Biogas Production in Municipal Wastewater Treatment Plants – Current Status in EU with a Focus on the Slovak Republic

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The presented contribution reviews actual status of biogas production in the European countries with a focus on the Slovak municipal WWTPs. In 49 monitored Slovak WWTPs (out of 520) the anaerobic digestion with biogas production is operated. The total volume of digestion tanks is about 195 000 m^3 but the total daily biogas production is only approx. 55 000 m^3 d^{-1}. From a technological point of view, the digestion tanks have sufficient space for considerable increase of biogas production. The increase can be achieved by the choice and dosing of external organic sources that could bring significant energy – economic contribution to WWTP operation without technological process adaptation (plant oils, fats, organic materials, etc.) or with a small technological process adaptation (food residues, food and agricultural products and wastes). The contribution describes the actual load parameters of digestion tanks, specific biogas production, electrical power capacity, and production on the Slovak WWTP obtained on the basis of a questionnaire from Slovak Water Companies.

Key words:
Anaerobic digestion, biogas, biowaste, municipal wastewater treatment plant, Slovak Republic

Introduction

Biological wastewater treatment plant (WWTP) is a facility for removal of mainly organic pollution from wastewaters. Organic pollution is partly transformed into sludge that, with the use of up-to-date technologies, represents an important energy source. Municipal WWTPs generate sludge as a by-product of physical, chemical and biological processes applied during wastewater treatment. Current daily amounts, expressed as dry solids (DS) range from 60–90 g DS per population equivalent (p.e.), i.e. almost 10 million tons of dry sludge per year for the EU.[1–2] Sludge disposal (agricultural use, incineration, and landfills) is often discussed because of increasingly restrictive environmental legislation.[3–4]

The energy present in sludge is obviously utilized in anaerobic digestion (AD). Digestion leads to the formation of biogas, rich in methane, which can be recovered, and used as an energy source, making it a great energy saver. The volume of biogas produced during the digestion process can fluctuate over a wide range; with typical values varying from 0.5 – 0.9 m^3 kg^{-1} VS degraded (for waste activated sludge).[5] This range depends on the volatile solids concentration of the sludge feed and the biological activity in the anaerobic digestion process. In the primary treatment of normal domestic wastewater, the yield of biogas is 15 – 22 $m^3/10^3$ cap.d. The typical biogas production in secondary treatment plants is increased to about 28 $m^3/10^3$ cap.d.[1] For mesophilic high-rate complete mix anaerobic sludge digesters the typical design criteria are organic loading rate in the range of 1.6 – 4.8 kg VS m^{-3} d^{-1} and hydraulic retention time between 15- 20 days.[1]

There are four main types of biogas applications: i) production of heat and steam; ii) electricity generation/co-generation; iii) use as vehicle fuel; and iv) (possibly) production of chemicals. These applications are governed by national frameworks like the tax system, subsidies, green energy certificates and increased feed-in tariffs for electricity, availability of heat or gas grids. Worldwide, biogas is mainly used in combined heat and power (CHP) applications, whereas various EU countries have embarked on programmes to achieve a growing share of biogas in the transport sector, especially attractive in view of the steady increase of the cost of fossil fuels.[3–4]

Anaerobic processes are used in European countries for sludge treatment and some of the oldest digesters are still in operation. In France, the oldest sludge digesters have been in operation since the end of the 1940s, while 17 % of the active digesters came into operation before 1970.[6] Until the end of the 1970s, the produced biogas was not

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always economically exploited. The gas was merely a by-product that smelt unpleasantly, possibly toxic, and was difficult to re-use. The best way was to burn it; at least it was simply released into the atmosphere. However, whenever tensions appeared in the energy market attempts were made to exploit this energy source.

