Attachment no. 3

SUMMARY OF SCIENTIFIC ACCOMPLISHMENTS

Description of a series of publications titled

By-products of solid waste management as unrecognized sources of endocrine-disrupting compounds, and the methods for limiting their environmental influence

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Department of Sanitary Engineering

Sylwia Fudala-Książek

Gdansk, 2018

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Sylwia Fudala-Księżak

1. NAME AND LAST NAME

Sylwia Fudala-Książek

2. DIPLOMAS AND SCIENTIFIC DEGREES RECEIVED, INCLUDING THE DEGREE TITLE, LOCATION AND YEAR OF RECEIPT, AND THE DOCTORAL DISSERTATION TITLE

- Doctoral diploma in technical sciences in the field of environmental engineering obtained at the Faculty of Civil and Environmental Engineering, Gdansk University of Technology (GUT) on December 14, 2011. The title of doctoral dissertation: The influence of landfill leachate on the effectiveness of municipal wastewater treatment plant. Promoter: Bernard Quant, Eng., PhD, habilitated, professor of GUT.
- MSc, Eng. Diploma in the field of environmental protection and management, with a grade "very good", obtained at the Department of Environmental Engineering, Faculty of Civil and Environmental Engineering, Koszalin University of Technology on July 26, 2004. The title of Master's thesis: The analysis of possible neutralization of waste originating from non-industrial wastewater treatment plants. Promoter: Adam Boguski, PhD, Eng.
- Postgraduate studies (two semesters) titled Technology of water, wastewater and solid waste. The studies conducted at the Faculty of Civil and Environmental Engineering, Koszalin University of Technology between 2003 and 2004 (ending date: September 14, 2004).
- Pedagogical studies (four semesters) at the Faculty of Management and Economics, Gdansk University of Technology in the years 2010-2012 (ending date: May 30, 2012)

3. INFORMATION ABOUT EMPLOYMENT IN SCIENTIFIC INSTITUTIONS

01 October, 2012 – now Faculty of Civil and Environmental Engineering; associate professor at the Department of Sanitary Engineering (full-time)

01 October, 2011 – September 30, 2012 Gdansk University of Technology, Faculty of Civil and Environmental Engineering; assistant professor at the Department of Sanitary Engineering (full-time)

01 February, 2010 – September 30, 2011 Gdansk University of Technology, Faculty of Civil and Environmental Engineering; assistant professor at the Department of Sanitary Engineering (half-time);

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4. ACCOMPLISHMENTS RESULTING FROM ARTICLE 16, PAR. 2 OF THE LAW ON SCIENTIFIC DEGREES AND TITLES AND DEGREES AND TITLES IN THE AREA OF ART, (DZ. U. 2016 r. poz. 882 ze zm. w DZ. U. z 2016 r. poz. 1311.)

4.1. Title of scientific accomplishment

The scientific accomplishment titled **By-products of waste management as an unrecognized source of micropollutants displaying estrogen-like biological activity, and the methods for limiting their environmental influence** encompasses a series of monothematic papers with the pooled **IF** value of **20.928** and the total number of points assigned by the Ministry of Science and Higher Education, **PM** equal **128.5** (considering own input) (listed in point 4.2.).

4.2. Monothematic series of publications contained in the summary of scientific accomplishments

1. **Fudala-Ksiazek S.**, Pierpaoli M., Kulbat E., Luczkiewicz A., 2016. A modern solid waste management strategy-the generation of new by-products. Waste Management, vol. 49, 516-29. doi: 10.1016/j.wasman.2016.01.022.

(IF = 4.669; PM = 40)

I estimate my input at 75%.

2. **Fudala-Ksiazek S.**, Luczkiewicz A., Kulbat E., Remiszewska-Skwarek A., 2016. Characteristics of liquid by-products generated at municipal solid waste plants (MSWP) in terms of treatment method choice. Rocznik Ochrona Środowiska, vol. 18(2), 952-963.

(IF = 0.808; PM = 15)

I estimate my input at 80%.

3. **Fudala-Ksiazek S**., Pierpaoli M., Luczkiewicz A., 2017. Fate and significance of phthalates and bisphenol A in liquid by-products generated during municipal solid waste mechanical-biological pre-treatment and disposal. Waste Management, vol. 64, 28-38. doi: 10.1016/j.wasman.2017.03.040.

(IF = 4.669; PM = 40)

I estimate my input at 80%.

4. **Fudala-Ksiazek S.**, Sobaszek M., Luczkiewicz A., Pieczynska A., Ofiarska A., Fiszka-Borzyszkowska A., Sawczak M., Ficek M., Bogdanowicz R., Siedlecka E.M., 2018. Influence of the boron doping level on the electrochemical oxidation of raw landfill leachates: Advanced pre-treatment prior to the biological nitrogen removal. Chemical Engineering Journal, vol. 334, 1074-184, doi: 10.1016/j.cej.2017.09.196

(IF = 6.216; PM = 45)

I estimate my input at 50%.

5. **Fudala-Ksiazek S.**, Pierpaoli M., Luczkiewicz A. 2018. Efficiency of landfill leachate treatment in a MBR/UF system combined with NF, with a special focus on phthalates and bisphenol A removal. Waste Management, vol. 78, 94-103; doi:10.1016/j.wasman.2018.05.012

(IF – 4.669, PM – 40)

I estimate my input at 80%.

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Summary

Item	Number of points	Percentage input per publication	Number of points, including % input	Impact Factor
Ad.1	40	75%	30	4.669
Ad.2	15	80%	12	0.705
Ad.3	40	80%	32	4.669
Ad.4	45	50%	22.5	6.216
Ad.5	40	80%	32	4.669
Sum	**180**	-	**128.5**	**20.928**

My mean input in the listed publications amounts to **73%**.

4.3. Description of scientific targets in relation to the aforementioned works and the results achieved, including their possible applications

After joining the European Union, Poland has had to assume a number of obligations, including the creation of legal basis for the sustainable management of municipal solid waste. The ramifications of a new program titled 'Zero waste' were introduced, according to which the future waste output should be prevented or minimized, while the storage of the already existing waste has to limited via recycling, and material and energy recovery. As a result of five-tier hierarchy for managing waste[1], only the waste whose output could not be prevented or reclaimed should end up at landfills. At the same time, in accordance with the Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste[2], the amount of biodegradable municipal solid waste for landfilling will be decreased. The significant changes in waste management have been undertaken in order to increase the effectiveness of natural resources use and to limit the environmental pressure related to managing the waste. The general purpose and measures proposed within the framework of 'zero waste' program are widely considered as beneficiary and desired, however, some solutions raise concerns. This is mainly due to the fact that the environmental impact assessment is not required for mechanical-biological treatment (MBT) plants processing mixed waste. Prior to landfilling, the mixed waste should be separated into fractions that will be fully or partially recovered. Consequently, it has been assumed that the newly created landfills, containing less substances prone to biodegradation, will emit lower amounts of greenhouse gases, while the quality of produced leachates in relation to inorganic pollutants content will become significant. These assumptions are based on modeling only, and thus require verification. The aforementioned aspect is particularly crucial for Poland and the new EU-member countries where the

[1]Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives
[2]Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste

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segregation of municipal solid waste is still not efficient enough due to the lack of ecological knowledge. Unsatisfactory waste segregation at source may result in the different emission potential of new landfill prisms than expected. Moreover, the management of landfill leachates is a significant but often omitted or downplayed issue in waste management. Landfill leachates (LLs) are liquid by-products generated during the storage of solid waste. Their composition depends on many factors, inter alia, the degree of waste decomposition, water content in the waste, atmospheric precipitation, and the way the landfill is used. In Poland, for many years, there were no legal regulations related to the segregation and storage of potentially hazardous waste, such as medical discards, residues of medications, pesticides and other herbicides, electrical and electronic waste (e.g. batteries), dyes, lacquers, plastics, ash, etc. As a result, leachates generated at the landfills have very complex chemical composition, while the determined indicator levels (e.g. COD, total nitrogen, ammonia) are many times higher than those measured in municipal wastewater. It should also be underlined that the landfill facilities in Poland and new EU-member countries usually exploit two types of prisms, i.e. modern prisms, MP that fulfill the EU requirements (exploitation started after 2010), and previous prisms, PP which have been exploited *ad hoc*, without separating the biodegradable fraction and insulating the bottom of the prism with the membrane liner.

Presently, in accordance with the decree of the Minister of Environment on landfills[3], landfill leachates should be monitored with regard to the following parameters: pH, electrolitycal conductivity, total organic carbon (TOC), the contents of selected heavy metals (Cu, Zn, Pb, Cd, Cr^{+6} and Hg), and the sum of PAHs (without specifying the individual compounds). However, the detailed data on landfill emissions of substances that influence the environment and human health (e.g. priority compounds within the framework of water policy[4]) is not yet available. Moreover, research on determining the emission potential of modern prisms, and the amount and quality of technological wastewater generated by mechanical biological treatment of waste is lacking. Due to the above, the management of wastewater and landfill leachate is an important problem for the waste treatment plants.

At present, managing the landfill leachates and technological wastewater in Poland is based on treating them together with municipal wastewater and/or pre-treating them, mainly via physico-chemical methods. Treating the leachates combined with municipal wastewater was one of the common solutions, although non-biodegradable persistent organic compounds

[3]Rozporządzenie Ministra Środowiska z dnia 30 kwietnia 2013 r. w sprawie składowisk odpadów (Dz.U. 2013 poz. 523)
[4]Dyrektywa Parlamentu Europejskiego I Rady 2013/39/UE z dnia 12 sierpnia 2013 r. zmieniająca dyrektywy 2000/60/WE i 2008/105/WE w zakresie substancji priorytetowych w dziedzinie polityki wodnej

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present in leachates increasingly become the center of interest. This fraction (so-called inert COD) increases COD of treated wastewater and thus the resulting payments for using the environment[5]. Moreover, the higher content of ammonium nitrogen in leachates inflowing to WWTP results not only in increased operation costs but also in costs related to the intensity of aeration and possible technological problems connected to the instability of biological removal of phosphorus[5]. On the other hand, the leachate pre-treatment in the waste treatment plants is mainly realized by reverse osmosis. This method is not a *sensu stricto* treatment because it only leads to the separation of pollutants. This results in the formation of high quality permeate and concentrate enriched in pollutants. The former is dumped into sewage or a receiving container, while the latter has to be managed further. At present, the concentrate is most often rerouted to the landfill prism which causes the enrichment of leachate and gives rise to many critical and, at the same time, costly technological problems.[6]

Another problem that still remains unrecognized is the management of technological wastewater originating from Regional Installations for Processing Municipal Solid Waste (RIPOK). The lack of data on the amount and quality of wastewater from mechanical and biological treatment of wastes in the segregating unit (SU) and composting unit (CU; composting of biodegradable fraction) causes that this wastewater is mainly returned to the landfill prism. The effect of this procedure on the biodegradation of waste and the emission potential of landfill prism has not yet been determined.

In connection with the above, I undertook scientific investigations aimed at testing the following hypothesis: **Novel methods of solid waste treatment generate by-products that constitute an unrecognized source of micropollutants which affect the environment and human health. Another important aspect of the realized work was to undertake measures aimed at minimizing the environmental costs related to the implementation of the 'zero waste' program.**

I conducted investigations in three thematic areas, as follows:

Theme no. 1: The quantitative and qualitative characterization of technological wastewater and landfill leachates generated by a solid waste treatment plant, and the

[5]Remiszewska-Skwarek A**.,** Fudala-Ksiazek S., Luczkiewicz A., 2016. The influence of industrial wastewater on the energy consumption and the efficiency of technological processes in municipal wastewater treatment plant. Rocznik Ochrona Środowiska vol. 8 (2), pp. 110-121

[6] Fudala-Ksiazek S., Pierpaoli M., Luczkiewicz A. 2018. Efficiency of landfill leachate treatment in a MBR/UF system combined with NF, with a special focus on phthalates and bisphenol A removal. Waste Management – in print, DOI: 10.1016/j.wasman.2018.05.012

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identification of processes taking place in modern prisms with a limited content of biodegradable compounds.

Theme no. 2: Characterization of endocrine active compounds present in technological wastewater and landfill leachate.

Theme no. 3: Effectiveness determination of selected methods for treating technological wastewater and landfill leachate in relation to the removal of macro- and micropollutants.

The research themes I decided to undertake are significant from the scientific and technological points of view. To the best of my knowledge, this is the first attempt (I) to characterize the emission potential of modern prisms, and (II) to quantitatively and qualitatively analyze landfill leachates and technological wastewater originating from mechanical-biological treatment (MBT) of waste (III) in relation to ensuring their effective and economical treatment. In the available literature, both domestic and foreign, the information on this subject is lacking.

