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Technical and Logistics Analysis of the Extension of the Energy Supply System with the Cogeneration Unit Supplied with Biogas from the Water Treatment Plant

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Summary. This paper shall present and explain the key aspects related to the issue of combined heat and power generation (CHP – Combined Heat and Power or Cogeneration). The cooperation with the water treatment plant launched allowed a closer look at the described technology as well as allowed the analyses and survey. The survey on the efficacy of the selected components of the cogeneration system was based on two cogeneration units fuelled with biogas produced in the sewage fermentation.
Key words: biogas, cogeneration, electricity, heat, generator, water treatment plant.

INTRODUCTION

The increasing number of population in the cities and villages as well as the fast pace of Poland's economic development have resulted in the increasing demand for water supply systems [12, 25]. To drain the increasing volume of sewage, new water treatment plants and sewage systems are being developed [1, 3, 5, 11]. Another solution applied consists in modernizing the existing water treatment plants and sewage drainage systems [6, 17, 28, 29]. During the recent years, the cogeneration systems fuelled with biogas have become most popular [7, 8, 16, 23]. It is estimated that in 2013, more than 32 thousand GWh will be produced from the biogas in cogeneration in an upward trend. It is also worth emphasizing that only half of the EU Member States use biogas to produce electricity (in 2013 they produced more than 20 thousand GWh) [4, 26, 27]. All that poses a great challenge in terms of the energy safety and environmental protection [15, 18, 30, 31], but also presents a significant contribution to the energy produced with the renewable energy sources [10, 13, 14, 21].

Pursuant to the Report on the Performance of the National Municipal Water Treatment Plan in 2012-2013, large cities had 1712 municipal water treatment plants in 2013. 525 plants with extended nitrogen and general phosphorus elimination system, 1111 plants providing biologic treatment and 76 entities with no active water treatment process due to the fact of being still under construction or another investment may be distinguished. The amount of the sewage dry waste residue in the water treatment plants amounted to 560050.7 Mg and 564229.9 Mg in 2012 and 2013 respectively [24]. The increased number of the residue produces resulted from the increasing capacity of the municipal water treatment plants as well as the application of more advanced technologies of extended bio-gene elimination systems [2, 9, 19, 20]. According to the forecasts, after 2015 the volume of the sewage processed in the technological processes within the water treatment plants will be approx. 642 thousand tons of dry waste residue.

CHARACTERISTICS OF THE FACILITIES AND DEVICES WITHIN THE UNIT UNDER ANALYSIS

The unit under analysis is a mechanical and biological water treatment plant. The facility was developed in the 1950-ties. The main modernizations performed within the water treatment plant in 2011 and 2013 included the extension of the power supply system with the cogeneration units fuelled with biogas [22]. It is assumed that the current daily volume of the sewage drained to the water treatment plant under analysis reached from 15000 to 19500 m^3/d. The sewage is drained to the plant with a gravitational canal and to the sewage collection station with gully emptiers. The station is equipped with the tumble grates with the screening press and grit separator. The so-called pre-treated sewage are conveyed to the equalization tank with the capacity of V=900 m^3. Then the sewage is pumped to the main pump room, where it is mixed with the municipal sewage. Then the sewage is flowed through the grit separator. The grit separator is powered by the compressed air from the blowers – eliminating approx. 90% of the mineral suspension with the typical grain size of 0.15 mm. The grit collected of the separator's bottom is discharged gravitationally and accumulated on the landfill. The waste with separated organic suspension are then directed to the organic pumping room, and pumped to one of the primary sludge thickener. The next step consists in placing the sewage in two primary settlement tanks, where the sewage sedimentation takes place. Light and easily falling suspension is accumulated on the settlement tank's bottom. The tanks installed are 30 m in diameter and 3 m deep radial with mechanical scraper floating sludge. The sediments collected in the funnel are drained by the hydrostatic pressure on the sewage band to the thickener chambers, and then further processed. The pre-treated sewage is then subject to the next treatment step – biologic water treatment. From the primary settlement tanks the sludge is directed to two denitrification chambers with the active volume of 2500 m³ of the active sludge. There the denitrification procedure takes place, namely the oxidized forms of nitrogen (nitrates) are reduced to the gaseous nitrogen. The process takes place in the anaerobic conditions. On the other hand, the nitrification process, being the next step in the procedure, takes place in the aerobic conditions. Within the stage, the solved organic carbon components are eliminated from the sludge and the organic nitrogen as well as the ammonia nitrogen is oxidized to the form of nitrates. This process applies the method of the low-impact active sediment method. The active sediment as well as the treated sewage are mixed and directed to two radial secondary settlement tanks that are 2.2 m deep and 35 m in diameter. Their task is to separate the active sediment from the treated sewage. Then the active sediment so produced is directed to the active sediment pump room, where it is divided into the recirculated active sediment and excess sediment. Having completed the whole sewage treatment procedure, the recirculated sediment on the line is directed to the airing chambers, while the excess sediment is being pumped through the primary settlement tanks. The sewage so treated is drained to the river. The sewage treatment procedure described above may be followed on the technical diagram (Fig. 1).

