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

I. Bodík,* S. Sedláček, M. Kubaská, and M. Hutnían
Institute of Chemical and Environmental Engineering,
Faculty of Chemical and Food Technology,
Slovak University of Technology, Radlinského 9, 812 37 Bratislava

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 m³ but the total daily biogas production is only approx. 55 000 m³ 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 m³ 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 m³/10³ cap.d. The typical biogas production in secondary treatment plants is increased to about 28 m³/10³ 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
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 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.

### 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, BOD₃ 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/10³ cap, and Poland (17.7 MWh/10³ cap), whereas Hungary has the lowest (12.0 MWh/10³ 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. This method is actually accepted in many EU-15 countries and is starting also in new EU countries. Schwarzenbeck et al. reported that more than 20 % of digester free capacity in German WWTPs is available for co-digestion processes. Chudoba et al. 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

### Table 1 – Primary production of biogas and electricity production from biogas in selected EU-countries in 2009

<table>
<thead>
<tr>
<th>Country</th>
<th>Landfills (GWh)</th>
<th>WWTPs (GWh)</th>
<th>BGP (GWh)</th>
<th>Electricity production (MWh/10³ cap)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>57</td>
<td>220</td>
<td>1642</td>
<td>638</td>
</tr>
<tr>
<td>Belgium</td>
<td>515</td>
<td>24</td>
<td>909</td>
<td>462</td>
</tr>
<tr>
<td>Czech Rep.</td>
<td>340</td>
<td>392</td>
<td>779</td>
<td>441</td>
</tr>
<tr>
<td>Denmark</td>
<td>72</td>
<td>233</td>
<td>854</td>
<td>325</td>
</tr>
<tr>
<td>France</td>
<td>5144</td>
<td>526</td>
<td>450</td>
<td>847</td>
</tr>
<tr>
<td>G. Britain</td>
<td>17147</td>
<td>2902</td>
<td>0</td>
<td>5591</td>
</tr>
<tr>
<td>Germany</td>
<td>3088</td>
<td>4497</td>
<td>41417</td>
<td>12562</td>
</tr>
<tr>
<td>Greece</td>
<td>538</td>
<td>142</td>
<td>2</td>
<td>217</td>
</tr>
<tr>
<td>Hungary</td>
<td>33</td>
<td>120</td>
<td>204</td>
<td>95</td>
</tr>
<tr>
<td>Italy</td>
<td>4208</td>
<td>58</td>
<td>901</td>
<td>1739</td>
</tr>
<tr>
<td>Poland</td>
<td>413</td>
<td>675</td>
<td>52</td>
<td>319</td>
</tr>
<tr>
<td>Slovakia</td>
<td>9</td>
<td>172</td>
<td>8</td>
<td>21</td>
</tr>
<tr>
<td>Slovenia</td>
<td>97</td>
<td>35</td>
<td>128</td>
<td>69</td>
</tr>
<tr>
<td>Spain</td>
<td>1628</td>
<td>116</td>
<td>383</td>
<td>527</td>
</tr>
<tr>
<td>Sweden</td>
<td>412</td>
<td>698</td>
<td>171</td>
<td>34</td>
</tr>
</tbody>
</table>

**EU total:** 34907 11671 50481 25169 34
OFMSW to increase the biogas production in the codigestion processes. The codigestion 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 m³ kg⁻¹ VS up to 0.54 m³ 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>
<thead>
<tr>
<th>WWTP</th>
<th>Design capacity of WWTP (p.e.)</th>
<th>Volume of digestion tanks (m³)</th>
<th>Specific volume per p.e. connected (L/p.e.)</th>
<th>Biogas production (m³ d⁻¹)</th>
<th>Biogas production per 1 p.e. connected (L/p.e. day)</th>
<th>Energy production per p.e. (W/p.e. day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bratislava I</td>
<td>1 092 000</td>
<td>34 500</td>
<td>89</td>
<td>9 636</td>
<td>25</td>
<td>36</td>
</tr>
<tr>
<td>Žilina</td>
<td>746 204</td>
<td>12 206</td>
<td>86</td>
<td>3 200</td>
<td>22</td>
<td>23</td>
</tr>
<tr>
<td>Lipt.Mikulá</td>
<td>619 096</td>
<td>8 460</td>
<td>40</td>
<td>4 109</td>
<td>19</td>
<td>none</td>
</tr>
<tr>
<td>Bratislava II</td>
<td>486 600</td>
<td>9 000</td>
<td>58</td>
<td>3 037</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Košice</td>
<td>391 700</td>
<td>18 600</td>
<td>98</td>
<td>4 680</td>
<td>25</td>
<td>17</td>
</tr>
<tr>
<td>Nitra</td>
<td>270 000</td>
<td>9 200</td>
<td>85</td>
<td>start</td>
<td>N</td>
<td>none</td>
</tr>
<tr>
<td>Levice</td>
<td>217 300</td>
<td>8 000</td>
<td>82</td>
<td>1 400</td>
<td>14</td>
<td>27</td>
</tr>
<tr>
<td>Trnava</td>
<td>217 000</td>
<td>11 450</td>
<td>88</td>
<td>2 600</td>
<td>20</td>
<td>none</td>
</tr>
<tr>
<td>Prešov</td>
<td>200 370</td>
<td>5 830</td>
<td>98</td>
<td>2 260</td>
<td>38</td>
<td>25</td>
</tr>
<tr>
<td>B. Bystrica</td>
<td>190 000</td>
<td>7 140</td>
<td>62</td>
<td>2 500</td>
<td>30</td>
<td>24</td>
</tr>
<tr>
<td>Slovakia total*</td>
<td>6 650 000</td>
<td>196 000</td>
<td>74*</td>
<td>58 000</td>
<td>19*</td>
<td>25*</td>
</tr>
</tbody>
</table>

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)
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 m³ (the smallest 600 m³ and the largest 34 500 m³). 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).

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 m³ of biogas was produced daily, representing an annual production of almost 20 mil m³ of biogas. The lowest biogas production is in WWTP Brezno (100 m³ d⁻¹), the highest in WWTP ÚČOV Bratislava (9600 m³ 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.

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 m³ of biogas were produced that theoretically represent about
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.

ACKNOWLEDGEMENTS

The presented contribution was supported by the Slovak Research and Development Agency under the contract No. LPP-0019-09. This contribution is also a result of the project implementation: National Centre for Research and Application of Renewable Energy Sources (ITMS: 26240120016), supported by the Research & Development Operational Programme funded by the ERDF.

List of abbreviations and symbols

AD – anaerobic digestion
BGP – biogas plant
BOD₅ – 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

References