

OAT HUSKS IN ANAEROBIC DIGESTION

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Abstract

Oat husks, a by-product from mills, are suitable to be used as litter material in animal barns especially in regions with scarcity of straw or other bedding materials. The performance of oat husks in anaerobic digestion was studied. Total methane potential of oat husks and degradation over time for both untreated and ground oat husks were determined using a test at bench scale. Based on the laboratory results and the individual methane yield of each manure component, the methane production of a full-scale innovative two-stage dry digestion plant (consisting of a continuous dry system followed by a fixed bed reactor for the enriched liquid phase) was evaluated in terms of contribution of the components in the solid dairy manure (including oat husks) to overall biogas generation.

Results from the laboratory tests indicate that the methane potential of oat husks (determined with $242 \text{ L}_N \text{ CH}_4 \text{ kg}^{-1} \text{ VS}_{\text{added}}$) is on the level of straw. At a digestion temperature of 37°C 65% of the total methane potential was converted within four weeks and 84% within six weeks, using untreated oat husks. The innovative dry digestion plant is suitable to process materials which in conventional wet digestion would experience high risk of stratification. Assessment of methane production from the different components of the digested manure reveals that methane production from the litter material represents a significant proportion of the total biogas generation.

1- INTRODUCTION

While so-called “dry digestion” processes with in general >20% Total Solids (TS) content are widely implemented to treat municipal solid waste, slurry-based liquid-phase digestion is the predominant technology in agricultural biogas production. At conventional slurry-plants, digestion of solid biomass is limited due to technical restrictions e.g. related to mixing and feeding devices. In addition, phase separation has been observed with lignocellulosic material (e.g. fibrous horse dung floating on top of the liquid phase [1]), which means that running a continuous slurry-based digester with higher ratios of such materials is unsuitable. Technologies appropriate for operation with elevated TS-contents are imperative, and in general transfer of expensive municipal systems will be limited due to different characteristics of the materials and the fact that smaller throughputs will in general be sought in agriculture.

An innovative continuous two-phase two-stage prototype biogas plant at the Yttereneby farm in Järna, Sweden resumed biogas production in 2003. The first stage was designed as solid-phase reactor (dry digestion, hydraulic retention time 26 days) and the second stage, digesting the liquefied output of the first stage (solid fraction is removed), as fixed bed reactor with 16 days retention time (Figure 1). A detailed documentation of the plant has been published [2,3], along with a careful assessment of its process efficiency [3]. The biogas plant digests solid dairy manure, a mixture of excreta, straw and oat husks. Oat husks, a by-product of the mill nearby, supplement the limited quantity of on-farm produced straw as litter material.

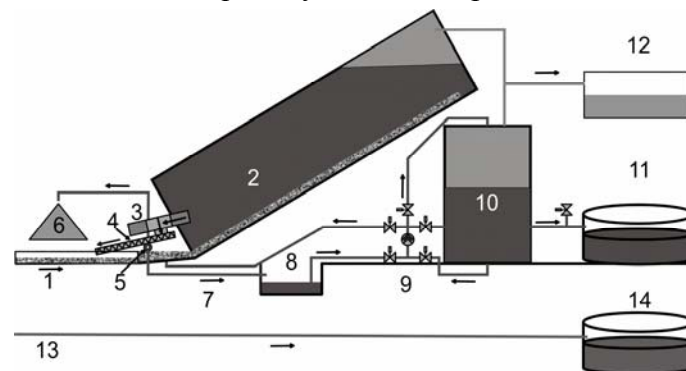


Figure 1: AD plant at the Yttereneby farm. 1 feeder channel; 2 first stage digester; 3 drawer for discharging; 4 discharge screw; 5 solid fraction separation screw; 6 solid residue after first stage; 7 drain pipe for liquid fraction; 8 liquid fraction buffer tank; 9 pump and valves; 10 second digester (fixed bed); 11 effluent tank; 12 gas sack; 13 urine pipe; 14 urine tank. [4]

Oat husks and straw are lignocellulosic biomass. Biogas production with this substrate type is a slow but steady process in which methane originates mostly from hemicellulose and cellulose, but not from lignin [5]. The reaction rate is directly related to the surface area to which hydrolyzing bacteria can attach [6]; hence size reduction of substrate particles is one approach for increased biodegradability [7].

Figures related to the biogas yield of cattle excreta and straw are available from literature, but performance of oat husks in AD has not been studied previously. In addition, the term manure is not precise, as it may be one of the following mixtures: faeces + litter, excreta = faeces + urine, excreta + litter, excreta + litter + left over of fodder, excreta + litter + leftover of fodder + wastewater, which makes it difficult to compare biogas yields reported for manure.