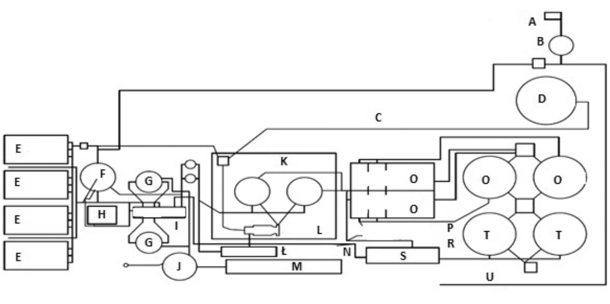

Fig. 1. Technical diagram of the water treatment plant [Own elaboration]: A – Sewage collection station, B – Equalization tank, C – Sediment water drainage, D – Main pump station, E – Sediment lagoon, F – OBF, G – WKF, H – Presses, I – WKF back-up facilities, J – Biogas tank, K – Primary settlement tanks, L – Grit separator, Ł – Settlement washer, M – Boiler room, N – Excess sediment, O – Denitrification chamber, P – Inner recirculation, R – Outer recirculation, S – Control room, T – Secondary settlement tank, U – Sewage supply

Sediment line – the sediment line's technology within the water treatment plant (Fig. 1) commences when the sludge is produced in the technological processes and through supplying the primary sediment and mixing it with the excess sediment in the 65 m³ thickener chambers. The primary sediment is directed gravitationally from the primary settlement tanks to the vertical thickeners with the mixers. The thickening procedure is performed from time to time. Water is drained from the sediment so produced gravitationally. Then the thickened sediment is pressed from the primary settlement tanks to two separated 3000 m3 fermentation chambers (WKF). When the WKF chambers are operating, the sediment's temperature is approx. 35 °C. The volume of fresh sediment directed to the chambers is approx. 100 m³/day, 1.6 kg/sec. Biogas produced in this procedure is drained from the cylindrical WKF chambers. Fermented sediment is directed to the open fermentation reservoir (OBF) with presses. The reservoir is an impounding tank designed to store the sediment. Eventually the sediment is dehydrated with a press. The sediment collected from the BF reservoir by the press is stored on four sediment lagoons. The final sediment is used to fertilise the sandy ground within the area of the water treatment plant.

Gas line – biogas i the final product of the gas line. Biogas produced in the fermentation in the WKF chambers is collected and stored in a 15500 m³ tank. Then the gas is directed to the boiler room equipped with two cogeneration units, with the power of 190 kWe and 250 kWe, as well as the central heating boiler. The gas reaching the boiler room provides the power supply for the room, supplies the industrial and office premises within the water treatment tank, as well as the whole installation heating the fermentation chambers. The excess of the gas so produced is burnt in a flare.

SURVEY ON THE FLOWS, SEDIMENT VOLUME AND BIOGAS PRODUCTION

In the case under analysis, the raw material used to produce the energy carriers comprised sewage delivered to the plant. During the analyses, the fact that data made available for analysis not always reflected the current status of the sediment used for technological processes was taken into consideration. This was because of the failures of the measuring equipment, due to the modernization and repair of the plant's units during the year. The diagram below (Fig. 2) shows significant variability of the volume of the sediment drained from WKF-1 and WKF-2 in the beginning of 2012. In view of the first four months of 2012, March was the most outstanding, because no measurements were recorded for 8 days in February and April, when the meter readings of 3 days of the month were not taken into consideration. Then the situation stabilized. The volume of the sediment drained from the fermentation chambers varied from 6000 to 7000 m³ a month.

