Jürgen Beck, Ralf Schmalzbauer and Thomas Jungbluth, Hohenheim

Thermal Utilization of Animal Wastes

Animal excrements contain considerable amounts of energy, which can be augmented by adding litter material. Thermally utilising animal wastes taps into a yielding regenerative energy source. To obtain the heating values of faeces, urine, litter substrates and solid manures for further alternative utilization, the substrates were first extensively investigated with adiabatic calorimetry. Except for urine the substances had an average heating value of about 20 MJ kg^{-1}. A pyrolysis plant laboratory supplemented this by measuring the net calorific values of the pyrolysis products.

Dr. Jürgen Beck is a scientist at the department Livestock Systems Engineering (Head: Prof. Dr. T. Jungbluth), Hohenheim University, Institute of Agricultural Engineering, Garbenstraße 9, D-70599 Stuttgart; e-mail: *jafbeck@uni-hohenheim.de*
DIa Ralf Schmalzbauer was a student at the department and is now member of the staff of the company WS-Reformer GmbH in D-71272 Renningen.
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Keywords

Animal manure, litter material, gross calorific value, net calorific value, pyrolysis, incineration

Literature

Literature references can be called up under LT 06320 via internet http://www.landwirtschaftsverlag.com/landtech/local/literatur.htm.

The regional problems with animal waste are of actual concern. To enhance their income, the livestockl farms have enlarged their herds continuously. The results were high stocking densities with increasing environmental problems such as over-manuring, emissions of harmful gases and odours, eutrophicated ground resp. surface waters, and additional dangers through pathogens [1]. These problems do not only exist with cattle, pigs and poultry, but also with horses. About 1.6 million persons in Germany ride more than 1 million horses and ponies. Many of the horses are kept in 7063 riding clubs or by private ownersm without reasonably using the plant nutrients in the manures. Today this is a considerable environmental problem (9 t per horse and year). The horse manure is now dry, bulky and poor in nutrient contents, due to increasing daily litter input per horse. Since more and more wooden litter substrates are used, the acceptance of these manures by crop farmers is reduced [2]. Today horse owners have to pay up to 430 Euro per horse and year for commercial waste treatment [3].

Aims

To solve the problem, a treatment process must be found, which would be able to reduce the waste mass and to eventually recover precious nutrient compounds e.g. phosphorus. Dried animal manures are traditional fuels in countries which lack fuel wood. It is therefore logic to consider them as a source of regenerative energy. This has been investigated in two laboratory trials. At first the heating values of different litter, faeces, urine and manure samples were determined [4] and subsequently the suitability of these waste materials for pyrolysis [5].

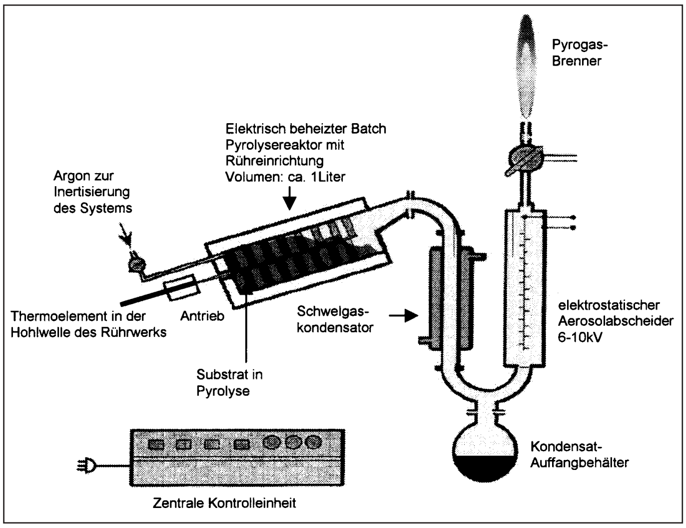

Fig. 1: Schematic illustration of the laboratory pyrolysis unit ([10], modified)

State of Knowledge

Compared to incineration or gasification, pyrolysis is done under exclusion of oxygen. The differentiation into separate process areas and phases of degassing is temperature dependent. With pyrolysis in general the following products are generated:

- combustible pyrolysis gases (smouldering gases),
- oils, tar and watery condensates as well as
- carbonaceous solid residues (pyrolysis coke).