Biogas production has slowly but steadily increased in the European WWTPs. The annual increase of biogas production is 4.5–5 %. The information about biogas production from different digestion systems (landfills, WWTPs and agricultural or municipal biogas plant – BGP) in selected European countries are reported in Table 1. Germany is the largest biogas producer in Europe generally in all biogas sources. Actual studies[7–8] have reported that Germany and Denmark have already reached their peak rates of biogas valorisation from sludge taking into account their population. On the other hand, Italy, Spain and France have a very low biogas production on WWTPs compared to their population capacities.

The objective of the presented contribution is not only to show the high potential of biogas production in European WWTPs (with a focus on new EU countries in Central Europe), but also to inspire operators to use sludge and other organic substrates more intensively for biogas production and its energy utilization. The situation in biogas production and possibilities for its exploitation in the Slovak Republic are presented.

Table 1 – *Primary production of biogas and electricity production from biogas in selected EU-countries in 2009*[7,8]

Country	Biogas production				
	Landfills	WWTPs	BGP	Electricity production	
	GWh	GWh	GWh	GWh	MWh/10^3 cap
Austria	57	220	1642	638	72
Belgium	515	24	909	462	44
Czech Rep.	340	392	779	441	43
Denmark	72	233	854	325	60
France	5144	526	450	847	14
G. Britain	17147	2902	0	5591	94
Germany	3088	4497	41417	12562	152
Greece	538	142	2	217	20
Hungary	33	120	204	95	9
Italy	4208	58	901	1739	30
Poland	413	675	52	319	8
Slovakia	9	172	8	21	4
Slovenia	97	35	128	69	34
Spain	1628	116	383	527	13
Sweden	412	698	171	34	4
EU total	**34907**	**11671**	**50481**	**25169**	**34**

Biogas production in WWTPs in Central European countries

The new EU countries from Central Europe (CE) such as the Czech Republic, Hungary, Poland, Slovenia and Slovakia have markedly improved management of WWTPs since entering into the EU (2004). Tightened legislative requirements on effluent parameters especially nutrients, BOD_5 and COD parameters, changes in optimisation and control were very important factors in operation and maintenance of WWTP. With the EU-funds, almost all large WWTPs in the new EU countries have been reconstructed and upgraded. In the frame of WWTP reconstruction, the digesters, equipment for biogas production, collection and usage were also modernised.

The production of biogas in municipal WWTPs represents a significant contribution to total biogas production in the presented CE countries; the highest value is reported in the Slovak Republic (91 %), followed by Poland (59 %) and Hungary (34 %). The lowest biogas production in WWTPs is in the Czech Republic (26 %) and Slovenia (13 %). On the other hand, the Czech Republic has the highest specific value of biogas production per capita with 38.4 MWh/10^3 cap, and Poland (17.7 MWh/10^3 cap), whereas Hungary has the lowest (12.0 MWh/10^3 cap). All these statistical data confirm that CE countries have comparable WWTP biogas production with the EU-15 countries and in many parameters even better (see Table 1).

To increase energy efficiency of WWTP operation many digesters are operated in co-digestion mode. Co-digestion of sludge with energy waste (i.e. organic fraction of municipal solid waste – OFMSW, organic industrial waste) is a possibility that could lead to several benefits.[9–11] This method is actually accepted in many EU-15 countries and is starting also in new EU countries. Schwarzenbeck *et al.*[12] reported that more than 20 % of digester free capacity in German WWTPs is available for co-digestion processes. Chudoba *et al.*[13] published data from Czech WWTPs (Veolia Voda Czech group only) with anaerobic digestion processes. From 33 monitored WWTPs where the biogas production process occurred, only 25 were equipped with biogas utilization units (minimally for heating of digesters or buildings) and only 16 had installed combined heat and power (CHP) units. Only on five of them were added external substrates and

