沙漠研究 **22**-1, 227 -230 (2012)
Journal of Arid Land Studies

"ICAL 1 / DT X"
－Refereed Paper－

Anaerobic Degradation of Halophyte Biomass for Biogas Production

Natalya AKINSHINA*[1)2)], Daisuke NAKA[2)], Kristina TODERICH[3)], Azamat AZIZOV[1)] and Hidenari YASUI[2)]

Abstract: Anaerobic degradation of wild halophytes (*Kalidium caspicum, Salicornia europaea* and *Climacoptera lanata*) from solonchaks of Kyzylkum desert in comparison with conventional glycophyte *Panicum coloratum* was studied. Lab-scale reactors were fed with dried and milled plant biomass. Tests were operated under batch and continuous mode at mesophilic (M) and thermophilic (T) temperatures. High concentrations of chlorides, sulphates, sodium and potassium and low contents of nutrients were revealed in the biomass. Batch-tests showed that total methane-yields at M and T conditions were similar. Maximum biogas was produced in result of anaerobic digestion of *Kalidium caspicum* (about 1000 mL CH_4 from 1L of sludge at T and M-conditions); 950/900 mL/L was obtained in result of digestion of *Salicornia europaea* at T and M respectively; digestion of *Panicum coloratum* produced about 900/800 mL/L and *Climacoptera lanata* - 880/700 mL/L. It was revealed that 72-90% of organic fractions of *K.caspicum* and 54-90% of *S.europaea* can be decomposed to CH_4 at 35ºC within 30-days whereas approximately 50-70% of organic matter was decomposed due to anaerobic degradation of *C.lanata* and *P.coloratum.* At T-conditions about 60-70% organic matter of the biomass was conversed into methane. Incubation at 55ºC accelerated the CH_4 conversion rate up to 2 times. Time differences of the anaerobic decomposition of various halophytes are related to variation of lignin content, different concentrations of nutrients and other chemical compounds in the biomass. Preliminary studies of anaerobic digestion of plant biomass under continuous mode demonstrated that it is possible to get about 300-500 mL CH_4 from 1L of anaerobic digestion sludge per day.

Key Words: Anaerobic digestion, Biogas, Halophyte biomass

1. Introduction

Recently, a number of reasons to find alternative energy sources have become obvious:

- Carbon-contained energy sources of the Earth are exhaustible;
- Many developing countries are on the way to multiply their energy demand;
- Energy resources become the main causes of many political and military conflicts around the world.

Biogas is one of types of renewable energy; actually it is generated from organic materials as they decay. Biogasification (methane fermentation) is a technology for recovering methane from an organic matter in anaerobic reactor. It is also referred to as "anaerobic digestion". The main component of biogas is CH_4 (55-70%) and CO_2 (30-45%).

On a worldwide basis, the biogas production process has significance as a robust and easily to establish low-cost technology for the treatment of organic matter like food waste, agricultural residuals, sewage sludge, animal slurry, manure and so on. In developing countries of Asia and Africa thousands of simple small-scale reactors are under operation now (Wang and Li, 2005; Yadvika *et al.*; 2004, Omer and Fadalla, 2003). Their benefits are related to sustainable waste management combined with decentralized energy production.

Currently, reduction of salinization in arid areas is one of the most important challenges for human life, at least 20% of world arable lands and more than 40% of irrigated lands are under salinization. Every year the area of salt affected land increases with 10 million hectares. Uzbekistan loses about 20000 hectares in a year by reason of high salinization or waterlogging (Baknell *et al.*, 2003). It is clear, that conventional crops can not grow in those conditions and so abandoned lands are being increased rapidly. That is the reason why it is necessary to develop agricultural production under saline conditions. Cultivation and sustainable utilization of wild or domesticated halophytic and salt-tolerant plants could play important role for salinity control, remediation of saline lands and improving of livelihood of rural communities in Central Asian region. Halophytes provide desalination of soils. Until recently, no serious research efforts had been made in Central Asia on the utilization of biomass of halophytes. It is known, that many halophytes have importance as grain, fodder, technical or medicinal plants. Moreover, some kinds of inedible plant biomass from high saline environments could become an

* Corresponding Author: n.akinshina@yahoo.com

University str., NUUz, Tashkent, 100174, Uzbekistan

1) Department of Applied Ecology, The National University of Uzbekistan named after Mirzo.Ulugbek, Uzbekistan

2) Faculty of Environmental Engineering, The University of Kitakyushu, Japan

3) International Center for Biosaline Agriculture sub-offce for Central Asia and Caucasus

important source of renewable sustainable energy in arid lands.

The main goals of presented research are:

- To study possibility of anaerobic digestion (AD) of some halophyte biomass for methane-gas production;
- To compare AD of halophytes in mesophilic and thermophilic conditions in lab-scale experiments.

