MAPPING AND CHARACTERIZATION OF ORGANIC WASTES FOR ANAEROBIC DIGESTION IN THE POLISH POMERANIAN REGION

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SUMMARY: Studies in the POM-BIOGAS project revealed that the Pomeranian region in Poland has many valuable organic wastes (especialy municipal solid waste and wastes from the food processing industries) which might be easily accessible and used in anaerobic digestion (AD) processes. Performed AMPTS (Automatic Methane Potential Test System) tests showed that both industrial and municipal wastes have a high specific biomethane potential (SBP) varying in the range of 300-520 Nml/gVS. The addition of industrial wastes to the organic fractions of municipal solid waste (MSW) increases the overall biogas production. Therefore AD of municipal bio-waste supplemented or enriched by industrial biodegradable wastes seems to be a very promising solution of organic waste handling and renewable energy production in Pomeranian region. Obtained values of SBPs for mixtures of municipal and industrial substrates were in agreement with both theoretical calculations and values given in the literature.

1. INTRODUCTION

Growth in the EU is still accompanied by increasing amounts of waste, causing unnecessary losses of materials and energy, environmental damage and negative effects on health and quality of life. It is a strategic goal of the EU to reduce these negative impacts, turning the EU into a resource efficient "Recycling Society". Resource efficiency and waste management are key elements of EU environmental policy and the Europe 2020 strategy.

Bio-waste is an important waste stream. It is estimated that it constitutes about 20 - 40 % of municipal solid waste (MSW). The potential of bio-waste in Europe equals to 80 M tpa (million tonnes per annum), while presently recycling of bio-waste in Europe is 24 M tpa, that means more than 50 M tonnes of bio-waste is wasted every year! Meanwhile, bio-waste has a potential to contribute to targets of the Renewable Energy Source (RES) Directive (2009/28/EC).

Anaerobic digestion (AD) naturally occurs in the nature. Its potential to generate methane has been recognized by engineers as an advantage, and nowadays it is widely applied around the word as an environmentally sustainable technology to manage organic waste (e.g. food, agricultural, industrial wastes).

This concept is not yet widely used in Poland due to a number of economic, social and technical barriers. Here, there are only about 210 biogas plants treating sewage sludge, animal manure and

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organic wastes, while in neighbouring countries (e.g. Germany) these figures are given in thousands. The total installed electrical power from biogas in 2013 in Poland was about 136 MW, whereas according to the adopted strategic documents this number should reach 802 MW in 2020.

Moreover, in regards to municipal waste and according to the National Waste Management Plan covering the years 2011-2014 and the outlook for the years 2015-2022 there is a need to reduce by 2020 the amount of municipal biodegradable waste that presently is landfilled, to 35% by weight of wastes generated in 1995. Additionally, the revised EU Waste Framework Directive (2008) includes a new 50 % recycling target for waste from households, to be fulfilled by 2020. Therefore, more efforts should be made in Poland to map and characterize available organic waste substrates, and to further develop anaerobic digestion technology as one of the solutions which can contribute to solving many environmental problems linked to organic waste management.

The Pomeranian Biogas Model project (POM-BIOGAS), funded by the Polish-Norwegian Research Programme with the main objective to provide innovative technological solutions for production and utilization of biogas generated from municipal and industrial organic waste, is one of the actions taken towards this development.

In previous studies in this project mapping available substrates showed that there is a vast potential of organic wastes in Pomeranian region, which could be digested, i.e. the organic fraction of municipal solid waste (OFMSW) and various streams of organic industrial waste coming from slaughterhouses, food processing, distilleries, etc. The "POM-BIOGAS" project also constitutes a task with the objective of characterization of the organic wastes mapped in the Pomeranian region, and in particular evaluation of their specific biomethane potential (SBP).