OFMSW to increase the biogas production in the co-digestion processes. The co-digestion experiences of the Czech Republic were compared with other large WWTPs in the CE countries (Germany and Hungary). As co-digestion substrates e.g. waste grease, food waste, glycerine, dairy waste, etc. were often used. From the reported data it is evident that the use of external substrates has increased specific biogas production from 0.45 m^3 kg^{-1} VS up to 0.54 m^3 kg^{-1} VS (under normal conditions – the temperature of 0 °C and pressure of 101325 Pa) which represents ca 20 % increase. Co-digestion leads to energy self-sufficiency of WWTPs. If operation of digesters runs without co-digestion the energy self-sufficiency rate of monitored WWTPs would average 40 %, co-digestion increases this value up to 53 %. Some monitored WWTPs (WWTP Pilsen with yeast waste, WWTP Braunschweig with grease waste) achieved the energy self-sufficiency on average 71.5 % and 66.3 % yearly, respectively. On the other hand, some negative aspects of co-digestion were also monitored, e.g. lower portion of methane in biogas, problems with dewatering, etc.[13]

As evident from Table 1, biogas production in Slovakia is dominant mostly in WWTPs. Recently, some agricultural biogas stations have been constructed and a few others are considered for construction, but due to the misty energy policy of the government in the area of renewable energy sources, they represent only a small share of biogas production. The energy economy of the state has led to a significant lag in relation to the developed EU countries, and Slovakia produces very small amounts of biogas energy. On the other hand, it is necessary to highlight that official data presented to European statistics are often incorrect and do not correspond with reality. The number of municipal WWTPs producing and treating biogas does not correspond with reality similarly as the amount of produced biogas and electrical power.

Biogas production in WWTPs in the Slovak Republic

With the aim of mapping the actual situation in production and utilization of biogas in municipal WWTPs, a query about actual parameters was prepared and sent to all operators of WWTPs. The first complex and real survey of basic parameters of WWTPs, digestion tanks, biogas production and electrical power production in the WWTPs was obtained in 2007,[14] in this paper the actual values (2009) are presented.

The next important goal of the contribution is to define "free" capacities in sludge and biogas management of individual WWTPs and to suggest their better efficiency, e.g. by adding various organic carbon sources that can promote the biogas production and consequently improve the efficiency transforming the biogas into heat or electrical power. Intense biogas production and utilization in Slovakia has great potential and could contribute to the economic operation of the Slovak WWTPs.

Sludge management

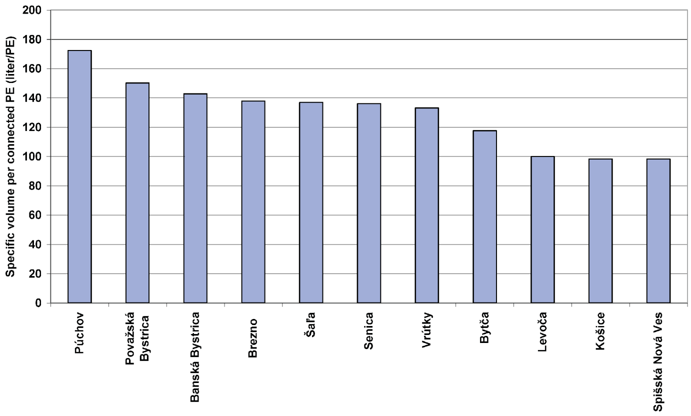
As obvious from Table 2, the total capacity of monitored WWTPs is more than 6.6 mil p.e., that is more than the number of inhabitants of the Slovak

Table 2 – *Summary of basic technological parameters of 10 largest municipal WWTPs with biogas production – year 2009 (* represents average value from all 49 monitored Slovak WWTPs with biogas production)*

WWTP	Design capacity of WWTP (p.e.)	Volume of digestion tanks (m^3)	Specific volume per p.e. connected (L/p.e.)	Biogas production (m^3 d^{-1})	Biogas production per 1 p.e. connected (L/p.e. day)	Energy production per p.e. (W/p.e. day)
Bratislava I.	1 092 000	34 500	89	9 636	25	36
Žilina	746 204	12 206	86	3 200	22	23
Lipt.Mikuláš	619 096	8 460	40	4 109	19	none
Bratislava II.	486 600	9 000	58	3 037	20	25
Košice	391 700	18 600	98	4 680	25	17
Nitra	270 000	9 200	85	start	N	none
Levice	217 300	8 000	82	1 400	14	27
Trnava	217 000	11 450	88	2 600	20	none
Prešov	200 370	5 830	98	2 260	38	25
B. Bystrica	190 000	10 000	143	2 100	30	14
Slovakia total*	**6 650 000**	**196 000**	**74***	**58 000**	**19***	**25***