I conducted studies in Pomorskie voivodship, an important ecosystem because of its landscape and economical values, which remains under strong anthropopressure. The research material consisted of the samples of leachate and technological water from two waste treatment plants, i.e. Eko-Dolina in Łężyce (metropolitan area surrounding the city of Gdynia) and Nowy Dwór near Chojnice (farmland and small town) (Fig. 1). The investigations were conducted as a multiannual sampling series (> 4 yr), which allowed for including the seasonal variability as well as the aging process of landfill prisms.

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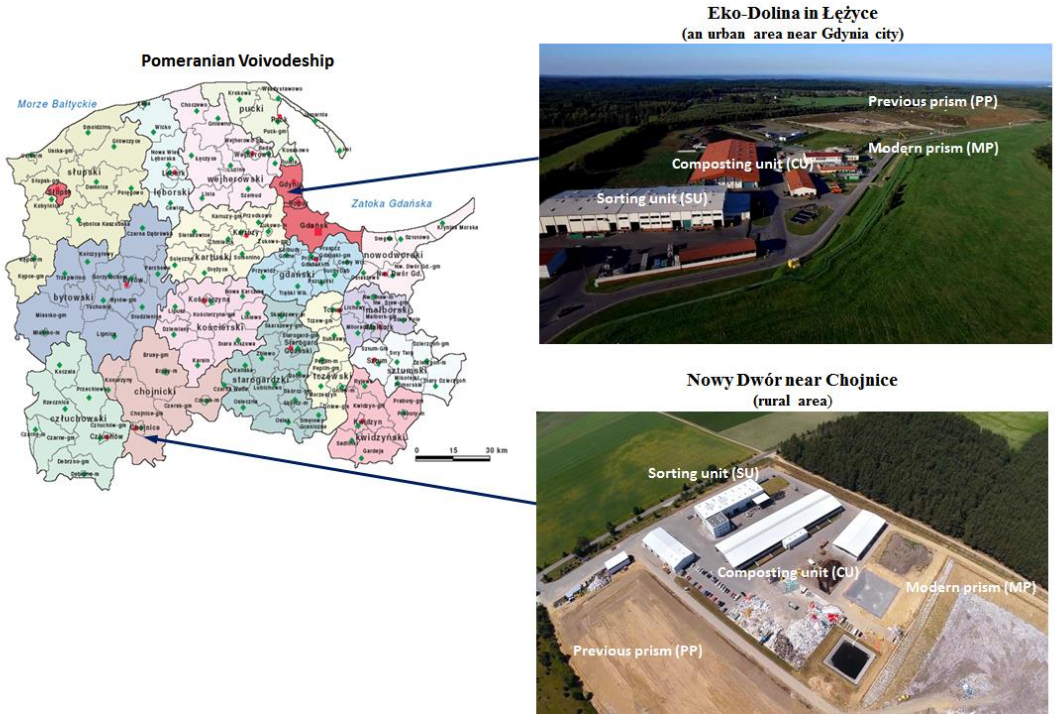

Fig. 1. Location of waste treatment plants in Pomorskie voivodship that were a subject of investigation.

In my work I used standardized research methodology. The basic physical and chemical indicators were analyzed in accordance with APHA[7] and included pH/temperature; conductivity assessed via electrochemical techniques; total nitrogen (TN) and its forms (N-NH_4, N-NO_3, N-NO_2); total phosphorus (TP) and orthophosphate (P-PO_4); chemical oxygen demand (COD) via spectrophotometric techniques; biological oxygen demand (BOD_5 and BOD_{20}) via manometric measurements; and total and inorganic suspension by weighing. In order to determine the presence of endocrine disrupting compounds (EDCs), bisphenol A (BPA), and selected phthalate esters (PAEs) such as, dimethyl phthalate (DMP), diethyl phthalate (DEP), di-n-butyl phthalate (DnBP), benzyl butyl phthalate (BBzP) and bis(2-ethylhexyl (DEHP), gas chromatography coupled to mass spectrometry (GC/MS) (Shimadzu QP2010 SE) was employed. Chromatographic separation was performed by using a ZB-5MS capillary column (Phenomenex). Moreover, appropriate extraction techniques were used to prepare solvent-based extracts (e.g. liquid-liquid extraction, LLE and solid phase extraction, SPE).

The taxonomic composition of organisms present in leachates, technological wastewater and municipal wastewater was determined by applying a metagenomic approach via next-

[7]American Public Health Association, American Water Works Association, Water Pollution Control Federation, and Water Environment Federation, 2005. Standard Methods for Examination of Water and Wastewater, 21st ed. American Public Health Association, Washington, D.C.

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generation sequencing. In addition, the temporary changes in microbial composition were analyzed by using real-time polymerase chain reaction (PCR) that is also called qualitative PCR (qPCR). This method was employed to search for the key functional genes engaged in methanogenesis (*mcr*A) and dissimilatory sulfate reduction (*dsr*A).

The obtained databases were statistically analyzed by applying the principal component analysis, PCA and independent component analysis, ICA. Such approach enabled the reduction of variables by rejecting insignificant variables and the variables that were strongly correlated with the main variables. Thus, it was possible to determine the indicator parameters that are crucial for describing the biological and chemical processes undergoing during mechanical-biological treatment of waste and inside the landfill prisms. The location of sampling stations is presented in Fig. 2

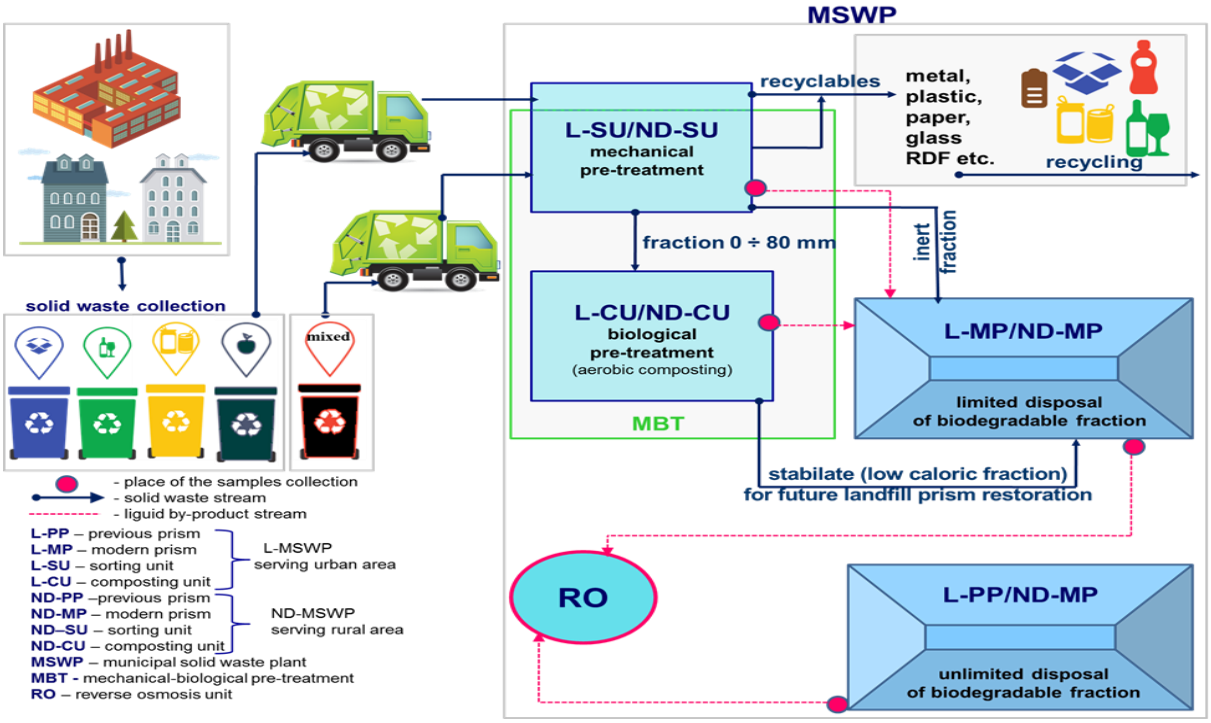

Fig. 2. Location of sampling stations.

Ad theme no. 1.

The quantitative and qualitative characterization of technological wastewater and landfill leachate generated by a solid waste treatment plant, and the identification of processes taking place in modern prisms with a limited content of biodegradable compounds.

It is a common knowledge that the amount of waste increases with increasing number of inhabitants and improving lifestyle level. However, the presently enforced EU regulations obligate to follow the ‘zero waste’ strategy which calls for the prevention or minimization of waste generation. In the case of already existing waste, waste reclamation and reduction in

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landfilling should be secured. In connection with the above, Poland and other EU member countries are obligated to, *inter alia*, limit the amount of biodegradable municipal solid waste destined for storage. The established limits for such waste (expressed as the percentage of total waste mass generated in 1995) were set at 75, 50 and 35% for the cut-off point years 2006, 2009 and 2013, respectively. Poland, who in 1995 was landfilling over 80% of municipal solid waste, received a 4-yr extension (75% until 2010; 50% until 2013; and 35% until 2020) together with Bulgaria, Cyprus, Czech Republic, Estonia, Greece, Ireland, Latvia, Lithuania, Malta, Portugal, Romania, Slovakia and Great Britain. The reduction in the content of organic substances in stored waste has a significant influence on biochemical processes that take place in landfill prisms and, in turn, on the amount and quality of by-products, including landfill leachate. It should be expected that the environmental pressure associated with modern prisms (MPs) exploited after 2010 will be significantly different from that of previous prisms (PPs).

Presently, the lack of data on the aforementioned difference between MPs and PPs precludes the proper identification of biochemical processes undergoing in modern prisms and determining their influence on the environment.

In connection with the above, I based the emission potential studies on the assumption that the biodegradation of municipal solid waste can be described via the qualitative and quantitative analysis of landfill leachate and biogas as by-products mirroring the *status quo* of the entire prism. At present, based on the quality and quantity of leachates and emitted biogas, the four subsequent phases of prism exploitation have been distinguished: 1st phase, i.e. oxidation; 2nd phase via low pH fermentation; 3rd phase, so-called unstable methane-phase; 4th phase, i.e. stable methane-phase; and 5th phase, i.e. oxidation in a previous prism (PP). In the case of modern prisms (MP) containing less substances prone to biodegradation, it has been assumed that the biogas emission will decrease, while the significance of inorganic pollutants in leachate will increase. The aforementioned assumptions are based on modeling and the landfill observations collected in countries that have been conducting the high-level segregation of waste at source for many years. In Poland and other new EU-member countries where the segregation of municipal solid waste is not very effective, the emission potential of modern prisms may be different than expected.

Nowadays, the main activities conducted by Regional Installations for Treating Municipal Solid Waste (RIPOK;) are recovery and neutralization. The installations receive mixed municipal solid waste and waste that has been collected via segregation at source. Both waste streams are sorted separately. The raw materials sorting unit receives waste segregated at

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source that will be processed as recycled raw materials (e.g. glass, paper, cardboard and plastics) and then forwarded to further treatment. This arrangement enables attaining the appropriate levels of recovery and recycling. On the other hand, in the sorting unit of mixed waste three basic fractions are separated, as follows:

- 0-80/100 mm fraction which contains over 80% of biodegradable waste present in mixed municipal solid waste
- 80/100-200/300 mm fraction which contains waste characterized by high potential for recycling as raw materials; it can be used for producing refuse-derived-fuels (RDFs)
- >200/300 mm fraction consisting of textiles, wood, cardboard, synthetic materials, etc. that can be partially recycled after the recovery; the remaining part of the fraction, usually highly caloric, is mostly used in the production of RDFs.

In some RIPOKs the 0-20 mm fraction is separated from the 0-80/100 mm fraction (e.g. at Eko Dolina Sp. z o. o. located near Gdynia). It is the inorganic fraction mainly consisting of ash, sand, soil and debris, which is used for technological purposes at the landfill, for example, for building the insulating layer that protects deposited waste. On the other hand, the organic fraction (20-80 mm) is used in the biological treatment of waste, namely, in stabilization (mainly during composting). The resulting stabilized material is usually employed in the on-going recultivation of landfill prisms. Waste unsuitable for segregation, a so-called ballast, is directed to landfill prisms. Moreover, in some waste treatment plants the green waste segregated at source, i.e. leaves, grass, branches, etc. can be composted disregarding the 0-80/100 fraction. Such units are called green composting units, for example, the unit at Eko Dolina Sp. z o. o.. All installations located at RIPOKs ensure that waste is processed according to the five-tier hierarchy, however, RIPOKs themselves also generate by-products.

During my studies, I collected research material from the following RIPOKs: Eko-Dolina in Łężyce, and Nowy Dwór near Chojnice. Both plants use mechanical-biological treatment of mixed waste, such as sorting (SU) and composting of biodegradable fraction (CU), as well as have the two types of landfill prisms, i.e. modern prism (MP) and previous prism (PP). In order to collect long-term observations of changes taking place in technological wastewater and landfill leachate, sampling was continued for five and three years, respectively. The added value of research conducted by me at the two RIPOKs was the possibility of analyzing leachate originating from modern prisms since the beginning of these structures. The basic

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parameters of solid waste treatment plants, sampling period, and sampling frequency are listed in Table 1.