2. METHODOLOGY

2.1 AMPTS

The Automatic Methane Potential Test System (AMPTS II) is a device used to determine the biogas potential of particular substrates or mixture of substrates (Figure 1). The system is based upon batch operation and nearly fully automatic and requires only careful set-up of the machine. The simple operation makes it easy to compare several substrates (or mixtures) at the same time and under exactly the same conditions.

Figure 1. Photo of AMPTS (II) apparatus.

The apparatus was developed by the company Bioprocess Control from Lund in Sweden. It consists of 15 digestion bottles/reactors (shown to the left), that can be run simultaneously. Each digestion reactor is connected via tubes to the CO_2 absorption bottles (shown in centre), which are filled with a 3M NaOH solution and an indicator (saturated solution in the presence of indicator change the colour). These are connected to the gas measurement or flow cell array (shown to the right), where gas is collected under levers submerged in water – the buoyancy of the gas lifts the lever, the gas is released and metered. The digestion bottles are submerged in a water bath which is held at a constant temperature, and each digestion bottle has an attached motorized stirring rod which stirs each reactor. Each digestion bottle will experience the exact same conditions, so theoretically the differences in measured methane volumes are solely due to the different substrates used.

2.2 Selection of substrates

Anaerobic digestion is a sustainable technology for converting a variety of substrates (waste sources) including manure, the OFMSW, and agricultural residues to energy in the form of biomethane. Furthermore, the digestion of multiple substrates has the potential to increase overall energy generation. In the current studies both single substrate and dual substrate digestion were tested.

The selection of substrates was done on the basis of the mapping results, summarising the potential of available organic substrates in the Pomeranian region. Table 1 shows main organic substrates which were identified in the radius of 50 km from Gdańsk being a centre of the region.

Table 1. Amounts of potentially available organic waste within a distance of 50 km from Gdańsk.

Waste type	Sludge (industrial and municipal) (100% total solids.)	Agricultural waste (livestock manure)	Biodegradable industrial waste	Biodegradable municipal waste
Amount [t/a]	28 192	2 270 722	446 676	535 333

Sludges represent the smallest amount of wastes. However, especially municipal sludge is usually treated at the Wastewater Treatment Plants (WWPT) where they are produced. Agricultural wastes represent the largest amount of mapped wastes, and the construction of biogas plants based on agricultural substrate is the most common and well known technology used around the world, as well as in Poland. Therefore these wastes (municipal sludge and agricultural waste) were considered the least interesting for further investigation in this project.

According to a European Commission report (Saveyn & Eder, 2014) about 68% of the total yearly production of bio-waste in the EU originates from municipal waste and 25 to 36% from industrial sources such as food processing industries. The data for the Pomeranian region allows us drawing a similar conclusion for that region. Both industrial and municipal wastes seem to be important and so far neglected sources of potential organic material suitable for biogas production.

Therefore it was decided to run tests of the following substrates, presented in Table 2.

Test no 1 was run to characterize different fractions of biodegradable municipal solid wastes, mainly fractions coming from households with 2 different collecting systems: with and without separate collection. Due to the fact that the water content of wastes coming from separate collection was high, this fraction was named as "wet', while wastes coming from regions without separate collection were named as "mixed" as various materials could be found. Moreover, from the "mixed" fraction two streams can be identified – a "mixed raw" stream which is delivered directly to the landfill, and a "mixed after sieving" stream which goes through a 100 mm sieve before normally being handled in a composting system. Samples of all fractions were collected in 60 liters bags. From every bag 1 kg of organic material was randomly selected by hand. Collected substrates were prepared according to the procedure described in chapter 2.3.

Test no 2 was run based on industrial organic wastes such as distillery waste, slaughterhouse waste, waste from the production of malt, and dairy and vegetable overdue waste from the supermarket. About 1 kg of each substrate was collected from producers and then prepared for testing.

Table 2. AMPTS test scheme.

