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Enhancement of methane production with horse manure supplement and pretreatment in a full-scale biogas process

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ABSTRACT

The increased demand for renewable energy resources worldwide has lead to a strong interest in biomass for energy and heat production. However, the use of energy crops competes with human food production for limited available arable land. Therefore, it is necessary to develop alternate feedstocks for anaerobic digestion and increase the use of agricultural residues and by-products. In this work, the usability of straw-based horse manure was investigated in a full-scale biogas plant over a period of 160 days. Additionally, for the improvement of the methane production, a mechanical disintegration device was tested. The results of this long-term study indicate that the digestion of horse manure is not sufficient without further disintegration. The pretreatment of the substrates caused an increase in specific methane production of approximately 26.5%. The determination of the degradation efficiency resulted in an almost complete degradation of the disintegrated substrates during the theoretical hydraulic retention time of 80 days. Regarding these results, the energy demand for the pretreatment is negligible. Therefore, the anaerobic digestion of lignocellulosic materials with an appropriate pretreatment is the suggested method for a sustainable and economically viable energy production.

1. Introduction

The microbial conversion of organic waste and by-products from agriculture and the food industry to biogas is well known and the process has been implemented for many years [1]. The anaerobic processing of these materials and generation of renewable energy offers many environmental benefits [2,3]. There is a fundamental consensus that this is the most favorable pathway of waste processing worldwide [4]. Due to legislatives regulations, the production and utilization of biogas in the European Union increased rapidly during the past years [5,6]. The German Renewable Energy Sources Act has played a particular role in the wide application of biogas technology in the agricultural sector [7]. Triggered by the highest volumetric methane yields, the digestion of energy crops increased dramatically and has replaced residues and wastes [8]. This shift in utilization of resources for biogas production leads to a strong competition for available arable land between energy production and the human food supply [9]. This results in rising prices for agricultural products and therefore affects the economic efficiency of biogas production [10].

Furthermore, it cannot be expected that the feed-in tariffs for electrical energy produced by renewable resources will increase. Therefore, the future challenge for the biogas branch is to prove its economic viability by optimizing the methane yield per unit input and decrease the acquisition costs for the substrates. Hence, a swift return to the use of agricultural residues and wastes is the key. In Germany, the leading country for biogas utilization, only 12% of the produced animal residues are processed by anaerobic digestion [11]. The application of liquid manures for biogas production is a commonly practiced technology. However, most agricultural biogas plants were not designed for the utilization of solid manures and other residues with higher solid contents [12,13].

The conversion of large fibrous particles result in swim layers inside the digester and cause procedural problems like clogging of pumps and pipes [14]. For this reason, only a small percentage of solid manure is utilized in conventional biogas plants [15,16]. The biodegradability of these substrates is also limited based on the recalcitrant of the biofibers and the high proportion of non-degradable materials [17]. Therefore, an appropriate treatment of the substrates is essential for achieving a sufficient degradation rate and methane yield [18]. The pretreatment of lignocellulosic materials for biogas production is the substance of a wide range of

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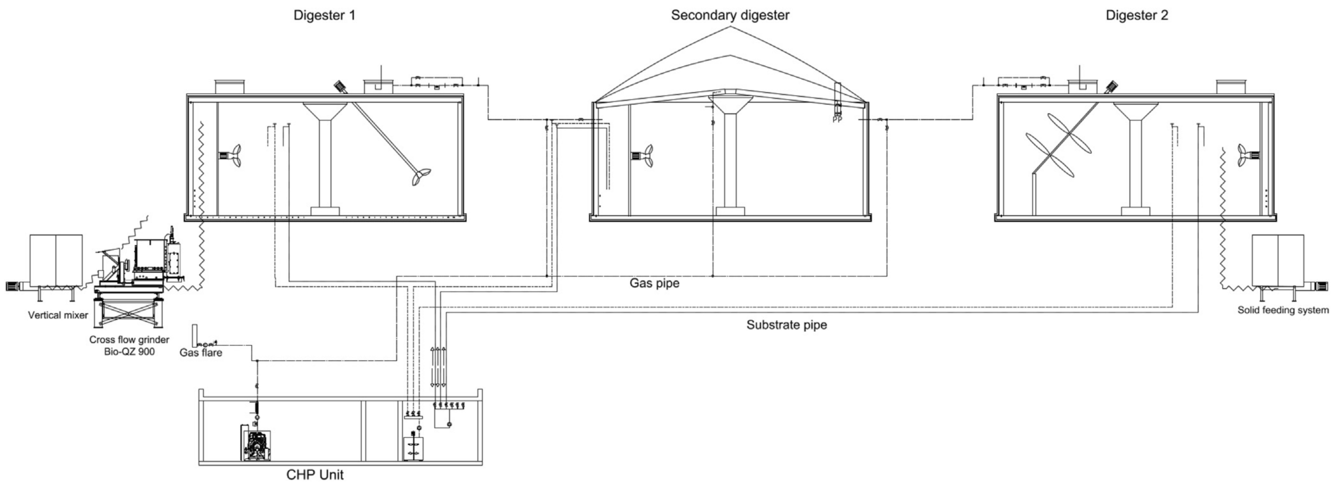

