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INCREASING THE UTILIZATION EFFICIENCY OF COMBUSTIBLE GASES FROM URBAN WASTE WATER

BY

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Abstract. The waste water from urban sewage treatment plants contains a series of substances (chemical elements) which have a great potential in terms of energy (they are combustible gases) and/or a strong negative impact on the environment (Asaftei & Iftimie, 2014; Dima, 1998).

The recovery of combustible gases (also known under the generic name of biogas) has a dual purpose: on the one hand, one that pertains to energy *i.e*., the production of electrical, thermal energy, etc.; on the other hand, which is actually the main aspect, the cutting down of the particularly harmful impact of such substances on the environment.

This paper continues to approach the issues presented by Asaftei & Iftimie, (2014), by evaluating the impact on the environment of complete combustible gas recovery and burning in order to produce thermal and, respectively, electrical energy.

In order to produce the two forms of energy, beside the Ygnis boiler (which produces only thermal energy), whose characteristics were presented by Asaftei & Iftimie, (2014), this study also makes use of a cogeneration group (motor-generator), which produces thermal and electrical energy in a combined system.

Key words: sewage treatment; combustible gases; electrical and thermal energy; environmental impact.

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1. Introduction

This study resumes the issues concerning the recovery and utilization of biogas from urban sewage collecting and treatment plants, by evaluating a practical process in the unfolding of which urban waste water may be turned to good account, with positive effects on the environment and also on other areas.

As shown by Asaftei & Iftimie, (2014), biogas can be obtained in special installations (digesters), in which sludge resulting from waste water is maintained at a certain temperature and starts to ferment (a process named anaerobic digestion, as it takes place in the absence of oxygen) and to generate combustible gases (hydrocarbons, hydrogen, carbon monoxide, hydrogen sulphied, etc.), as well as a series of non-combustible gases (carbon dioxide, sulphur dioxide, etc.); irrespective of their type, these gases have a strong negative impact on the environment; hydrocarbons, carbon monoxide and dioxide, hydrogen, hydrogen sulphied, etc., are also known as greenhouse effect gases (GES) (Dima, 1998; http://biogaz.ugotech.ro/).

As known, the mixture of gases made up of methane, hydrogen, carbon dioxide, oxygen, nitrogen, water vapors, etc., is also generically named biogas; it is formed through the decomposition of organic waste, out of the organic waste component, in a humid environment and in the absence of oxygen – the Anaerobic Digestion technique, DA.

As already mentioned, the recovery of combustible gases (methane, carbon monoxide, hydrogen and hydrogen sulphied) serves a double purpose: on the one hand, an energy pertaking purpose; on the other hand, and this is in fact the main aspect, the cutting down of the extremely noxious impact on the environment.

Starting from these considerations, the rest of the study presents the technological improvements that have been performed on the installation in order to optimize the process by means of which biogas is obtained and utilized with benefic effects, first and foremost on the environmental level, as well as on the economic level.

2. The Installation for Obtaining and Using Biogas

As mentioned earlier, the biogas production installation includes an installation in which the process of anaerobic digestion takes place (digester installation), presented by Asaftei & Iftimie, (2014), as well as an installation for producing the thermal energy necessary for bringing the sludge to an optimum temperature and keeping it at this optimum temperature for the fermentation process to be carried out.

The digestion process depends mainly on two factors, *i.e.*, the type of bacteria used for initiating and maintaining the fermentation process, and, respectively, the temperature at which this process takes place in the absence of air (Asaftei & Iftimie, 2014; Dima, 1998).

Biogas production takes place in two digester installations in which sludge is introduced. The anaerobic digestion process is made with mesophile bacteria. The optimum temperature of the sludge under permanent duty is maintained in the range 33,...,37^{o}C (Fig. 1).