Test 1	Test 2	Tests 3
biodegradable municipal wastes from a municipal waste landfill	biodegradable industrial wastes	based on results from test 1 and 2
- mixed raw – municipal wastes without separate collection - mixed after sieving - municipal wastes without separate collection after sieving (100 mm) - wet from separate collection - municipal organic wastes from separate collection - green wastes - grass, branches, leaves etc	- distillery - slaughterhouse - malt production - supermarket – overdue milk products and vegetables	includes two mixtures of municipal and industrial substrates: - mixed after sieving + supermarket waste - wet from separate collection + malt waste

2.3 Preparation of substrates and TS/VS analysis

One of the main challenges of the AMPTS tests is the preparation of the feed of the digesters (bottles). Substrates were coming from different sources and were not homogenous and had different in concentrations of total solids (TS) and volatile solids (VS), while one of the principles is to feed each bottle with the same amount of VS. In most cases it was necessary to dilute the samples beforetesting. It was done by mass, not volume. After blending of each substrate, water was added to obtain a TS between 2.5 and 3%, to feed easier into the AMPTS bottles, and also to obtain more representative sample (dilution makes it easier to stir/blend). After dilution substrates were blended and mixed in a high speed mixer. All tests were run in triplicate for each substrate.

The total solids and volatile solids were measured according to the standrds: PN-EN 12880 (TS) and PN-EN 12879 (VS).

Inoculum was taken from the digester at Gdańsk-Wschód WWTP, and those samples were also analysed for TS and VS content.

Once the VS % for each substrate and the inoculum were determined, calculations were done to determine how much of the substrate shall be put in each bottle. The VS % of the inoculum (g/g) was divided by the VS % of each substrate satisfying two conditions: the ratio of VS % of inoculum: VS % of substrate is equal to 2, and the total mass is equal to 400 grams. This was done for all four substrates (or mixtures of substrates) in every test, but the lowest inoculum mass necessary to satisfy these conditions was used for all 15 reactors (bottles). This was done for control purpose - the same inoculum amount was placed into each reactor including the 3 control bottles containing inoculum only. The other triplicates were recalculated using the lowest inoculum mass, which means the total mass was slightly less for those bottles.

Prapared substrates were placed in the reactors of the AMPTS. After about 30 days of digestion the apparatus was stopped and the results were analysed.

3. RESULTS AND DISCUSSION

The results of AMPTS from each test were methane productions for all 15 bottles filled up with substrates + inoculum (12 bottles) and inoculum alone (3 bottles). From these results, for each triplicate, averages were calculated. Next, all values of the methane production of substrates with inoculum were corrected by the amount of methane produced by inoculum alone. Figure 2 presents biomethane production (BMP) for all 3 tests.