Table 1. Basic characteristics of the solid waste treatment plants

	Eko Dolina Łężyce	**Nowy Dwór**
Location	- it serves the metropolitan area close to Gdynia; 460 000 inhabitants - it receives ca. 200 000 Mg/yr of solid waste of which 130 000 Mg is municipal waste, including 97 000 Mg of biodegradable fraction	- it serves the rural area near Chojnice; ca. 150 000 inhabitants - it receives ca. 34 000 Mg/yr of solid waste of which 28 000 Mg is municipal waste, including 8 500 Mg of biodegradable fraction
Sorting unit (**SU**)	- in operation since 2010 - capacity of 150 000 Mg/yr - wastewater volume generated during the sorting process amounts to ca. 0.7 m^3/d	- in operation since 2013 - capacity of 35 000 Mg/yr - wastewater volume generated during the sorting process amounts to ca. 0.4 m^3/d
Composting unit (**CU**)	- in operation since 2010 - indoor composting unit for biological treatment of organic waste in the amount of 30 000 Mg/yr - wastewater volume generated during composting amounts to ca. 15 m^3/day	- in operation since 2013 - indoor composting unit for biological treatment of organic waste in the amount of 18 000 Mg/yr - wastewater volume generated during composting amounts to ca. 2 m^3/day
Modern prism (**MP**)	- in operation since 2011 - leachate generated in the amount of ca. 71 m^3/day	- in operation since 2013 - leachate generated in the amount of ca. 10 m^3/day
Previous prism (**PP**)	- in operation from 2003 until 2011 - leachate generated in the amount of ca. 39 m^3/day	- in operation from1992 until 2013 - leachate generated in the amount of ca. 20 m^3/day
Sampling period	From Nov 2011 until Oct 2016	From Dec 2013 until Nov 2016
Sampling frequency	Once a month	Once a month

Based on the obtained research results, I concluded that the previous prisms (PPs) generated leachate with COD and ammonia concentrations much higher than those of so-called modern prisms, the latter being exploited by applying the technology of the limited storage of biodegradable waste. Independent of the sampling site, ammonia was the main nitrogen form present, which confirms the occurrence of organic matter degradation and the limited use of ammonia in microbiological process due to low oxygen availability.

The multidimensional statistical analysis of the obtained database of physical and chemical parameters allowed the identification of two phases in the qualitative composition of leachates from the modern prism (MP). The first shorter phase (from the start of prism exploitation up to 7 months) was mainly characterized by increased suspension level, and the higher values of COD, BOD_5, and $N\text{-}NH_4$ and SO_4^{2-} concentrations. This finding points to the occurrence of the initial oxidation of organic matter contained in stored waste. In the second phase, a visible decrease in the values of SO_4^{2-} and BOD_5 was observed which was the indication of the faster assimilation of biodegradable organic compounds in the presence of, *inter alia*, sulfates acting as electron acceptors. From the scientific point of view, it is critical that the conducted physical and chemical analyses be confirmed by metagenomic analysis. The real-time

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polymerase chain reaction (qPCR) applied in this study identifies the genes involved in dissimilatory sulfate reduction (*dsr*A). The metagenomic data showed that an increase in *dsr*A genes is correlated to decreasing SO_4^{2-} concentration in leachates and increasing methane concentration in the resulting biogas. At the same time, an increase in key genes involved in methanogenesis (*mcr*A) was observed. Moreover, these changes were also reflected in the taxonomic composition of leachates, e.g. the number of obligatory anaerobic species belonging to the domain *Archaea* (*Methanobacteriales* and *Methanosarcinales*, kingdom *Euryarchaeota*) increased from 0.42% in the first few months up to 23.04% after 37 months of prism exploitation. The aforementioned microorganisms produce methane as the metabolic end-product.

It should be stressed that, after five months of MP exploitation, the new-generation sequencing data showed a visible increase in the number of microbes that are able to metabolize complex organic matter. In the same time period, specific changes took place in the investigated plant in relation to managing wastewater, i.e. technological wastewater from reverse osmosis (concentrate) and technological wastewater from SU and CU. At the beginning, all this wastewater was directed to previous prism (PP), and after PP recultivation, to modern prism (MP). The aforementioned wastewater was rich in ammonia (up to 1 610 mg $N\text{-}NH_4/L$) as well as organic matter (COD up to 52 980 mg O_2/L) of which more than half was biodegradable ($BOD_5/COD > 0.5$). In connection with the above, although the loads of basic parameters characterizing landfill leachates (COD, BOD_5, TN, $N\text{-}NH_4$) generated at MP were lower than those observed in leachates originating from PP, and the aging of modern prism was much faster, the expected reduction in the emission of greenhouse gases most likely will not be achieved. This is due to the wastewater management practices used by RIPOK. Therefore, in order to determine the real emission potential of modern prisms, the size and degradation time of the additional loads of organic carbon and nitrogen should be considered, as these loads are transferred to MP with technological wastewater.

Based on the performed studies, I was able to prove that also high Cl^- concentrations in landfill leachate result from the re-routing of technological wastewater. The concentrate formed during reverse osmosis is particularly rich in chloride (up to 7 500 Cl^-/dm^3). Contrary to organic substances, atoms with only one ionic charge, such as Cl^-, are not retained by the waste mass, while the concentrate re-routing has a direct enrichment effect on leachate.

It should be noted that technological wastewater produced by mechanical-biological treatment (MBT) of mixed waste originating from the metropolitan area surrounding Gdynia (Eko Dolina Sp z o. o. in Łężyce) was characterized by the higher values of specific chemical

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parameters than those determined for technological wastewater generated by the similar facility located in the rural and small town area (Zakład Zagospodarowania Odpadów Nowy Dwór Sp. z o.o. near Chojnice). This finding is mainly connected to the composition of landfilled waste, which in Poland differs significantly between the urban and rural areas[8]. In Eko Dolina plant (Łężyce) 77.6% of received municipal solid waste is considered biodagradable, while in Nowy Dwór plant, only 30%. Besides the larger amounts of paper and plastics being generated in urban areas (mostly related to food habits), in rural and small town areas some solid waste, due to its caloric value, is used as fuel in individual heating systems. This has been confirmed by the higher share of small fraction (ash) in the waste stream originating from rural areas, particularly in winter.

In summary, the results of my research prove the following:

- Technological wastewater (CU and SU) generated during mechanical-biological treatment (MBT) of waste is a usually neglected component of the by-products stream, although it contains significant loads of organic substances and ammonia
- Metagenomic analysis can be a useful tool for better understanding and elucidation of biochemical processes taking place in landfill prisms
- Based on the physical, chemical and metagenomic analyses, it has been established that landfill prisms containing the limited amounts of biodegradable waste (MP) age faster than previous prisms (PP) that are not subject to limitations.
- The emission potential of modern prisms (MP) should be determined taking into consideration that an additional load of carbon and nitrogen compounds is possible due to the transfer of technological wastewater from SU and CU.
- The lack of detailed data on the amount and quality of technological wastewater and landfill leachates generated during the waste treatment processes constitutes a significant hindrance in the development and implementation of effective methods for treating them.

The research results described above fill in the gap that exists in the literature dealing with the quantity and quality of landfill leachate and technological wastewater generated by solid waste treatment plants. The aforementioned problems is particularly important in Poland where, to the best of my knowledge, such studies have not been conducted until now.

[8]Boer Ed, Jedrczak A, Kowalski Z, Kulczycka J, Szpadt R, 2010. A review of municipal solid waste composition and quantities in Poland. Waste Manag. 30, 369–377. doi:10.1016/j.wasman.2009.09.018

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The aforementioned results were presented in the publications listed below that are included in the summary of scientific accomplishments:

- **Fudala-Ksiazek S.**, Pierpaoli M., Kulbat E., Luczkiewicz A., 2016. A modern solid waste management strategy-the generation of new by-products. Waste Management, vol. 49, 516-29. doi: 10.1016/j.wasman.2016.01.022.

(IF = 4.669; PM = 40)

- **Fudala-Ksiazek S.**, Pierpaoli M., Luczkiewicz A., 2017. Fate and significance of phthalates and bisphenol A in liquid by-products generated during municipal solid waste mechanical-biological pre-treatment and disposal. Waste Management, vol. 64, 28-38. doi: 10.1016/j.wasman.2017.03.040. Epub 2017 Apr 2.

(IF = 4.669; PM = 40)

The results described above were presented in reports and at scientific conferences, as follows:

- Luczkiewicz A, Kotlarska E., Baraniak A., Kulbat E., *Fudala-Ksiazek S.*, 2016. Liquid by-products from solid waste treatment - overlooked sources of emerging pollutants. **3rd IWA Specialized International Conference Ecotechnologies For Wastewater Treatment (ecoSTP16)** 27-30 June 2016, Cambridge, UK; poster
- **Fudala-Książek S**., Pierpaoli M., Kulbat E., Łuczkiewicz A., 2016 Emerging pollutants in liquid by-products generated during solid waste management. **ASSM2016 - Advances in Sustainable Sewage Sludge Management. 5th International Conference The Biodegradable** Waste In Circular, 18-21 September 2016, Krakow; oral presentation

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Ad theme no. 2.

Characterization of endocrine active compounds present in technological wastewater and landfill leachate

Another research theme that I undertook was the continuation of quantitative and qualitative analysis of technological wastewater and landfill leachates generated by the solid waste treatment plants. The solid waste management system is extremely complex, while its functioning must fulfill many rules of sustainable development. One of these rules is to gain the acceptance and develop appropriate habits in relation to waste management among the inhabitants who are the main 'contractors' of the recycling at source strategy. This is particularly important in Poland (and in other so-called new EU-member countries) where the waste segregation is still unsatisfactory, the recycled raw materials are of low quality, and hazardous waste (medical waste, pharmaceuticals, pesticides, etc.) is illegally mixed with municipal waste. As a result of mechanical-biological treatment (MBT) and landfilling of solid waste, compounds which have an effect on the environment and human health can be possibly washed out and/or biodegraded and then permeate into technological wastewater and landfill leachate. In connection with the above, besides a detailed analysis of organic compounds and nutrients, characterization of micropollutants in by-products generated by the solid waste treatment plant is also critical. This issue is important due to the fact that the implementation of effective methods for treating technological wastewater and landfill leachate prior to their disposal into municipal sewage or natural water basin/watercourse is required.

In my studies I paid particular attention to bisphenol A (BPA) and phthalate esters (PAEs), which are the compounds that can negatively affect the hormonal system in humans and animals[9]. Bisphenol A (BPA; 2,2-Bis(4-hydroxyphenyl)propan) is a synthetic organic compound that has been in commercial use since 1957, mainly as a monomer in the production of polycarbonates and epoxy resins. Nowadays, it is widely used in the synthetics industry, chemical and metal industries and construction business (in 2013, the global production of BPA reached ca. 6.8 million tons). Phthalate esters (PAE; alkyl/aryl esters of 1,2-benzenedicarboxylic acid) are also used in the production of plastics as plasticizers, and in the production of resins that are the basis ingredient of lacquers, dyes, laminates and glues. Moreover, phthalates with low-molecular-weights (LMW), e.g. diethyl or dimethyl phthalates

[9]Schug, T.T., Janesick, A., Blumberg, B., Heindel, J.J., 2011. Endocrine disrupting chemicals and disease susceptibility. J. Steroid Biochem. Mol. Biol. 127, 204–215. http://dx.doi.org/10.1016/j.jsbmb.2011.08.007.

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are also used in cosmetics, body care products, medicines, pharmaceuticals, waxes, inks, detergents, insecticides, and other daily use products[10].

