BIOGAS PRODUCTION FROM FISH WASTES IN CO-DIGESTION WITH SEWAGE SLUDGE

R. Tomczak-Wandzel[1] and E. Levlin[2,3]

1 Gdańsk University of Technology, Chemical Faculty, Narutowicza Str. 11/12, 80-233 Gdansk, Poland (E-mail: r.wandzel@interia.pl)
2 IVL Swedish Environmental Research Institute, Hammarby Sjöstadsverk
3 Dep. of Land and Water Resources Engineering, KTH, Royal Institute of Technology, Stockholm, Sweden (E-mail: levlin@kth.se)

ABSTRACT
Fish wastes have great potential as a source of high valued organic carbon for methane production but also have limitation (high content of ammonia nitrogen). Anaerobic treatment of fish wastes is possible with co-digestion. The main issue for co-digestion process lies in balancing several parameters in the co-substrate mixture: macro- and micronutrients, C:N ratio, pH, toxic compounds, biodegradable organic matter and dry matter.
The aim of this work is to find optimal co-digestion substrates to enhance biogas production from fish wastes. The investigation give the answer about useful for determining the most proper ratios of different co-substrates that provide an optimized biodegradation potential or enhance methane potential. This work examines the potential for methane production from anaerobic co-digestion fish wastes, grass and sewage sludge (primary and secondary). Different type of inoculum were used (different SRT). The experiments were carried out in mesophilic temperature with using *Automatic Methane Potential Test System* (AMTPS II).

KEYWORDS
fish waste, anaerobic digestion, methane potential

INTRODUCTION

Capture fisheries and aquaculture supplied the world with about 143 million tonnes of fish in 2008. Of this, nearly 81 percent (115 million tonnes) of world fish production was destined for human consumption (providing an estimated apparent per capita supply of about 17 kg). The rest (27 million tonnes) was used for nonfood purposes (FAO, 2010). In 2008, 39.7 percent (56.5 million tonnes) of world fish production was marketed as fresh, while 41.2 percent (58.6 million tonnes) of fish was frozen, cured or otherwise prepared for direct human consumption (FAO, 2010).

The amount of fish wastes (by-products and by-catch) depends on many factors: fish species, size, season and catch methods, processing technique, local regulations, market, etc. For example, when it is directly performed at sea, the gutting operation (guts, liver and other viscera) generates, in mass, approximately 16% of the total weight of the fish. Fish wastes are mainly produced in shore-based processing facilities. After processing, the remainder of the fish generally consists of head, viscera, frames, lugs, flaps and skin (if skinless fillets are produced). The edible portion of the different fish species varies between 35% for catfish to 53% for herring, of the total fish weight (SEAFISH, 2001). The respective generated wastes, out of the total fish mass, are therefore 65% for catfish and 47% for herring. In the UK for example, and on average, 43% of the fisheries resources is used for human consumption; the remainder of the fish (fish wastes) consists of onshore processing wastes (35%), waste at sea (5%) and discard at sea (17%). In such a case, one can see the overwhelming advantage of aquaculture in terms of efficiency of wastes processing since there is no disposal and all the remaining can be processed. In addition, fish wastes are produced on the spot and there is therefore no logistics involved in the process which can generate extra costs, risks and above all environmental impacts mainly due to the GHG emissions generated by the transports (SEAFISH, 2001).

