Biogas production from sugarcane filter cake: Start-up strategies, co-digestion with bagasse and plant design

Leandro Janke[a,b], Athaydes Leite[c], Marcell Nikolausz[c], Walter Stinner[a]

[a] Department of Biochemical Conversion, Deutsches Biomasseforschungszentrum gemeinnützige GmbH, Torgauer Straße 116, 04347 Leipzig, Germany

[b] Faculty of Agricultural and Environmental Sciences, Chair of Waste Management, University of Rostock, Justus-von-Liebig-Weg 6, 18059 Rostock, Germany

[c] Department of Environmental Microbiology, Helmholtz Centre for Environmental Research – UFZ, Permoserstraße 15, 04318 Leipzig, Germany *assign layout "Standard"*

Abstract

The Sugarcane Industry in Brazil is responsible for generation of different types of organic wastes. Bagasse and small share of straw have already been used as solid fuel in cogeneration systems in general. Meanwhile, there are other kinds of by-products, as filter cake and vinasse, which have been completely unused from the energy point of view. The idea of converting such unused wastes into additional energy is gaining attention, especially driven by some Government commitments on increasing the renewable energy generation combined with the reduction of carbon dioxide emissions.

The anaerobic digestion process is able to contribute with additional renewable energy production, in the form of electricity from biogas or even biomethane, keeping meanwhile the current practice of recycling the nutrients contained in these wastes on the sugarcane fields. However, for a successful application in industrial scale, the anaerobic digestion process must be carefully evaluated in terms of selection of appropriate inoculum, process kinetics, and plant design, among other aspects.

The present research evaluated different inocula for the biogas reactors start-up, the utilization of filter cake as single substrate for biogas production and the combination with bagasse in a co-digestion system (70% of filter cake and 30% of bagasse in fresh basis). Moreover, different options for the biogas utilization (combined heat and power or upgrading to biomethane) integrated to an average size sugarcane plant (2.5 M ton year^{-1}) were assessed.

Therefore, six laboratory scale (5 L volume) continuous stirred tank reactors (CSTRs) were operated during approximately 140 days under mesophilic conditions (±38°C). To understand the applicability of an alternative and locally available inoculum (fresh cow manure) over the conventional start-up system (digestate from another biogas reactor), the kinetic and energy benefits of co-digestion with bagasse, and finally the simulation of biogas production in an average size sugarcane plant were analyzed.

The results demonstrate that it is possible to utilize fresh cow manure as inoculum for biogas production from sugarcane filter cake and bagasse. However, a previous acclimation of the fresh cow manure is required due to its high volatile organic acids concentration. The mono-digestion of filter cake achieved an average biogas yield of 430 mL gVS^{-1} with 59% of methane content during the steady phase (hydraulic retention time of 28 days and organic loading rate of 3.0 g VS L.d^{-1}).

In contrast, for the co-digestion of filter cake and bagasse an average biogas yield achieved 347 mL gVS^{-1} with 54% of methane content was determined during the steady phase (hydraulic retention time of 35 days and organic loading rate of 3.0 g VS $L.d^{-1}$). For the simulation of large scale biogas production, the combined heat and power unit of an average sized sugarcane plant operated as mono-digestion of filter cake would have an installed capacity of 4.3 MW_{EL} (±15,500 MWh_{EL} $year^{-1}$) or alternatively a biomethane production of ±12,000 m^3_{STP} day^{-1}.

In case of co-digestion of bagasse, the biogas plant would have a combined heat and power system with an installed capacity of 4.5 MW_{EL} (±16,500 MWh_{EL} $year^{-1}$) or alternatively a biomethane production of 12,500 m^3_{STP} day^{-1}.

The results demonstrate that co-digestion of bagasse produce less biogas than mono-fermentation of filter cake, even its substrate composition presenting a better balance of nutrients (C:N ratio of 40:1) in comparison to filter cake mono-digestion (C:N ratio of 24:1). The less biogas production of co-digestion can be explained by the high lignin content found in bagasse, which could have hampered the conversion of cellulose and hemicellulose of bagasse into biogas. To avoid this situation a more effective pre-treatment is suggested to improve the conversion of the fibers fraction of bagasse. During the present research only a physical pre-treatment by grinding in 10 mm was used.