Republic (in amount of p.e. the industrial contribution is calculated). The real data on exploitation of Slovak WWTPs show that many WWTPs are operated below the designed capacity (closing of many industrial factories connected to municipal WWTP, decreasing of specific wastewater production, decreasing of people equivalent connected to municipal WWTP, etc.). It is necessary to consider that the old free capacities of activated sludge systems are usually used for upgrading WWTPs on nutrient removal requirements, but the volume capacities of digester tanks are still free. Therefore, the majority of digestion tanks in Slovak WWTPs are under low-load operation.[14]

The total volume capacity of the digestion tanks in all Slovak WWTPs is ca 196 000 m^3 (the smallest 600 m^3 and the largest 34 500 m^3). Specific volume (SV) of digestion tanks responding to one connected p.e. (Litre/p.e.) is relatively high. The average value of SV is 74 L/p.e., the smallest value of SV is measured in WWTP Zvolen (18 L/p.e.) and the highest value of SV is achieved in WWTP Púchov (172 L/p.e.). As it is seen from Fig. 1, many WWTPs have specific volumes of digestion tanks extremely high (higher than 80–100 L/p.e.), which in most cases can be assigned to ineffective sludge management (in some WWTPs part of volumes is out of operation, but total volume was reported in the statistical data).

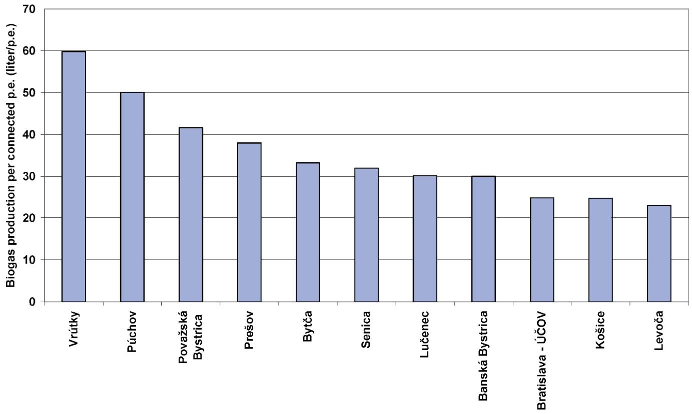


F i g . 1 – *Slovak WWTPs with the highest specific volumes of digestion tanks*

The next important parameter affecting operation of digestion tanks is hydraulic retention time (HRT) of sludge in digestion tank. In Slovakia, the average HRT of sludge in digestion tanks (together with storage tank) is about 33 days, ranging between 12 to 92 days. All presented data indicate that most digestion tanks in WWTPs are over-dimensioned or insufficiently charged. Although some existing WWTPs are recently under reconstruction or they are planned to be reconstructed and the amount of connected inhabitants will increase, most WWTPs have free capacities for treatment of external substrates in digestors.

Biogas management

In all 49 monitored WWTPs the biogas management was operated. Nevertheless in some WWTPs there are no available data on biogas production (start-up of operation of biogas production, reconstruction of sludge management etc.). In 2007, in Slovak WWTPs about 55 000 m^3 of biogas was produced daily, representing an annual production of almost 20 mil m^3 of biogas. The lowest biogas production is in WWTP Brezno (100 m^3 d^{-1}), the highest in WWTP ÚČOV Bratislava (9600 m^3 d^{-1}). The values of specific biogas production (litre of biogas/p.e.) in Slovak WWTPs vary between 5 L/p.e. (WWTP Pezinok) and 60 L/p.e. (WWTP Martin – Vrútky) with average value in all examined WWTPs 20 L/p.e. Fig. 2 shows the specific biogas production in 10 WWTPs with the highest biogas production.