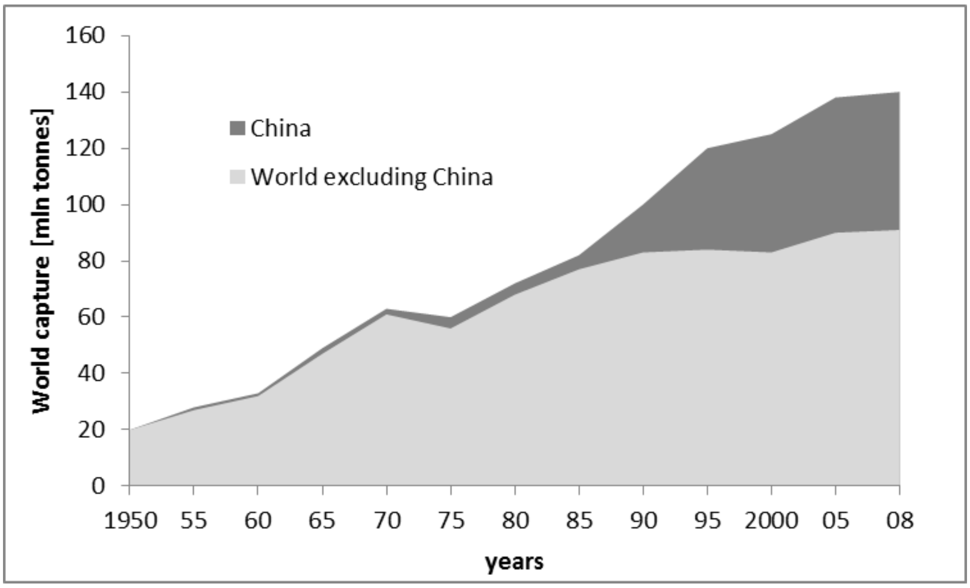

Figure 1. World capture fisheries and aquaculture production (FAO, 2010)

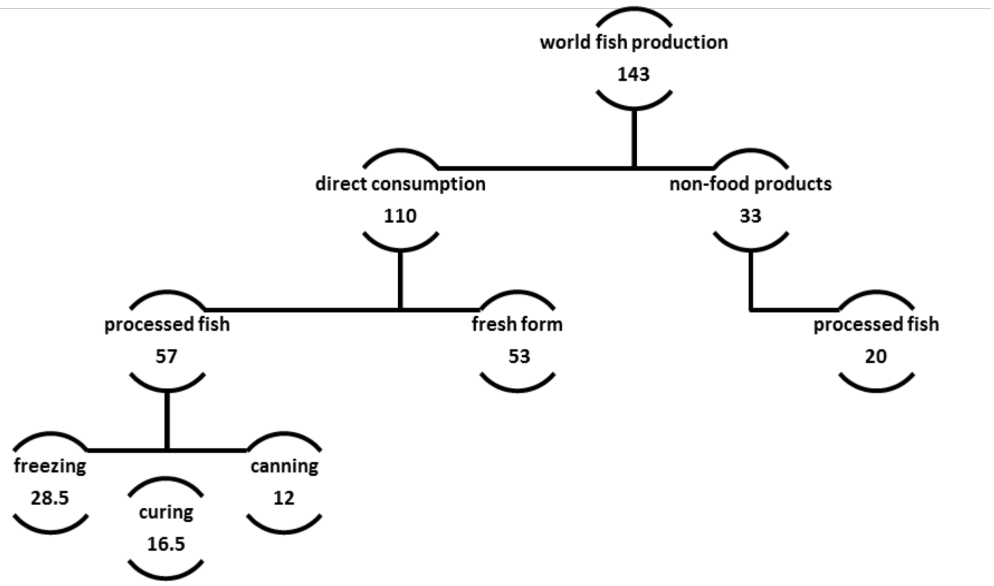

Figure 2. Utilization of world fisheries production (focus on processed fish). Curing refers to preservation and flavoring processes by smoking and by the addition of a combination of salt, sugar and either nitrate or nitrite (FAO, 2008; ENERFISH, 2011).

Due to the worldwide decline of fish stocks, a better use of by-catch and by-products is very important. Fish wastes have great potential as a source of high valued organic carbon for methane production but also have limitation (high content of ammonia nitrogen). Anaerobic treatment of fish wastes is possible with co-digestion. The main issue for co-digestion process lies in balancing several parameters in the co-substrate mixture: macro- and micronutrients, C:N ratio, pH, toxic compounds, biodegradable organic matter and dry matter.

Anaerobic digestion of biomass is a commonly used process utilizing troublesome waste and producing biogas. A significant number of biogas plants have been built, mainly in Northern Europe, and now the concept is spreading all over the world. Biogas plants treat various types of organic residues including sewage sludge, food industry residues and municipal solid waste. Anaerobic digestion of fish wastes is also possible but currently there are not so many industrial application.