PAEs and BPA are used in many market productions, therefore the products containing these chemicals and reaching their end-of-lifecycle, and/or the packaging in which they were distributed end up in the waste stream. Once there, such waste is treated in various ways in accordance with the local rules. The mode of release of the aforementioned compounds into the environment depends on how they are bound to the matrix. For example, phthalates are not an integral part of the polymeric structure of plastics, therefore they are easily released under the influence of UV radiation or temperature (starting at ~50°C)[11]. In the case of BPA, inappropriate waste management, e.g. garbage burning is an additional emission route of this chemical to the environment. **In connection with the above, I formulated the hypothesis that technological wastewater and landfill leachate may be the unrecognized source of endocrine active compounds, *inter alia*, BPA and PAEs.**

During my investigations, I determined the levels of BPA and selected PAEs, i.e. dimethyl phthalate (DMP), diethyl phthalate (DEP), di-n-butyl phthalate (DnBP), benzyl butyl phthalate (BbzP), and di-2-ethylhexyl phthalate (DEHP) in technological wastewater and landfill leachate by means of solid phase extraction (SPE) and gas chromatography coupled to mass spectrometry (GC/MS) (see text above). Among the analyzed phthalates, the compounds DEHP, DnBP and BBnP were identified as endocrine disrupting chemicals (EDCs) within the framework of the EU program REACH (Registration, Evaluation, Authorization and Restriction of Chemicals). Thus, these compounds disrupt the hormonal system in humans which results in many so-called civilization diseases, e.g. fertility disorders, disorders of sex development, increased incidence of hormone-dependent cancers (among others, breast, prostate, ovarian and testicular cancers), and damage to fetus as well as in disruption of metabolism, obesity and diabetes[12],[13]. DEHP is also listed as a priority substance under the Water Framework Directive[14,15]. In the case of BPA, so far its harmful effect on the human

[10]Hubinger, J.C., Havery, D.C., 2006. Analysis of consumer cosmetic products for phthalate esters. J. Cosmet. Sci. 57, 127–137.
[11]Heudorf U., Mersch-Sundermann V., Angerer J.: Phthalates: toxicology and exposure. Int. J. Hyg. Environ. Health, 2007; 210: 623-634
[12] Schug, T.T., Janesick, A., Blumberg, B., Heindel, J.J., 2011. Endocrine disrupting chemicals and disease susceptibility. J. Steroid Biochem. Mol. Biol. 127, 204– 215. http://dx.doi.org/10.1016/j.jsbmb.2011.08.007.
[13]Zama A.M., Bhurke A., Uzmcu M., 2016. Effects of Endocrine-disrupting Chemical on Female Reproductive Health. The Open Biotechnology Journal, 10, 54-75
[14]Dyrektywa 2000/60/WE Parlamentu Europejskiego i Rady z dnia 23 października 2000 r. ustanawiająca ramy wspólnotowego działania w dziedzinie polityki wodnej
[15]Prawo wodne, ustawa z dnia 20 lipca 2017 r.

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health has not been unequivocally proven. However, due to alarming reports[16], in January 2011, the European Union passed the EU Directive 2011/8/UE, which bans the use of bisphenol A in the production of, among others, bottles for feeding babies[17].

Based on the obtained results, I concluded that PAEs and BPA occurred in both technological wastewater and landfill leachate, although the range of determined concentrations (that depended on sampling site location) was couple times higher than the values measured in municipal wastewater and surface waters. The highest concentrations of PAEs and BPA were observed in technological wastewater originating from the sorting unit (8 201 and 292 µg/L, respectively) and the composting unit (993.5 and 1 795 µg/L, respectively). In the case of SU, PAEs mainly consisted of DMP, DEP and DEHP. These compounds, due to their low-molecular-weights, have relatively hydrophilic character and can be easily released from, for example, synthetic resins, glues, printing ink, etc. and thus may be washed out from the sorted waste stream. On the other hand, the wastewater generated by composting (CU) was a rich source of BPA, DEP and DEHP, while the other PAEs were found only sporadically. The residual amounts of paper, plastics, multimaterial packaging and textiles, that are not effectively removed from the waste stream reaching the composting unit, become the source of BPA and PAEs in technological wastewater from CU[18]. Moreover, another poorly recognized source of BPA may be ashes originating from waste burning[19]. The results of my research confirm the aforementioned hypothesis because the higher BPA concentrations were noted in technological wastewater from the composting unit in the rural area (waste treatment plant Nowy Dwór near Chojnice), where ash from the household heating systems constituted a significant share of mixed waste. In the case of 40-day composting, besides washing out of PAE and BPA from the waste matrix, one should also consider the potential biodegradation of these compounds[20,21]. However, based on the conducted investigations, it can be stated that mostly phthalates with low-molecular-weights

[16]Diamanti-Kandarakis E., Bourguignon J.-P., Giudice L. C., Hauser R., Prins G. S., Soto A. M., Zoeller R. T A.C., 2009. Endocrine-Disrupting Chemicals: An Endocrine Society Scientific Statement. Endocrine Reviews, 30(4), 293–342, doi: 10.1210/er.2009-0002

[17]Dyrektywa Komisji 2011/8/UE z dnia 28 stycznia 2011 r w odniesieniu do ograniczenia stosowania bisfenolu A w butelkach z tworzyw sztucznych do karmienia niemowląt

[18]den Boer, E., Jedrczak, A., Kowalski, Z., Kulczycka, J., Szpadt, R., 2010. A review of municipal solid waste composition and quantities in Poland. Waste Manage. 30, 369–377. http://dx.doi.org/10.1016/j.wasman.2009.09.018.

[19]Kurata, Y., Ono, Y., Ono, Y., 2008. Occurrence of phenols in leachates from municipal solid waste landfill sites in Japan. J. Mater. Cycles Waste Manage. 10, 144–152. http://dx.doi.org/10.1007/s10163-008-0200-x.

[20]Josse, J., Husson, F., 2016. MissMDA: a package for handling missing values in multivariate data analysis. J. Stat. Softw. 70. http://dx.doi.org/10.18637/jss. v070.i01.

[21]Wang, Y., Fan, Y., Gu, J.-D., 2004. Dimethyl phthalate ester degradation by two planktonic and immobilized bacterial consortia. Int. Biodeterior. Biodegrad. 53, 93–101. http://dx.doi.org/10.1016/j.ibiod.2003.10.005.

(DEP and DMP) underwent biodegradation because other PAEs oand BPA were present in technological wastewater from CU. This finding indicates that these substances do not undergo biodegradation in the used composting systems.

Biodegradation was a key factor in relation to the presence of PAE and BPA in landfill leachate[22,23]. Jonsson et al.[20] found a strong correlation between the hydrolysis of PAEs and methanogenic flora. The data obtained during my investigations confirmed this finding because I did not detect PAEs in leachate originating from previous prisms (PP), which were in the methanogenic phase. The content of PAEs in leachate originating from modern prisms (MP) visibly dropped after two years of exploitation. This was correlated to the increased percentage share of methane in biogas and the higher number of *Archaea* in the taxonomic structure of the landfill prism.

The methanogenic data also confirmed the presence of bacteria capable to degrade PAEs and BPA. These organisms mainly belonged to *Proteobacteria* (alpha, beta and gamma), *Actinobacteria, Bacteroidetesi* and *Firmicutes* (*Clostridia* and *Bacilli).* However, it should underlined that BPA was less prone to biodegradation than PAEs, which was in agreement with the literature data. The BPA concentrations in landfill leachate ranged from 37.3 to 8 052 µg/L.

Based on the conducted research, I established the following:

- Landfill leachate and wastewater, generated during mechanical-biological treatment (MBT) of waste via sorting and composting, contain the concentrations of PAEs and BPA that are couple times higher than those reported for surface waters and municipal wastewater.
- The main source of BPA and PAEs in technological wastewater originating from SU and CU are residual amounts of paper, plastics, multimaterial packaging and textiles, which cannot be effectively removed from the mixed waste stream during sorting.
- In the case of PBA, ash originating from waste burning in individual heating systems may be an additional source of emission.

[22] Jonsson, S.J., Ejlertsson, J., Svensson, B.H., 2003. Transformation of phthalates in young landfill cells. Waste Manage. 23, 641–651. http://dx.doi.org/10.1016/S0956-053X(03)00099-0.

[23] Peng, Y.-H., Chen, Y.-J., Chang, Y.-J., Shih, Y., 2015. Biodegradation of bisphenol A with diverse microorganisms from river sediment. J. Hazard. Mater. 286, 285–290. http://dx.doi.org/10.1016/j.jhazmat.2014.12.051.

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- DEHP, a compound considered as carcinogenic in humans (Group 2B) (IARC, 1987)[24] and listed among 45 priority substances that require monitoring according to the EU water policy[25] (EU, 2013), was the main component of phthalates found in technological wastewater.
- During my own investigations, I confirmed the presence of endocrine active compounds in technological wastewater and landfill leachate, which indicates that further scientific research on the effective removal of these substances is needed.

The aforementioned results were published in the following article:

- Fudala-Ksiazek S, Pierpaoli M, Luczkiewicz A, 2017. Fate and significance of phthalates and bisphenol A in liquid by-products generated during municipal solid waste mechanical-biological pre-treatment and disposal. Waste Management, vol. 64, 28-38. doi: 10.1016/j.wasman.2017.03.040. Epub 2017 Apr 2.

(IF = 4.669; PM = 40)

The results described above were presented in reports and at scientific conferences, as follows:

- **Fudala-Ksiazek S**, Pierpaoli M, Luczkiewicz A, 2017. Liquid by-products generated during municipal solid waste management as a source phthalates and bisphenol A. **IWA 10th Micropol & Ecohazard Conference**, 17–20 September 2017, Vienna, Austria; oral presentation.
- Łuczkiewicz A., Jankowska K., **Fudala-Książek S.**, 2017. Ograniczenie emisji mikrozanieczyszczeń ze źródeł zorganizowanych do morskich wód przybrzeżnych (Mitigation of the micropollutants discharged into the marine coastal waters). I **Konferencja Naukowa Polskich Badaczy Morza 2017**, Sopot, Poland; oral presentation.

[24] International Agency for Research on Cancer, 1987. Overall evaluations of carcinogenicity: an updating of IARC monographs (No. 1 to 42). IARC Monographs on the Evaluation of the Carcinogenic Risks to Humans. World Health Organization, Lyon, France

[25] EU, 2013. Directive 2013/39/EU of the European Parliament and of the Council of 12 August 2013 amending Directives 2000/60/EC And 2008/105/EC as regards priority substances in the field of water policy.

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Ad theme no. 3.

Effectiveness determination of selected methods for treating technological wastewater and landfill leachate in relation to the removal of macro- and micropollutants

Based on the results of own research presented above (themes 1 and 2), I established that technological wastewater and landfill leachate constitute a significant reservoir of nutrients and organic compounds, including phthalates (PAEs) and bisphenol A (BPA) that affect human health. In connection to the above, I undertook yet another research theme, namely, the effectiveness analysis of methods for treating landfill leachate that are aimed at limiting the negative impact of leachate on the environment.

Treating the landfill leachates is an important engineering challenge, as I mentioned before. Conventionally, leachates were transported or pumped onto municipal wastewater treatment plants. However, the resulting input load of pollutants, mainly nitrogen compounds and poorly biodegradable or inert organic matter, limited the effectiveness of technological processes as well as increased the costs of treatment due to more stringent regulations with regard to treated wastewater[26].

When searching for the method that is not based on treating landfill leachate at the municipal biological treatment wastewater plants, the managers of solid waste treatment plants often opted for reverse osmosis. The method enables effective pre-treatment of leachate and is frequently described as no service required. Unfortunately, this is far from the reality. Most of technologist using reverse osmosis indicate that, besides significant exploitation costs (the replacement of membranes and filters, and the purchase of reagents), its long-term application does not solve the problem with leachates. Actually, the problem can even be aggravated because of generated concentrate that has to be treated, as I previously mentioned.

In connection to the above, it became important to search for environment-friendly and socially acceptable methods for the effective treatment of leachate. In my research I analyzed two new approaches that could be implemented in relation to treating leachates, which are based on (I) processes of advanced oxidation by using electrolysis, and (II) biological processes enhanced by separation in membrane bioreactors (MBR).

In recent years, research on the use of electrochemical processes for treating landfill leachate has been conducted, mainly because such processes result in the efficient oxidation of organic compounds and ammonia. However, the reported effectiveness differed in

[26]Remiszewska-Skwarek A., Fudala-Ksiazek S., Luczkiewicz A., 2016. The influence of industrial wastewater on the energy consumption and the efficiency of technological processes in municipal wastewater treatment plant. Rocznik Ochrona Środowiska vol. 8 (2), pp. 110-121.

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dependency on the process conditions and the type of electrode materials (e.g. TiO2/RuO2, Ti/SnO2, Ti/Pt, Ti/PbO2)[27,28,29], including boron-doped diamond electrodes (BDD)[30,31,32]. In the case of BDD, commercially available electrodes were mainly employed to conduct the additional treatment of landfill leachate[33,34,35] with regard to the removal of persistent organic compounds.

To the best of my knowledge, the effectiveness of BDD electrodes with different dopant levels in pre-treating the real landfill leachates was assessed for the first time during my investigations. In this work the BDD electrodes with the B/C ratios of 500 ppm (BDD-0.5k), 5000 ppm (BBD-5k) and 10000 ppm (BDD-10k) were used. The experimental study was conducted on the samples of leachate originating from previous prism (PP), with the BOD_5/COD ratio <0.1, which precluded the application of biological treatment. The analyzed leachate samples contained negligible amounts of total suspension (26 mg/L) and relatively high concentrations of chloride and sulfate (3 191 mg Cl^-/L and 1 860 mg SO_4^{2-}/L, respectively), which was crucial for performing electrolysis. The leachates were also characterized by high ammonia concentration (2 270 mg N-NH_4/L), which constituted 90% of total nitrogen, and COD at the level of 4 225 mg O_2/L. Moreover, bisphenol A (BPA) present in landfill leachate at the level of 1 539.6 μg/L was used as a potential indicator of micropollutants removal. The experiments were performed in the specially designed set up consisting of a magnetic stirrer (ES24, Wigo, Poland), thermostat and the 200 ml cell. Three electrodes were placed inside the cell, i.e. the BDD electrode as an anode, tantalum plate as a

[27]Cossu R., Polcaro A.M., Lavagnolo M.C., Mascia M., Palmas S., Renoldi F., 1998. Electrochemical treatment of landfill leachate: oxidation at Ti/PbO2 and Ti/SnO2 anodes, Environ. Sci. Technol. 32, 3570–3573, http://dx.doi.org/10.1021/es971094o.