Total methane potential of oat husks and degradation over time for both untreated and ground oat husks was determined. Based on the laboratory results and the individual methane yield of each manure component, methane production of the two-stage dry digestion plant in Järna was assessed in terms of contribution of the manure components to overall biogas generation. Experimental and methodological procedures in laboratory testing and results of applying the

findings to the full-scale plant have been described in detail in a previous publication [4]. This publication compiles and evaluates the main findings and amends additional information.

2- MATERIALS AND METHODS

The biogas yield of oat husks was determined at the laboratory of the Institute for Agricultural Engineering at the University of Hohenheim with the Hohenheim Biogas Yield Test (HBT). The HBT is a patented batch test (German patent DE10227685), in which the reactor is a 100 cm³ glass syringe (flask sampler) with a capillary extension. Flask samplers are rotated in a motor-driven rotor during the anaerobic digestion (incubator). The generated biogas expands and presses the stopper out of the flask. The volume of the generated biogas is recorded periodically by reading the position of the stopper in the scaled flask. After every reading the stopper is pushed back to evacuate the biogas. The transfer of gas into an analyser provides a measure of the volumetric methane content of the dried biogas. For more details see [4,8].

Oat husks were collected from the Yttereneby farm. Triplicate samples of both untreated and ground oat husks (< 1 mm) were digested. Grinding was performed using a laboratory cutting mill (type Retsch SM300; bottom sieve with aperture size 1 mm). A representative sample of the homogenized material was assured by applying the quartering method. Each HBT flask contained 0.5 g of test substrate and 30 cm³ of digested liquid manure as inoculum. Additionally, mere inoculation material was digested as zero variant with three replicates. Incubator temperature was set to 37°C. One of the replicates of untreated oat husks failed. Gas volumes were corrected to norm litres (L_N), taking into account norm pressure and norm temperature (1.013 bar, 0°C), as well as the gas yield from the inoculum.

The total methane potential of oat husks was determined from the experimental data obtained with ground oat husks in the HBT. After 49 days, the test was brought to an end. The total methane potential $G_{pot} = G(t \rightarrow \infty)$ was calculated by extrapolation, based on a non-linear curve fit for the experimental data of the decay phase (declining gas production rate, see Figure 2). A previous publication describes the methodology in detail [9]. It was assumed that gas production in the decay phase could be best described by the sum of two decay functions in the following form (with $G(t)$: methane yield at time t ; a , b_1 , b_2 , k_1 , k_2 : const.):

$$G(t) = a + b_1 \exp(-k_1 t) + b_2 \exp(-k_2 t) \quad (1)$$

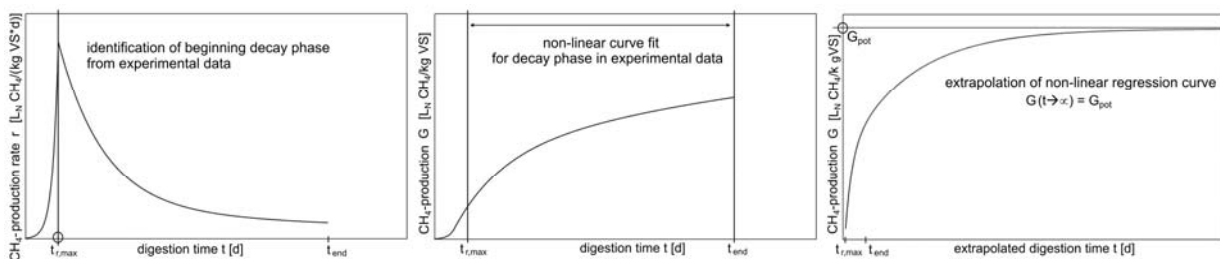


Figure 2: Methodology for determination of total methane potential (G_{pot}) by extrapolation from experimental data [9].

The actual methane yield depends not only on the total methane potential, but also on digestion time and degradation kinetics, which are influenced by substrate characteristics and process conditions. The exploitation degree $q_t = G_t/G_{pot}$ indicates the proportion of G_{pot} released at a specific point in time.