Recycling and energy recovery of incontinence waste (INKOCYCLE): Anaerobic treatment of adult diapers

Johanna Heynemann, Steffen Herbert, Thomas Luthardt-Behle, Harald Weigand, Ulf Theilen

Technische Hochschule Mittelhessen, Kompetenzzentrum ZEuUS, 35390 Gießen, Germany

Abstract

Due to the demographic change in Europe the amount of incontinence waste is expected to increase drastically. In Germany, the incontinence waste stream is currently estimated as 200,000 metric tonnes per year. The „INKOCYCLE"-Project focuses on a combination of energy and material recovery from adult incontinence waste. Energy recovery is pursued by anaerobic digestion of the biodegradable fraction of the diapers whereas material recovery options are targeted for the digestion residue. The anaerobic digestion of the biodegradable organic fractions results in 663 L biogas per kg organic dry residue, with an average composition of 56 % CH_4 and 44 % CO_2. Based on the original waste the gas yield is 155 L biogas per kg of used diapers. The digestion residue mostly consists of the non-biodegradable plastic components, adhering biomass and the superabsorbent polymer. The calorific value of the 'plastics fraction' (dry residue 42 %) is about 12 MJ per kg of washed digestion residue.

Keywords

incontinence waste, diapers, thermophilic anaerobic digestion, biogas, continuous wet fermentation

1 Introduction

1.1 The research project „INKOCYCLE"

Due to the demographic change in Europe the amount of incontinence waste (used adult diapers) is expected to increase drastically. In Germany, the incontinence waste stream is currently estimated as 200,000 metric tonnes per year (MEYER, 2014). This corresponds to a share of 1.4 % by weight of annual residual waste in Germany (Destatis, 2014). About 60 to 80 % of the residual waste of German Aged Care Facilities (ACFs) consists of used incontinence products (BECHER, 2009). Cost pressure in the health care sector demands for economically and ecologically sound management systems for this waste stream.

Since the organic carbon content of incontinence waste are above the waste acceptance criteria for landfilling the only secured way of disposal is incineration. The research project "INKOCYCLE" (project number: 03FH006PX2, funded by the Federal

Ministry of education and research) aims at the development of a cost effective and ecologically sound alternative to the conventional disposal as well as the elaboration of an overall concept for the treatment of incontinence waste, incorporating waste logistics. Energy recovery is pursued by anaerobic digestion of the biodegradable fraction of the incontinence waste coupled with the use of the dried fermentation residue as refuse derived fuel (RDF).

1.2 Incontinence products

Incontinence products for adults were introduced in Europe in the late 1960s. The products are adapted to the needs of the users, their gender and the strength of incontinence. The use of incontinence products enables users to preserve their dignity and to participate in their social environment without negative effects of their disease. Furthermore, modern incontinence products can be decisive for whether patients suffering from incontinence can remain in their domestic surroundings or must move to an ACF (EDANA, 2012).

Within the research project three types of incontinence products are distinguished, i.e., diapers for faecal and urine incontinence, templates for urine incontinence and bed pads for additional protection of beds, wheelchairs and furniture. These products differ by form and mass proportion of components but are structurally similarly.

A modern incontinence product consists primarily of a multi-layered body of pulp with an incorporated absorbent polymer (SAP). The latter is to absorb and store the urine and prevents the bacterial degradation of urine into ammonia and carbon dioxide, thus avoiding odours. The contact side is build-up by a skin-friendly nonwoven made of polypropylene (PP). A liquid-impermeable film made of polyethylene (PE) protects the clothing and the surroundings of the person concerned. Elastic cuffs ensure a good fit and prevent leakage of urine or faeces.

In the following, the percentage compositions of the different types of incontinence products are represented graphically. Components such as adhesive tape (to fix) and rubber bands (for better comfort) are grouped under the category “Others”.

The structural design of adult diapers is not substantially different from baby diapers. However, the construction must adapt to the user specification, like the greater body weight and volume of the excreta, thus the distribution of the product components is different.

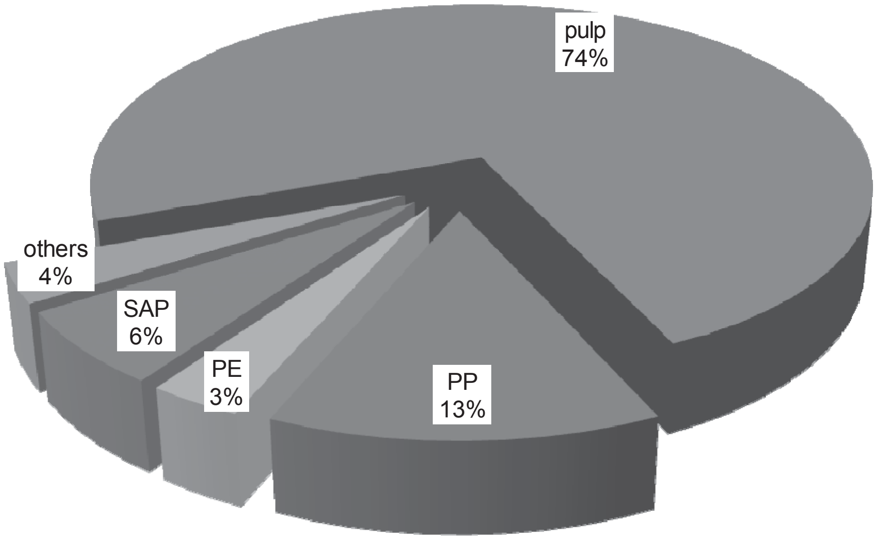

Figure 1 percentage composition of adult diapers (ABENA, 2013)

Templates are structured similarly to diapers, but they lack the lateral wings and a possibility of fixing to the body. Special mesh or protective pants are used for fixing.

