FACULTY OF CIVIL
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TABLE OF CONTENTS

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The structure of electricity consumption in wastewater treatment plants

Key words: *wastewater treatment, energy consumption`s diagram, energy efficiency*

Abstract: The main focus of the article is on the energy consumption in Wastewater Treatment Plants (WWTPs) from the viewpoint of its distribution on individual blocks, systems or devices. Conventional systems were taken into account, and additionally a few non-standard plants. To develop energy distribution diagrams archival data from several Polish conventional plants were used, and, additionally, complimentary data from a few non-conventional WWTPs from the USA. During development of the detailed energy usage diagram, a few methods were elaborated with varying degrees of accuracy, allowing estimation of proper results even with incomplete data. These methods were compared with available literature and methods currently used. Based on the above materials, a compact summary was developed, showing the distribution of the energy consumption of the wastewater treatment plants with a biological stage contaminant removal.

1. Introduction

Despite of many research on energy efficiency and energy distribution in environmental engineering systems there are still many unknown or unsolved issues. Situation in the waste water treatment industry always was a little different than in other sectors. Energy issues never were on the first place on "the list of concerns", the greatest possible effluent quality was for a very long time a primary goal. However, some papers were published in seventies and eighties of last century in which this issue was addressed but the noticeable increase of interest started 25-30 years ago. Reasons for this increase interest were various and may be different in different regions/countries. Two most obvious were economy and ecology: rising energy costs and increasing pressure on environment protection including CO_2 emissions reduction. Moreover, probably one of the technological factors was development of more advanced automation and on-line monitoring systems, new technologies, and more efficient machinery and control software. The most valuable papers were published in the last 15 years.

Summing all up, there is still a lot of work that could and should be done regarding energy efficiency of Wastewater Treatment Plants (WWTPs). Also, revisions of some theories and assumptions due to ongoing technological development may be required.

2. Methods

This research was based on data from 6 small, conventional WWTPs in Southern Poland (located near Kraków agglomeration), and four non-conventional plants in USA). Because of the protection of corporate data, applicable to several objects, all names of the plants were changed. (By „conventional system” authors understand a common type of WWTP in UE or US, consisting of two stages of treatment with activated sludge (mechanical + biological) and biological C_{org}. N, and P. removal)

2.1 Descriptions of studied WWTPs.

Conventional two-stage (mechanical + biological) WWTPs with active-sludge reactor type with aerobic and anaerobic conditions, are listed below in ascending order according to the designed average daily flow rate.

Plant A was designed for flow rate Q_{avdp} =114 m^3/d, PE = 813; single technological line with continuous bio-reactor type. The plant was designed for TSS (Total Suspended Solids), organic carbon and additionally nitrogen and phosphorous removal. [1] [2] During studied period, years 2007 and 2008, treatment plant was under constant and substantial overflow (about 3 times greater than a designed average daily flow), despite that actual BOD loading of raw wastewater was about 98% of assumed at the designing stage.

Excess sludge from both primary and secondary sedimentation was directed into an Imhoff sedimentation tank for anaerobic stabilization. After such stabilization and thickening sludge from the Imhoff tanks was directed to Sludge Drying Beds (SDB) for dewatering. SDB - dewatering system of excess sludge due to natural evaporation of water from sludge distributed over a large area. Highly effective in terms of total removal of water (over 50%) but not sufficiently efficient in terms of overall process duration (days to even months) and area needed [4]. After stabilization and dewatering, sludge was exported to Central Sludge Processing facility located in one of the two major City WWTPs.

Plant B was designed for flow rate Q_{avdp} = 165 m^3/d and PE = 1 100; with continuous biological reactor type for TSS, organic carbon and additionally nitrogen and phosphorus removal. [1] [2]It had two parallel technological lines. During studied period (years 2007 and 2008) the treatment plant was under constant and substantial overflow (flow rate was almost two times greater than a designed average daily flow). Also BOD loading was 25% higher than designed.

Excess sludge (both, primary and secondary) was directed into thickener and then to non-mechanical dewatering at the sludge drying beds. After such stabilization and dewatering, sludge was exported to central sludge processing facility located in one of the two major City WWTPs.

Plant C was designed for flow rateQ_{avdp} = 225 m^3/d and PE = 1 500, with continuous biological reactor type for TSS, organic carbon and additionally nitrogen and phosphorus removal. [1] [2] Two parallel technological lines were constructed for more flexibility operation. During the studied period, years 2007 and 2008, treatment plant worked almost in designed parameters: average daily flow was almost equal to designed one while BOD loading exceeded only about 11%. Operation conditions were stable.

Excess sludge (both, primary and secondary) was stabilized and thickened in anaerobic conditions in an Imhoff sedimentation tank, and after that was exported to a central sludge processing facility located in one of the two major City WWTPs.

Plant D was designed for flow rate Q_{avdp} = 251 m^3/d and PE = 2 375, with a SBR reactor type for organic carbon, TSS, and additionally nitrogen and phosphorous removal.[2] [3] Similar to the Plant C, two parallel technological lines were constructed. The Plant treated sewage from wastewater collection system and delivered by septic haulers. During studied period (years 2010 and 2011) the treatment plant operated under almost constant underflow conditions with small, around 15% to 25% lower than designed flow. As far as BOD loading, plant was also under-loaded: average BOD load was about 33% smaller than designed one.

Excess sludge (both, from primary and secondary stages) was stabilized in aerobic conditions and dewatered mechanically on a small belt-press. Dewatered and stabilized sludge was exported outside the treatment plant for further disposal.

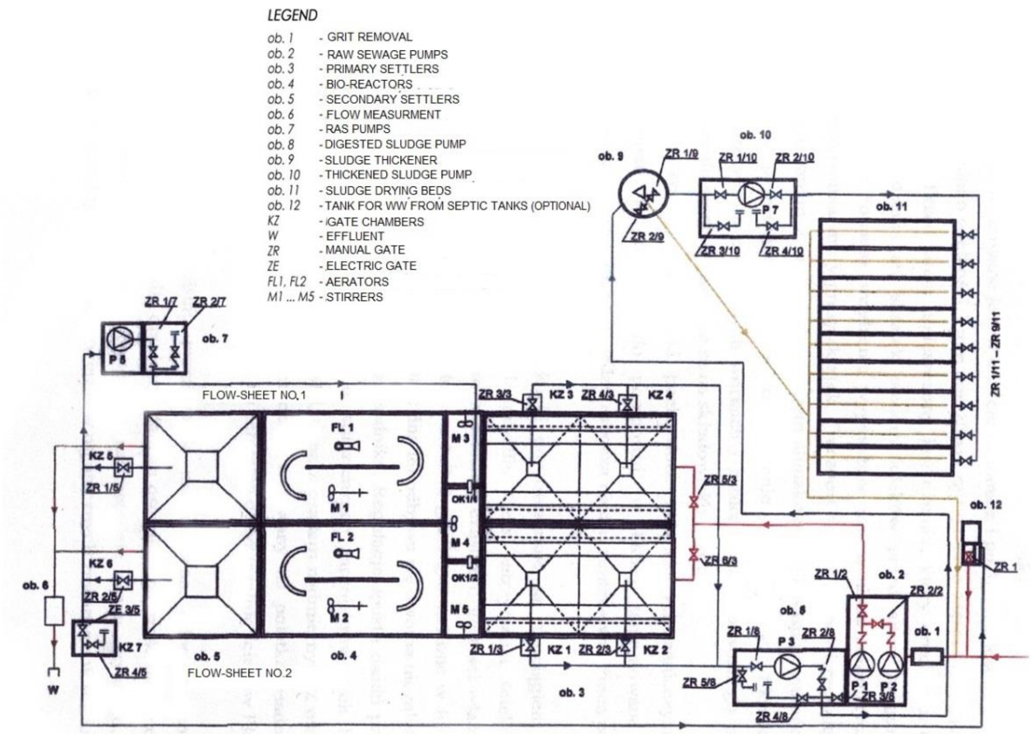
Plant E was designed for flow rate Q_{avdp} = 325 [m^3/d] and PE = 1 613, with activated sludge bio-reactor for organic carbon, and additionally total nitrogen, and total phosphorus removal. [1] [2] As in previous plant, two parallel technological lines were constructed. During the studied period (years 2007 and 2008) treatment plant was under constant and substantial overflow (flow rate was almost 2,25 times greater than a designed average daily flow) and the BOD loading was over twice higher than designed one.

Excess sludge from primary and secondary sedimentation was directed into an Imhoff tank for anaerobic stabilization then to sludge drying beds for water evaporation. After stabilization and dewatering, sludge was exported to central sludge processing facility located in one of the two major City WWTPs.

Plant F was designed for flow rate Q_{avdp} = 563 m^3/d and PE = 2 707, with activated sludge reactor for TSS, organic carbon, and additionally nitrogen and phosphorous removal. [1] [2] Similar to the previous plants two parallel technological lines were constructed. During the studied period (year 2007 and 2008) treatment plant was under constant and significant underflow; actual average daily flow was about half of the designed one). Despite that BOD loading was only 25% smaller than designed one, what indicates high concentration of organic pollutants in raw wastewater.

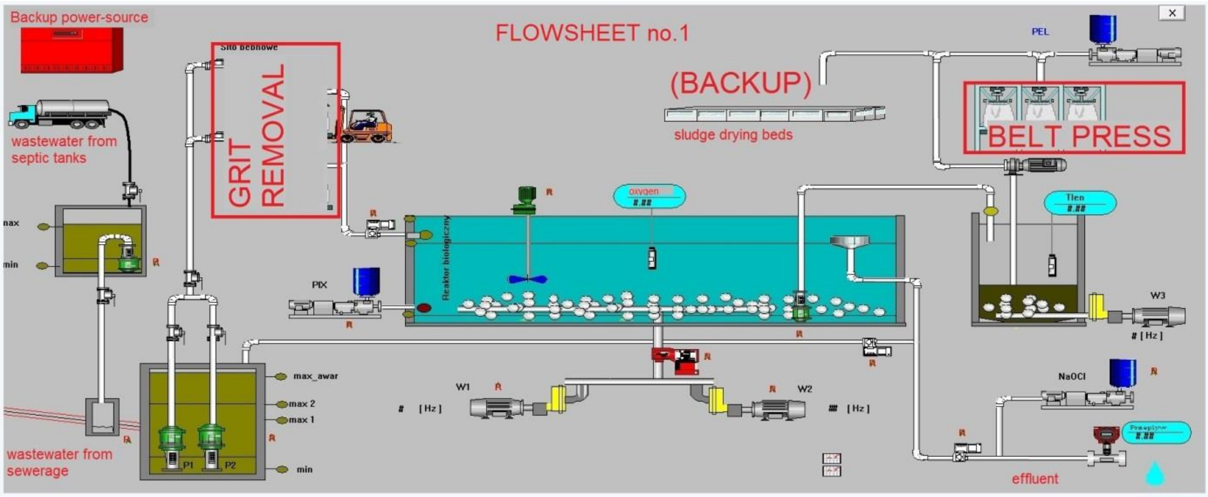
Excess sludge from primary and secondary sedimentation was stabilized in anaerobic conditions and thickened gravitational. After stabilization and dewatering, sludge was exported to central sludge processing facility located in one of the two major City WWTPs.

Flow sheets: Plants A, B, C, E, F are based on a similar design with only slight differences needed for local conditions, therefore chart on a Picture 1 should be treated as representative for all these WWTPs:



Picture 1.Flow sheet of the Wastewater Treatment Plant E, representative also for plants A, B, C, and F.
Source: Adamczyk U. Analiza kosztów eksploatacyjnych wybranych małych oczyszczalni ścieków,praca dyplomowa, promotor Mucha Z Politechnika Krakowska, Kraków 2009

Plant D is based on a different design so it has different chart (see Picture 2).



Picture 2. Flow sheet of WWTP D

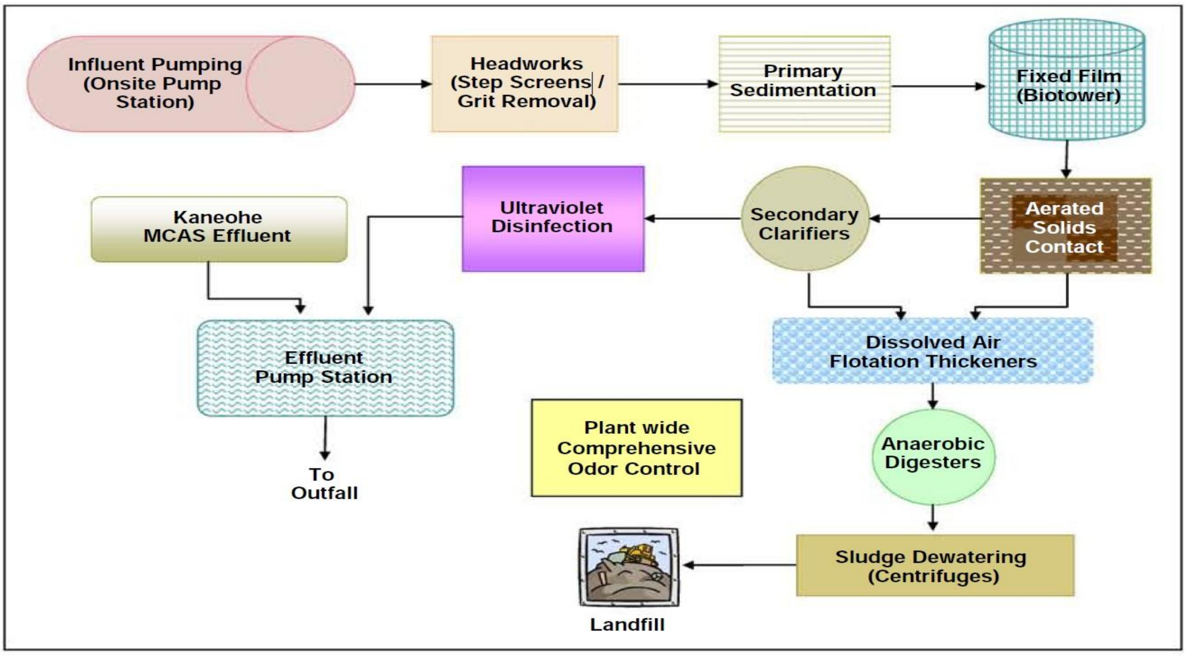
Source: Print-screen generously shared by plant`s operator and updated by the authors.

Non-conventional plants located in USA.

Plants are grouped according to technology similarity. Two of them (Plant G and Plant H) are good examples of totally different approach for wastewater treatment then in Europe. The other two (Plant I and Plant J) are the examples of less complex approach to treatment of wastewater.

Plant G was design for flow rate Q_{avdp} = 56 781 m^3/d (15 MGD - Millions of Gallons (US) per Day) (data on PE were not available) for organic carbon, and TSS removal [5]. It has got two parallel technological lines consisting biotower with fixed-film and aerated solid contactor as the two stages biological treatment. Plant was operated under NPDES standards (National Pollutant Discharge Elimination System (EPA), legal requirements regulating water protection matters for various industries, facilities and individual US citizens. NPDES are mostly prepared individually for each applicant [7][8]). Plant`s capability of nutrient removal is unclear. Despite constant aeration anoxic and anaerobic zones may occur in both Fixed Film Biotowers and Aerated Solids Contact reactors therefore biological nitrogen removal is probable. Biological phosphorus removal is significantly less probable [6]. Unfortunately there were no data available about nutrient removal efficiency. Actual daily average flow rate during studied period was about 45 420m^3/d (12 MGD) which was 80% of designed flow rate. Unfortunately data on raw sewage quality and BOD loading were not available. Final stage of treatment was disinfection by UV treatment, although, it was damaged during studied period due to a flood, and not fully operated; therefore its impact on energy usage is not clear.

Excess sludge was initially thickened in dissolved air floatation thickeners then stabilized in anaerobic conditions, and finally dewatered in centrifuges. Fully treated sludge was transported to a sanitary landfill. WWTP also has plant wide comprehensive odor control system.



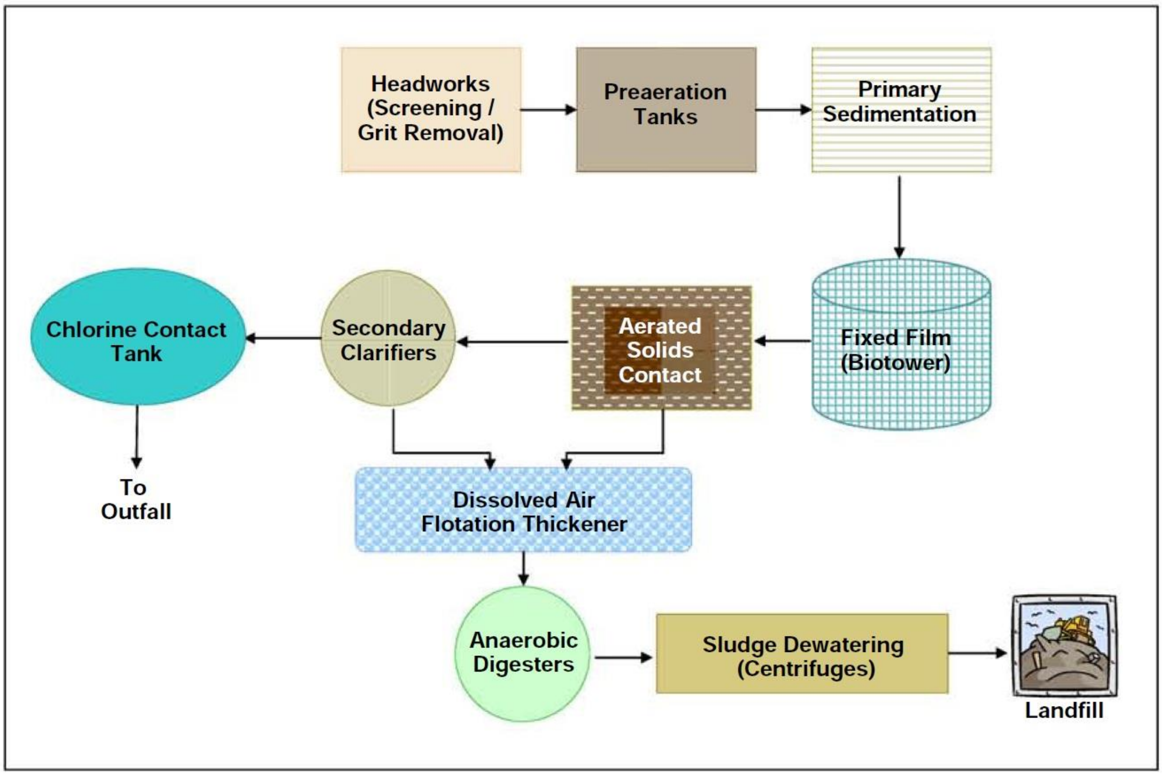
Picture 3.Flow sheet of the wastewater treatment plant G.

Source: U.S. Environmental Protection Agency, Region 9, Energy Assessment Report for County of Honolulu Kailua Wastewater Treatment Plant, Kailua, Hawaii April 2010.

This plant was substantially bigger than the rest of plants presented in this paper, but there are two reasons for including it in our presentation. Firstly, it`s an example how sophisticated the larger WWTPs are; the concept stays the same but its implementation needs numerous devices (including back-ups), much more than usually needed in small plants. This has significant impact on a complexity of energy distribution. Secondly, having energy distribution from smaller and larger plants someone can estimate if they are really different or rather similar. Finally, this plant, and the second one with Biotowers instead of Bioreactors, allows to compare these two designs in terms of energy distribution (for more details see section 3).

Plant H was designed for flow rate Q_{avdp} = 18 927 m^3/d (5 MGD) (data on PE were not available) with fixed-film biotower and aerated solids contractor as a two-stage biological treatment [9]. The plant had two parallel technological lines Plant was operated under NPDES and was designed to treat Organic Carbon and Total Suspended Solids. Plant`s capability of nutrient removal is unclear. Despite constant aeration, anoxic and anaerobic zones may occur at both Fixed Film Biotowers and Aerated Solids Contact tanks. Biological nitrogen removal is probable in such conditions but phosphorus bio-removal is significantly less probable [6]. Unfortunately there were no data on nutrient removal efficiency to verify this theory. Actual daily average flow during studied period (from 07.2008 to 06.2009) was about 11 350 m^3/d (3 MGD) which is about 60% of flow rate for which the plant was designed. Unfortunately no data on raw sewage quality were available. Final stage of treatment was disinfection of treated wastewater in a chlorine contact tank.

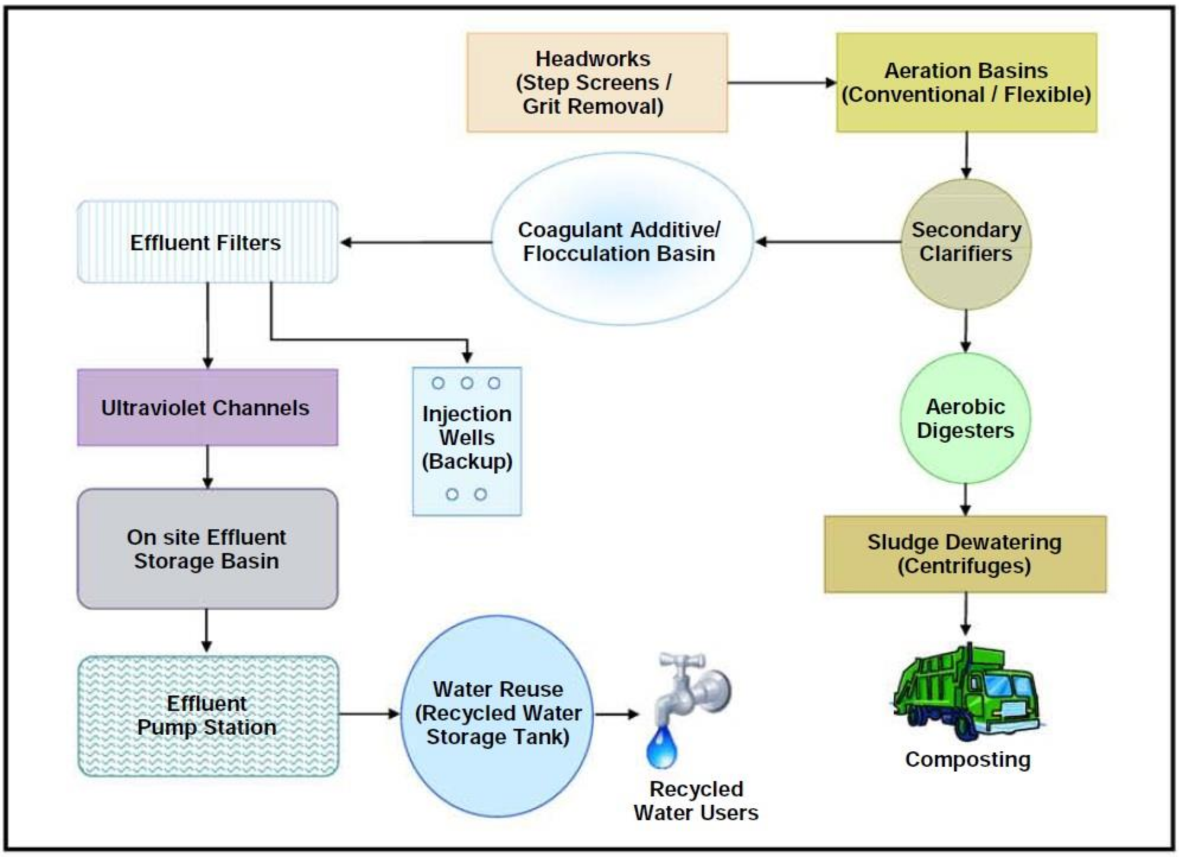
Excess sludge (primary and secondary) was initially thickened in dissolved air floatation thickeners then stabilized in anaerobic conditions, and finally dewatered in centrifuges. Such treated sludge was transported to a sanitary landfill.



Picture 4.Flow sheet of WWTP H.

Source: U.S. Environmental Protection Agency, Region 9, Energy Assessment Report for County of Honolulu Hilo Wastewater Treatment Plant, Hilo, Hawaii April 2010.

Plant I was designed for flow rate Q_{avdp} = 28 390 m^3/d (7,5 MGD), (data on PE were not available) with aeration basins for Total Suspended Solids and biological Carbon removal [10]. Plant's design didn't allow biological phosphorus or nitrogen removal. The plant had two parallel technological lines and was operated under NPDES (National Pollutant Discharge Elimination System; EPA). During the studied period (from 12.2008 to 11.2009) constant underflow was observed: flow rate was about 13250 m^3/d (3,5 MGD) which is about 47% of designed average daily flow. Unfortunately no data on raw sewage quality are available. This plant is a so called Water Reclamation Facility (WRF) which means that the WWTP and a Water Treatment Plant (WTP) are integrated in one system. Sludge from a secondary sedimentation was pumped into the aerobic digesters, and then dewatered in centrifuges. Finally, was composted and reused. Also the reclaimed water (Wastewater after treatment in WWTP and WTP.) is reused to water local green areas and nearby golf courses. This means that 100% of influent is being reused, however, a backup way of effluent disposal was available. This is good example how flexible wastewater management and WWTPs design can be. Of course for this study energy consumption at the WWTP part was separated from the rest of facility

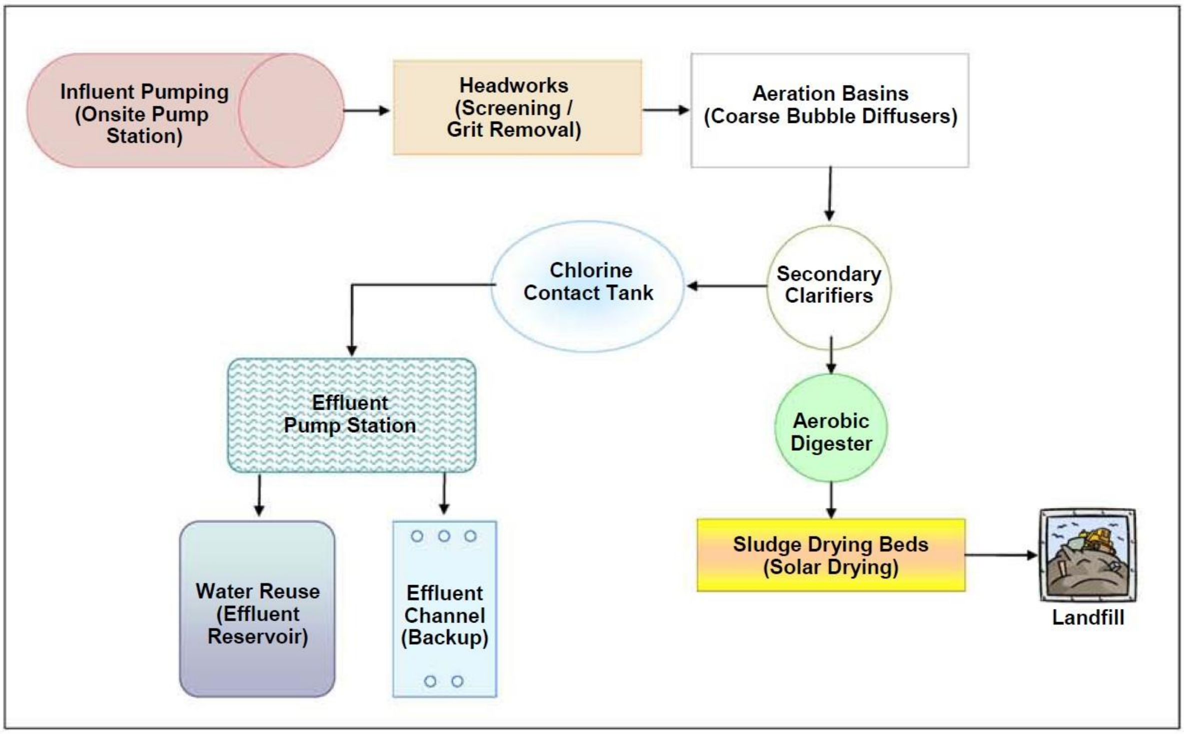


Picture 5. Flow sheet of WWTP I.

Source: U.S. Environmental Protection Agency, Region 9, Energy Assessment Report for County of Kihei Hilo Wastewater Treatment Plant, Kihei, Hawaii April 2010.

Plant J was designed for flow rate Q_{avdp} = 1 135 m^3/d (0,3 MGD), (data on PE were not available) with aeration basins for biological treatment (Total Suspended Solids and Organic Carbon removal) [11]. The plant had two parallel technological lines and was operated under NPDES. During the studied period (from 07.2008 to 06.2009), constant underflow was observed: flow rate was about 950 m^3/d (0,25 MGD) which is about 83% of designed average daily flow. Unfortunately no data on raw sewage quality were available. Also, due to ongoing upgrading, standard screening and grit removal were offline during the study. Its flow chart is similar to the plant I: wastewater flowed to secondary clarifiers and treated wastewater was directed into chlorine contact tank and was mostly reused for watering of green areas.

Sludge from secondary sedimentation was pumped into the aerobic digesters then dewatered with Solar Sludge Drying Beds (scheduled to be replaced by centrifuges during the upgrading). Dewatered and stabilized sludge was landfilled.



Picture 6.Flow sheet of WWTP J.

Source: U.S. Environmental Protection Agency, Region 9, Energy Assessment Report for County of Kauai, Waimea Wastewater Treatment Plant, Waimea, Hawaii April 2010.

2.2 Methods of energy distribution evaluation

Energy distribution is mostly expressed in kWh or as percentage of total energy consumption per device in given time-frame. Therefore a separate energy consumption value of each device must be determined. Number of devices is connected directly with plant`s size and it`s quite intuitive that bigger plant needs more powerful equipment as well as some stand-by facilities due to required higher system reliability. There are several ways to determine individual energy consumption. During the research and literature studies three methods of determination were developed and polished after being confronted with literature.

These methods differ in their degree of accuracy. The higher the accuracy, the method is more expensive and time-consuming. Methods were sorted in ascending order according to their accuracy. Preparation of a plant`s equipment list is essential for any method of evaluation. Of course, more monitored devices, the better accuracy of evaluation.

Method 1: Simplified estimation is based only on assumptions of nominal motors sizes and work times. It is the least accurate way to determine energy usage distribution in the WWTP (or any other facility) also the least expensive. It is recommended for design and pre-evaluation purposes. This approach is based on a following simple equation:

$$E_d[kWh] = P\,[kW] * T[h]; \qquad (1)$$

where:

E_d – device total energy usage,

P – motor size,

T – assumed total work time of a device.

The assumptions are not entirely true. First of all, work-time of devices may be different than assumed one. Secondly, energy consumption by the motors depends on many factors and varies over time [12] [13] [14] and total energy consumption does not have to be equal to theoretical value. The gap between calculated and real electricity usage is connected with flexibility of the engines and the greatest difference would occur in the case of modern motors with Variable-Frequency Drive (VFD) or adjustable-frequency drive (AFD)(VFD and AFD are two different names/abbreviation for the same motor type)[15]. Nevertheless such approach is not entirely useless. Costs of such evaluation is almost negligible comparing to profits which the operators can have, which makes it a useful design tool and indeed may be found in a lot of WWTPs projects.

Method 2: mixture of estimation and measurements.

Method is very similar to the first one, although its accuracy is higher. Proportion between actual information and assumptions determine how reliable obtained energy distribution is, and affects cost of evaluation as well. In this case mostly archive data from WWTP and energy provider are used. WWTPs have often archived work times of single devices which can be multiplied by nominal power use (as in equation (1)) and compare with facility total energy consumption. This method was used to evaluate energy usage diagram for plant D (see chapter 3 for the results). As it turned out this approach can give reasonable results and may be applied if detailed analyses are not necessary or too expensive for that moment.

Method 3: based mostly on measurements.

Used for advance evaluation purposes and is based on actual data collected during long-term measurements. The most precise evaluation would have 100% of equipment and systems gauged. Obviously such situation is not possible, even sometimes unwanted, because the WWTPs are complex installations and composed of dozens of subsystems and thousands of devices. Therefore, sometimes it is not reasonable to consider individual device separately.

Proper evaluation is time-consuming and expensive. Electric gauges prices range from 12 € to 243 € [16] and not all devices can be measured by the cheapest ones. There is of course matter of measurements' quality and accuracy, data storage and accessibility. Some devices are even capable of Wi-Fi or other types of wireless connections for remote measurements and data processing. Obviously, the electric meters are only part of total costs. More expensive is labor cost for measurements and data processing. For small plant such costs could be unacceptable. Therefore, there is no point to measure separately energy consumption of each device. They could be grouped into reasonable subsystems. On the other hand excessive simplification will eventually lead researcher to method 2. As in many other cases, healthy balance must be achieved. For this reason, someone who is trying to analyze WWTP energy distribution should have knowledge of wastewater treatment technology and used equipment as well as understand of electrical systems. Usually a team of qualified specialists will be able to indentify vital devices and subsystems required for the separate measurements. Such team should include an environmental engineer, an electrical engineer, a mechanical engineering, a specialist in automation, and an economist. In last few years the US EPA has published a few manuals on improvement of energy efficiency at wastewater treatment plants. Authors' original ideas, conceptions and experience were confronted with available literature [5] [9] [10] [11] [17] [18] [19] [20] which resulted in development of following recommendation of energy evaluation steps.

1) Decision of evaluation accuracy, and estimation of costs,
2) Establishment of rules for cooperation with energy provider,
3) Gathering all available archive data from WWTP and energy provider,
4) Selection of devices for individual metering, and subsystems which should and can be evaluated ,
5) Modification of the plant's electric grid and installation of the gauges,

6) Measurements and data archiving,
7) Data analysis,
8) Development of conclusions and recommendations,
9) Gauges deinstallation.

Ad 1) Step that has got impact on all following steps. Preparing for energy evaluation both the plant's operator and the evaluation team must know what degree of accuracy should be achieved. If it's meant to be a detailed evaluation it will be expensive. The goals have to be specified and clear for all partners. A plant administrator should know a cost of evaluation
Ad 2) Good cooperation with plant's energy provider is very helpful,
Ad 3) Archive data may prove useful, and provide additional, sometimes vital information,
Ad 4) This point is directly connected with the first one: initial assumptions are put into real actions. Below are a few useful tips:

- biological treatment stage along with pumping are usually main energy users (see section 3); the system should be decompose as much as it possible and measured with high accuracy; both work-time and energy consumption of single devices should be analyzed,
- since mechanical treatment (screenings, primary sedimentation, and grit removal) usually contributes modestly to overall energy consumption, it may be treated as a single subsystem,
- administrative buildings can be studied as a one subsystems, or some systems may be excluded and measured separately, usually the heating, air conditioning and lighting,
- sludge treatment may be considered as one subsystem (single gauge for entire sludge processing line); when energy usage occur to be higher than acceptable then detailed studies shall be performed
- some plants have got disinfection stage for treated wastewater, similar to the mechanical stage it can be treated as a single subsystem, or decomposed and fully evaluated

Ad 5) Installation of the gauges must be performed by a specialist (preferable one of the plants employees) measuring devices cannot be installed in random points of the grid or by amateur. Proper installation is vital to the quality of results and prevents WWTP against any breakdowns caused by damaged electrical grid. This step is even more important if gauges are not simple counters but advanced measuring devices with automatic data storage, remote access etc

Ad 6) All measurements shall last at least complete year to cover all possible seasonal changes in energy consumption. Any interruptions (in gauging) or not complete coverage of facility's equipment are harmful to the quality of final results. Another important factor is a frequency of data collection (the higher the better), which leads again to point No.1. If the meter is simple device performing only measurements, read-outs will be performed manually one or few times a day by a member of evaluation team or plant's worker. However, if a meter can record data on its own, frequency will be much higher and limited only by common sense or meters data storage capabilities. Of course, automated and on-line measuring devices are more expensive than simple counters. The measurements should be checked periodically for their correctness, whatever method of measurements is installed. First, checkup should be performed after 2-4 weeks and confronted with Table 1 or similar. Such action allows noticing the errors and identification the reasons.

Ad 7) Data analysis provides clear information on plants energy distribution. If the measurements were on-line the amount of data may be overwhelming. It is important to convert raw data into more useful form, for example summary tables or diagrams. Of course one of the most important things is constructing clear, understandable energy distribution summary at the end.

Ad 8) Processed data allows forming recommendations for further actions. However possibilities of improving wastewater treatment energy efficiency or methods of decreasing electric bills are not main focus of this paper.

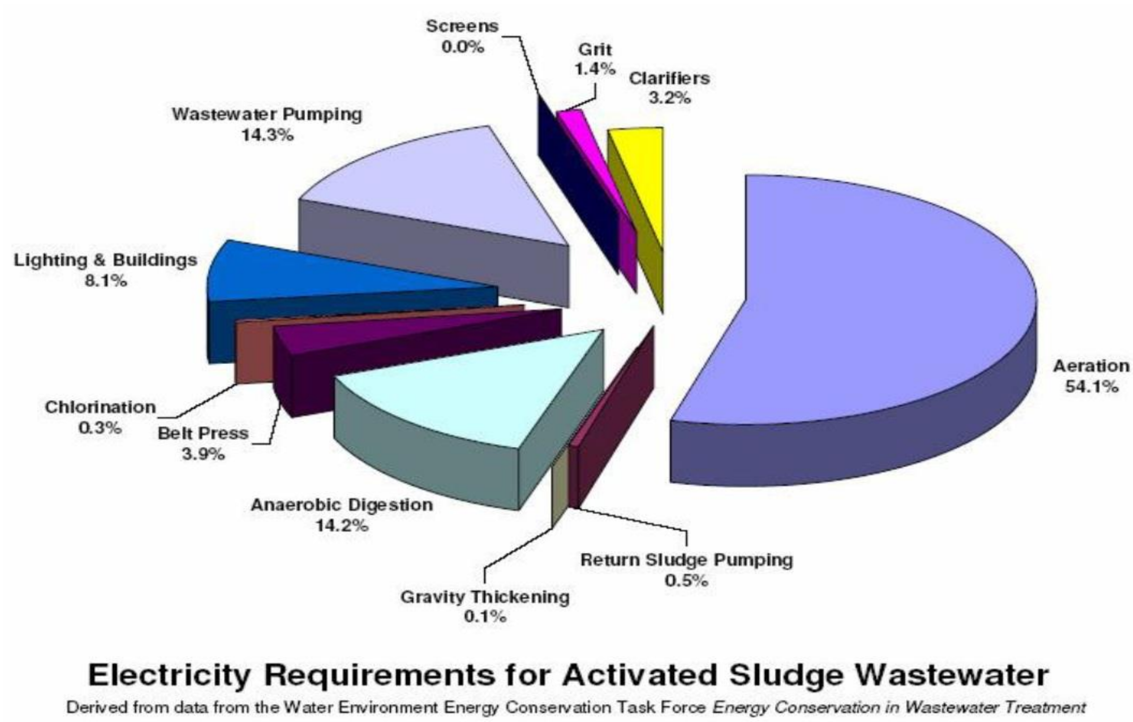
Ad9) A measuring grid may be left at a WWTP after finished evaluation for further data collection, or may be disassembled and reused at other plants (after recalibration and necessary adjustments).

2.3 Examples of energy distribution

Obviously there is no one and universal energy distribution diagram for WWTPs as there is no universal design. There are of course standard processes, installations and equipment but even if there were two identical facilities, the operating conditions won`t be the same, therefore energy consumption will be different

Anyone familiar with waste water treatment technologies and WWTPs designing is able to identify the most energy-consuming process, but sorting it out in correct order is more difficult. When we took interest in this topic our first guess was the pumping could be the most energy-consuming process. Our guess was not fully correct. Literature studies showed however that pumps were one of the major energy consumer but in many cases not the biggest one. In most cases aeration is the biggest energy user at the WWTPs.

An example of energy distribution diagram for WWTP with anaerobic sludge digestion is shown on Picture 7. [17]

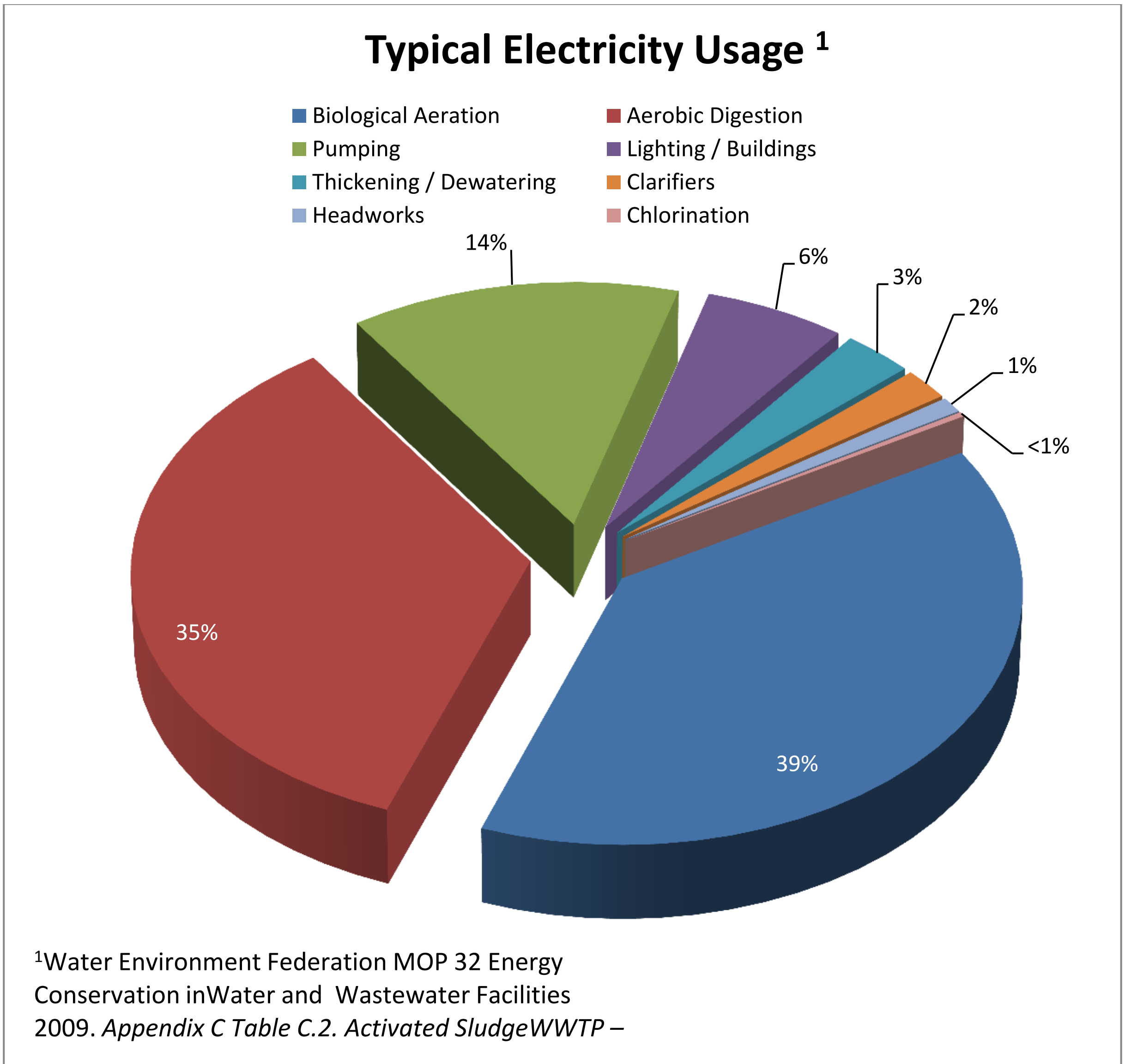


Picture 7.Energy distribution for WWTP with anaerobic sludge digestion.

Source: U.S. Environmental Protection Agency, Innovative Energy Conservation Measures at Wastewater Treatment Facilities, Sheboygan Regional WWTP, May 2012

This diagram is one of the most detailed one that can be found. As it was mentioned before, total decomposition of some processes is not always reasonable but sometimes is necessary. Sometimes is good to know that part of equipment is so efficient or its contribution is so insignificant that there is no point in modernization efforts and better to focus on other devices. Also such detailed diagram justifies earlier statement that if it's reasonable, some devices can be grouped and visualized under one label; for example, mechanical treatment as a subsystem, without dividing into screens, grit removal, primary sedimentation, etc.