There are about 37 plants in Sweden where different kinds of organic waste is collected and treated by means of anaerobic digestion and 135 WWTP with sludge digestion (Swedish Energy Authority, 2011). The amount of digested food waste, industry and slaughterhouse waste exceeds 400 000 ton/year of which 110 000 tonnes/year is co-digested in WWTP. The production of biogas was 1000 GWh (3.6 PJ/year) of which 60 % was produced in WWTP. It is estimated by Lantz et al. (2007) that that potential use of household and restaurant waste, separated at source together with industrial organic waste (e.g.from the food industry) if fully used could give 1860 GWh (6.7 PJ/year). There are digestion plants with capacities ranging from 6000 tonnes/year to 65 000 tonnes/year. Most of the co-digestion plants use manure as main raw material and organic industrial waste (e.g. slaughterhouse waste, waste from adjacent food industries) as supplementary raw material. The primary target of most of these plants is to handle a waste material and from this waste produce a bio fertilizer and also biogas that can be sold as a fuel. The ban of disposal of organic waste into landfills has resulted in an increased demand for biological treatment capacity and some of the existing plants will increase their capacity and a number of new plants are in the feasibility study phase (ENERFISH, 2011).

The number of co-digestion plants in Sweden will grow as the possibilities to dispose organic waste into landfills disappear and more cities tend to move toward separation of waste. The possibilities to use digestate as fertiliser has been improved through a third party certification system for digestate. This system has been developed in co-operation between a number of different organisations in Sweden and is widely accepted. Still some obstacles need to be broken but the certification system is a long step toward a more general acceptance of digestate as a resource in the agricultural sector (ENERFISH, 2011).

The aim of this work is to find optimal co-digestion substrates to enhance biogas production from fish wastes. The investigation give the answer about useful for determining the most proper ratios of different co-substrates that provide an optimized biodegradation potential or enhance methane potential.

The study was conducted at Hammarby Sjöstadsverk on behalf of IVL - Swedish Environmental Research Institute with assistance of a thesis worker (Almkvist, 2012). Hammarby Sjöstadsverk is a R&D facility for wastewater purification situated at Henrikdsdals WWTP in Stockholm, owned by IVL and KTH Royal Institute of Technology.

MATERIALS AND METHODS

This work examines the potential for methane production from anaerobic co-digestion fish wastes and sewage sludge (primary and secondary). Different type of inoculum were used (different SRT).

The experiments were carried out in mesophilic temperature with using *Automatic Methane Potential Test System* (AMTPS II).

Methane potential test

A Biochemical Methane Potential (BMP) test is the most used tool to provide a measure of the anaerobic degradability of a given substrate. This method is a simple and fast way to determine the suitability of a substrate for anaerobic digestion and the potential methane yield therein. It is also commonly used to evaluate the potential in the co-digestion of mixed wastes to enhance the digester performance. Moreover BMP tests can measure the residual organic material remaining after treatment that can still be used to convert to biogas and the non-degradable part remaining (Moody et al, 2009). The use of BMP tests provides a relatively inexpensive, simple and repeatable method to make comparisons of the anaerobic digestibility and potential biogas potential between different substrates (Owens et al, 1993). The methane potential is expressed in terms of standard temperature and pressure (STP) ml CH_4 per 1 g of VS added (mL CH_4 / g VS) (Hansen et al, 2003).

Experimental design

The batch digestion tests for methane potential were carried out using Bioprocess Control's AMPTS II equipment (Fig. 3). The instrument setup can be divided into four units (Fig. 4). Unit A is a thermostatic water bath used for reactor incubation. In each reactor a small amount of substrate and inoculum are incubated at desired temperature and mixed by a slow rotating agitator. Biogas is produced in each reactor and passes to the next unit. Unit B is a CO_2 fixing step, the biogas produced in each reactor goes through an individual vial containing an alkali solution (NaOH). Gases such as CO_2 and H_2S are removed by chemical reactions and CH_4 is the only gas that passes through unchanged. Unit C is the gas volume measuring device, after CH_4 passes through the alkali solution it is analyzed using a wet gas flow measuring device. This flow cell measuring device works by the principle of liquid displacement. When a defined volume of gas is accumulated, the flow cell lifts open and the bubble of gas can be seen emerging through the water. After the flow cell has opened and clicked back down, a digital pulse is generated and recorded in the computer program. Each flow cell is connected to Unit D, this is a data acquisition unit that together with a computer; records, analyzes and displays the resulting methane production.

