INVESTIGATION OF MAIZE COBS CRUSHING – PREPARATION FOR USE AS A FUEL

by

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Maize crop residues have great significance, particularly in developing countries, where the harvest of maize ears and their natural drying is widely applied. After drying and grain threshing, maize cobs are available for energetic use on farmers' yards. Shortcomings for their energetic utilization by combustion, in comparison with wood, are higher contents of potassium, chlorine, and nitrogen, and lower ash softening point. Tests in small wood chip boilers showed that the size of maize cobs should be reduced in order to facilitate better combustion and feeding with commonly used screw conveyors. Desirable length of particles should be 1-1.5 of their diameter. Within the framework of the Eureka project, a low-cost maize cobs crusher was developed and tested. It consists of a drum with six rows of knives, stationary comb-like knives, and a screen situated below the drum. The test resulted with working parameters that enable appropriate size reduction. Analyses of crushed material showed that over 80% of particles were in the range of 3.15-45 mm, less than 1% smaller than 1 mm, and less than 1% larger than 63 mm. This granulation is comparable with size class P45 for wood chips in accordance with standard DIN CEN/TS 14961. Further investigations should focus on improving the combustion facilities, in order to avoid formation of ash slag, and keeping exhaust gas characteristics within values defined by legislation.

Key words: *maize cobs, crushing, biofuel*

Introduction

Maize belongs to the dominant field crops worldwide. The quantity of maize crop residues yield has been reported by many authors. The reported stover mass, specified relatively to grain mass, is in the range 0.9 [1] and 1.0 [2]. The influence of stover removal on soil fertility was also elaborated [3]. Graham *et al.* [2] defined the limit value of removed stover without negative impact on soil fertility to be about 28%.

Yield of maize cobs is seldom reported. Kromer *et al.* [4] reported the share of cobs in whole maize plant to be between 9.8% and 10.6%. Pordesimo *et al.* [5] presented the following shares of maize plant parts: 45.9% grain, 27.5% stalk, 11.4% leaf, 8.2% cob, and

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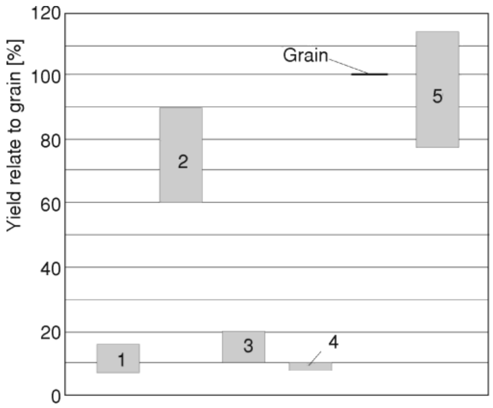

Figure 1. Ranges of relative yields of maize crop residues, dry matter (yield of maize grain is 100%)
1 – first 20 cm of stalk above the ground, 2 – stalk with leaves without first 20 cm above ground, 3 – cob, 4 – husks, 5 – residual parts (overall 2, 3, and 4), [7]

7.0% husk, on a dry matter basis. Hoskinson *et al.* [6] investigated harvesting of all maize residual mass using different cutting heights. The share of maize cobs was about 9% of total above ground biomass. Still, this share varied in dependence on cutting height.

It is more useful to express the yield of maize cobs relatively to grain yield, since the latter is almost always recorded. The range of relative yield of maize plant parts, calculated on a dry matter basis, has been reported by Martinov *et al.* [7] and is presented in fig. 1. The first 20 cm of maize stalks above ground were treated separately since it is not usable for energetic purposes.

In conclusion, the relative yield of maize cobs is between 10% and 20% of the grain mass. As an average share, a relative yield of 18% can be used.

In developed countries, harvesting of maize is mostly performed using universal combine harvesters with adequate header and working parameters adjusted for this operation. Maize crop residues' harvesting is still not appropriately solved [6]. Problems are the low density and the mostly high moisture content of stover, containing stalks, leaves, cobs, and husks.