Diagram on Picture 8 is not as detailed as previous one. Some processes were grouped, as suggested before. For example, "headworks" stands for screens and grit removal but still it is only 1 % of total energy consumption, this is really insignificant in comparison with any of 3 major energy consumers. It is interesting study sludge processing at the Picture 8. The amount of energy for aeration at aerobic activated sludge digestion at the Waste Activated Sludge reactor (WAS) is almost equal to the energy needed for aeration of bio-reactor at main line of wastewater treatment. It shows that aerobic sludge processing sometimes requires huge amounts of energy. [18]



Picture 8.Energy distribution for WWTP with aerobic sludge digestion.
Source: U.S. Environmental Protection Agency Region 3 and PADEP, MatthewYonkin, PE, BCEE, CEM, Energy Efficiency Roundtable (Energy Audits & Guaranteed Savings/Performance Contracts), May 2012

It is worthy to notice that summed up sludge and reactor aeration give about 75% of total plants energy consumption, what is within the acceptable range for aeration in general.

Both, Picture 7 and Picture 8, give fair visualization of energy distribution at WWTPs. Additionally, the authors created a Table 1, containing most probable ranges of percentage of energy usage by different processes, based on the own research and literature review [17] [18] [19] [20] [21].

Table 1. The most probable percentage of total energy consumption for wastewater treatment processes

Process	% of total energy consumption
Aeration	30-75
Pumping	10-40
Lighting / Buildings*	5-25
Clarifiers	1-5
Screens	*0-1*
Grit & Grease removal	*1-9*
Headworks**	1-10
Stirrers***	5-20
Sludge Thickening / Dewatering	1-10

* including heating / air conditioning

** Headworks were divided into "screens" and "G&G removal" to highlight that screens contribution to total headworks energy usage shall be significantly smaller than rest of the devices.

*** excluding clarifiers

Source: compilation based on numerous publications [5] [9] [10] [11] [17] [18] [19] [20] [21].and own researches.

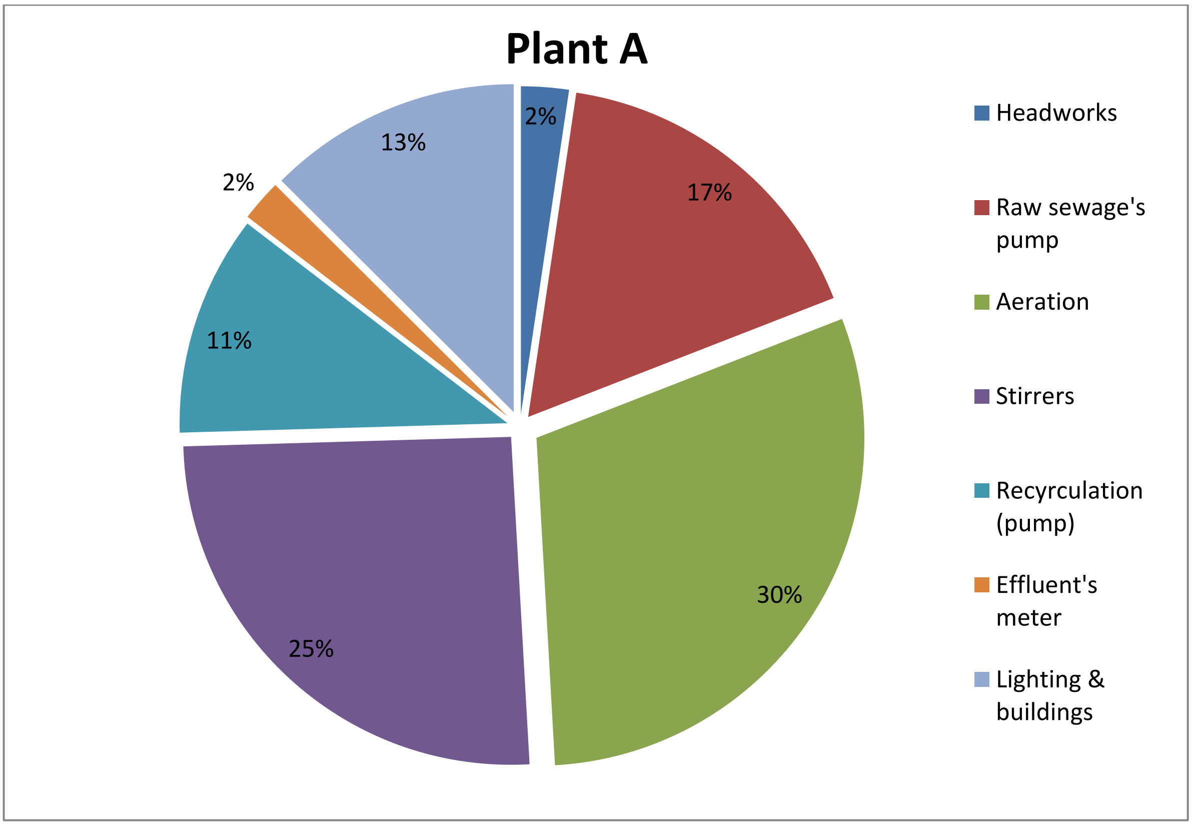
The limits ranges shown in the Table 1 are obviously not fixed. They are the most probable values but actual results at some studied plant might exceed or be lower than those suggested by the authors. Unfortunately there is no way to determine exact values, it is no proper to make a statement that "*If energy consumption for aeration is greater than 81% the process is ineffective and should be modernized*". However, the greater the excision the higher the probability of an error or highly unique situation. For example, at one of the objects studied by Królikowski and Wawrentowicz energy usage for "Lighting and Buildings" was about 90% of plants total energy consumption [21]. This was not any error; measurements were correct, gauges undamaged. However, plant's administration was located in big office building along with many others departments, therefore final results were distorted by energy usage unrelated to the WWTP's electricity consumption.

3. Results

Energy distributions are presented in the same order as the plants descriptions in section 2.1, and also are divided into two groups; Plants A-F and G-J (see Pictures 9 to 21 and Tables 2, 3, 4 and 5).

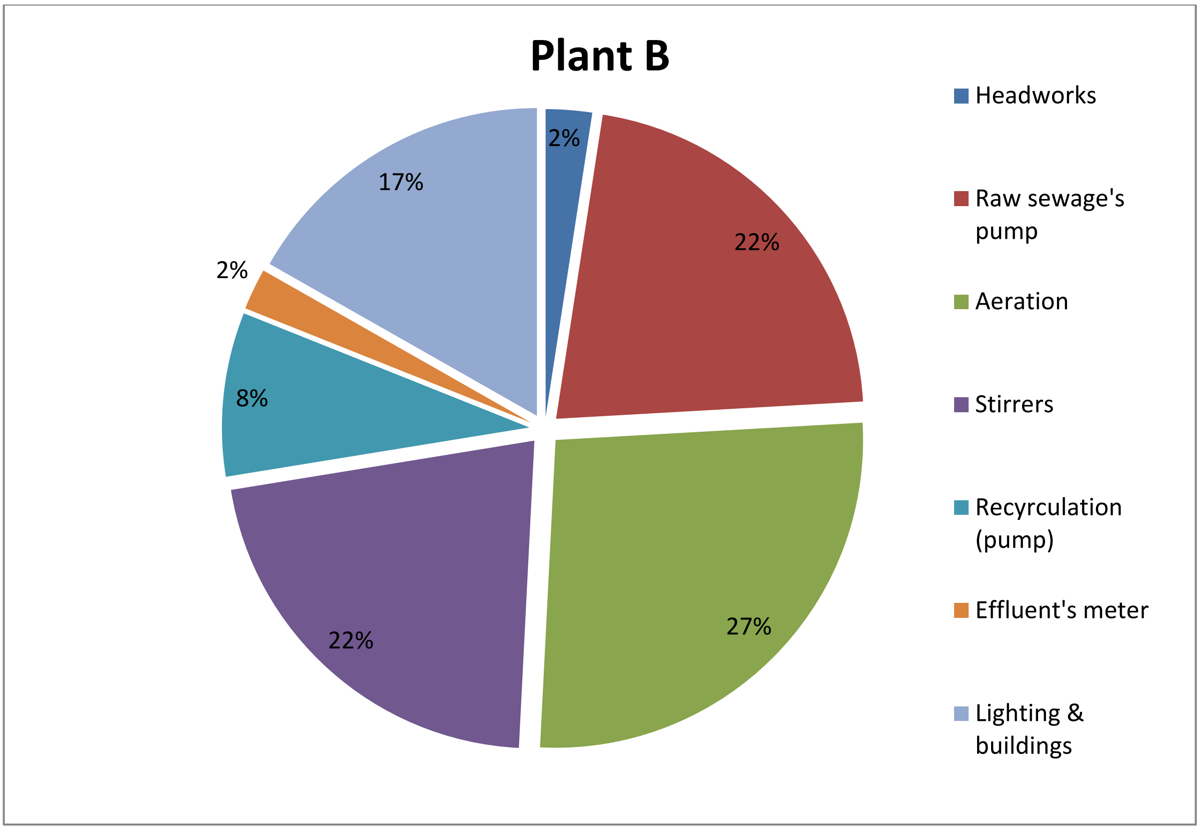
As it is shown at the diagrams aeration for objects A, B, C, E, F ranges from 27% to 46%, however plant D uses about 65% of its total energy consumption for the aeration. Such high energy consumption for aeration in Plant D could be due to high BOD and COD concentrations which caused necessity for extensive aeration and consequently energy consumption. Also work cycle of the SBR plants favors aeration as the most expensive process in terms of energy usage. This is the example how important are information on technology in energy analysis.

In case of plants A, B, E and F, determination of second process of highest energy usage is tough challenge. Raw sewage's pumping energy consumption is almost equal to stirrers; however the mixing process uses a little more power than pumping of raw sewage.



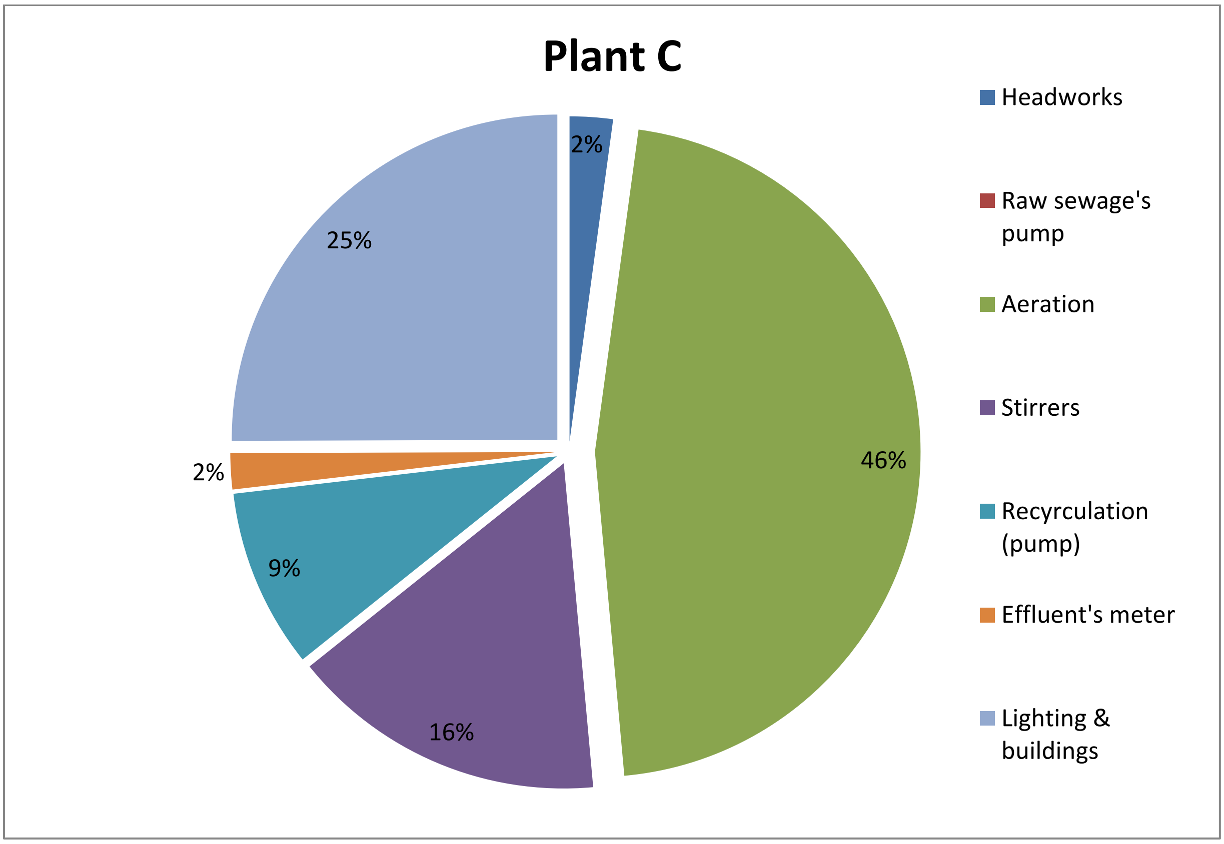
Picture 9. Energy distribution for WWTP A. 2007-2008

Source: Adamczyk U. Analiza kosztów eksploatacyjnych wybranych małych oczyszczalni ścieków,praca dyplomowa, promotor Mucha Z Politechnika Krakowska, Kraków 2009



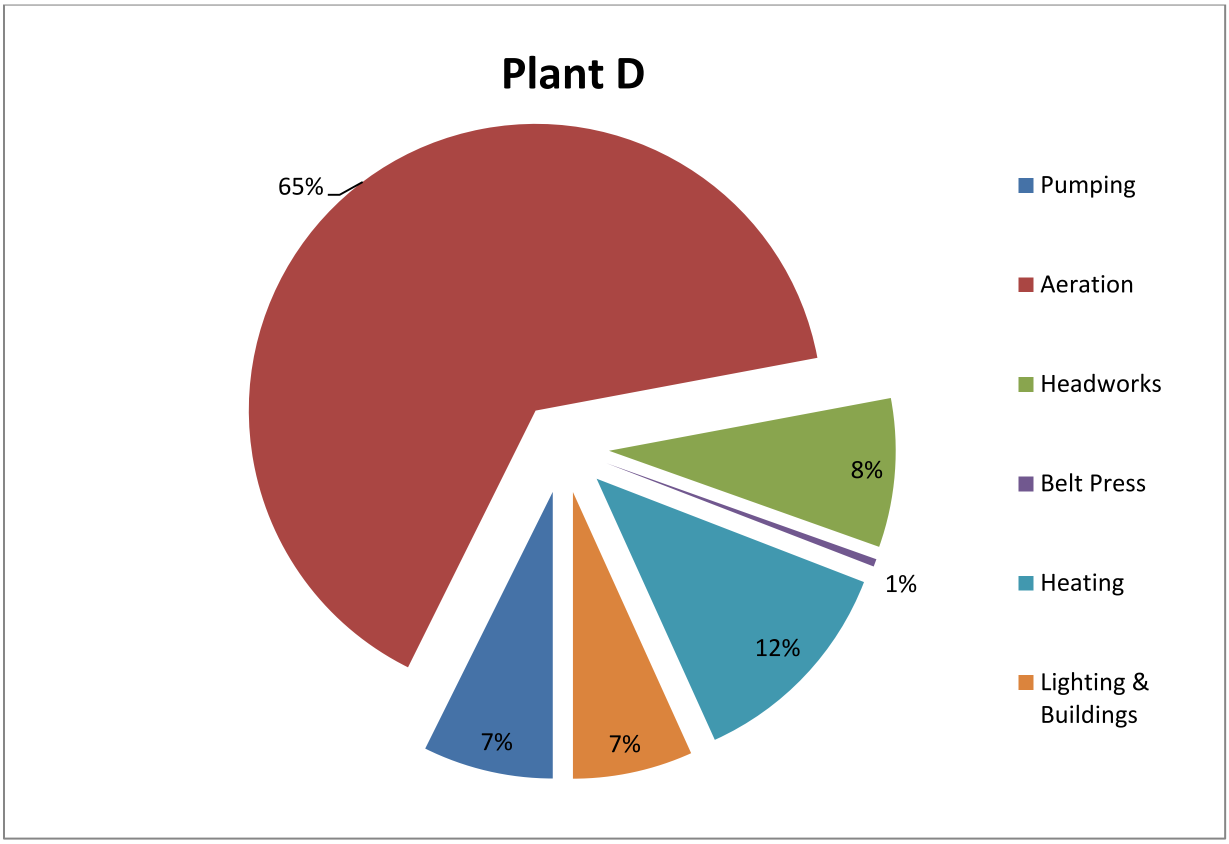
Picture 10. Energy distribution for WWTP B. 2007-2008

Source: Adamczyk U. Analiza kosztów eksploatacyjnych wybranych małych oczyszczalni ścieków,praca dyplomowa, promotor Mucha Z Politechnika Krakowska, Kraków 2009

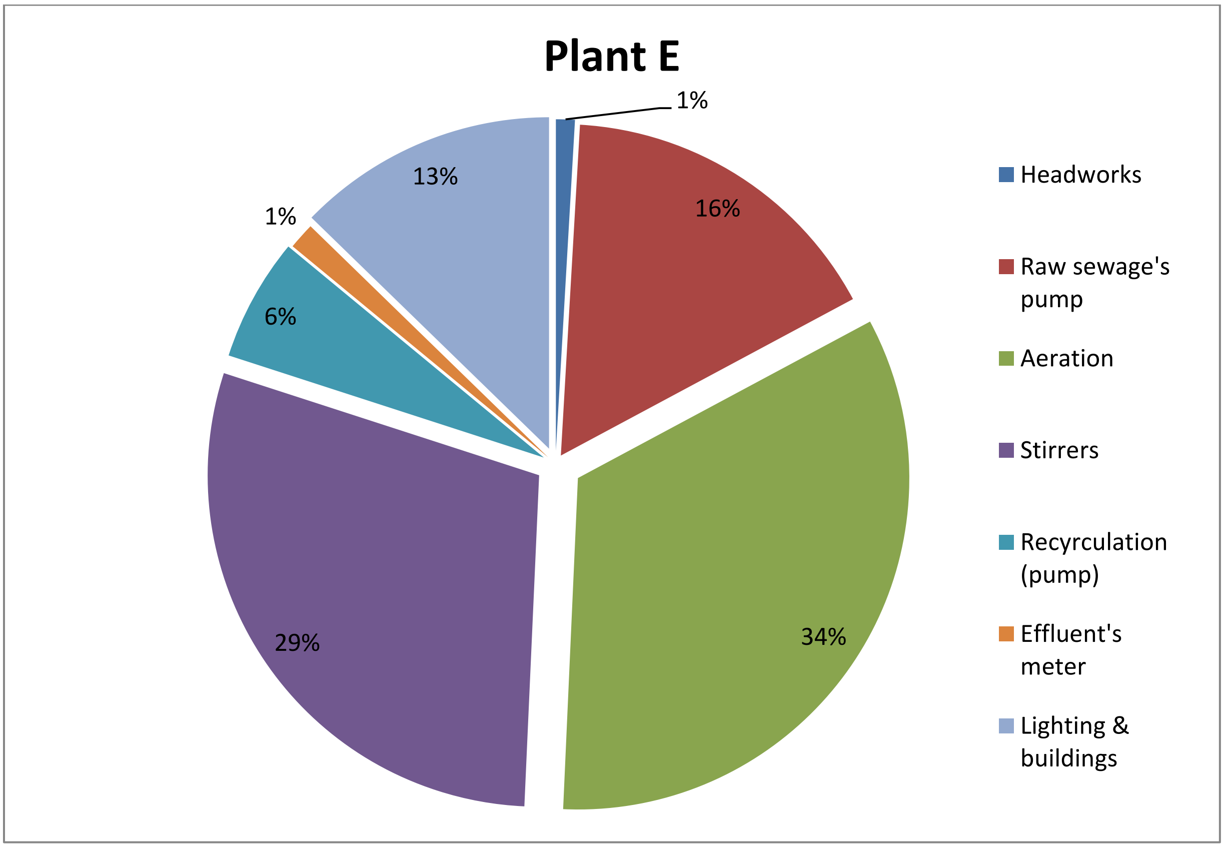


Picture 11. Energy distribution for WWTP C. 2007-2008

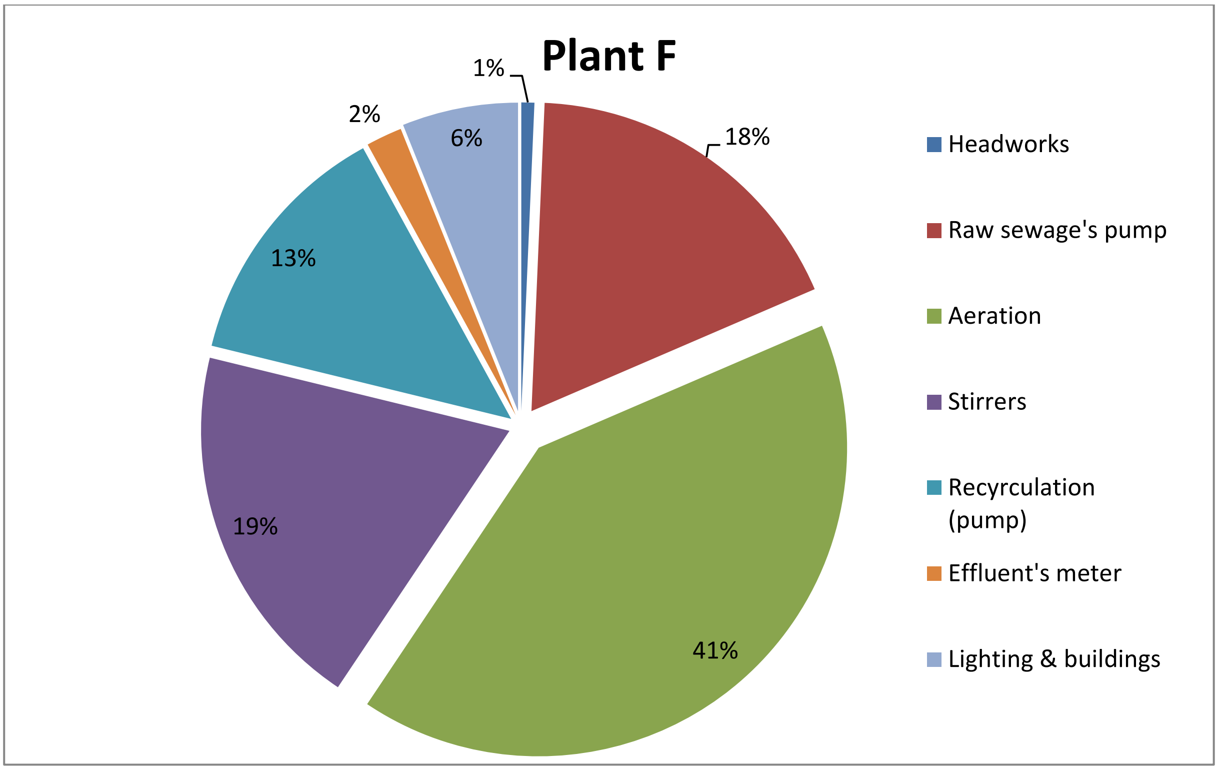
Source: Adamczyk U. Analiza kosztów eksploatacyjnych wybranych małych oczyszczalni ścieków,praca dyplomowa, promotor Mucha Z Politechnika Krakowska, Kraków 2009



Picture 12. Energy distribution for WWTP D. 2010-2011
Source: own researches (Ciepliński J, Mucha Z)



Picture 13. Energy distribution for WWTP E. 2007-2008
Source: Adamczyk U. Analiza kosztów eksploatacyjnych wybranych małych oczyszczalni ścieków,praca dyplomowa, promotor Mucha Z Politechnika Krakowska, Kraków 2009



Picture 14. Energy distribution for WWTP F. 2007-2008

Source: Adamczyk U. Analiza kosztów eksploatacyjnych wybranych małych oczyszczalni ścieków,praca dyplomowa, promotor Mucha Z Politechnika Krakowska, Kraków 2009

Table 2 Annual energy usage per device, percentage of total energy usage (average) Plant D

Process	2010 [kWh]	2011 [kWh]	2010 [%]	2011 [%]	2010-2011 [%]
Pumping	11 179	12 457	7,10	7,57	7,34
Aeration	104 621	103 799	66,41	63,09	64,71
Headworks	12 776	14 236	8,11	8,65	8,39
Belt Press	660	729	0,42	0,44	0,43
Heating	19 910	19 910	12,64	12,10	12,36
Lighting & Buildings	8 392	13 396	5,33	8,14	6,76

Source: own researches (Ciepliński J, Mucha Z)

Table 3: Annual energy usage per device, percentage of total energy usage (average) Plant A-F (Plant D excluded)

Process	Energy consumption by process [%]				
	Plant A	Plant B	Plant C	Plant E	Plant F
Headworks	2,35	2,43	2,14	0,92	0,68
Raw sewage's pump	16,74	21,67	0*	16,25	17,85
Aeration	30,01	26,70	46,42	33,53	40,86

Stirrers	25,44	21,63	15,70	29,27	19,42
Recyrculation (pump)	10,88	8,61	8,90	6,00	13,22
Effluent's meter	2,05	2,17	1,79	1,29	1,89
Lighting & buildings	12,53	16,78	25,05	12,72	6,08

*Raw sewage's pump located outside of the plant

Source: Adamczyk U. Analiza kosztów eksploatacyjnych wybranych małych oczyszczalni ścieków,praca dyplomowa, promotor Mucha Z Politechnika Krakowska, Kraków 2009

Situation changes when all pumping processes are summed, then pumping uses more energy than mixing. Plants C and D are different in this matter. A raw sewage pump of the Plant C is located outside the plant and there was no data available on its energy consumption. Lack of pumps energy usage caused higher values for the rest of the processes. This is probable explanation why such high result in “lighting and buildings” category is observed at this plant.

The plant D on the other hand was a SBR type, so treatment processes were conducted differently than in continuous flow-type plants. Stirrers of this plant were equipped with low-size electric motors thus they were omitted during construction of the energy distribution. Also due to an operation characteristics of the SBR plants it can be said that stirrers work-time at the plant D was relatively short in comparison to the stirrers in the plants with continues flow-type technology. The stirrers in Plant D worked periodically while the stirrers at plants with constant flow worked constantly. The same mechanism (pumps working periodically) combined with low flow rates resulted in such low energy consumption by pumping processes at the plant D.

Next important part at these pie-charts is “lighting and building” costs. Since it is uneconomical to measure energy usage of all devices, especially office equipment, a lot of low-power equipment can be hidden under this label. Although, in some cases it is convenient to exclude some devices. A heating system at the Plant D was studied separately for the following reasons. As it can be noticed, heating system generated about 12% of overall annual energy consumption. Since the Plant D was located in mountain region thus experienced rather harsh winters. The consequence is high energy usage for heating. This again highlights how important is to consider local conditions while conducting energy analyses.

Plants discussed above were however small conventional plants mostly fitting into theoretical image of WWTP's energy distribution based on available literature data. Interesting questions are: "Is this true for other plants as well? Will it be similar for bigger plants and will other WWTP's designs fit into this scheme? What impact will have elaboration's level of detail?" Definitely list of devices will be bigger, especially for the big WWTPs. Two tables from the US EPA's evaluations will serve as example of enormous gap between big, highly sophisticated plant and the small one (see Tables 4 and 5).

Table 4: Major Equipment Inventory List(Based on an average 660,000 kilowatts per month[4], 12 MGD wastewater, (Major Equipment is defined as 10 hp or greater)WWTP G

No.	Equipment Description	Equipment Size[1] [hp]	Equipment Load[2] [kW]	Est. Operational Hours[3] [hrs/yr]	Est. Energy Usage[4] [hrs/yr]	% (1)	% (2)
1	Administration / Maintenance Buildings Estimated Load		60	2900	174000	2,20	2,00
2	IPS Raw Pumps w/ VFDs (3 units)	75	2x40= 80	8760	701000	8,85	8,05
3	IPS Raw Pump w/ VFD	100	1x50= 50	8760	438000	5,53	5,03
4	Primary Sludge Pumps (3 units, 1 per tank, 3 online typically)	10	3x6= 18	2190	39000	0,49	0,45
5	Primary Grit Pumps (2 units)	7,5	2x5= 10	1095	11000	0,14	0,13
6	Primary Scum Pumps (2 units)	7,5	2x5= 10	1095	11000	0,14	0,13
7	Primary Effluent Pumps (2 units)	30	1x20 20	1095	22000	0,28	0,25
8	Headworks Odor Ctrl Fan	25	OFF	n/a	n/a	n/a	n/a

9	Primary Odor Ctrl Fan (2 units)	75	1x50= 50	8760	438000	5,53	5,03
10	Secondary Odor Ctrl Fan (2 units)	150	1x75 75	8760	657000	8,30	7,54
11	Biotower Pumps - Smaller Units #1,2,7,8	75	2x40= 80	8760	701000	8,85	8,05
12	Biotower Pumps - Larger Units #3,4,5,6	100	1x70= 70	8760	613000	7,74	7,04
13	Secondary Blowers (4 units, 1 of 4 typically online for solids contact tanks and UV bulb cleaning)	100	1x60= 60	8760	526000	6,64	6,04
14	Primary Sulfur Slurry Pumps (2 units)	25	OFF	n/a	n/a	n/a	n/a
No.	Equipment Description	Equipment Size[1] [hp]	Equipment Load[2] [kW]	Est. Operational Hours[3] [hrs/yr]	Est. Energy Usage[4] [hrs/yr]	% (1)	% (2)
15	Primary Catalyst Recirculation Pumps (3 units)	25	OFF	n/a	n/a	n/a	n/a
16	Secondary Catalyst Recirculation Pumps (2 units)	50	OFF	n/a	n/a	n/a	n/a
17	Waste Activated Sludge Pumps (3 units)	5	2x3= 6	2190	13000	0,16	0,15
18	Return Activated Sludge Pumps (6 units)	20	2x13= 26	8760	228000	2,88	2,62
19	Effluent Pumps (2 Electric Units #1 and #2 are 5500gpm units)	400	1x250 = 250	6570	1642000	20,73	18,86

20	Effluent Pumps (2 Electric Units #6 and #7 are 10,400gpm units)	400	1x250 = 250	2190	547000	6,91	6,28
21	Effluent Pumps (3 Diesel Geni Units #3, #4 and #5 are 5500gpm units)	400	Standby	n/a	n/a	n/a	n/a
22	Centrifuges (3 units, 2 run 5hours/day, 4days/week)	45	2x30= 60	1600	96000	1,21	1,10
23	Dewatering Bldg Odor Control Fan (Site indicates this unit runs 7hours/day)	50	1x30= 30	1600	48000	0,61	0,55
24	Centrifuge Sludge Pumps	20	2x12= 24	1600	38000	0,48	0,44
25	Digester Boilers (4 units, 4 online typically 24/7)	1	4x<0.5 < 2	8760	n/a	n/a	n/a
26	Digester Sludge Pumps with VFDs (6 units, 2 online typically 24/7)	30	2x20= 40	8760	350000	4,42	4,02
27	Digester Grinders (4 units, 1 per digester)	7,5	2x4= 8	8760	71000	0,90	0,82
28	Sludge Thickener Pumps with VFDs (2 units)	10	1x5= 5	2920	15000	0,19	0,17
29	DAF Sludge Pressurization Pumps (2 units)	100	1x60= 60	8760	526000	6,64	6,04
30	DAF Pocket Pump (locally set to run 6-10hours/day)	7,5	1x5= 5	2920	15000	0,19	0,17
31	UV Disinfection Station (Estimated) Service Status during period unknown		avr 90	8760	788000[6]		9,05
	TOTAL:			(1)	7920000	100	
				(2)	8708000		100

Table 4 continuation: Major Equipment Inventory List(Based on an average 660,000 kilowatts per month[4], 12 MGD wastewater, (Major Equipment is defined as 10 hp or greater)WWTP G

Notes:

1. The equipment size includes nameplate horsepower (hp) rating of the equipment.

2. The equipment load includes measured average amperage readings taken at time of site on site survey to calculate power in kilo-watts (kW) considering the efficiency rating if available and operating characteristics.

3. Hrs/yr is hours per year.

4. Estimated energy usage (kWh/yr is Kilowatt-hours per year) is based on equipment and operating conditions. Energy use may not equal the product of the equipment size (kW) and the operating hours per year (hrs/yr) values shown.

5. The total site estimated energy use captures upwards of 95% or more of annual site energy use.

6. The UV system operation during the utility analysis period is unclear. Therefore, the kWh associated with the disinfection is placed in brackets.

Source: U.S. Environmental Protection Agency, Region 9, Energy Assessment Report for County of Honolulu Kailua Wastewater Treatment Plant, Kailua, Hawaii April 2010.

Table 5: Major Equipment Inventory List(Based on an average 26,050 kilowatts per month[4], 0.25 MGD wastewater, (Major Equipment is defined as 1 hp or greater)WWTP J

No.	Equipment Description	Equipment Size[1] [hp]	Equipment Load[2] [kW]		Est. Operational Hours[3] [hrs/yr]	Est. Energy Usage[4] [hrs/yr]	[%]
1	Influent Pump Station Pumps (PS #A, 2 units)	25	1x17.3	17,3	630 each	21800	6,97
2	Sludge Pump #1 (Using Fuel Oil Geni)	7,5		0	0	0	0,00
3	Sludge Drying Bed Underdrain Pumps (2 units)	3	1x2.2	2,2	100 each	430	0,14
4	Aeration Primary Blower (1 unit, 100% Operation)	25	1x16.5	16,5	8760	144400	46,19

5	Aeration Primary Blowers (2 units) (1 unit, 40% Operation)	25	1x16.5	16,5	1752 each	57700	18,46
6	Froth Spray Pump	2		0	0	0	0,00
7	Effluent Pump	25	1x17.2	17,2	2640	45300	14,49
8	Effluent Pumps (2 units)		1x3.5	3,5	150 each	1040	0,33
9	Administration / Maintenance Buildings Estimated Load		avr	3	4380	13100	4,19
10	Lighting Load		avr	3,9	2900	11300	3,61
11	Balance of Plant Load		avr	2	8760	17520	5,60
12	Headworks	n/a	OFF		n/a	n/a	n/a
	TOTAL:					312600	100

Table 5 continuation: Major Equipment Inventory List(Based on an average 26,050 kilowatts per month[4], 0.25 MGD wastewater, (Major Equipment is defined as 1 hp or greater)WWTP J

Notes:

1. The equipment size includes nameplate horsepower (hp) rating of the equipment.

2. The equipment load includes measured average amperage readings taken at time of site on site survey to calculate power in kilo-watts (kW) considering the efficiency rating if available and operating characteristics.

3. Hrs/yr is hours per year.

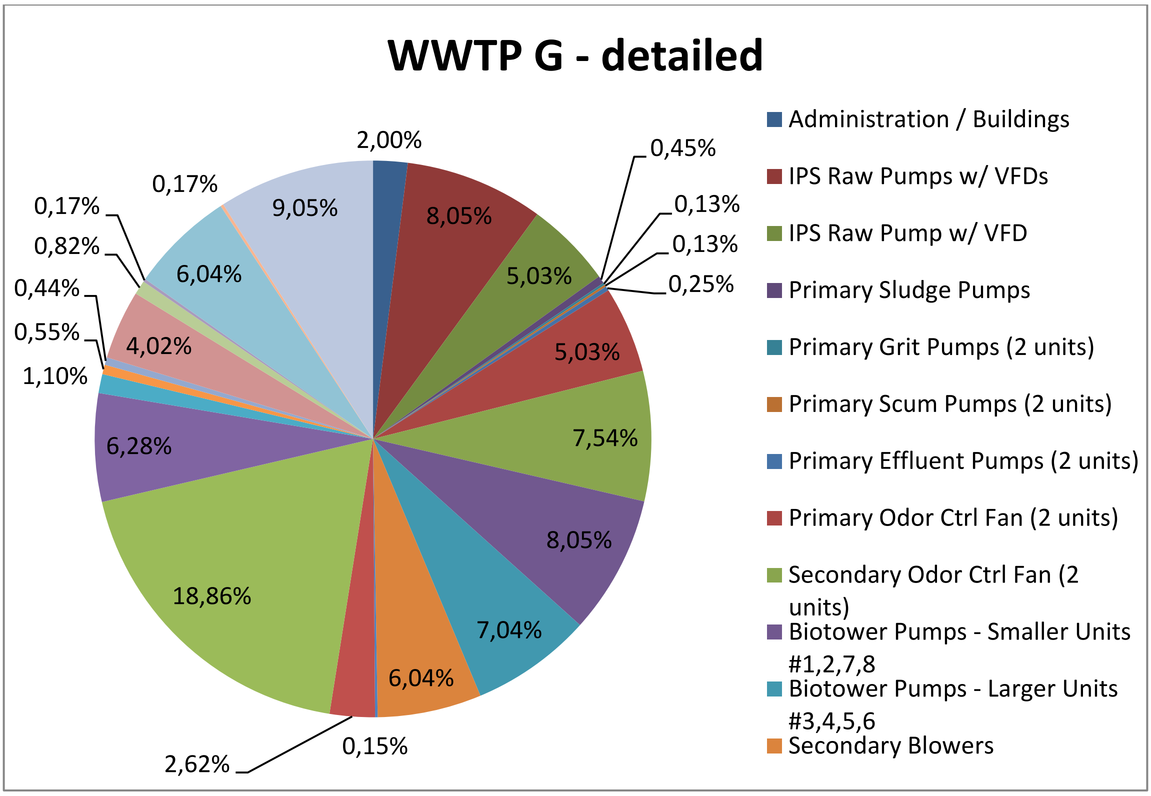
4. Estimated energy usage (kWh/yr is Kilowatt-hours per year) is based on equipment and operating conditions. Energy use may not equal the product of the equipment size (kW) and the operating hours per year (hrs/yr) values shown due to truncating.

5. The total site estimated energy use captures upwards of 95% or more of annual site energy use.

Source: U.S. Environmental Protection Agency, Region 9, Energy Assessment Report for County of Kauai, Waimea Wastewater Treatment Plant, Waimea, Hawaii April 2010.

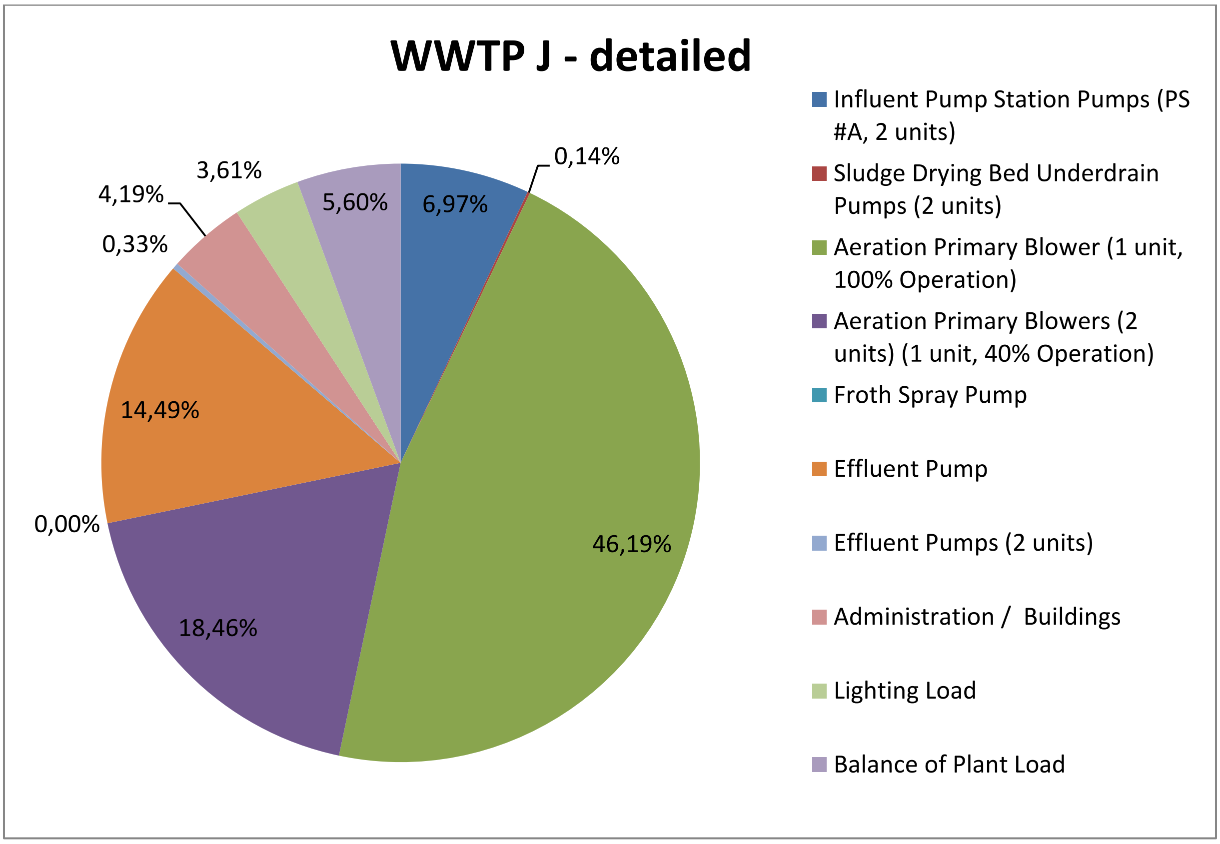
The Plant G can be considered as one of the small plants, not much sophisticated and complicated, but still a lot of devices had to be taken into account. However there are far more important issues to notice than size of a table 4. At first the notes under the tables and other vital information will be discussed. These notes give basic information about what, why, and how was measured/estimated. Some of them are fundamental to proper understanding of results by people who were not involved directly into the study. First important information is included in a table's title. Even such detailed study is based on a few assumptions or simplifications: daily flow, and monthly energy usage is considered as fixed and equal monthly average. Thanks to mild and rather stable climate these assumptions are justified but still, these are assumptions. One of the most important assumptions in these publication is selection of the parts of the plant equipment which had to be included in the study (and measured), and which one may be excluded (not measured at all). In case of the USEPA studies the devices were divided into "a major" and "a minor" according to their "size" (nominal power in horse power, in which 1 hp is equal to approximately 0.746 kW). While comparing tables 4 and 5 additional information, it is easily to notice that in the first case "major equipment" starts above 10 hp, while for the second one limit drops to only 1 hp. It may seem obvious, but decision how to select equipment which must be included in the studies is fundamental for the results. This leads to note no. 5 *"The total site estimated energy use captures upwards of 95% or more of annual site energy use"*. As it was stated before, there is no point in measuring 100% of plant's energy usage, but also ignoring too many of the devices will eventually make results unreliable. Quoted case studies represents probably optimal approach to this problem. Last noteworthy note is point 4 which determines method used for measurements, and also highlights issue mentioned earlier, because actual energy usage may differ from calculated one. It is important to point that out, because someone unfamiliar with the energy usage topic may just multiply motor size by work-time and think that measured energy usage written in the table is wrong because calculations results are different.

However, data presented as a table are good for detailed analyses. Diagrams usually are better in terms of readability. But as was stated in section 2 not processed data should not be presented because it is possible that diagram created from raw data may be unclear.



