

Ref: C0257

## ***Maize cobs for energetic use – Properties and challenges as fuel for small scale combustion***

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### **Abstract**

Recently, there has been increased interest and research in the bioenergy sector for the development of new energy resources to meet the demand of modern standard of living. While there are numerous types of biomass, certain characteristics make some biomass materials more desirable for energy production. Moisture content, chemical composition, particle size, energy content as well as energy density of the feedstock are the major factors that should be considered in the selection and evaluation of a desirable fuel for energy production. In addition to other agricultural residues, the use of maize cobs as a biomass feedstock offers promising possibilities for renewable energy production and is getting more and more under consideration as competitive agricultural solid biofuel. Especially in regions which are dominated by arable land, with a low forest percentage, this biomass source might be used for the production of heat in biomass boilers. In Austria approximately 200.000 ha of maize for maize kernel production are cultivated. As rough estimation 1 t of maize cobs per ha can be harvested. This makes an overall potential of 200.000 t per year of maize cobs for the use as raw material and for energy purposes. Based on the master table of the European standard EN 14961-1:2010 Solid Biofuels – Fuel Specifications and Classes – Part 1: General Requirements an Austrian standard has been developed. The specific Austrian standard is titled: ÖNORM C 4003: Maize cob – Requirements and test methods. This document comprises as many as necessary but as few as possible normative and informative parameters and limits. A national funded research project works on procedural analyses of maize cobs usability. Within this project, a comprehensive fuels evaluation based on fuel analyses according to ÖNORM C 4003: Maize cob – Requirements and test methods with nearly 50 different maize cob samples, as well as combustion trials at two different biomass combustion plants have been performed. While the net calorific value of maize cobs based on dry matter is comparable to wood fuels, the energy density is significantly lower, which influences the fuel transport and storage as well as the feeding system of the combustion plant. Beside comparably high contents of N, S and Cl, the adverse ash melting behavior of maize cobs put high requirements on fuel bed temperature control to avoid slagging problems. Special respect must be regarded to the total dust emissions. Due to their high level further filter concepts will be needed to reach the emission targets of applicable regulations. In summary, it can be stated that maize cobs could be a desirable alternative to wood fuels. Especially in small scale biomass boilers, further research and development is needed to adapt the existing thermochemical conversion technologies and to gain low dust emissions as well as an acceptable slagging behavior.

**Keywords: maize cobs, combustion, biomass, bioenergy**

## 1 Introduction

Presently, the market of fossil fuels is unstable and their prices are constantly rising. As a consequence there is an increased awareness for CO<sub>2</sub>-neutral biomass as fuels for heat production. Furthermore, the European Commission recently presented the 2030 policy framework for climate and energy, where expectations are that by 2030, the share of renewable energy will be of at least 27% and biomass can play an important role [1]. In this respect, the recent European policies on biomass have driven consumption of solid biofuels up to new records every year. However, the growing competition for woody biomass in the heating sector, sawmills and pulp industries are increasing the price of wood [2]. Therefore the utilization of alternative, so called "new" biomass fuels in combustion processes, covering energy crops and agricultural residues, has gained rising relevance. Within the broad variety of agricultural residues, maize cobs represent an interesting source of biomass with high potential in many European countries. New developments in harvesting technology have created the possibility to harvest maize cobs as a by-product of maize harvesting. Since that time maize cobs are more and more under consideration as competitive agricultural solid biofuel. Especially in regions which are dominated by arable land, with a low forest percentage, this biomass source might be used for the production of heat in biomass boilers. In Austria approximately 200.000 ha of maize for corn production are cultivated [3]. As rough estimation 1 t of maize cobs per ha can be harvested. This makes an overall potential of 200.000 t per year of maize cobs for the use as raw material and for energy purposes.

Depending on the cultivation and harvesting technology, the corn variety and the climatic conditions, maize cobs have several varying characteristics when compared with other agricultural biomass feedstock. The Austrian standard ÖNORM C 4003: Maize cob – Requirements and test methods has been developed on the basis of the European standard EN 14961-1: 2010-04-01 Solid Biofuels – Fuel specifications and classes – Part 1: General requirements. This national standard includes a general master table with the most relevant quality parameters. These parameters are the length, the amount of fines (particles < 3,15 mm), portion of husks and stalks, water content, ash content, content of nitrogen, chlorine and sulphur. The so called informative parameters are the ash melting behaviour (deformation temperature, DT), the bulk density, the net calorific value and the contents of major and minor elements [4].