Figure 3. Picture of the *Automatic Methane Potential Test System* (AMTPS II) at Hammarby Sjöstadsverk (Almkvist, 2012).

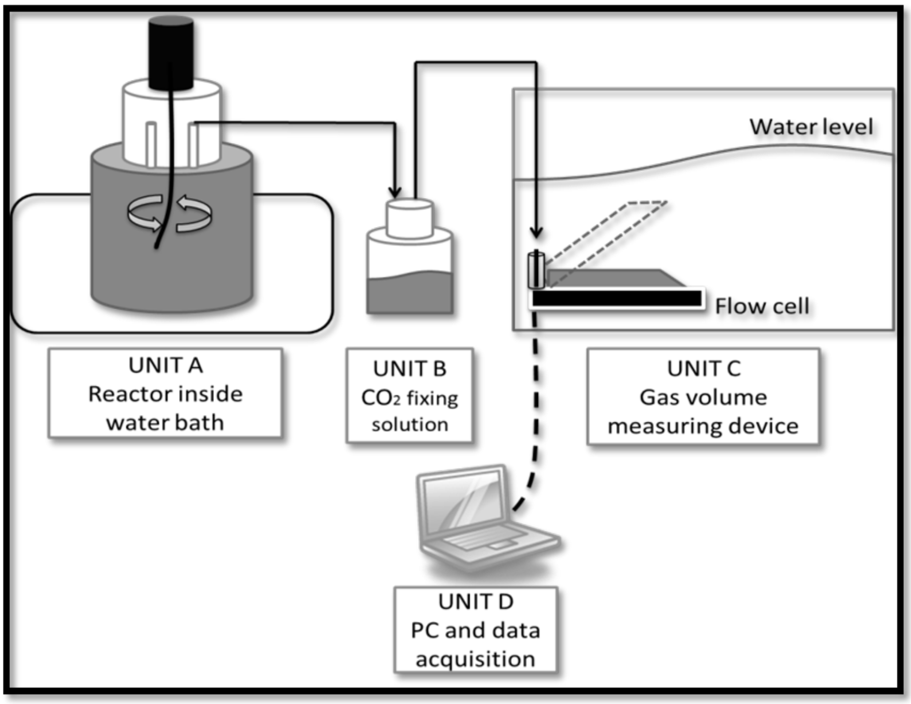

Figure 4. Schematic view of the experimental setup (Rodriguez, 2011)

Inoculum and substrate

The inoculum used in all compositions substrate was digested sludge from the anaerobic reactor from Hammarby Sjöstadsverk pilot plant. Inoculum was collected from the CSTR reactor (Continuous Stirred Tank Reactor). The tank reactor is continuously mixed with a volume of 10 m^3 and a temperature about 37± 0.5°C. The retention time (HRT) for the digested sludge was over 20 days. The ratio between inoculum and substrate was 2:1.

Primary sludge was taken from Hammarby Sjöstadsverk sedimentation basin that has volume 2.5 m^3, retention time (HRT) for primary sludge was about 2 hours and the input flow rate (OLR) to the reactor was 1.2 m^3/h. Secondary sludge was taken from Hammarby Sjöstadsverk biodegradation reactor (activated sludge) that had volume 5.4 m3, residence time (HRT) for secondary sludge was then about 4.5 hours and the organic loading rates (OLR) was 1.2 m^3 /h.

Six different compositions were investigated. The digestion was running under mesophilic conditions (37 ± 0.5 °C) and was stirring periodically. In Table 1 the composition of the experiment are presented. The ratio was 1:1:1 by weight.