[28]Moraes P.B., Bertazzoli R., 2005. Electrodegradation of landfill leachate in a flow electrochemical reactor, Chemosphere 58, 41–46, http://dx.doi.org/10.1016/j.chemosphere.2004.09.026.

[29]Deng Y., Englehardt J.D., 2006. Treatment of landfill leachate by the Fenton process, Water Res. 40, 3683–3694, http://dx.doi.org/10.1016/j.watres.2006.08.009.

[30]Yoo H., Oh K., Lee G., Choi J., 2017. RuO2-doped anodic TiO2 nanotubes for water oxidation: single-step anodization vs potential shock method, J. Electrochem. Soc. 164, H104–H111, http://dx.doi.org/10.1149/2.1201702jes.

[31]Labiadh L., Barbucci A., Carpanese M.P., Gadri A., Ammar S., Panizza M., 2017. Direct and indirect electrochemical oxidation of Indigo Carmine using PbO2 and TiRuSnO2, J Solid State Electrochem. 21, 2167–2175, http://dx.doi.org/10.1007/s10008-017-3559-6.

[32]Clematis D., Cerisola G., Panizza M., 2017. Electrochemical oxidation of a synthetic dye using a BDD anode with a solid polymer electrolyte, Electrochem. Commun. 75, 21–24, http://dx.doi.org/10.1016/j.elecom.2016.12.008.

[33]Cabeza A., Urtiaga A., Rivero M.-J., Ortiz I., 2007. Ammonium removal from landfill leachate by anodic oxidation, J. Hazard. Mater. 144, 715–719, http://dx.doi. org/10.1016/j.jhazmat.2007.01.106

[34]Zhou B., Yu Z., Wei Q., Long H., Xie Y., Wang Y., 2016. Electrochemical oxidation of biological pretreated and membrane separated landfill leachate concentrates on boron doped diamond anode, Appl. Surf. Sci. 377, 406–415, http://dx.doi.org/10.1016/j.apsusc.2016.03.045.

[35]Anglada Á., Urtiaga A., Ortiz I., Mantzavinos D., Diamadopoulos E., 2011. Boron-doped diamond anodic treatment of landfill leachate: evaluation of operating variables and formation of oxidation by-products, Water Res. 45, 828–838, http://dx.doi.org/10.1016/j.watres.2010.09.017.

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cathode, and Ag/AgCl/0.1 M KCl as a reference electrode. Due to the novel technological approach, particular attention was paid to the efficiency of electrochemical oxidation with regard to organic matter (expressed as COD, Bod_5, BOD_{20}) and ammonia. The effect of other parameters such as current density (12.5; 25; 50 mA cm^{-2}), pH (3.0; 5.0; 7.6) and the presence of Fe^{2+} ions (10 mg/L) was also assessed.

Based on the obtained results, it was found that the oxidation effectiveness of selected parameters was correlated to the sp3/sp2 coefficient on the surface of BDD electrodes, thus to the ratio of sp3 bonds occurring in the diamond structure to the sp2 bonds in graphite. An increase in the number of latter resulted in the higher selectivity of BDD electrodes toward ammonia oxidation. The increased sp3/sp2 ratio gave higher effectiveness with regard to the oxidation of organic compounds. This phenomenon can be explained by the formation of oxidants other than $OH^{\cdot}$ free radicals, e.g Cl_2/HOCl, which could possibly be connected to the high content of chloride in landfill leachate. It should be underlined that the degradation of organic matter (including BPA) was conducted until obtaining mainly inorganic derivatives, not more oxidized intermediate products. To summarize, landfill leachates subjected to electrolysis showed a visible reduction in the content of organic matter, including BPA, however, the analyzed samples were still characterized by high ammonia concentrations. In connection to the above, a preliminary pre-treatment of landfill leachate by means of electrolysis, the removal of poorly biodegradable organic matter allows for the further reduction of total nitrogen from leachates via biological pathway, by using anaerobic ammonia oxidation (e.g. Anammox)[36,37].

Also, the investigations with the application of MBT system were conducted on semi-industrial scale at the solid waste treatment plant Eko Dolina (Łężyce), where the simultaneous treatment of leachates originating from MP and PP is necessary. The MBT module was operated in the mode of subsequent anoxic and oxic phases, with external ultrafiltration (MBR/UF) and optional nanofiltration (MBR/UF/NF) (see Fig. 3). HyperFlux ultrafiltration modules were made of polyethersulfone (PES; Berghof). NF90-400/34i NF nanofiltration module (DOW Filmtec^{TM}) was made of thin-layer polyamide composite characterized by a molecular weight cut-off in the range of 200-400 D for the maximum working pressure of 41 bar.

[36] Li T., Li X., Chen J., Zhang G., Wang H., 2007. Treatment of landfill leachate by electrochemical oxidation and anaerobic process, Water Environ. Res. 79, 514–520, http://dx.doi.org/10.2175/106143006X115435.
[37]Qiao S., Yin X., Zhou J., 2016. Application of cathode modified by reduced graphene oxide/polypyrrole to enhance anammox activity, RSC Adv., 6, 97208–97215, http://dx.doi.org/10.1039/C6RA18941E.

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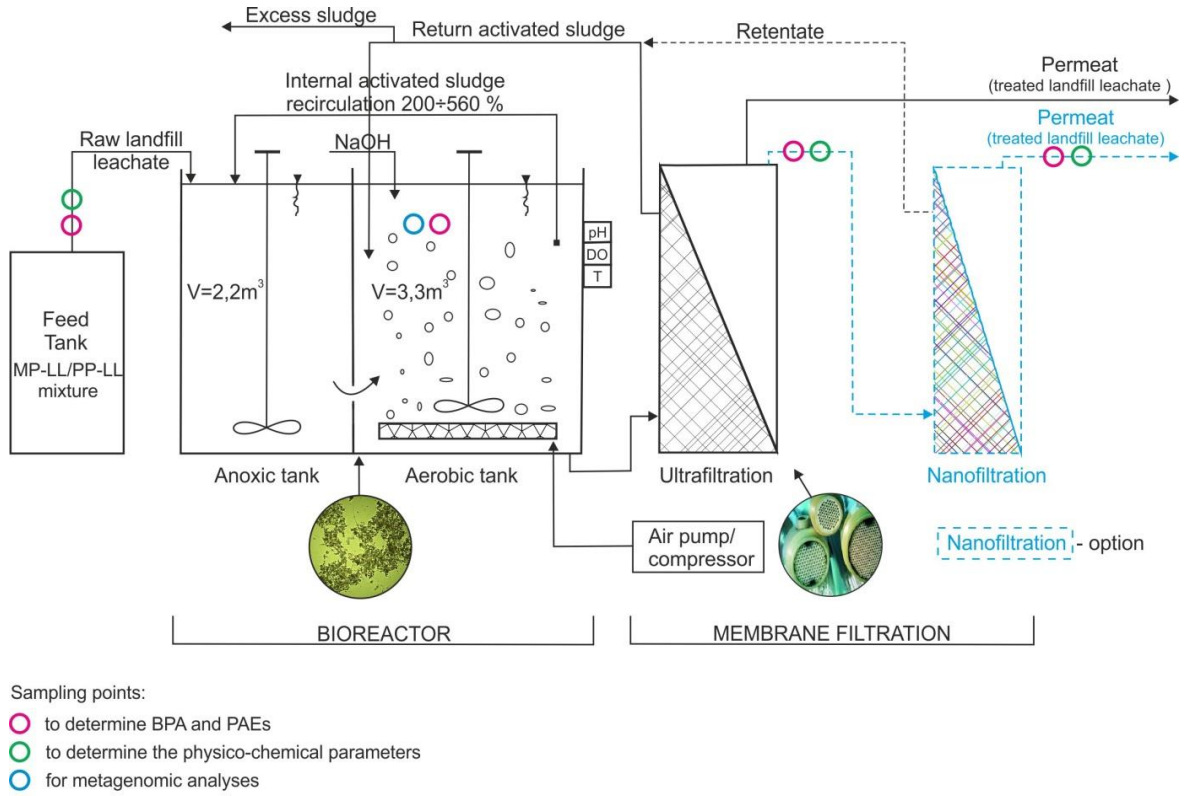

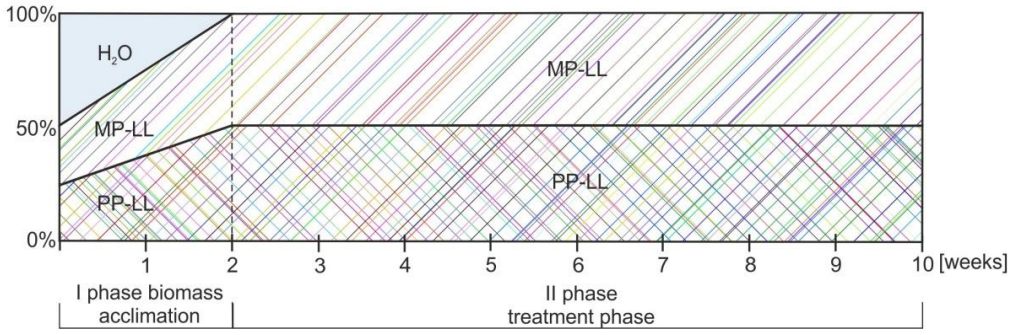

Fig. 3. Schematic representation of MBR/UF/NF system with the marked points of sample collection prior to analysis.

The experiment was divided into two phases, i.e. the acclimation of activated sludge (phase I), where MBR was fed with the diluted mixture of landfill leachates originating from modern (MP) and previous (PP) prisms for 14 days, followed by phase II during which the proper 8-week working period occurred (see Fig. 3), namely, the treatment of mixed leachates (1:1 ratio) without diluting with tap water. The leachate mixture was characterized by the high values of COD (up to 6 509 mg O_2/L), ammonia (up to 1 371 mg N-NH_4/L), total nitrogen (up to 1 458 mg N/L) and chloride (up to 2180 mg Cl^-/L). The ratio of BOD_5 to COD in the leachate mixture during the experiment was, on average, 0.52. Activated sludge from the leachate treatment plant in Cronheim (Ennest Deponie Cronheim, Germany) served as an inoculum for MBR.

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Based on the obtained results, I established that the untrafiltration module-aided bioreactor (MBR/UF) effectively removed nutrients and organic substances from landfill leachates. The quality of treated leachates, except for chloride (> 1000 mg Cl^-/L), fulfilled the parameters required for dumping wastewater into the sewage system. In connection to the above, the additional use of nanofiltration module in a pilot study was only justifiable to reduce the chloride content in the MBR/UF/NF effluent that did not exceed 250 mg Cl^-/L. The contents of total nitrogen and total phosphorus in the effluent remained below 10 mg N/L and 1 mg P/L, respectively, and thus fulfilled the requirements for dumping the treayed wastewater into the receiver. The relatively constant, high effectiveness of MBR/UF/NF module, which was independent of technological processes connected to activated sludge and the configuration of membrane modules limiting their fouling, was in favor of the set up. Unfortunately, the total exploitation cost of MBR/UF/NF (without the personnel cost) is ca. 22.5 PLN/m^3 (5.4 EUR/m^3), which is slightly lower than the costs associated with the use of reverse osmosis (ca. 29 PLN/m^3 equivalent to 6.9 EUR/m^3). The exploitation of MBR/UF module was estimated at 14 PLN/m^3 (3.3 EUR/m^3; analysis for the year 2017). Moreover, the results obtained during my investigations confirmed the literature reports on the effectiveness of MBR/UF with the activated sludge biomass as systems that efficiently remove micropollutants. Maintaining the activated sludge for long time allows for the development of microbial consortia which are capable to degrade even poorly degradable organic compounds. This observation has been confirmed by metagenomic analysis that I conducted. The outcome of this research indicates that the structure of activated sludge becomes rebuilt in relation to the inoculum. The presence of bacteria capable to degrade BPA and PAEs in the activated sludge was determined; the found microorganisms belonged to, *inter alia*, *Clostridium* (1.00%; phylum *Firmicutes*), *Mycobacterium* (0.41%) and *Rhodococcus* (0.31%; phylum *Actinobacteria*) and *Sphingomonas* sp. (0.27%), and other bacteria from the family *Sphingomonadaceae (*class *Alphaproteobacteria*). It was also found that aerobic and anaerobic (Anammox) organisms that oxidize ammonia coexisted with denitrifying bacteria. The results of my investigations suggest therefore that the effective removal of nitrogen is possible even when the access to degradable organic compounds is limited. The optimization of the aforementioned biological pathways requires further research.