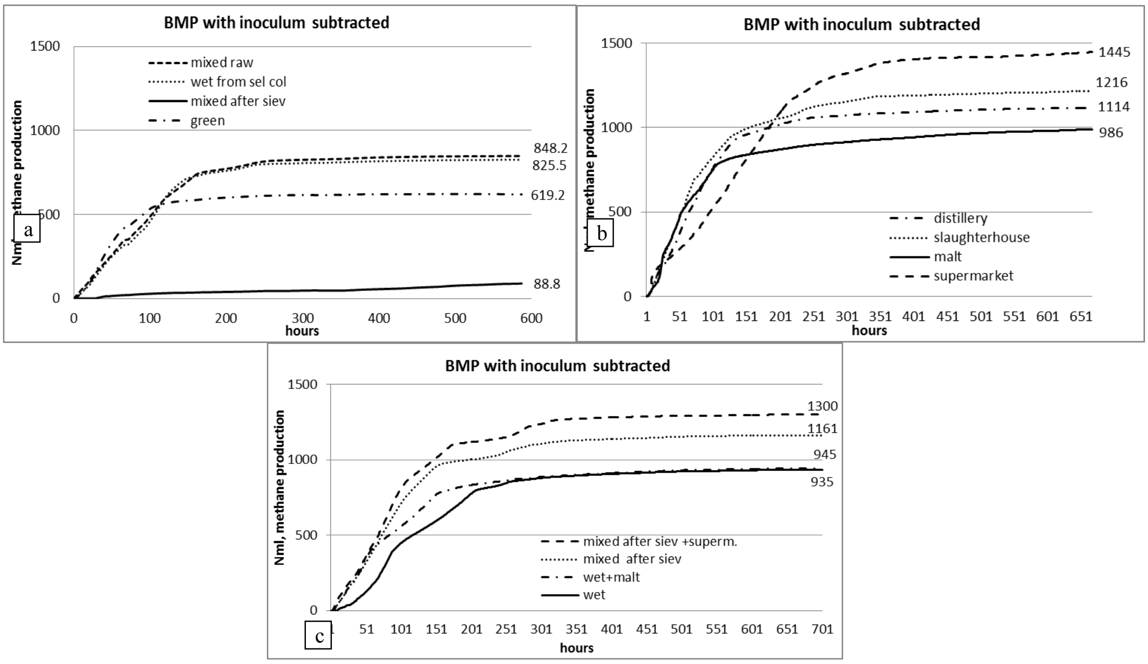


Figure 2. Biomethane production in test no 1 (a), test no 2 (b), and test no 3 (c).

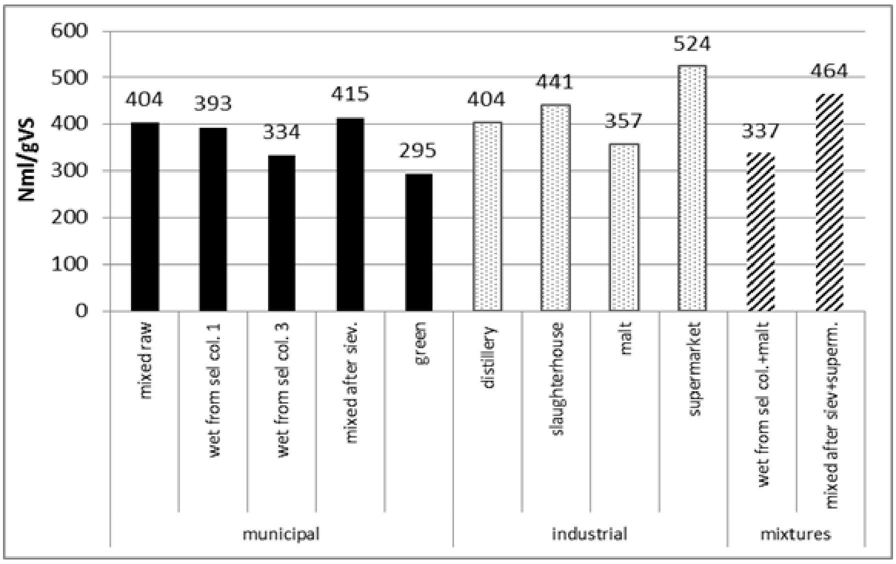
The highest value of biomethane production in test no 1 was obtained for raw "mixed" fraction and "wet" from separate collection. It was expected to get a higher value for wet fraction which theoretically should contain more organic material. However, one must remember that samples were randomly collected by hand and might not constitute representative samples. Green wastes had an expected lower BMP value than wastes from households while an unexpected low value was recorded for mixed organic fraction coming from sieves. It was probably due to a material in the sample which could interfere with the digestion process. Therefore, this value was rejectedand the substrate was included again in test no 3.

In test no 2 all substrates indicated a high biomethane production. The highest value of production equal to 1445 Nml was noticed for wastes coming from supermarkets.

Due to the fact that municipal waste is the most reliable, still growing and easily available stream of wastes it was decided to repeat the use of two municipal organic fractions ("wet" and "mixed after sieving"), as well as combine them in mixtures with two other industrial wastes: (1) supermarket waste which indicated the highest BMP and (2) malt waste which had BMP at the same level as municipal wastes (test no 3).