2. Materials and Methods

Anaerobic degradation of plant biomass for biogas production was studied. This is a complex microbial process in which organic compounds are degraded into methane, carbon dioxide and hydrogen by variety of anaerobes. The treatment systems can be classified by their dominant microorganisms: mesophilic (used at 30 to 40ºC) and thermophilic (used at 50 to 60ºC). Obtained biogas is usually utilized as fuel or for electricity production. Fermented residues of the process can be used as liquid fertilizer and row material of compost.

It is a 4-stage process: hydrolysis, acidification, acetogenesis and methanogenesis. In the first phase anaerobic bacteria use enzymes to decompose high molecular organic substances such as proteins, carbohydrates, cellulose and fats into low molecular compounds. During the second phase acid forming bacteria continue the decomposition process into organic acids, carbon dioxide, hydrogen sulphide and ammonia. Acid bacteria form acetate, carbon dioxide and hydrogen during the acetogenesis phase. The methanogenesis phase involves methane forming bacteria producing methane, carbon dioxide and water.

Three wild halophytes (*Kalidium caspicum*, *Salicornia europaea* and *Climacoptera lanata*) were taken from wet and dried solonchaks of Kyzylkum desert (Uzbekistan). Conventional glycophyte *Panicum coloratum* was taken for comparison. Plant biomass was dried at 105ºC during 24 hours and well-milled before the investigation.

Lab-scale experiments on anaerobic degradation of the biomass were conducted in batch and continuous modes. Water bathes were used as heaters for batch type reactors with stirring or shaking. Continuous mode reactors (4L glass cylinders with automatic stirring and heating control) were fed by dried biomass every day (retention time - 20 days, organic loading rate - 3.3 gCOD/L).

Concentrations of Cl^-, F^-, NO_3^-, SO_4^{2-}, PO_4^{3-} in water extracts of the biomass (0.1g DM[1] in 100 mL distill water stirred 1 hour and filtered through 0.45 µm) were measured according to standard methods using Ion Chromatography System DIONEX ICS-1000, IonPac AS11-HC Column.

[1] DM – dry matter

Soluble organic carbon (Sol.org.C) was measured in the same water extracts using Total Organic Carbon Analyzer TOC-L CSH/CSN Standalone Model ("Shimadzu").

Ash for the analysis was prepared by burning of plant dry matter in melt pots at 600ºC during 1 hour. Element analysis of plant materials was conducted using Varian Atomic Absorption Spectrophotometer AA240FS by standard method.

"OriginPro7.5" was used for statistical analysis of experimental data.

3. Results and Discussion

Taking into consideration that examination of biomass properties is necessary before planning gasification, measurements of water content, total mineral content and soluble organic carbon concentration were conducted. Results are presented in **Table 1**.

It was revealed that the halophytes contain very high concentrations of mineral compounds (about 40-50% of DM) as contrasted with conventional grass (5% of DM). It confirms that they are strong euhalophytes and can remove significant amounts of various salts from saline environment and accumulate them in plant tissues. Two fold soluble organic carbon concentrations in comparison with other plants (about 166 g/kg DM) were determined in DM of *Kalidium caspicum*.

Ion chromatographic analysis of water extracts of the biomass detected high content of chlorides and sulphates in the halophytes; about 100-200 and 20-70 g/kg DM respectively (**Table 2**). *Salicornia europaea* contained the highest Cl^--concentration (228.4 g/kg DM) and *Climacoptera lanata* had the highest SO_4^{2-}-content (68.93 g/kg DM). Low concentrations of phosphorus and traces of ammonium (essential nutrients for bacterial community) were revealed in the plant biomass. *Kalidium caspicum* contained significant amount of NO_3^--ions as compared to the other plants.

High contents of Na (130-170 g/kg DM) and K (20-45 g/kg DM) were determined in the halophyte biomass (**Table 3**). This fact can be considered as disadvantage for using of halophyte biomass for biogas production in anaerobic conditions as it is known that toxicity by salts for anaerobic bacteria is usually associated with the cations and not with the anions of the salts (Carlos Augusto de Lemos Chernicharo, 2007).

To avoid toxic effects of high concentrations of sodium and potassium in anaerobic digesters continuously fed by halophyte biomass it is necessary to adjust hydraulic retention time and organic loading rate correctly. The other way is a co-digestion and mixed feed (for instance, halophytes + conventional energy plants, halophytes + manure, etc.).

Results obtained from batch-tests have showed that total methane-yields at mesophilic and thermophilic conditions were similar (for instance, see **Fig. 1**). Maximum biogas was produced in result of anaerobic digestion (AD) of *Kalidium caspicum* (about 1000 and 1100 mL CH_4 from 1L of sludge at T and M-conditions); 950/900 mL/L can be produced by *Salicornia europaea* at T and M-conditions respectively; AD of *Panicum coloratum* can generate approximately 900/800 mL/L and *Climacoptera lanata* – 880/700 mL/L.

