

## CHARACTERIZATION AND PREPARATION OF BIOMASS FOR CO-COMBUSTION WITH COAL

Volker Siegle, Hartmut Spliethoff, Klaus R.G. Hein  
University of Stuttgart, IVD, Pfaffenwaldring 23, 70569 Stuttgart, Germany  
Tel. / fax: #49-711-685-3575 / #49-711-685-3491

### INTRODUCTION

The reduction of the greenhouse gas CO<sub>2</sub> is the topic of many discussions in Europe. The substitution of CO<sub>2</sub> neutral fuels like biomass for coal in energy production could help to reach this aim. A fast attainable way for the use of biomass is to directly replace part of the coal in power plants. First, demolition and waste wood as well as wood residues from the forest and residual straw from agriculture should be used for co-combustion. In a second step specially cultivated energy plants like salix, poplar and also energy cereals should be taken into account. For the cultivation of salix and poplar farmers have only little experience. Cereal cultivation, however, is state of the art. Therefore the use of cereals as energy crops for co-combustion seems to be a promising technique.

### BIOMASS ANALYSIS

In Germany, analyzing biomass for thermal use is subject to the problem that there are no generally valid guidelines for the method way of carrying out the analysis. Therefore the usual, and also reasonable, methods applied are the same as in solid fuel analysis. To a large extent, this way seems to be justifiable, yet might also arise difficulties. This problem shall be demonstrated by taking the determination of the ash content as an example.

That is, the incineration temperatures for wood fuels, according to the standards (Table 1), vary between 550 and 815°C. For strawlike fuels, there are no regulations at present. The dependence on the incineration temperature of the measured ash content in various fuels is presented in Figure 1. It can be seen that the ash content of all the examined biomass types decreases with rising incineration temperatures. This decrease, however, is particularly clear in the case of straw. The ash content at low temperatures most likely corresponds to content of mineral matter. The part of mineral matter in coal is usually 10% above the ash content. The "content of ash" of the straw sample incinerated at 500°C is 22% above its content at 800°C, the wood sample even shows a difference of 50%.

To find out the inert parts that escape from the ashes at the higher incineration temperature, the main ash components of the incinerated sample were analyzed.

Figure 2 exemplifies the concentrations of ash components, referring to the fuel, of samples of different incineration temperatures. It is evident in particular that the concentrations of calcium, potassium, and magnesium decrease with rising incineration temperatures.

In the case of potassium, a remarkable minimum can be noted in the temperature range of 700°C, both with straw and with wood, which means that the potassium escapes. At higher incineration temperatures, the 700°C range is passed quickly, hence, less potassium escapes because it can be bound to other ash components.

The decreasing ash contents with rising temperatures are of major importance for both pure biomass combustion and co-combustion of biomass in pulverized fuel firing at flame temperatures of 1300 to 1400°C and more, since the escaping substances may substantially contribute to slagging and corrosion. Furthermore, for the ash balance, the consequence arises therefore that the high volatile components have low recovery rates. For instance, by the ash balance of a pure straw flame only 50 per cent of the potassium could be recovered, yet almost 90 per cent of the less volatile sodium. Once the substance has volatilized, it not necessarily deposits again on ash particles when the condensation temperature is reached but on all the available surfaces and thus is lost for the balance, but contributes to slagging and corrosion.

### Biomass Heating Value and its Components

For the investigation of natural biomasses, more than hundred different biomass types were analyzed with regard to their contents of carbon, hydrogen, nitrogen, sulfur and chlorine, and to get their heating value. In addition, analyses analogous to the proximate analysis of coal, were carried out on the biomasses to find out the contents of volatiles, fixed carbon and ash. The fuels investigated were various sorts of straw, wood, whole plants and grains. The volatiles content of

all the biomasses typically range from 76 to 82 per cent. Their fixed carbon content is between 15.5 and 19 per cent. The average carbon content reaches from 47.5 per cent in whole plants and grains over 49.2 in miscanthus to about 51 per cent in wood. Like the carbon content, the average heating value of the biomasses, too, rises from whole plants to wood, i.e. from about 17.6 MJ/kg of annual whole plants over miscanthus with 18 MJ/kg to 18.7 MJ/kg of wood. The mean values, referring to dry, of the investigated biomass components are summarized in Table 2.