There are several benefits from expanding the spectrum of biomass raw materials used in small-scale combustion systems. Agricultural residues have a huge potential due to their wide range and large quantities produced annually. Furthermore the use of agricultural residues can provide an additional source of income for farmers and more job opportunities for green jobs and agricultural engineering industry. Beside the economic benefits, the utilization of agricultural residues show the ecological potential of restoring degraded lands and preventing soil erosion [5].

While small-scale wood combustion systems have been well developed and reached a high quality level in Europe, the utilization of agricultural residues as a fuel is an ongoing challenge. The elemental composition of new biomass fuels is often rich in alkali metals as well as N, S, and Cl [6]. Compared to wood fuels, the combustion of these new biomass fuels of agricultural origin lead to higher NO<sub>x</sub>, HCl and SO<sub>2</sub> emissions and may also cause the formation of dioxins and furans [7]. Due to higher contents of critical inorganic elements, ash related problems like aerosol and deposit formation, corrosion and slagging can be expected. Especially the higher dust emissions and the slagging can disturb the combustion process and lead to higher CO emissions or unwanted shutdowns of the boiler [8].

The emissions and ash related problems in the line of the combustion of maize cobs in large scale combustion plants are well investigated and under control due to technical measures. But there is still insufficient information available regarding the suitability in small-scale systems. The introduction of new biomass fuels like maize cobs that potentially may cause higher emissions as conventional fuels should be first evaluated based on results from combustion tests. In order to investigate relevant combustion related characteristics of maize cobs, combustion tests as well as comprehensive fuel quality analyses have been performed by Josephinum Research in cooperation with the Austrian biomass boiler manufacturer Hargassner and the BLT Wieselburg within a national project financed by The Austrian Research Promotion Agency (FFG).

## 2 Materials and methods

### 2.1 Fuels Properties

All conducted fuel quality analyses were done according to the relevant standard methods. A list of all properties is presented in Table 1.

**Table 1:** Analysis parameters and their corresponding determination standard

Parameter	Analysis standard
Length [mm]	Manual measurement
Amount of fines < 3,15 mm [weight-%]	EN 15149-1
Portion of husks and stalks [weight-%]	Description in ÖNORM C 4003
Moisture content [weight-% as received]	EN 14774-2
Ash content [weight-% of dry basis]	EN 14775
Nitrogen content [weight-% of dry basis]	EN 15104
Chlorine and sulphur content [weight-% of dry basis]	EN 15289
Ash melting behaviour [°C], Deformation temperature (DT)	CEN/TS 15370-1
Bulk density as received [kg.m <sup>-3</sup> ]	EN 15103
Net calorific value on dry basis [MJ.kg <sup>-1</sup> ]	EN 14918
Content of major and minor elements [mg.kg <sup>-1</sup> ]	EN 15290, EN 15297

The physical and thermo-chemical properties of the maize cobs mostly were done in the laboratories of the BLT in Wieselburg Austria. The laboratory in Wieselburg is accredited as test lab for liquid and solid biofuels according to EN ISO/IEC 17025:2007.

### 2.2 Combustion equipment

The combustion tests were performed with two different biomass boilers originally designed for wood chips and wood pellets. Both boilers, commercially available for standard wood fuels, have not been redesigned or modified for the utilization of maize cobs. The first boiler had a nominal thermal capacity of 150 kW and was equipped with a lambda sensor, a screw feeder and a horizontally moving grate, a water cooled furnace consisting of a primary and a secondary combustion zone as well as a multi-cyclone for fly ash precipitation.

The second boiler had a nominal thermal capacity of 60 kW and was equipped with a lambda sensor and a rotating grate for ash removal. This boiler was without any secondary measure for reduction of dust emissions.

In order to control the combustion temperature both boilers were applied with flue gas recirculation below the grate.

### 2.3 Experimental test setup

The combustion plants were installed at the BLT boiler test bench in Wieselburg, Lower Austria. The heating tests were performed with different maize cob fuels cropped by different harvesting systems in autumn 2011, 2012 and 2013. The combustion tests were carried out according to the standard EN 303-5:2012-10: Heating boilers - Part 5: Heating boilers for solid fuels, manually and automatically stoked, nominal heat output of up to 500 kW - Terminology, requirements, testing and marking [9]. During the test runs the combustion plants have been operated with maize cobs from the beginning and the tests have been performed at full and partial load (30 % of full load). A schematic layout of the experimental setup is presented in Figure 1.