In result of numerous batch-mode experiments it was revealed that about 60-70% organic matter of the plant biomass can be decomposed at 55°C. At 35ºC 72-90% of organic fraction of *Kalidium sp.* and 54-90% of *Salicornia sp.* can be conversed to CH_4 during 30-days incubation period and

Table 1. Dry matter content, total mineral content and soluble organic carbon concentration of plant biomass.

Plant species	Dry matter content, %	Total mineral content, % from fresh weight	Total mineral content, % from dry weight	Soluble organic carbon, g/kg DM
Kalidium caspicum	23.01 ± 0.39	9.47 ± 0.6	42.84 ± 2.48	165.67 ± 26.8
Climacoptera lanata	21.76 ± 0.5	10.09 ± 0.44	51.62 ± 6.6	81.67 ± 1.54
Salicornia europaea	18.35 ± 1.27	6.75 ± 0.76	38.64 ± 1.64	77.33 ± 8.8
Panicum coloratum	not measured	not measured	5.01 + 0.15	81.18 ± 0.27

Table 2. Anion content of plant biomass.

	g/kg DM			
	Kalidium sp.	*Climacoptera sp.*	*Salicornia sp.*	*Panicum sp.*
Cl^-	105.29 ± 17.52	165.53 ± 18.01	228.41 ± 55.27	14.35 ± 2.41
SO_4^{2-}	23.36 ± 2.36	68.93 ± 6.74	30.91 ± 7.63	1.92 ± 0.1
NO_3^-	24.15 ± 4.91	1.17 ± 0.34	1.29 ± 0.75	4.78 ± 0.67
PO_4^-	4.36 ± 1.07	1.03 ± 0.31	2.18 ± 0.96	1.51 ± 0.11
F^-	0.94 ± 0.06	0.99 ± 0.06	0.509 ± 0.031	0.64 ± 0.04

Table 3. Concentrations of some metals in plant biomass.

	g/kg DM			
	Kalidium sp.	*Climacoptera sp.*	*Salicornia sp.*	*Panicum sp.*
Na	153.59 ± 10.59	169.69 ± 10.36	133.07 ± 7.7	2.14 ± 0.09
K	18.72 ± 0.73	21.57 ± 0.94	45.01 ± 2.42	2.53 ± 0.005
Mg	3.49 ± 0.47	4.45 ± 0.19	8.09 ± 0.06	1.11 ± 0.01
Ca	3.04 ± 0.07	4.54 ± 0.07	3.57 ± 0.17	Not measured
Fe	1.02 ± 0.08	0.37 ± 0.06	1.04 ± 0.04	0.14 ± 0.005

1.Mesophilic conditions (35ºC, F/M=0.2, COD_{ADL}=21.47 g/L)

2.Thermophilic conditions (55ºC, F/M=0.2, COD_{ADL}=20.5 g/L)

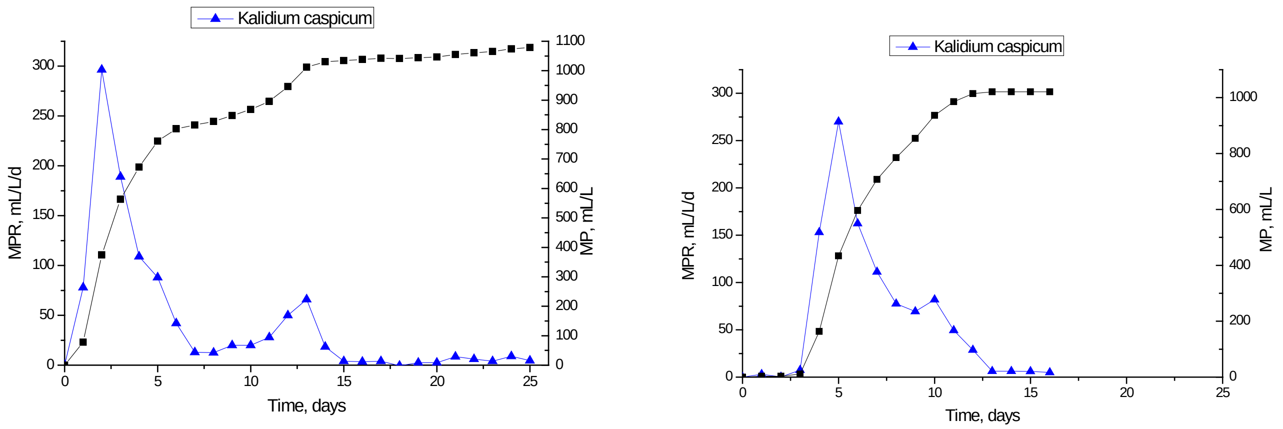

Fig.1. Methane production rates and cumulative methane yields at anaerobic digestion of plant biomass.