The heating value can on the one hand be measured with a calorimeter or on the other be calculated with empirical formulae by elementary analysis. Boie has developed a formula for young fuels (younger than hard coal), which was tested to find out whether it would be applicable also to the youngest fuel, biomass. As a first step though, the expected standard deviations of the two determining methods were compared. To this end repeated determinations of the upper heating value (UHV) of different coals and biomasses were carried out with a calorimeter. The same was done to determine in addition the content of carbon, hydrogen, nitrogen and sulfur as well as the moisture and the ash content. The standard deviation with calorimeter determination method is 150 kJ/kg. From the element contents, the LHV can be evaluated with Boie's formula. With this method of heating value determination, the mean standard deviation was 200 kJ/kg. Thus, in the case of biomasses with their usual heating values between 16,000 and 20,000 kJ/kg, the deviation is about 1 per cent of the full-scale value for both determination methods. These deviations are the limits of accuracy of the analysis systems, and, first of all, they are independent of the fact whether Boie's equation holds or not.

In Figure 3, the lower heating values evaluated according to Boie are outlined above the measured values. The mean values are in the range given by Boie of  $\pm 420$  kJ/kg. Wood, in this case, is rather found at the upper margin whereas the values of gramineous biomass such as straw, whole plants and cereals lie at the lower margin of this range, i.e. Boie's formula calculates the heating value of these fuels by 2.5 per cent too low. This corresponds to the experiences by STÜLPNAGEL ET AL. who obtained values of annual crops which were too low by 3.3 per cent. The scatter around the mean values is clearly lower with the homogeneous biomasses wood and miscanthus than with whole plants, grains, and straw. The conclusion to be drawn from this is that in establishing the heating value by ultimate analysis and Boie's formula, on average, sufficiently precise values will result but by single analyses greater deviations have to be taken into account.

#### **Preparation of Whole Plants for Co-Combustion in Pulverized Fuel Firings**

Whole cereal plants consist of a straw and a grain part. The weight percentage of these two component parts are more or less equal, and the same holds for their weight-related heating value. The density, however, of the two elements differ considerably. The grain's density is distinctly higher than that of straw, which entails a higher energy density of the grain. The measurement of the density is based on gas displacement. In this method, an empty reference sample vessel and another vessel filled with a weighed sample are filled at liquid-nitrogen temperature ( $-196^{\circ}\text{C}$ ) with the same amount of gas. The displaced volume is then evaluated by the pressure difference developing this way. Consequently, the weight data of the probe being given, the particle density can be calculated.

The particle density of straw, and of wood, too, depends on the grain size. Through the increasing size reduction by milling, inclusions of air in the cells and capillaries are opened and accessible for gases. In the coarse state, these inclusions are part of the solid volume. For particle sizes smaller than  $300\ \mu\text{m}$ , this means higher densities. Grains are denser in the state of rawness than straw. Their density, too, increases with smaller grain sizes.

The size reduction of straw and wood is done principally by cutting along the grain, i.e. elongated fibrous particles are produced. Grain milling results in rather compact spherical particles. Decisively important for the ignition and combustion of particles in a pulverized fuel firing is the proportion of surface to volume which, in turn, depends on the particle size.

Figure 3 demonstrates the dependence of surface on volume for different particle forms. The spherical form appears to be the most unfavorable whereas elongated particles show a better surface-to-volume proportion. This makes obvious that grains, in order to complete combustion within the given residence time in a pf firing, have to be ground to a finer size than straw. This could also be demonstrated by combustion experiments.

#### **Combustion Experiments**

For combustion experiments to compare straw and whole plants, straw was milled in a cutting mill with a 6 mm insert sieve, for the whole plants was used a 1.5 mm insert sieve. The obtained mean particle size was about 1 mm with straw, and 500  $\mu\text{m}$  with whole plants. In order to obtain a yet finer grinding, one whole plant was milled several times which brought about a mean particle size of 110  $\mu\text{m}$ . These fuels were combusted in varying thermal shares combined with hard coal in the IVD experimental pf firing facility and analyzed with regard to their burnout. In the case of a decreasing share of the coarsely milled whole plant in co-combustion, a drop in the burnout degree can be recognized whereas with straw and the very finely ground whole plant, the burnout degree stays constantly high. This means that straw in whole-plant preparation has to be ground much too finely in order to have the grain part burned out completely, too.

A complete burnout is the precondition for subsequent pollutant-reducing measures. Because of the high fuel nitrogen content of whole plants, increased  $\text{NO}_x$  emissions from combustion will have to be reckoned on. For this reason, primary  $\text{NO}_x$ -reducing measures in whole-plant utilization are especially important.