It occurred that an addition of supermarket wastes to municipal "mixed after sieving" fraction increased biogas production of about 12%. Mixture of municipal wet fraction with industrial malt waste which indicated in previous test a methane production at the same level as municipal waste, gave nearly the same value of produced methane as pure wet fraction.

In further step of biomethane production analysis, based on the measurements of VS and BMP of each substrate and mixtures, the Specific Biomethane Potential (SBP) were calculated and are presented in Figure 3.



mixed raw = municipal wastes without separate collection,

wet from sel. col. = municipal organic wastes from separate collection, values obtained from the test 1 and 3,

mixed after siev. - municipal organic wastes without separate collection after sieving,

green - grass, branches, leaves etc.

Figure 3. Specific biomethane potential (SBP) of organic wastes in the Pomeranian region, Poland.

Obtained results of SBPs for mixtures are in agreement with theoretical calculations based on mesured SBP of each substrate separately and the actual ratio:

-wet from selective collection +malt: 334*0.5 + 357*0.5 = 345.5 ml CH_4/g VS,

-mixed after sieving + supermarket: 415* 0.5 + 524*0.5 = 469.5 ml CH_4/g VS.

In the Pomeranian region, with exception of the green wastes, the results of the specific biomethane potential obtained by the AMPTS tests did not differ much, regardless of whether the MSW fraction have undergone a selective collection or not, achieving yields between 334 and 415 ml CH_4 /g VS. The mixed municipal fraction, containing organic as well as inorganic matter that will not yield any methane production, gave a yield in the same range as the organic wet fraction of MSW, what can lead to conclusion that the selective collection had no influence on the methane production. However, as mentioned before, one must remember that samples were taken randomly by hand and might not reflect the real situation. According to studies performed in Denmark, where the municipal solid waste is source-separated in the households by separating the organic fraction into paper bags, Hartmann and Ahring (2005) found that such organic fraction of MSW produced maximum yields of 400 ml CH_4/g VS in tests, while Angelidaki and Ellegaard (2003) presented the same value for Danish source separated organic household waste and a value between 400-500 ml CH_4/g VS for the non-sorted waste. However, if MSW is not source-separated, a pre-processing phase is necessary to remove plastics, metals, glass, stones and any other objects not suitable for anaerobic digestion. This can be performed mechanically, with the help of screens, presses, aerators or sensor sorting, or it can be done manually (Ward et al., 2008).

Similarly, for the mixed fraction and the wet fraction, the methane yield of the mixed fraction, after being sieved through an 100 mm mesh, did not differ from the yield of the whole mixed MSW fraction and the organic wet fraction of MSW.

Green municipal solid waste, composed of gardening wastes such as branches and leaves, gave a lower yield (295 ml CH_4/g VS), which is comparable to yields obtained from the digestion of biomass high in cellulose. Normally these yields will be in the range of 100-300 ml CH_4/g VS (Estevez et al., 2012; Ward et al., 2008; Angelidaki and Ellegaard, 2003). In plant cells, cellulose is linked to hemicellulose and lignin, this last one not degradable at all during anaerobic digestion (Zhang et al., 2007). When lignin is associated with cellulose, it acts as a barrier, preventing the hydrolyzing enzymes from entering and disturbing the cellulose structure, and making the hydrolysis phase the limiting step in the whole anaerobic digestion process (Deublein and Steinhauser, 2008; Zhang et al., 2007). The recalcitrant nature of some of these components will then result in slow and incomplete degradation and thus lower methane production.

The methane yields obtained from the industrial wastes tested varied between 357 and 524 ml CH_4/g VS. All these wastes are usually comprised of easily hydrolysable compounds such as fats and proteins, so their methane potentials are expected to be high (Angelidaki and Ellegaards, 2003) what makes them excellent candidates to perform co-digestion with not easily degradable materials as cellulosic biomass and manures that possess high content of fibers.