Fig. 1. Flow scheme of the research biogas plant "Unterer Lindenhof" [37].

scientific publications [19]. The investigated methods can be classified into physical, biological, chemical and physicochemical pretreatments [20]. Depending on the treated substrate, all methods resulted in an increase in methane yield between 5 and 20% in batch digestion tests [21,22]. The results of the enzymatic treatments are contradictory [23,24]. Additionally, the feasibility of practical application must be taken into account. Although the chemical and thermo-chemical pretreatments resulted in the highest methane yield increase, the feasibility for application at existing agricultural biogas plants is questionable [19]. A promising technology for pretreatment in full-scale application is mechanical disintegration [25]. Due to the change in structural features and decrease in particle size, the accessibility of substrate surface area increases [26], thereby increasing the specific methane yields of the substrates and decreasing the degradation time [18]. This also reduces mechanical problems, substrate viscosity and thereby avoids floating layers [27,28]. In addition, the mechanical pretreatment offers the opportunity to use alternate substrates with a higher fibrous content like solid manure and agricultural residues for biogas production [29,30].

An abundant potential resource for anaerobic digestion in Germany is horse manure. More than one million horses produce approximately twelve million tons of manure per year [31,32]. Normally, the bedding material dominates the composition of the horse manure. In Germany, straw is the most commonly used bedding material for horse stalls [33]. The disposal of the manure became increasingly difficult due its low fertilizer quality for crop production. Therefore, the digestion of the horse manure in agricultural biogas plant is an interesting alternative.

The methane yields and digestibility of horse manure in lab scale was reported in literature [16,34]. Nevertheless, the usability of straw-based horse manure in a continuous full-scale biogas plant is not yet reported. Further results indicate that the processing of such fibrous materials is not possible in continuously stirred tank reactors. Therefore, the aim of this study was to investigate the feasibility of horse manure in agricultural biogas plants and to determine the effects of the lignocellulosic materials on the biogas process over a period of approximately 160 days. Additionally, there is a lack of information about the necessity and effects of mechanical disintegration. Thus, a cross-flow grinder was installed at the research biogas plant for the mechanical substrate pretreatment and to determine the effects of the disintegration on the full-scale biogas process. The alteration of the degradation efficiency of the substrates due to the pretreatment was also studied.

2. Materials and methods

2.1. Full-scale investigations

In this work, the full-scale investigations were performed during a period of 160 days at the research biogas plant "Unterer Lindenhof" of the University of Hohenheim. The research biogas plant was previously described by Naegele et al. [35]. The biogas plant consists of two main digesters and one secondary digester with a working volume of 800 m^3 each (Fig. 1). To ensure a constant process temperature (40.0 ± 1.0 °C), each continuous stirred tank reactor possesses a heating system. Every digester is equipped with a separate solid feeding system, consisting of a vertical mixer and the feeding screws. A cross-flow grinder (Bio-QZ, MeWa, Gechingen, Germany) was set up and integrated between the vertical mixer and digester 1. The cross-flow grinder is patented as a decomposing device for the disintegration of recycling materials [36]. The Bio-QZ consists of a cylindrical working chamber with two rotating staggered steel chains located on the bottom of the working chamber. For the pretreatment of biomass, the working chamber is filled with a portion of substrate and the disintegration runs for a definable time span. During this working mode, the rotating chains cause radial and vertical material flow in the working chamber. The high flow velocity and the particle collisions of the substrates lead to a significant increase in particle surface area and defibration of lignocellulosic materials. For altering the pretreatment intensity, the bulk of the substrate portion and the retention time in the working chamber can be modified. In this trial, the treatment time was set to 15 s and the filling of the cross-flow grinder finished when the current draw reached 65% of the maximum. To estimate the electric energy demand of the cross-flow grinder, an electronic three-phase transformer connected meter (DAB 13000, ABB, Zürich, Suisse) was installed.

For the appropriate mixing of the digester content, each digester is equipped with a submersible motor mixer (4670, ITT Flygt AB, Sweden). Additionally, a propeller incline shaft agitator (Biogator HPR I, REMA, Germany) is installed in digester 1 and digester 2 incorporates a paddle incline agitator (Biobull, Envicon, Germany). In general, the mixing of the digester slurry takes place every 25 min for 5 min.

The research biogas plant is in operation since 2008. To ensure a constant and sufficient gas production for the combined heat and power unit with an electrical power of 192 kW, each digester was fed with a total amount of 8.8 ± 2.0 t FM (fresh matter) per day.