Primary measures for  $\text{NO}_x$  reduction should be interpreted as interventions in the combustion course in order to prevent formation of nitrogen oxides from the outset. This can be done either by staged air injection and reburning, respectively, or by an adequate injection of the fuels through the burner. Fig. 5 shows the different ways of fuel injection with a multi-fuel burner. In the case of the configuration "preblended", the fuels are blown in together via the annular orifice, each with 50 m<sup>3</sup>/h carrier air, and with "preblended central" both fuels are injected central. The configurations "coal central" and "biomass central" mean that one of the fuels is injected by the central orifice and the other one by the annular orifice. The effects of the different burner configurations on  $\text{NO}_x$  emissions with various shares of whole plants are represented in Fig. 6.

#### **Cereal and Coal Preblended via Annular Orifice**

In case of the annular-orifice injection, the fuel has already been well mixed with the swirled secondary air when entering the first reaction phase. This results in an increased oxidation of the fuel nitrogen into nitrogen oxide. If biomass and coal are injected through the annular orifice, the  $\text{NO}_x$  emissions slightly decrease with an increasing share of biomass despite the higher nitrogen input. The reason for this are the different ways nitrogen is captured in the two fuels and the lower tendency of the biomass nitrogen to convert into  $\text{NO}_x$ .

#### **Cereal via Centre, Coal via Annular Orifice**

In this configuration, the primary air is split into two even fractions: one injected through the annulus as coal transport air, the second injected through the centre to transport the biomass. The two fractions are the same for all the coal/biomass ratios. As a result, when a pure coal flame is fired, the coal enters the combustion chamber already mixed with only the half of the total primary air. This is the reason why for this flame the  $\text{NO}_x$  emissions are somehow lower with this configuration than with the previous one.

Then, taking small whole-plant shares, the  $\text{NO}_x$  emissions slowly rise until the biomass amount has consumed all its available primary air quantity. From a biomass share of 20% of the thermal input on, the  $\text{NO}_x$  emissions drop distinctly because the fuel is injected into the substoichiometric, inner recirculation zone and part of the fuel nitrogen becomes reduced to elementary nitrogen.

#### **Cereal via Annular Orifice, Coal via Centre**

The pure coal flame here emits the smallest amount of  $\text{NO}_x$  since the whole fuel nitrogen reaches the substoichiometric, inner recirculation zone. With larger shares of biomass, the  $\text{NO}_x$  emissions increase though this rise is less distinct than the drop of the curve in the above case. With a 35% share of biomass the input of nitrogen by biomass and by coal is the same amount each. Consequently, the curves of this configuration are supposed to cut those of the previous configuration in this area. Yet they only do so with a biomass share between 40 and 50%. The reason for this is again the lower tendency of the biomass nitrogen to oxidize into  $\text{NO}_x$ , even if there is enough oxygen available in the area of the biomass injection.

#### **Cereal and Coal Preblended via Centre**

In the fourth configuration, the fuel mixture of cereal and coal, and thus the entire fuel nitrogen, is centrally fed to the inner recirculation zone. The  $\text{NO}_x$  emissions, for biomass shares up to 40%, show the same behavior as in the previous configuration "cereal via annular orifice, coal via centre". However, with more than 40% of biomass, the  $\text{NO}_x$  emissions decrease. The reason for this is that more fuel nitrogen is entered by the biomass than by the remaining coal share. With this burner configuration, the lowest  $\text{NO}_x$ -emission level of the whole sequence of experiments is

achieved with a 100%-cereal flame. The fuel (with these flames) is injected into the inner recirculation zone with two times the primary air amount, i.e. with a high impulse. Due to the lacking oxygen in this zone, only little fuel nitrogen is oxidized into  $\text{NO}_x$ .

## CONCLUSIONS

- Establishing the heating value of biomass by ultimate analysis and Boie's formula, on average, sufficiently precise values will result but by single analyses greater deviations have to be taken into account.
- Because of the different grinding character and particle structure of straw and grain the grain have to be ground finer than the straw to reach sufficient burnout.
- If in an existing swirl burner premixing of fuel is not possible or not desired because of other disadvantages, the fuel with the higher nitrogen content should be injected through the centre into the inner recirculation zone.
- The fuel-N of biomass has a lower tendency to convert into  $\text{NO}_x$  than the fuel-N of coal.