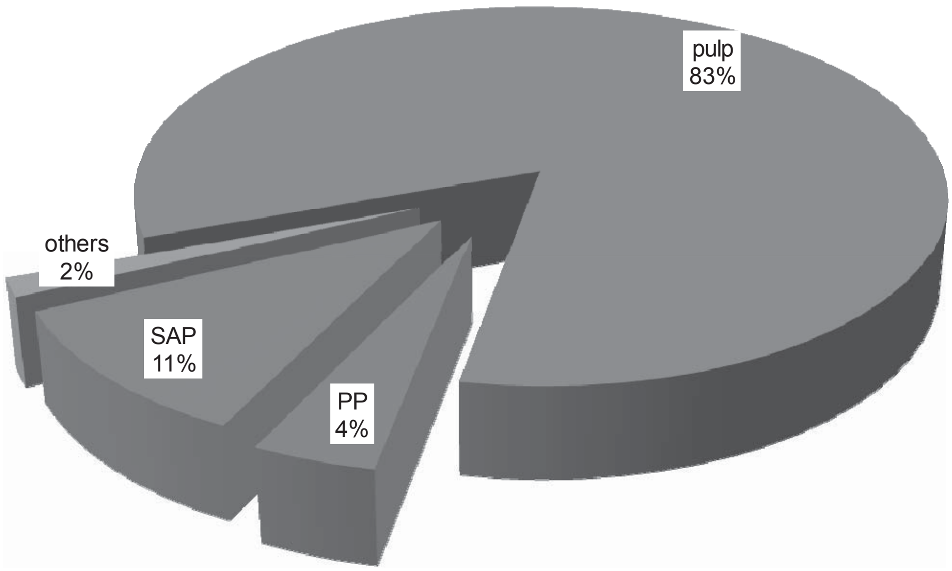

Figure 2 percentage composition of templates (ABENA, 2013)

Bed pads belong to the body distant aids and usually consist of several layers of pulp and a foil for moisture protection. There are types with or without the addition of superabsorbent polymers.

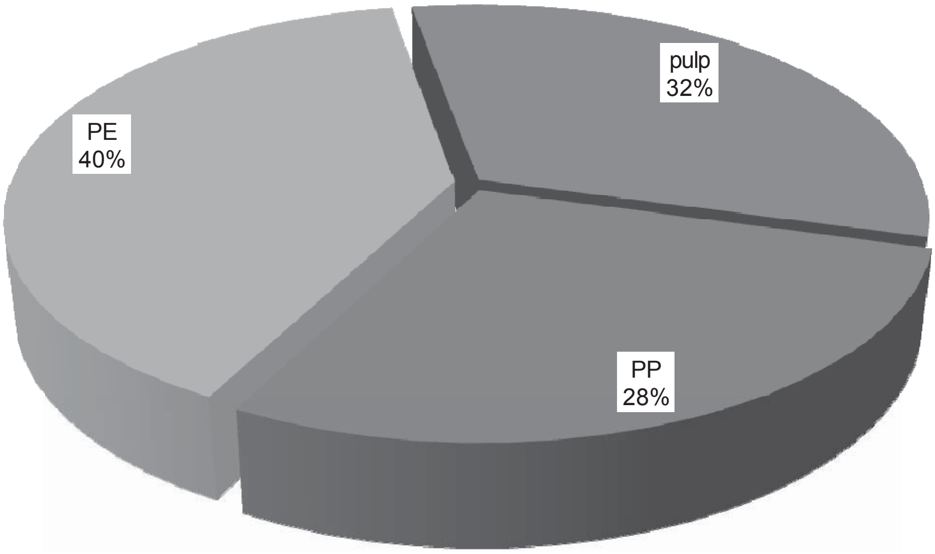

Figure 3 percentage composition of bed pads (ABENA, 2013)

2 Material and methods

2.1 Separation and collection concept

The collection of centrally produced incontinence waste in ACFs is relatively easy compared to single households. Within the framework of this study the incontinence waste is collected at an ACF nursing station with a full in patient care for 21 residents.

The nursing staff collect the used incontinence products in separate containers directly in the patient's room. This prevents a mixing with other waste fractions. Using a decentralized hygiene system the separately collected waste is vacuum-sealed. This allows a hygienic storage with simultaneous volume reduction and a considerable minimization of odour (THEOCARE, 2014).

At the beginning of the collection special attention was paid to the avoidance of incorrect sorting by the nursing staff. The involvement of employees in the research and specific instructions could insure that there was no mixing of incontinence waste with other waste fractions, especially with potentially infectious material or sharps.