Picture 15. Fully detailed energy distribution for WWTP G. 2008-2009

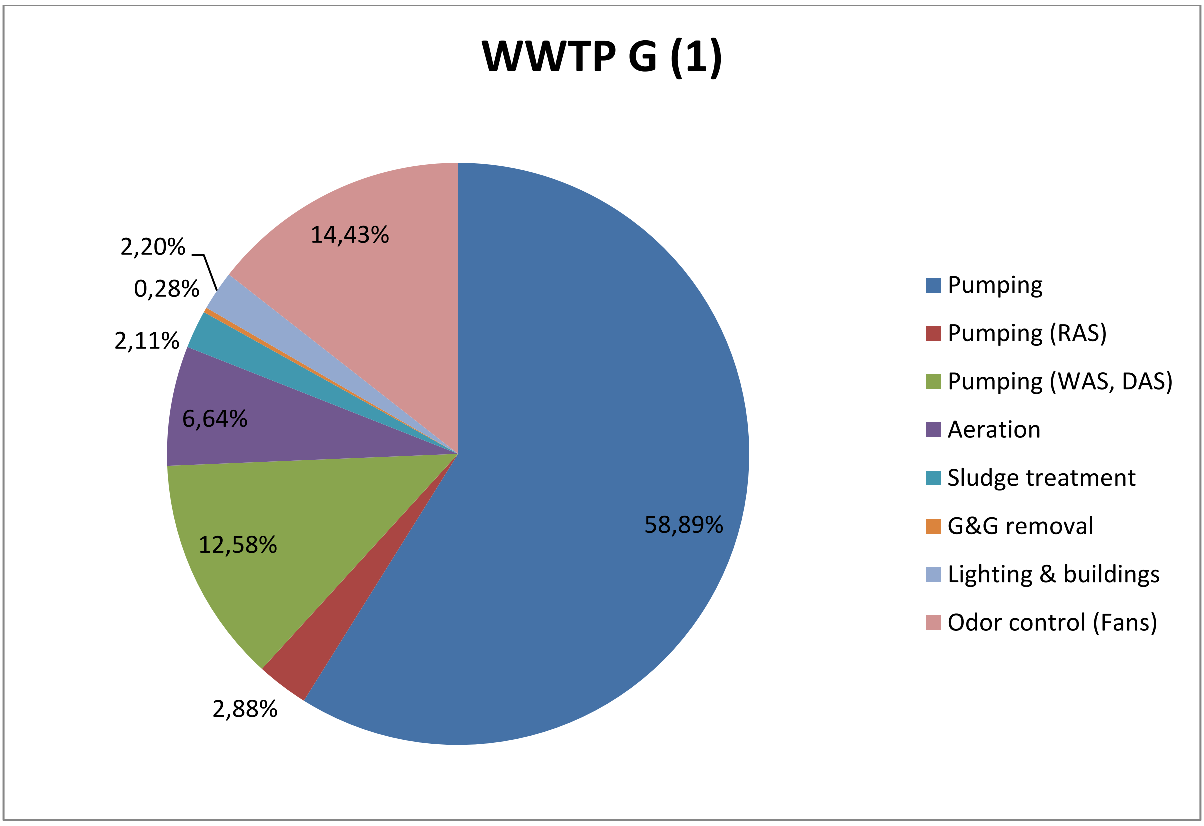
Source: U.S. Environmental Protection Agency, Region 9, Energy Assessment Report for County of Honolulu Kailua Wastewater Treatment Plant, Kailua, Hawaii April 2010.



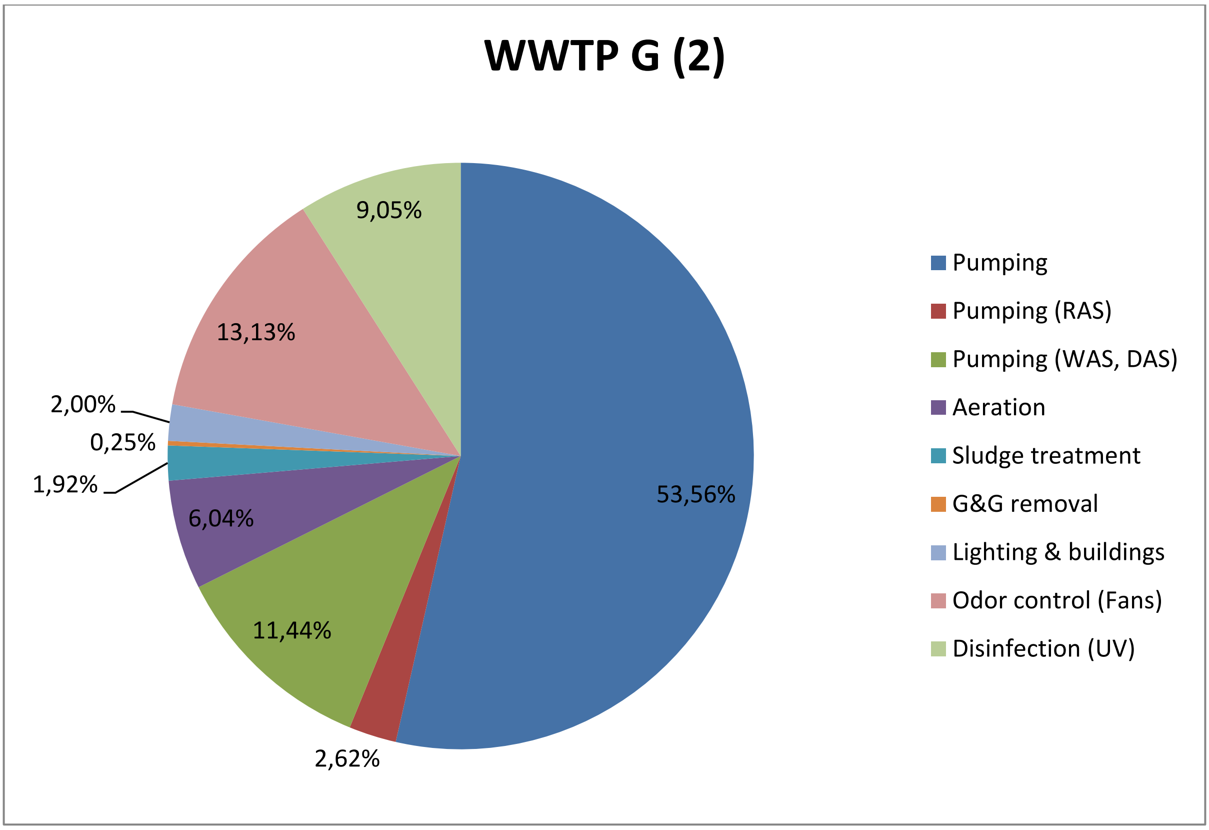
Picture 16. Fully detailed energy distribution for WWTP J. 2008-2009

Source: U.S. Environmental Protection Agency, Region 9, Energy Assessment Report for County of Kauai, Waimea Wastewater Treatment Plant, Waimea, Hawaii April 2010.

Diagram in Picture 15 is rather unclear, and the legend is in 2/3 invisible. Diagram shown in Picture 16 is more readable than for plant G shown in Picture 15, but still legend is rather unclear. This level of details is vital for performing any actions, but is not handy when it comes to present results. Therefore, the results should be edited and simplified (grouped). The observations were grouped into following categories: Pumping, Pumping of RAS (Return Activated Sludge), Pumping of WAS (Waste Activated Sludge) and DAS (Digested Activated Sludge), Aeration, Sludge treatment, Great & Grease removal, Lighting & buildings, Disinfection, Others. Please note that for plant G due to two versions of energy distribution, two diagrams were created as well. This also shows that evaluating team always can face unpredictable situations creating unclear results. In this case impact wasn`t very significant however it was noticeable (±9% of total plant’s energy consumption) thus ignoring it and presenting only one version wouldn’t be a good course of action. The edited diagrams are presented in the Pictures 17 to 21.

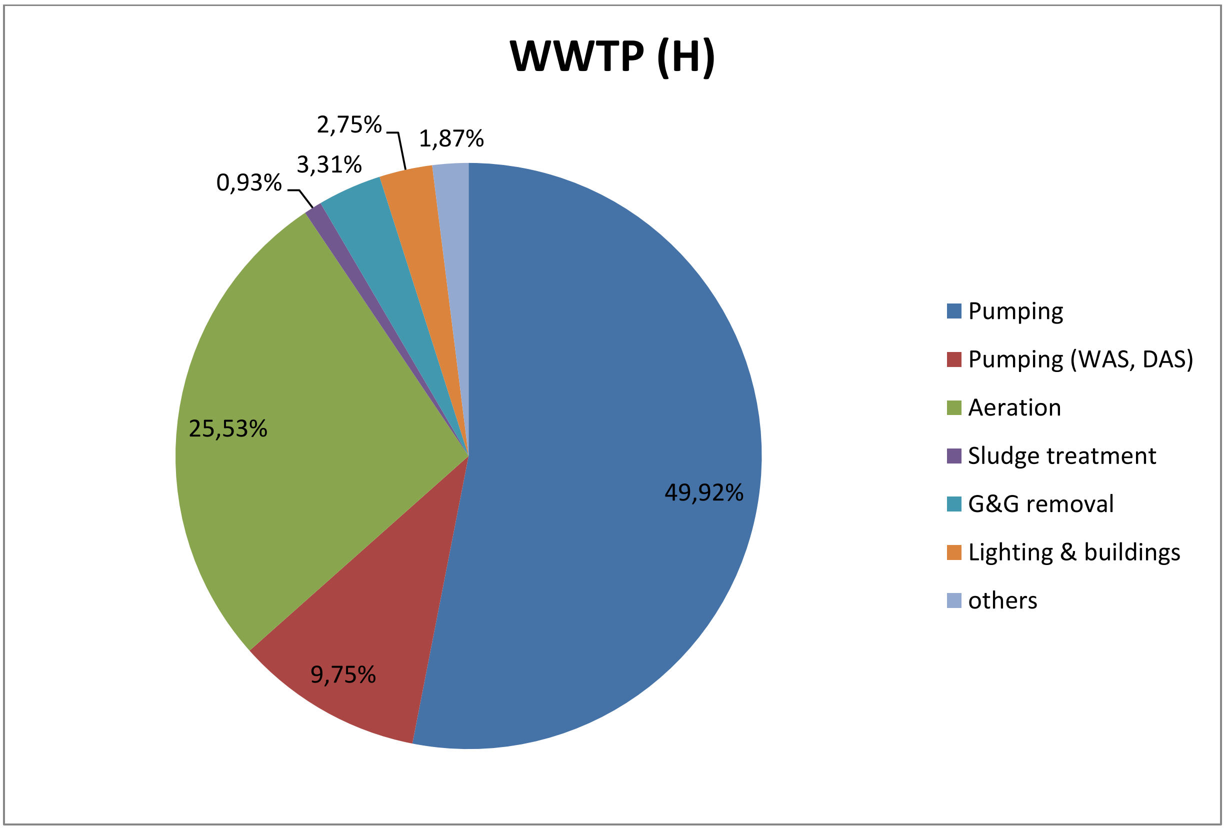


Picture 17. Simplified energy distribution for WWTP G (UV disinfection excluded). 2008-2009
Source: U.S. Environmental Protection Agency, Region 9, Energy Assessment Report for County of Honolulu Kailua Wastewater Treatment Plant, Kailua, Hawaii April 2010.



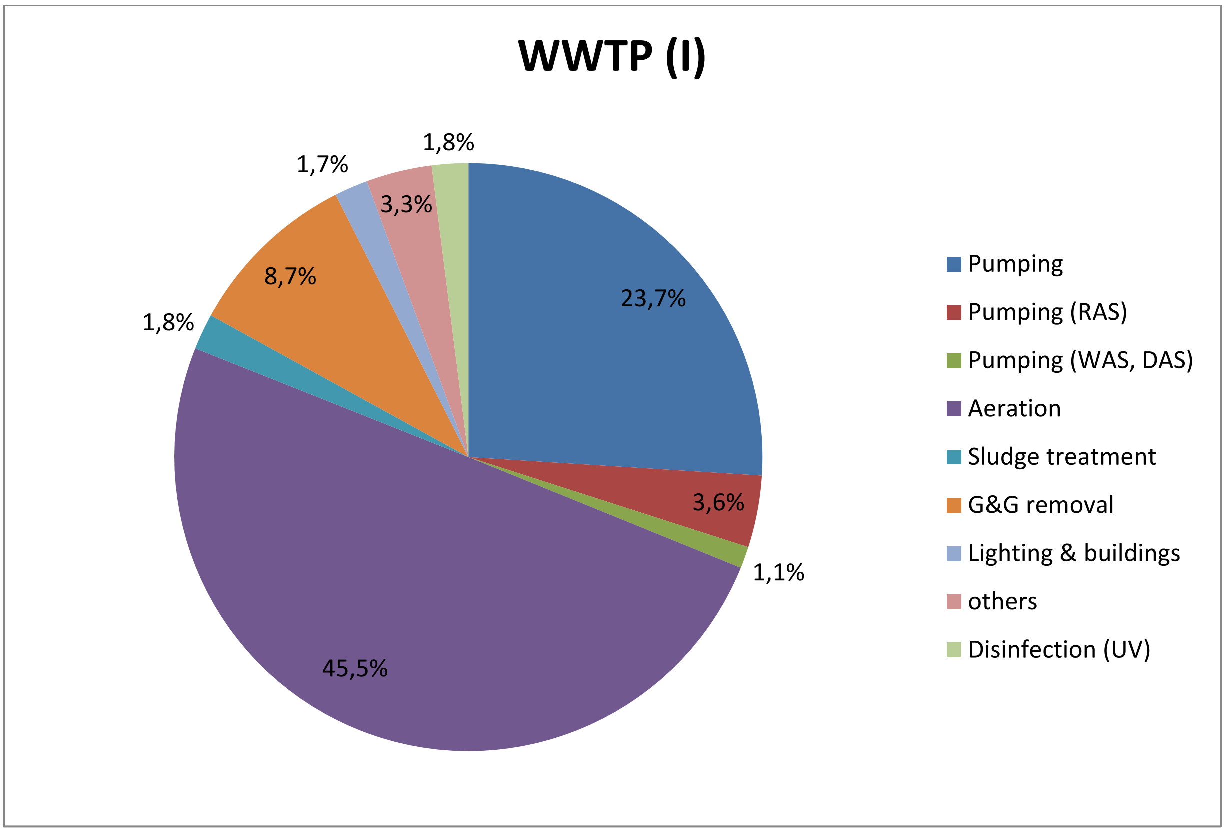
Picture 18. Simplified energy distribution for WWTP G (UV disinfection included). 2008-2009

Source: U.S. Environmental Protection Agency, Region 9, Energy Assessment Report for County of Honolulu Kailua Wastewater Treatment Plant, Kailua, Hawaii April 2010.



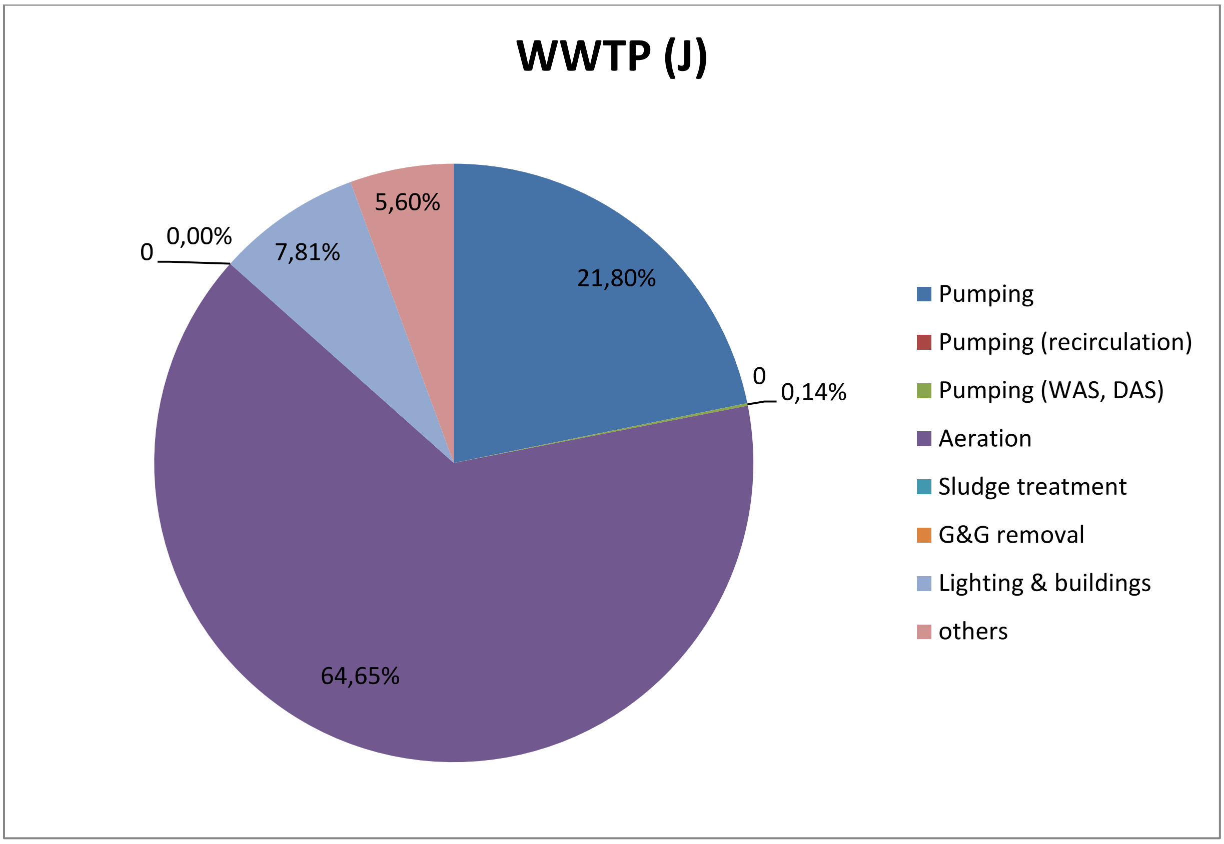
Picture 19. Simplified energy distribution for WWTP H. 2008-2009

Source: U.S. Environmental Protection Agency, Region 9, Energy Assessment Report for County of Honolulu Hilo Wastewater Treatment Plant, Hilo, Hawaii April 2010.



Picture 20. Simplified energy distribution for WWTP I. 2008-2009

Source: U.S. Environmental Protection Agency, Region 9, Energy Assessment Report for County of Kihei Hilo Wastewater Treatment Plant, Kihei, Hawaii April 2010.



Picture 21. Simplified energy distribution for WWTP J. 2008-2009

Source: U.S. Environmental Protection Agency, Region 9, Energy Assessment Report for County of Kauai, Waimea Wastewater Treatment Plant, Waimea, Hawaii April 2010.

As it was mentioned before, two of these plants (G and H) are non-conventional and the other two (I and J) could be called conventional two decades earlier but today are a little outdated according to plants' designs in most European countries. However the plants I and J have very similar energy distributions to the plants from A to F. Aeration is definitely the most energy-consuming process, yet the smaller the plant, the more energy usage is for the aeration. Second process, in terms of energy consumption, is pumping. Basically these two processes dominate plants energy usage (up to 85 %). Interesting difference in Polish plants, where energy usage for "lighting and building", it is about two times greater. It can be explained by different climates. In Poland, electric heating uses significant amounts of energy during winter time. Unfortunately there is no information if WWTPs I and J have got air conditioning, what can be considered as equivalent to heating installation in Polish plants.

The plants G and H are different than previous ones. They have got bio-towers combined with aerated solid contactors instead of conventional biological treatment (see details in section 2.1). Although the bio-towers are kind of another bio-reactor type [22], their construction and operation are different than "classic" bio-reactors such as activated sludge or trickling filter for example. Differences between these two systems are not the main topic of this paper and will not be discussed in detail, however, the effects of these differences on energy distribution are significant. Bio-tower energy requirements for aeration are much lower than for "classical" biological plants, and reflection of this can be found in the diagrams in pictures 17, 18 and 19 They are obviously aerated [5] [9], but in case of plant G aeration system for Bio-towers was so small that was not included in *"major equipment list"*, and blowers were used mostly to supply second stage of this tandem with air (aerated solids contactors). Therefore, the effect was unique comparing to most conventional plants: almost 75%(1) or 68%(2) of total energy consumption went to the pumping systems. Due to unclear information regarding UV disinfection, two distribution diagrams were made, thus values will be given for each one (excluding(1) and including(2) UV disinfection system) It was smaller for the plant H, yet still it was almost 60% of total energy usage, what is rather impossible for conventional plants operated under normal conditions. Nevertheless, the plant H had got reasonable energy usage for aeration purposes (about 25% of total), whereas the plant G had got extremely low energy consumption for aeration 6,64%(1) or 6,04%(2). However this plant is also equipped with plant-wide advanced odor control system which needs to blow out a lot of air from various plant facilities. Therefore energy used by the system fans was 14%(1) or 13%(2). This, combined with enormous amounts of pumped wastewater is most probable responsible for such low outcome for aeration. Worth mention is hypothetical energy consumption by UV disinfection system in plant G. Estimated value was about 9% of plant's total energy consumption. Of course energy usage for UV disinfection is directly proportional to quantity of treated wastewater therefore for plant I it was only about 2%. This is important information for Poland. Nowadays, most of WWTPs in Poland have no effluent's disinfection systems, however, most likely that will change in the future and such knowledge will be useful for designing purposes.

4. Conclusions

(1) Wastewater Treatment Plants design has significant impact on plants energy distribution,

(2) Aeration and pumping are two most energy consuming processes for conventional plants

(3) Good knowledge about local conditions and access to archived data are important for correct energy usage evaluation as well as very helpful when unusual situation occur during the survey

(4) Even the most detailed and professional survey may encounter unpredictable situations which could have impact on final results; for example random breakdown of one of the plant devices

(5) Energy evaluation based on mixed estimation and measurements are able to give reasonable results, however can be used only to form primary recommendations, or as a first stage of detailed study

(6) Highly detailed energy measurements are essential for the preparing energy saving programs, however the results are not easy to comprehend , therefore, simplification of the diagrams are recommended

(7) Very detailed survey of energy distribution is still expensive and time, however this will probably change due to general technological development

References:

1. Adamczyk U.*Analiza kosztów eksploatacyjnych wybranych małych oczyszczalni ścieków,*praca dyplomowa, promotor Mucha ZPolitechnika Krakowska, Kraków 2009
2. Legal requirements applicable effluent quality in Poland since 24.07.2006, http://isap.sejm.gov.pl/DetailsServlet?id=WDU20061370984 (*Rozporządzenie Ministra Środowiska z dnia 24 lipca 2006 r. w sprawie warunków, jakie należy spełnić przy*

wprowadzaniu ścieków do wód lub do ziemi, oraz w sprawie substancji szczególnie szkodliwych dla środowiska wodnego (***Dz.U. 2006 nr 137 poz. 984), Załącznik nr 1***)

3. Mucha Z., *Koncepcja technologiczna rozbudowy oczyszczalni ścieków w D*., Kraków, marzec 2008r
4. Lawrence K. Wang, Nazih K. Shammas, Yung-Tse Hung:*Biosolids Treatment Processes; section 13 Drying Beds p.403*, Humana Press, 2007
5. U.S. Environmental Protection Agency, Region 9, *Energy Assessment Report for County of Honolulu Kailua Wastewater Treatment Plant*, Kailua, Hawaii April 2010.
6. SIMCOE Engineering Group Limited, Hydromantis Inc., *Brockville Water Pollution Control Centre Upgrade, Class Environmental Assessment Report, Technical Memorandum No. 2 Secondary Treatment Options Initial Review*, City of Brockville December 2004
7. U.S. Environmental Protection Agency: National Pollutant Discharge Elimination System (NPDES) http://cfpub.epa.gov/npdes/
8. U.S. Environmental Protection Agency: (NPDES) - Clean Water Act http://cfpub.epa.gov/npdes/cwa.cfm?program_id=45
9. U.S. Environmental Protection Agency, Region 9, *Energy Assessment Report for County of Honolulu Hilo Wastewater Treatment Plant*, Hilo, Hawaii April 2010.
10. U.S. Environmental Protection Agency, Region 9, *Energy Assessment Report for County of Maui, Kihei Wastewater Reclamation Facility*, Kihei, Hawaii April 2010.
11. U.S. Environmental Protection Agency, Region 9, *Energy Assessment Report for County of Kauai, Waimea Wastewater Treatment Plant*, Waimea, Hawaii April 2010.
12. Schneider Electric Motion USA, *ELECTRIC MOTORS (General Information for all Motors)*, April 2012
13. U.S. Department of Energy, Motor Challenge Programme, *Determining Electric Motor Load And Efficiency*, *http://www.motor.doe.gov/*
14. Brandser O., *Motor Efficiency, Power Factor, and Load*, Electrical Construction and Maintenance (http://ecmweb.com/motors/motor-efficiency-power-factor-and-load), August 2013
15. Carrow R. S., *Electrician's Technical Reference: Variable Frequency Drives*, Delmar (division of Thomson Learning) Albany, USA 2001
16. Sample offer of electric gauges: http://jdmetering.co.uk/electricity-metering.html?dir=asc&limit=30&order=price

17. US EPA, *Innovative Energy Conservation Measures at Wastewater Treatment Facilities,* Sheboygan Regional WWTP, May 2012.
18. US EPA Region 3 and PADEP, MatthewYonkin, PE, BCEE, CEM, *Energy Efficiency Roundtable (Energy Audits & Guaranteed Savings/Performance Contracts),* May 2012.
19. US EPA, *Wastewater Management Fact Sheet: Energy Conservation*, July 2006
20. Wawrentowicz D. *Energochłonność komunalnych oczyszczalni ścieków typu SBR*, praca doktorska, promotor Królikowski A.J., Politechnika Białostocka, Białystok 2001
21. Królikowski A., Wawrentowicz D. *Struktura zużycia energii elektrycznej w sekwencyjnych oczyszczalniach ścieków,* IV Kongres Kanalizatorów Polskich POLKAN '99, Łódź 1999
22. Rumana Riffat,*Fundamentals of Wastewater Treatment and Engineering p.175*, CRC Press, 2012

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The implementation of CHP systems in existing district heating systems in Poland

Key words: *combine heat and power, cogeneration, district heating*

Abstract: Cogeneration of heat and electricity is an interesting alternative to coal fuel boilers common in Poland. CHP is an important way to meet the needs of European countries in terms of energy efficiency and environmental protection. The introduction of cogeneration system based on the heating system has a number of advantages that are also presented in the article. In addition, the article focuses on two practical implementations of cogeneration in the existing district heating in Poland. The heating system of discussed heat-generating plants is based on coal dust burning. The modernization of a heat generating plant in Sokolow Podlaski is an example of the CHP installation based on ORC whereas the modernization of district heating in Sierpc provides for an installation of cogeneration genset with gas engines powered by natural gas. Both practical implementations are to illustrate and recognize the possibilities of the adaptation of the CHP systems to every district heating system.

1. Introducion

Combined heat and power (CHP), also known as is a technological process for the simultaneous production of electric energy and useful heat. It leads to more efficient utilisation of primary energy than in the case of separate production. The use of cogeneration brings considerable savings in the final energy production; moreover, it is ecologically beneficial because it contributes to the decrease of the level of gases emissions, especially CO2. Cogeneration is promoted by the European Union Directive 2003/54/EC and 2004/8/EC. High-efficiency cogeneration based on a useful heat demand is a priority given the potential benefits of cogeneration with regard to saving primary energy, avoiding network losses and reducing emissions of greenhouse gases. In addition, efficient use of energy by cogeneration can also contribute positively to the security of energy supply.[1]

CHP is not a single technology, but an integrated energy system that can be modified depending upon the needs of the energy final user.The main problem of cogeneration systems is the fact that advantages of CHP cannot be fully utilised due to the limited heat demand. The complex analysis of a cogeneration unit should take into account the characteristics of the heat receiver which can vary, for example, seasonally and during the daytime[2,3].

1.1. CHP in practice

In the technological process of CHP electricity is produced and resulting waste heat, inseparably connected with the process, is used for heating residential buildings, public as well as commercial buildings, and industrial establishments. CHP is an excellent way to integrate local energy supply so that local demand for industrial steam, domestic hot water, and for heating the premises as well as their possible cooling can be combined with parallel production of electricity in accordance with Figure 1. The typical advantages of such integrated systems include full fuel flexibility, higher quality of air in cities, and highly effective use of available primary energy sources [2].

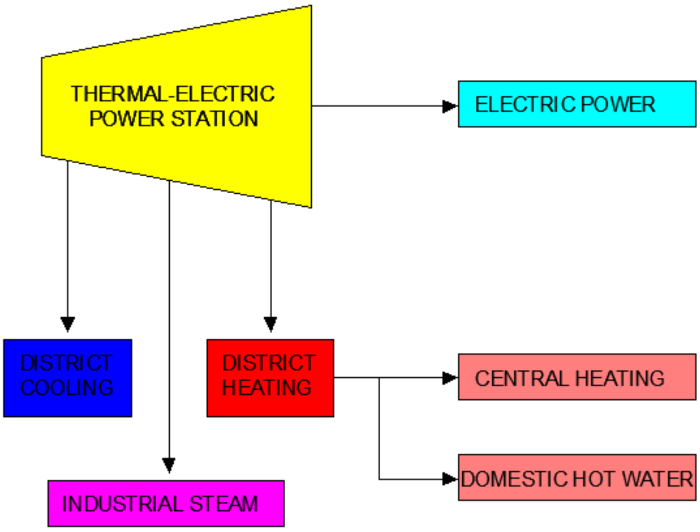


Figure 1. Products of the CHP process

Source:BASREC: Podręcznik dla instytucji o CHP oraz DH [4].

Due to the high efficiency of CHP, emissions of greenhouse gases associated with the energy industry are lower than in any other method of power generation based on fossil fuels and biofuels. In the production of heat and electricity fuel is a major cost's component. In typical cases, the cost of fuel is about 50 % of the overall cost of the energy companies in the countries of the European Union and about 70 % in the economies of countries in transitional period. For this reason, further efforts are required to improve energy efficiency in the generation and transmission of energy [3].

1.2.Advantages of CHP

Energy efficiency of CHP is usually about 40 % higher than the efficiency of separate production of electricity in a condensing power plant and of heat in a heat-only boiler (HoB), assuming they use the same fuel. In other words, the CHP consumes 30% less fuel than the separate production of electricity and heat does, as shown in Figure 2.

In separate condensing power plants, usually gas- or coal-fired, or in nuclear power plants even from 40 to 70 % of fuel consumption is dispersed in the environment by condensation and losses through chimneys – into seas, rivers, lakes and directly into the atmosphere. High fuel efficiency of the CHP is an important advantage of this solution in the energy sector, while exerting an important and positive impact on the energy industry and environmental protection .

The figure 2 shows that production of 100 units of electricity and heat requires 310 units of fuel at the energy efficiency of 64.5 % in the ordinary condensing power plants and gas-fired boilers, while it uses only 222 units of fuel at energy efficiency of 90 % in a gas fired power plant in a combined cycle (Sankey diagram).

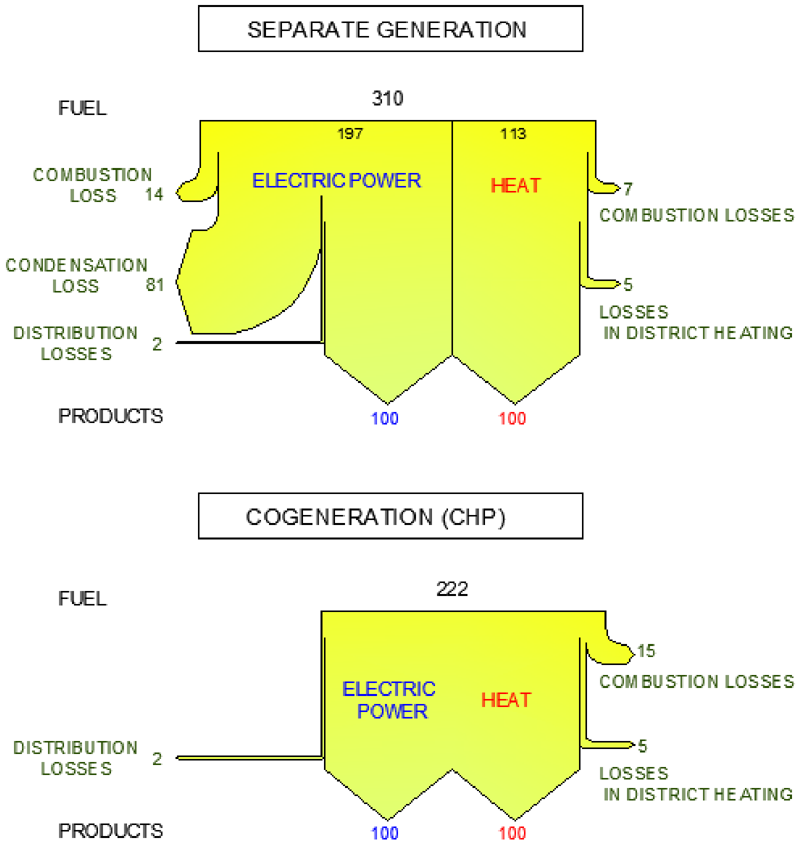


Figure 2. Production of electric energy and heat in a separate generation and in cogeneration(CHP)

Source:http://www.imp.gda.pl/bioenergy/a/busines/Cogeneration.pdf [2].

2. Material and methods

The cogeneration as a heat source encompasses a wide range of technologies, which make it possible to adapt it to every heating system. Among the available technological solutions of CHP the most popular solutions are[5]:

1) A cogeneration block with a gas engine powered by natural gas
2) A cogeneration block with a gas engine powered by biogas
3) A cogeneration block with a gas turbine powered by natural gas
4) A cogeneration block with a steam turbine and a biomass-fired boiler
5) A cogeneration block with ORC turbogenerator and a biomass-fired thermal oil boiler

The article presents two of the above mentioned technical solutions of CHP systems. Both of those heating systems are based on a boiler fired by coal dust. The first solution described in the article is in a heat plant in Sierpc where gas engines powered by natural gas are used. The second example concerns a modernization in Sokolow Podlaski based on biomass using ORC. At the beginning of the modernization process in both cases a detailed analyses of the selection of cogeneration systems were made. The analyses were based on the following points :

1) The distribution of heat load –especially an analysis of an hour load when the heating system works for domestic hot water
2) Availability of fuel
3) Site conditions
4) Supply of fuel

2.1. Gas-fired cogeneration systems

The technique of combined production of energy carriers in gas cogeneration systems, including, above all, the systems of small and medium power, has become widespread. The main difference with respect to a steam power plant is to use a single device as a source of electricity and heat at the same time. Furthermore, in systems of small power, as a rule, production of electric energy is independent of the process of heat generation. This means that generation of electricity is possible in the complete absence of heat demand, without changing the energy efficiency of the device [6].

The classification of the CHP system to a group of small cogeneration systems depends not only on the thermal and electrical power but also factors such as [6]:

– machine used (engine, gas turbine or other) ,- the type of fuel used ,
– configuration of the system (number of units)
– form of co-operation with the power grid,
– form of management of generated heat

These elements are distinguishing features characteristic of small cogeneration systems in comparison to a steam power plant

A typical cogeneration system consists of :

– a reciprocating engine or gas turbine
– generator
– system of heat exchangers or a waste-heat boiler
– automatic control system (often remote)
– system of air filters and flue system (with silencer)
– adsorption chiller (in air conditioning or cooling systems)

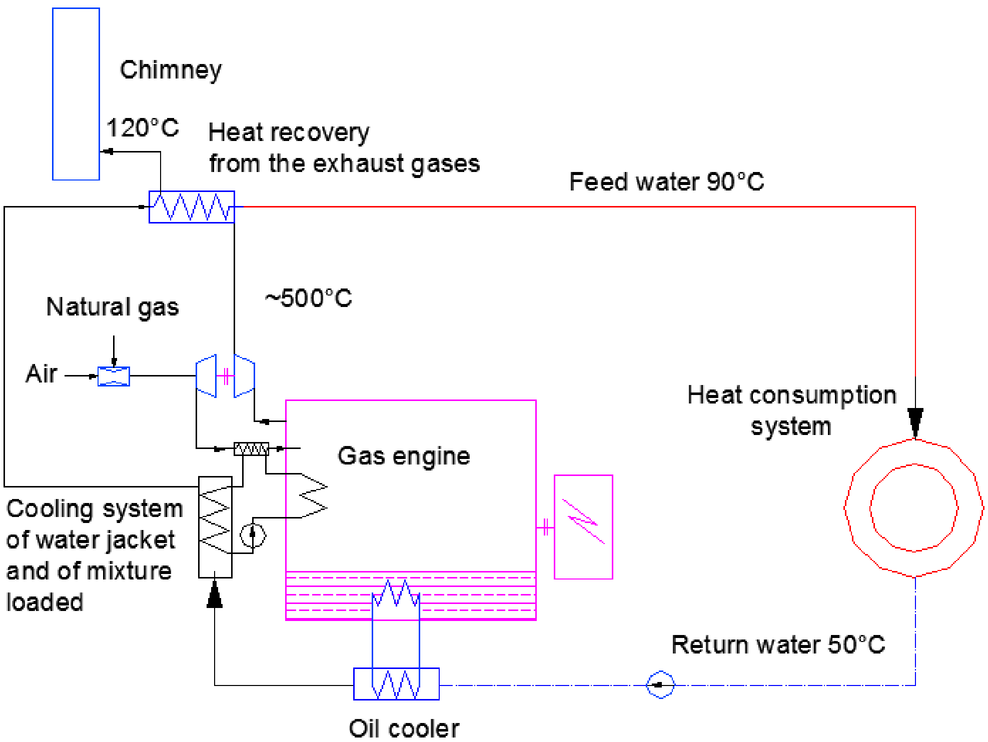


Figure 3. A diagram of CHP system with gas reciprocating engine

Source: Skorek J., Kalina J., Gazowe układy kogeneracyjne [6]

In the presented combined system gas reciprocating engine drives a generator. The heat referred to as waste heat is partially used in heat exchangers. In this arrangement exchanger system is expanded, because in the engine there are several heat sources with different temperatures such as:

- cooling system of water jacket
- cooling system of sump (drip pan)
- cooling system of mixture loaded
- hot exhaust gases

Usually occurring variation in demand for heat causes the complexity of the heat schemes in small thermal power plants. In most cases, a gas engine co-operates with reserve - peak boilers and / or heat storages. Reserve - peak boilers are often powered by a fuel other than gas system. Moreover, in the system with a reciprocating engine, especially of higher power, additional cooling tower is installed which enables the device‘s operation at the time of complete absence of heat .

In the CHP systems most commonly produced heat carrier is hot water. In the case of relatively low- performance of the carrier, both substantial cooling of exhaust gases and the receipt of heat from low-temperature sources (engines) take place, which in turn leads to a very efficient use of the chemical energy of the fuel.

The exhaust gases produced in small CHP systems have relatively high temperature, enabling the production of various heat carriers which can be used by many final consumers. In the system saturated process steam or slightly superheated stem can be produced, and such a system can be used in the food industry. The implementation of superheat steam of high degree in the CHP system will significantly expand the scope of its application. A steam of such parameters is required , e.g. in the food industry, chemical industry, or thermal power plants.

Reciprocating engines and gas turbines available on the market are offered by manufacturers in a wide range of power, so that it is possible to precisely match the CHP unit to the needs of the recipient. Table 1 shows the general characteristics of the basic CHP systems with reciprocating engines and gas turbines. For comparison, the parameters of the conventional steam power plant are presented. It should be noted that the CHP systems in relation to the steam power plant are characterized by increased efficiency of electricity generation and significantly higher rates of co-generation factor. This is due to the fact that the electrical power of CHP based on gas practically does not depend on the actual heat load. Both the system with a reciprocating engine and one with a gas turbine can work all the time with nominal electrical power in a full range of heat load (0-100 %). Increasing the heating power of the system results in mere reduction in rate of co-generation factor due to the fact that electric power is not changed. A different situation occurs in steam power plants where the increase in thermal power always causes a reduction of electric power in low-pressure part of the turbine [2,6].

Table.1 .Technical characteristic of basic CHP units.

Type of a device	Fuel	Power range [kW]	Electrical efficiency $\eta_{el.CHP}$ [%]	Overall efficiency $\eta_{c.CHP}$ [%]	Co-generation factor σ	Heat carrier
Steam turbine	any fuel	>250	7÷20	75÷84	0,1÷0,33	steam, hot water
Gas turbine – simple system	oil, natural gas and other gases	>350	15÷40	65÷85	0,4÷0,8 (about 0.2with reloading)	steam, hot water
Gas turbine-combined system	oil, natural gas and other gases	>7300	35÷55	73÷85	to 1,45	steam of medium parameters, hot water
Two-burner reciprocating engine	natural gas+diesel	2000÷17000	35÷42	65÷84	0,66÷0,91(about 0.4 with reloading)	hot water, less common: steam of low parameters
Gas reciprocating engine	natural gas and other gases	5÷6500	25÷40	70÷90	0,5÷1,0	hot water, less common: steam of low parameters
Microturbine	natural gas	25÷450	25÷30	75÷85	0,5÷0,65	hot water (to 90°C)

Source: Skorek J., Kalina J., Gazowe układy kogeneracyjne [6],

2.2. ORC technology

The development of the ORC technology started in the 60s of the last century and is today fairly commercialised at utilisation of the heat sources [7]. The technology based on Organic Rankine Cycle (ORC) appeared as an opportunity for local thermal-electric power plants using biomass. As for a technological system with ORC, a pressure oil boiler is used instead of a classical steam boiler (Fig.4) and its heat source is the biomass-fired boiler. Moreover, organic substance (silicone oil) replaces steam or liquid water as working medium.

Both the thermodynamic calculations of ORC technological system as well as the calculations of steam-water ORC are done identically while the only difference occurs when the silicone oil properties need to be taken into consideration for both - liquid and vapour state. In a closed thermodynamic cycle with a special organic working medium electric energy (medium voltage) and low-temperature heat are produced by ORC [7,8].

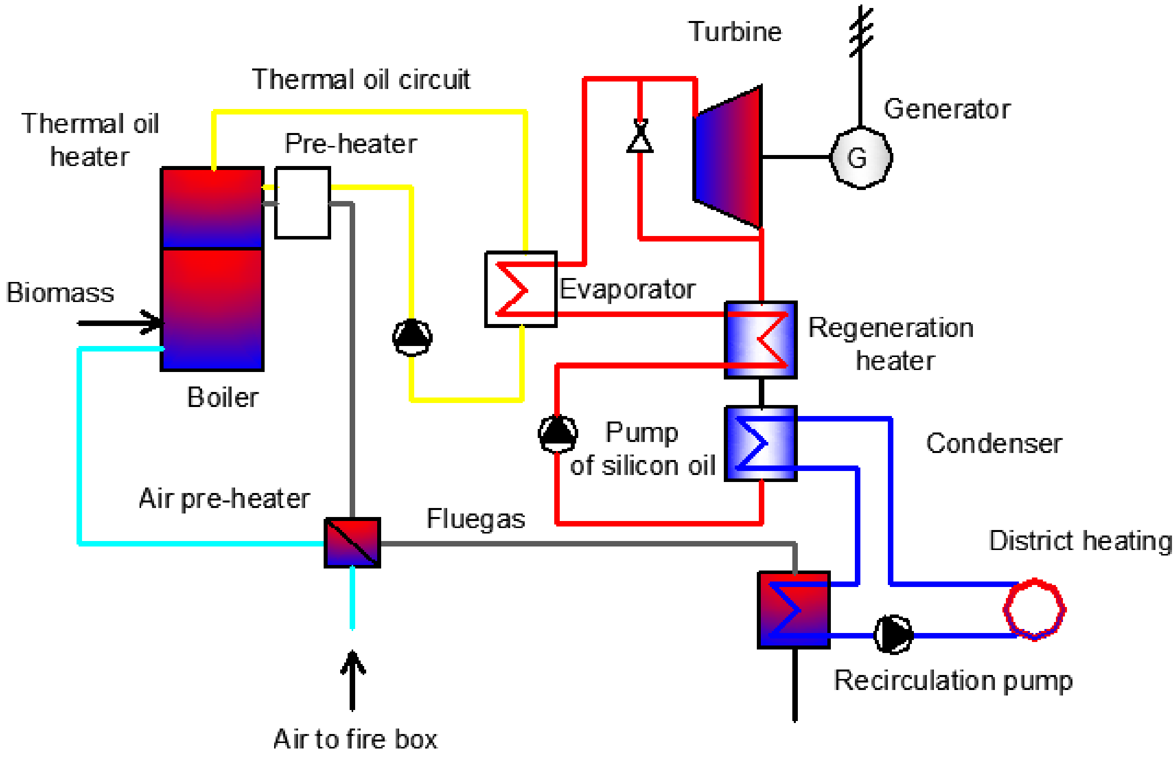


Figure 4 Basic shame of the ORC power plant

Source: http://old.cieplej.pl/prezentacje/doe2004/MENU/IV_EDOE/2_dzien/pdf/4.pdf [8].

In order to utilise biomass, which became a remarkably important renewable energy source with a high level of accessibility, Combined Heat and Power system can be applied. Also, biomass can be a long-lasting power supply and is often economically profitable. The energy obtained through CHP is especially maximized in small power systems (from a few hundred kW electric to one or two MW electric) erected near the heat consumer.