To estimate the biogas potential of solid dairy manure and its components at the full-scale plant in Järna, recorded data were used. The daily amount of dairy manure including the

individual proportions of excreta, straw and oat husks, as well as main parameters of each of the fractions and of the mixture (TS, volatile solids (VS)) were derived as described in detail in [4]. The specific methane yields of excreta and straw were taken from literature [10], and together with the experimentally determined methane yield of oat husks the anticipated methane production of the full-scale plant was calculated as sum of the methane production from all components. For this, methane generation after 26 days and 42 days respectively for each manure component needs to be known. Finally, the calculated total methane production was compared to actual measured production recorded at the farm plant.

3- RESULTS AND DISCUSSION

The total methane potential G_{pot} of oat husks was determined as $242 \text{ L}_N \text{ CH}_4 \text{ kg}^{-1} \text{ VS}_{added}$ (see Figure 3). Compared to data reported for digestion of straw as discussed in [4], this can be assessed to be in the same range as that of wheat straw or lower.

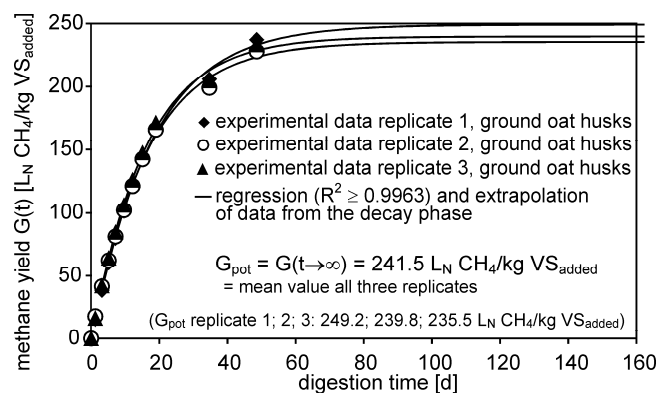


Figure 3: Determination of total methane potential G_{pot} of oat husks by extrapolation from experimental data obtained with ground material in optimized batch test (HBT) [4].

It is not only the total methane potential, but degradation kinetics which influences actual methane production over digestion time. Methane yield of untreated oat husks reached after 49 days of retention $G_{49} = 218.5 \pm 0.3 \text{ L}_N \text{ CH}_4 \text{ kg}^{-1} \text{ VS}_{added}$ ($n = 2$, mean \pm actual deviation) (Figure 4). The mean methane content over the entire digestion time was $51.8 \pm 0.1\%$, with intermediate maximum methane content of up to 64.2%.

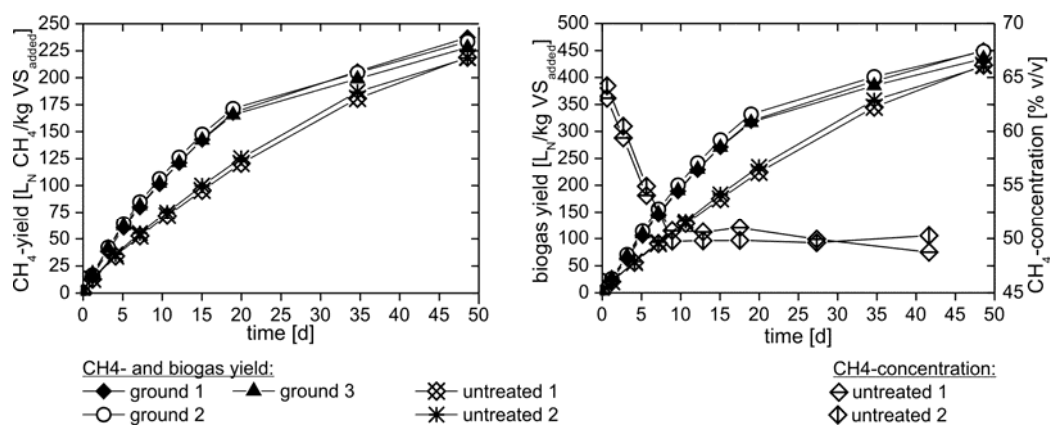


Figure 4: Methane and biogas yield from untreated oat husks and ground oat husks, and biogas methane concentration from untreated oat husks plotted against retention time (HBT, 37°C; methane concentration is mean value of the reading interval and plotted here in the middle of the reading interval) [4].

Comparison of untreated and ground oat husks shows that grinding increased the methane yield significantly only if retention time was below 30 days. Increasing particle surface area enhances biodegradation but does not affect ultimate methane yield. Consequently, in the present experiment differences between ground and untreated oat husks gradually became smaller with longer digestion times.