2.2 Sorting and balancing of incontinence waste

Due to the variety of used incontinence products an accurate recording and a subsequent balancing of the waste was carried out. The incontinence products were identified and sorted, then counted and weighed.

Based on the manufacturer's specification on the product components, plus their type-related mass fractions of individual components (ABENA, 2013) and the sorting results the material composition of the incontinence waste could be determined. Also parameters such as the average load with urine and faeces, as well as the mass of biodegradable components could be calculated.

The basis for the calculation of the biodegradable share of incontinence waste is represented graphically in Figure 4. The loading of the different product types was estimated during the sorting and set as follows: diapers are loaded with 80 % urine and 20 % faeces, templates and bed pads with 90 % urine and 10 % faeces. The value for the organic dry matter (ODM) listed in Figure 4 was taken from the literature (DWA, 2008) and confirmed by own measurements.

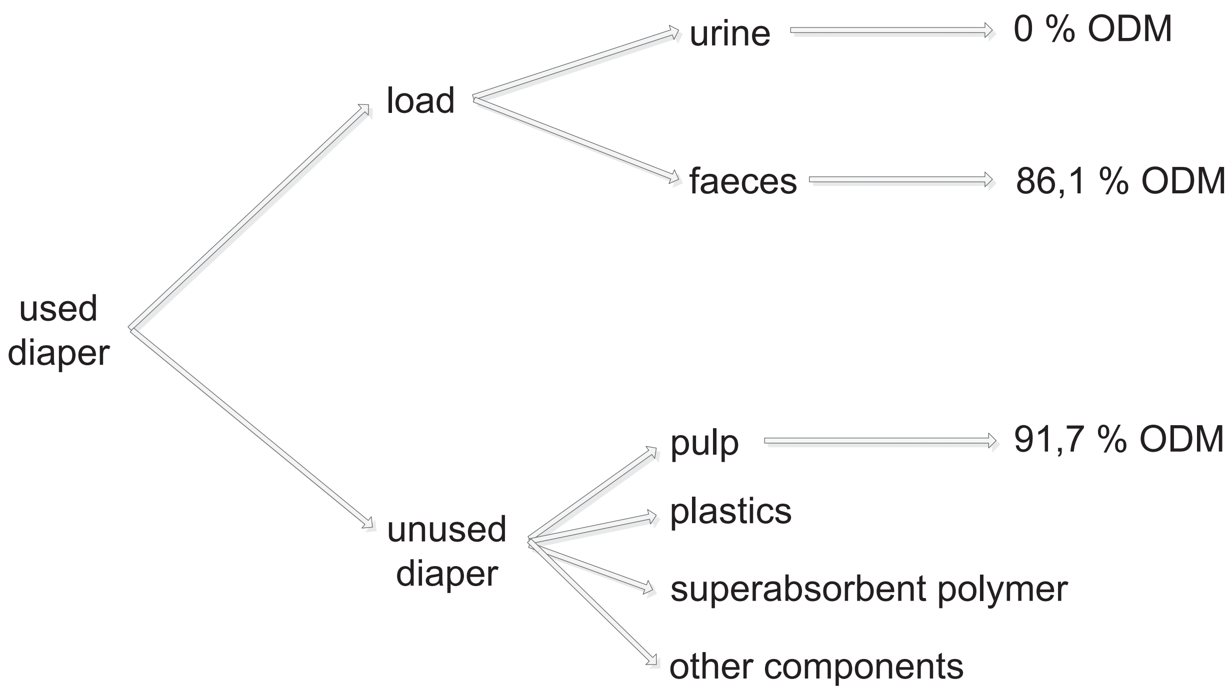

Figure 4 graphical representation of the basis for the calculation of the biodegradable share of incontinence waste

2.3 Thermophilic anaerobic digestion

The digestion of incontinence waste is conducted as a wet thermophilic fermentation process, for inoculation sludge from a municipal wastewater treatment plant was used. The horizontal reactor with a capacity of 1000 litre is operated in a temperature range of 53 to 57 °C.

The used incontinence products are shredded using a twin shaft shredder. The crushed and loosely stacked substrate is charged via a spiral conveyor and enters a hydraulically sealed collection funnel. To support the substrate feeding process water is recirculated simultaneously. An intermittently operated paddle agitator ensures a homogeneous mixing of the substrate and facilitates the discharge of the generated biogas. The latter leaves the reactor through a gas dome and passes a condensate trap and a gas meter. The composition of the biogas is measured discontinuously (sampling by gas bag). The digestion residue is discharged by displacement on a 2 mm sieve and is separated from the process water. The process water is recirculated into the fermenter.

