	4	4
Number of hammers	-	20	10	12	20	12
Hammer breadth	mm	5.0	4.8	5.0	4.6	4.4
Sieve width	mm	120	132	126	120	106
Sieve length	mm	560	470	600	560	580
Open proportion of sieve area						
with Ø 0,8 (1,3)[a] mm sieve	%	4.4	12.7 [a]	8.9 [a]	9.1	5.5
with Ø 3,0 mm sieve	%	11.8	13.4	15.5	16.9	14.8
with Ø 4,5 (6,3)[b] mm sieve	%	17.8	13.3	19.4 [b]	19.3	21.1
with Ø 10 mm sieve	%	21.3	26.1	-	21.9	10.4

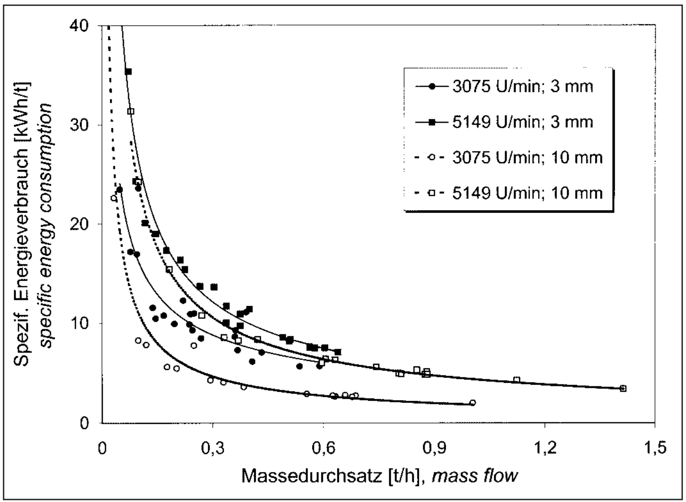

Fig. 1: Specific energy consumption of the hammermills depending on throughput for a selected number of rpm and different sieve meshes

~ 800 kg/m³. Average grain diameter derived from three samples was 8.12 mm and in each of the five investigated hammermills the rpm was varied in five steps from 3075 to 5149 min⁻¹ for each of four to five sieves with Ø from 0.8 to 10 mm and for each rpm step, the throughput was changed, generally in five steps so that in total around 500 measurements were carried out.

Energy consumption

The investigated hammermills showed a strict linear dependence of power requirement on throughput with the zero point at idling and the increase determined by the sieve mesh hole diameter and rpm. This led to a hyperbolical relationship between the specific energy consumption and grain throughput. In this context, type of hammermill was of lesser importance (*fig. 1*).

Milling fineness

The granular parameters of the meal were determined mainly by the sieve mesh hole diameter and the hammermill rpm. The average final particle diameter $x_{50;E}$ was around 1/2 to 1/15 of the sieve mesh hole diameter. With increasing radial velocity, this was decreased by 0.05 to 0.20 mm for every additional 10 m/s. The sieve performance curves were in the main normally distributed. A comparison between two commercially available maize meals available in Brazil showed relatively good agreement with the sieve performance curves for meal produced with a 3 mm sieve and average rpm.

Calculations and evaluations

For a comparative evaluation of specific energy consumption W_{spez}, reference to the sieve mesh hole diameter is a rough simplification. Critical here is the degree of fineness of the hammermilled material. Different calculation models can be found for this in the literature. These depend on half-empirical rudiments on the basis of the average particle size at the beginning $x_{50;A}$ and the final particle size $x_{50;E}$ after milling [4, 5] as with the particle size reducing models according to Rittinger

$$W_{spez} = C_R \cdot \eta\ (1/x_{50;E} - 1/x_{50;A}) \qquad (1)$$

according to Kick

$$W_{spez} = C_K \cdot \eta\ \log(x_{50;A}/x_{50;E}) \qquad (2)$$

according to Bond & Wang

$$W_{spez} = C_B \cdot \eta\ (x_{50;A}/x_{50;E})^{1/4} / x_{50;E}^{\ 1/2} \qquad (3)$$

Should regression analyses be carried out on the basis of the recorded measurements and the equations (1) to (3), the product of the respective material coefficient C and the degree of efficiency η can be calculated. It comprises

$$C_R \cdot \eta = 5{,}01 \quad \text{für } R^2 = 0{,}55 \qquad (4)$$

$$C_K \cdot \eta = 6{,}44 \quad \text{für } R^2 = 0{,}28 \qquad (5)$$

$$C_B \cdot \eta = 3{,}06 \quad \text{für } R^2 = 0{,}46 \qquad (6)$$

With a coefficient of determination of R^2 = 0.55, the, in total, best agreement of the measured and of the recorded values was achieved for particle diameter $x_{50;E}$ >36 mm (sieve- Ø > 0.8 mm) according to the Rittinger concept (*fig. 2*).

Conclusions

Specific energy consumption of the investigated hammermills lay in the range from 2 to over 50 kWh/t grain maize, mainly influenced by the sieve mesh hole diameter, grain throughput and rpm. Under favourable working conditions, e.g. optimum rpm and high throughputs, consumption of 12 kWh/t was usually not exceeded where sieves with a mesh hole diameter ≥ 3 mm were used and results, therefore, were similar to comparable European makes [6, 7, 8]. The energy efficiency has to be evaluated in relation to the degree of fineness achieved. For production of maize meal with an average particle diameter of x50;E ≥ 1 mm, the specific energy consumption of the here investigated hammermills was less than 6 kWh/t whereby the individual mills returned construction-influenced differences. Of the known literature models for calculating energy requirement, that from Rittinger [4, 5] agreed best with the measured results and therefore can be recommended for use in this context.

In total it can be accepted that the five investigated DPM hammermills suitable for use in small farms with two of them achieving a good degree of energy efficiency over a wide range of final particle sizes. However, against the accepted practice, the grain should not be milled smaller than is required (average particle diameters from 0.5 to 1.0 mm for pigfeed) [9, 10]

In that this size is also required mainly for human nutrition, preferred sieves applied should have a mesh hole diameter of ≥ 3 mm. Compared with the energy consumption with the 0.8 mm sieve currently generally used, this reduced specific energy consumption by between 20 and 80%.

Meal produced with the 3 mm sieves comprises similar particle size spectrums to the usual commercially available meal. In the marketing of meal produced in this way care must, however, be taken because, contrary to industrially produced maize meals, the material has only a limited storage life in that small-scale producers as a rule don't degerminate the grain.

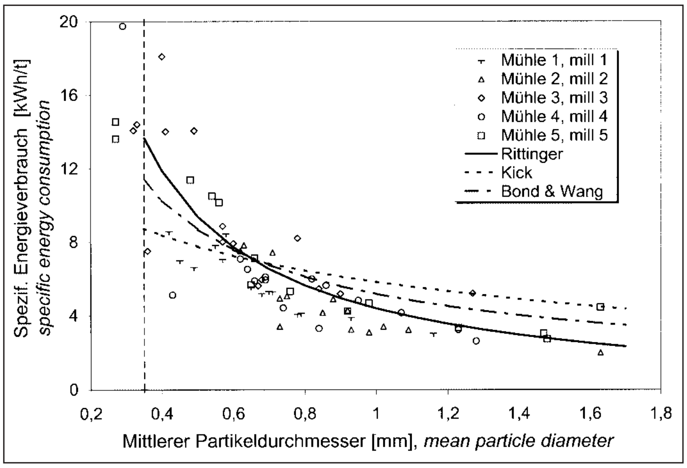

Fig. 2: Minimum specific energy consumption of the hammermills depending on throughput with a range of rpm and final particle diameters