## REFERENZES

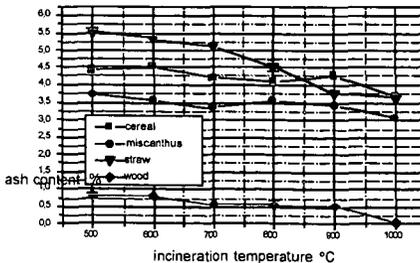
R. Stülpnagel et al.: Investigations for a cheap estimation of the net calorific values of different biomasses, 7th E.C. Conference, Biomass for Energy and Industry, S. 969 - 973, 5.-9.Oct.92, Florence, Italy

**TABLE 1: Incineration temperatures of different standarts**

	application	incineration temperature
ASTM D 3174	Coal, Coke	700 - 750 °C
ASTM E 830	RDF	750 + 25 °C
ASTM D1102	Wood	580 - 600 °C
DIN 51 719	Coal, Peat,	815 + 15 °C
DIN 51 749	charcoal	710 + 15 °C
DIN 52 182	wood pellets	550 °C
Ö-Norm 1074	wood	815 °C

**TABLE 2: Analysisdata of biomass, dry basis**

	volatiles wt %	fixed C wt %	C wt %	H wt %	N wt %	S wt %	Cl wt %	LHV kJ/kg
cereals	79,5	16,0	47,6	5,3	1,13	0,13	0,41	17,6
grain	80,5	17,2	47,5	5,4	1,86	0,11	0,26	17,8
straw	79,5	14,5	46,8	5,4	1,0	0,1	0,5	17,4
Miscanthus	81,0	16,1	49,2	5,8	0,24	0,08		18,0
wood	80,5	17,4	50,9	5,7	0,5	0,09	0,1	18,7



**Fig. 1: ash content depended on incineration temperature**

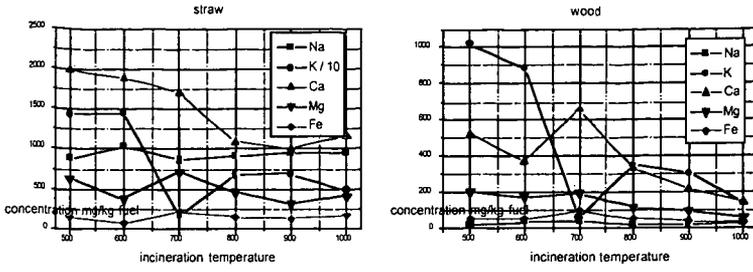


Fig. 2: Concentration of the ash components at different incineration temperatures

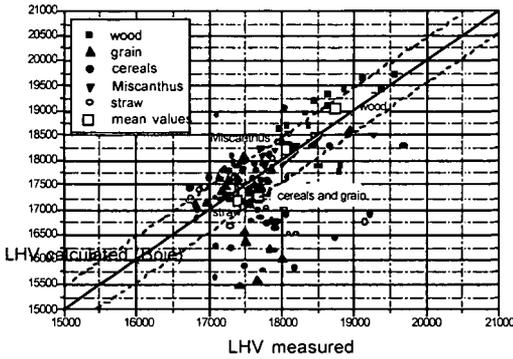


Fig. 3: LHV measured compared with LHV calculated

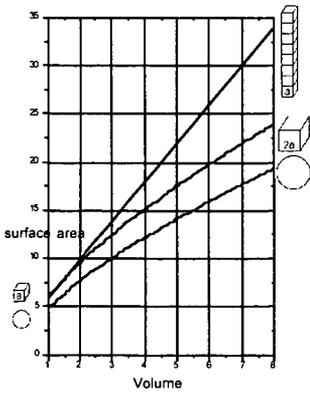


Fig. 4: Dependence of surface on volume

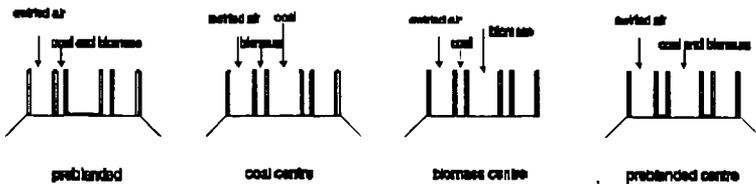


Fig. 5: Burner configurations

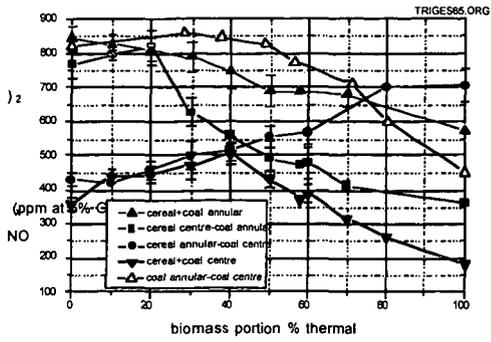


Fig. 6: NO<sub>x</sub> emissions with different burner configurations