In developing countries, a picker-husker or manual picking of ears is used for maize harvesting. Ears are naturally dried. In Serbia, maize growing is highly represented and covers about 38% of arable land. Even more important is the fact that about 80% of the maize in Serbia is grown on small and medium farms with an agricultural area of less than 200 ha [8]. The natural drying of maize ears contributes to reduction of total fossil consumption considerable. After drying period, at the end of February or in the first half of March, and threshing of grains, the maize cobs remain on the farmers' yard. The moisture content of the cobs is usually 10-12%, about 2% lower than that of the grains. This is traditionally used as a fuel, but usually in very simple and inefficient facilities [9].

According to a thorough study of available biomass potentials for energy purposes, maize cobs represent the biggest biomass potential in Serbia with a value of 1.2 Mt per year [10]. As an example in other regions, Wilaipon [11] reported an energetic potential of maize cobs in Thailand to be of over 12 Mt per year.

The lower heating value of maize cobs has been reported by a couple of authors. Kromer and Martinov [4] found a value 14.6 MJ/kg for material with 15% moisture content, while Martinov *et al*. [7] measured approximately the same value for identical moisture content. Schneider *et al*. [12] measured lower heating values of maize cobs for different maturity stages and obtained values of 17.2-18.1 MJ/kg based on dry matter. A value of 18.2 MJ/kg for dry matter was reported by Zabaniotou *et al*. [13] and Ioannidou *et al.* [14]. Based on a moisture content of 15%, the heating value is very close to that mentioned previously. Wilaipon [11] referred an average lower heating value of maize cobs of 14.2 MJ/kg, but the corresponding moisture content was not reported. In summary, the lower heating value of maize cobs is comparable with other crop residues and even above average.

Schneider *et al*. [12] also measured other characteristics of maize cobs. For mature plants, the contents of elements important for the combustion process were: Chlorine 0.1%, potassium 0.5%, phosphorus 0.08% and nitrogen 0.6%. The ash content was measured to be about 1.3% based on dry matter. Zabaniotou *et al*. [13] measured 2.1%, and much higher, as pyrolysis residue, 8.06% [14].

Maize cobs may be used as a raw material for many products [15], as well as for ethanol production [16, 17]. Still, their utilization as a fuel for combustion facilities is dominant, especially in rural areas of developing countries. Traditional stoves and new facilities have mostly low efficiencies of less than 60% and cause high emissions of pollutants [9, 10, 18]. In spite of this, the use of maize cobs as energy source for household heating and process energy is auspicious due to:

- their price which is lower than for other crop residues and fossil fuels, and availability on the farm,
- their utilization which do not impact food production, and
- their use, which can contribute to better economy of farming and, moreover, rural development.

Due to similar chemical composition, the ash characteristics of maize cobs are comparable with other crop residues. The softening point which is less than 1000 °C and the higher ash content are reasons why maize cobs are less favorable for combustion than wood. Therefore, some additional improvements of facilities are needed to avoid high temperature corrosion and to reduce emissions of pollutants and solid particles to below the limits defined by legislation.

First own tests showed that adopted wood chip boilers with under-feed firing system may be suitable for combustion of maize cobs. Whole maize cobs, usually obtained after shelling, are not suitable for combustion and feeding in small wood chip boilers. For the two-phase combustion, with controlled first phase of gasification, the best would be to have spheroid or ellipsoid form of particles. This means that the desirable length of crushed cobs should be in the range 1-1.5 of cob's diameter. The same granulation is suitable for a feeding system with screw conveyors. The particle size reduction and its definition is a first step toward standardization of this type of fuel, as it has been done for wood chips in DIN CEN/TS 15149 parts 1 to 3 [19-21].

Size reduction of maize cobs has not been investigated frequently. The desirable particle size distribution depends on the usage. In some cases, the request is to achieve smaller pulverized particles, as it is the case for methanol production or for making of briquettes and pellets. For this purpose, a hammer mill is used most frequently [15, 22, 23]. For combustion, bigger particles are more suitable. Undersize particles, *e. g.* smaller than 1 mm, cause complete instead of two-phase combustion, generation of flying sparks and increase feeding problems. Additionally, production of bigger particles is less energy consuming. The machine for size reduction should be as simple as possible, with adequate low costs, to enable its adoption by farmers in rural areas.

The objectives of this investigation were:

- to develop a low-cost machine for size reduction of dry maize cobs, and
- to find out the range of working parameters of the machine, in order to achieve the appropriate particle size for combustion and feeding with a screw conveyor.

