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Emissions during combustion of biogas effluents

Increasing amounts of biogas effluents require novel approaches of treatment. The thermal utilization of biogas effluents seems to be a promising alternative to using these effluents as fertilizer. Therefore this paper shows first results of combustion experiments and attests the general suitability as fuel. Flue gas emissions did not exceed the limit values. Coarse ash composition indicates the potential of recycling the ash and using it as fertilizer.

Keywords
Digestate, biogas, combustion, emissions

Abstract
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The number of biogas plants in Germany has doubled in the last 5 years. This has resulted in a fourfold increase in the amount of electrical energy developed. Presently there are 3,900 biogas plants with a total output of 1,376 MW. In 2009, 780 new generating plants with a total output of 200 MW_{el} are expected to be built.

When going through the fermentation process, the digestate remains as a by-product of the substrate. Due to the increasing number of biogas plants the utilisation of digestates is continuously approaching its ecological limits. Furthermore, in many regions in Germany, the utilization of digestates in plant production is limited by the fertilizer controls act and the prevailing surplus nutrients in agricultural land. The transportation over long distances is cost-intensive and often the economical limiting factor. The drying of digestates can be economically efficient and is also technically feasible. As well as being utilized as fertilizer, thermal utilisation has also become a key topic for discussion. As a result biogas-operating authorities are showing great interest in the employment of digestates as fuel.

For this reason, this paper examines the general suitability of digestates for use as solid fuel. At present, digestates are neither included in the literature nor generally accepted as standard fuel or as secondary fuel. The main reason for this is the lack of expertise available on the characteristics of digestates as fuel, its combustion behaviour as well as the composition of emissions. This work attempts to close this gap, by characterising the digestates pellets as a fuel and determining the combustion behaviour in a standard bi-

Fig. 1

Biomass heating system Ökotherm with water-cooled through

Table 1

Elementary composition of the digestate pellets (based on dry matter) compared with spruce wood according to [1]. The bold values are limit values according to DIN 51 731

Element	Unit	Digestate 1	Digestate 2	Spruce wood with bark
Hydrogen	%	5,5	5,2	6,3
Nitrogen	%	2,86	1,54	0,13; **0,3**
Chloride	%	0,843	0,265	0,005; **0,03**
Sulfur	%	0,864	0,328	0,015; **0,08**
Mercury	mg kg^{-1}	0,07	0,04	**0,05**
Zinc	mg kg^{-1}	304	125	**100**
Cadmium	mg kg^{-1}	0,29	0,15	**0,5**
Copper	mg kg^{-1}	58,8	18,2	**5,0**
Lead	mg kg^{-1}	4,4	0,78	**10,0**
Phosphorus	%	1,29	1,14	-
Potassium	%	1,37	1,59	0,13
Chromium	mg kg^{-1}	13,2	21,5	**8,0**
Arsenic	mg kg^{-1}	0,93	0,54	**0,8**
PCB	mg kg^{-1}	<0,001	<0,001	-

omass combustion plant and to assess the flue gas emissions with respect to the allowable limits

Materials and methods

The digestates for the combustion experiments originate from two biogas plants. Biogas plant no. 1 was fed with renewable raw material with the following substrate composition: silo maize (complete plants), grass, grass silage and potatoes. Biogas plant no. 2 was fed with the following substrate composition: maize silage, chicken dung, corncob mix (CCM), green grass silage (sweet sorghum, Sudan grass), straw and pig slurry. The digestate was dried until a water content of 15 to 20% had been reached with a loose powdery consistency. Finally the digestate was formed into pellets. A major reason for doing this was to improve the combustion logistics to facilitate transportation and storage capability as well as to investigate its commercial capability as fuel. As laid down by DIN CEN/TS 14961 the digestate pellets were classified according to their properties such as diameter, moisture, ash, sulphur, fine fraction and nitrogen content. The analysis of trace and bulk elements as well as for heavy metals is according to DIN ISO 11466, DIN EN ISO 17294-2, DIN EN ISO 11 885, DIN EN 1483 and DIN ISO 13878. To determine the PCB (polychlorinated biphenyl) the procedures laid down by the VDLUFA manual were adhered to. The abrasion resistance was determined according to DIN CEN/ TS 14961. For the combustion experiments a biomass heater with a nominal power output of 49kW was used **(figure 1)**.

This biogas plant of the type Ökotherm® is a standard product from A.P. Bioenergietechnik GmbH and is suitable for the thermal processing of wood chips as well as other biomass solid fuels including straw, hay, miscanthus, rapeseed oil cake or horse manure. The boiler is classified as a pusher-type grate boiler with a water-cooled combustion trough and automatic ash removal. In the combustion trough there exist holes on both sides for the primary and secondary air inlets. The lambda probe is positioned in the flue gas exhaust of the boiler. To remove dust from flue gas, an electrostatic filter from A.P. Bioenergietechnik was fitted to the boiler. The temperature and composition of the flue gas was measured at the boiler outlet and at the input to the flue gas exhaust. To determine O_2, CO_2, NO_X, and CO values the gas analyser type RBR-Ecom® KD was used. The dust particle count was determined using the particle analyser type FW 100 from SICK MAIHAK. The combustion experiments were conducted for a period of 20 hours for each type of fuel. Therefore, when the nominal power output had been reached, which is the maximum power achievable, all the flue gas measurements were taken in one-second intervals. The fusibility of fuel ash is according to DIN 51730. The basic composition of the combustion chamber ash was determined using X-ray fluorescence (XRF).