Table 4. Share of different organic fractions (in respect of biodegradability) of plant biomass.

Organic fractions (%):	*Slowly convertible to CH_4		*Very slowly convertible to CH_4		Inert	
	Meso	*Thermo*	*Meso*	*Thermo*	*Meso*	*Thermo*
Kalidium caspicum	40	39	>30	32	<30	29
Climacoptera lanata	21	35	>29	27.5	<50	37.5
Salicornia europaea	19	24	>39	43	<42	33
Panicum coloratum	35	41.5	>21	20	<44	36

*On the basis of AD-kinetics analysis (according to CH_4-production rate) we determined at least two main types of organic fractions with different rates of digestion by anaerobic bacteria: slowly and very slowly convertible to CH_4.

approximately 50-70% of organic matter of *Climacoptera* sp. and *Panicum* sp. can be digested at the same conditions.

Incubation at 55ºC accelerated CH_4 conversion rate up to 2 times due to specific thermophilic microorganism's reaction rates. Under laboratory experiments about 80% of cumulative methane yield at T-conditions was obtained within 5-7 days, at M-conditions it took 25-30 days. Higher rates of fermentation under thermophilic conditions have not led to a higher cumulative methane production. There were no big differences in the total methane yield at 35ºC and 55ºC. Probably, it is related with similar biodegradability of plant biomass for thermophilic and mesophilic bacterial communities. It is necessary to continue studies of anaerobic digestion of the plant biomass to determine exactly amounts of inert organic matters and other organic compounds in respect of velocity of their biodegradation.

Shares of different organic fractions of the biomass were calculated on the base of data on COD-conversion percentage during AD at mesophilic and thermophilic conditions, results are shown in **Table 4**. It was revealed that 30-50% of the organic fractions were inert and not capable to be biodegraded. Biomass of *Kalidium capsicum* was degraded better than other plants.

The diversity of the conversion efficiencies could be attributed to different chemical composition of halophytes biomass. It was displayed that any plant biomass contains at least three fractions with various biodegradable kinetics. Differences in the anaerobic decomposition of the halophytes are associated with the variation of lignin content, which is considered as hardly biodegradable organics, different nutrients concentrations and some chemical compounds, which are considered as inhibitors for an anaerobic digestion.

Preliminary study of anaerobic digestion of plant biomass under continuous mode demonstrated possibility to get about 300-500 mL CH_4 from 1L of anaerobic digestion sludge per day.

4. Conclusion

Biomass of halophytes should be considered as a valuable source of renewable energy production.

Anaerobic digestion is the most widely used method of organic waste and agricultural residuals disposal, it reduces the total mass of wastes significantly, produces energy and generates liquid or solid fertilizers, and it makes the process profitable from economical and environmental point of view.

It is clear that using of halophytic biomass for biogas production in saline arid lands gives numerous advantages. There are usually no other conventional crops or wild glycophytes in conditions of saline land or water resources, where halophytes can survive. There are no any competitions for land or water use in those areas. In addition, often there are no any other sources of energy for households of small local communities in remote desert areas under salinization. Moreover, soil desalination and melioration could be achieved in result of cultivation of halophytes. Thus, it is necessary to emphasize low resource cost, environmental benefits and improving of living standards of local communities owing to utilization of saline plant biomass for biogas production.

References

Baknell J., Klychnikiva I., Lampetty J., Landell M., Skatasta M., Turman M. (2003): *Irrigation in Central Asia. Social, economical and environmental aspects.* Report of Division of Environmentally and Socially Sustainable Development of World Bank, February, 2003.

Carlos Augusto de Lemos Chernicharo (2007): *Anaerobic Reactors.* IWA Publishing, London, UK, 175 p. ISBN: 1 84339 164 3.

Omer A.M., Fadalla Y. (2003): Biogas energy technology in Sudan. *RenewableEnergy*, **28** (3): 499-507.

Wang X.H., Li J.F. (2005): Influence of using household biogas digesters on household energy consumption in rural areas - a case study in Lianshui County in China. *Renewable & Sustainable Energy Reviews*, **9** (2): 229-236.

Yokoyama S., Matsumura Y. (2008): *The Asian Biomass Handbook*. The Japan Institute of Energy. 326 p.

Yadvika, Santosh, Sreekrishnan T.R., Kohli S., Rana V. (2004): Enhancement of biogas production from solid substrates using different techniques - a review. *Bioresource Technology*, **95** (1): 1-10.