For the particle size distribution of maize cobs, standards developed for wood chips as a fuel could be used.

Materials and methods

Maize cobs

For the experiment were taken cobs of three typical locally grown hybrids: *FAO 400*, *FAO 600*, and *FAO 700*. They represent hybrids of early, medium-late, and late maturity, respectively. After first crushing tests, no significant differences of crushed material were recorded among these three groups. Consequently, further experiments were performed only for the medium late hybrid (*FAO 600*) that is dominant in local production. The moisture content of cobs was in the range of 11-13% (weight base).

Dimensions and bulk density

There were measured cobs' length, maximal diameter and diameter at midpoint. Twenty measurements were done for samples collected from five typical locations of maize production in Serbia.

For the density measurement it was used a metal cylindrical container, 1 m high and 0.31 m in diameter. This container was filled by free fall of material from a height of 0.5 m. After filling of the tube, the mass of cobs was measured before and after crushing, and the bulk density was calculated. Each measurement was performed for at least five samples from five locations.

Crushing machine

Dry cobs are brittle, and it was supposed that for their size reduction, crushing would be more convenient than cutting. A cutting device would need an additional device for longitudinal orientation of cobs, making the design of the machine more complicated and expensive. Milling, typically by means of a hammer-mill, results in more intensive size reduction and increase of undesirable small particles.

The scheme of the crusher developed for this purpose, in the framework of the *Eureka 3414* project, is presented in fig. 2.

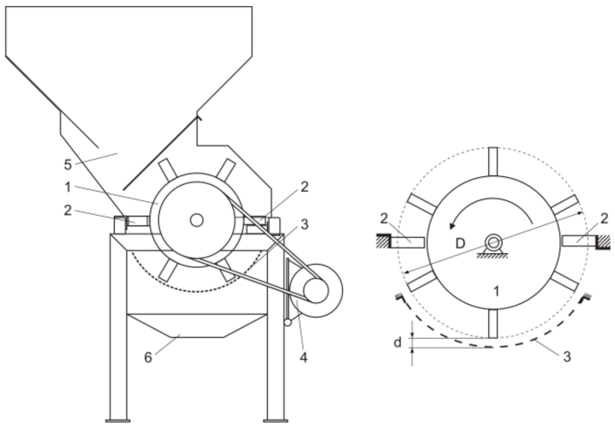

Figure 2. Scheme of developed maize cobs crusher: 1 – drum with six lines of spirally situated knives, 2 – stationary comb-like knives, 3 – screen, 4 – belt drive, 5 – inlet hopper with dosing slider; and 6 – outlet hopper

The inlet hopper (5) is designed in such a way that it enables dosing and perpendicular orientation of maize cobs. Crushing of the cobs is performed between the drum and the stationary knives. The length of all knives is 75 mm, the diameter at the top of the drum knives, D, is 500 mm and the width of the drum, L, is 500 mm. The screen (3) situated below the drum with knives is designated only to prevent too long particles from dropping down.

The relevant working parameters that were tested included the following:

– screen (3) openings: 20, 30, and 35 mm were selected, with maximal open area (minimal perforation step),
– rpm (revolutions per minute) of drum with knives: 220, 320, 420, and 520 per minute were tested, whereby the rpm of the electric motor was changed using a frequency converter,
– distance of screen to knives (*d*): 20, 30, and 40 mm were applied, and
– operation with only one (left handed on fig. 2) or both stationary knives.

Crusher was driven by electric motor, 2.2 kW, and V-belt transmission.

For every group of working parameters were provided at least five tests with not less than 20 kg of cobs.

Tests of crushed material

For the determination of particle sizes were used test sieves. Screen mesh sizes 0.63--40 mm were selected, with mesh step ratio R5 (fifth root of ten, ≈1.6). For the openings up to 6.3 mm, woven cloth screens in accordance with DIN 4185 part 1 [24], were used. Sieve diameter was 200 mm. For openings 10, 16, 25, and 40 mm, perforated plates in accordance with DIN 4185 part 2 [25], were used, and sieve diameter was 400 mm. Longer particles were measured manually and classified into two groups: 40-63 mm and longer. For the group with a particle length of up to 6.3 mm, the arithmetic mean of neighboring mash was taken as representative value. For bigger sieve openings, particle sizes were measured manually, and the median was used as the representative value of the group. Minimum sample volume was 4 L and scale accuracy was 0.1 g, in accordance with DIN CEN/TS 15149-1 [26]. For each measurement five representative samples were taken.