Supermarket waste used in the tests consisted mainly of food waste such as overdue dairy products and fruits. The obtained yield was in line with the yields found in literature for food wastes (472 ml CH_4/g VS) (Ward et al., 2008) and for returned dairy products (520 ml CH_4/g VS) (Carlsson and Uldal, 2009).

Slaughterhouse waste is a co-substrate often used in biogas plants in Denmark. This waste has a high content of grease and proteins and its yield normally varies between 300 and 700 ml CH_4/g VS (Deublein and Steinhauser, 2008). The soft tissues and bowels are the fractions with the highest biogas potential (Carlsson and Uldal, 2009).

Organic waste streams coming from the beverage industry can vary in the methane production yields. Malt waste has shown specific methane potentials of 350 ml CH_4/g VS (Tshiteya, 1985) correlating very well with the results obtained in this study (357 ml CH_4/g VS). Distillery waste, also called stillage, vinasse, or thin stillage (Wilkie et al., 2000) is the aqueous by-product obtained after the distillation of ethanol which can be produced from different material (e.g. sugar crops, starch crops, dairy products or cellulosic materials as crop residues, herbaceous energy crops, bagasse, wood, or municipal solid waste). As reported by Willkie et al. (2000), the fermentation of these different carbohydrates gives waste streams which, when subjected to the anaerobic digestion, will achieve different methane production yields. They can normally vary between 150 and 400 ml CH_4/g VS (De Paoli et al, 2011; Angelidaki and Ellegaard, 2003; Willkie at al., 2000). Table 3 presents specific biomethane potential of different organic substrates.

The results of methane yields of different substrates in this study are in good agreement with values presented by other authors in Table 3.

It is also well-known that co-digestion of different types of organic wastes may improve the methane production in anaerobic digestion processes (Estevez et al., 2012; Ward et al., 2008; Angelidaki and Ellegaard, 2003). Methane yields can be increased since in a co-digestion mixture the carbon to nitrogen ratio (C/N) can be adjusted and better meet microbiological requirements, and also provide better availability to trace elements. Improvement of the biomethane production from MSW by the addition of other substrates was also registered in this study and should be taken into account in the future waste management in the Pomaranian region in Poland.

Table 3. Specific biomethane potential of different substrates.

Waste (substrate)	*Methane yield (ml CH_4/g VS)*	*Literature reference*
MSW, unsorted	400-500	Angelidaki and Ellegard, 2003
MSW, sorted organic fraction	400	Angelidaki and Ellegaard, 2003 Hartmann and Ahring, 2005
Green wastes	100-300	Angelidaki and Ellegaard, 2003 Carlsson and Uldal, 2009
Slaughterhouse waste	300- 700	Deublein and Steinhauser, 2008 Carlsson and Uldal, 2009 Schnürer and Jarvis, 2009
Fish waste	400-550	Ahring et al., 1992
Food waste	472	Ward et al., 2008 Carlsson and Uldal, 2009
Overdue dairy products	520	Carlsson and Uldal, 2009
Distillery waste	150-400	Willkie et al., 2000 Schnürer and Jarvis, 2009
Malt waste	350	Tshiteya, 1985

5. CONCLUSIONS

Conducted mapping and characterization studies showed that there are many valuable organic wastes which might be easily accessible and used in biogas plants in the Pomeranian region in Poland. Special attention should be given to the municipal organic waste which is still an underestimated source of energy. Its increasing amounts are now a serious waste management problem, while it could be seen as a reliable and stable stream of substrates for biogas plants. The second significant source of organic waste for biogas plants in the Pomeranian region seems to be wastes from the food processing industries.

Performed AMPTS tests showed that both industrial and municipal waste have a high specific biomethane potential, as one kg of VS (volatile solids) coming from those wastes can give up to 500 Nl of biomethane.

Anaerobic digestion of municipal bio-waste supplemented or enriched by industrial biodegradable wastes seems to be a very promising solution of organic waste handling and renewable energy production in the Pomeranian region.

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