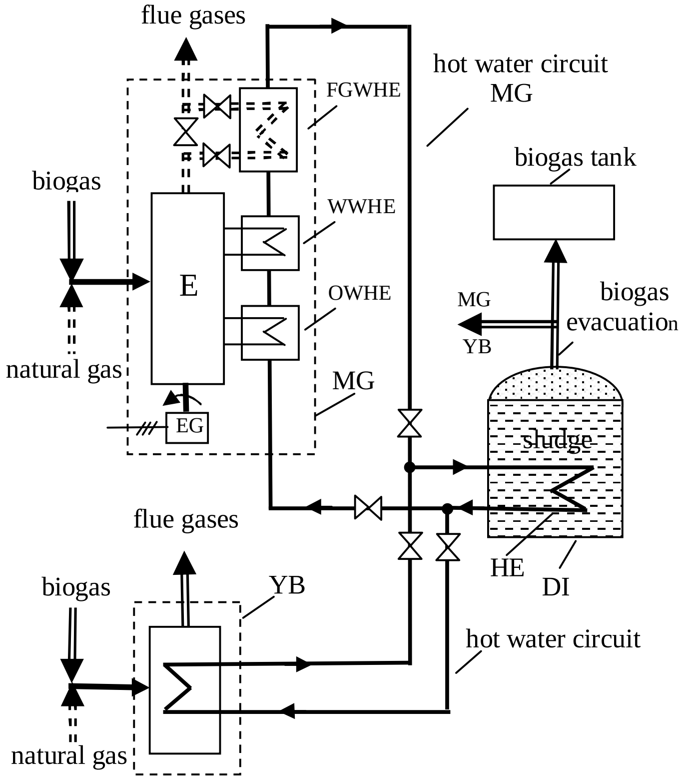

Fig. 1 – Diagram of biogas production, harnessing and use installation: MG – motor-generator; E – internal combustion engine; EG – electric generator; OWHE – oil-water heat exchanger; WWHE - water-water heat exchanger; FGWHE – flue gases-water heat exchanger; YB – Ygnis boiler; DI – sludge anaerobic digester installation; HE – hot water-sludge heat exchanger.

In order to reach and maintain this temperature range, the sludge is heated with a surface heat exchanger HE (immersed in the sludge) through which hot water circulates.

As mentioned before, during the first stage (Asaftei & Iftimie, 2014), the thermal energynecessary for the production of hot water was provided only by the Ygnis boiler (YB), which was the only consumer of the biogas produced in the digester installation DI. This had the disadvantage that during the warm season, the high outside temperatures decreased a lot the functioning time, and, respectively, the boiler biogas consumption; under these conditions there existed a surplus in the biogas production, as compared to the necessary consumption. A part of this surplus was introduced in a tank (gasmeter), while the excess was released in the atmosphere, after first being oxidized (burnt); this fact represented a big disadvantage.

As a consequence, during the second stage, the consumption of the whole quantity of biogas supplied by the digester installation throughout a year was provided for the purchase and setting up of a motor-generator (cogeneration group) MG which functioned in tandem with the Ygnis boiler; this way, the losses of combustible gases were eliminated by burning the excess of biogas. It should also be pointed out that in order to carry out the sludge heating process, the heat exchanger in the digester installation is connected in parallel both with the Ygnis boiler hot water supply circuits and with those of the motor-generator; in the latter case, the hot water takes over the heat from the lubricating oil circuit and from that of motor M cooling water (in the OWHE, and respectively, WWHE, and, respectively, from the flue gases evacuated in the atmosphere (in the FGWHE); in this last case, the recovery of heat from the flue gases may or may not happen, depending on the quantity of heat necessary for maintaining an optimum anaerobic digestion process.

It should be pointed out that the Ygnis boiler, as well as the motor-generator also include a spare natural gas supply, that can start to operate in case:

a) the amount of biogas produced is not enough to be able to obtain the optimum sludge temperature (in the digester installation); this situation may appear in the cold season (in winter), when the outside temperatures decrease very much;

b) the biogas supply installations of the boiler and of the motor-generator are not available.

3. Environmental Impact Assessment

The evaluation was made during a whole year, and for the optimum operation of the digester installations thermal energy produced in the Ygnis boiler and/or in the motor-generator through the burning of biogas was used. In this situation, pollution is caused by the combustion gases, released into the atmosphere from the furnaces corresponding to the two pieces of equipment.

The determination of the parameters needed in order to assess the impact on the environment involved previous installation measurements during the operating periods of the two pieces of equipment in order to determine the biogas consumption, the Ygnis boiler total running time and, respectively, the motor-generator running time, the hot water parameters, the production of electrical and thermal energy, the burning gases parameters, and, respectively, the combustion air parameters, in the period considered.

In each case (Ygnis boiler and, respectively, motor-generator), only the permanent duty was taken into account; the transitory initial phases when the installations were started in a cold state were not taken into consideration; the permanent working conditions of the two installations are characterized by alternating start-ups and stops. The installations are started when the temperature of the sludge in the digester installation reaches the minimum of the optimum digestion interval, *i.e.* 33ºC; alternatively, the installations are stopped when the sludge temperature reaches the maximum of the optimum digestion interval, *i.e.* 37ºC.