Calculation of the anticipated methane yield at the farm biogas plant in Järna requires knowledge of the methane yield after 26 and 42 days respectively. Linear interpolation of the experimental data for untreated oat husks results in $G_{26} = 147.9 \pm 2.7 \text{ L}_N \text{ CH}_4 \text{ kg}^{-1} \text{ VS}_{\text{added}}$ after 26 days and $G_{42} = 202.1 \pm 1.3 \text{ L}_N \text{ CH}_4 \text{ kg}^{-1} \text{ VS}_{\text{added}}$ after 42 days.

After 49 days 90% of the total methane potential G_{pot} of (untreated) oat husks had actually been converted ($q_{49} = G_{49}/G_{\text{pot}} = 0.90$). A digestion time of 42 days released 84% of the total methane potential ($q_{42} = 0.84$) and a digestion of 26 (28) days released 61% (65%) of the total methane potential ($q_{26} = 0.61$, $q_{28} = 0.65$). Comparison with experimental data for other slowly degradable lignocellulosic biomass (Table 1) indicates that degradation kinetics for oat husks was faster, as a higher part of the methane potential was released earlier in time.

Biomass	q₂₆	q₂₈	q₄₂	q₄₉	q₇₄	Reference
Oat husks	0.61	0.65	0.84	0.90		As reported here
Horse dung with straw		0.52	0.62		0.74	[9]
Wheat straw	0.49		0.61			Derived from data in [10]

Table 1: Exploitation degree $q_t = G_t/G_{\text{pot}}$ for different digestion times and different biomass [11].

Table 2 compiles the calculated daily biomass input and methane production of the prototype biogas plant. The present data do not permit a precise assessment of the actual retention time of the individual components in the system; some of the biomass leaves the system with the solid fraction of the first digester after 26 days and some leaves with the effluent of the second digester after 42 days. It is not possible to determine with precision the origin (component-specific) of the liquefied organic material metabolized in the second reactor. However, the calculated methane production of the entire process ranges between 41.8 and 60.9 $\text{m}^3 \text{ CH}_4 \text{ d}^{-1}$. The results show that oat husks may contribute up to 80% to the overall methane production of the prototype biogas plant.

Biomass	FM kg d ⁻¹	VS g kg ⁻¹ FM	VS kg d ⁻¹	26 days (first-stage reactor) m ³ CH ₄ d ⁻¹	42 days (first + second stage) m ³ CH ₄ d ⁻¹
Manure	2000	170	340	41.8 to 46.3	54.9 to 60.9
Excreta	1717	58	99	7.4 to 11.9	8.1 to 14.1
Straw	26	870	23	2.2	2.7
Oat husks	257	849	218	32.2	44.1

Table 2: Biomass input and calculated anticipated methane production in the two-stage prototype biogas plant in Järna [4].

The highest measured total biogas production of the prototype biogas plant was 91.5 $\text{m}^3 \text{ d}^{-1}$. When applying the measured methane content of 65% (v/v), the maximum methane production was 59.5 $\text{m}^3 \text{ CH}_4 \text{ d}^{-1}$, which meets the maximum calculated production in Table 2.

4- CONCLUSIONS

Oat husks and mixtures of solid manure containing oat husks (and straw) are suitable for methanisation in a continuous dry digestion process. Dry digestion may be particularly appropriate for solid manure containing straw and/or oat husks because there are no problems with materials floating on top as in wet digestion.

The total methane potential of oat husks was determined with $242 \text{ L}_N \text{ CH}_4 \text{ kg}^{-1} \text{ VS}_{\text{added}}$. Digestion of untreated oat husks at 37°C in a batch laboratory experiment converted 65% of the total methane potential within four weeks and 84% within six weeks. Results indicate that the methane potential of oat husks is on the level of straw, but digestion of oat husks may proceed faster. Grinding accelerated digestion of oat husks during the first weeks. However, grinding of oat husks used as litter requires additional time and energy input and is therefore not reasonably feasible. Expensive pre-treatment procedures for lignocellulosic biomasses contained within solid manure seem in general inappropriate for utilisation on single farms.

Litter materials (straw, oat husks) spread in the stanchion barn of a dairy cattle stall can be a valuable source for biogas production. Since the manure is a mixture of various components, assessment of the specific contribution of individual components to the total biogas generation is difficult and a comparison of experimental data is hardly possible. Results of this study provide evidence, that methane originating from litter material represents a significant proportion of total biogas generation on solid manure basis. Methane generation from oat husks within the manure contributed up to 80% of the total production of a two-stage dry digestion plant in Sweden. However, the actual proportion obtained from litter material may vary according to substrates but especially according to the farmer's stall management.

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