Figure 3 presents the graphic presentation of the biogas meter readings in the fermentation chambers and cogeneration unit. The absence of readings during the three months of 2013 was caused by the failure of WKF-1. It may be noted that the cogeneration unit's biogas meter rapidly reaches the volume exceeding 50000 m³ of the biogas produced. One shall also note that its volume rapidly decreases and stabilizes at 21000 m³ of the biogas produced a month.

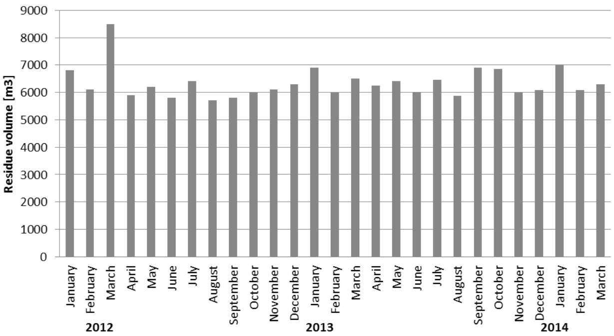

Fig. 2. Volume of the residue collected from the WKF in the years 2012-2014 [Own elaboration]

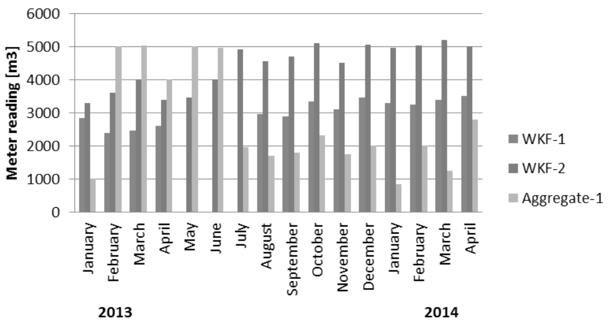

Fig. 3. Biogas tank status for the individual biogas producing devices [Own elaboration]

Generated energy – in 2012 only one unit generating approx. 120 MWh of power was operating (Fig. 4). However, when the second 250 kW unit was installed in the middle of 2013, the power generated by the first unit decreased drastically (now it varies from 40 to 50 MWh). The installed 250 kW unit operated at the average load of 170 MWh that year, while the other unit operated at the average load of 40 kWh during the first four months of that year. Currently, most of the heat and power demand for the water treatment plant under analysis is generated by the 250 kW cogeneration unit. The 190 kW unit is a device used for generating energy supplying the total demand.

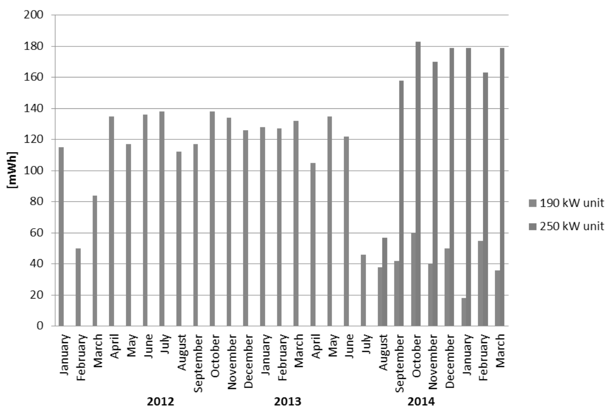

Fig. 4. Volume of the energy produced in the years 2012-2014 [Own elaboration]

Consumed energy – it shall be underlined that the total plant's demand on the carriers such as energy and heat is not completely covered by both cogeneration units and the central heating boiler. To cover the total electricity and heat demand, the plant purchases some power from its distributor. The diagram below (Fig. 5) shows the floating electricity demand and production within the two years. The increased volume of the energy generated and consumed was caused by the installation of the additional cogeneration unit. In this case, the decreased volume of the energy purchased from the distributor by 40% resulting in the reduced cost of the energy supply is positive. The electricity and heat generated with the use of the cogeneration units covers 60% of the entity's demand on the two energy carriers.