It should be underlined that the expected amount of biodegradable organic matter in landfill leachate, which decreases with increasing time, points to the fact that MBR/UF systems might require additional feeding from the external carbon source in order to sustain denitrification. To avoid extra cost due to the use of conventional carbon source

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(e.g. methanol or ethanol), I proposed to utilize technological wastewater generated by mechanical-biological treatment (MBT) installations (wastewater from CU and/or SU) due to its high biodegradability[38]. I would like to stress that based on my studies and own technological solutions, the MBR/UF system supplemented with wastewater originating from the composting unit has been in operation at Eko Dolina (Łężyce).

Based on the conducted research, I was able to establish the following findings:

- Electrochemical treatment of landfill leachate generated by so-called previous prisms is a promising method that enables the oxidation of poorly degradable organic compounds, including bisphenol A, to their inorganic forms.
- Selective oxidation of carbon and nitrogen compounds at the boron-doped diamond electrode (BDD) depended on the ratio of sp3 bonds present in diamond to sp2 bonds in graphite.
- Selective oxidation of poorly degradable organic matter at the BDD electrode allows for further treating of leachate via biological pathway by using, for example, Anammox.
- The MBR/UF system effectively removed nutrients and organic substances from landfill leachate.
- Inoculated activated sludge of MBR/UF system showed high potential for biodegradation/biotransformation of BPA and PAEs, as confirmed by metagenomic analysis.
- The application of MBR/UF/NF systems for treating landfill leachate is justified in case the chloride reduction is needed or, as an optional measure, during the adaptation period or when technological problems are encountered in relation to activated sludge.
- The technological studies conducted by me demonstrated that the treatment of landfill leachate in MBR/UF systems is an alternative to reverse osmosis. Moreover, the application of the BDD electrodes enables the reduction in the stream of non-biodegradable micropollutants disposed into the environment.

[38]Fudala-Ksiazek S., Luczkiewicz A., Kulbat E., Remiszewska-Skwarek A., 2016. Characteristics of liquid by-products generated at municipal solid waste plants (MSWP) in terms of treatment method choice. Rocznik Ochrona Środowiska, vol. 18(2), 952-963.

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The results presented above were published in the following articles:

- **Fudala-Ksiazek S.,** Luczkiewicz A., Kulbat E., Remiszewska-Skwarek A., 2016. Characteristics of liquid by-products generated at municipal solid waste plants (MSWP) in terms of treatment method choice. Rocznik Ochrona Środowiska, vol. 18(2), 952-963

  (IF – 0,808, PM – 15)

- **Fudala-Ksiazek S.**, Sobaszek M., Luczkiewicz A., Pieczynska A., Ofiarska A., Fiszka-Borzyszkowska A., Sawczak M., Ficek M., Bogdanowicz R., Siedlecka E.M., 2018. Influence of the boron doping level on the electrochemical oxidation of raw landfill leachates: Advanced pre-treatment prior to the biological nitrogen removal. Chemical Engineering Journal, vol. 334, 1074-184, doi: 10.1016/j.cej.2017.09.196

  (IF = 6.216; PM = 45)

- Fudala-Ksiazek S., Pierpaoli M., Luczkiewicz A. 2018. Efficiency of landfill leachate treatment in a MBR/UF system combined with NF, with a special focus on phthalates and bisphenol A removal. Waste Management – in print, DOI: 10.1016/j.wasman.2018.05.012

  (IF – 4.669, PM – 40)

The aforementioned results were presented in reports and at scientific conferences, as follows:

- **Fudala-Ksiazek S**., Kulbat E., Luczkiewicz A., Kowal P., Makinia J., 2014. Landfill leachate treatment in a pilot activated sludge system – a case study in Poland, **IWA Activated Sludge – 100 Years and Counting!" 12- 14 June 2014 Essen, Germany**; poster.

- **Fudala-Książek S., 2015.** Oczyszczanie odcieków z regionalnych składowisk w oczyszczalniach ścieków. **XXV Konferencja Eksploatacji i rekultywacji składowisk odpadów**, Krynica Zdroj, 17-19 February 2015; oral presentation.

- **Fudala-Książek S.**, Kulbat E., Łuczkiewicz A., 2015. Charakterystyka odcieków składowiskowych i kierunki ich utylizacji. Conference titled „Ścieki przemysłowe – wyzwania technologiczne i ekonomiczne", Sopot, 19-20 November 2015; oral presentation.

- **Fudala-Ksiazek S**., Luczkiewicz A., Kulbat E., Remiszewska-Skwarek A., 2016. Characteristics of liquid by-products generated at municipal solid waste plants (MSWP) in terms of treatment method choice. **V Ogólnopolski Kongres Inżynierii Środowiska**, Lublin, 29 May-1 June 2016; oral presentation.

- Sobaszek M., **Fudala-Książek S.**, Łuczkiewicz Bogdanowicz R., Siedlecka E.M., 2018. Electrochemical oxidation of raw landfill leachate on carbon based electrodes. **Hasselt Diamond Workshop 2018 - SBDD (Surface and Bulk Defects in Diamond) XXIII**, 7-9 March 2018, Hasselt, Belgium; poster.

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Summary

The results of scientific investigations confirm the hypothesis formulated by me, i.e. novel methods of solid waste treatment generate by-products that constitute an unrecognized source of micropollutants which affect the environment and human health. The following conclusions have been drawn based on these results:

- Technological wastewater generated during mechanical-biological treatment (MBT) of solid waste is a usually neglected component of the stream of by-products that form at the plant, although it contains significant loads of organic substances, ammonia and endocrine active substances, such as bisphenol A (BPA) and phthalates (PAEs).
- The concentrations of bisphenol A (BPA) and phthalates (PAEs) in landfill leachate and technological wastewater were couple times higher than those measured in surface waters or municipal wastewater.
- The main component of phthalates present in technological wastewater was bis(2-ethylhexyl (DEHP), a compound considered as carcinogenic in humans (Group 2B, IARC) and identified as a priority substance within the framework of water policy.
- Landfill prisms with limited amounts of biodegradable waste (MP) age faster than prisms without the set limits on such waste type (PP).
- The emission potential of modern prisms (MP) should be estimated under consideration that the additional load of the carbon and nitrogen compounds is introduced via technological wastewater dumped on the prism.

Another important aspect of the realized work was undertaking measures aimed at the minimization of environmental costs in connection to the implementation of 'zero waste' program. Based on the obtained research results, I formulated the following conclusions:

- Electrochemical oxidation at the boron-doped diamond (BDD) electrodes constitutes an innovative and promising method for treating landfill leachate generated by so-called previous prisms (PP) in connection to the degradation of poorly biodegradable organic compounds (including bisphenol A) to their inorganic forms.
- Selective oxidation of poorly degradable organic matter at the BDD electrodes allows for further treatment of leachate via biological pathway by using, for example, Anammox.
- The MBR/UF system effectively removed organic substances (including bisphenol A and phthalates) and nutrients by combining the biodegradation potential of inoculated activated sludge with the separation techniques.

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- The MBR/UF system is an environment-friendly and economical alternative to the presently used reverse osmosis.
- The enhancement of MBR/UF systems with NF is justified in case the salinity reduction (e.g. chloride removal) is needed, or in order to maintain the required quality of effluent during the adaptation period or technological problems with the activated sludge.
- Metagenomic analysis may be a useful tool for better understanding of both biochemical processes in landfill prisms and the degradation potential of activated sludge biomass used for treating landfill leachate and technological wastewater.
- The lack of detailed knowledge about the quantity and quality of technological wastewater and landfill leachate generated via the processing of solid waste is a significant hindrance in the development and implementation of effective methods for their treatment.

To the best of my knowledge, the main threats connected to the realization of the 'waste-to-resource' strategy, i.e. considering solid waste as a resource, have been defined **for the first time in the studies conducted by me**. Particular attention was paid to mechanical-biological treatment (MBT) of solid waste, which generates technological wastewater requiring the advanced treatment, and that *de facto* contradicts the philosophy of 'zero waste'. Therefore, it is suspected that the real environmental costs of implementing the waste hierarchy might be underestimated.

The research I conducted fits well into the priorities of the 7th Environment Action Programme (7EAP, 2013) which turns attention to basic research needed for elaborating a more systematic approach to new and emerging threats connected to waste processing. At the same time, the programme addresses the lack of pertinent monitoring data that is considered as a significant gap in the implementation of tasks related to water protection. The obtained study results became a basis for the guidelines on treating technological wastewater and landfill leachate, implementations (among others, the full-scale implementation of MBR), and scientific papers that had been published in leading journals in the field of waste management. The results may also serve as materials for the discussion on the rational management of waste, which has a crucial meaning for the environment and economy.

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5. DESCRIPTION OF THE REMAINING SCIENTIFIC AND RESEARCH ACCOMPLISHMENTS

5.1. Prior to receiving PhD

I started my Master's studies in 1999 at the Faculty of Civil and Environmental Engineering, Koszalin University of Technology. Under the guidance of Tomasz Modelewski, PhD, I managed the Student Science Club at the Department of Environmental Biology. In 2003, within the framework of Student Science Club, I was the main organizer of a 2-week summer scientific camp on Drawsko Lake in Zachodnio-pomorskie Voivodship. The outcome of these scientific investigations, titled Diversification of primary production in the water column of a mesotrophic lake, were presented at the 10th national student seminar 'Environmental biotechnology', Wisła-Jarzębata, 28-30 November 2003. The seminar was organized by Silesian University of Technology (Gliwice), Faculty of Environmental Engineering and Energy, Department of Environmental Biotechnology. Also, within the framework of the same seminar, I gave the oral presentation titled 'The analysis of possible neutralization of waste from the municipal wastewater treatment plant' that had been based on the preliminary results of my Master's thesis research. In 2004, I defended my thesis titled 'The analysis of possible neutralization of waste from the wastewater treatment plant processing domestic and industrial wastewater', receiving a very good note and the degree of Eng., MSc. in the field of Environmental Engineering. Adam Boguski, Eng., PhD served as my academic adviser.

The following publications are based on the outcome of my Master's thesis research:

- **Fudala-Książek S.**, Boguski A., 2008. Ocena jakości skratek i zawiesiny mineralnej z oczyszczalni ścieków w aspekcie ich unieszkodliwiania. Gaz, Woda i Technika Sanitarna. T. 82, nr 5, s. 26-32.

During the last year of my Master's studies, I started a 2-semester postgraduate course dealing with Technology of Water, Wastewater and Solid Waste. I finished the course in September 2004.

In October 2005, I commenced doctoral studies at the Faculty of Civil and Environmental Engineering, Gdansk University of Technology. In the academic year 2006/2007, I was on the dean's leave, waiting for the outcome of the grant competition of the Ministry of Science and Higher Education. After receiving funds for the project titled 'Variability of ecotoxicological and microbiological threats associated with biological treatment of landfill leachate from municipal waste treatment plants' (no. N 523 077 32/2900), I returned to the Gdansk

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University of Technology in the academic year 2007/2008 to continue my doctoral research. Bernard Quant, Eng., PhD habilitated, professor at GUT was my promoter and the manager of the aforementioned grant which has been the basis of my doctorate. Moreover, in 2008, I received funding from the Voivodship Fund for Environmental Protection and Water Management in Gdansk for the project titled 'Combined treatment of landfill leachate and wastewater in a municipal wastewater treatment plant (WFOŚ/D/201/187/2010). In 2010, I received the research grant titled 'The influence of landfill leachate dumping on the effectiveness of a municipal wastewater treatment plant' (no. N N523 557 538,). The obtained funds allowed me to conduct the scientific investigations of the influence of adding landfill leachate to municipal wastewater on the biological processes of wastewater treatment. These studies were performed by using two laboratory models that I had made myself, i.e. A2O flow-through system, and sequential biological reactor (SBR). The scientific and applicative values of my research have been recognized and I was awarded with Scholarship 'Innodoktorant' within the framework of Priorytet VIII Program Operacyjny Kapitał Ludzki, działanie 8.2, poddziałanie 8.2.2 'Regionalne Strategie Innowacji', that was finansed from the EU Social Fund, Polish national budget, and the budget of self-goverment of Pomorskie Voivodship. The funding was realized by the Department of Economic Development, the Marshall's Office of Pomorskie Voivodship. Prior to receiving PhD, I presented the results of my investigations at six international and two domestic conferences (Att. no. 4, II.J.2 item 6).

On December 14, 2011, I received the doctoral degree in technical sciences in the field of environmental engineering at the Faculty of Civil and Environmental Engineering, Gdansk University of Technology. My doctoral dissertation was titled 'The influence of landfill leachate dumping on the effectiveness of municipal wastewater treatment plant'. Professor Bernard Quant, Eng., PhD habilitated served as my promoter.