Table 1. Substrate composition for the experiment

Sample	Substrate 1	Substrate 2	Substrate 3	Inoculum
1	Grass	Fish meat		Digested sludge
2	Grass	Intestines		
3	Sludge	Fish meat		
4	Sludge	Intestines		
5	Sludge	Intestines	Fish meat	
6	Grass	Intestines	Fish meat	

Substrate:

- Fish meat - Cod (*Gadus morhua*)
- Intestines - Perch (*Perca fluviatilis*)
- Trimmings grass
- Mixed sludge (primary and secondary sludge) from Hammarby Sjöstadsverk

RESULTS AND DISCUSSION

This chapter presents the results of experimental tests: the volume of produced methane, the accumulated methane and how much methane was produced per day from the different substrate compositions.

Figure 4 shows the amount of methane accumulated from the different compositions. After 24 days the highest volume of methane (about 2000 Nml CH_4) was observed for the sample 4 and 5 (sludge + intestines; sludge + intestines + meat). The worst results were obtained for the mixture with grass (about 1230 Nml CH_4).

The obtained results are consistent with expectations. The fish viscera contains huge amount of enzymes, which enhance the first stage of fermentation namely hydrolysis. The primary sludge is a good source of easy biodegradable carbon. Therefore such mixture will be the best solution to utilize fish waste.

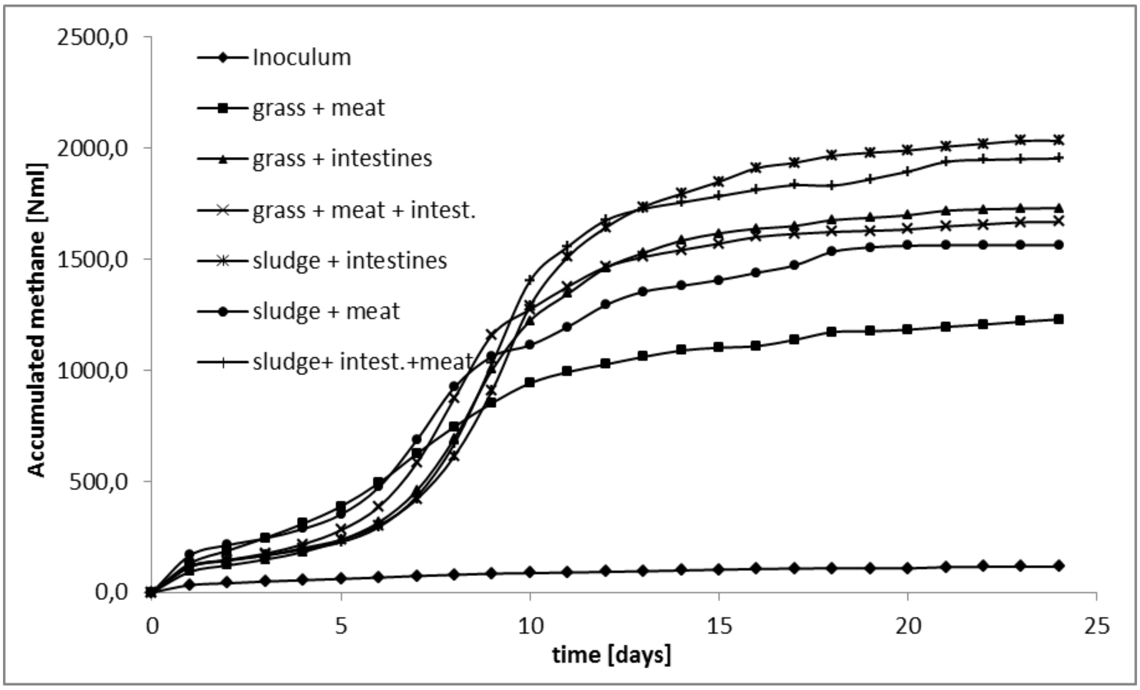

Figure 4. Accumulated volume of methane production during 24 days of experiment.

In figure 5 daily flow of methane during 24 days of experiments are presented. The highest flow rate was observed between 7 to 12 day of the investigation. After 12 days the biogas production decreased significantly.