During the test runs relevant data such as flue gas temperature, boiler load, combustion air and flue gas flows were recorded. A constant flow of flue gas was extracted and continuously measured using standard flue gas analyzers for O<sub>2</sub>, CO<sub>2</sub>, CO (NGA), NO<sub>x</sub> (CLD), and OGC (FID). The particle matter was sampled isokinetically using a gravimetric method according to

EN 303-5:2012, Annex A - Manual measurement of particles in the gas flow, gravimetric determination of particle load with filter systems. The particle size distribution has been measured by using an ELPI (Electrical Low Pressure Impactor).

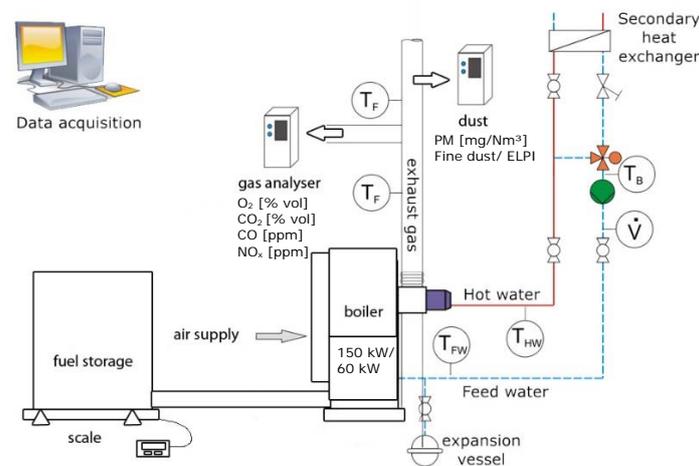


Figure 1: Scheme of the experimental setup used and positions of measurement points.

### 3 Results

#### 3.1 Combustion related fuel characteristics

The whole process of the thermochemical conversion of biomass fuels, including combustion system, solid and gaseous emissions are strongly influenced by their physical characteristics and chemical composition. Therefore the investigation of the fuel quality of maize cobs compared to conventional wood fuels is an important issue addressed in this publication. Almost 55 different maize cob samples, coming from different maize varieties and harvesting technologies, have been analysed within the project. In Table 2 the results of the fuel analyses are summarised as well as the limits within the ÖNORM C 4003:2012 are presented.

Table 2: Analysis results versus the limits of the ÖNORM C 4003:2012

Parameter	Limits	Analysis samples	Average	Minimum	Maximum
Amount of fines < 3,15	≤ 1,0 [w-%]	28	2.20	0.40	11.10
Portion of husks and stalks	≤ 5,0 [w-%] ≥ 5,0 [w-%]	13	5.55	0.16	18.23
Moisture content	≤ 20 [w-%] 20 % < x ≤ 30 [w-%] > 30 [w-%]	55	37,8	14,5	67,50
Ash content	≤ 4,0 [w-%]	55	1,93	1,09	3,56
Nitrogen (N) content	≤ 0,70 [w-%] ≤ 1,50 [w-%]	5	0.46	0.08	0.79
Chlorine (Cl) content	≤ 0,15 [w-%]	9	0.20	0.17	0.26
Sulphur (S) content	≤ 0,10 [w-%]	9	0.04	< 0.02	0.06
Ash melting behaviour	---				
SST	[°C]	39	741	525	1137
DT		39	831	935	1137
HT		39	1086	935	1342
FT		39	1167	990	1408
Bulk density (wf)	--- [kg/m³]	15	112	50	165
Net calorific value	--- [MJ/kg]	55	17.54	16.99	17.88
Carbon content	--- [w-%]	5	47.07	45.80	48.57
Hydrogen content	--- [w-%]	5	6.21	6.07	6.59

The data clearly show the differences of maize cobs compared to wood fuels. Maize cobs show a lower bulk density with an average value of 112 kg/m<sup>3</sup> whereas wood chips have a typical

bulk density of about 200 kg/m<sup>3</sup> and wood pellets more than 600 kg/m<sup>3</sup>. Furthermore the N and S content of maize cobs are higher and especially for CI, the results show values 10 times higher than the one usually measured for wood fuels. These concentrations show a high risk of high temperature corrosion, HCl and SO<sub>x</sub> emissions. While the net calorific value is in a similar magnitude, the ash content is higher than for wood chips or pellets. Due to the high content of ash forming elements, like Si and K as well as the low Ca concentration, maize cobs show a significant different ash melting behavior. The average deformation temperature of below 850 °C could lead to problems during the combustion process in the heating boiler. One of the major problems regarding the thermal use of maize cobs is the water content at the time of harvest, especially in region north of the Alps. In Lower and Upper Austria, the measured water content of maize cobs ranges between 40 and 65 %, depending on climatic conditions and Maize variety, with the consequence that maize cobs have to be dried before storage and combustion. Otherwise mold growth and deteriorating fuel quality result within a few days.