During my doctoral studies (October 2010), I started a 2-yr educational course at the Pedagogical Institute at the Faculty of Management and Economy, GUT. I finished the course in 2012, which allowed me to work as a teacher.

Moreover, in the years 2010-2013, I participated as a contractor in the project N N523 493134, financed by the Ministry of Science and Higher Education, titled 'Antibiotics in aquatic environment and the transfer of antibiotic resistance by the bacteria originating from activated sludge', 2008-2011, (Att. no. 4, II.J.2 item 6). I was interested in the aspect of microbial drug resistance propagation via biological treatment processes of wastewater. My task encompasses, among others, the physico-chemical analysis of wastewater and the interpretation of the obtained results. Based on the investigations conducted on lab-scale and

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technical scale, it was established that the municipal wastewater is an important vector of drug resistant bacteria in urban areas, while the wastewater treatment may create conditions that are advantageous for the propagation of drug resistance.

The results of these studies were published in the following papers:

- Łuczkiewicz A., **Fudala-Książek S.**, Jankowska K., Quant B., Olańczuk-Neyman K., 2010. Diversity of fecal coliforms and their antimicrobial resistance patterns in wastewater treatment model plant. Water Science and Technology, 61 (6),1383-92,

  IF = 1.197, PM = 20,

- Łuczkiewicz A., Jankowska K., **Fudala-Książek S.**, Olańczuk-Neyman K., 2010. Antimicrobial resistance of fecal indicators in municipal wastewater treatment plant. Water Research, 44 (17), 5089-97,

  IF = 6.2942, PM = 45,

- Łuczkiewicz A., **Fudala-Książek S.**, Jankowska K., Quant B., Olańczuk-Neyman K., 2010. Antimicrobial resistance of *Enterococcus* spp. in municipal wastewater treatment plant – model study. Polish Journal of Environmental Studies, vol. 2, Series of Monographs, HARD, 146-152,

  IF = 0.961, PM = 15,

In the years 2010-2013, I participated in the realization of the project *Innowacyjne źródło węgla dla wspomagania denitryfikacji w komunalnych oczyszczalniach ścieków* [Innovative carbon source for enhancing denitrification in municipal wastewater treatment plants] financed within the framework of Program Operacyjny Innowacyjna Gospodarka, poddziałanie 1.3.1 Nr UDA – POIG.01.03.01-22-140/09-00 (Att. no. 4, II.J.2 item 10). The aim of the project was to determine the effect of adding external carbon source on the kinetics of denitrification and the stability of bacterial consortia in activated sludge. Testing of denitrification rates was conducted in adapted and non-adapted sludge for the selected conventional (ethanol) and alternative (waste from alcohol factories and distilleries) sources of organic carbon. Based on the obtained results, it was concluded that the application of alternative external sources of carbon in municipal wastewater treatment plants will result in faster denitrification rates reaching the values measured during the supplementation with wastewater treated mechanically, i.e. 1.3 (±0.6) mg N/(g smo·h). The use of fusel oils is particularly justified because at the concentrations that ensure effective denitrification, they do not act as a strong selective agent in relation to activated sludge microorganisms and promote a stable development of bacterial consortia. The themes of undertaken research have been recognized and awarded with the award of distinction in the competition Innowacje 2012, Technicon Innowacje at XVIII Targi Techniki Przemysłowej, Nauki i Innowacji. The

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obtained results were presented at numerous scientific conferences (Att. no. 4, II.L.2 item 7, III.B2 item 17, 29).

The obtained research results were published in a paper listed below:

- Mąkinia J., Czerwionka K., Oleszkiewicz J., Kulbat E., **Fudala-Książek S.**, 2011. A Distillery By-Product as an External Carbon Source for Enhancing Denitrificationin Mainstream and Sidestream Treatment Processes. Water Science and Technology, vol. 64 (10), 2072-2079.
  (IF = 1.197; PM = 20)

In parallel with my scientific work, I was also getting professional experience. In February 2004, I was employed as laboratory personnel Zakłady Energii Cieplnej (Człuchów) to analyze the quality of boiler water, and caloric value of fuels, etc. In January 2005, I started to work in Gdańskie Przedsiębiorstwo Energetyki Cieplnej, at first as an Inspector of environmental protection and then as a designer (2006-2009). My professional duties included, among others, designing the heating pipeline networks, central heating installations and hot water lines, modernization of individual and cluster hubs, etc. The delivery of the projects and the author's supervision of the construction of the aforementioned networks and installations allowed me to gain valuable experience that is so important for every day work at the technical university.

To summarize, prior to receiving PhD in December 2011, I co-authored a chapter in the monograph (Att. no. 5, II.E.1 item 2), five JCR-listed articles (Att. no. 5, II.A.1), and three articles not listed in the JCR database (Att. no. 5, II.E.1). The results of my research were presented at 11 international conferences (I actively participated in eight of them) and two domestic conferences (I actively participated in both of them) (Att. no. 5, II.L.1 and III.B.1). The full texts of five presentations (four in international, and one in domestic materials) were published in the post-conference materials (Att. no. 5, III.B.1). In the years 2007–2011, I was the contractor of seven grants, including the research doctoral grant that was also financed by the WFOŚiGW (Att. 5, II.J.1). Moreover, I co-authored six construction and working designs in the field of sanitary engineering (Att. 5, II.B.1) and several conceptual plans aimed at the modernization and construction of heating hubs in the area of Gdansk and Sopot.

5.2. After receiving PhD

After receiving a doctoral degree in technical sciences, I have become employed at the Department of Sanitary Engineering, Faculty of Civil and Environmental Engineering, GUT in the position of research assistant; since September 2012, I have continued the employment there as an adjunct.

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Besides the scientific accomplishments, my research work can be divided into the following three directions:

Theme no. 1: Taxonomic analysis and antimicrobial resistance among bacteria for the genus *Pseudomonas* spp. present in municipal wastewater.

Theme no. 2: Emission of pharmaceuticals/micropollutants from point sources.

Theme no. 3: Rational management of wastewater and sludge aimed at limiting the energy use by municipal wastewater treatment plants.

Ad theme no. 1

Taxonomic analysis and antimicrobial resistance among bacteria from the genus Pseudomonas spp. present in municipal wastewater

I continued research on antimicrobial resistance in relation to bacteria from the genus *Pseudomonas* spp. which, due to their high metabolic activity, are capable of colonizing many diverse niches, *inter alia*, activated sludge. The samples of raw wastewater, treated wastewater and activated sludge from the aeration tank were collected at the wastewater treatment plant Gdańsk-Wschód. The obtained analytical results demonstrated that the species *P. putida* dominated (53.5%), while 21.7% of isolates were identifies as *P. aeruginosa* and only 5.7% as *P. fluorescens*. *P. pseudoalcaligenes* and *P. veronii* were other bacterial species that had been identified.

The isolates from the genus *Pseudomonas* (n = 125) were mainly resistant to β-laktam antibiotics; the occurrence of strains resistant to cefepime, the fourth-generation cephalosporins used only in hospitals, is of interest. Bacteria from the genus *Pseudomonas* isolated from the activated sludge tank had statistically significant ($p < 0.05$) higher resistance in relation to almost all antibiotics tested in both raw and treated wastewater. The obtained data suggest that *Pseudomonas*, being denitrifying microbs present in the flocs of activated sludge, live longer during the wastewater treatment process than, for example, indicator or disease-causing bacteria. Therefore, *Pseudomonas* are exposed for longer periods of time to subinhibitory concentrations of antibiotics and their metabolites while residing in wastewater. The extended exposure time is a selective factor that favors drug resistant bacteria which leads to the stabilization of the acquired bacterial properties.

The obtained results were published as stated below:

- Luczkiewicz, A., Kotlarska, E., Artichowicz, W., Tarasewicz, K., **Fudala-Ksiazek, S.,** 2015. Antimicrobial resistance of *Pseudomonas* spp. isolated from wastewater and wastewater-impacted marine coastal zone. Environmental Science and Pollution Research. 22 (24) 19823-19834.

(IF = 2.618; PM = 30)

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Ad theme no. 2

Emission of pharmaceuticals/micropollutants from point sources

Another research theme in the scope of my scientific interests is the emission of pharmaceuticals from point sources. I have realized my studies within the framework of the EU project „*Model Areas for Removal of Pharmaceutical Substances in the South Baltic"* (STHB.02.02.00-SE-0038/16) (2017-2020), which is a flagship project of the European Regional Development Fund, being realized within the framework of Program Interreg South Baltic. The project aims at developing measures against the marine pollution with pharmaceuticals in the Baltic Sea region. The project is realized in cooperation with Kristianstad University (Sweden), The Coastal Union Germany (Germany), University of Rostock (Germany), Environmental Protection Agency (Lithuania), Klaipeda University (Lithuania) and Gdansk Water Foundation.

Pharmaceuticals are chemical compounds which are widely used in ambulatory and clinical medicine, veterinary practice, agriculture and animal husbandry. At present, limiting the emission of pharmaceuticals and their presence in various environmental components is one of the most important challenges of environmental policy. Due to their biological activity, pharmaceuticals have been classified as so-called emerging contaminants (ECs), or emerging pollutants (EPs). The presence of pharmaceuticals in the environment may results, for example, in genetic changes in bacterial populations and the spread of drug resistance (resistance to antibiotics), or to the occurrence of harmful effects related to disrupted hormonal equilibrium in land organisms (endocrine disruptors).

Presently, pharmaceuticals that are most frequently used in medicine can be grouped as follows: analgesics (non-steroidal anti-inflammatory drugs, narcotic and non-narcotic drugs); antibiotics (β-lactam antibiotics, macrolides, fluoroquinolones, aminoglycosides, sulfonamides and tetracyclines); β-blockers; psychoactive (caffeine), psychotropic and antiepileptic (diazepam, carbamazepine) substances; regulators of fats (bezafibrates, clofibric acid, fenofibric acid), estrogens and hormone compounds (estriol, estradiol, estrone, 17α-etynylestradiol); and other drugs used to treat cancer. The ingested pharmaceuticals usually enter the metabolic pathways, although they can become released from the organism not only as metabolites (active or inactive biologically), but also in their unchanged form. In connection to the above, wastewater (municipal and from animal farms and pharmaceutical industry) and the wastewater treatment installations (WWTPs, enclosed bodies of water, etc.) are the main emitters of pharmaceuticals to the environment. Due to improper utilization of

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medical waste and drug residues, which are dumped in regular household waste instead of special containers and stored at the landfill, the resulting landfill leachate is also of significance.

The ongoing research is aimed at collecting information on the consumption of pharmaceuticals in the shore regions of Sweden (Scania), Germany (Mecklemburg), Lithuania (Klajpeda) and Poland (Pomerania). The evaluation of further emission of pharmaceuticals into the environment (in this case, to the coastal waters of the Baltic Sea) is also attempted.

Within the framework of the conducted research, 23 pharmaceuticals were analyzed in the samples of raw and treated wastewater collected from four WWTPs, i.e. Oczyszczalnia Gdańsk – Wschód, Oczyszczalnia Gdynia - Dębogórze, Oczyszczalnia Swarzewo and Oczyszczalnia Jastrzębia Góra (Fig. 4). Moreover, the presence of antibiotics was assessed in the samples of seawater collected directly at the marine outfall (at the bottom) through which the treated wastewater is dumped into the Baltic, and from the marine surface waters above the outfall pipe. In the case of Jastrzębia Góra, where treated wastewater is discharged to Czarna Wda River, the water samples were collected from the main current area before the outfall pipe (upper river) and behind the pipe (lower river). The last analyzed site was the Vistula river mouth in the Gulf of Gdansk. The sampling sites are presented in Fig. 4.