2.4 Treatment of the digestion residue

After fermenter passage and the removal of the process water, the digestion residue mostly consists of the non-biodegradable plastic components of incontinence products. Also included are adherent biomass, a part of the superabsorbent polymer and a large proportion of adhesive liquid.

For further treatment the digestion residue must be separated from the adherent superabsorbent polymer, since its gelatinous consistency hampers dewatering. In two consecutive washing cycles 10 kg portions of digestion residue are treated in a washing drum with 40 litre service water. The washing water is cleared from the SAP by sieving (0.1 mm) and then treated in an aerobic laboratory wastewater treatment plant.

The washed digestion residue predominantly consists of the plastic components and is addressed as the ‘plastics’ fraction. The ‘plastics’ fraction is further dewatered by a hydraulic press at a pressure of 3,000 hPa.

2.5 Investigation of hygienization

For further use of the ‘plastics’ fraction it is necessary to ensure its hygienization. In addition, the sanitizing effectiveness of the fermentation process must be demonstrated in accordance with pertinent legislation.

Hygienization is defined as a reduction of active or colony forming units by 4, typically 5 log-levels, i.e. by 99.99 or 99.999 %. The verification of sanitizing of the anaerobic digestion was performed by microbiological investigations of in- and output samples (crushed incontinence waste, unwashed digestion residue). During a ten-day-period, 5 samples from both the input and the output were taken and were analysed for total bacteria counts at 37 °C, E. coli, faecal streptococci and salmonella.

3 Results and discussion

3.1 Composition of incontinence waste

The incontinence waste of the nursing station consists of 72 % diapers, 20 % bed pads and 8 % templates.

This includes 38 % biodegradable components and 18 % non-biodegradable components. Urine (37 %) and pulp (35 %) constitute the dominant components.

The composition of the waste, as well as the distribution of the organic and inorganic constituents depend on the type (see Figures 1 to 3) and the manufacturer of the incontinence products. It is therefore to be expected that the wastes of individual ACFs differ.

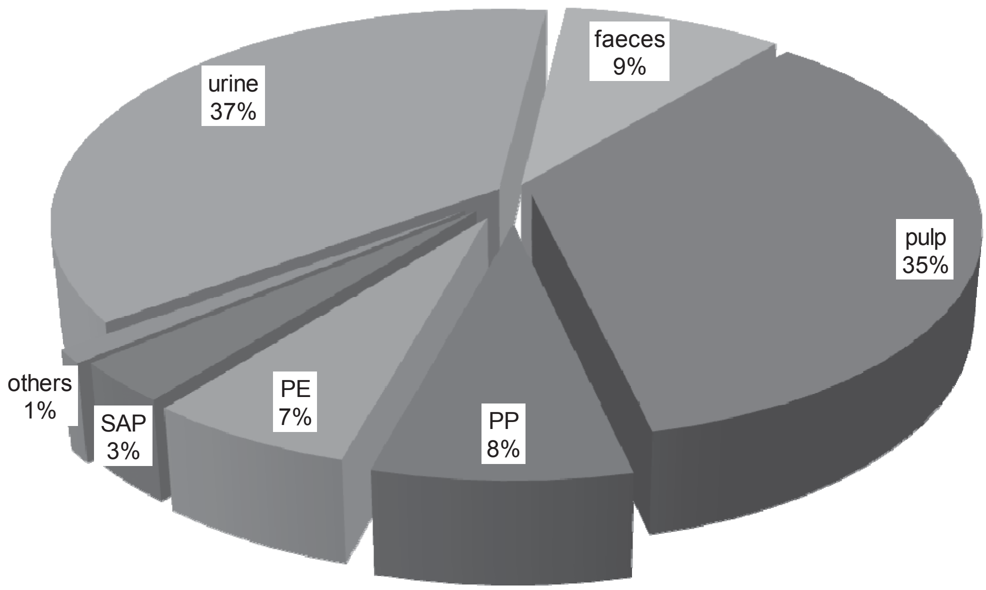

Figure 5 percentage composition of incontinence waste from an ACF

3.2 Anaerobic biodegradation

3.2.1 Adaption phase

At the beginning of the pilot scale experiment the fermenter was filled with urban mesophilic sludge. The transition from mesophilic (35 °C) to thermophilic (55 °C) temperature conditions was carried out in two steps. In the first heating phase, the internal temperature of the fermenter was raised within three days to 42 °C. After a holding period of 5 days, the second temperature increase followed and within three days the final temperature of 55 °C was reached. During these phases a daily addition of 15 kg of sewage sludge served as the substrate.

Monitoring of the transition involved the measurement of organic acids. In a stable digestion process, hydrolysis is in balance with the acidogenic, the acetogenic, and the methanogenic phase. An interference of anaerobic degradation is manifest by an increase in the concentration of organic acids. When thermophilic conditions are approached the balance changes since hydrolysis is favoured by increased temperatures. 16 days after the transition period the concentration of organic acids was largely constant indicating stable thermophilic conditions.