Properties of the digestate pellets

According to the results of the analysis the digestate pellets were classified as follows:

- digestate 1 – D10; M15; A6.0+; S0.20+; F2.0+; N3.0
- digestate 2 – D06; M15; A6.0+; S0.2+; F2.0+; N3.0

Digestate 1 shows a calorific value of 15.8 MJ kg^{-1} with water content of 9.2%. The pellets from digestate 2 showed a calorific value of 15.0 MJ kg^{-1} with a water content of 9.9%. Both calorific values in contrast to spruce wood pellets with 16.3 MJ kg^{-1} and a water content of 12% can be considered as being promising. The elementary composition of the digestate pellets in comparison with spruce wood can be viewed in **table 1**.

The values in bold characters are the threshold values for wood pellets given by DIN 51731. The high values particularly for nitrogen, chloride and sulphur can be regarded as being critical because they are relevant to the emissions. In comparison to spruce wood a ten-fold increase in potassium has a significant influence on the fusibility of fuel ash and therefore will reduce the ash softening point. Combustion technological processes without adequate combustion grid cooling can lead to the formation of caking and slagging of ash. The ash softening points for digestates 1 and 2 were found to be at 1,090 and 1,110°C re-

Table 2

Coarse ash composition compared with spruce wood ash according to [1, 3] in % by weight of dry matter

Element	Digestate 1	Digestate 2	Spruce wood
P_2O_5	13,1	23,8	2,6
K_2O	8,8	20,8	6,4
MgO	1,4	5,4	6,0
CaO	17,2	22,8	41,7
SiO_2	11,6	19,2	25,0

spectively and remained below those values for wood ash with values between 1300 and 1400°C. The melting point of digestate was found to be between 1320 and 1,390°C. Nevertheless comparing this with straw and culm shaped fuel, the ash softening behaviour can be considered as being positive. Hartmann et al. (2007) observed ash melting already starting from 911°C [1]. The ash content of digestates pellets 1 and 2 with values from 18.3% and 14.6% respectively can be considered as being high and in some cases could lead to an increase in the running and disposal costs for large scale plants. In comparison to this, the values of ash content for spruce wood and wheat straw are 0.6 and 5.7% respectively.

Gas emissions

At combustion a maximum power of around 40 kW was generated. The attained efficiency of the biomass combustion was 85%. During the combustion of digestate 1 when the mean flue gas temperature was 227°C and oxygen content was 10.5%, a mean dust particle concentration of 125mg m_N^{-3} was measured. By employing an electrostatic filter this could be reduced to a mean value of 50mg m_N^{-3} with a mean CO_2 value of 10.1%. With respect to the 11.0% O_2 content in the flue gas the mean concentration of carbon monoxide (CO) amounted to 344 mg m_N^{-3} and 418 mg m_N^{-3} for nitrogen oxides (NO_X). For similar flue gas temperatures and an O_2 content of 11.5% the dust particle concentration for the combustion of digestate 2 on average amounted to 133 mg m_N^{-3} and could be reduced to 54 mg m_N^{-3} by employing an electrostatic filter. The CO_2 concentration amounted to 130 mg m_N^{-3} and the NO_X concentration 497 mg m_N^{-3}. According to the appendix of revision 4 of BImschV (Federal Emission Control Act), digestate pellets are not classified as standard but as non-standard fuel. Up to a thermal output of 100 kW, formal compliance to BImschV is not required. On the other hand the criteria of 150 mg m^{-3} for dust particles and 2000 mg m^{-3} for SO_2 must be adhered to as stipulated by revision 1of BImschV. These limits were not exceeded when conducting the experiments. For processing plants with a thermal output <1 MW the tighter limits of concentration imposed by the TA Luft (German Technical Instructions on Air Quality Control) for a CO value of 250 mg m^{-3} as well as the limits for C_{ges} (50 mg m^{-3}), NO_2 (400 mg m^{-3}) and SO_2 (2000 mg m^{-3}) must be complied with. Criteria for nitrogen oxides can be easily met by selecting the optimum parameters for the combustion process. For C_{ges} and SO_2 there are presently no results available and therefore no conclusion can be drawn.

Composition of ash

Table 2 shows the composition of the coarse ash in comparison with spruce wood. The digestate ash generally shows a higher concentration of the main nutrients of plants. Traces of nitrogen were not detected because it had almost completely dissipated during combustion. The silicon oxide content was found to be below normal values for spruce wood and can be regarded as being innocuous, since silicon oxide reacts ecologically neutral with soil and is readily soluble [2]. The aluminium oxide content in comparison to that in spruce wood can also be regarded as being innocuous. The concentration of the elements Cu, Zn, Co, Mo, As, Ni, Cr, Pb, Cd, V and Hg was below the detection limit of 0.1%. For further detailed investigations of heavy metal contaminants an accurate verification procedure should be implemented. Essentially, it can be assumed that the agricultural utilization of coarse ash from digestates can be regarded as being innocuous.

Conclusions

Digestate pellets are showing great potential as a marketable mono fuel. The production of pellets without additives is feasible and the mechanical stability is satisfactory. Nevertheless, the high ash content requires a greater expenditure for the producer and for waste disposal. For private use at home digestate pellets have only a limited use due to the odour produced during storage. For the utilization in agriculture and in large-scale heating plants no disadvantages could be identified. The chemical composition of the fuel and emissions are dependent on the substrates added during fermentation, which means that no general independent conclusion could be formulated. Hence, there is a requirement for further research to investigate the relation between substrates and emissions during the combustion process.

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