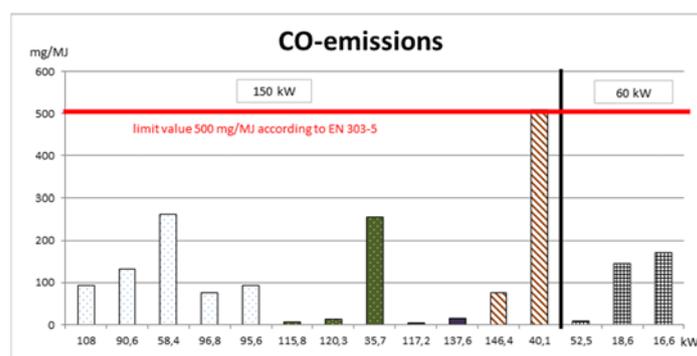
**Figure 2:** Pictures of maize cobs with low and high content of husks and molded cobs during storage of non-dried material.

## 3.2 Emissions

Strongly related to the properties of biomass are gaseous and particulate emissions generated by the combustion process.

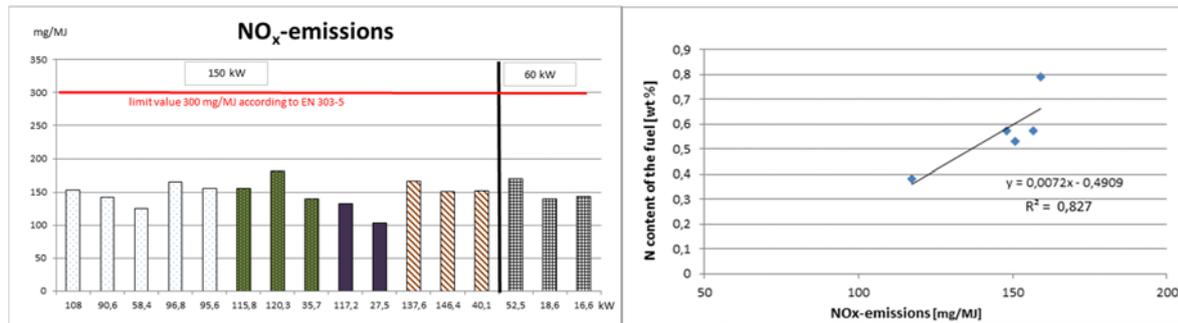
### 3.2.1 Gaseous emissions

The CO emissions varied significantly among the performed combustion tests and were in general higher than in the case of wood combustion. The graph below shows, that the CO-emissions are lower with higher heat capacity, in case of the 150 kW boiler as well as for the 60 kW heating boiler. The red line is marking the legal requirements defined in the EN 303-5:2012 Appendix C.2 for Austria with 500 mg/MJ. All performed combustion tests with both boilers, different maize cob fuels (shown with different colors of the bars) and heat capacities fulfill the CO emissions legal requirements. The enhanced CO concentration of one combustion test could be partly explained, that slag formation during combustion could have caused an uneven flow of combustion air through the fuel bed and therefore affects the char and gas-phase burnout.



**Figure 2:** CO-emissions in mg/MJ referring to the EN 303-5:2012 Appendix C.2 for Austria.

Figure 3 shows the NO<sub>x</sub> emissions and the nitrogen conversion rate as the correlation of different nitrogen contents of the used maize cob fuels and the NO<sub>x</sub>-emissions. Under normal operating conditions, the combustion temperatures are below 1300 °C and therefore the NO<sub>x</sub>-emissions are expected to be due to the nitrogen bound in the fuel [10].



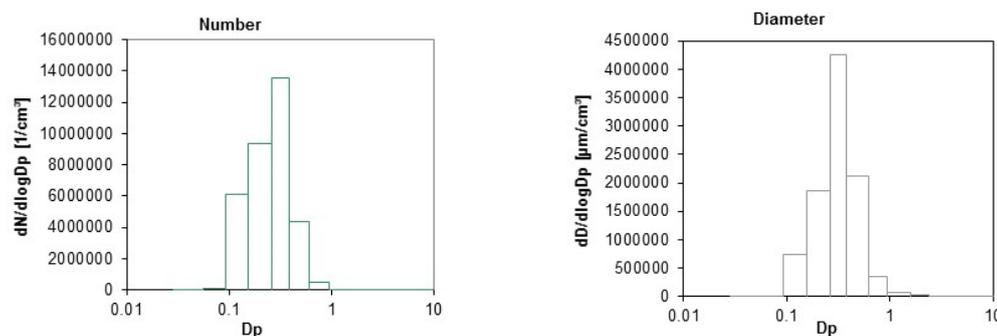
**Figure 3:** NO<sub>x</sub>-emissions in mg/MJ referring to the limit value of EN 303-5:2012 Appendix C.2 for Austria and in correlation with the N content of the maize cob fuels.