After reaching the stable thermophilic operation the substrate was gradually changed from sewage sludge to incontinence waste. The addition of sewage sludge was discontinued and a daily quantity of 4 kg incontinence waste (fresh matter) was chosen as starting value. The amount of substrate was then increased in 2 kg steps every 5 days until reaching a loading rate of 8 kg/d without negative effects on fermenter operation. This holds for the maximum loading rate of 12 kg per day applied during the experiment.

3.2.2 Gas production and gas quality

The anaerobic digestion of the biodegradable fractions resulted in 663 litres biogas per kg organic dry matter, this corresponds to a biogas production of 155 litres per kg fresh matter. On average, the biogas consisted of 56 % methane, 44 % carbon dioxide and 250 ppm hydrogen sulphide. These values are comparable to literature values for rye (whole plant) or grass silage (FNR, 2004). Figure 6 shows the time course of the concentrations of biogas components.

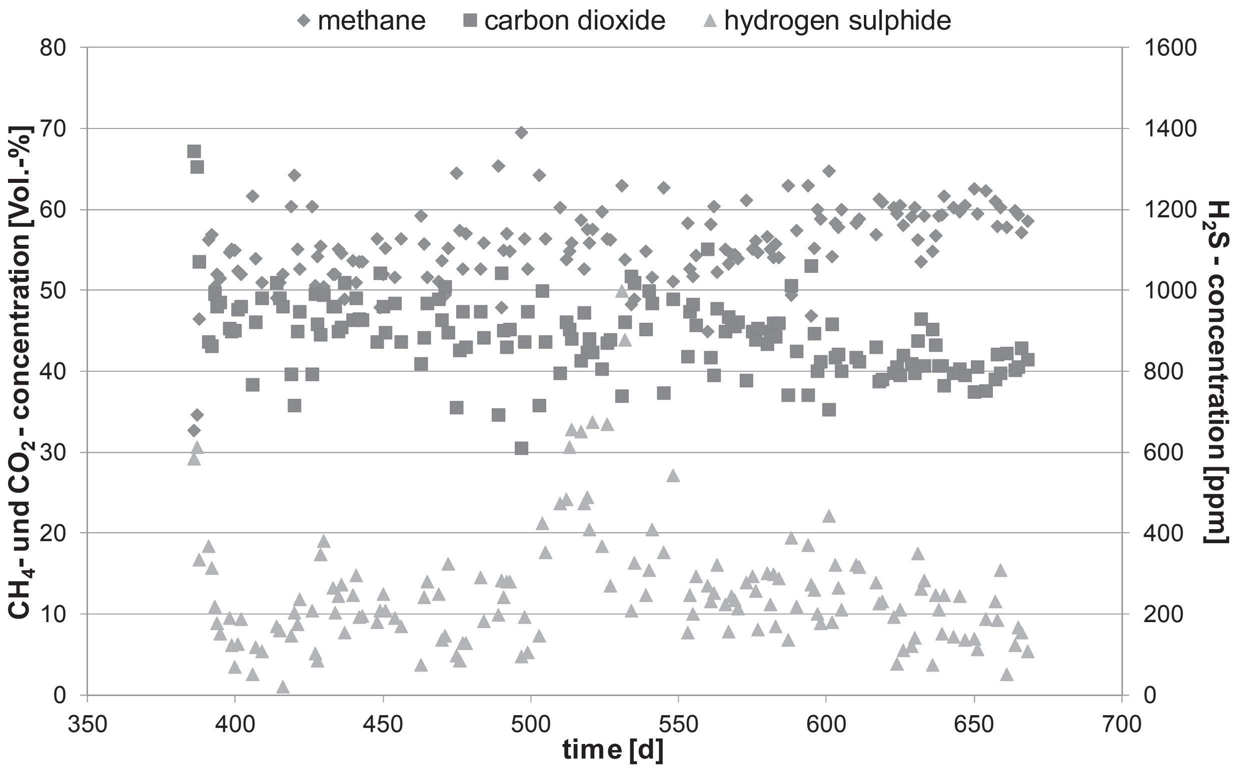

Figure 6 time course of the concentrations of biogas components

3.3 Composition of the ‘plastics’ fraction and disposal options

The ‚plastics‘ fraction includes all non-biodegradable components of the incontinence products, a small amount of biomass (approximately 2 %) and a moisture content of 58 %. The percentage composition of the ‘plastics’ fraction is shown in Figure 7.