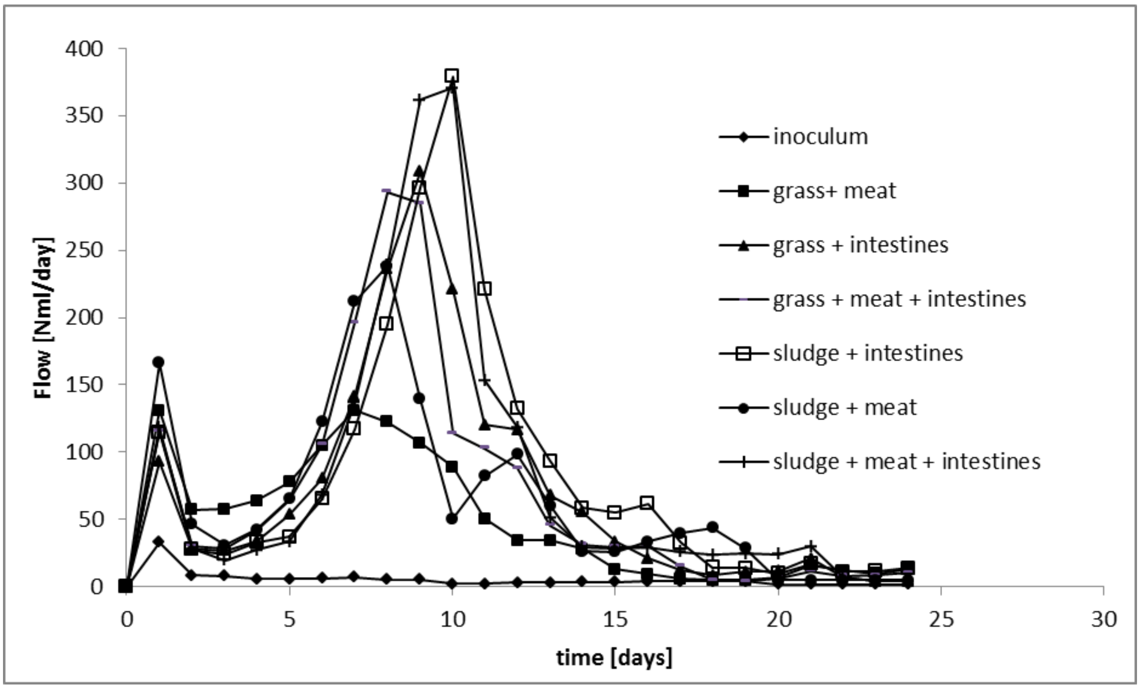

Figure 5. Daily flow of methane during 24 days of experiments.