In terms of advantages ORC technology when compared to other technologies offers the following [9,10]:

- High cycle efficiency (especially if used in cogeneration plants);
- Very high turbine efficiency (up to 90%);
- Low mechanical stress of the turbine, due to low peripheral speed
- Low rotational speed of the turbine making it possible to employ the direct drive of the electric generator without reduction gear;

- Lack of erosion of the turbine blades, due to the absence of the moisture in the vapour nozzles;
- Very long operational life of the machine due to the characteristics of the working fluid, that, unlike steam, is non eroding and non corroding for valve seats tubing and turbine blades;
- No water treatment system is necessary.

Among other advantages are: simple start-stop procedures, quiet operation, minimum maintenance requirements and good partial load performance.

2.2.1. ORC System description

A turbogenerator working as a normal steam turbine to transform thermal energy into mechanical energy and finally into electric energy through an electric generator is the main principle of the Organic Rankine Cycle. An organic fluid, being an alternative to water steam, is vaporised by the ORC. Due to the fluid's higher molecular mass when compared to the molecular mass of water, rotation of the turbine and lower pressure and erosion of the metallic parts and blades are slowed down [11].

In comparison to the biomass Combined Heat and Power plant the whole process is based on the thermodynamic cycle described below [10,11]:

1. A heat source heats thermal oil to a high temperature, typically about 300°C, in a closed circuit;
2. The hot thermal oil is directed to and from the ORC module in closed circuit. In the ORC the organic working fluid of the ORC evaporates in a suitable heat exchanger system (pre-heater and evaporator);
3. Organic vapour expands in the turbine, producing mechanical energy, further transformed into electric energy through a generator;
4. The vapour is then cooled by a fluid in a closed circuit and condensed. The water warms up at about 80 - 90°C and it is used for different applications requiring heat;
5. The condensed organic fluid is pumped back into the regenerator to close the circuit and restart the cycle.

A high overall energy efficiency characterises the ORC cycle: 98% of incoming thermal power in the thermal oil is transformed into electric energy (around 20%) and heat (78%), with extremely limited thermal leaks, only 2 % due to thermal isolation, radiance and losses in the generator; the electric efficiency acquired in non cogenerative cases is much higher (around 24% and more) [9].

The ORC (Organic Rankine Cycle) applies the low boiling point fluids (mostly organic) in the thermal Rankine cycle. The thermodynamic cycle and the relevant scheme of components are reported in Figure 5.

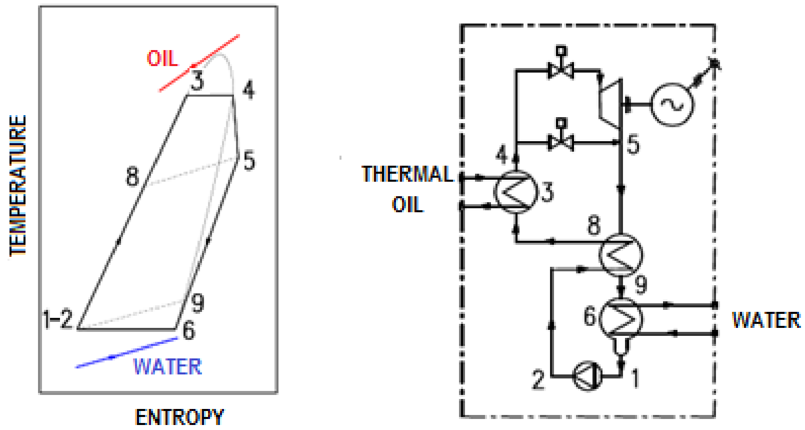


Figure 5Termodynamic cycle and components of an ORC unitTh

Source: http://www.turboden.eu/en/public/downloads/10A02943_paper_marco.pdf [9]

The turbogenerator uses the hot temperature thermal oil to pre-heat and vaporise a suitable organic working fluid in the evaporator (8⇒3⇒4). The organic fluid vapour powers the turbine (4⇒5), which directly drives the electric generator through flexible coupling. The exhaust vapour flows through the regenerator (5⇒9) where it heats the organic liquid (2⇒8).

Finally, the vapour is condensed in a water cooled condenser (9⇒6⇒1). The organic fluid is then pumped (1⇒2) to the regenerator and then to the evaporator, thus completing the sequence of operations in the closed-loop circuit [11].

3. Results and discussion

3.1. Identified problems

One of the main problems affecting the heating systems in county towns such as Sierpc and Sokołów Podlaski is a significant emission of gas and particulate pollution into the atmosphere from burning of coal. The emission of dust and tar substances, i.e. soot, poses the greatest threat. The process of pollution dispersion in the atmosphere is complicated, depending on the balance of the atmosphere, the roughness of the terrain; it is not always possible to clearly define the area of contamination. In fact, pollution, under certain meteorological conditions mainly related to wind rose and the inverse states of the atmosphere, can be transported over long distances directly affecting the air quality in these areas (a large part of the overall contamination background).

The problem of high levels of emissions of air pollution into the atmosphere is a direct result of the technical condition of operating equipment, a type and quality of fuel burned and a method for purifying exhaust gases. A large number of local boiler houses and household furnaces both of which cause low emissions significantly reduce air pollution. The problem of low emission is being continuously solved through the elimination of local boiler houses while connecting them to the district heating system.

3.2. The heating plant in Sierpc before modernization

Sierpc's heating system is based on a central heat source, transmission networks and heat distribution centres. The heating company in Sierpc produces and supplies thermal energy to residential buildings and public facilities. The thermal energy produced by the coal dust heating plant is sent through high-parametre network to final users. The district heating system includes exchange heat distribution centres. Some of them are equipped with regulatory and weather compensators.

The plant is located at Przemysłowa St. 2a, Sierpc. The site encompasses following buildings :

- the main building of the heating plant
- an electric switchboard building

There is also a chimney made of reinforced concrete.

The site also includes:

- hardened fuel storage area
- hardened slag storage area
- paved roads .

The site is equipped with the following utilities:

- electricity network of low and high voltage
- water supply
- sewerage system.

Currently in the boiler station boilers with a total capacity of 34.9 MW are installed: – three boilers WR -10 with a capacity of 11.63 MW producing heat from coal dust. The boilers consist of cyclone deduster extractors. The exhaust ducts behind the cyclones connect into one duct discharging exhaust gas to a chimney.

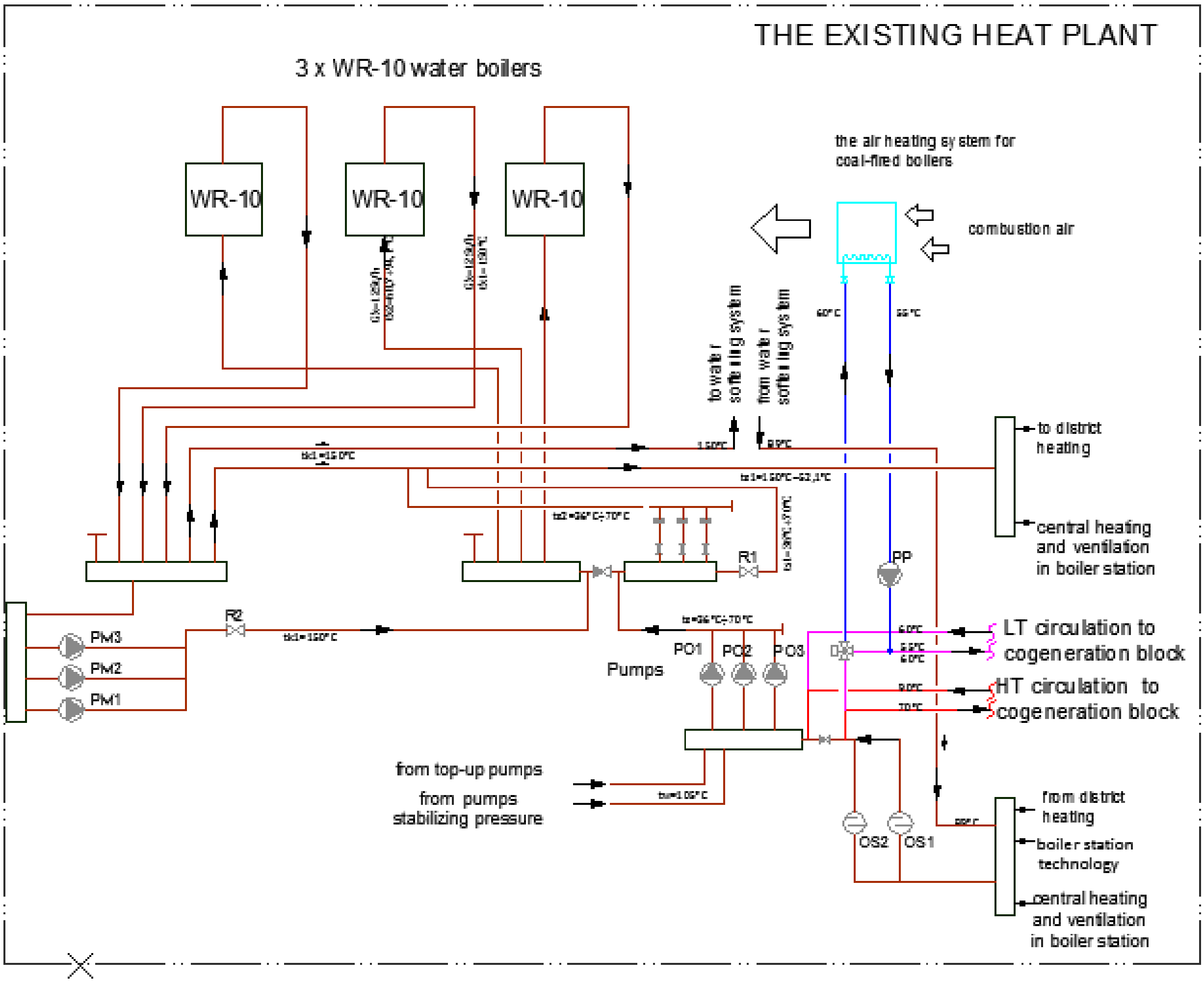


Figure 6.An existing technological system of Sierpc

Source: Brynkiewicz J., Filipkowski W. P.P.H.U. JuWa Białystok Projekt budowlany,, Przebudowa ciepłowni węglowej na źródło ciepła bazujące na skojarzeniowej produkcji energii cieplnej i elektrycznej opartej na paliwie gazowym'' [12]

3.3.Description of the proposed solution-Sierpc

The modernization of the city heating plant is based on using natural gas for heat and electricity production in a high-performance combination. The city heating plant in Sierpc will change into a thermal electric power station by modernizing, expanding and adapting existing installation to a designed cogeneration system. The system will consist of four cogeneration gensets with a capacity of approximately 9,422 MW supplied with natural gas GZ -50 . The modernization project envisages installation of four cogeneration blocks. The cogeneration gensets will be placed in a building designated specifically for this purpose, located at the site next to the existing electrical substation. The heat produced by the cogeneration gensets will be received by the district heating network. Heat transfer will take place through pre-insulated heat installation to the heating plant main building, and heat-transfer medium's circuit will be forced by the existing circulation pumps

The minimum average daily heat output has a significant impact on the size of the chosen gas engines. The general idea is for the engine to operate for a period of 7,500 8,000 hours per year with close to nominal load, which in turn will bring the greatest production and sale of electricity. Remaining time (approx. 750 - 1000 hours per year) is earmarked for maintenance and services .Therefore, the minimum thermal power of the daily production during the summer of 2.3 - 2.4 MWt was chosen.

The work distribution of individual devices, production of electricity and heat, gas demand, and the cost of fuel illustrate the tables below. The following assumptions were made:

- daily heat output - 2.72 MW
- efficiency of electricity production - 42.0%
- efficiency of heat production - 48.1 %
- overall production efficiency - 90.20 %
- Tariff Group for the purchase of natural gas - in W7B
- tariff for natural gas - valid from 01.10.2010
- operating time - 10% (per month) downtime for necessary maintenance operations is taken into consideration

Table 2.Characteristic of the heat source after modernization

Parameter	Value
Source power infuel	11,45 MWh
Type of fuel	natural gas
Calorific value	0,036 GJ/m^3
Fuel consumption	6689463,05 m^3
Energy in fuel - heat	240820,67 GJ/rok
Thermal energy - production	113133,34 GJ/rok
Gas engine	4x1,2 MWe
Electric energy-production	27441,35 MWh

Source:Brynkiewicz J., Filipkowski W. P.P.H.U. JuWa Białystok Koncepcja techniczno-ekonomiczna;,, Modernizacja systemu ciepłowniczego Sierpca polegająca na przebudowie istniejącej ciepłowni węglowej na źródło ciepła bazujące na skojarzeniowej produkcji energii cieplnej i elektrycznej uzyskanej ze spalania gazu ziemnego'' [13].

Table 3.Production and sales of energy from gas engines - prognosis

No	Specification	Unit	Month												Total
			I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1	Min. thermal power - for the selection of gas engines	MW	5,51	5,51	5,51	5,51	2,30	2,30	2,30	2,30	5,51	5,51	5,51	5,51	
2	Max.thermal power–gas engines	MWt	5,51	5,51	5,51	5,51	2,30	2,30	2,30	2,30	5,51	5,51	5,51	5,51	
3	Max. electric power –gas engines	Mwel	4,82	4,82	4,82	4,82	2,00	2,00	2,00	2,00	4,82	4,82	4,82	4,82	
4	Hours of operation – 2 gas engines	h	0,00	0,00	0,00	0,00	669,60	648,00	669,60	669,60	648,00	0,00	0,00	0,00	3 304,80
5	Hours of operation – 4 gas engines	h	669,60	604,80	669,60	648,00	0,00	0,00	0,00	0,00	0,00	669,60	648,00	669,60	4 579,20
6	Sales of electric energy from gas engines	MWh	2902,3	2621,4	2902,3	2808,6	1205,2	1166,4	1205,2	1205,2	2811,0	2902,3	2808,6	2902,3	27441,3
7	Thermal power productionfrom gas engines	MWh	3 321,7	3 000,2	3 321,8	3 214,6	1 386,1	1341,3	1 386,1	1 386,1	3 213,4	3 320, 5	3 213,4	3 320,5	31 425,9
		GJ	11958,3	10801,1	11958,3	11572,6	4989,9	4828,9	4 989,9	4 989,9	11 568,4	11 954,0	11 568,4	11 954,0	113 133,3

Source:Brynkiewicz J., Filipkowski W. P.P.H.U. JuWa Białystok Koncepcja techniczno-ekonomiczna; „ Modernizacja systemu ciepłowniczego Sierpca polegająca na przebudowie istniejącej ciepłowni węglowej na źródło ciepła bazujące na skojarzeniowej produkcji energii cieplnej i elektrycznej uzyskanej ze spalania gazu ziemnego'' [13].

3.1.1. Cogeneration genset

CHP units with their equipment have been chosen taking into account the following assumptions:

- units will be supplied with natural gas GZ -50
- units' power was chosen for the optimal operation with constant power
- because of acoustic reasons units will be placed in concrete sound-absorbing "capsules"
- thermal water systems will be equipped with cooling towers with glycol circuit as emergency heat consumers
- at the outlet exhaust gases of 120 ° C from the engines will be used in the economisers .
- Four GUASCOR POWER gensets were designed with the basic technical parameters:

Table 4.Gas engine specification

Gas engine specification		
Engine type	SFGM 560	
Engine power	985	kW
Mean effective pressure	14	bar
Exhaust temperature	380	°C
Exhaust gas flow	5086	kg/h
Combustion air mass flow	1581	kg/h
Combustion air temperature design	25	°C
Ventilation air flow	68950	°C

Source: Design materials from Guascor Power [14]

Table 5.Gas engine parameters

Engine parameters		
Bore	160	mm
Stroke	175	mm
Displacement	56,3	dm^3
Number of cylinders	16	
Compression ratio	11,7:1	
Mean piston speed	8,8	m/s
Lube oil content	232	dm^3
Typical mean lube oil consumption	0,2	g/kWh
Generator efficiency	97,2	%

Source: Design materials from Guascor Power [14]

Table 6.Energy balance specification

Energy balance		
Electrical power	957	kW
HT water heat	709	kW
LT water heat	150	kW
Exhaust cooled to 120°C	423	kW
Engine radiation heat	35	kW
Generator radiation heat	28	kW
Fuel consumption	2456	kW
Mechanical efficiency	40,1	%
Electrical efficiency	39	%
Thermal efficiency	52,2	%
Total efficiency	91,2	%

Source: Design materials from Guascor Power [14].

Table 7.System specification

System parameters		
HT water flow	70	m^3/h
LT coolant flow rate min./max.	25/30	m^3/h
HT water heat	200	dm^3
HT water temperature max.	90	°C
LT coolant temperature	55	°C
Exhaust backpressure max.	45	mbar
Max. pressure loss in front of air cleaner	5	mbar
Gas flow pressure, fixed between	50-240	mbar

Source: Design materials from Guascor Power [14].

Table 8.Genset dimensions

Genset Dimensions		
Width	1736	mm
Length	4584	mm
Height	2475	mm
Dry weight genset	9300	kg

Source: Design materials from Guascor Power [14]

It was assumed that the exhaust from two gas engines of cogeneration gensets would power one economizer. Table no.6 shown an economizer basic data.

Table 9.Economiser parameters

Economiser parameters		
Material	stainless	steel
Exhaust temperature input	120	°C
Exhaust temperature output	50	°C
Exhaust flow	8000	Nm^3/h
Exhaust pipe diameter input	Ø400	mm
Exhaust pipe diameter output	Ø400	mm
Heat yields	approx.230.	kW

Source: Design materials from Viessmann [15]

Cogeneration genset are designed for operation as stand-alone systems because of the automatic control system which eliminates the need for a constant supervision by man. The main components of the unit are:

- gas engine powered by natural gas
- electric synchronous generator
- supporting frame
- heat recovery system
- control, security and monitoring system

3.1.2. The location of the cogeneration gensets building

CHP units of 4 x 957 kWe will be placed in the specifically designated building. The location of the building at the site of the heating plant near the existing substation.

3.1.3. Technological system

A technological system of the thermal electric power station with cogeneration gensets is shown in the schematic diagram (Figure 7).

As far as the heat receiving side is concerned, CHP units will be connected in series to the coal heating plant’s technological system. This means that the water returning from the district heating network will be directed to CHP units heat exchangers and after heating it will be pumped through the main circulation pumps of the mentioned heating plant. HT and LT hest will be distributed and carried out by separate pipelines. In winter season, with high temperatured returning water, LT heat will heat air needed for combustion in coal-fired boilers. LT heat distribution control will be carried out using a three-way valve .

Summary of basic equipment is shown in the table below

Table 10.Basic equipment

Symbol in Figure 7	Device	Quantity
AK	Genset with engine type SFGM 560	4
ECO	Condensing economizer made of stainless steel	2
W3	HT heat exchangers	1
CH1	Cooling tower	1
PG1	Circuit glycol pump	1
NWG1	Diaphragm expansion tank	1
W2	LT heat exchangers	1
CH2	Cooling tower	1
PG2	Circuit glycol pump	1
NWG2	Diaphragm expansion tank	1
KBZ/KBP	Supply/return collecting pipe for HT system - Ø300mm	1
NWHT	Expansion tank	1
KPZ/KPP	Supply/return collecting pipe for LT system - Ø300mm	1
NWLT	Expansion tank	1
KEZ/KEP	Supply/return collecting pipe for economiser system – Ø150mm	1

Source: Brynkiewicz J., Filipkowski W. P.P.H.U. JuWa Białystok Projekt budowlany,, Przebudowa ciepłowni węglowej na źródło ciepła bazujące na skojarzeniowej produkcji energii cieplnej i elektrycznej opartej na paliwie gazowym'' [12]

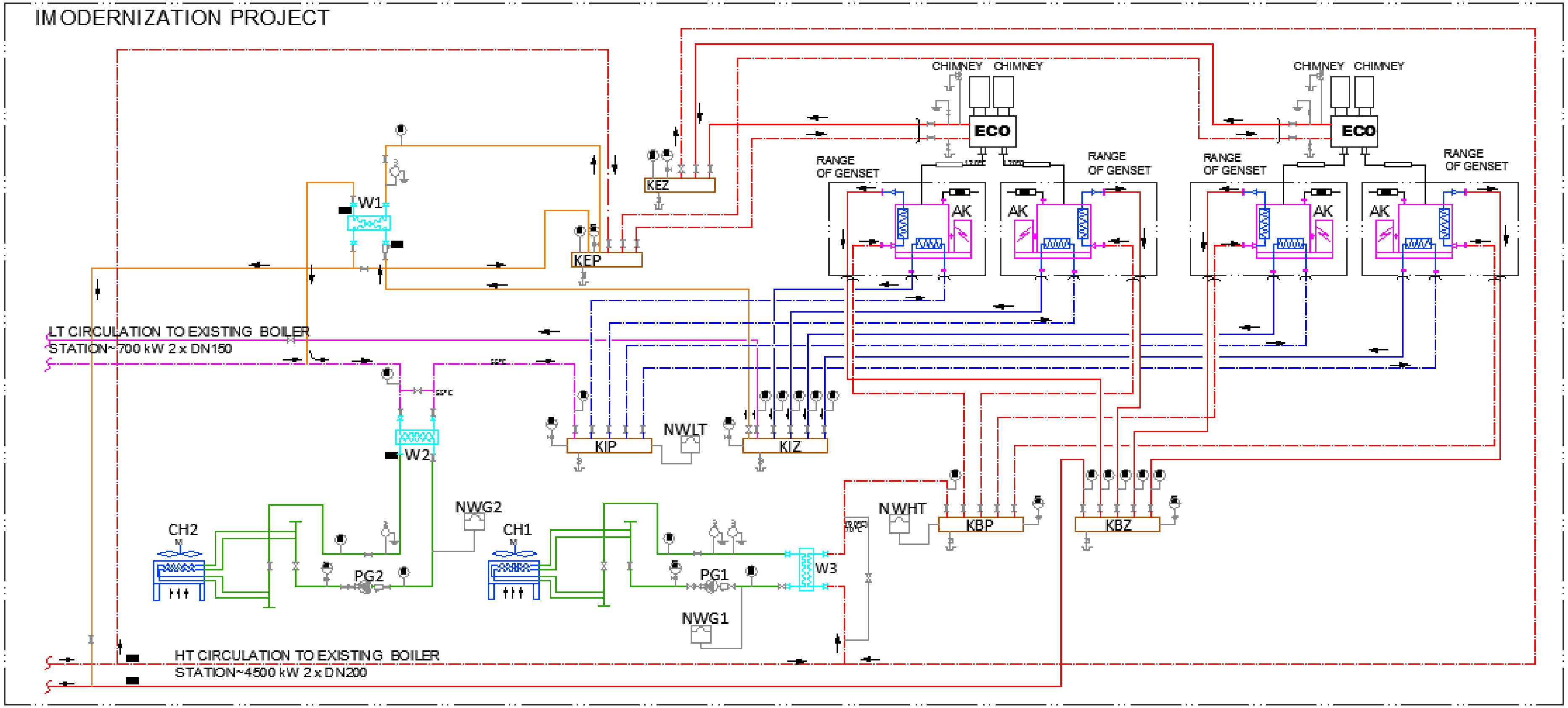


Figure 7 Technological system of the thermal electric power stationin Sierpc

Source: Brynkiewicz J., Filipkowski W. P.P.H.U. JuWa Białystok Projekt budowlany,, Przebudowa ciepłowni węglowej na źródło ciepła bazujące na skojarzeniowej produkcji energii cieplnej i elektrycznej opartej na paliwie gazowym'' [12]

3.1.4. OSH and fire protection

The proposed heat and power station, if properly used, does not pose a threat to the environment and is completely safe. The plant should operate trained staff with knowledge of the actions of individual installations and OSH . Detailed terms of health and safety should be in Manual boiler station. Different devices installed in the power plant must be operated in accordance with operating and maintenance manual (O&MM). All devices should have a safety certificate .

The building cogeneration shall be labeled in accordance with European Union standards for a way out , a location of fire fighting equipment .

The building for cogeneration units based on natural gas GZ -50 as a fuel does not qualify for explosion hazard zone, with an average fire load density to 500 MJ/m^2. The room with transformers and cogeneration units are dedicated fire zones.

3.1.5. Environmental Issues

The modernization of the heating system of Sierpc based on cogeneration units fueled by GZ -50 will improve environmental conditions. As for air protection, emissions from the combustion of coal will decrease. During the heating season a part of the heating needs will be covered by heat from cogeneration. In the summer time domestic hot water will be provided by cogeneration units , while coal-fired boilers will be disabled.

The emission of noise from the cogeneration units will be limited as a result of them being enclosed by sound-absorbing concrete "capsules" and the use of acoustic silencers at the inlets and outlets of the cooling air as well as the outlets of exhaust gases.

The exploitation of the cogeneration units will result in the production of a small amount of waste in the form of engine oil due to its exchange and its remains on oil filters. The spent engine oil will be utilised by a specialist company.

As far as wastewater is concerned an amount of 0.25 m^3/day is expected from cleaning the floors and basins .

3.1.6. Electrical Installations

For rooms with cogeneration units the following installations should be provided :

- power systems for equipment associated with cogeneration units and for units' auxiliaries
- lighting installation in the units' room, machine rooms and distribution transformer station
- emergency lighting system
- lightning protection system

- 230 V machines' sockets

Summary of electrical power :

Table 11.Set of electrical powers

No	Device	Installed power
1	Cogeneration gensets auxiliaries (oil pump , pump for main circuit and intercooler)	4 x 25 kW
2	Circuit glycol pump PG1	4kW
3	Circuit glycol pump PG2	4 kW
4	Cooling tower CH1	6 x 3.1 kW
5	Cooling tower CH2	6 x 3.1 kW
6	Exhaust fan in the units room	8 x 2.2 kW
7	Heating and ventilation unit	4 x 0.18 kW

Source: Brynkiewicz J., Filipkowski W. P.P.H.U. JuWa Białystok Projekt budowlany,, Przebudowa ciepłowni węglowej na źródło ciepła bazujące na skojarzeniowej produkcji energii cieplnej i elektrycznej opartej na paliwie gazowym'' [12]

3.1.7. Objectives of the project - the impact

A main objective of the project the implementation of national energy policy in the field of high efficiency, combined heat and power in scattered plants at the municipal level. The primary purpose of the construction of the CHP system based on the combustion of natural gas is to reduce greenhouse gas emissions and other pollutants into the atmosphere by changing the type of fuel burned from coal dust to natural gas.

The project will result in [12,13]:

- significant reduction of pollutants emitted into the atmosphere resulting from the combustion of coal dust (Table 12, Table13)
- improving the efficiency of heat and electricity production (the use of modern equipment in a CHP plant)
- improve the efficiency of the use of primary energy contained in the fuel through the production of heat and electricity in combination
- reducing the cost of production of heat and electricity
- adjustment of the produced thermal energy to the temporary demand of customers resulting also in lowering the losses of thermal energy transfer (the exchange of heat network for pre-insulated network and the replacement of the heating distribution centre)

Table 12.Emissions

Calculations of air pollution emission were based on „Materiały informacyjno -instruktażowe Ministerstwa Ochrony Środowiska , Zasobów Naturalnych i Leśnictwa nr 1/96 ""Wskaźniki emisji substancji zanieczyszczających wprowadzanych do powietrza z procesów energetycznego spalania paliw"

State before modernization						
Type of fuel	***Fuel consumption [t/rok], [m3/rok]***	***Substance***	***Index [kg/t], [kg/m3], [kg/GJ]***	***Annual emission [t/rok]***	***Parametre K***	***Annual emission t***
Coal dust	6 428,03	*SO2*	9,6	61,71	1,00	***61,71***
		Nox	4	25,71	0,75	***19,28***
		Dust	50	64,28	0,75	***48,21***
	Fuel consumption	*CO*	10	64,28	0,00	***0,00***
	(GJ/Mg)	*CO2*	2100	13 498,86	0,00	***0,00***
	22,00	*BaP*	0,0016	0,01	30 000,00	***308,55***
		Soot	0,080	0,51	3,75	***1,93***
Electric energy	98 788,85 [GJ/rok]	*SO2*	0,319	31,51	1,00	***31,51***
		Nox	0,468	46,23	0,75	***34,67***
		Dust	0,288	28,45	0,75	***21,34***
	Energy in fuel	*CO*	0,036	3,56	0,00	***0,00***
		CO2	262,0	25 882,68	0,00	***0,00***
		BaP	0,0035	0,35	30 000,00	***10 372,53***
		Soot	0,00014999	14,82	3,75	***55,57***
Total- emission before modernization		***SO2***		**93,22**	1,00	***93,22***
		Nox		**71,95**	0,75	***53,96***
		Dust		**92,73**	0,75	***69,55***
		CO		**67,84**	0,00	***0,00***
		CO2		**39 381,54**	0,00	***0,00***
		BaP		**0,36**	30 000,00	***10 681,08***
		Soot		**15,33**	3,75	***57,49***
State before modernization						
Type of fuel	***Fuel consumption [t/rok], [m3/rok]***	***Substance***	***Index [kg/t], [kg/m3], {kg/GJ]***	***Annual emission [t/rok]***	***Parametre K***	***Annual emission t***
Natural gas	6 689 463,05	*SO2*	80,00	0,54	1,00	***0,54***
		Nox	1 920,00	12,84	0,75	***9,63***
		Dust	14,50	0,10	0,75	***0,07***
		CO	270,00	1,81	0,00	***0,00***
		CO2	1 964 000,00	13 138,11	0,00	***0,00***
		BaP	0,00	0,00	30 000,00	***0,00***

	Soot	0,00	0,00	3,75	***0,00***
Total- emission after modernization	***SO2***		**0,54**	1,00	***0,54***
	Nox		**12,84**	0,75	***9,63***
	Dust		**0,10**	0,75	***0,07***
	CO		**1,81**	0,00	***0,00***
	CO2		**13 138,11**	0,00	***0,00***
	BaP		**0,00**	30 000,00	***0,00***
	Soot		**0,00**	3,75	***0,00***

Source:Brynkiewicz J., Filipkowski W. P.P.H.U. JuWa Białystok Koncepcja techniczno-ekonomiczna;,, Modernizacja systemu ciepłowniczego Sierpca polegająca na przebudowie istniejącej ciepłowni węglowej na źródło ciepła bazujące na skojarzeniowej produkcji energii cieplnej i elektrycznej uzyskanej ze spalania gazu ziemnego'' [13]

Table 13.Reduction of pollution

Substance	*Reduction [t/rok]*	*Reduction [%]*
SO2	**92,69**	**99,4**
Nox	**59,10**	**82,1**
Dust	**92,63**	**99,9**
CO	**66,03**	**97,3**
CO2	**26 243,44**	**66,6**
BaP	**0,3560**	**100,0**
Soot	**15,332**	**100,0**

Equivalent emission 10 945,06 99,91%

Source: Brynkiewicz J., Filipkowski W. P.P.H.U. JuWa Białystok Koncepcja techniczno-ekonomiczna;,, Modernizacja systemu ciepłowniczego Sierpca polegająca na przebudowie istniejącej ciepłowni węglowej na źródło ciepła bazujące na skojarzeniowej produkcji energii cieplnej i elektrycznej uzyskanej ze spalania gazu ziemnego''; [13]

3.1.8. Justification of the project:[12]

- the primary fuel in a modernized CHP plant will be natural gas which will produce 60 % of heat and 100 % of the electricity,
- a modern installation of combined heat and power based on the combustion of natural gas will be introduced,
- a designed project is in accordance with UE directives encouraging the increase in energy produced in combination in Poland
- an investment under discussion is in line with Polish energy policy to promote renewable energy sources, including the obligation to purchase heat from unconventional and renewable sources (Regulation of the Minister of Economy of January 2001)

- the technical correctness of the system will be obtained through :
  - increasing the thermal power source from 27.85 MW to 31.45 MW. This will allow to add new customers. Technological systems of boiler station and the network's size will be adjusted to the heat demand in consumers,
  - elimination of significant heat loss during transmission through the modernization of the network (as a part of the modernization the network will be made in the system of pre-insulated pipes with a correction of their bandwidth to the existing and future needs) and heat distribution centers (significant improvement in the transformation of the heating medium)
  - efficient power management and desired environmental effect resulting from a high degree of automation of thermodynamic processes and their monitoring
  - fully taking into account the issue of the system modernization, which in turn will allow to fit the size of the heat source and distribution network to a reduced demand for heat in residential and public buildings guaranteeing security of heat supply and proper settlement of the recipients.
  - elimination of local boiler stations which are a source of low-emission
- the project will bring additional benefits in the form of :
  - development of the region; it will influence the city's rank in terms of recreation and tourist attractiveness because the care for the environment and clean air would be a good marketing asset for the promotion of the region),
  - reviving the local economic activity - supplying gas to Sierpc will enable the development of small business in the city.

3.4 An existing Heating Plant in Sokołów Podlaski

District heating network of Sokołów Podlaski is led out from the city heat plant. It encompasses the major part of the city, hence the city heating system is based on it. High-temperature water boilers produce heat from common in Poland bituminous coal burning in the heat-only boiler station in Sokołów Podlaski. The boiler station in Sokołów Podlaski consists of three WR-5 water boilers, each produces 5,8 MW of heat. The all-year-round working heat generation station produces heat of the following parameters:

- output power 17,4 MW (3x5,8)
- temperature in winter: 131/58˚C
- temperature in summer: 58/42˚C

– nominal pressure: 1,6 MPa

The boilers are equipped with forced draught and dedusting system. The dedusting system consists of cyclone deduster extractor, industrial fans for each boiler and a common steel chimney of 60 meters. WR-5 boiler has a non-working sulphate removal installation. The boiler's work is hand-managed by stokers according to thermometer's readings:

3.5 Suggested solution- Sokołów Podlaski

The plant's modernization includes the WR-5 water boiler being disassembled and replaced by 1,2 MW gas boiler. The summer season and its low demand for heating will result in the gas boiler working in order to heat water in domestic hot water systems, while during heating season a designed biomass boiler will become a basic boiler and will generate heat for hot domestic water and central heating. Two existing WR-5 boilers will be peak load boilers. Also, a thermal electric power station will be constructed in the non-build-up area nearby due to the lack of place in existing building of the heat plant. The new power station will have room for biomass combustion with exhaust gas heater based on thermal oil powering the ORC operating system. The power of biomass boiler working on thermal oil is 9,97 MW. Technological system of a boiler room and a thermal electric station's work is shown in Figure 8.

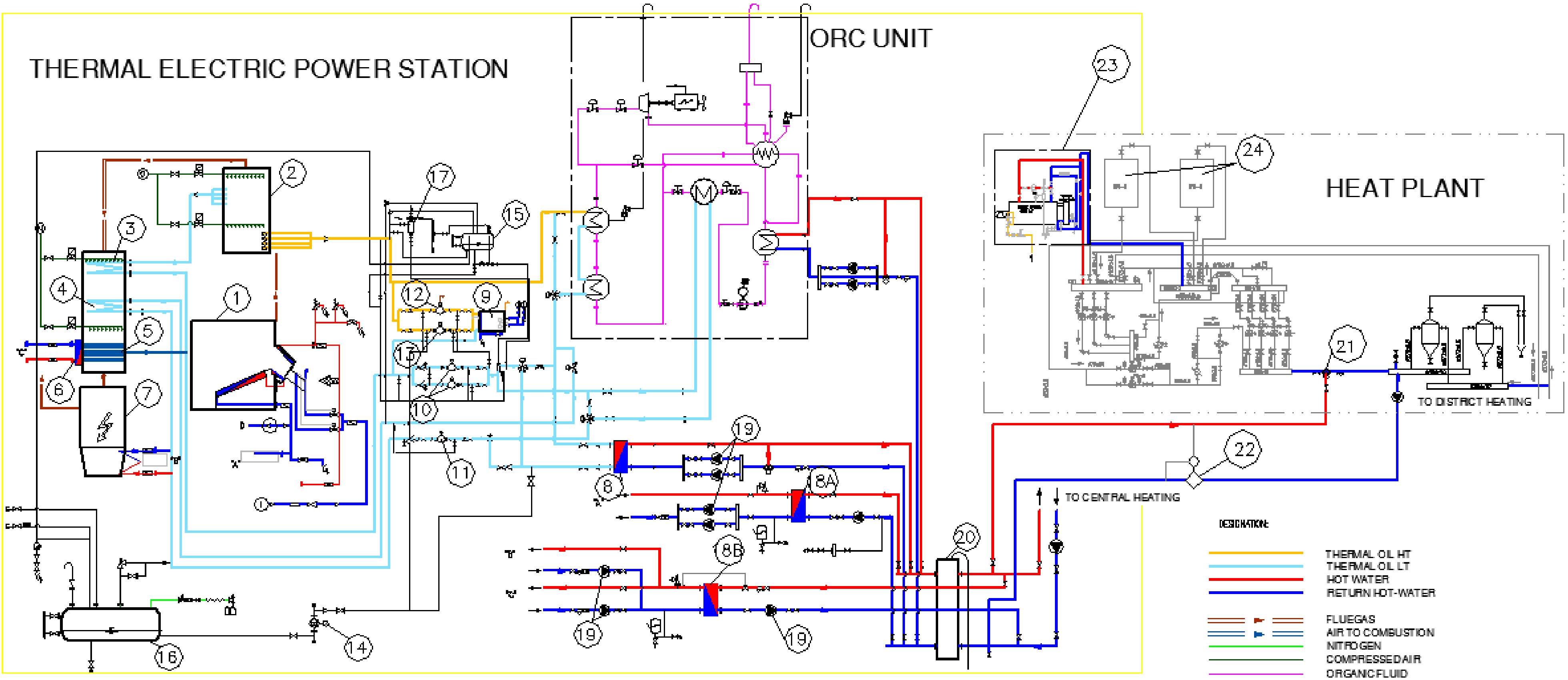


Fig.8 Technological system of Sokolow Podlaski

1-Fire box with, 2-Exhaust gas heater, 3-Economiser I fluegas/thermal oil (HT), 4-Economiser II fluegas/thermal oil (LT), 5-Fluegas/air preheater LUVO, 6-Water/air preheater, 7- Electrostatic precipitator, 8-Thermal oil/ water heat exchanger, 9-Emergency cooler, 10-Recirculation pump HT (main loop), 11-Recirculation pump LT (split- loop), 12-Recirculation pump (emergency loop, diesel drive), 13- Recirculation pump (emergency loop, electric), 14-Filling pump, 15-Expansion tank, 16-Storage tank, 17-Gas separator, 18A,18B-Heat exchanger, 19- Recirculation pump, 20-Hydraulic balance , 21-Three-way valve, 22 Ultrasonic heat meter, 23-Gas boiler, 24- WR-5 water boiler.

Source: Brynkiewicz J., Filipkowski W. Rzendzian E. Ostrowska-Bućko A. Projekt wykonawczy: ,,Budowa wysokosprawnego układu skojarzonej produkcji ciepła i energii elektrycznej w oparciu o spalanie biomasy w Sokołowie Podlaskim" 2012 P.P.H.U. „JuWa" Białystok [16]

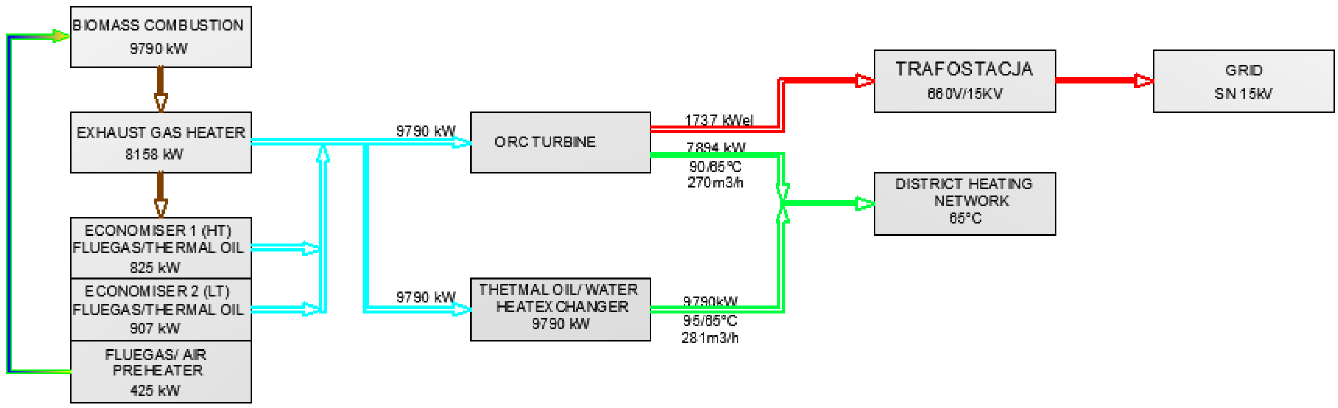
3.5.1 Technology's description

The heat generated by a heat source which is a biomass fired boiler, is directed to the thermal oil in an exhaust gas heater that is further channelled into the turbine in ORC unit. ORC installation generates electricity and low temperature heat in a closed thermodynamic cycle based on the Organic Rankine Cycle. The heat is transferred to the heating water in following elements of the system [16,17]:

- the ORC condenser - the power of 7843 kW, the parameters of the water 90/65°C and a flow of 270 m3/h
- grate cooling - the power of 315 kW, the parameters of the water 80/65°C and a flow of 35 m3/h
- thermal oil/water heat exchanger in the absence of current or partial production of electricity by the ORC system – 9790 kW maximum output, the parameters of the water 95/65°C and a flow of 281 m3/h.

Heating water piping will be included in the suction manifold circulation pumps in the existing solid fuel boiler with three-way valve.

Fig.9 Block diagram of components



Source: Brynkiewicz J., Filipkowski W. Rzendzian E. Ostrowska-Bućko A. Projekt wykonawczy: „Budowa wysokosprawnego układu skojarzonej produkcji ciepła i energii elektrycznej w oparciu o spalanie biomasy w Sokołowie Podlaskim" 2012 P.P.H.U. „JuWa" Białystok [16]

The main Components of the CHP system:

The biomass combustion furnace:

The heat source is a biomass combustion where woodchips can be burned. Specifications of biomass combustion are presented in Table No.14 [18]

Table 14. Fuel specification

Fuel specification		
Biomass types	woodchips	
Size distribution	G30 –G50	
Bulk density	200-400	kg/m3
Temperature	5–40	°C
Minimum water content	40	% of wet mass
Maximum water content	60	% of wet mass
Max. nitrogen content	0,2	%
Ash melting temperature	1100	°C

Source: Design materials from VAS [18]

Table 15. Biomass combustion specification

Biomass combustion		
Thermal output (ratet power)	9790	kW
Fuel power input	12434	kW
Continuously variable power range:	30-100	%
Cycle efficiency:	85-88	%
Max. biomass consumption:	5169	kg/h
Gas temperature fire box:	1020	°C
Exhaust gas temperature:	185	°C
Volume flow rate:	30366	mN^3/h
Combustion air	24612	kg/h
Primary air	16736	mN^3/h
Secondary air	8863	mN^3/h
Flue gas recirculation	10654	mN^3/h

Source: Design materials from VAS [18]

Biomass firing system components:

- Fire box with grate system
- Primary air fan
- Secondary air fan
- Flue gas fan
- Emergency chimney
- Hydraulic ash conveyor
- Hydraulic floor conveyor
- Chain conveyor

- Hydraulic ram feeder
- Electrostatic precipitator
- Chimney
- Ash container

Thermal oil boiler system [16,17,18]

- Exhaust gas heater (thermal output: 8158 kW, flue gas temperature 1020°/370°C, thermal oil temperature 312°/260°C)
- Economiser 1 fluegas/thermal oil (HT) (thermal output:825 kW, flue gas temperature 370°/300°C, thermal oil temperature 260°/254°C)
- Economiser 2 fluegas/thermal oil (LT) (thermal output:907 kW, flue gas temperature 300°/222°C, thermal oil temperature 254°/134°C)
- Fluegas/air preheater LUVO (thermal output: 485 kW, fluegas temperature 222°/185°C, air temperature 40/140°C)
- Water/air preheater (power 72 kW)
- Thermal oil/ water heat exchanger (thermal output: 9790 kW, water temperature 65°/102°C, thermal oil temperature 270°/202°C)
- Emergency cooler thermal oil/water (thermal output: 2234 kW, water temperature 20°C, water volume flow rate 6 m^3/h, thermal oil temperature 315°/285°C, volume flow rate 129 m^3/h)
- Recirculation pump HT (main loop) (volume flow rate 269 m^3/h, head pressure 88 m H_2O)
- Recirculation pump LT (split- loop) (volume flow rate 13 m^3/h, head pressure 27 m H_2O)
- Recirculation pump (emergency loop, diesel drive) (volume flow rate 129 m^3/h, head pressure 27 m H_2O)
- Recirculation pump (emergency loop, electric) (volume flow rate 129 m^3/h, head pressure 27 m H_2O)
- Filling pump (volume flow rate 2580 m^3/h)
- Expansion tank (volume 10134 dm^3, max. operating temperature 320°C, max. operating pressure: 0,5 bar)
- Storage tank (volume 30161 dm^3, max. operating temperature 320°C, max. operating pressure: 0,5bar)
- Gas separator (max. operating temperature 320°C, max. operating pressure: 13 bar)

3.5.2 ORC Turbogenerator

The ORC installation generates electric energy and low temperature heat in closed thermodynamic cycle. The high temperature diathermic oil is provided to ORC process. The working medium is heated in the evaporator and evaporates. Working fluid vapours drive the turbine coupled through an elastic clutch directly with the generator. Exhaust vapour from the turbine flows to the regenerator where it heats up organic liquid. Next, the vapour is condensed in the condenser, cooled by the water returning from return line of water circuit. Condensed organic liquid is finally pumped to the regenerator and partially to the interchanger of 1. and 2. degree (split) and then to the evaporator thus completing the sequence of operations in the closed-loop circuit.