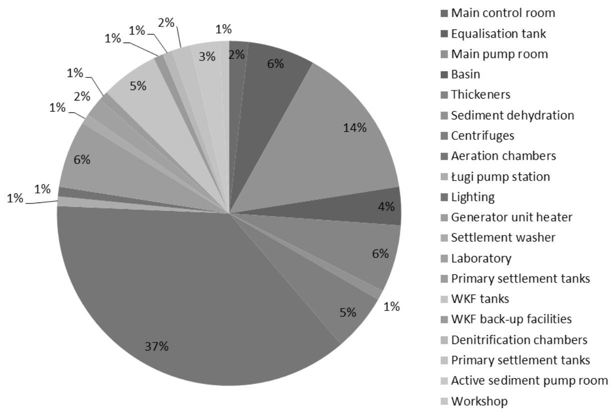

Fig. 5. Statement on the energy used within the treatment plant [Own elaboration]

SURVEY ON THE ELECTRICITY CONSUMPTION WITHIN THE WATER TREATMENT PLANT

In the middle of 2012, the investment aimed at launching the first cogeneration system fuelled with biogas with the design power of 190 Kw of electricity and 250 kW of heat respectively, was completed. The second investment was completed in 2013, which allowed using the other system at the load of 250 kW of electricity and 350 kW of heat (Fig. 6).

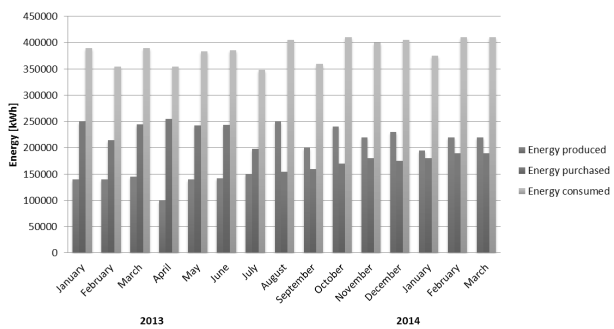

Fig. 6. Statement on the electricity consumption within the water treatment plant [Own elaboration]

Electricity and heat delivered by the biogas-powered boiler is used on the plant to heat the office and industrial premises and to heat the WKF chambers. Below we present the annual percentage electricity consumption by the devices installed within the water treatment plant under analysis (Fig. 7).

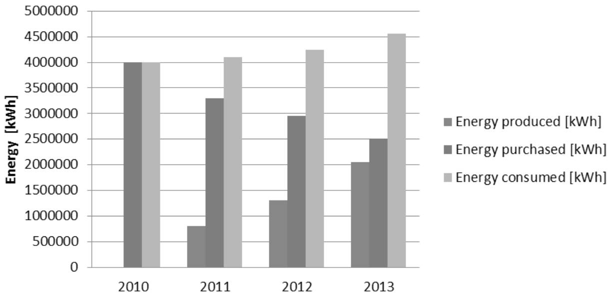

Fig. 7. Annual electricity consumption within the water treatment plant [Own elaboration]

CONCLUSIONS

The performed analyses and surveys of the installed biogas 190 kW and 250 kW cogeneration units suggest that this solution is definitely beneficial in terms of generating electricity and heat within the water treatment plant under analysis. Electricity and heat is used within the entity under analysis to meet its own needs such as: heating the industrial, technical and office premises as well as providing the power supply to the devices operating within the plant. With the cogeneration units more than 60% of the aggregate demand on the electricity and heat is covered by the plant, with the biogas production volume at 85 m^3/h. It shall be underlined that by installing the units, the distributed energy consumption was reduced by approx. 40%.

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ANALIZA TECHNICZNO-LOGISTYCZNA NADBUDOWY SYSTEMU ENERGETYCZNEGO O AGREGAT KOGENERACYJNY ZASILANY BIOGAZEM Z OCZYSZCZALNI ŚCIEKÓW

Streszczenie. Celem pracy było przedstawienie i omówienie kluczowych zagadnień związanych z tematyką skojarzonej produkcji energii elektrycznej i ciepła (CHP – Combined Heat and Power lub Cogeneration). Podjęta współpraca z oczyszczalnią ścieków pozwoliła na bliższe przyjrzenie się opisywanej technologii oraz umożliwiła przeprowadzenie analiz wraz z badaniami. Badania efektywności wybranych elementów układu kogeneracyjnego zostały oparte o dwa agregaty kogeneracyjne zasilane biogazem powstałym z fermentacji pościekowej.

Słowa kluczowe: biogaz, kogeneracja, energia elektryczna, ciepło, agregat, oczyszczalnia ścieków.