Mention should be made that, depending on the amount of heat required, in the period under study, the two pieces of equipment operated both simultaneously and alternatively. Taking these considerations into account, Tables 1 and 2 present the results of the measurements and calculations related to the indicators that determine the degree of pollution of the environment during the functioning with biogas of the Ygnis boiler and of the motor-generator, respectively (Carabogdan *et al.*, 1986; Patraşcu *et al.*, 2001). From the results presented in Tables 1 and 2, it can be noticed that carbon dioxide is the only component that has a polluting effect (greenhouse effect gas) which is present in the flue gases released from the Ygnis boiler flue and, respectively, from the motor-generator flue in the duty period considered.

Table 1
Measured and Calculated Parameters of the Ygnisboiler when Operating with Biogas (bg)

Parameter	Symbol	Average regime
Methane gas, [%]	CH_4	65.9
Carbon dioxide, [%]	CO_2	32.6
Carbon monoxide, [ppm]	CO	<50
Oxygen, [%]	O_2	0.2
Nitrogen, [%]	N_2	0.6
Low Calorific Value, [kJ/Ncm.bg]	H_i	23,848
Measured flow, [Ncm.bg/h]	B_{bg}	64.5
Temperature, [ºC]	t_{wt}	49
Hot water turn cycle flow, [cm/h]	D_{wt}	80
Heat eliminated during hot water turn cycle, [MJ/h]	Q_{wt}	16405
Temperature, [ºC]	t_{wr}	45
Hot water return cycle flow, [cm/h]	D_{wr}	80
Heat eliminated during hot water return cycle, [MJ/h]	Q_{wr}	15,066
Oxygen, [%]	O_2	3.481
Carbon dioxide, [%]	CO_2	11.236
Nitrogen, [%]	N_2	70.148
Specific carbon dioxide, [Ncm/Ncm.bg]	–	0.980
Excess air coefficient	λ	1.23

The calculation results regarding the total estimated pollutant (CO_2) amount are synthetically presented in Table 3, where the density of carbon dioxide was considered equal to 1.977 kg/Ncm, the total number of the boiler operation hours being equal to 1,600 h in the case of the Ygnis boiler, and, respectively, equal to 2,486 h for the motor-generator.

Table 2
Measured and Calculated Parameters of the Motor-Generator when Operating with Biogas (bg)

Parameter	Symbol	Average regime
Methane gas, [%]	CH_4	65.9
Carbon dioxide, [%]	CO_2	32.6
Carbon monoxide, [ppm]	CO	<50
Oxygen, [%]	O_2	0.2
Nitrogen, [%]	N_2	0.6
Low Calorific Value, [kJ/Ncm.bg]	H_i	23,848
Measured flow, [Ncm.bg/h]	B_{bg}	105
Temperature, [ºC]	t_{wt}	52
Hot water turn cycle flow, [cm/h]	D_{wt}	35
Heat eliminated during hot water turn cycle, [MJ/h]	Q_{wt}	7,617
Temperature, [ºC]	t_{wr}	43.5
Hot water return cycle flow, [cm/h]	D_{wr}	35
Heat eliminated during hot water return cycle, [MJ/h]	Q_{wr}	6,372
Oxygen, [%]	O_2	3.094
Carbon dioxide, [%]	CO_2	11.485
Nitrogen, [%]	N_2	69.952
Specific carbon dioxide, [Ncm/Ncm.bg]	–	0.980
Excess air coefficient	λ	1.2

Table 3
Total Amount of Carbon Dioxide Released in the Atmosphere Through the Flue Gases

Thermal equipment	Total amount of biogas consumed Ncm/year	Amount of CO_2 resulting from the CH_4 burning process, [t]	Amount of CO_2 in the biogas, [t]	Total amount of CO_2, [t]
Ygnis boiler	103,200	200	65	265
Motor-generator	250,530	485	148	633
Total	353,730	685	213	898

Given the density and the concentration of methane (CH_4) in biogas, of 0.717 kg/N.cm, and, respectively, 65.9% CH_4 – the total amount of methane contained in the biogas consumed in the period under study was equal to 233,108 N.cm/year and, respectively, 167 t/year. If it is take into account the fact that the global warming coefficient of methane is equal to 21 units, it follows that the polluting potential that might be exerted on the environment by the amount of methane taken into account (in case it could migrate freely in the atmosphere) would the similar to the polluting potential that might be exerted, in a period of 100 years, by an equivalent quantity of carbon dioxide, equal to 4,175 t/year. It can be noticed that this value is much bigger than the amount obtained by burning the methane from the biogas (in the Ygnis boiler flue and, respectively, in the motor-generator combustion chamber, which represents only 685 t/year.