The working medium in the ORC unit is Xiameter(R) from siloxane group which is characterised by advantageous thermodynamic properties.

ORC installation is designed as a circuit system in which the working medium:

1) is preheated in the preheater

2) is heated and vaporized due to heat exchange with thermal oil;

3) expands in a turbine that drives a generator;

4) is cooled (while still in the gaseous phase) in the preheater which is designed for preheating the organic medium in liquid form;

5) is condensed in a heat exchanger- condenser, which transfers heat to the water cycle;

6) is pressurised by the feed pump to the pressure required to drive the circulation.

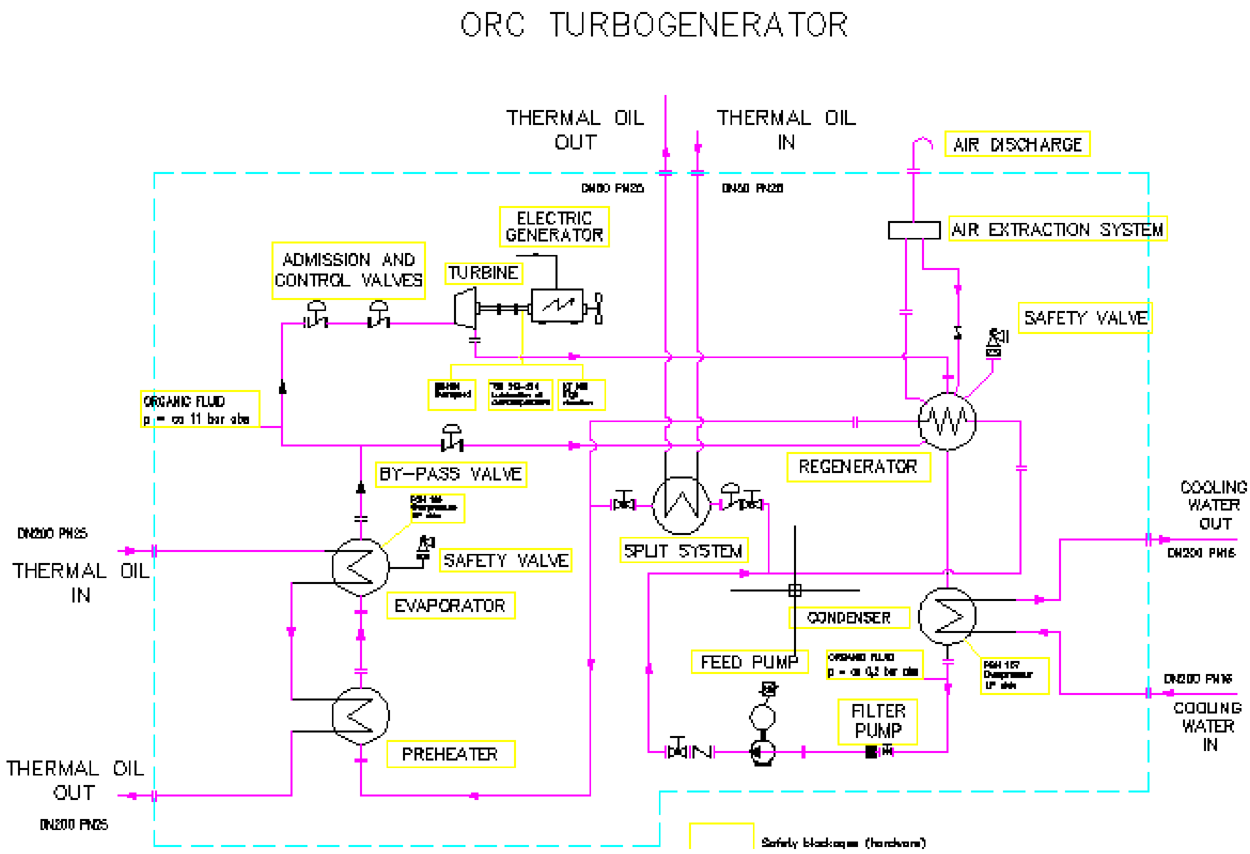


Fig.10 Scheme of the ORC

Source: Brynkiewicz J., Filipkowski W. Rzendzian E. Ostrowska-Bućko A. Projekt wykonawczy: ,,Budowa wysokosprawnego układu skojarzonej produkcji ciepła i energii elektrycznej w oparciu o spalanie biomasy w Sokołowie Podlaskim" 2012 P.P.H.U. ,,JuWa" Białystok [16]

The ORC unit's work is fully automatic and does not require supervisory personnel during both: regular operation and emergency situations. In the case of failure ORC unit is disconnected automatically from the thermal oil circuit and from the grid. In this case emergency take-off system receiving heat energy generated by the thermal oil boiler is turned on (by-pass thermal exchanger - water transferring heat directly to the district heating network).

Table 16. Parameters of 1.68 MWel ORC module

Biomass combustion	
Source of energy:)	thermal oil in a closed circuit
Operating temperature of thermal oil:	300/250 °C
Heating water temperature (inlet/outlet)::	60/80 °C
Electric power net:	1,680 kW
Heat output:	7950 kW
Electric Generator:	asynchronous, three-phase
Turbine type::	low speed, the dual stage

Source: Turboden- Organic Rankine Cycle Turbogenerators for Clean Electric Energy Production
http://www.turboden.eu/en/home/index.php [9]

ORC system is delivered as a complete module ready to use. The scope of delivery includes all the components with piping, valves and auxiliary equipment that are necessary for the proper operation of the installation [16].

- Pre-heater - in ORC pre-heater organic working medium is heated by a heat exchanger with thermal oil.
- Evaporator - in the ORC evaporator organic working medium is heated and evaporated through the removal of heat from the thermal oil.
- Regeneration heater - after leaving the turbine organic working medium vapour, in regeneration heater, directs the heat to the working medium in the form of liquid delivered by the feed pump. major part of the thermal energy contained in the vapour leaving the turbine is used to heat the working medium in liquid form.
- Condenser – in the ORC condenser the organic working medium vapour is condensed due to heat transfer to the water circuit.
- Turbine – in the turbine vapour of the organic working medium is expanded; vapour leaving the turbine is overheated.
- Generator - directly driven electric generator is connected to the turbine via a flexible coupling and is designed as a bipolar, three-phase asynchronous generator.
- The pump of working medium
- The leak control system. ORC installation is equipped with a leak control system working continuously for the detection of organic working medium during operation.

3.5.3 System heat receipt

The heat is transferred to the water network from:

- ORC condenser - the power of 7843 kW, the parameters of the water 90/65°C and a flow of270 m^3/h
- grate cooling system - the power of 315 KW, the parameters of the water 80/65°C and flow of 35 m^3/h
- exchanger thermal oil/water in the absence of current or partial production of electricity by the ORC unit - maximum output of 9790 kW, the parameters of the water 95/65°C and a flow of281 m^3/h.

To avoid the impact of the changes in the flow rates, temperatures and pressure of district heating water on the work of ORC unit and to ensure the independence of individual systems' work hydraulic coupling is used. The flow of water in the lattice water cycle through the hydraulic clutch will be enforced by the circulation pumps existing in the heat plant and the water to the hydraulic balance will be directed by three-way valve.

In order to force the hot water circulation between the condenser and hydraulic balance two vortex pumps in parallel setup were used (as ORC recirculation pump).

In order to force the hot water circulation between the thermal oil/water heat exchanger when there is no electric power consumption or when there is only partial production of power by ORC unit two centrifugal pumps were designed to work (the thermal oil/water circulation pump).

In order to maintain a minimum temperature of water flowing into the condenser of ORC unit and into thermal oil/water heat exchanger at 65°C three-way mixing valves were used.

Because of the difference in the pressure between grate combuster's cooling installation (6 bar) and lattice water network (16 bar) a brazed plate heat exchanger was used in order to separate the circuits (grate cooling heat exchanger).

Vortex pumps on the primary and secondary sides were used for the purpose of cooling the grate. As a protection of the grate cooling system there were designed both: a membrane safety valve and diaphragm expansion vessel.

3.5.4 Justification of the modernization [16, 17]:

1. The implementation of the project in Sokolow Podlaski will improve efficiency and technical reliability of the heating plant as well as the whole system.

2. The company's profitability will definitely increase. As a result, the quality of the air in the region will improve thanks to dangerous compounds' reduction.
3. The implementation of the project will ensure infallibility of the heat energy supplies by leaving fine coal boiler as a cold reserve.
4. It will serve as a peak power supply if low outside temperatures occur. A valid argument is also the fact that fine coal as well as biomass are local fuels produced within the country; it lowers the risk of cuts in fuel's supply.
5. Biomass-fired cogeneration system and a modernized fine coal boiler as a peak source will make it possible for the heating plant to keep a required thermal power (min. 20 MW) and to sell CO_2 surpluses. It will give the company additional income of about 1 mln PLN every year [19].

Table 17.Emissions

Type of pollution	State before modernization	State after modernization	Reduction of pollution	
	Emission [Mg/rok]		Mg/rok	%
SO_2	73,89	15,076	79,53	84,06%
NOx	30,8	12,045	27,37	69,44%
Dust	207,8	23,665	239,18	91,00%
CO	77	50,69	47,86	48,56%
CO_2	16 163,00	2 004,35	18 690,94	90,31%
BaP	0,01	0,001	0,01	95,00%
Soot	0,37	0,79	-0,31	-65,50%

Source: Żendzian E. Ostrowska-Bućko A. Brynkiewicz J., Filipkowski W. Projekt Technologiczny, ,,Budowa wysokosprawnego układu skojarzonej produkcji ciepła I energii elektrycznej w oparciu o spalanie biomasy w Sokołowie Podlaskim'' 2011 P.P.H.U. „JuWa" Białystok; [19]

3.5.5 Summary

The implementation of cogeneration system based on heating system have advantages as follows [9,10,17]:

– better utilization of primary energy
– lower emission of pollution in comparison to existing coal-based heat-only boiler station -
– prolonged time of utilization of fossil fuels

- no need for extension of existing transmission network
- chance for quick increase in generating capacity (possibility to produce a few thousand Mega Watts of electric power in full cogeneration in existing heating systems)
- obligation to connect buildings to a heating system powered by cogeneration sources, where 75% of heat is produced by high-efficient cogeneration
- diversification of the income companies dealing with heating systems and the chance to improve their financial results.

4. Conclusion

1. The implementation of cogeneration techniques into existing district heating systems based on the coal combustion is an action that allows to adjust the Polish district heating to changing conditions and at the same time enables development.
2. .Available on the market cogeneration technologies can be used in any heating system regardless of the temperature characteristics .
3. The best effect is achieved through cogeneration units that use a heating system for the production of electricity and allow to introduce this electricity as a leading product of the company.
4. The technology of cogeneration should be considered separately for each heating system . The thermal loads and parameters of the heating system as well as the availability of fuel should be examined in detail.
5. The use of cogeneration systems increase the efficiency and technical reliability of existing Heating Plants and the whole system . This helps to ensure security of supply of thermal energy and allows to connect new customers, which currently, due to the condition of the boiler, is impossible.
6. The main advantages offered by the CHP are following:
    - the global saving of fuels' chemical energy as well as reduction of emissions (in relation to the distribution economy implemented in condensing power plants and boiler houses,
    - reduction of the cost of providing the objects in heat and electrical energy
7. The implementation of the cogeneration system of small power in a heat plant can improve the parameters in the plant's operation during periods of low heat loads. [20]

8. Small cogeneration systems are mostly based on gas fuels. The installations using liquid fuels are rarely adopted due to the higher cost of fuel (eg of diesel) and a difficult exploitation similar to the exploitation of coal (transport and storage, higher levels of pollutant emissions , etc.)
9. The use of gas fuels increased flexibility of energy systems, reduced a size of the devices, eliminated the need for cumbersome transport and for fuel storage. In addition, gas-powered cogeneration systems have a positive impact on reducing global emissions caused by energy systems .

References:

1. DIRECTIVE 2004/8/EC OF THE EUROPEAN PARLLAMENT AND OF THE COUNCIL of 11 February 2004 on the promotion of cogeneration based a useful heat in the internal energy market and amending Directive 92/42/EE
2. Kiciński J., Lampart P., Institute of Fluid Flow Machinery, Polish Academy of Sciences: Cogeneration in large and small scale; http://www.imp.gda.pl/bioenergy/a/busines/Cogeneration.pdf
3. Figat K., Przedsiębiorstwo Energetyczne w Siedlcach Sp. z o.o. ,Stowarzyszenie Niezależnych Wytwórców Energii Skojarzonej :,,Kogeneracja- optymalizacja doboru technologii szansą rozwoju przedsiębiorstwa Ciepłowniczego. Dylematy przedsiębiorstw ciepłowniczych;http://www.snwes.pl/files/KOGENERACJA__OPTYMALIZACJA_DOBORU_TECHNOLOGII_SZANSA_ROZWOJU_PRZEDSIEBIORSTWA_CIEPLOWNICZEGO.pdf
4. Nuorkivi A.BASREC: Podręcznik dla instytucji o CHP oraz DH. Dokument udostępniony przez: Krajową. Agencję. Poszanowania Energii S.A. http://www.kape.gov.pl/PL/Dzialalnosc/Energetyka/CHP_DH_dla_instytucji.pdf
5. Grzesiek A. ;Układy kogeneracyjne. Doświadczenia z wdrażania i eksploatacji. „Energetyka Cieplna i Zawodowa" - nr 5/2010
6. Skorek J., Kalina J., Gazowe układy kogeneracyjne, Wydawnictwo Naukowo-Techniczne Warszawa 2005
7. Klonowicz W.,Hanausek P.,,General conditions affecting the ORC technology design when applied to the electricity generation of electricity generation'', In Heat Transfer and Renewable Sources Energy, Eds: Stachel A.A., Mikielewicz 2012

8. Wojciechowski H.: Układy kogeneracyjne z organicznym obiegiem Rankine'a wykorzystujące biomasę Politechnika Wrocławska; http://old.cieplej.pl/prezentacje/doe2004/MENU/IV_EDOE/2_dzien/pdf/4.pdf
9. Turboden- Organic Rankine Cycle Turbogenerators for Clean Electric Energy Production http://www.turboden.eu/en/home/index.php
10. Riccardo Vescovo: ORC recovering industrial heat- power generation from waste energy streams. Cogeneration & On-Site Power Production Magazine, Volume 10 Number 2 March - April 2009
11. Roberto Bini, Marco Di Prima, Alessandro Guercio; Organic Rankine Cycle (ORC) in biomass plants: an overview on different applications; 2010; http://www.turboden.eu/en/public/downloads/10A02943_paper_marco.pdf
12. Brynkiewicz J., Filipkowski W. P.P.H.U. JuWa Białystok Projekt budowlany,, Przebudowa ciepłowni węglowej na źródło ciepła bazujące na skojarzeniowej produkcji energii cieplnej i elektrycznej opartej na paliwie gazowym'' 2012
13. Brynkiewicz J., Filipkowski W. P.P.H.U. JuWa Białystok Koncepcja techniczno-ekonomiczna;,, Modernizacja systemu ciepłowniczego Sierpca polegająca na przebudowie istniejącej ciepłowni węglowej na źródło ciepła bazujące na skojarzeniowej produkcji energii cieplnej i elektrycznej uzyskanej ze spalania gazu ziemnego'' 2011
14. Design materials from Guascor Power;
http://www.guascor.com/guascor_eng/sistemas_potencia.php
15. Design materials from Viessmann http://www.schematy.info/
16. Żendzian E. Ostrowska-Bućko A. Brynkiewicz J., Filipkowski W. Projekt wykonawczy: ,,Budowa wysokosprawnego układu skojarzonej produkcji ciepła i energii elektrycznej w oparciu o spalanie biomasy w Sokołowie Podlaskim" 2012 P.P.H.U. „JuWa" Białystok
17. Ostrowska-Bućko A, ,,The modernisation of heat generating plant in Sokołów Podlaski as an example of combined heat and power installation based on ORC'', Monographs:,,Environmental engineering-trough a young eye''Vol.3 Białystok 2013
18. Design materials from VAS www.vas.co.at
19. Żendzian E. Ostrowska-Bućko A. Brynkiewicz J., Filipkowski W. Projekt Technologiczny, ,,Budowa wysokosprawnego układu skojarzonej produkcji ciepła I energii elektrycznej w oparciu o spalanie biomasy w Sokołowie Podlaskim'' 2011 P.P.H.U. „JuWa" Białystok

20. Kalina J., Skorek J.:Analiza Techniczno-ekonomiczna opłacalności nadbudowy elektrociepłowni parowej turbiną gazową i kotłem odzyskowym, Materiały IV Krajowej Konferencji Gazterm 2001, Międzyzdroje 2001

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Changes of quantitative and qualitative parameters of wastewater treatment plant in Stawiski

Key words: *sewage treatment plant, organic pollutants, efficiency, domestic waste water*

Abstract: The purpose of this paper was to present the quality and quantitative parameter changes of raw and treated sewage in water treatment plant in Stawiski and evaluation of its efficiency, in the years 2005 – 2013. Mechanical- biological treatment plant in Stawiski, in accordance with Annex 1 to the Regulation of the Minister of Environment from 24 July 2006, belongs to the second class of objects (2000 - 9999 PE). The results of raw sewage and treated were analyzed. On this basis the efficiency of wastewater treatment plants, loads of pollutants in the raw wastewater has been determined. In addition, statistical analysis was performed with a view to identify changes determinants in concentrations and removal effects of the tested components. Average removing effect for individual analyzed components in the studied period, amounted to 98.1% for BOD_5, 92.2% for COD_{Cr}, and 96.1% for suspensions.

5. Introduction

Continuous effectiveness observation of the technological process is one of the basic elements of sanitation infrastructure and its impact on the environment control method. Particularly important in this case is aqueous environment. Very often treated sewage receivers are small watercourses which, because of their specificity, are the most vulnerable to changes of chemical and biological components [5, 6].

It is worth mentioning that treated wastewater, discharged from small sewage treatment plants (10,000 PE) located in rural areas [12]. Inadequately treated sewage from rural areas can transport to the water inter alia oversize loads of nutrients, causing eutrophication of the receiver [9].

Mechanical - biological treatment plants must meet the requirements of treated waste water. Acceptable values of pollutants in the wastewater discharged from facilities in Poland is regulated by the Regulation of the Minister of Environment in 2006 and 2009 [11]. Table 1 shows the maximum values of pollutants in waste water discharged to the receivers and the minimum percentages of pollutant reduction. Sewage treatment plants are disunited with respect to PE (population equivalent).

6. Characteristic of sewage treatment plant in Stawiski

Municipal sewage treatment plant in Stawiski purifies domestic waste water which inflows from gravity sewer system. At the sewage treatment plant there is a storage point for sewage from municipality area. Capacity of the plant was designed for the following volumes of wastewater:

-hourly maximum flow- 30,82 $m^3 \cdot h^{-1}$

-daily average flow -370 $m^3 \cdot h^{-1}$

-maximum daily flow -554 $m^3 \cdot h^{-1}$

-maximum flow for year - 202210 $m^3 \cdot year^{-1}$

Domestic waste water transported from the community of Stawiski are delivered to the storage point (two concrete chambers equipped with gratings), from where sewage are getting to wastewater treatment plant technological system. Waste water from the city of Stawiski runs through gravity sewer system to two sewage pumping stations, located on Dluga and Ogrodowa Street, from where they are pressed into the expansion chamber - a tank of rectangular base. Then the sewage flows to the radial sand trap, where the removal of solids is performed. From radial sand trap wastewater flow to the anaerobic chamber equipped with a horizontal stirrer, whose task is the selection for metabolic filamentous bacteria and the initial phase of biological phosphorus removal [8].

Table 1. Maximum pollutant values or minimum percentages of pollutants reduction in treated waste water for domestic and municipal waste relased into water and soil

No.	Indicator	Unit	Maximum pollutant values or minimum percentages of pollutants reduction for PE				
			I	II	III	IV	V
			under 2.000	from 2.000 to 9.999	from 10.000 to 14.999	from 15.000 to 99.999	100.000 and over
1.	Five Day Biochemical Oxygene Demand (BOD_5)	$mgO_2 \cdot dm^{-3}$	40	25	25	15	15
		min. % reduction	-	70-90	70-90	90	90
2.	Chemical Oxygene Demand by dichromiate (COD_{Cr})	$mgO_2 \cdot dm^{-3}$	150	125	125	125	125
		min. % reduction	-	75	75	75	75
3.	Overall Suspension	$mg \cdot dm^{-3}$	50	35	35	35	35
		min. % reduction	-	90	90	90	90

4.	Total Nitrogen (sum: $N_{Kj}=N_{org}$+N-NH_4, N-NO_3, N-NO_2)	$mgN\cdot dm^{-3}$	Indicators standardized only in cases of discharge to lakes	15	10
		min. % reduction		80	85
5.	Total Phosphorus	$mgP\cdot dm^{-3}$		2	1
		min. % reduction		85	90

Source: Rozporządzenie Ministra Środowiska… 2009

After phosphorus removal, sewage flows into the first aerobic chamber in which occurs aeration process via diffusers disk with a diameter of 270 mm powered by side-channel fan of type SC40C with 7.5 kW motor, with a capacity of 300 m^3/h and overpressure equal to 300 mbar. Air demand is adjusted on the basis of readings obtained from oxygen probe SENCO type IOMm, sensor SENCO OS-8t processes signal on the measured value. From the first aeration chamber sewage flows into the second aeration chamber. The chamber is equipped in such disk diffusers, as in the first aeration chamber. After the aeration process flows to secondary settling tanks, from which are discharged through larval with combs to control well. From the control well sewage flows into measuring device (electromagnetic flow meter MPP04), where the current quantity of treated sewage discharged into a drainage ditch is registered [8]. From second aeration chamber sludge is recirculated to anaerobic chamber and to first aeration chamber with usage of INFRA200TEKO pump.. External recirculation of sludge from the secondary settling tanks to the aeration chamber is carried out by airlift pumps. In contrast, the removal of excess sludge from the second aeration chamber is followed by a INFRA100TEKO pump. Excess sludge is directed to sludge stabilization chambers, where it is aerobically stabilized and concentrated. It is then dewatered on a belt press type MONOBELT NP08CK, from where it goes to the sludge drying beds. Sewage treatment plant in Stawiski has four sludge drying beds made of concrete, insulated by izolbet [8].

Figure 1. Anaerobic chamber

Source: Own elaboration

Figure 2. First aerobic chamber

Source: Own elaboration

Figure 3. Second aerobic chamber

Źródło: Own elaboration

Figure 4. Sludge stabilization chamber

Source: Own elaboration

Sludge dewatering takes place in the period from November to April. In the rest of the year sludge goes to cane lagoon, which bottom and sides are lined with foil of thickness equal to 0.5 mm. At the lagoon bottom, there are located drainage pipes and filtration layer.

Filtration layer consists of the following fractions: 20 - 63 mm - 25 cm thick; 2.4 - 6.8 mm - 20 cm thick, friable sand with a thickness of 25 cm [8].

Figure 5. Belt press

Source: Own elaboration

The sand has been planted with cane in amount of 25 pieces per 1 m^2. Arranged drainage pipes are connected with a aggregate well. Dewatered sludge, after positive test results, is used to fertilize the soil intended for purposes other than farming in accordance with Decision no. BŚ.6233.8.2011 [8].

According to Annex 1 of the Regulation of the Minister of Environment of 24 July 2006 (Dz. U. 137 poz. 984 with subsequent amendments) maximum values of pollutants for wastewater treatment plants in Stawiski, whose PE is in the range of 2000 – 9999, amounting to 2630, may not exceed the following values:

- BOD_5 - 25 $mgO_2 \cdot dm^{-3}$
- COD_{Cr} - 125 $mgO_2 \cdot dm^{-3}$
- Overall suspension- 35 $mg \cdot dm^{-3}$

7. Area and method of study

The study was conducted in the years 2005 - 2013 in samples of raw and treated sewage, collected in sewage treatment plants in Stawiski (PE = 2630). Facility elected to the research is comprised in second group of sewage treatment plants (Table 1), by classification of Regulation of the Minister of Environment [11]. Mechanical-biological treatment plant in Stawiski is an object that works in flow technology.

Studies of raw and treated sewage were performed 2 times a year, in June and December, in the years 2005-2013 by the Regional Inspectorate for Environmental Protection Delegation in Lomza. The analyzes included:

- COD_{Cr} – in accordance to PN-ISO 15705:2005
- BOD_5 – in accordance to PN-EN 1899-1:2002 and PN-EN 1899-2:2002,
- Overall Suspension – in accordance to PN-EN 872:2007,
- Sewage inflow- electromagnetic flow meter MPP04

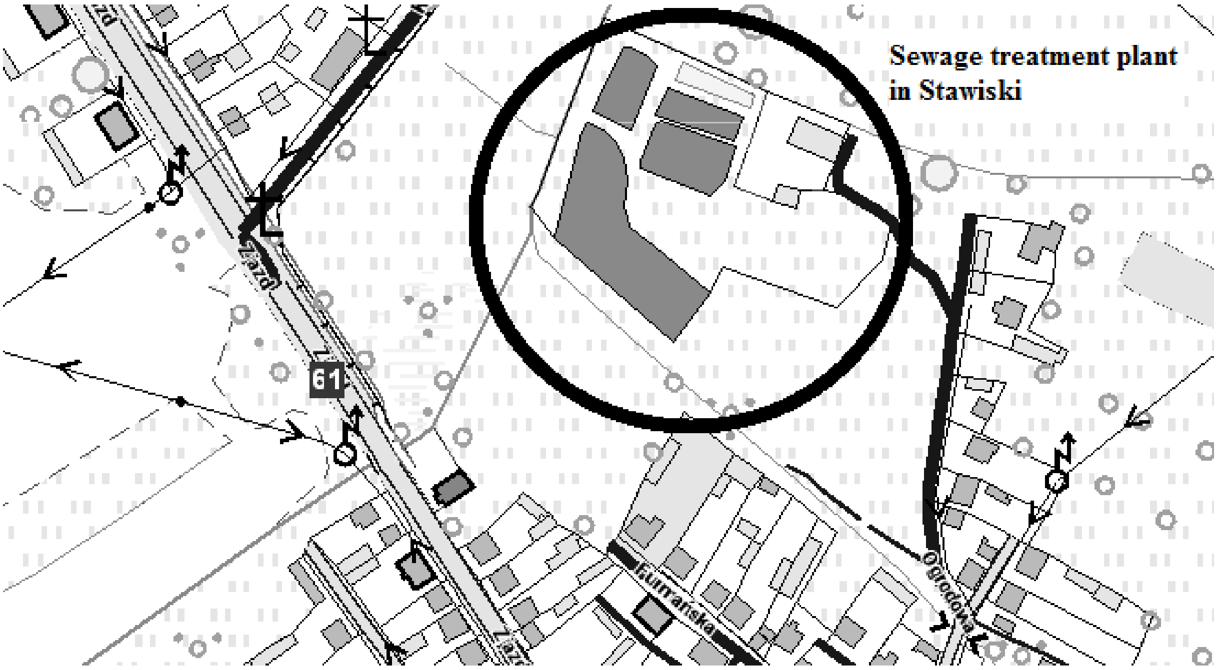


Figure 6. Municipal Wastewater Treatment Plant in Stawiski

Source: www.geoportal.gov.pl

On the basis of obtained result standard deviations, arithmetic mean, median, minimum, maximum values and parametric Pearson and non-parametric Spearman correlation coefficients were calculated. Calculations carried out using STATISTICA 10

Loads of each analyzed component was determined by the following equation [2]

$$Ł = Q_{śr} \cdot S_r$$

where:

Ł – component load [kg· month^{-1}]

$Q_{śr}$- average monthly sewage flow [m^3·month^{-1}]

S_r- value or concentration of component [g·m^{-3}]

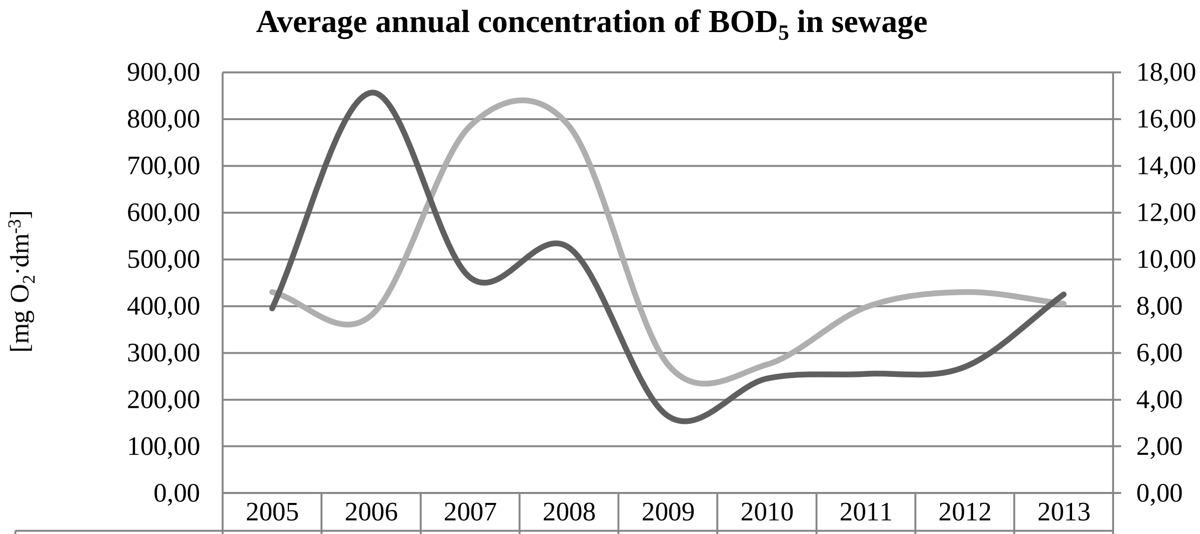
8. Study results and discussion

The studies results are presented in figures from 7 to 11.

The average value of BOD_5 (Fig. 7) was characterized by high volatility during research period. The highest BOD_5 in the raw sewage was observed in 2007 and 2008, which amounted to 785 mg $O_2 \cdot dm^{-3}$. In contrast, the lowest average annual BOD_5 value equal to 275 $mgO_2 \cdot dm^{-3}$, was recorded in 2009 and 2010. In other years, the average value of BOD_5 remained at a level close to 400 $mgO_2 \cdot dm^{-3}$.

The average annual value of BOD_5 in treated sewage, similarly to raw sewage, was characterized by high volatility. The maximum annual average value of BOD_5 in treated sewage- 17.1 $mgO_2 \cdot dm^{-3}$, was observed in 2006, while the lowest, 3.3 $mgO_2 \cdot dm^{-3}$, was observed in 2009. The rest of study period BOD_5 subject to fluctuations ranging from 4.9 to 10.5 $mgO_2 \cdot dm^{-3}$.

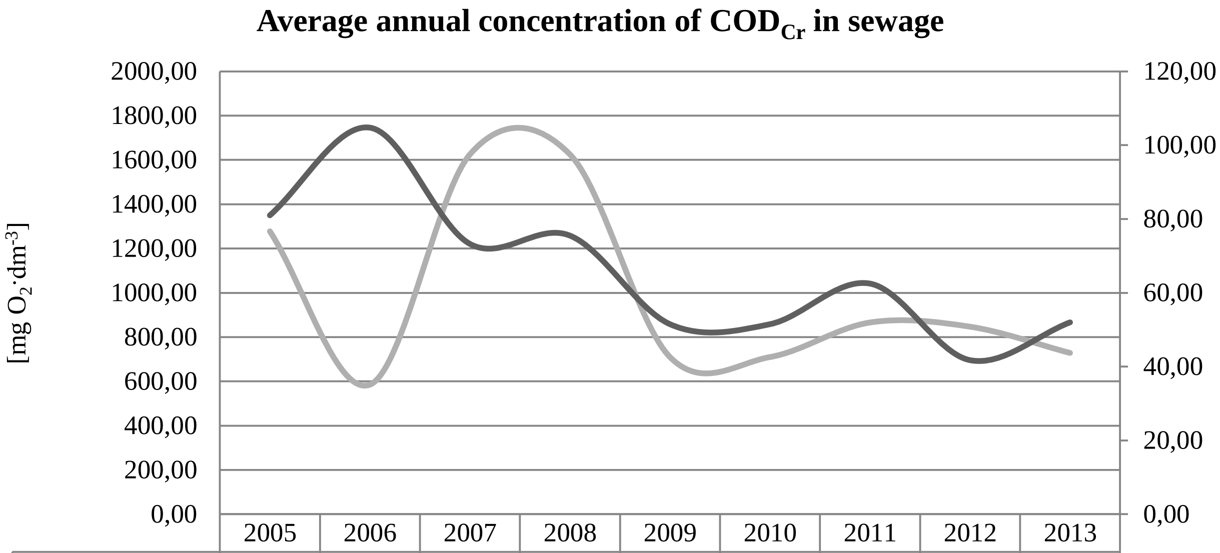
Average annual value of COD_{Cr} in study period from 2005 up to 2013 is shown in Figure 8. COD_{Cr} concentration was characterized by extreme volatility. The highest value of COD_{Cr} in raw sewage was observed in 2007 and 2008. It amounted to 1625 $mgO_2 \cdot dm^{-3}$. The lowest value of COD_{Cr}, amounting to 710 $mgO_2 \cdot dm^{-3}$, was observed in 2009 and 2010. In the rest of research period average CODCr value ranged from 728.5 to 1277.8 $mgO_2 \cdot dm^{-3}$.



	2005	2006	2007	2008	2009	2010	2011	2012	2013
BOD raw	430,00	380,00	785,00	785,00	275,00	275,00	397,50	430,00	405,00
BOD treated	7,90	17,13	9,23	10,50	3,30	4,90	5,10	5,40	8,50

Figure 7. The average annual value of BOD_5 in raw and treated sewage

Source: Own elaboration on ZGKiM data basis



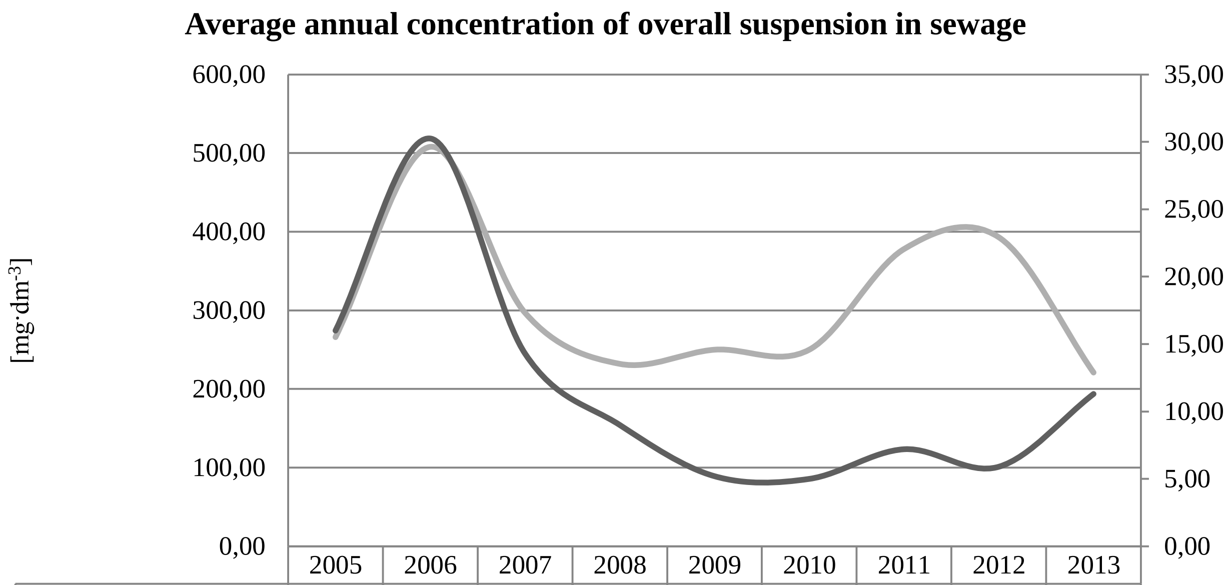
	2005	2006	2007	2008	2009	2010	2011	2012	2013
COD raw	1277,75	585,25	1625,00	1625,00	710,00	710,00	866,00	847,00	728,50
COD treated	81,00	104,75	73,25	75,50	51,50	51,50	62,50	41,75	52,00

Figure 8. The average annual value of COD_{Cr} in raw and treated sewage

Source: Own elaboration on ZGKiM data basis

The mean concentration of overall suspension during the analyzed period is shown in figure 9. Just as the average value of BOD_5 and COD_{Cr} concentration of overall suspension was characterized by high volatility in the years 2005-2013. Highest concentration of overall suspension in the raw sewage was observed in 2006 and was to 508 mg·dm^{-3}. The lowest concentration of this parameter, at the level of 221 mg·dm^{-3}, was observed in 2013. In the rest of study period the concentration of overall suspension was varied in the range from 232 to 393 mg·dm^{-3}.

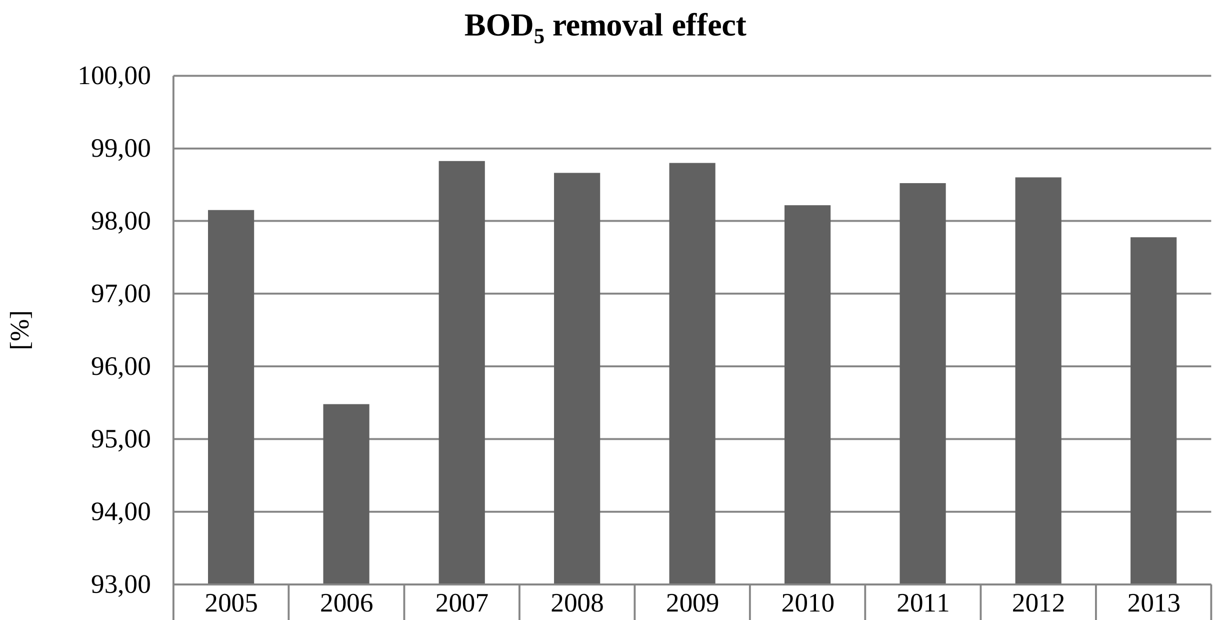
The mean concentration of overall suspension in treated wastewater, as in the case of CODCr, was characterized by a downward changes trend. Maximum concentration of overall suspension in treated wastewater was observed in 2006 itwas equal to 30.3 mg·dm^{-3}, while the lowest concentration, of 5 mg·dm^{-3} was observed in 2010. In the remaining years of research concentration of overall suspension ranged from 5.2 to 16 mg·dm^{-3}.



	2005	2006	2007	2008	2009	2010	2011	2012	2013
Suspension raw	266,00	508,00	297,00	232,00	250,00	250,00	378,00	393,00	221,00
Suspension treated	16,00	30,25	14,30	9,00	5,20	5,00	7,20	5,90	11,30

Figure 9. The average annual value of overall Suspension in raw and treated sewage

Source: Own elaboration on ZGKiM data basis



	2005	2006	2007	2008	2009	2010	2011	2012	2013
BOD effect	98,15	95,48	98,82	98,66	98,80	98,22	98,52	98,60	97,78

Figure 10. BOD_5 removal effect in the years 2005-2013

Source: Own elaboration on ZGKiM data basis

The average BOD_5 removing effect, shown in figure 10 , was characterized by a linear changes trend. Based on the carried out results and calculations it can be seen that the lowest effect for impurities, characterized as BOD_5, removal was observed in 2006. It was less than 95.5 %, while the highest- more than 98.8 % was observed in 2007. For the rest of study period efficiency of wastewater treatment plants for BOD_5 removal remained at a level close to 98% and did not vary significantly. It is worth mentioning that period of the lowest efficiency of BOD_5 removal in wastewater treatment plants in Stawiski coincides with the highest observed values of this parameter in the raw sewage flowing into the treatment plant. Observed effect of BOD_5 removal from wastewater was similar to that exhibited by Chmielowski and Śliwowski in 2009 [3], ranging from 96.4 to 99.8%.

The average COD_{Cr} removal effect is shown in figure 11 it was characterized by analogy, in relation to BOD_5 changes trend. On the basis of obtained results it can be concluded that the lowest impurities removal effect characterized for CODCr was observed in 2006. It was then less than 81%. In contrast, the highest removal efficiency for CODCr, was equal to 95.5% in 2007. In the rest of study period, the efficiency of the sewage treatment plant for removal COD_{Cr} was ranging from 92.7 to 95.4%.