The shares of the products depend on pyrolysis temperature. At low temperatures proportionally more pyrolysis oils and cokes are generated. Higher temperatures are able to shift the balance to a higher gas generation [6, 7]. The medium temperature pyrolysis (500 °C until 800 °C), having been used in the own trials, generates during the smouldering process mainly permanent gases (H_2, CO_2 and CH_4) out of the liquid organic products and out of the solid carbon [8].

Material and Methods

To estimate the energy potential in animal residues a first investigation has been carried out. The trials in adiabatic calorimetry included five different wooden litter substrates, four consisting of straw, three of chopped hemp and flax stems, as well as six different horse faeces and two horse manures, which were tested for their gross calorific and also their net calorific values. The freed energy was determined from the dried and minced substrate samples of 0.7g each, after they had been incinerated in the pure oxygen atmosphere of a bomb calorimeter (IKA C4000 A, [9]) at the Institute of Animal Nutrition at Hohenheim University.

The pyrolysis products were obtained at a reactor temperature of 550°C in the laboratory pyrolysis unit at the Institute for Sanitary Engineering, Water Quality and Solid Waste Management of Stuttgart University and got subsequently evaluated for their net calorific values. Prior to every measurement the reactor, the condenser for smouldering gases, and the electrostatic aerosol trap were individually weighed after having been cleaned. Subsequently the reactor (*Fig. 1*) was filled with pre-dried substrate (faeces, urine or litter). After assembling the lab pyrolysis unit, the system was flushed with argon (for inertisation). By activating the electric heating (target temperature 650 °C, heating rate 3 K s^{-1}) the experiment started, and meanwhile the reactor got heated up to 550 °C. The escaping pyrolysis gas flowed through the water cooled condenser (cooling temperature 7°C), where the condensable share was separately collected. The permanent gas streamed subsequently through the electrostatic aerosol trap (voltage 6 to 10 kV), where it was purified from smallest particles, before it burnt above the ignition flame. During the experiment temperature inside the reactor and height of the flame were measured. Apart from that, the generated condensate and the intensity of the condensate flow was visually evaluated and the beginning of H_2O – condensation was registered. With the increase of the condensate flow the first pyrolysis products condensed as tar and oil. After the cooling phase (over night) the unit always had to be deconstructed to pieces which had to be weighed. The processing of a single sample lasted therefore between 3 and 4 hours. The amount of residue, i.e. pyrolysis coke, condensable share of pyrolysis gas (tars and oils) and permanent gas (H_2, CO) were determined by mass subtraction. From the results mass balances were compiled.

Results

In total gross calorific values of about 20 MJ kg^{-1} dm were analyzed for the substrate groups with exception of urine. If the litter variants were regarded in particular, the following ranking (by gross calorific value) with decreasing values was found: Wood ⇒ fiber plants ⇒ straw.

After urine had been added to the litter substrates, the gross calorific value decreased by nearly 20 % (if saturated). If additionally faeces were mixed to litter and urine, as they are regular components of manure briquettes, the gross calorific value kept an average high level. During the pyrolysis investigations the gross and net calorific values of the single pyrolysis products (coke and smouldering gas) were analyzed from different litter substrates, from manure briquettes out of horse manure, as well as from faeces and urine originating from pigs, cattle and horses (*Table 1*).