The particle mass for every length group were measured for all tests (five samples of each of five tests), average values and coefficient of variation calculated, whereby extreme values were excluded. The calculated values were compared for different working parameters in order to check their eventual overlapping. Average values of cumulative distribution by mass were presented in the diagram for log-normal distribution, according to DIN 66144 and the method defined by Batel [27]. The points representing cumulative distribution per mass were transformed into linear co-ordinates and the least square method was used for calculation of the representative line. Regression analysis, probability 90%, was used for testing of linearity of particle size distribution, expressed as coefficient of correlation. For all parameters were obtained medians, and calculated average value and calculated coefficient of variation.

The particle size distributions were evaluated as it is usual for wood chips [28], in accordance with standards DIN CEN/TS 14961 and ÖNORM M 7133 [29, 30].

Results and discussion

Dimensions and bulk density

The results of dimension and density measurements are given in tab. 1 (SD – standard deviation).

Table 1. Measured dimensions of maize cobs and bulk density before and after crushing

	Cobs' dimensions, [mm]	
	Median	Standard deviation
Length	186.2	20.8
Maximal diameter	27.1	1.6
Diameter at midpoint	25.2	1.1
	Bulk density, [kg m^{-3}]	
	Median	Standard deviation
Non crushed	104	8.9
Crushed	227	14.2

According to the results and set-up preconditions, the length of crushed cobs was limited to 40 mm (about 1.5 of maximal diameter). This dimension was suitable also for a screw conveyor as feeding facility. Comparing with data in standard DIN CEN/TS 14961, this represents the group signed as P45, or G50 in the Austrian standard ÖNORM M 7133.

The density of the crushed cobs was more than double the density of unprocessed. This may serve as a guideline for dimensioning of the container of the combustion facility.

Crushing results

The tests showed that screen openings of 20 and 30 mm were not applicable. By using these openings the crushed material rotated inside the working space, does not pass through screen openings. Only with a sieve opening of 35 mm, a continuous material flow was achieved.

An example of a particle size distribution is presented in fig. 3. The representative line allows for the evaluation of the distribution in accordance with the requirements defined in standard DIN CEN/TS 14961 for wood chips.

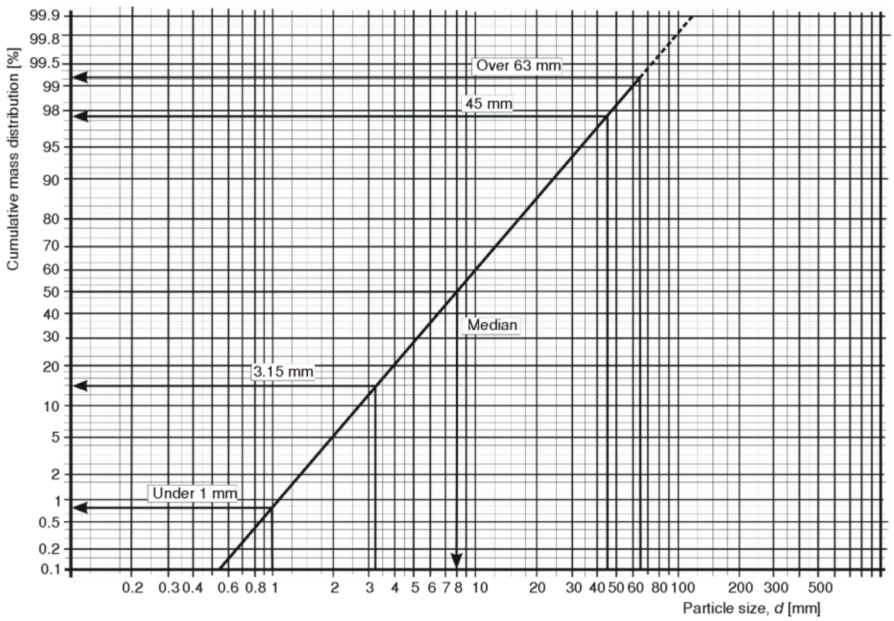

Figure 3. Example of particle size distribution: Test no. 15

The complete results of the crushing tests are presented in tab. 2. For every single working parameter, significant values, range of particles in the range 3.15-45 mm, undersized <1 mm, and oversized >63 mm were taken from the log-normal particle size distribution diagram. Median was calculated as well.