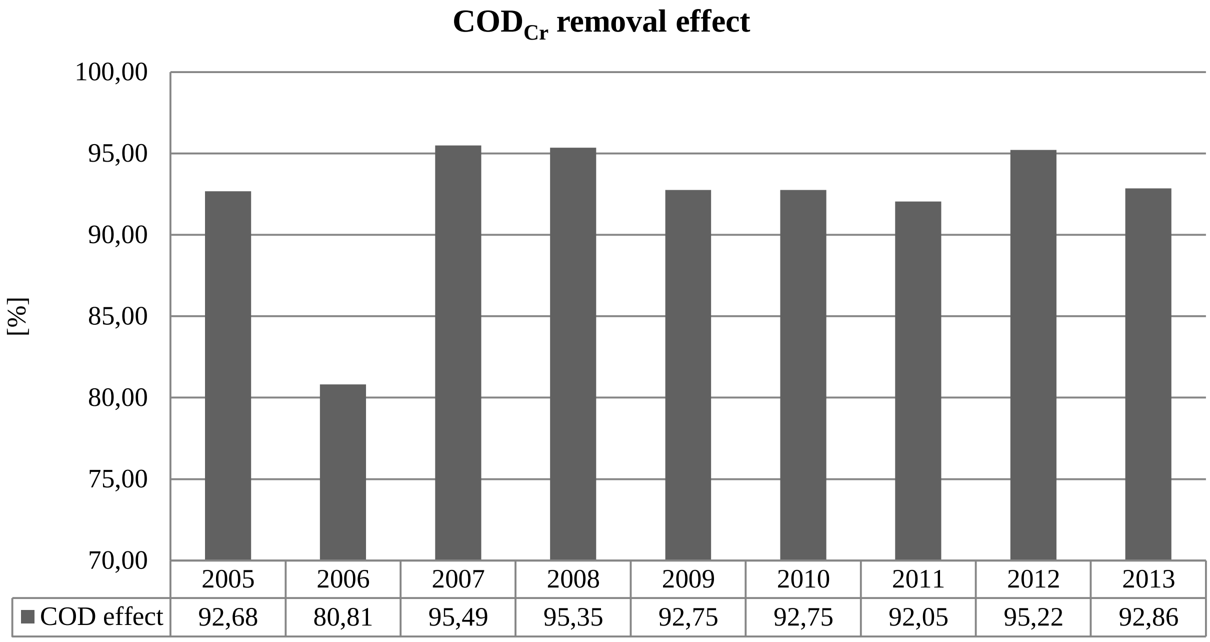
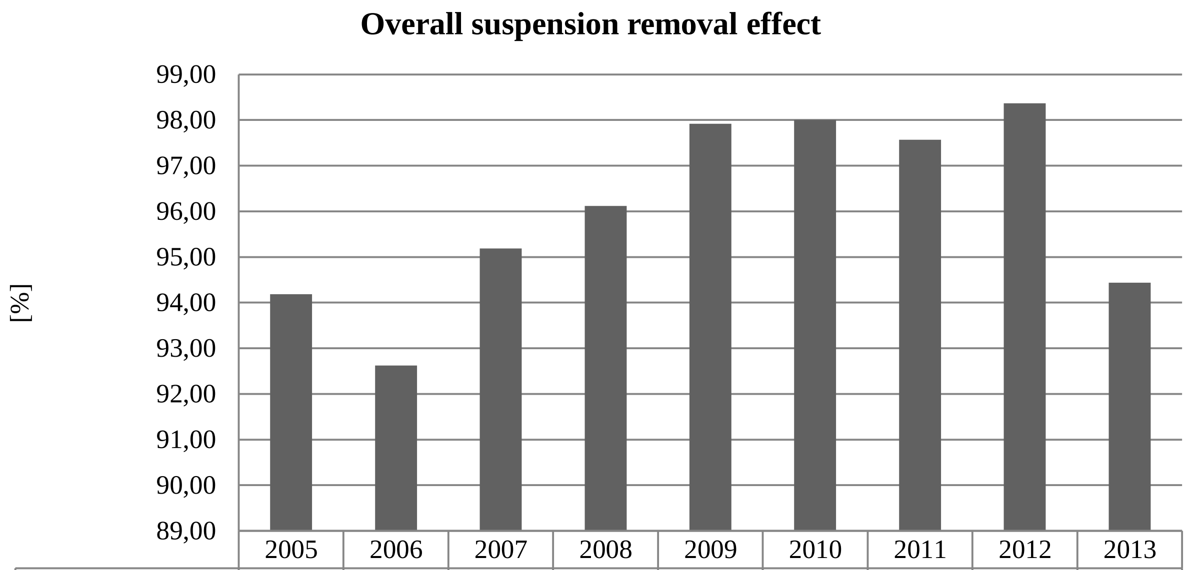


Figure 11. COD_{Cr} removal effect in the years 2005-2013

Source: Own elaboration on ZGKiM data basis

Lower removal efficiency of COD_{Cr} from wastewater in mechanical - biological treatment plant was reported by Bojanowska and Pepliński, 2002 [1]. In results presented by authors average COD_{Cr} removal effect was approximately 92%.

Average effect of removing overall suspension, presented in figure 12, was characterized by a increasing changes trend.



	2005	2006	2007	2008	2009	2010	2011	2012	2013
Suspension effect	94,19	92,62	95,19	96,12	97,92	98,00	97,57	98,37	94,44

Figure 12. Overall suspension removal effect in the years 2005-2013

Source: Own elaboration on ZGKiM data basis

On the basis of obtained results it can be stated that the lowest removal effect of overall suspensions from wastewater was obtained in 2006, which amounted to just over 92.6%. Overall suspension was removed from wastewater with the greatest effect in 2012, which then was close to 98.4%. Other average removal for overall suspension wastewater treatment plants in Stawiski in example for 2005, 2013 and 2007-2011, ranged from 94.2% to 98%. Period of the lowest removal efficiency for overall suspension, as in the case of BOD_5 and COD_{Cr} falls within the period of greatest concentration of these impurities in raw wastewater.

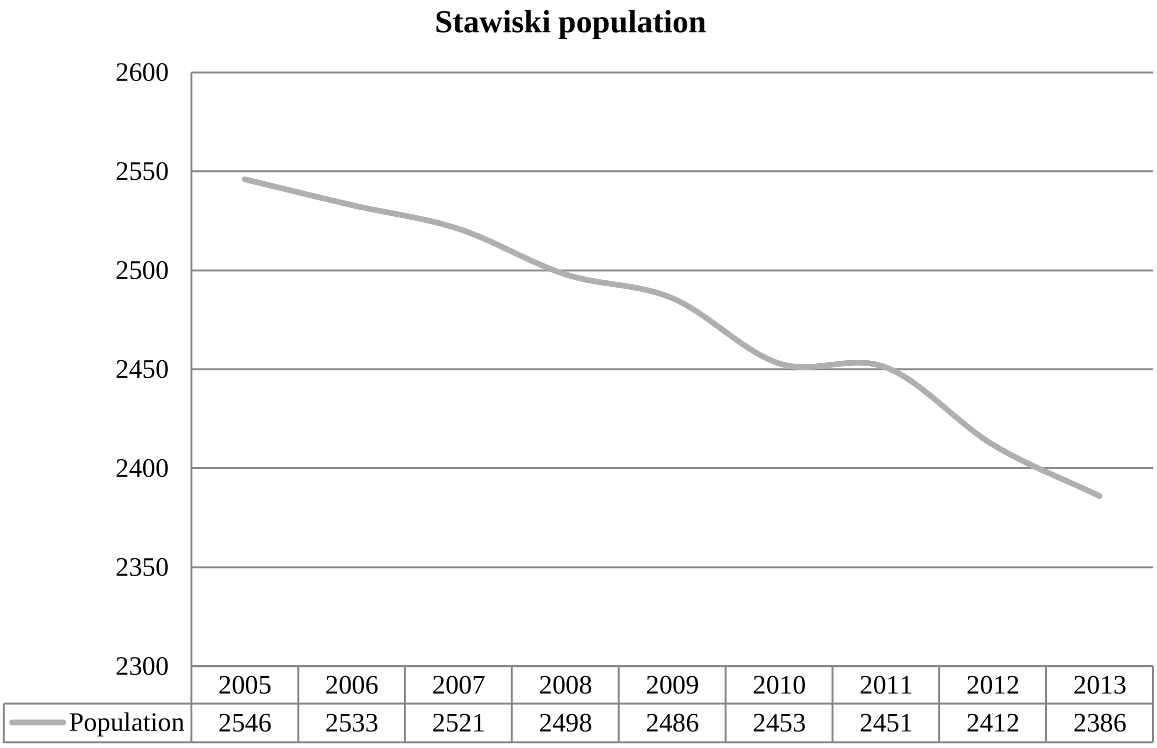


Figure 13. Stawiski population in years 2005- 2013

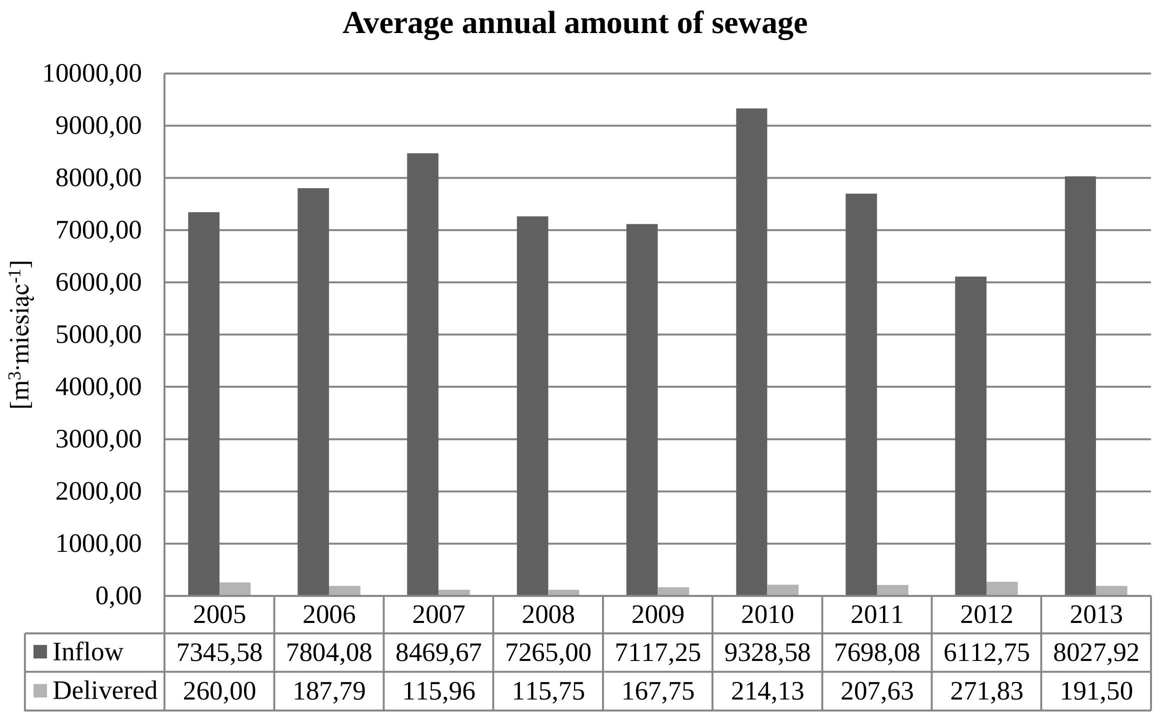
Source: Own elaboration on UM Stawiski data basis

Population of Stawiski (Fig. 13) in each subsequent year of study was decreasing. Most people lived in Stawiski in 2005 (2,546 people), and the least in 2013 (2,386 people).

The average annual volume of wastewater (Fig. 14) inflowing from gravity sewer system in the study period was very different and did not depend on the number of Stawiski inhabitants. The largest inflow of sewage, amounting to 9328.58 $m^3 \cdot month^{-1}$ was observed in 2010, and the lowest in 2012, which was equal to 6112.75 $m^3 \cdot month^{-1}$. A similar situation was observed in case of sewage brought to wastewater treatment plant by septic tankers. The largest volume of sewage delivered to treatment septic tanker of 271,83 $m^3 \cdot month^{-1}$ was recorded in 2012, and the lowest in 2008, equal to 115.76 $m^3 \cdot month^{-1}$.

The average BOD_5 load of inflowing wastewater to the treatment plant in Stawiski, shown in Figure 15, as the value of BOD5 in inflow (Fig. 7), did not show a uniform changes trend. In variation of BOD_5 load, maximum was observed in 2007. It was then 18.22 $kg \cdot d^{-1}$. In contrast, the smallest load of BOD_5 in raw sewage was observed in 2009, when reached the level of 5.36 $kg \cdot d^{-1}$. The calculated minimum and maximum load of BOD_5 coincides with maximum and minimum value of BOD_5 in raw wastewater.

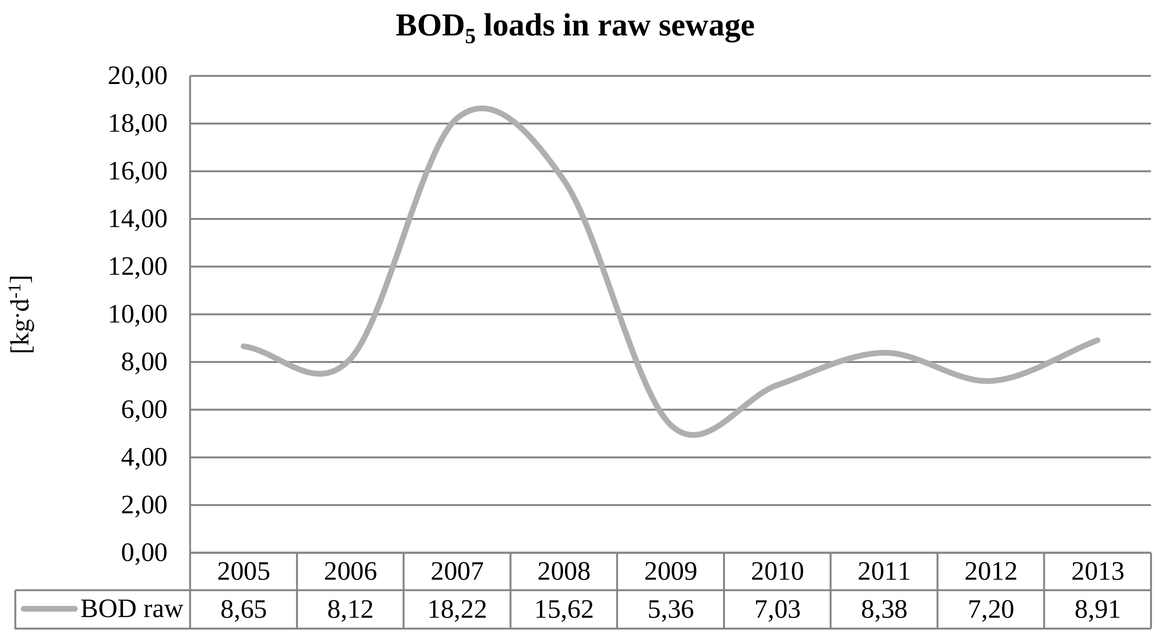
Comparing data on the number of residents in Stawiski (Fig. 13) with obtained BOD_5 loads there cannot be concluded a significant effect of population on average BOD_5 load in raw wastewater inflowing to wastewater treatment plant from city.



	2005	2006	2007	2008	2009	2010	2011	2012	2013
Inflow	7345,58	7804,08	8469,67	7265,00	7117,25	9328,58	7698,08	6112,75	8027,92
Delivered	260,00	187,79	115,96	115,75	167,75	214,13	207,63	271,83	191,50

Figure 14. The average annual volume of raw sewage in the years 2005 - 2013

Source: Own elaboration on ZGKiM data basis



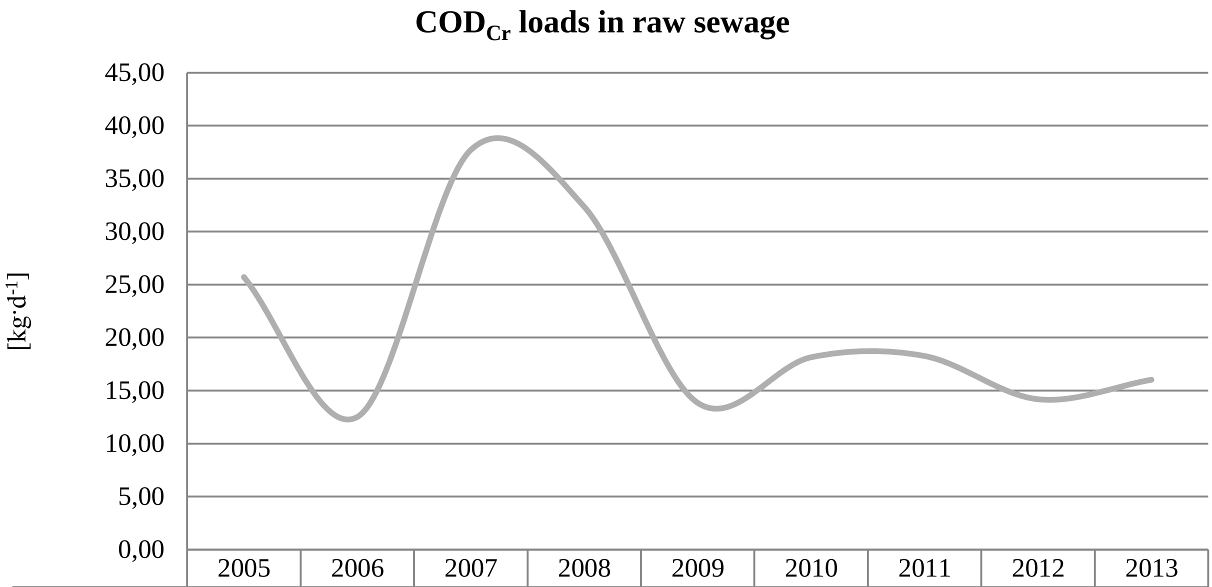
	2005	2006	2007	2008	2009	2010	2011	2012	2013
BOD raw	8,65	8,12	18,22	15,62	5,36	7,03	8,38	7,20	8,91

Figure 15. BOD_5 load in raw sewage in the years 2005-2013

Source: Own elaboration on ZGKiM data basis

The average COD_{Cr} load (Fig. 16) of sewage inflowing into the treatment plant, like the value of this component in the raw wastewater, was characterized by the same changes trend, as in the case of BOD_5 load. In the course of CODCr load variation, maximum was observed in 2007, which was equal to 37.71 $kg \cdot d^{-1}$ and a minimum in 2009, which amounted to 13.84 kg·d^{-1}. The resulting minimum and maximum pollutants loads of COD_{Cr} coincides with the maximum and minimum value of COD_{Cr} in raw sewage.

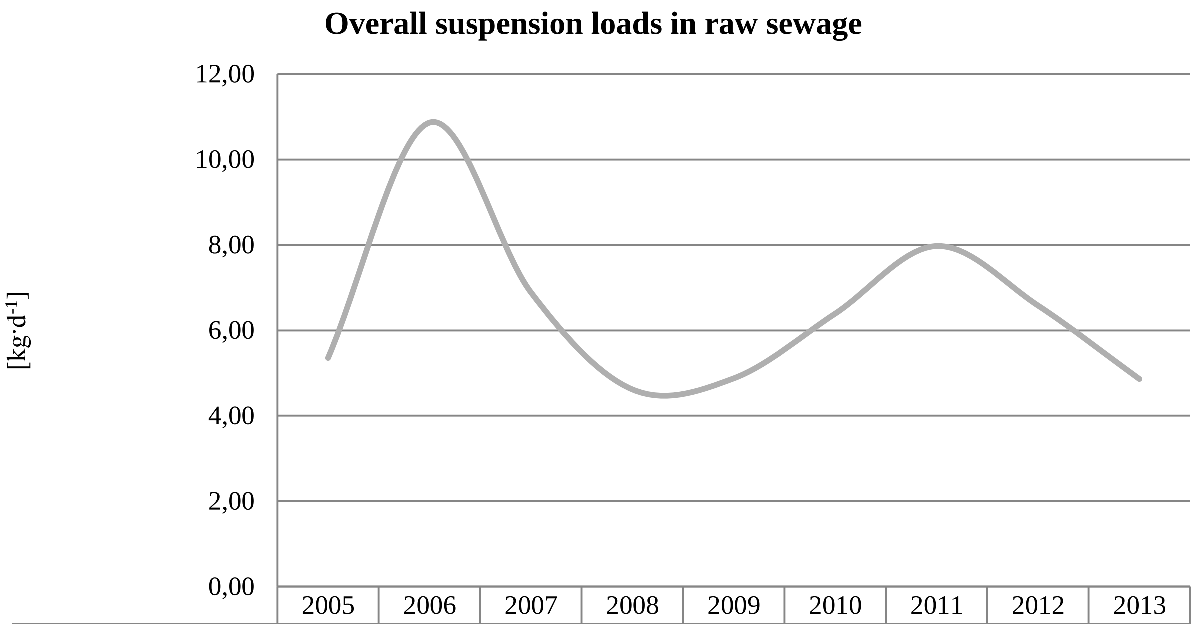
Comparing data on the number of residents in Stawiski (Fig. 13) with obtained loads of COD_{Cr}, as in the case of BOD_5, you cannot conclud a significant effect of population on average CODCr load in raw sewage flowing into the municipal sewage treatment plant.



	2005	2006	2007	2008	2009	2010	2011	2012	2013
COD raw	25,71	12,51	37,71	32,34	13,84	18,15	18,26	14,18	16,02

Figure 15: COD_{Cr} load in raw sewage in the years 2005-2013

Source: Own elaboration on ZGKiM data basis



	2005	2006	2007	2008	2009	2010	2011	2012	2013
Zawiesina surowe	5,35	10,86	6,89	4,62	4,87	6,39	7,97	6,58	4,86

Figure 16: Overall suspension load in raw sewage in the years 2005-2013

Source: Own elaboration on ZGKiM data basis

The average annual load of overall suspension (Fig. 16) during the study period was characterized by a trend similar to the sine wave changes. Observed two maximums - in 2006 and 2011, amounting to respectively 10.68 and 7.97 $kg \cdot d^{-1}$ and one minimum load of this component in 2008, equal to 4.62 $kg \cdot d^{-1}$.

Like rest of the analyzes, there was no significant effect of population on overall suspension load in wastewater flowing into the sewage treatment plant in the city.

Based on the results obtained from treated and raw sewage the correlation coefficients of linear and nonlinear were calculated, in order to describe efficiency structures of municipal wastewater treatment plant. Individual Pearson and Spearman correlation coefficients presented in Tables 2 and 3. To describe phenomena of wastewater treatment those correlations were used, which module was equal to 0.70 or more.

In case of concentration of overall suspension in the raw sewage, a strong negative linear correlation (R = -0.71) with respect to COD_{Cr} removal effect eas observed. The negative correlation indicates that removal effect of COD_{Cr} decreases with increasing concentration of overall suspension in the raw wastewater. Described dependence was not obtained in Spearman nonparametric test, in which the correlation coefficient was -0.39, suggesting a weak relationship between the variables.

In case of overall suspension concentration in treated wastewater there was observed a strong positive linear correlation with value of BOD_5 (R = 0.91) and relation with COD_{Cr} (R = 0.89) in treated sewage. This relationship was also confirmed by nonparametric test, in which the correlation coefficients were equal to 0.82 and 0.86 for BOD_5 and COD_{Cr} value. On the basis of the correlation analysis results that clearly indicates that with the increase in concentration of overall suspension in the treated sewage increases the value of BOD_5 and COD_{Cr}. In addition, there was a strong negative linear correlation between the concentration of overall suspension and removal efficiency of BOD_5 (R = -0.86) and COD_{Cr} (R = -0.81).

In case of BOD_5 in the raw sewage, a strong positive parametric and non-parametric correlation was obtained with respect to value of CODCr in raw sewage. Linear correlation coefficient was equal to 0.91while non-parametric test value was equal to 0.89. The results of statistical analysis were confirmed by Kowalski in his studies presented in 1989 [7], which showed that biochemical oxidation processes may allow to obtain information about chemical and biological properties of components present in wastewater.

There was no statistically significant correlation between either of variables, and the amount of inflowing sewage from city or the waste transported in slurry tank.

Only one statistically significant positive correlation between amount of residents, and value of COD_{Cr} in treated sewage was observed. Linear Pearson's correlation coefficient for this pair of variables was equal to 0.80, while non-parametric Spearman test was 0.78.

Shown in the Table 4 standard deviations suggest that in studied period there were significant changes in values and concentrations of individual analyzed components in raw sewage. Standard deviation for overall suspension concentration was equal to 96.19 with arithmetic mean 310.56, standard deviation for BOD_5 was equal to 191.96 at arithmetic mean equal to 462.50, and standard deviation values for COD_{Cr} was equal to 405.22 with arithmetic mean 997.17.

Similar results were obtained in treated wastewater. Standard deviation for overall suspension concentration was equal to 8.04 at arithmetic mean equal to 11.57, for BOD_5 standard deviation was equal to 7.90 with arithmetic mean equal to 7.99, while the standard deviation for COD_{Cr} was equal to 62.50 at arithmetic mean equal to 65.97

Standard deviations in case of removal effects were much lower than in case of values and concentrations. Therefore it can be concluded that the process of wastewater treatment was not significantly disturbed by external factors or equipment failure.

Similar removal effects for individual components from wastewater were obtained Przybyła et al., 2009 [10]. Research carried out by them in three sewage treatment plants in Wielkopolska showed that average removal effects for BOD_5 stood at 94.4, 90 and 99%. Pollutants removal from sewage characterized by parameter COD_{Cr} was 88.3, 85.4 and 97.1%, for overall suspension 94.3, 88.7 and 99%.

Similar results, for removal effects, to those obtained in Stawiski were also noted by Długosz and Gawdzik, 2013 [4]. Theirs studies shown that process of mechanical - biological treatment was causing a reduction for BOD_5 at level close to 96%, COD_{Cr} by 90%, overall suspension by 97%. Objects analyzed by Długosz and Gawdzik belonged to the second group of sewage treatment plants, according to the Decree of the Minister of Environment from 24 July 2006 [11].

Obtained parametric correlation coefficients between BOD_5, COD_{Cr} and overall suspension, are similar to results obtained by Wisniewska-Kadżajan et al., 2012 [13]. Authors conducted research in selected sewage treatment plants in Siedlecki province, obtained parametric correlation coefficients between BOD_5 and COD_{Cr} amounted to 0.79, between BOD_5 and overall suspension to 0.52 and between COD_{Cr} and overall suspension to 0.58.

Tabele 2: R Pearson linear correlation coefficients

	Overall suspension raw*	Overall suspension treated**	BOD_5 raw	BOD_5 treated	COD_{Cr} raw	COD_{Cr} treated	Overall suspension removal effect	BOD_5 removal effect	COD_{Cr} removal effect	Sewage inflow	Amount of transported sewage	Population
Overall suspension raw	1,00	0,60	-0,16	0,50	-0,37	0,46	-0,24	-0,65	**-0,71**	-0,24	0,26	0,18
Overall suspension treated	0,60	1,00	0,10	**0,91**	-0,04	**0,89**	**-0,90**	**-0,86**	**-0,81**	0,09	-0,09	0,57
BOD_5 raw	-0,16	0,10	1,00	0,34	**0,91**	0,30	-0,23	0,28	0,39	-0,04	-0,64	0,31
BOD_5 treated	0,50	**0,91**	0,34	1,00	0,11	**0,86**	**-0,85**	**-0,80**	-0,69	0,09	-0,30	0,46
COD_{Cr} raw	-0,37	-0,04	**0,91**	0,11	1,00	0,23	-0,12	0,48	0,55	-0,03	-0,50	0,44
COD_{Cr} treated	0,46	**0,89**	0,30	**0,86**	0,23	1,00	**-0,81**	-0,68	-0,68	0,13	-0,28	**0,80**
Overall suspension removal effect	-0,24	**-0,90**	-0,23	**-0,85**	-0,12	**-0,81**	1,00	**0,71**	0,59	-0,17	0,17	-0,48
BOD_5 removal effect	-0,65	**-0,86**	0,28	**-0,80**	0,48	-0,68	**0,71**	1,00	**0,95**	-0,14	-0,11	-0,24
COD_{Cr} removal effect	**-0,71**	**-0,81**	0,39	-0,69	0,55	-0,68	0,59	**0,95**	1,00	-0,13	-0,09	-0,33
Sewage inflow	-0,24	0,09	-0,04	0,09	-0,03	0,13	-0,17	-0,14	-0,13	1,00	-0,32	0,09
Amount of transported sewage	0,26	-0,09	-0,64	-0,30	-0,50	-0,28	0,17	-0,11	-0,09	-0,32	1,00	-0,28
Population	0,18	0,57	0,31	0,46	0,44	**0,80**	-0,48	-0,24	-0,33	0,09	-0,28	1,00

Source: Own elaboration

Tabele 3. Nonparametric Spearman correlation coefficients

	Overall suspension raw*	Overall suspension treated**	BOD_5 raw	BOD_5 treated	COD_{Cr} raw	COD_{Cr} treated	Overall suspension removal effect	BOD_5 removal effect	COD_{Cr} removal effect	Sewage inflow	Amount of transported sewage	Population
Overall suspension raw	1,00	0,28	-0,03	0,14	-0,16	0,18	-0,04	-0,10	-0,39	-0,14	0,32	0,26
Overall suspension treated	0,28	1,00	0,44	**0,82**	0,21	**0,86**	**-0,93**	-0,40	-0,18	0,17	-0,20	0,60
BOD_5 raw	-0,03	0,44	1,00	0,58	**0,89**	0,31	-0,21	0,35	0,66	-0,16	-0,22	0,19
BOD_5 treated	0,14	**0,82**	0,58	1,00	0,27	**0,74**	**-0,72**	-0,25	0,17	0,17	-0,43	0,42
COD_{Cr} raw	-0,16	0,21	**0,89**	0,27	1,00	0,24	-0,05	0,52	0,59	-0,12	-0,23	0,18
COD_{Cr} treated	0,18	**0,86**	0,31	**0,74**	0,24	1,00	**-0,88**	-0,33	-0,31	0,19	-0,37	**0,78**
Overall suspension removal effect	-0,04	**-0,93**	-0,21	**-0,72**	-0,05	**-0,88**	1,00	0,52	0,32	-0,30	0,28	-0,58
BOD_5 removal effect	-0,10	-0,40	0,35	-0,25	0,52	-0,33	0,52	1,00	0,63	-0,28	-0,43	0,00
COD_{Cr} removal effect	-0,39	-0,18	0,66	0,17	0,59	-0,31	0,32	0,63	1,00	0,02	-0,32	-0,22
Sewage inflow	-0,14	0,17	-0,16	0,17	-0,12	0,19	-0,30	-0,28	0,02	1,00	-0,12	0,05
Amount of transported sewage	0,32	-0,20	-0,22	-0,43	-0,23	-0,37	0,28	-0,43	-0,32	-0,12	1,00	-0,28
Population	0,26	0,60	0,19	0,42	0,18	**0,78**	-0,58	0,00	-0,22	0,05	-0,28	1,00

Source: Own elaboration

Tabele 4: Basic statistics

	Overall suspension raw*	Overall suspension treated**	BOD_5 raw	BOD_5 treated	COD_{Cr} raw	COD_{Cr} treated	Overall suspension removal effect	BOD_5 removal effect	COD_{Cr} removal effect	Sewage inflow	Amount of transported sewage	Population
Aritmetic mean	310,56	11,57	462,50	7,99	997,17	65,97	96,05	98,12	92,22	7685,4	192,5	2476
Median	266,00	9,00	405,00	7,90	847,00	62,50	96,12	98,52	92,75	7698,1	191,5	2486
Standard deviation	96,19	8,04	191,96	4,16	405,22	19,64	2,05	1,05	4,48	903,8	54,7	55
Minimum	221,00	5,00	275,00	3,30	585,25	41,75	92,62	95,48	80,81	6112,8	115,8	2386
Maximum	508,00	30,25	785,00	17,13	1625,00	104,75	98,37	98,82	95,49	9328,6	271,8	2546
<25%	250,00	5,90	380,00	5,10	710,00	51,50	94,44	98,15	92,68	7265,0	167,8	2451
>75%	378,00	14,30	430,00	9,23	1277,75	75,50	97,92	98,66	95,22	8027,9	214,1	2521

Source: Own elaboration

*- raw sewage inflowing from gravity sewer system in Stawiski

**- treated wastewater in mechanical-biological process

9. Conclusion

1. Municipal sewage treatment plant in Stawiski meets the criteria set for purified waste water in Regulation of the Minister of Environment from July 24, 2006, novelized in 2009, and the conditions specified in water permit.
2. Average removal effect for various contaminants from wastewater treatment plant in Stawiski in studied period, was high and amounted for BOD_5- 98.1%, 92.2% for COD_{Cr}, and 96.1% for overall suspensions.
3. Changes in the population haven't affected to a significant degree average contamination loads of in wastewater flowing into the treatment plant in Stawiski.
4. Minimum and maximum values of BOD_5 and COD_{Cr} in raw and treated sewage, were recorded in the same period.
5. Występują silne dodatnie korelacje parametryczne i nieparametryczne pomiędzy stężeniem zawiesin ogólnych, a wartościami BZT_5 i $ChZT_{Cr}$ w ściekach oczyszczonych. Strong positive parametric and nonparametric correlations were observed between concentration of overall suspension, and the values of BOD_5 and COD_{Cr} in treated sewage.

Podziękowania

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Literature:

1. Bojanowska I., Pepiliński M.: Optymalizacja pracy oczyszczalni ścieków w Tczewie w zakresie usuwania biogenów i związków węgla. Ochrona Środowiska, 3(86), 31-36, 2002.
2. Bugajski P.: Ładunki zanieczyszczeń charakteryzujące ścieki pochodzące z budynków szkolnych na terenach wiejskich. Infrastruktura i Ekologia Terenów Wiejskich, 14/2010, 137- 145, 2010

3. Chmielowski K., Ślizowski R.: Ocena skuteczności usuwania zanieczyszczeń w oczyszczalni ścieków w Tarnowie. Infrastruktura i Ekologia Terenów Wiejskich, 5/2009, 137- 146, 2009.
4. Długosz J., Gawdzik J.: Ocena skuteczności funkcjonowania oczyszczalni ścieków w Barczy (woj. Świętokrzyskie), Proceedings of ECOpole, 7(1), 311- 317, 2013.
5. Heindrich Z., Witkowski A.: Urządzenia do oczyszczania ścieków. Wydawnictwo Seidel- Przywecki, Warszawa, 2005.
6. Kiedryńska L. Papciak D., Granops M.: Chemia sanitarna. Wydawnictwo SGGW, Warszawa, 2006.
7. Kowalski T.: Analiza chemicznych i biochemicznych właściwości zanieczyszczeń występujących w ściekach. Ochrona Środowiska 1989, 1(38), 13- 16, 1989.
8. Operat wodno-prawny na odprowadzanie ścieków z miejskiej oczyszczalni ścieków w Stawiskach do rzeki Dzierzbia, gmina Stawiski, powiat Kolno, woj. Podlaskie, Łomża 2013.
9. Pawęska K., Kuczewski K.: Charakterystyka odpływu ścieków oczyszczonych odpływających z terenu oczyszczalni roślinno-glebowej. III Ogólnopolski Kongres Inżynierii Środowiska, Lublin, wrzesień 2009.
10. Przybyła C., Bykowski J., Filipiak J.: Efektywność funkcjonowania gminnych oczyszczalni ścieków, Rocznik Ochrony Środowiska **(Annual Set The Enviroment Protection**), 11, 231- 239, 2009.
11. Rozporządzenie Ministra Środowiska w sprawie warunków, jakie należy spełnić przy wprowadzaniu ścieków do wód lub do ziemi, oraz w sprawie substancji szczególnie szkodliwych dla środowiska wodnego z dnia 24 lipca 2006r. (Dz. U. nr 137 poz. 984) oraz 28 stycznia 2009 r. (Dz. U. nr 27 poz. 169).
12. Tomczuk B.: Zmienność ilości ścieków i nieczystości ciekłych oraz ładunku zanieczyszczeń na przykładzie oczyszczalni ścieków komunalnych w Lipsku n. Biebrzą. Inżynieria Ekologiczna, 24, 145- 153, 2011.
13. Wiśniewska- Kadżajan B., Jankowski K., Sosnowski J.: Skuteczność oczyszczania ścieków komunalnych w wybranych oczyszczalniach powiatu Siedleckiego. Ochrona Środowiska i Zasobów Naturalnych, 52, 32- 41, 2010.
14. www.geoportal.gov.pl

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Wastewater and sludge management in chosen dairy WWTP plants in Podlaskie province

Keywords: *wastewater management, dairy WWTP, sludge treatment, modernization.*

Abstract: This paper presents the overview of wastewater and sludge management in chosen dairy wastewater treatment plants in podlaskie province. The modernization of wastewater and sewage sludge treatment facilities is considered. The result of research work presented in this paper presents changing in wastewater characteristic within the time and represents the importance and timeliness of modernization measures were taken.

1. Introduction

The Podlasie Province is an agricultural area with dominating food industry. This part of country is usually called “Green Lungs of Poland” As many as 9 out of 100 biological WWTP (wastewater treatment plant) in the region receive sewage from dairy industry. The flow capacity of the biggest dairy plant which is also presented in this paper is generated more than 7000 m^3/day of sewage while the total amount of sewage sludge after treatment is nearly 2500 tons of dry mass per year. Sewage sludge is by- product in the process of sewage treatment, the way of its finale utilization depends on many factors among others physico-chemical composition of sewage which is put through the treatment process and the method of its processing. The quantity of sewage sludge among others dairy sludge, will rise together with the load of sewage (Dabrowski 2006,2009). The possibility of sewage sludge recycling to the environment, for instance as a fertilizer, depends on its physical-chemical composition and sanitary quality. Polish legal requirements define the conditions that have to be fulfilled before the sludge may use for soil fertilization. High efficiency of industrial wastewater is very important to protect natural environment in Podlaskie Province.

2. Characteristic of wastewater and sewage sludge in dairy WWT Plants

According to investigation conducted in the period of 1998-2000 by Boruszko et al.(2000), the amount of treated sewage in Podlaskie province reached about 138 000 m^3/d among others about 9070 m^3/d was treated by individual dairy systems. While analyzing problems connected with the amount of sewage and sewage sludge in Podlaskie province in 2008, there was observed the increase of dairy sewages, which are treated in individual dairy waste water treatment plants in the province. According to the data of Dabrowski (2009), this amount reached 12 000 m^3/d. . While assessing the quantity of dairy sewage, it is necessary to take into account the fact that during last years the rate of the used water and generated sewage decreased in relation to the amount of processed milk (Dabrowski, 2009). The changes, which were observed in individual dairy waste water treatment plants, are proved by such parameters like personal equivalent (P.E.) or the amount of sludge produced during sewage treatment. The quantity of sludge in dairy waste water treatment plants rose from 1140 tons d.m. in 1998 to almost 3700 tons d.m. in 2008 (Dabrowski, 2009). In the biggest plant located in the town of Wysokie Mazowickie (Mlekovita Diary Cooperative) there was noticed the increase of generated sludge from 600 to almost 2200 tons d.m. in analogous period of 10 years (Dabrowski 2009). Such a situation is typical in dairy W.W.T. plants (Bartkiewicz 2010). Nowadays nine plants using individual treatment systems exist in Podlaskie Province. This paper covers information about two of them located in Bielsk Podlaski and Wysokie Mazowieckie.

Table 1 shows the basic parameters of chosen systems of diary sewage treatment in Podlaskie province according to the data from 2009. Table 2 shows current parameters in 2013.

Table 1.Characteristics of chosen dairy WWTP-s in Podlaskie province, 2009

Plant	Sewage quantity m^3/d	P.E.	Sludge amount Mg d.m. y^{-1}
WysokieMazowieckie	5500	277000	2200
BielskPodlaski	700	9800	230

Source: Dabrowski, 2009

Table 2. Characteristics of chosen dairy W.W.T.P-s in Podlaskie province, 2013

Plant	Sewage quantity m^3/d	P.E.	Sludge amount Mg d.m. y^{-1}
WysokieMazowieckie	7550 (design)	340000 (design)	2500
BielskPodlaski	950	24000	250

Source: Dabrowski

Apart from the quantity of sewage and sludge there was given personal equivalent (P.E.) characteristic for each object describing the level of load, which is treated by diary water waste treatment plants. The average BOD_5 in diary sewage is about 6 to 10 times higher than in case of municipal sewage. It is proved by the own research and also by literature (B.A.T.,2005, Ochrona, 1998).

3. Characteristic of Mlekovita and Bielmlek W.W.TP.s

3.1.Technologies and facilities for sewage treatment

The dairy plant in Wysokie Mazowieckie belongs to the Mlekovita company. It processes 360 million dm^3 of milk per year and is one of the largest dairy plants in Poland. Since it was built in 1980s, the plant had its own biological WWTP using activated sludge method for sewage treatment. The sewage treatment technology did not differ from other plants in the country and it focussed on the carbon compounds removal. It consisted of high- and low-loaded activated sludge, surface aerators, aerobic sludge stabilization and sludge drying beds – the schedule quite often successfully implemented in Poland (Dabrowski, 2006) Figure 1 is presenting plant before modernization in 2013.

Fig. 1 WWTP in Wysokie Mazowieckie before modernization

Source: M. Kajurek

The analysed WWTP started operation in 1987. The inflow of sewage was about 3500 m3/d. The dairy sewage inflowed to horizontal sand trap via manually cleaned screens, then to high-loaded activated sludge chamber (the first stage) and through transitional sedimentation tank outflowed to the low-loaded activated sludge chamber (the second stage). Final treatment took place in the secondary sedimentation tank. Sludge processing consisted of simultaneous aerobic stabilization and dewatering at the drying bed (Dabrowski, 2011)

Development of the dairy plant, increasing load of sewage, operation problems with the old treatment system and new requirements concerning nitrogen and phosphorus concentrations in treated sewage resulted in modernization of the treatment system. The entirely new WWTP was built using the old constructions. The modern biological system for nutrient removal was developed though chemical precipitation of phosphorus is also possible. The mechanical treatment part was also modernized; sludge regeneration chamber was adapted for phosphorus precipitation. Sewage from dephosphatation chamber outflow to high-loaded activated sludge chamber, where the sludge concentration was about 3.5 kg/m3. After clarification in the transitional sedimentation tank, the sewage is directed to low-loaded activated sludge chamber.. In this chamber simultaneous nitrification and denitrification occurs. The modern surface aerators provide adequate conditions for the processes of nitrification and denitrification. The oxygen monitoring placed in the chambers help to keep the oxygen concentration at pre-defined level. The final treatment of sewage occurs at four radial-flow sedimentation tanks. The treated sewage outflows to the receiver via measuring tube. The WWTP was designed for the average daily flow of sewage of 5700 m3/d. In 2001 the transitional sedimentation tank stopped working and the cascade unit was introduced in its place. The sludge processing line was completely changed during modernization. Aerobic stabilization in a separate chamber at the temperature of 36oC, press dewatering and lime conditioning was introduced. The former sludge drying beds are used for temporary sludge deposition (Kajurek 2007). Next modernization was completed In 2013, figure 2 presenting New system. Flotation process was implemented as anaerobic sewage sludge stabilization, heat and electric energy is produced. Figure 3 is presenting fermentation chamber.

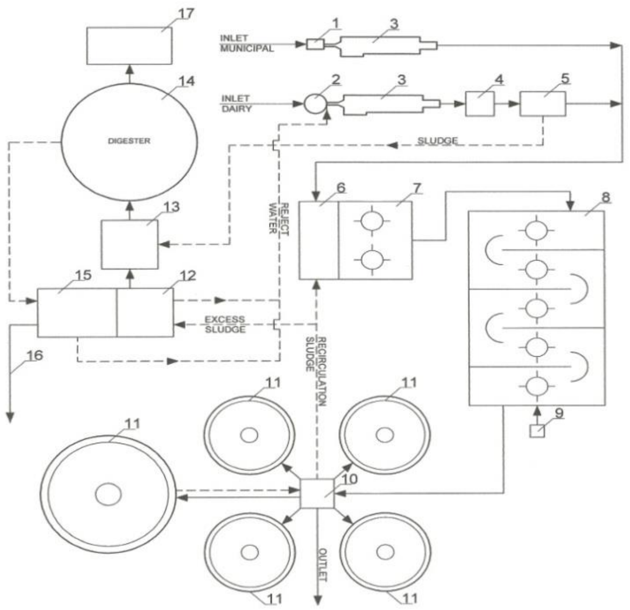

Fig. 2 Flow diagram of Wysokie Mazowieckie W.W.T.P.

Source: W. Dąbrowski

1 - raw wastewater; 2 - screens; 3 - sand trap; 4 - anaerobic chamber; 5 - two stage activated sludge system; 6 - sedimentation tank; 7 - final effluent; 8 - recirculation; 9 - excess sludge; 10 - aerobic stabilization; 11 - thickener; 12 - filter press; 13 - lime conditioning; 14 - coagulation; 15 - reject water; 16 - collecting chamber; 17 - agricultural reuse of sludge

Fig 3.Fermentation chamber and biogas storage

Source: W. Dabrowski

The W.W.T.P. in Bielsk Podlaski has been built in the 1970s. The production plant started operation more than fifty years ago. The technological scheme of the plant was typical for 70's of the 20th century (Dabrowski, 2008). It was designed for inlet of 1800 m^3/d. Circulations chambers with surface aeration, where sewage came after pre-aeration, were the basic elements of the system. Outlet was organized after two vertical secondary clarifiers. Recirculation flow was directed to regeneration chamber and the rest flow – to circulation chamber (Wiater, Dabrowski, 2013). In 2000 was implemented chemical phosphorus removal. In 2012 was launched a process of modernization of Bielsk Podlaski dairy W.W.T.P. with installation S.B.R. reactors (Wiater, Dabrowski, 2013). Figure 4 and 6 are presenting new facilities, figure 5 is presenting scheme of treatment.