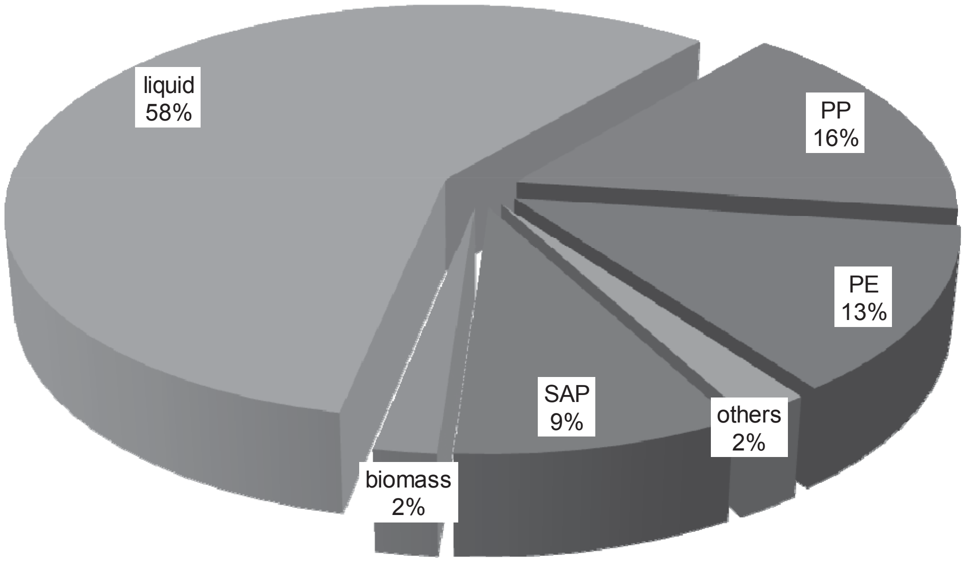

Figure 7 percentage composition of the ‘plastics’ fraction

One possible way of recovery for the ‘plastics’ fraction would be material recycling. The plastic mixture seems basically suitable for material recovery, because the components PP and PE are compatible with each other. However material recycling is made hampered by variable purity and low output rates. Despite proof of sanitation (see section 3.4) plastics recyclers contacted would not accept the ‘plastics’ fraction.

Another possibility is the thermal recycling of the ‘plastics’ fraction. The calorific value of the used incontinence products is in the range of 7,400 to 9,000 kJ/kg (MEIER-CIOSTO, 2002). This value is considerably below the statutory limit of 11,000 kJ/kg, according to Section 6, Paragraph 2 KrW-/AbfG this is not an energy recovery.

Since this may not apply to the digestion residue, the ‘plastics’ fraction was subjected to calorimetric analysis. On average, the ‘plastics’ fraction has a calorific value of 11,862 ± 578 kJ/kg original matter, with a moisture content of 58 %. Thus, through the anaerobic digestion the heating value of the output is increased above a critical value of 11,000 kJ/kg, i.e. incineration of the residue is, indeed, energy recovery.

3.4 Results of microbiological tests

Before the treatment, at least 11,000,000 cfu/g faecal streptococci were detected; the concentration of E. coli was in the range of 9,300 to 11,000,000 cfu/g. The salmonella result was negative for both the in- and output. In the output faecal streptococci and E.

coli were substantially reduced to < 5.000 cfu/g faecal streptococci and < 3 to 460 cfu/g E. coli (INFU, 2015).

4 Conclusion

It could be shown, that through separation of the incontinence waste into a biologically degradable and a non-degradable residue the disposal pathway of incontinence waste may be shifted towards energy recovery. The 'plastics' fraction can possibly substitute regular fuels in thermal processes. The calorific value may be further increased by further drying. Pertinent studies employing various drying techniques are underway.

The quality of biogas produced by the anaerobic degradation of organic components from the incontinence waste seems suited for combustion, e.g. in a cogeneration plant after elimination of hydrogen sulphide.

5 Perspectives

In the course of the project more sites of the participating clinic group will be included in the investigations. The objective is to increase the mass flow of incontinence waste. This is first done by inclusion of the other clinic sites; if applicable, the catchment area will be extended to other ACFs in the immediate vicinity of the clinic locations. Using this data, it should be possible to plan a large-scale fermentation plant and to determine its overall efficiency. Furthermore, logistics (routes, frequency of collection, etc.) will be accounted for. The conventional way of incontinence waste disposal by incineration and its anaerobic digestion coupled with the use of the 'plastics' fraction in a refused derived fuel (RDF) plant will be compared including an energy and CO_2 balance.