Table 2. Results of crushing test

No.	Drum rpm, [min.$^{-1}$]	Distance of knives *d*, [mm]	Second stationary knifes	Significant size fractions, [%]			Average median value, [mm]	Coefficient of correlation
				3.15-45 mm	<1 mm	>63 mm		
1	220	20	yes	81	0.0	8.0	17.5	0.75
2	320	20	yes	88	0.2	2.0	13.0	0.84
3	420	20	yes	86	0.5	1.5	9.5	0.86
4	520	20	yes	85	0.8	0.5	7.5	0.89
5	220	30	yes	76	0.0	12.0	20.0	0.73
6	320	30	yes	88	0.0	3.5	14.0	0.79
7	420	30	yes	86	0.3	3.0	12.0	0.83
8	520	30	yes	84	0.7	0.8	8.0	0.87
9	220	40	yes	82	0.0	7.0	17.5	0.74
10	320	40	yes	86	0.0	5.0	16.0	0.79
11	420	40	yes	89	0.2	2.0	12.0	0.83
12	520	40	yes	86	0.5	1.8	10.0	0.83
13	220	20	no	79	0.0	10.0	23.0	0.78
14	320	20	no	88	0.3	2.0	11.0	0.84
15	420	20	no	84	0.8	0.8	8.0	0.89
16	520	20	no	86	0.5	2.0	10.0	0.85
17	220	40	no	81	0.0	9.0	18.0	0.73
18	320	40	no	83	0.0	7.0	18.0	0.76
19	520	40	no	86	0.5	3.0	11.0	0.83

First and second specifications of standard DIN CEN/TS 14961 for wood chips are that for all working parameters more than 80% of particles are in the range of 3.15-40 mm, and less than 5% of particles are smaller than 1 mm. The limitation of oversized particles, less than 1% over 63 mm, was fulfilled for certain working parameters, no. 4, 8, and 15 (shaded rows in tab. 2), and almost for 3. Obtained particle size distribution of crushed maize cobs fully corresponds to size classes of wood chips P45 and G50, in accordance with DIN CEN/TS 14961 and ÖNORM M 7133, respectively.

Acceptable working parameters are: drum rotational speed 420-520 per minute, screen opening 35 mm, knife distance to screen 20-30 mm, use of two or one stationary knifes (if the distance *d* is 20 mm).

For the tested crusher, the capacity was found out to be about 250 kg/h. This can enable the supply of about three average (four member) households in Serbia during heating season.

The feeding and combustion of crushed cobs preliminary test was performed in a boiler commonly used for combustion of coarse wood chips with underfeed stoker. Feeding and combustion were successful (fig. 4), but after a few hours of operation ash slag was created. Consequently, the combustion chamber should be adapted to such a fuel with lower ash melting point.

Figure 4. Test of feeding and combustion of crushed maize cobs in coarse wood chips boiler

Conclusions

The investigation showed that the developed crusher could be successfully used for size reduction of dry maize cobs. Using appropriate working parameters of rpm in the range of 420-520 per minute, sieve opening 35 mm, sieve distance to knives 20 or 30 mm, and use of one or two stationary knifes, a particle size distribution was achieved that is comparable with wood chip dimension group P45 in accordance with standard DIN CEN/TS 14961, and G50 in the Austrian standard ÖNORM M 7133. This also met well with the set-up objectives to achieve a majority of over 60% crushed cobs with a ratio of length to diameter at midpoint of 0.2-1.5. Such material is suitable for combustion and feeding with a screw conveyor. The results of this study may serve as the background for future standardization of particle size distribution of this type of solid biomass fuel.

Bulk density of crushed maize cobs was more than double in comparison with unprocessed cobs which allows for better use of a fuel hopper and a more efficient feeding conveyor.

The developed crusher is simple, low-cost type, and has the capacity for supplying three households to meet their heating needs. The crusher has already been used by farmers.

Future investigations should focus on the improvement of combustion facilities for the use of maize cobs as fuel, in order to reduce exhaust gas emissions and avoid melting of ash.

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