F i g . 2 – *Slovak WWTPs with the highest specific biogas production*

The parameter of specific volume of biogas production (in litres per day) per litre of volume of digestion tank (in litres) is also interesting from the point of view of effectiveness of sludge management. WWTPs with good and effective sludge management (operating in optimal conditions, e.g. HRT about 20 days and organic loading rate about 2 kg VS m^{-3} d^{-1}) achieve higher values of the parameter than WWTPs with low biogas production, high tank volumes etc. The average specific volume of biogas production in all executed WWTPs is 0.33 L L^{-1} d^{-1}, the values vary from 0.05 L L^{-1} d^{-1} (WWTP Brezno) to 0.83 L L^{-1} d^{-1} (WWTP Bánovce n/B.).

Production of electrical power

In all executed WWTPs 21 mil m^3 of biogas were produced that theoretically represent about

125 GWh of energy. From 49 executed WWTPs only 21 of them have installed the equipment for electrical power generation (combined heat and power production – CHP) with total installed performance of 4.3 MW (individual WWTPs with performance range of 22–1600 kW). In 2009, in all presented WWTPs 35 000 kWh of electrical power was totally produced daily, representing 12.8 GWh annually. Average daily production of electrical power in WWTP with CHP was about 9.3 kWh/p.e. year or 380 kWh/1000 m^3 of digestion tanks per day. According to the information from water companies many WWTPs have serious intention of installing or enlarging production of electrical power.

Increase of biogas production

As stated earlier, most Slovak municipal WWTPs have free technical and technological capacities for biogas production increase. It is clear that increase of biogas production from sludge produced in WWTP is limited, which is why only external sources of organic materials can be considered. The range of used external sources of organic materials is wide and most used materials in municipal WWTPs are, as follows:[15–16]

– Food industry intermediate products (waste and inconvenient raw materials, low-quality food, etc);

– Industrial intermediate products and wastes (chemical industry, treatment of organic materials, etc.);

– Wastes from restaurants, expired food;

– Green municipal waste, wastes from markets, etc.;

– Separately collected organic wastes from inhabitants;

– Wastes from animal husbandry, slaughter-houses, etc.

The use of external organic energy substrates could (in most cases) complicate the technology (worsening of sludge water quality, decreasing of sludge dewatering, etc.), and it would be necessary to add some technological units (sanitary and pasteurizing reactor) but the resulting effect would definitely in all cases be positive – important increase of biogas production and from long-term view improvement of economic indicators of the operation.

Conclusion

The capacity of sludge and gas management in Slovak WWTPs is insufficiently utilized. From the technological point of view, the digestion tanks have sufficient capacity for a considerable increase of biogas production. The increase can be achieved by sufficient choice and dosage of external organic sources that can cause a significant energy – economic contribution to WWTP operation without technological process adaptations (plant oils, fats, organic materials, etc.) or with a small technological process adaptation (food residues, food and agricultural products and wastes). In cooperation with municipalities the biogas treatment with bio-fuel production for public transport seems to be very interesting.

91 % of the biogas production in Slovakia originates from wastewater treatment plants, which is relatively high in comparison with EU. This relation is caused by insufficient number of biogas plants in Slovakia. However, this situation should be changed in future, since the tendency of building new biogas stations is increasing, and also the biogas potential from landfills should be raised.

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List of abbreviations and symbols

AD – anaerobic digestion
BGP – biogas plant
BOD_5 – biochemical oxygen demand, mg L^{-1}
CE – central Europe
CHP – combined heat and power
COD – chemical oxygen demand, mg L^{-1}
DS – dry solids, g L^{-1}
HRT – hydraulic retention time, d
OFMSW – organic fraction of municipal solid waste
pe – population equivalent
SV – specific volume, L pe^{-1}
VS – volatile solids, g L^{-1}
WWTP – wastewater treatment plant

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