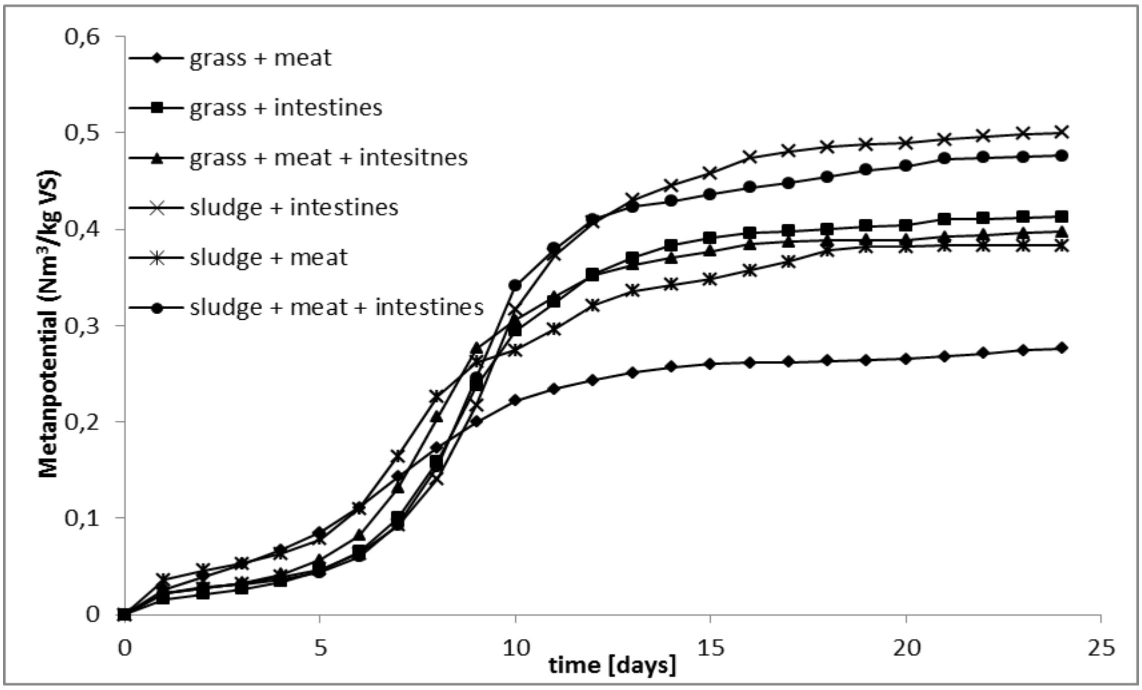

Figure 6. Methane potential for the different type of mixture.

Results from this study have shown that the most suitable substrate composition is mixture with fish intestines and sewage sludge (0.50 Nm^3 CH_4/kg VS). The methane production was highest on day 10, when the composition of intestines and sludge produced 378.9 Nml of methane.

CONCLUSIONS

This study showed that methane gas is quite possible to obtain from fish waste and by-catch mixed with different substrate under anaerobic conditions. The results from these experiments showed that a mixture of secondary sludge and primary sludge from Hammarby Sjöstadsverk with intestines gave the highest value for methane production in relation to the amount of organic material present in the sample. This composition also had the highest daily methane production. One explanation for that results could be that the mixture of primary and secondary sludge mixed with viscera contained a considerable amount of easy biodegradable carbon that compensated the high concentrations of ammonia nitrogen in digested fish waste and fish intestines.

The mixture with grass addition gave the lowest methane production from the all tested substrates. The grass used for the experiments did not contain sufficient amount of biodegradable carbon, which could compensate the high levels of ammonia nitrogen in the fish.

The results of the experiments will form the basis for the design of a large-scale biogas plant for the anaerobic utilization of cod and by-catch in Simrishamn (Skåne). Simrishamn is the largest fishing port and the municipality's largest employer. The biogas can be upgraded into fuel for fishing boats in the area.

REFERENCES

Almkvist, M.H. (2012) Biogaspotential från fiskrens och bifångst Master thesis Kemiteknik KTH.

ENERFISH, Market study, 2011.

Hansen, T.L., Schmidt, J.E., Angelidaki, Il, Marca, E., Jansen, J.C, Mosbaek, H. & Christensen, T.H., (2003) Method for determination of methane potentials of solid organic waste. Waste Management, 24(4), 393-400.

Lanz, M., Svensson, M., Björnsson, L. & Björnsson, P. (2007) The prospects for an expansion of biogas systems in Sweden — Incentives, barriers and potentials, Energy Policy 35, 1830–1843

Moody, L., Burns, R., Wu-Hann, W. & Spajić, R., (2009) Use of Biochemical Methane Potential (BMP) Assays for Predicting and Enhancing Anaerobic Digester Performance. Agricultural Engineering, 44th Croatian & 4th International Symposium on Agriculture, 930-934.

Owens, J.M. & Chynoweth, D.P., (1993) Biochemical methane potential of municipal solid-waste (MSW) components. Water Science & Technology, 27, 1-14.

Rodriguez, L.C. (2011) Methane potential of sewage sludge to increase biogas production. Master thesis Land and Water Resources Engineering, KTH, Stockholm Sweden TRITA LWR Masters Thesis LWR-EX-11-22

SEAFISH, Fish waste production in the United Kingdom. The quantities produced and opportunities for better utilisation. SEAFISH, report number SR537, 2001.

Swedish Energy Authority, (2011) Produktion och användning av biogas år 2010, ES 2011:07

The state of world fisheries and aquaculture, FAO, 2008.