It should be mentioned that these results correspond to an amount of sludge of approximately 100 t that is introduced daily in the digester install.

4. Conclusions

Harnessing and burning biogas in a controlled manner in the Ygnis boiler furnace and/or in a motor-generator combustion chamber can provide the heat required by the process of sludge anaerobic digestion (in an urban sewage treatment plant). This can practically make this process independent in terms of energy; moreover, it can provide the production of a significant amount of electrical energy (about 215,244 kWh/year), that permits the cutting down of the cost of utilities, as well as the amortization over time of the pieces of equipment that contribute to biogas harnessing and burning.

The existence of a motor-generator in the installation makes it possible to use the biogas more efficiently, as compared to the case in which the wastewater treatment plant is endowed only with the Ygnis boiler. The higher the outer temperatures, *i.e.*, the spring-autumn season, the more obvious this becomes; weather permitting, as was the case in the period of analysis under study, the motor-generator period of functioning may be extended until the cold season (December).

The existence of the motor-generator renders unnecessary the burning of the excess gas in the free atmosphere (especially in the warm season), since, as mentioned, this biogas surplus is utilized in a useful manner. This is different from the sewage treatment plants, which are endowed with a single biogas consumer (a boiler) (Asaftei & Iftimie, 2014).

In what concerns the impact on the environment, it should be mentioned that besides the carbon dioxide fraction that results from the controlled methane oxidation (released in the environment through the flue gases), there alo exists a carbon dioxide fraction that is normally found in the biogas harnessed by the anaerobic digester installations (Table 3).

As shown in Table 3, the amount of carbon dioxide that results only from the oxidation process of the methane found in the biogas in the period under study (a whole year) is approximately equal to 685t/year. If we take into account the total amount of biogas and, respectively, a percentage of 32% CO_2 in its composition, it follows that the total amount of carbon dioxide discharged in the atmosphere (evaluated for the whole period under study) increases with about 213t/year, *i.e.*, with 898t/year in total.

In conclusion, we can estimate that equipping the sewage treatment plant with a motor-generator does not have, at first view, a significant effect on the environment; instead, it brings about a much more efficient use of the biogas surplus, especially in the warm season, which consists in the generation of a significant amount of electrical energy (about 215,244 kWh/year) as mentioned before.

But even if at first view the setting up of the motor-generator does not overtly entail significant favourable effects on the environment, such effects exist in a covert manner.

Thus, by producing on its own a certain amount of electrical energy (used for internal service consumption), an equivalent amount of such energy will no longer be taken from the electricity grid, and, consequently, this amount will no longer be generated in power plants; as a consequence, a corresponding quantity of fossil fuels (for example) will no longer be consumed by power plants and, as an effect, a certain amount of pollutants (that might result through the burning of these fuels) will no longer be released in the atmosphere, thus cutting down pollution to a certain extent.

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CREŞTEREA EFICIENȚEI DE UTILIZARE A GAZELOR COMBUSTIBILE REZULTATE DIN APELE UZATE ORĂŞENEŞTI

(Rezumat)

Apele uzate din instalațiile orăşeneşti de epurare conțin o serie de substanțe (elemente chimice), care au un potențial energetic deosebit (sunt gaze combustibile) şi/sau un puternic impact negativ asupra mediului inconjurător (Asaftei & Iftimie, 2014; Dima, 1998).

Recuperarea gazelor combustibile (cunoscute şi sub denumirea generică de biogaz) are un scop dublu: pe de o parte, unul energetic şi anume producerea de energie electrică, termică, etc., iar pe de altă parte, de fapt aspectul primordial, reducerea impactului deosebit de nociv al unora din aceste substanțe asupra mediului inconjurător.

În aceasta lucrare este reluată tematica prezentată de Asaftei & Iftimie, (2014), evaluându-se efectele pe care le are asupra mediului înconjurător recuperarea şi utilizarea în totalitate a gazelor combustibile pentru producerea de energie termică şi respectiv, electrică.

Pentru a produce cele doua forme de energie, se utilizeaza de aceasta dată în afară de un boiler Ygnis (care produce numai energie termică), caz prezentat de Asaftei & Iftimie, (2014), şi un grup de cogenerare (motogenerator), care produce în sistem combinat energie termică şi electrică.