Fig. 4 Flotation unit during modernization.

Source: W. Dąbrowski

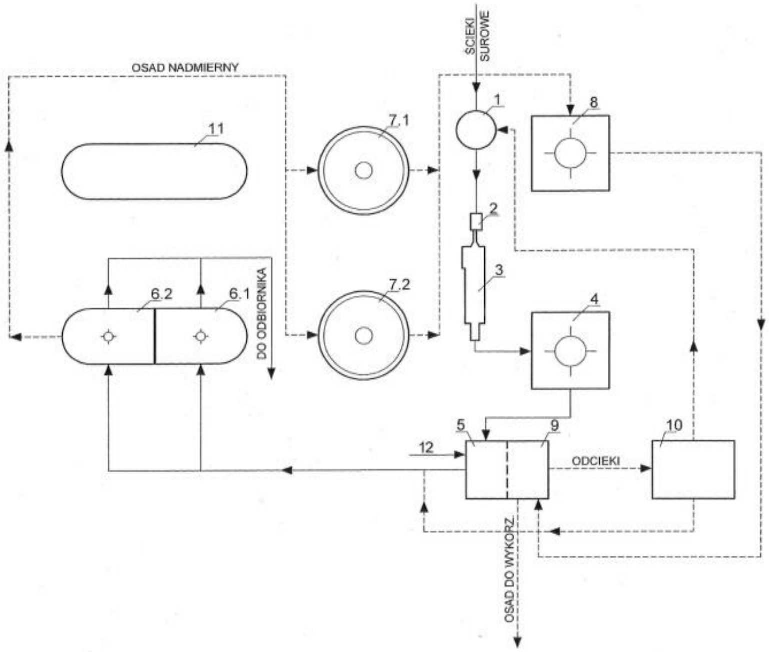

Fig. 5 Flow diagram of Bielsk Podlaski W.W.T.P.

source: Wiater, Dabroski 2013 (Fig 1. Flow diagram, W.W.T.P. Bielmlek Bielsk Podlaski 2012)

1 – pumping station; 2 – sieve; 3 – sand trap; 4 – averaging tank; 5 – flotator; 6 – S.B.R.; 7,8 – thickener; 9 – aerobic stabilization; 10 – filter-press; 11 – sediment storage.

Fig. 6 Old and new system for WWT in BielskPodlaski.

Source: Dąbrowski

Reconstruction was designed for inlet of 750 m^3/d and BOD concentration 1500 mgO_2/dm^3. Raw wastewater through pumping station (1) goes to mechanical treatment on sieve (2) and sand trap (3) and come to averaging tank (4). After averaging tanksewage is directed to flotator (5). Biological treatment is held in two sequencing reactors (6.1, 6.2) equipped with mixing turbine aerator. Table 2 is presenting basic parameters of both plants.

Table 2.Average characteristics of raw wastewater of chosen dairy WWTP

W.W.T.P.	BOD_5 [mg O_2/l]	COD [mg O_2/l]	Total N [mg N/l]	N-NH_4[mg N-NH_4/l]	Total phosphorus [mg P/l]
Wysokie Mazowieckie	3120	4360	69	3,1	14,5
BielskPodlaski	1520	1890	65	1,8	9,8

Source: Dabrowski, 2008

3.2.Technologies and facilities for sludge treatment

Diary waste water treatment plant in Wysokie Mazowickie is one of the biggest objects of this type in Poland but also in Europe. In the summer period this plant processes over two millions of liters of milk per day and night. Up to 2000, this diary waste water treatment plant worked according to typical system of Promlecz with simultaneous stabilization of dewatering sludge on filter beds, which were commonly used in the beginning of the 90-s of the last century. After modernization and introduction of intensive biological and chemical sewage treatment, the amount of sludge rose over twice. The increase of sludge reached 5200 kg of sludge dry matter per day on average reaching the increase rate on the level of 0,46 kg d.m./kg BOD_5 (Dabrowski, 2009)

After modernization in 2000 Wysokie Mazowieckie W.W.T.P. was implemented following scheme of sewage sludge treatment: aerobic stabilization, press dewatering and lime conditioning. There were used separate chambers in aerobic stabilization, which processed mechanically thickened sludge. Stabilization time ranged between 5 to 8 days, the process is exothermic and the stabilization temperature reached 30-36 ^{0}C. In order to limit the temperature increase in chambers and to provide suitable air change, under the cover of each chamber there is pressed air in amount of 2,5 thousands m^3/h. After stabilization process, sludge was dewatered with filterpress,there is possibility of additional lime stabilization. The changes in the treatment system resulted in a major increase of the sludge amount, from600 tons d.m./year before modernization, to 900 tons d.m. /year in 2001, and to almost 1700 tons in 2005. Such a large amount of sludge is due to the high average BOD_5 in raw sewage, which was equal to 3200 mgO_2/l in 2005 (Dabrowski 2005).. Modernization of W.W.T.P. in 2013 was based on anaerobic stabilization of excess sludge and flotation sludge. Heat and electric energy is produced during anaerobic stabilization. In Bielsk Podlaski excess sewage sludge is stabilized in aerobic conditions. Final dewatering is provided by press. In both plants sewage sludge after treatment is used as a fertilizer.

The results of the analysis presented in Table 3 show that heavy metals content in sludgefrom diary W.W.T. plants is low, sharply below the limit values, which allows to use sludge as fertilizer in some crops. Low metal content is one of criteria, which conditions the possibility of recycling of diary sludge to environment.

Table 3. Heavy metals content in sewage sludge from dairy W.W.T.P-s

Plant	Quantity of heavy metals mg/kg d.m.						
	Pb	Zn	Cu	Cd	Ni	Cr	Hg
WysokieMazowieckie	10,2	170	22,4	0,52	3,1	4,6	0,18
BielskPodlaski	5,8	163	20,0	0,40	3,3	4,3	0,19

Source: Dabrowski, 2006

Table 4. Biogenic compounds content in sewage sludge from dairy W.W.T.P-s

Plant	Chosen characteristic parameters				
	N-total g/kg d.m.	P-total g/kg d.m	Mg g/kg s.m	Ca g/kg d.m	Organic substances %
WysokieMazowieckie	93,6	17,0	3,9	28,0	82,1
BielskPodlaski	26,9	1,9	6,8	61,9	74,2

Source: Dabrowski, 2006

4. Own research, methods and sampling

In order to obtain results showing current characteristics of raw wastewater coming to chosen W.W.T.P-s, a series of tests were performed. Samples were collected on inlets of chosen stations before passing through treatment facilities.

Concentration of following pollutants were measured:

- Organics (BOD_5, COD)
- Ammonium ions ($N\text{-}NH_4$)
- Total phosphorus

COD, $N\text{-}NH_4$ and total phosphorus amounts were applied by test recommended by Merck. Biochemical Oxygen Demand was determined using OXI-TOP with WTW facilities. All determinations were carried out in laboratory of Department of Technology in Environmental Engineering and Protection, B.U.T..

5. Results and discussion

Achieved results are of wastewater characteristic is presented in Tables 5 and 6.

Table 5. Characteristics of raw wastewater, Wysokie Mazowieckie

WWTP	Series	BOD_5[mg O_2/l]	COD [mg O_2/l]	$N\text{-}NH_4$[mg $N\text{-}NH_4$/l]	Total phosphorus [mg P/l]
WysokieMazowieckie	I	2800	4100	1,9	26,8
	II	3200	5600	3,2	34,5
	II	3100	4200	3,9	30,0

Source: Own research

Table 6. Characteristics of raw wastewater, Bielsk Podlaski

WWTP	Series	BOD_5[mg O_2/l]	COD [mg O_2/l]	Ammonia [mg N-NH_4/l]	Total phosphorus [mg P/l]
BielskPodlaski	I	1200	2100	2,4	16,5
	II	1400	2280	2,5	20,1
	II	1490	2380	2,8	15,8

Source: Own research

Table 7 and 8 sare presenting comparison between average data of obtained results and data presented in Table 2.

Table 7.Comparison of raw wastewater characteristics of Wysokie Mazowiecki dairy W.W.T.P.

Characteristic	Own research, 2013	2008
BOD_5[mg O_2/l]	3033	3120
COD [mg O_2/l]	4633	4360
N-NH_4[mg N-NH_4/l]	3	3,1
Total phosphorus [mg P/l]	30,4	14,5

Source: Own research

Table 8.Comparison of raw wastewater characteristics of Bielsk Podlaskie dairy W.W.T.P.

Characteristic	Own research, 2013	2012
BOD_5[mg O_2/l]	1363	1520
COD [mg O_2/l]	2253	1890
N-NH_4[mg N-NH_4/l]	2,6	1,8
Total phosphorus [mg P/l]	17,5	9,8

Source: Own research

Comparison of average parameters measured by BOD, COD, ammonia and phosphorus obtained in own research with previous year's data shows a tendency in raw wastewater characteristic changing. In both cases there is no significant difference between BOD and COD, but was detected growth of nutrient compounds (ammonia ions and total phosphorus). In case of Wysokie Mazowiecki treatment plant were determined 2,7% decrease of BOD_5, 6,3% increase of COD, 3,2% decrease of ammonia ions and 109,7% increase of total phosphorus. In case of Bielsk Podlaskie treatment plant were determined 10,3% decrease of BOD_5, 19,2% increase of COD, 44,4% increase of ammonia ions and 78,6% increase of total phosphorus. The phosphorus and nitrogen concentrations mostly depends on water management in the dairy plant and types of chemicals used to wash devices. Study shows visible increasing of phosphorus compounds within the time.

6. Final conclusions

Performed study contains present characteristic of raw wastewater of chosen dairy W.W.T.P-s. In both cases increase of total phosphorus amount was determined. BOD_5 and COD characteristic of Wysokie Mazowiecki and BielskPodlaskie plants changed with time insignificantly. To compare with municipal W.W.T.P. value of organic matter measured by BOD and COD is much higher in dairy W.W.T.P. (Dymaczewski 1997). Both analyzed system are modern and ready for high efficiency of sewage treatment. This is very important for water environment protection. Changing of parameters In raw wastewater can be explained by changings in technological process of milk production and equipment maintenance. Study confirms the importance of modernization which took part in both cases.

References:

1. B.A.T.; Najlepsze Dostępne Techniki, wytyczne dla branży mleczarskiej, (2005), Ministerstwo Środowiska, Warszawa.
2. Bartkiewicz B., Umiejewska K.: (2010), Oczyszczanie ścieków przemysłowych, PWN.
3. BORUSZKO D.,DBROWSKI W., MAGREL L. 2000: Bilans cieków i osadów ciekowych w oczyszczalniach cieków województwa podlaskiego, Fundacja Ekonomistów rodowiska i Zasobów Naturalnych., Białystok: pp.44.
4. Dabrowski W. .; Management and utilization of sewage sludge from dairy industry wastewater treatment plants; IWA Specialized Conference: state of the art , challenges and perspectives, , pp 734-737 Moscow 2006
5. Dabrowski W.; Treatment and final utilization of sewage sludge from dairy waste water treatment plants located in Podlaskie province; Contemporary Problems of Management and Environmenal Protection Vol.4, 2009. Sewages and Waste Materials in Environment, chapter 10, pp 141-151
6. Dabrowski W.; Wastewater, sludge and reject water management in dairy wastewater treatment plants; 7th International Conference ENVIRONMENTAL ENGINEERING, Vilnus 2008
7. Dabrowski W.Gospodarka ściekowa oraz osadowa w zakładach przemysłu mleczarskiego, stan obecny oraz perspektywy rozwoju- monografia pod redakcją

Kazimierza Szymańskiego, Komitet Chemii analitycznej PAN, Politechnika Koszalińska,tom 7, 149-162, 2011.

8. Kajurek M.: Studies on heavy metals contents changes during treatment of sewage from dairy Wastewater treatment plant, Polish Journal of Environmental Studies, vol.16 no 2A, 665-668, 2007.
9. Ochrona środowiska w przemyśle mleczarskim (1998) Fundacja Programów Pomocy dla Rolnictwa (FAPA), Warszawa.
10. Poradnik eksploatatora oczyszczalni ścieków (1997), red. Dymaczewski Z., OleszkiewiczJ.A., Sozański M., PZiTS Poznań.
11. Wiater J., Dąbrowski W.: Określenie możliwości zmniejszenia obciążenia oczyszczalni ścieków mleczarskich przez zastosowanie wydzielonego oczyszczania odcieków z przeróbki osadów; ŚRODKOWO-POMORSKIE TOWARZYSTWO NAUKOWE OCHRONY ŚRODOWISKA; Tom 15, 2013.

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Agricultural biogas plants

Key words: *anaerobic digestion, biogas plant, energy resources, energy*

Summary: Agricultural Biogas is a set of devices used to keep methane fermentation of organic substrates produced on the farm, and enabling their use in the fermentation process. The main raw materials for the production of biogas in a biogas plant are the droppings of farm animals, grass, straw, leaves and stems of plants growing, growing as a main crop waste the agri-food industry, as well as sewage sludge. The key products are biogas and organic fertilizer. Methane fermentation allows for the production of biogas - ecologically clean fuel and disposal of hazardous waste . It is also part of future plans for technology in animal breeding. It contributes to reducing the environmental load substances such as methane, hydrogen sulfide, ammonia, nitrogen oxides. The paper presents the process of the production of biogas, methane fermentation systems, the concept of the biogas plant. Characterized substrates used in agricultural biogas plants and presents options for further use of biogas. It has been shown that agricultural biogas plants can be a new, stable source of income for agricultural entrepreneurs, providing energy independence of the region, while saving the environment. Presented are currently operating in Poland agricultural biogas plants, the raw materials used by them and of biogas and energy.

1. Introduction

The increase in oil prices, rising greenhouse gas emissions, and above all, concerns about security and energy self-sufficiency cause that country are stepping up efforts to diversify energy sources and put special emphasis on renewable sources. Implementation of the core objectives of energy policy also forces the development of renewable energy. The production of energy from alternative sources ensures positive ecological effects, and contributes to the development of less developed regions [1].

Biogas production is seen as one of the most important sources of renewable energy. It provides additional environmental benefits and can generate more income for farmers [2]. Agricultural biogas plants so enjoy every time more and more popular. Are implemented on a large scale throughout the world. Have been used as biological systems to treat organic waste, using biomass from energy plantations targeted [3]. The processes of methane fermentation of biomass in biogas plants have a very great future. They allow to reduce methane emissions during uncontrolled biochemical processes associated storage products and agricultural waste, such as manure, manure or other waste agricultural production [4].

2. Agricultural biogas plant

2.1.Construction and operation of agricultural biogas plant

The biogas plant is a complete installation of processing biomass into biogas. In recent years, a number of technological solutions tailored to the specific needs of each investor. The choice of the technology depends primarily on the type of feedstock processed and the use of biogas. Table 1 shows the technological possibilities.

Table 1. Classification of available technologies for biogas production

Criterion	Technology	Explanation
The dry matter content in the fermentation chamber	Fermentation wet	Fermentation substrates are liquid chamber of the dry residue of less than 15%
	Fermentationdry	Solid substrates with a high content of dry residue
The process temperature	Mesophilic,32-42°C Thermophilic, 50-57°C	The most commonly used Rarely used
Number of stages of the process	Single stage	One fermentation chamber
	Multistage	Two or more chambers fermentation connected in series
The degree of separation of the different phases of the fermentation process	Single phase	The phases hydrolysis and methane production occur with equal intensity in the same reactor
	Multiphase	Higher intensity of hydrolysis and methanogenesis in separate reactors
A method of dispensing substrates	Continuous	Dosage substrate evenly and continuously; constant production of biogas
	Periodic	Fermentation chamber is filled with cargo substrates. After fermentation most of the residues are removed. Gas production reaches its maximum at the beginning of the process and decreases with time

Source: Fachagentur Nachwachsende Rohstoffe e.V. (2006), Kujawski O. (2009) [5,6]

The process by which the biogas produced is called the methane fermentation. For the fermentation process are responsible bacteria in anaerobic conditions. The process can be divided into four basic phases and the three main groups of cooperating microorganisms [7,8].

- Phase I – insoluble organic compounds, which include: proteins, fats and carbohydrates are converted by the bacteria producing the appropriate enzymes that hydrolyze, or trenching hydrolase responsible for the chemical bond by hydrolysis. Proteases break down proteins, and are responsible for the glycosidase breakdown of carbohydrates and lipases are divided into smaller portions fats. As a result of the above mentioned enzymes are obtained soluble monomers or dimers. These processes are responsible for the speed of the fermentation process, as a precondition for the other phases of degradation, generating methane formation. It is important that not all organic matter is decomposed in the process of hydrolysis, because the remainder (approximately 40% to 50% depending on the origin) is not biodegradable due to lack of appropriate enzymes who can spread the polymers to monomers or dimers.
- Phase II – resulting in a Phase I monomers and dimers are metabolized to short organic acids having from one to six carbon atoms in the molecule. Most arise acids such as formic, acetic, propionic, butyric, valeric and caproic. Also arise: methyl alcohol and ethyl alcohol and formaldehyde and acetaldehyde. The waste products of the reaction are carbon dioxide and hydrogen gas. Conversion of the products acetic acid occurs only when the energy supply from the outside. This reaction may also take place freely, which is to be exothermic, while the hydrogen is continuously eliminated - in an environment where the partial pressure thereof is sufficiently low, which occurs during the reduction of CO_2 to CH_4 [8,9]. The lower hydrogen partial pressure, the more the reduced product is formed which is more desirable. In the stable system the way to obtain methane runs through acetates, hydrogen and carbon dioxide, while the remainder of the acids and aldehydes correspond to a marginal role. Such a course of fermentation and the production of more energy, and methanogenic bacteria can be directly used substrates for the production of methane. If the fermentation process produce large amounts of acids containing more than two carbon atoms they can not be used by the methanogenic microorganisms. These acids are converted in the next phase [8,10].
- Phase III – usually organic acids containing from three to six carbon atoms, are converted by the bacteria into acetic acid, hydrogen and carbon dioxide. These products may serve as starting materials methanogenic bacteria for the production of methane. This phase is the hardest because of the energy consumption. If the reaction occurs spontaneously hydrogen must be removed from the system and the partial pressure may reach a maximum of 400 Pa.

- Phase IV - methanogenesis - produced methane. The stoichiometric calculation shows that about 65% to 70% of the methane production in the reduction process acetates. That is why acetates are one of the most important intermediate substrates that generate methane formation [8,11].

In the fermentation chamber all of these steps occur in parallel. Next to each other live microorganisms responsible for the various stages of fermentation. They are connected with each other dependencies nutrients and live in relative equilibrium. The presence of all groups of microorganisms and their proper proportions determine the appropriate course of fermentation, and thus the quality of the biogas. The imbalance between microorganisms results in change in the composition of biogas, even the total elimination of methane.

The biogas plant consists of the following elements, as shown in Figure 1 [12]:

- delivery part of the substrate,
- fermentation tank,
- biogas storage tank,
- tank fermented substrate,
- device for the use of biogas, such as cogeneration unit.

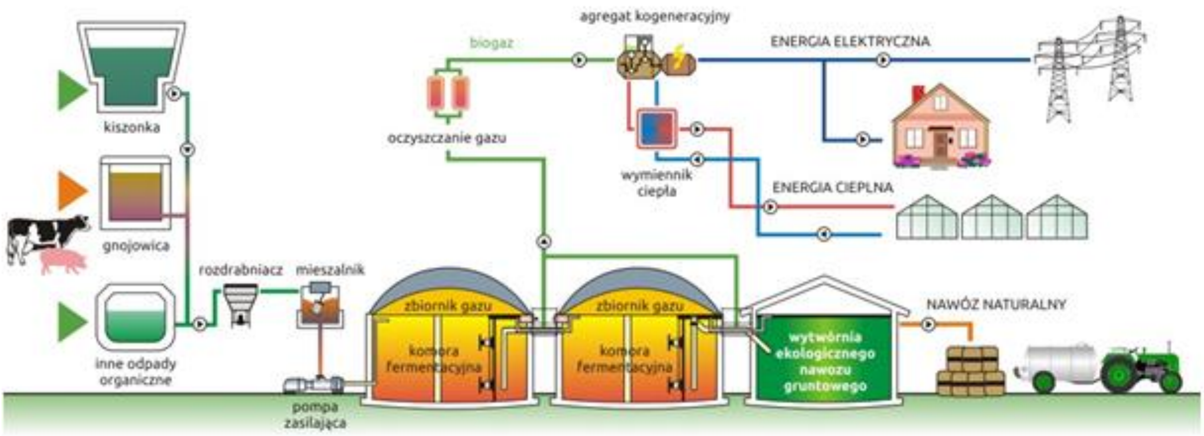

Figure 1. Construction of agricultural biogas plant

Source: http://bio-power.pl/schemat-dzia%C5%82ania-biogazowni.html [12]

The method of administration of the substrate depends on its type. Loose of materials such as silage crops, are served using special trays equipped with augers or piston pumps. Smooth substrates, such as slurry, distillers are delivered to a small buffer tank, from which are automatically pumped into the fermentation chamber. A more complicated system pretreatment of substrates is used for slaughterhouse waste, which are subjected to a pasteurisation or hygenisation. For reasons of sanitary reception of such waste is held in a separate, enclosed building, referred hall receptions. Hall admission is equipped with bio-filters that remove odors. Depending on the category, meat waste is thermally treated, with different parameters, in the pasteurizer. After cooling to a suitable temperature of the whole biomass is passed to the the fermentation chamber - a tank which is a process of organic matter decomposition and the biogas production in. Typically, it is a closed container or steel reinforced concrete. Depending on the type of substrate, its physico-chemical properties and the quantities of raw material, the plant employs a low concrete tanks equipped with agitators, or high side of the vertical steel stirred tanks. Proper selection of the fermentation chamber is necessary to ensure constant conditions the activity of methane bacteria, the entire volume of the tank. Hence, it is extremely important optimal mixing, which allows more evenly substrate portions, to maintain a constant temperature, pH value, and also is important for the release of methane. Thermal insulation of the fermentation chamber is important because the process can take place effectively at specific temperatures, are optimal for the growth of microorganisms. It also heats the contents of the chamber, particularly during the winter months. The biogas released in the digester is collected in the storage tank. Typically, it is tank with double membrane acting at the same time the function of the roof to the storage tank fermented substrate or secondary the fermentation chamber - depending on the specific biogas plant technology. Biogas tank provides the buffer capacity for the receiving device, which may be cogeneration unit. Thus, despite fluctuations in the production of biogas, which is a typical phenomenon, the device can operate stably. CHP unit or module, is currently the most popular device for the use of biogas. Burning gas produces electricity at the same time and heat. The gas supplied to it must be dried and stripped of hydrogen sulfide, which in combination with steam and hydrogen sulfide acid forms will cause severe damage. Removing hydrogen sulphide in the biogas plant takes place in a digester or in a biogas tank, using biological methods. The couple is condensation between the biogas tank and cogeneration device in system components or a special dehydrator.

In addition to the biogas formed by the fermentation of a liquid containing several to dozen percent of dry weight. It is a substance with a high quality fertilizer. It includes elements included in the biomass, and do not take direct part in the formation of biogas, which can include nitrogen, phosphorus, potassium, magnesium, calcium and others. Many of them occur in the form of dissociated salts, which makes them readily available for the plants. Most fermented substrate (digestate) is used as a liquid fertilizer. Due to the restriction of the use of fertilizer, occurring, for example, in the winter, it is necessary tank of sufficient capacity to store the fertilizer until it is pourable. Each biogas plant must therefore be equipped in the tank [12].

2.2.Raw materials for biogas production

Currently, the most commonly used is to process the biogas mixture of several substrates. It is this diversity of substrates promotes a better process parameters and increases security to ensure the supply of raw material. Feedstock for biogas plants must provide [**Błąd! Nie można odnaleźć źródła odwołania.**]:

- high efficiency of biogas production,
- stable fermentation process,
- the possibility of using the resulting digestate in accordance with applicable law.

In large biogas plants use a common fermenting a mixture animal manure and waste from the food industry or energy crops. Practice shows that supplementation with animal manure substrates with higher content of dry organic matter per unit mass (or volume) and high energy affects the increase in biogas production. however, the composition and amount of the reactants do not change in an uncontrolled way during the process,.

In small agricultural biogas plants is recommended to combine animal manure only from energy crops. Table 2 shows the biogas yield capabilities from different sources [**Błąd! Nie można odnaleźć źródła odwołania.**].

Table 2. Characteristics of selected plants and selected products for biogas yield

Base	The dry matter content (%)	The dry matter content of organic (%)	The yield of biogas (m^3/t)	The content of methane CH_4 (% vol.)
		Natural fertilizers		
cattle slurry	8-11	75-82	200-500	60
pigs slurry	about7	75-86	300-700	60-70
cattle manure	about25	68-76	210-300	60
pigs manure	20-25	75-80	270-450	60
hens manure	about32	63-80	250-450	60
		Plants		
maize silage	20-35	85-95	450-700	50-55
rye	30-35	92-98	550-680	about55
grass silage	25-50	70-95	550-620	54-55
		Products of the agricultural industry		
brewers grains	20-25	70-80	580-750	59-60
graindecoction	6-8	83-88	430-700	58-65
potato decoction	6-7	85-95	400-700	58-65
pomace	25-45	90-95	590-660	65-70

Other substrates for biogas plants				
waste fittings	5-20	80-90	400-600	60-65
gastric contents	12-15	75-86	250-450	60-70
Grasses				
mown grass	about12	83-92	550-680	55-65

Source: Land Technik Weiher Stephen H.Mitterleitner (Latocha 2009) [14]

Among the animal waste from farms to production of biogas can be used liquid manure, slurry or manure, which have different properties depending on: the species of animal, their feeding and breeding way, as well as the composition and proportions of ingredients. The most commonly used is the slurry – a mixture of feces and urine of farm animals. Animal faeces have a lower productivity than organic wastes from the agro-food and plant biomass. The use of manure has a positive effect on the process and the possibility of obtaining a good manure [**Błąd! Nie można odnaleźć źródła odwołania.**].

Biomass waste from farms or grown for the purpose of energy crops with a high efficiency of biogas production plays an important role. The most frequently used are: corn, beets, grass and sorghum, mostly in the form of silage. Plants may be used in whole or in part (fruit, tubers, leaves, seeds).

In larger agricultural biogas plants are used waste from food processing, fruit and vegetable. However is not recommended for use it in small installations, due to operating difficulties. Waste is an efficient substrate for biogas production. They can be: waste from the fruit and vegetables, dairy, bakery, sugar, distillery or meat. Due to the large diversity of properties of individual substrates assess the suitability of each of them to production of biogas should be carried out separately.

In order to determine the parameters of individual elements of the technological installation, must first make a detailed analysis of the substrates. Then calculate the production resulting from the fermentation biogas, electricity and heat. The calculation may be based on published atlases of biogas feedstock productivity rates (expressed in cubic meters per tonne of dry organic matter). Usually given as minimum and maximum values, but recommended to take the bottom values. Much more accurate calculation can be obtained by performing trials fermentation, but it can be done only in the later stages of the project. The use of waste in biogas plants belonging to the category of sanitary-epidemiological, causing the need for their hygenisation, has a direct impact on the technology, forcing the installation of equipment for hygenisation [**Błąd! Nie można odnaleźć źródła odwołania.**]. Table 3 shows the dependence of the installed capacity and the demand for biogas plants and cultivation area silage.

Table 3. In demand for silage and minimum acreage depending on the installed capacity of CHP

Installed power	The demand for biogas	Sauerkraut is 100% of the substrate				Minimum acreage under cultivation of
		The minimum requirement for silage				
	m^3	tons/year	tons/month	tons/week	tons/day	ha
1 MW	3650000	21000	1750	420,00	60,00	440
500 kWe	1825000	10500	875	210,00	30,00	220
300 kWe	1095000	6300	525	126,00	18,00	132
200 kWe	730000	4200	350	84,00	12,00	88
100 kWe	365000	2100	175	42,00	6,00	44
50 kWe	182500	1050	87,5	21,00	3,00	22
30 kWe	110606	636	53,0	12,73	1,82	13,3
20 kWe	73000	420	35,0	8,40	1,20	8,8
10 kWe	36500	210	17,5	4,20	0,60	4,4
5 kWE	18250	105	8,8	2,10	0,30	2,2

Source: MRiRW(K.Żmuda) [15]

2.3.Stages of the construction of biogas plants

The practice of construction of biogas plants in Poland shows that the time needed for the preparation of project documentation, obtaining permits and decisions and agreements is approximately two years, while the construction, start-up and commissioning of biogas plants takes more than a year. Parallel to obtaining the necessary permits formal legal and technical documents takes place process of raising funds for the project[**Błąd! Nie można odnaleźć źródła odwołania.**].

Stage I is the identification of the scope of the project - at this stage, considering the different variants of technological and organizational legal form of implementation and financing concepts. The choice of investment option to a significant extent determine economic issues. The key elements of properly conducted identification include: site selection, analysis of technological variants and demand for manufactured products, and legal risks, as well as the study of the advisability of the project.

Identification of scope of the project should begin with an analysis of substrates: their availability, delivery and evaluation to ensure the productivity of biogas per tonne of substrate. The next step is to determine the whole supply chain, the type and quantity of substrates and their treatment. Need to check whether the substrates are available locally, or it will be necessary setting down of them. The decisive criterion is the cost trasportation. When planning the use of energy crops should specify the available acreage and class of land under cultivation. If the substrates are transported, assess the possibility of expansion of local roads. Initial plans to use substrates must also be analyzed from a legal (in the case of fermentation slaughterhouse waste, hazardous waste disposal or use of digestate as manure) [**Błąd! Nie można odnaleźć źródła odwołania.**].

Choosing the right location influences the success and profitability of the investment. The basic step is the analysis of the legal status of land for the investment and the assessment of the chances of getting a positive location decision. It is important that the location of neighboring parcels of land and a safe distance from the neighbors, as well as the amount of available land. For smaller biogas plants is sufficient land area of 1.5 ha.. It is necessary to examine the possibility of isolating the plot of the biogas plant by creating a special green belts.. The size and dimensions of the plot have an impact on the choice of production technology, the kind used substrates and solutions for the supply of feedstock and digestate discharge [**Błąd! Nie można odnaleźć źródła odwołania.**].

It should be an inventory of infrastructure potentially possible to adapt to the needs of the biogas plant. Due to the necessity of driving the raw materials for biogas plants by heavy duty vehicles is required for access road surface adapted to truck traffic. Important is the availability of the network infrastructure: plumbing, heating, electricity, and roads. At the initial stage of the investment decision is necessary to obtain a preliminary opinion on the location of the biogas plant environment. This serves the reduce the negative impact of of biogas plants in the environment. Due to the possible consequences of failure are required to biogas plant was located at a distance of over 300 m from human habitat, residential buildings located on the lee side and protected areas. It is also recommended to minimize the transport of raw materials and waste digestate through built-up areas. Biogas plants should also be isolated fence and green belts from adjacent areas inhabited.

For large biogas plants at this stage it is necessary to perform a full feasibility study. For smaller biogas plants may prove to be too big expense, and therefore it is recommended to study the advisability of the project. A more detailed financial analysis will help do banks offering loan for the project. An important element of the risk analysis and the sensitivity of the project [**Błąd! Nie można odnaleźć źródła odwołania.**].

Stage II involves obtaining the necessary permits - consent for the project is one of the most important issued in the process of investment and construction. Its release is necessary to obtain a zoning decision and the decision on the construction permit. After obtaining all the required documents mayor issues a decision on the environmental conditions of approval for the project. Taking into account the fact that public consultations are provided in the EIA procedure, investors in small agricultural biogas plants should be well in advance to inform interested parties of its intention to build a biogas plant. They are not required to do so by law, but they should, do it in their own interest to avoid social conflicts in a given location. The investor submits an application to the appropriate regional distribution company for a decision on conditions for connection to the network. In the case of large biogas plant with an electrical capacity of more than 2 MWel operator may require the expertise terminal, which determine the impact of the installation being connected to the power system. Documentation associated with the acquisition of the zoning decision depends on whether there is a local spatial development plan of the area in which the investment is to be located. It provides a direct basis to apply for a building permit. Failing to identify ways of developing and building the land by way of a zoning decision. It is a decision setting the terms for a change in land use through the construction of an object or perform other works.

In the case of a small agricultural biogas implementation of the project requires the conclusion of a number of agreements with various entities and at different stages. Their correct legal structure reduces the investment risk. Agreement for the implementation of typical agricultural biogas plant is agreement on: the supply of substrates (for feedstock supplied from outside), connection to the grid, complex design work, supply of technology and investment performance, delivery and reception of media, including the sale of heat, insurance during construction financing of the investment project (contract with a financial institution) [**Błąd! Nie można odnaleźć źródła odwołania.**].

The so-called Phase III is the development of technical documentation and obtaining a decision on the construction permit. It begins with an inventory, which involves vetting of land and buildings on it is located, preparing the minutes describing the existing damage or confirming their lack of photographic documentation and execution of the object. Then - assessing the adaptation of existing facilities to the needs of the biogas plant. Technical and technological project should include: characterization and description of the production process including technological schemes and term demand for raw materials, products, equipment, quantities and types of waste and how to manage them; statement of machines and equipment manufacturing facilities; lists of all production and ancillary facilities; factors determine the demand for energy and other media detailed guidance for industry projects and specialized publications (including environmental). The project includes the construction project plot or land development and architectural and construction project (including technical and technological), developed by industry designers with building license or installation. Each of the branches is agreed by authorized experts in the field of health and safety, fire and sanitary-hygienic. Obtaining a decision on the permit for the construction of a building ends formal legal step of preparing investment and allows you to start the construction work.The decision is valid for three years and during that time the investor has to start construction work. The procedure in order to issue a building permit (the project together with the arrangements) is a test of the completeness and correctness of the entire formal legal process of preparing investment [**Błąd! Nie można odnaleźć źródła odwołania.**].

In Stage IV, takes construction and operation - the most important moments for the project are the designer's supervision technology and start-up technology designer and the initial period of operation. A safe option is the agreement with the contractor, ensuring delivery of devices, execution starting, management and servicing during the warranty period, or for at least two years from the completion of the investment (the terms of the operator guarantees penalties for not achieving the expected level of revenues).The purpose of the biogas plant start-up is to check the operation of installed devices under full load, and reliability, designed to achieve technological and economic operating parameters as well as to determine the optimal parameters of the devices. Start-up consists of the following stages: mechanical "dry" - without giving the media; hydraulic - during which start-up is carried out using a neutral medium (water) technology - with a proper medium (substrate, biogas) and assumed parameters of technological achievement. During the start-up technology, it is also "immunize" biogas suitable bacterial strain. They are collected in the form of slurry (a few tankers) from another biogas plant or from a nearby sewage treatment plant. The final stage of commissioning of biogas plants, from a formal point of view, is to control the inspection of construction supervision. As construction for the installation of gas, is also subject to inspection by the Fire Department and the Office of Technical Inspection. Prior to obtaining permission to use it is also necessary to get the appropriate permissions: Issue and to operate in the recovery or disposal of waste. Since 2011, the company applies for registration energy companies involved in the production of agricultural biogas, conducted by the Agricultural Market Agency, at the same time abolished the obligation to apply for a license to generate electricity [**Błąd! Nie można odnaleźć źródła odwołania.**].

2.4.The advantages of the operation of biogas plants

Biogas plant provides many benefits, among them [17]:

- production of energy using renewable sources - is the ecological effects, which fits in the Polish energy policy and the European Union;
- production of electricity and heat in a continuous mode (use of cogeneration);
- reduce the consumption of fossil fuels and reduce greenhouse gas emissions into the atmosphere;
- reduction of organic matter, which provides an increase in the concentration of minerals present in the mass digestate in the form of easily absorbed by plants;
- the possibility of disposing of manure of farm animals;
- neutralize odors from manure or manure as a result of the use of methane fermentation process;
- creating a stable local market of agricultural products while allowing access to high-quality natural fertilizer;
- activation of local businesses using electricity and / or heat from the biogas plant.

3. The research methodology

Specified place functioning of agricultural biogas plants in Poland, the type and capacity of the system for the production of agricultural biogas installed capacity and annual capacity of the plant for the production of electricity and heat based on data from the Agricultural Market Agency of 20.02.2014.

Developed graphically production of agricultural biogas, electricity and heat from agricultural biogas in 2011-2012 and the first half of 2013, based on data from the Agricultural Market Agency.

4. Discussion of results

Data on agricultural biogas plants operating in Poland are presented in Table 4.

Lp.	Name entrepreneur	Place of business	Range and the nature of the business	Type of installation	The annual capacity of the installation for the production of agricultural biogas (m^3/year)	The installed power of the		The annual capacity of the installation for the production	
						electrical(MWe)	heat(MWt)	electricity(MWhe / year)	heat (MWht / year)
	Poldanor S.A.	Polna 3 street 77-220 Koczała Pomeranian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	8 212 500	2,126	2,206	16 761,384	17 392,104
		Pawłówko 77-320 Przechlewo Pomeranian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	3 802 655	0,946	1,101	7 458,260	8 680,284
		Płaszczyca 77-320 Przechlewo Pomeranian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	2 299 500	0,625	0,680	4 927,500	5 361,120
		Nacław 14B 76-006 Nacław West Pomeranian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	2 299 500	0,625	0,686	4 927,500	5 408,424
		Świelino 30 7 6-020 Bobolice West Pomeranian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	2 299 500	0,625	0,686	4 927,500	5 408,424

Lp.	Name entrepreneur	Place of business	Range and the nature of the business	Type of installation	The annual capacity of the installation for the production of agricultural biogas (m^3/year)	The installed power of the		The annual capacity of the installation for the production	
						electrical(MWe)	heat(MWt)	electricity(MWhe / year)	heat (MWht / year)
		Uniechówek 77-310 Debrzno Pomeranian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	4 100 200	1,063	1,081	8 380,700	8 522,604
		Giżyno 78-540 Kalisz Pomorski West Pomeranian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	4 100 200	1,063	1,081	8 380,000	8 520,000
		Kujanki 77-300 Człuchów Pomeranian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	1 124 470	0,330	0,342	2 602,000	2 696,000
2.	Biogaz Agri Sp. z o.o.	Niedoradz 67-106 Otyń Lubusz Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	631 000	0,252	0,291	1 300,000	1 500,000
3.	Elektrownie Wodne Sp. z o.o.	Liszkowo 87-93 88-190 Złotniki Kujawskie Kuyavian-Pomeranian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	7 400 000	2,126	1,198	14 400,000	8 100,000

Lp.	Name entrepreneur	Place of business	Range and the nature of the business	Type of installation	The annual capacity of the installation for the production of agricultural biogas (m^3/year)	The installed power of the		The annual capacity of the installation for the production	
						electrical(MWe)	heat(MWt)	electricity(MWhe / year)	heat (MWht / year)
4.	Biogaz Zeneris Sp. z o.o.	Skrzatusz 64-930 Szydłowo Greater Poland Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	2 102 400	0,526	0,505	4 607,760	4 423,800
5.	Eko-Energia Grzmiąca Sp. z o.o.	Sportowa 5 street 78-450 Grzmiąca West Pomeranian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	7 000 000	1,600	1,600	13 500,000	14 500,000
6.	BIO-WAT Sp. z o.o.	Metalowców 22 street 58-100 Świdnica Lower Silesian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	4 000 000	0,900	1,100	7 200,000	8 800,000
7.	BIO-BUT Sp. z o.o.	Łabędzka 54 street, Łany Wielkie 44-153 Sośnicowice Silesian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	2 470 915	0,526	0,540	4 471,000	4 625,000
8.	Bioelektrownia Sp. z o.o.	Uhnin 141 21-211 Dębowa Kłoda Lublin Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	4 500 000	1,200	1,160	10 000,000	9 600,000

Lp.	Name entrepreneur	Place of business	Range and the nature of the business	Type of installation	The annual capacity of the installation for the production of agricultural biogas (m^3/year)	The installed power of the		The annual capacity of the installation for the production	
						electrical(MWe)	heat(MWt)	electricity(MWhe / year)	heat (MWht / year)
9.	Bioenergy Project Sp. z o.o.	Konopnica 121 96-200 Rawa Mazowiecka Łódź Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	9 353 755	1,998	2,128	17 083,000	18 194,000
10.	Allter Power Sp. z o.o.	Mełno 86-330 Mełno Kuyavian-Pomeranian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	6 200 000	1,600	1,800	12 800,000	14 400,000
11.	Wikana Bioenergia Sp. z o.o.	Zamojska 26C street 21-050 Piaski Lublin Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	4 250 000	0,999	1,039	8 000,000	9 600,000
12.	AWW Wawrzyniak Sp. j.	Zbiersk Cukrownia 61 62-830 Zbiersk Greater Poland Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	4 176 558	1,600	1,620	12 800,000	12 960,000
13.	Biogal Sp. z o.o.	Boleszyn 7A 13-308 Mroczno Warmian-Masurian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	7 840 000	2,000	2,020	15 200,000	15 360,000

Lp.	Name entrepreneur	Place of business	Range and the nature of the business	Type of installation	The annual capacity of the installation for the production of agricultural biogas (m^3/year)	The installed power of the		The annual capacity of the installation for the production	
						electrical(MWe)	heat(MWt)	electricity(MWhe / year)	heat (MWht / year)
14.	Gospodarstwo Rolne Kargowa - Klępsk Ryszard Maj	Klępsk 53 66-111 Nowe Kramsko Lubusz Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas) -	4 633 117	1,000	1,400	8 147,000	11 406,000
15.	P.P.-H.-U. "SERAFIN" Sp. z o.o.	Szklarka Myślniewska 68A 63-500 Ostrzeszów Greater Poland Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	3 000 000	0,660	0,640	5 493,000	5 326,000
16.	Elektrociepłownia Bartos Sp. z o.o.	Czarnowska 56C street 26-065 Piekoszów Świętokrzyskie Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	2 464 000	0,800	0,855	6 200,000	6 350,000
17.	Polskie Biogazownie "Energy Zalesie" Sp. z o.o.	Osiedlowa 4 street, Zalesie 46-146 Domaszowice Opole Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	8 000 000	2,000	2,016	17 520,000	17 660,000
18.	Südzucker Polska S.A.	Ząbkowicka 53 street 57-100 Strzelin Lower Silesian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	9 894 549	2,000	2,065	17 520,000	18 089,000

Lp.	Name entrepreneur	Place of business	Range and the nature of the business	Type of installation	The annual capacity of the installation for the production of agricultural biogas (m^3/year)	The installed power of the		The annual capacity of the installation for the production	
						electrical(MWe)	heat(MWt)	electricity(MWhe / year)	heat (MWht / year)
19.	DMG Sp. z o.o.	Koczergi 56B 21-200 Parczew, Lublin Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	3 900 000	1,200	1,300	10 200,000	11 050,000
20.	"BIO-POWER" Sp. z o.o.	Zaścianki 86 21-560 Międzyrzec Podlaski Lublin Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	3 500 000	1,200	1,251	9 000,000	9 300,000
21.	Cargill Poland Sp. z o.o.	Mac Millan 1 street Bielany Wrocławskie 55-040 Kobierzyce Lower Silesian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	1 300 000	0,526	0,581	3 400,000	3 750,000
22.	Biogas plant Rypin Sp. z o.o.	Starorypin Prywatny 51 87-500 Rypin Kuyavian-Pomeranian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas))	6 881 090	1,875	1,780	15 000,000	14 240,000
23.	Minex-Invest Sp. z o.o.	Łęguty 15 11-036 Gietrzwałd Warmian-Masurian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	4 561 200	1,200	1,220	10 200,000	10 370,000

Lp.	Name entrepreneur	Place of business	Range and the nature of the business	Type of installation	The annual capacity of the installation for the production of agricultural biogas (m^3/year)	The installed power of the		The annual capacity of the installation for the production	
						electrical(MWe)	heat(MWt)	electricity(MWhe / year)	heat (MWht / year)
24.	"EKOENERGIA WKM" Sp. z o.o.	Orchówek, Garbarska 16 street 22-200 Włodawa, Lublin Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	3 500 000	1,063	1,299	8 326,000	9 394,000
25.	Nadmorskie Elektrownie Wiatrowe Darżyno Sp. z o.o.	Darżyno 76-230 Potęgowo Pomeranian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	7 700 000	2,400	2,448	19 000,000	19 500,000
26.	Zakład Usługowo-Handlowy "Wojciechowski" Zdzisław Wojciechowski	26-300 Opoczno Łódź Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	1 883 314	0,500	0,646	4 000,000	5 168,000
27.	EL-KA Sp. z o.o.	Byszewo 17 73-150 Łobez West Pomeranian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	4 400 000	1,165	1,201	9 320,000	9 608,000
28.	BIOGAZ Przemysław "Łąkrol" Sp. z o.o. sp. komandytowa	Przemysław 72-315 Resko West Pomeranian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	7 000 000	1,600	1,600	13 500,000	13 500,000

Lp.	Name entrepreneur	Place of business	Range and the nature of the business	Type of installation	The annual capacity of the installation for the production of agricultural biogas (m^3/year)	The installed power of the		The annual capacity of the installation for the production	
						electrical(MWe)	heat(MWt)	electricity(MWhe / year)	heat (MWht / year)
29.	FARM FRITES POLAND S.A.	Abrahama 13 street 84-300 Lębork Pomeranian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	3 500 000	1,200	1,223	9 328,000	9 787,000
30.	PFEIFER & LANGEN GLINOJECK S.A.	Zygmuntowo 38 06-450 Glinojeck Masovian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	7 305 840	1,560	1,653	13 665,000	14 480,000
31.	Elektrownia Biogazowa "Borzęciczki" Sp. z o.o.	Borzęciczki 29 63-720 Koźmin Wielkopolski Greater Poland Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	3 600 000	1,200	1,320	7 694,000	8 000,000
32.	Agro Bio Sp. z o.o.	Sławkowo 15 11-400 Kętrzyn Warmian-Masurian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	1 680 000	0,400	0,445	3 200,000	3 560,000
33.	"Eco-Progres" Sp. z o.o.	Giże 4 19-400 Olecko Warmian-Masurian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	4 240 000	1,063	1,104	8 400,000	8 832,000

Lp.	Name entrepreneur	Place of business	Range and the nature of the business	Type of installation	The annual capacity of the installation for the production of agricultural biogas (m^3/year)	The installed power of the		The annual capacity of the installation for the production	
						electrical(MWe)	heat(MWt)	electricity(MWhe / year)	heat (MWht / year)
34.	Ośrodek Hodowli Zarodowej "Gajewo" Sp. z o.o.	Tragamin 82-200 Malbork Pomeranian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	2 880 000	0,800	0,798	6 660,000	6 640,000
35.	ADLER BIOGAZ Sp. z o.o.	Ryboły 1/1 16-060 Zabłudów woj. Podlaskie Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	4 380 000	1,000	1,006	7 800,000	7 847,000
36.	Gospodarstwo Rolne w Bukowie Sp. z o.o.	Kalsk 69A 66-100 Sulechów Lublin Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	5 000 000	1,140	1,060	9 000,000	12 500,000
37.	ENEA Wytwarzanie S.A.	Liszkowo 87-93 88-180 Złotniki Kujawskie Kuyavian-Pomeranian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	7 400 000	2,126	1,198	14 400,000	10 300,000
38.	Instytut Zarządzania i Samorządności Sp. z o.o.	Lipowa 7A street 58-210 Łagiewniki Lower Silesian Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	2 697 500	0,800	0,412	6 017,500	3 419,600

Lp.	Name entrepreneur	Place of business	Range and the nature of the business	Type of installation	The annual capacity of the installation for the production of agricultural biogas (m^3/year)	The installed power of the		The annual capacity of the installation for the production	
						electrical(MWe)	heat(MWt)	electricity(MWhe / year)	heat (MWht / year)
39.	Biogaz Działyń Sp. z o.o.	Działyń 24, 62-271 Działyń Greater Poland Voivodeship	Electricity generation from agricultural biogas in cogeneration system	Mesophilic fermentation; engine mono fuel (gas)	3 712 000	0,999	1,014	8 320,000	8 440,000

Source: been formulated on the basis of: Agricultural Market Agency, as of 20.02.2014 r. http://www.arr.gov.pl/data/02004/rejestr_biogazowni_rolniczych_21022014.pdf [18]

The amount of agricultural biogas production is shown in Figure 2 The amount of agricultural biogas plants in 2011-2012 and the first half of 2013, respectively, is illustrated in charts 3 and 4.