The EN 303-5:2012 does not define NO<sub>x</sub> emission limits, but in Austria, one of the only European country with legal NO<sub>x</sub> emissions regulations for agricultural fuels, the legal requirements for NO<sub>x</sub> are defined with maximum 300 mg/MJ. With measured values between 105 and 180 mg/MJ NO<sub>x</sub> all the performed combustion tests fulfill the legal requirements according to the Austrian law.

### 3.2.2 Dust emissions

The particle emissions are a critical point regarding the combustion of agricultural fuels. The alkaline metals are the responsible fuel components for the inorganic fraction of dust emissions. Further relevant elements are S, Cl, and heavy metals such as Zn [8]. Compared with CO and NO<sub>x</sub>, the emissions of particulate emissions during the maize cobs combustion tests were in general much higher than in the case of woody fuels. The high dust emissions observed during tests are connected to the high contents of alkali metals and sulfur. A strong correlation between dust emissions and ash contents of the used fuels, as often mentioned in literature, could not be observed. The legal requirements for dust emissions of automatically stoked boilers with standardized non-woody fuels are restricted in Austria with 60 mg/MJ and from 2015 with 35 mg/MJ, in Germany even lower with approximately 13 mg/MJ. None of the performed tests with maize cob fuels fulfilled these restrictive limits. In general, to reach the critical level of legal requirements, secondary measures for controlling particle emission might be indispensable.

In Figure 4 the particle size distribution of the aerosol emissions are presented. The graphs show the distribution by number of hits and diameter, with a well-marked peak located on the sixths impactor stage between 0.263 and 0.384 μm.



**Figure 4:** Particle size distributions of fine dust emissions measured during a combustion test with maize cobs.

### 3.2.3 Ash and slagging

The higher ash content is responsible for the ash deposition. As presented in 3.1 the ash content of maize cobs is two to four times higher than in wood fuels. Therefore the work for ash deposition is increased in the same ration. That the combustion of maize cobs carries the risk for slagging could be derived from the changed ash melting behavior. Especially in case of thermal output of higher than 130 kW (boiler 1) ash sintering as well as slag formation could be observed. However with lower heat capacity and lower grate temperature, only minor sintering and slagging occurred, which had no noticeable effect on the combustion process or operational reliability of the boiler.

## 4 Conclusions

In practice maize cobs are used to replace wood chips as fuel for heat production. In order to evaluate the suitability of maize cobs as fuel for small scale heating boilers, it is important to investigate the combustion related fuel properties as well as the capability of the existing small-scale combustion technology. Therefore comprehensive fuel quality analyses with several different maize varieties have been carried out and commercially obtainable wood fuel boilers have been used to investigate the gaseous and particulate emissions, the slag tendency as well as the reliability of boiler operation in case when wood chips are replaced by maize cobs without any technical modifications. Following conclusions can be drawn:

- In the maize production regions of western Lower Austria and Upper Austria the biggest challenge is to get the maize cobs dry enough for avoiding storage losses. In most cases an artificial drying is necessary. But at the harvest time the dryer capacities are fully covered with the maize kernels.
- In general the set limits for the respective parameter in the Austrian Standard ÖNORM C 4003 are suitable for the characterisation of the maize cobs with the exception of the chlorine content, this value is mostly over the set limit stated in the Austrian standard.
- The emissions from maize cob combustion are in general higher than during the combustion of woody biomass. The legal requirements defined in the EN 303-5 could partly satisfied. The particle emissions are a critical issue and further investigations with secondary measures for the reduction of particle emission are needed.
- The high dust emissions result in ash accumulation on the heat exchanger walls, which reduced the boiler efficiency and decreased the cleaning interval.

The results and experiences of these investigations show the limitations of the existing technology and provide important information for development of special maize cob fueled small scale combustion systems.

## 5 Acknowledgements

The results presented have been carried out in a national project called "Maisspindeln – Grundlagenuntersuchung zu Verwertungsmöglichkeiten von Maisspindelnutzung (FFG No. 832117)" in cooperation with Josephinum Research and Hargassner GmbH. The project was financially supported by The Austrian Research Promotion Agency (FFG). The authors are gratefully acknowledged for the collaboration and the funding.

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