6 References

Abena	2013	Produktdaten Abena GmbH, Zörbig.
Becher, E.	2009	Ein Entsorgungs- und Energiekonzept spart Rohstoffe und Geld „Windel-Willi für saubere Geschäfte“. Entsorga Magazin 10. Deutscher Fachverlag, Frankfurt am Main, ISSN: 0933-3754
Destatis	2014	Abfallbilanz 2012; Statistisches Bundesamt
DWA	2008	DWA-Themen, Neuartige Sanitärsysteme. Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V., Hennef, ISBN: 978-3-941089-37-2
Edana	2012	Daten und Fakten Inkontinenzprodukte. Edana. www.edana.org

FNR	2004	Handreichung Biogasgewinnung und -nutzung, 2004. Fachagentur Nachwachsende Rohstoffe e.V., ISBN 3-00-014333-5
INFU	2015	INFU mbH, Geschäftsbereich PlanCoTec, Neu-Eichenberg
Meier-Ciosto	2002	Entsorgung von Windel- und Inkontinenzabfall. Abteilung: Abfallwirtschaft, Altlasten und Bodenschutz. Bayrisches Landesamt für Umwelt
Meyer, P.; Meyer, P.; Neuhaus, T.	2013	Ökologische Bilanz der Entsorgung von Inkontinenz-System-Abfall aus öffentlichen Einrichtungen. Fachzeitschrift Müll und Abfall. Erich Schmidt Verlag, Berlin
THEOcare	2014	Produktupdate 2014 INKO)(naut. THEOcare Hygiene GmbH. www.theocare.de

Author's addresses:

Prof. Dr. Ulf Theilen
Technische Hochschule Mittelhessen
Wiesenstraße 14
D-35390 Gießen
Telefon +49 641 309 1836
Email Ulf.Theilen@bau.thm.de
Website: www.thm.de

Prof. Dr. Harald Weigand
Email Harald.Weigand@kmub.thm.de

Dipl.-Ing. Johanna Heynemann, M.Sc.
Email Johanna.Heynemann@zeuus.thm.de

Dipl.-Ing. Steffen Herbert
Email Steffen.Herbert@kmub.thm.de

Dipl.-Ing. Thomas Luthardt-Behle
Email Thomas.Luthardt-Behle@bau.thm.de

Increase of Functionality and Energy Efficiency in Organic Waste Recovery

Klaus Fricke

Braunschweig Technical University

Waste and Resources Management Department

Axel Hüttner and Thomas Turk

IGLux Witzenhausen GmbH, Göttingen

Abstract

The effective use of biogenic residues makes an important contribution towards resource conservation and climate protection. These residues include biomass products generated alongside the actual product as by-products, residue or waste or wastewater in different sectors of the economy. In this context, a research project entitled "Raising Energy Efficiency in the Recovery of Biogenic Residues" (FKZ-Nr.: 03KB022) investigated the energy efficiency of treatment and recovery technologies currently used for biogenic residues and identified potential for optimisation.

The R&D project determined the status quo and potential to develop and optimise the digestion of solid waste streams, such as biowaste, green waste and residual waste. This work focused on material flow management, design and technology. Optimisations that have been developed and already put into practice by individual facilities served as a primary source of data.

This data also helped to explore whether the different technologies and process controls in use for fermentation varied efficiency in energy provision, offering approaches for optimisation. This presentation also depicts trends in recent years with the goal of deriving potential future trends in plant technology and process control.

Keywords

Organic waste, biowaste, green waste, biogenic residues, waste recovery, anaerobic digestion, material flow management, energy efficiency, process technology, process control.

1 Data collection methodology

Besides the basic types of process technology and process control, a number of overlapping parameters influence biogas production. The specific quality of fermenter input is especially significant, such as regional variations in material quality and the proportion of kitchen waste. The current survey could not provide adequately satisfactory underlying data, especially on material-specific influences.

Plants do not uniformly determine the quantity of biogas that they produce. Some of them directly measure the gas flow and some calculate backwards indirectly from the amount of power generated. The latter methodology is expected to yield significant amounts of misinformation affected by the availability of combined heat and power (CHP) plants. The evaluation did not reflect unusually low biogas yields that respondents clearly blamed on operating problems not relating to the process.

Gathering energy consumption data proved extremely difficult since none of the digestion plants reviewed had data showing specific energy consumption broken down by process stage. In many instances, operators only had data about energy consumption by the entire facility – composting and digestion – and the energy saving potential of each process stage could not be identified for this reason.

Reliable data about the demand for heat from the survey was only provided by a small number of plants. Secondary data was used to determine heat demand. This data comes from verification activities as part of plant clean-up measures, from information from plant suppliers and from calls for tenders or bids. Parameters were used indirectly to review their plausibility that helped to assess the demand for heat. This data is thus based on information from operators to only a limited degree.

2 Measures to optimise functionality and energy efficiency in the digestion of biowaste and green waste

These measures encompass:

- Material stream management
- Technology and operation
- Gas recovery
- Vulnerability analysis

2.1 Material stream management

Biowaste and green waste are subject to both quality-related and quantity-related seasonal changes.

Spikes in biowaste deliveries are expected to occur in the summer and autumn, in particular, and make it harder to design for consistent capacity utilisation. Biowaste rich in kitchen waste can generate much more gas than garden waste. For instance, some facilities had gas yields up to twice as high when garden waste arisings are low – mainly between January and March – than in the summer and autumn months. The annual