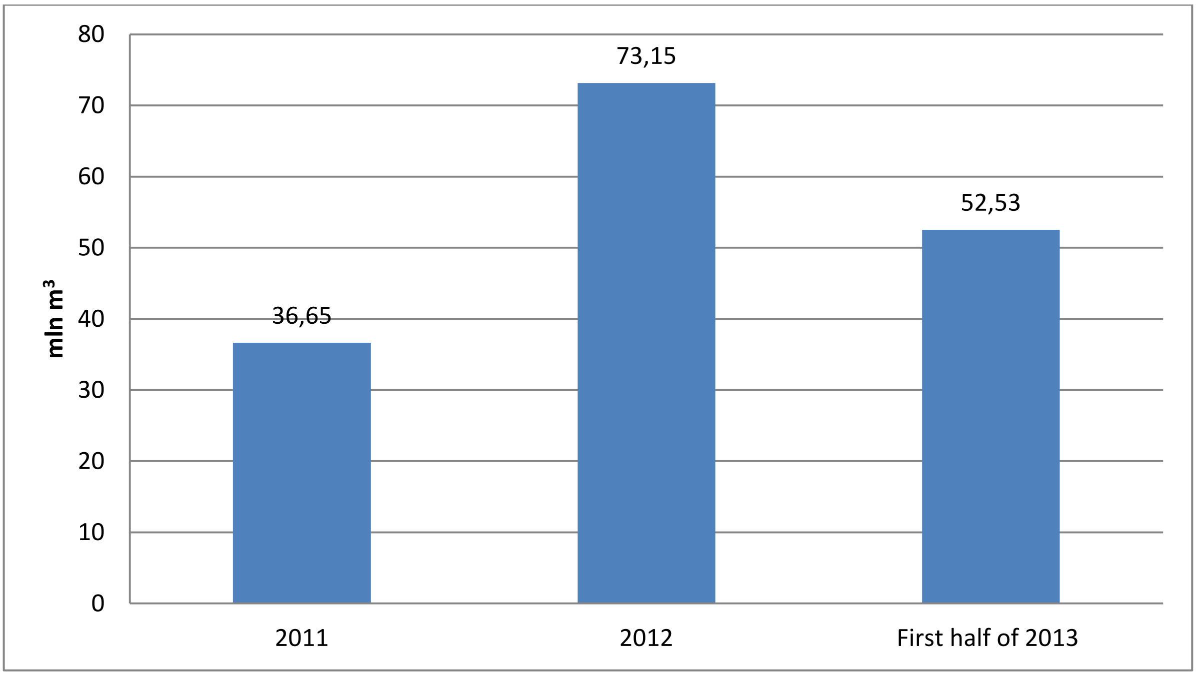

Figure 2. Agricultural biogas in 2011-2013 (first half)

Source: Own calculations based on data AMA.

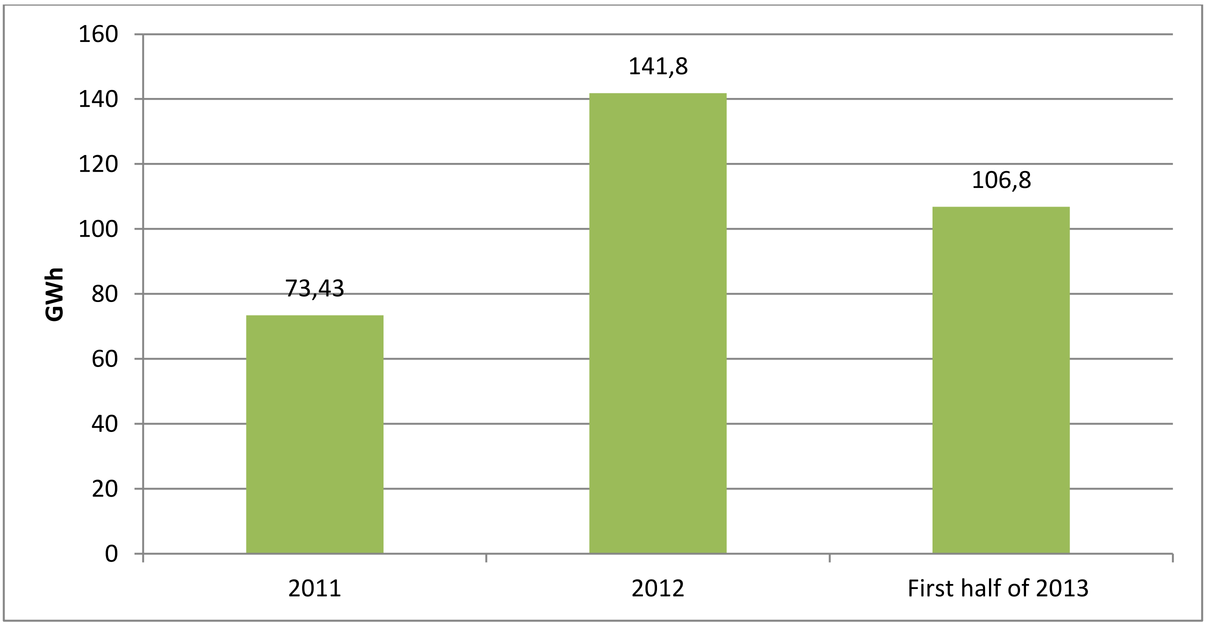

Figure 3. Electricity production from agricultural biogas in 2011-2013 (first half)

Source: Own calculations based on data from AMA.

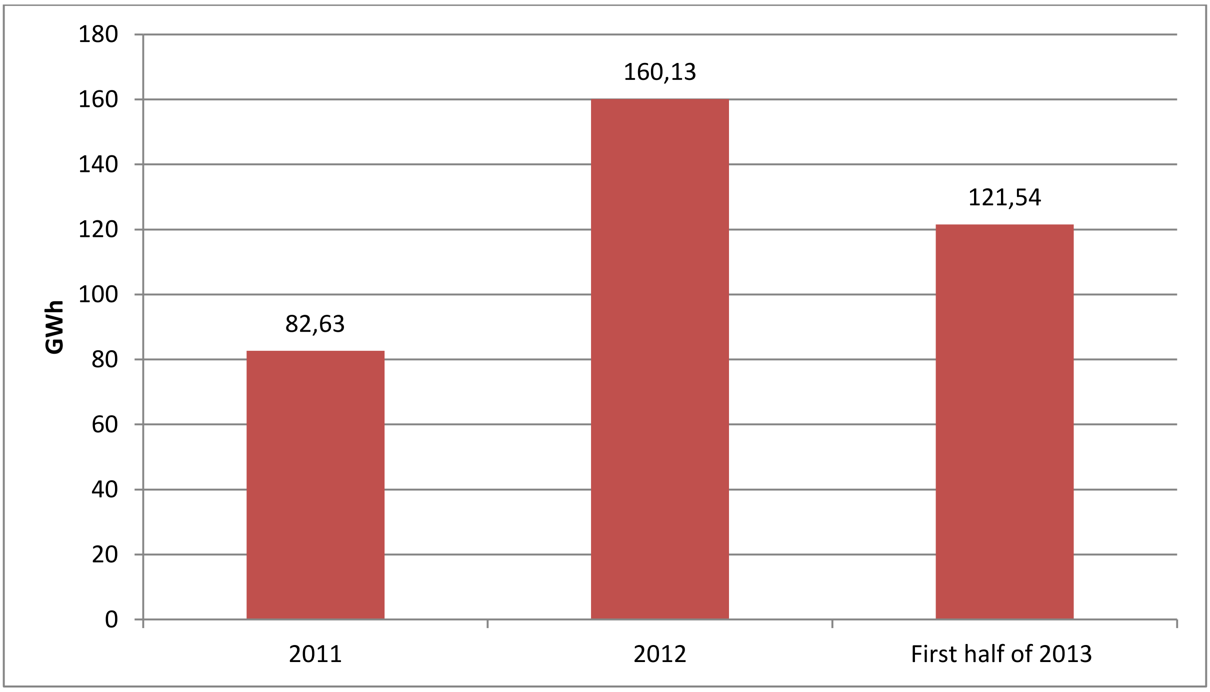

Figure 4. Heat production from agricultural biogas in 2011-2013 (first half)

Source: Own calculations based on data from AMA.

According to the Agricultural Market Agency in 2011 for the production of agricultural biogas was used 469 416.06 tonnes of raw material, in 2012 – 917 121.56 tonnes of raw material, while in the first half of 2013 – 748 358,80 tonnes of raw material. In 2011, the dominant substrates were liquid manure (57% of total starting materials), corn silage (23%), decoction of the distillery (7%), as shown in the Figure 5. In 2012, the same predominant substrates liquid manure (38% of the total reactants), corn silage (26%), decoction of the distillery (16%), however, reported the introduction of the other, to yield biogas. Remains of fruits and vegetables have significantly increased their share - constitute 9%. The share of each commodity is shown in Figure 6. In the first half of 2013 the use of manure (28 % of all substrates) , corn silage (19 %) , distillery slops (22%) is maintained at a high level. There has also been a high proportion of liquid waste from potato processing (17 %). The data are shown in Figure 7.

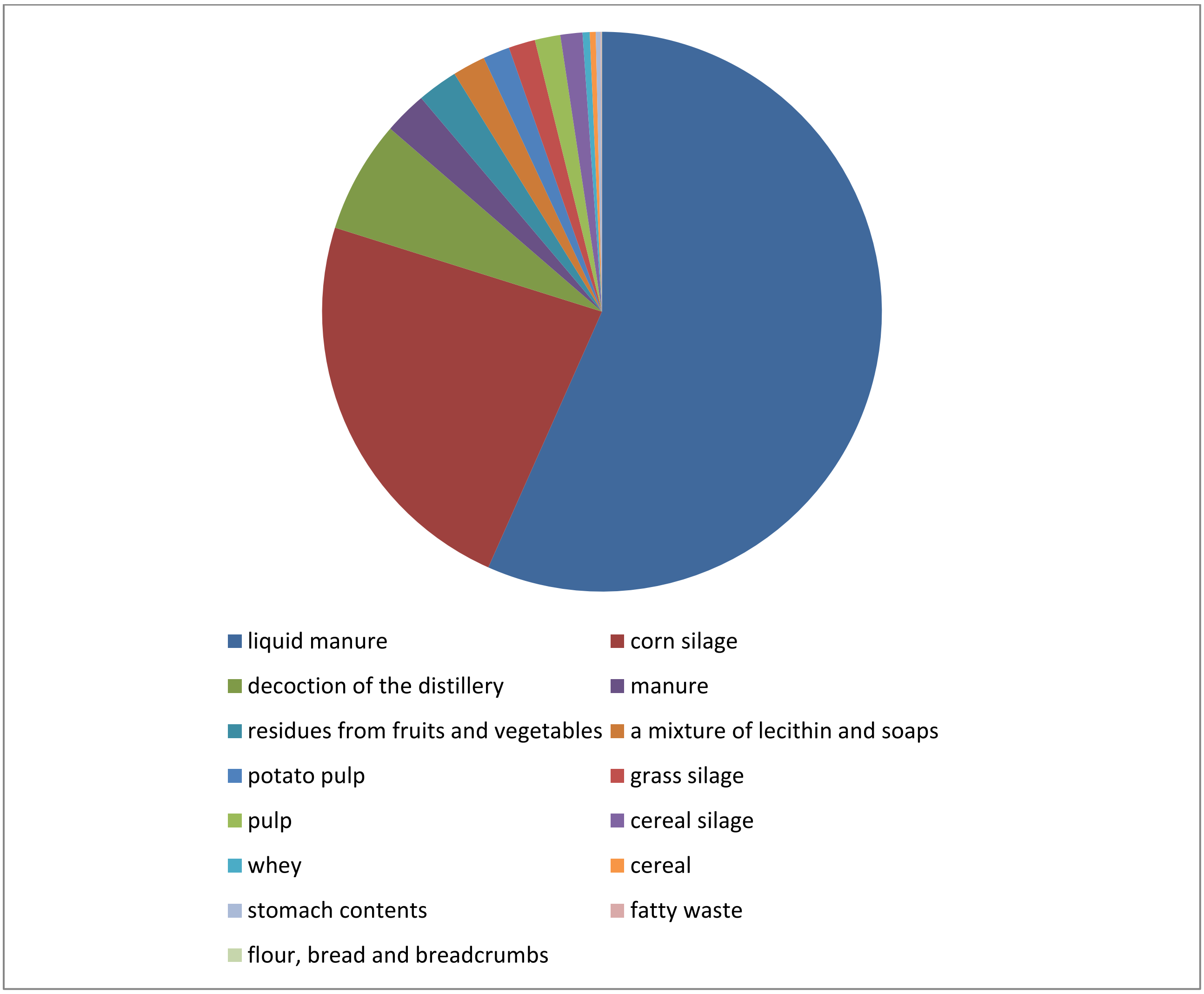

Figure 5 Percentage of raw materials consumed in the production of agricultural biogas in 2011

Source: Own calculations based on data from AMA

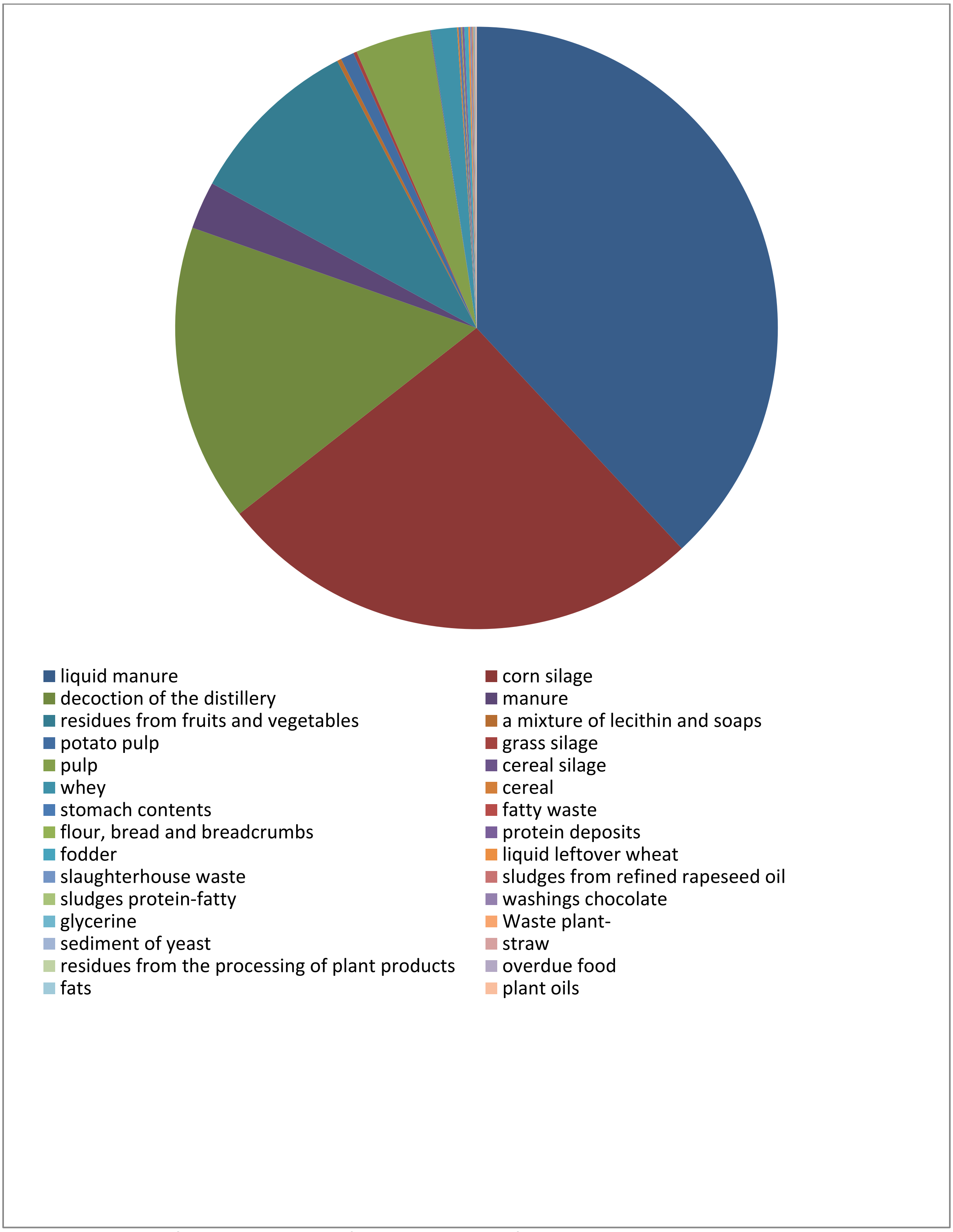

Figure 6 The share of raw materials used for the production of agricultural biogas in 2012

Source: Own calculations based on data from AMA

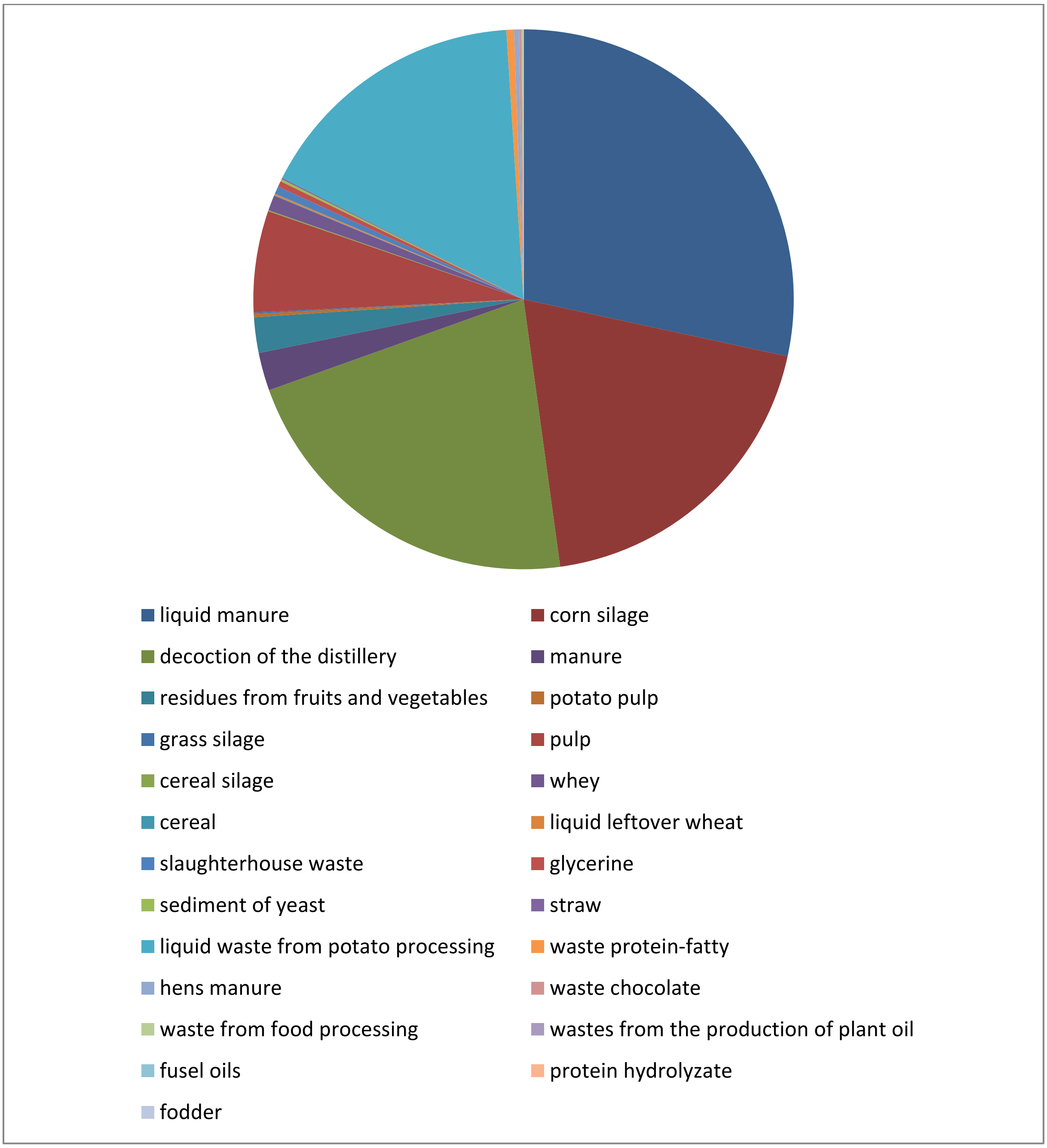

Figure 7 The share of raw materials used for the production of agricultural biogas in the first half of 2013

Source: Own calculations based on data from AMA

Conclusions:

1. Construction of biogas plants is supported by grants from the European Union. This creates real opportunities for increasing attempts to provide entrepreneurs with agricultural energy self-sufficiency.
2. Number of farms engaged in livestock farming and having the ability to crop, for example, maize for biogas, has the ability to secure adequate quantities of agricultural waste and solid substrates, which allow to produce significant amounts

of electricity and heat.

3. There has been an increase in agricultural biogas plants, and hence increased production of agricultural biogas. Data from the first half of 2013 indicates that biogas production again increased compared to the previous year. Currently registered 39 energy companies involved in the production of agricultural biogas.
4. It has been shown that the search for new substrates which will produce more biogas.

References:

1. Khanna M., Dhungana B., Clifton-Brown J.: *Costof producing miscanthus and switchgrass for bioenergy in Illinois.* Biomass and Bioenergy. Vol. 32 s. 482–493, 2008.
2. Kopiński J., Matyka M., MadejA: *The influence of natural conditions on the profitability of growing maize for biogas.* Annals of SERIES. T. 13 Issue 5 pp. 35-38, 2011.
3. Fischer T., Krieg A.: *Design and construction of biogas plant.*Krieg &Fischer, 2007
4. Szlachta J.: *The possibility of biogas production from agricultural products.* Presentation at the International Conference in Warsaw IBMER, s.223-229, 2008.
5. Fachagentur Nachwachsende Rohstoffe e.V. (2006) Handreichung Biogasgewinnung und –nutzung, Instytut für Energetyk und Umwelt gGmbH, Bundesforschungsanstalt für Landwiirtschaft, Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V., Gülzow, Niemcy,
6. Kujawski O.: *Technology Review biogas production (first part).* Clean Energy No. 100 – 2009/12.
7. Faulstich M., Bilitewski B.:, *Stand der Technik der Biogasanlagen, Beiträge zur Abfallwirtschaft* - Schriftenreihe des Institutes für Abfallwirtschaft und Altlasten technische Universität dresden, Band 7: Anaerobe biologischeAbfallbehandlung, Drezno 1998, 9-33.
8. Pilarski K., Adamski M.: *Prospects for biogas production taking into account the reaction mechanisms in terms of quantitative and qualitative analysis of fermentation processes.* Journal of Research and Application in Agriculture Engineering" 2009, Vol. 54(2).

9. Schlesinger W.H.: Biogeochemistry. An analysis of global change, Academic Press, San Diego 1997, 231-238.
10. Schink B. (1997): Energetics of Syntrophic Cooperation in Methanogenic Degradation Microbiology and Molecular, Biology reviews, 61 (2), 262-280.
11. Smith M.R., Zinder S.H., Mah R.A. Microbial methanogenesis from acetate, Proc. Biochem. 1980, 15:3439
12. BioPower: *Diagram of the plant.* Access 21.02.2014: http://bio-power.pl/schemat-dzia%C5%82ania-biogazowni.html
13. Polish Biogas Plants: *How does a biogas plant.* Access 21.02.2014: http://biogazownie.pl/fermentacja-metanowa.html
14. Institute for Sustainable Development in cooperation with the Institute for Renewable Energy: *Small Biogas Plant Agriculture*. Brochure published as part of the project "With energy environment friendly for you brother" Warsaw 2011.
15. Latocha L.: Materials from the training "Renewable energy sources for home and business 2010.
16. Żmuda K : Materials from conference "Renewable energy for home and business" Clean energy "monthlies 2010.
17. Polish Group Biogas: *More energy from nature. Biogas plant in the municipality of Czernikowo.* Access 23.02.2013: http://www.czernikowo.pl/plik,16833,prezentacja-polskiej-grupy-biogazowej-sp-z-o-o.pdf
18. Agricultural Market Agency: *Registry energy companies involved in the production of agricultural biogas.* Access 20.02.2014:. http://www.arr.gov.pl/data/02004/rejestr_biogazowni_rolniczych_21022014.pdf

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Using cementation and fertilization in industrial wastewater cleaning from copper

Key words: *copper cementation method, fertilization, wastewater*

Abstract: The purpose of this paper is the experimental study of the technological effect cleaning solution of copper cementation method and fertilization. Prospective use of metallic iron to recover copper.

1. Introduction.

Development of industry in Ukraine is accompanied by the considerable increase of contamination of environment . The sewage treatment plants of cities are unable to disinfect mixture of domestic and sewer waters. Sediment, appearing not always can be used with the purpose of receipt of after product, from the presence of far of admixtures, thrown down by industrial enterprises.

Simultaneously with industrial effluents the far of valuable components is lost - annually with the effluents of galvanic enterprises 0,46 tons of copper are thrown down ,while the requirements of Ukraine in this metal make approximately 120-140 thousand ton /year.

One of ways of decision of this problem is using resources saving flow scheme of processing galvanic productions, effluents line of copper plating with the repeated use of cleared water, and connections of heavy metals. Considerable influence on contamination connections of copper has a production of PCBS, where depending on their structural features the different variants of technological processes are accepted. In the processes of production of PCBS appears the concentrated solution with maintenance of copper Cu (II) a more than 50 g/ dm^3. Cleaning of the concentrated solution which includes copper can be produced by different ways, including by renewal copper means of iron. As the last the ferrous shaving is, used so finely dispersible particles of iron as powder by largeness 0, 5-0, 7 mm. At application of the ferrous shaving complication of process consists of subsequent dissociating from her to the copper, the use of ferrous powder that is more effective therefore

$$Cu^{2+} \rightarrow Cu^{0} \rightarrow E^{0} = +0,3456B$$
$$Fe^{2+} \rightarrow Fe^{0} \rightarrow E^{0} = -0,4736\ B \qquad (1)$$

Formation of copper and dissolution of particles of iron take place on next step:

$$CuCl_2+Fe=FeCl_2+Cu$$
$$Fe^0+Cu^{2+}\rightarrow Fe^{2+}+Cu^0$$

(2)

A process flows in a limit volume of reactor in a sour environment at interfusion. For two substances, being of interest, copper and iron (A and B) of being in a reactor, formation of hard phase we can express, as

$$kA^{2+}+\beta^0\rightarrow A^0+ k\beta^{2-}$$

(3)

Accepted the reaction of copper renewal and oxidization of iron as homogeneous (k is a stechiometrical coefficient). Taking into account that efficiency of realization process of renewal copper makes in stakes from unit and iron dissolves fully. The effect of cleaning of solution on a copper arrives at 98-99%. The remaining concentration of copper in solution in this case makes 500-250 mg/dm^3, that considerably exceeds the possible concentration of copper for an up cast in the reservoirs with fish setting objects.

As a result of the done operation crystallization of copper is produced in the volume of solution in a reactor with formation of powdery copper and concentrated solution of salts, containing the copper of Cu (II) and iron of Fe (II).

The next stage of cleaning solution from the ions of copper consists of joint moving away of copper and iron with formation of hard phase of ferrits. Formation of ferrits - salts of ferrous acid of $HFeO^2$ produced of different ways and finds a wide use in a modern technique. In technologies of water treatment one of basic dignities of ferrits consists of possessing of magnetic properties, that allows to dissociate them from other un magnetic substances, by the magnetic field. Connections of iron, answering the general formula $MoFe^2O^3$(M- is an ion two valency threw), behave to the ferrits.

Capacity of metals for formation of ferrits to be among Ca<Zn<Co<Ni<Cu.

Maximal activity by education ferrits shows a copper that possesses properties of catalyst in the processes of ferritisation.

Formation of ferrits at treatment of solution of containing Fe(II), depends on a pH, temperature and amount of the oxygen used as an oxidant. In a number of cases, as results of our researches showed receipt of oxides of iron and ferrits, can be and without blowing out by air.

The receipt of ferrits takes place in two stages:

- in the first stage are formed hydroxides

$$xM^{2+} +(3-(X)Fe^{2+} + 6OH^{-} \rightarrow MxFe_{3-x} (OH)_6 \quad (4)$$

- oxidation hydroxides to the oxides

$$MxFe_{3-x} (OH)_6 +1/2\ O_2 \rightarrow MxFe_{3-x} \quad (5)$$

At formation of hard phase connection between a temperature (in the range of 40-80°C), of concentration of iron (of 1-4 g/dm^3) and pH 7,5-12,5 shows up in that at the increase of maintenance of iron diminishes area of value of pH, within the limits of that there is ferritisation, and the increase of temperature causes expansion of this area. Copper ions being in solution results in their effective moving away in the process of ferritisation. We developed low-temperature synthesis of copper ferrite and determine optimal parameters of it obtaining: pH value of ≈ 9.0; air bubbling for oxidation of Fe (II) at rate of about 1 cm^3/s; duration of the ferritisation process depends on temperature; it lasts approximately 30 min at temperatures over 60°C. The process of ferrite formation may be accelerated (almost twice) by addition of crystalline ferrite particles. The necessary amount of the crystallisation initiator reaches about 0.05 g/dm^3. Using X-ray diffraction and electron microscopy we have studied structures of materials produced. They are insoluble in water, contain magnetite and copper ferrite with ferromagnetic properties, and therefore might be easy separated from solutions with usage of special magnetic filters. Kinetic of ferrite removing process has been investigated for design and selection of optimal regime for work of sorbtion filters.

2. Research of process of water treatment from a copper in static terms in the process of it cementation on the particles of ferrous powder.

The tests of moving away of copper carried out in static terms on model solution in the process of it cementation on the ferrous particles of powder in a reactor, the general sizes of column of that made 4 x4x12 of cm.

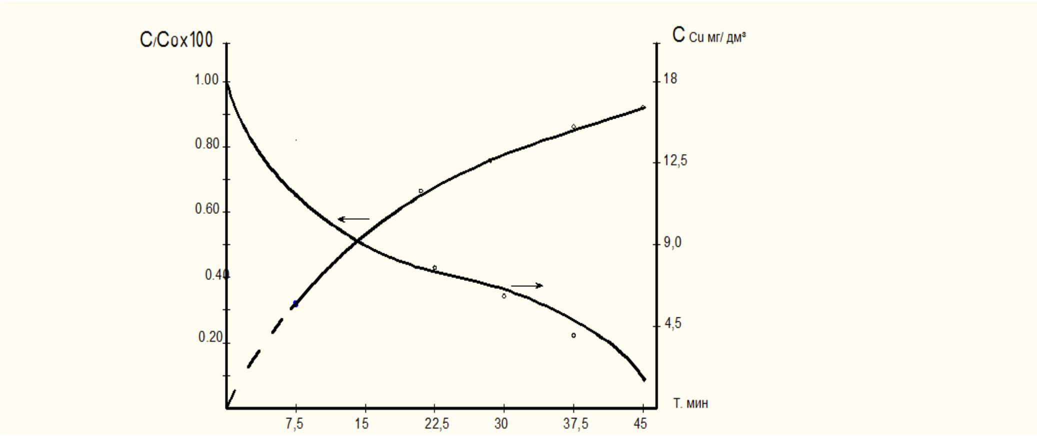
Ferrous powder as particles by a largeness a 0,5-0,7 mm was situated on the tissue lining and placed in solution containing a copper. The area of surface of particles made 1,13 mm^2, particles laid out by a layer in a 1-2 mm, thick and their area at the sizes of column a 40x40 mm(in a plan) makes 5,8 cm^2, 9224 mm^2(92 cm^2) at the amount of layers 3, here the general area of ferrous particles makes 276 cm^2.

Taking, into account that the process of dissolution takes place from a surface, and a reactor is executed as a column with the row of shelves on that ferrous powder, took place we were estimate efficiency of dissolution, taking into account the general surface of particles, the results of experiments are presented in a table.

Table. 1. Changes of copper maintenance.

№	experiments time Min.	The content of copper in solution, g/cm^3	Reducing the amount of copper in solution g/cm^3	The effect of treatment C/C_0 x100%	Amount of copper that come g
1.	2.	3.	4.	5.	6.
1.	7.5	$12{,}02 \times 10^{-3}$	$5{,}98 \times 10^{-3}$	33,2	$95{,}0 \times 10^{-3}$
2.		$12{,}02 \times 10^{-3}$	$5{,}98 \times 10^{-3}$	33,2	$95{,}0 \times 10^{-3}$
3.		$12{,}1 \times 10^{-3}$	$5{,}9 \times 10^{-3}$	32,9	$94{,}0 \times 10^{-3}$
4.		$11{,}97 \times 10^{-3}$	$6{,}03 \times 10^{-3}$	33,5	110×10^{-3}
5.		$12{,}04 \times 10^{-3}$	$5{,}96 \times 10^{-3}$	33,1	110×10^{-3}
6.	15	$8{,}75 \times 10^{-3}$	$9{,}25 \times 10^{-3}$	51,4	148×10^{-3}
7.		$8{,}59 \times 10^{-3}$	$9{,}47 \times 10^{-3}$	52,6	151×10^{-3}
8.		$8{,}67 \times 10^{-3}$	$9{,}33 \times 10^{-3}$	51,8	167×10^{-3}
9.		$8{,}61 \times 10^{-3}$	$9{,}39 \times 10^{-3}$	52,2	169×10^{-3}
10.		$8{,}56 \times 10^{-3}$	$9{,}44 \times 10^{-3}$	52,4	151×10^{-3}
11.	22.5	$8{,}40 \times 10^{-3}$	$9{,}6 \times 10^{-3}$	63,3	152×10^{-3}
12.		$8{,}32 \times 10^{-3}$	$9{,}68 \times 10^{-3}$	63,8	165×10^{-3}
13.		$8{,}37 \times 10^{-3}$	$9{,}63 \times 10^{-3}$	63,5	164×10^{-3}
14.		$8{,}28 \times 10^{-3}$	$9{,}72 \times 10^{-3}$	64	169×10^{-3}
15.		$8{,}35 \times 10^{-3}$	$9{,}65 \times 10^{-3}$	63,6	168×10^{-3}
16.	30	$4{,}86 \times 10^{-3}$	$13{,}14 \times 10^{-3}$	73	210×10^{-3}
17.		$4{,}95 \times 10^{-3}$	$13{,}05 \times 10^{-3}$	72,5	215×10^{-3}
18.		$4{,}75 \times 10^{-3}$	$13{,}25 \times 10^{-3}$	73,6	205×10^{-3}
19.		$4{,}86 \times 10^{-3}$	$13{,}13 \times 10^{-3}$	73,4	208×10^{-3}
20.		$4{,}89 \times 10^{-3}$	$13{,}11 \times 10^{-3}$	72,8	212×10^{-3}
21.	37.5	$3{,}06 \times 10^{-3}$	$14{,}94 \times 10^{-3}$	83	222×10^{-3}
22.		$2{,}77 \times 10^{-3}$	$15{,}28 \times 10^{-3}$	84,4	225×10^{-3}
23.		$2{,}71 \times 10^{-3}$	$15{,}51 \times 10^{-3}$	86,4	227×10^{-3}
24.		$2{,}93 \times 10^{-3}$	$15{,}07 \times 10^{-3}$	83,7	224×10^{-3}
25.		$2{,}66 \times 10^{-3}$	$15{,}34 \times 10^{-3}$	85,2	226×10^{-3}
26.	75	$1{,}54 \times 10^{-3}$	$16{,}46 \times 10^{-3}$	81,4	265×10^{-3}
27.		$2{,}01 \times 10^{-3}$	$15{,}99 \times 10^{-3}$	88.5	260×10^{-3}
28.		$1{,}98 \times 10^{-3}$	$16{,}02 \times 10^{-3}$	88,3	256×10^{-3}
29.		$1{,}9 \times 10^{-3}$	$16{,}1 \times 10^{-3}$	89,4	258×10^{-3}
30.		$1{,}5 \times 10^{-3}$	$16{,}5 \times 10^{-3}$	91,2	264×10^{-3}

Table shows changes of copper maintenance, that driven in the process of cementation on the particles of iron, water containing a copper is presented by solution $CuCl_2$, concentration of copper of 18 x10 - 3 g/dm^3, pH = 1,5; temperature of solution 20 ^oC . Volume of solution containing a copper, made 160 cm^3, and common amount of ferrous particles - 95 g.



Picture 1.

The results of researches testify to, that change of amount of copper in solution, in static terms, in time it is possible to present correlation

$$v = K_0 C^n$$

(6)

V- is speed of chemical reaction of formation copper due to renewal on the metallic's, K_0 – constant speed of chemical reaction, *n*- is an order of reaction, for determination of reaction order graphic method is used ,it is Known, that for the order of reaction 1,2,3 decision of equalization following:

$$\ln C = \ln C_0 - Kt; \quad \frac{1}{C} = \frac{1}{C_0} + Kt$$

(7)

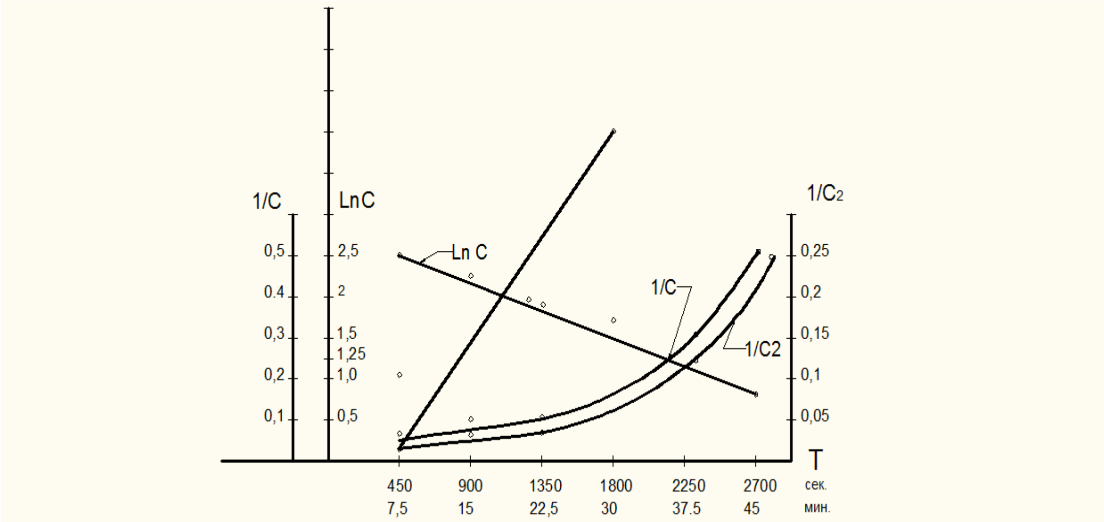
$$\frac{1}{C_2} = \frac{1}{C^2{}_0} + 2Kn \quad \text{it is graphically expressed } \ln C = f(t)$$

$$\frac{1}{C} = f(t) \; And \; \frac{1}{C_2} = f(t)$$

(8)

A function is most close to linear dependence corresponds to the order of reaction. In this case $\ln C = f(t)$ and from we are accept $n = 1$.

Reaction the second order $\frac{1}{C} = f(t)$ and reaction of the third order $\frac{1}{C_2} = f(t)$ presented:



Picture 2.

We are undertake the attempt of construction of mathematical model of process of cementation obtained experimental data allow to build the mathematical model of flowing process of cementation.

Undertaken studies allowed setting the high effect of water treatment from a copper, to get copper powder and set factors influencing on a process cementations. The technology allows utilisation of toxic industrial waste with production of a marketable product - magnetostriction material.

References:

1. Kochetov G.M. Emelianov B.M, Ternovtsev V.E.(1998). Improvement of Water Treatment : Heavy Metals
2. Alex Goldman MODERN FERRITE TECHNOLOGY Pittsburgh, PA, USA Library of Congress Control Number: 2005933499