The coke samples represented, depending on substrate a share of 26.6% up to 66.5%, whereas the shares of smouldering gas varied between 33.5 and 73.4%. Subsequently the input substrates as well as the pyrolysis cokes were treated in an elementary analysis. The C-, H-, N-contents of the input substrates were compared to those of the generated pyrolysis cokes. Therefore the content of the energy carrier carbon was increased by up to 36.1%, thus increasing the energy content. By using the data from the elementary analysis the net calorific value of the input substrates and of pyrolysis cokes could be approximately calculated.

The *net calorific values (H_u) of the pyrolysis coke samples* were, apart from pig faeces and the whole group of urine substrates, higher than the net calorific values (H_U) of the input substrates. The net calorific values of the cokes from litter substrates were between 60 % to 80 % higher than the net calorific values of the input substrates, whereas the cokes from faeces merely arrived at + 25 %. An exception was coke from pig faeces, which had around 10 % lower net calorific value than the input. For this effect the ash and carbon contents were responsible.

As the ash contents in the group of urines reached maximum values (up to 64.2% in dm of cattle urine input) and the C-contents were very small, all urine variants showed a reduced net calorific value of the pyrolysis cokes compared to the input substrates. In the case of cattle urine only a corrupt negative net calorific value could be calculated (high ash contents, low contents in C, N and S, possibly mistakes during sampling and processing).

The *net calorific values (H_u) of pyrolysis gases* from litter substrates and manure briquettes ranged between 11890 kJ kg^{-1} (hemp stems - B) and 14272 kJ kg^{-1} (flax stems - W). In the faeces group, net calorific values for horse and cattle faeces of about 15000 kJ kg^{-1} were calculated. Pig urine reached 11300 kJ kg^{-1}, whereas the pyrolysis gases from horse urine achieved up to 15318 kJ kg^{-1}. In available publications strongly differing information was found about the net calorific value of pyrolysis gases. For waste material from pig husbandry a net calorific value of 3256 kJ kg^{-1} was found out [11]. These data must be compared under restriction because the focus of this trial was on gas generation with different process parameters (e.g. temperature and pressure).

Table 1: Calorific value (H_o) and heating value (H_u) of input substrates, pyrolysis cokes and gases (n.b. = not analysed)

Substrate	Input substrate H_o* (kJ kg^{-1})	Input substrate H_u (kJ kg^{-1})	Input substrate H_o (kJ kg^{-1})	Coke H_u (kJ kg^{-1})	Gas H_u (kJ kg^{-1})
Hemp stems - B	19337	17113	18431	29656	11890
Hemp stems - W	19672	18113	19453	30541	13423
Flax stems - W	20063	18240	19580	29190	14272
Miscanthus	n.b.	16563	17793	24902	12437
Straw pellets - B	18739	16485	17782	26585	12011
Straw pellets - S	19429	17807	19169	27898	13379
Wood granulate - R	20114	18363	19724	31695	13075
Manure briquette	19409	17983	19345	29239	12159
Pig faeces	n.b.	18948	20332	17542	19770
Cattle faeces	n.b.	17843	19139	21278	15730
Horse faeces (mare)	19070	18004	19332	23622	14297
Horse faeces (pregnant mare)	19087	17791	19087	22247	14966
Horse faeces (stallion)	19142	18417	19735	23397	15403
Pig urine	n.b.	10527	11362	9706	11300
Cattle urine	n.b.	8288	8981	*-1820*	n.b.
Horse urine	9464	8792	9407	4047	15318

*measured values [4]

Conclusions

Farm yard manures have a considerable CO_2 – neutral energy potential with thermal utilization. One thermal process to win energy from these substrates is pyrolysis. To use its final products as biogenous fuels could be in future a promising solution to reduce the partly considerable manure excesses on farm and regional basis. Hereby not only the manure masses are radically reduced; after the final utilization of the pyrolysis coke only a nutrient rich ash fraction without nitrogen remains.

Nevertheless it is possible to generate e.g. from one ton of fresh horse manure about 83 kg of pyrolysis coke with a net calorific value of about 2 420 000 kJ (~674 kWh) thus being equal to about 58 l of fuel fuel.