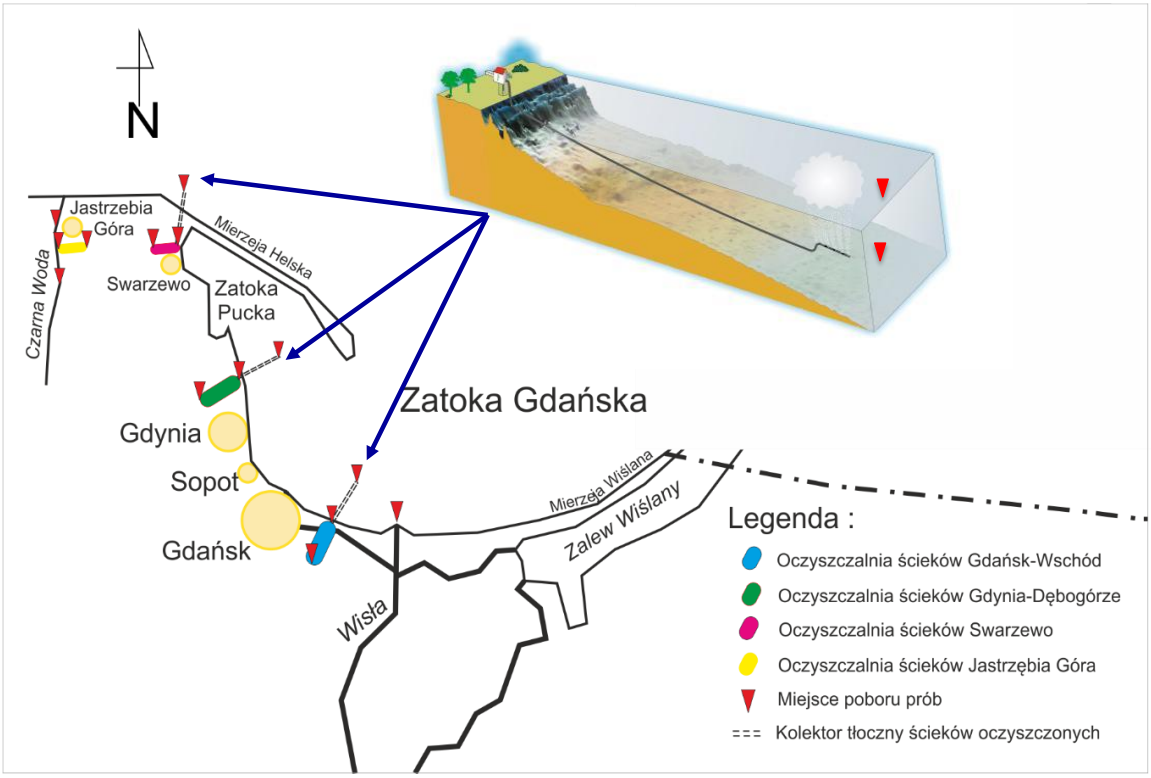

Fig 4. Location of sampling sites for the analysis of 23 pharmaceuticals.

The preliminary study results showed that the analyzed pharmaceuticals were present in raw and treated wastewater. This means that some pharmaceuticals do not become

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biologically degraded (e.g. azythromycin). Commonly used pain killers such as, paracetamol, ibuprofen or diclofenac occur in raw sewage at very high concentrations of above 390 000.00 ng/L. However, it should be underlined that these drugs undergo biodegradation in activated sludge, with an exception of diclofenac. It is an important observation that diclofenac as well as macrolide antibiotics were detected in the wastewater receivers, i.e. Gulf of Gdansk, Baltic Sea and Czarna Wda River. Vistula River is also a significant source of pharmaceuticals.

In summary, the preliminary results of my investigations demonstrated that treated wastewater is a source of pharmaceuticals classified as emerging contaminants (ECs) that are also described as emerging pollutants (EPs), which have a significant effect on the natural environment. In addition, I conduct research aimed at finding effective methods for treating wastewater which would enable limiting the emission of ECs into the receiving water body.

Research has been conducted within the framework of the following grant:

- **Interreg South Baltic Programme 2014-2020** (Project No STHB.02.02.00-SE-0038/16) entitled: Model Areas for Removal of Pharmaceutical Substances in the South Baltic (MORPHEUS); realization period: 2017-2020; **contractor**

The obtained preliminary results were presented at the conference listed below:

- Łuczkiewicz A., Jankowska K., **Fudala-Książek S.**, 2017. Ograniczenie emisji mikrozanieczyszczeń ze źródeł zorganizowanych do morskich wód przybrzeżnych (Mitigation of the micropollutants discharged into the marine coastal waters). I Konferencja Naukowa Polskich Badaczy Morza 2017, Sopot, Poland; oral presentation

Ad Theme no. 3

Economical management of wastewater and sludge aimed at limiting the energy use by municipal wastewater treatment plants

Nowadays, most of the Polish wastewater treatment plants operates based on the activated sludge method. There are many various technological solutions and equipment systems for treating wastewater, which translates into different energy needs of individual WWTP. In recent years, advanced studies in relation to lowering the energy use of WWTPs have been conducted. The main undertaken themes include the aeration processes and sludge management. This is due to the fact that these processes require vast amounts of energy. The aeration of bioreactors may use from 50 to 90% of electric energy consumed by the whole plant (depending on its size and technological solutions applied), while the energy cost can constitute from 15 to 50% of the total operating budget [39,40,41,42]. On the other hand, the

[39]Remiszewska-Skwarek A., 2014a. Napowietrzanie w bioreaktorach, jako główny konsument energii w oczyszczalni. Porównanie rozwiązań, sposoby optymalizacji - materiały seminaryjne: „Efektywność energetyczna oczyszczalni ścieków – możliwości optymalizacji kosztów eksploatacyjnych", WFOŚiGW, Gdańsk 2014

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implementation of highly effective methods of biological and chemical treatment of wastewater, particularly aimed at better removal of nutrients and improved reduction of organic substances to fulfill the requirements of the Water Framework Directive[43] caused an increase in the volume of generated sludge. It is noteworthy that the sludge management is one of the most problematic issues for the entire water supply and sewage sector in Poland. The solutions to problems associated with the ongoing operation of the plant (lack of stabilization of activated sludge, limited possibilities of the final sludge utilization), economical problems (costly re-designing of installation that is not available for many plants) and a negative effect on the environment (poor management of sludge resulting in the pollution of natural environment) are the basics of today's sludge management.

Since January 1, 2016, another problem has emerged for the WWTP operators, i.e. a ban on the sludge deposition at municipal landfills[44]. Therefore, a search for novel, economical and highly efficient solutions in sludge management is extremely crucial. Bearing in mind that the present cost of sludge processing constitutes from 50 to 70% of the operating budget in the majority of WWTPs, a decrease in this cost by even 1-2% will give concrete financial outcome.

In connection to the above, being a technological engineer, I undertook the pertinent thematic investigations in relation to applicative research that would allow the following:

1. limit the energy consumption of aeration by changing the steering system of this process,
2. limit the amount of sludge that requires utilization, and improve the biogas production via the application of eco-innovative thermal disintegration technology which increases the technological and energetic effectiveness of sludge processing.

In the case of the first above theme, I conducted research within the framework of the project titled 'Improved energy consumption of a wastewater treatment plant as a result of changed steering system of the aeration process', financed in the form of targeted grant by

[40]Remiszewska-Skwarek A., 2014b. Optymalizacja procesu napowietrzania na przykładzie GOŚ „Dębogórze" - materiały seminaryjne: „Efektywność energetyczna w procesach oczyszczania ścieków", Gdańska Fundacja Wody, Gdańsk 2014.

[41]Remiszewska-Skwarek A., 2015. Napowietrzanie za mniej. Kierunek Wod-Kan, 2/2015(608), s. 20-30.

[42]Woźniak-Vecchie 2014. Biologiczne oczyszczanie ścieków. Sztuka napowietrzania. Magazyn instalatora 3 (187), s. 46-48.

[43]DYREKTYWA 2000/60/WE PARLAMENTU EUROPEJSKIEGO I RADY z dnia 23 października 2000 r. ustanawiająca ramy wspólnotowego działania w dziedzinie polityki wodnej

[44]Rozporządzenie Ministra Gospodarki z dnia 16 lipca 2015 r. w sprawie dopuszczania odpadów do składowania na składowiskach (Dz.U. 2015 poz. 1277)

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Voivodship Fund for Environmental Protection and Water Management (contract no. WFOŚ/D/825/204/2016) and realized in 2016-2018, where I acted as the project manager. The aim of the project was to elaborate and implement the advanced model of steering the aeration process in two wastewater treatment plants in Pomorskie voivodship located in Luzino and Sławki. Within the framework of the project a modular program for the predictive steering of aeration system was designed which depended on the wastewater quality (ammonia and nitrate concentrations), but not on the oxygen concentration in the aerobic tank. Next, the aforementioned system was implemented in Luzino and Sławki, which included the construction of specific equipment, i.e. ion-selective sensors for analyzing the oxygen and ammonia concentrations, and controllers. The energy consumption of the wastewater treatment plants was analyzed prior to and after the implementation of the predictive steering system of aeration process. The effect of new system on the course of biological processes and, therefore, its influence on the plants' effectiveness was also analyzed.

The obtained results showed a decrease in the electric energy use after the implementation of overriding steering system by, on average, 13 and 20% in Luzino WWTP and Sławki WWTP, respectively. Moreover, the mean drop in energy use at the Luzino plant was from 1.45 to 1.25 kWh/m^3, while in Sławki plant, from 0.61 to 0.49 kWh/m^3. The implementation of the new system increased the effectiveness of ammonia removal during nitrification by 63 and 82% in Luzino and Sławki, respectively. Moreover, it has been demonstrated that for the respective net cost of 1 kWh of 0.21 and 0.46 PLN in Luzino and Sławki, the mean annual savings in energy cost amounted to 15 063 and 23 842 PLN, respectively. The annual costs of electric energy in 2017 were 124 060 and 225 000 PLN in Luzino WWTP and Sławki WWTP, respectively.

In the case of the second theme dealing with lowering the energy consumption related to sludge management, I am conducting research within the framework of the project titled 'Eco-innovative technology of thermal disintegration that increases the technological and energetic effectiveness of sludge processing', partially financed by the Voivodship Fund for Environmental Protection and Water Management in Gdansk within the competition "Pomorskie projekty badawczo-rozwojowe" edycja 2017 (proposal no.: RX-15/10/2017, contract no.: WFOŚ/D/201/6/2018; realization period: 2017-2019). I also manage this project. The project realization encompasses studies on low-temperature disintegration and optimization of working conditions, i.e. temperature, the amount of sludge fed to the system, the volume of added air, retention time, and the size of biogas production. The

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analyzed technology of thermal disintegration can be used in small wastewater treatment plants, as the process for stabilizing and hygenizing of sludge, as well as in large ones which have Closed Tank Fermenters in order to intensify the biogas production. The proposed low-temperature disintegration is conducted at temperatures below 100^{o}C, thus it can be assumed that the energy needed for heating the sludge will be lower by ca. 70% compared to the high temperature (above 100^{o}C) process with the same exposure time.

The described research on low-temperature disintegration is in the first stage of its realization, however, the test results showed a ca. 10% increase in biogas production due to the application of this procedure.

The aforementioned studies have been conducted within the framework of the following grants:

- **WFOŚ/D/825/204/2016**, **targeted grant** from Voivodship Fund for Environmental Protection and Water Management in Gdansk, titled „*Poprawa energochłonności oczyszczalni w wyniku zmiany systemu sterowania procesem napowietrzania*; realization period: 2016-2017.
- **WFOŚ/D/201/6/2018**, project titled „***Ekoinnowacyjna technologia dezintegracji termicznej zwiększająca efektywność technologiczną i energetyczną procesu przeróbki osadów ściekowych***", partially funded by Voivodship Fund for Environmental Protection and Water Management in Gdansk in the competition "Pomorskie projekty badawczo-rozwojowe" edycja 2017; proposal no. RX-15/10/2017; contract no. WFOŚ/D/201/6/2018; realization period: 2017-2019.

The preliminary results of the studies were presented at the following seminars:

- Remiszewska-Skwarek A., **Fudala-Książek S.,** Łuczkiewicz A. 2016. Bacterial biomass activity as an important parameter to assess the process of methane fermentation (Aktywność biomasy bakteryjnej jako ważny parameter oceny procesu fermentacji metanowej). 5th Baltic Biogas Forum, 16 June 2016, Gdansk; poster.
- **Fudala-Książek S.**, Remiszewska-Skwarek A., Łuczkiewicz A., Chodnicki M., Zaborowska E.2018. „Poprawa energochłonności oczyszczalni w wyniku zmiany sytemu sterowania procesem napowietrzania". Project financed by Voivodship Fund for Environmental Protection and Water Management in Gdansk (project no. RI-18/2016; contract no. WFOŚ/D/825/204/2016)." Seminar, March 2018, Gdansk; oral presentation.

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6. SUMMARY OF SCIENTIFIC ACCOMPLISHMENTS

6.1. Prior to receiving PhD

In the years 2004 – 2011, I published nine scientific papers (Att. no. 5, II.A.1; II.E.1), including five articles in the JCR-listed journals (Att. no. 5 II.A.1). I participated in 13 conferences (Att. no. 5, III.B.1); at three of them I presented the oral presentation (Att. no. 5, II.L.1).

The aforementioned publications were the outcome of six projects (including one international project; Att. no. 5, II.J.1). I acted as project contractor in four projects. I managed two projects single-handedly, i.e. my doctoral research grant (Att. no. 5, II.J.1 item 5) and the project financed by WFOŚiGW in Gdańsku (Att. no. 5, II.J.1 item 4).

In 2009, my activities were awarded with the stipend 'Stypendium Innodoktorant' within the framework of Priority VIII of Operational Programme Human Capital, realized by the Department of Economic Development of the Marshall's Office of Pomorskie Voivodship (Att. no. 53, II.K.1).

While performing my professional duties at the Gdańskie Przedsiębiorstwo Energetyki Cieplnej, I authored six construction and working designs (Att. no. 5, II.B.1) and several conceptual plans for the re-construction, liquidation and construction of new heating hubs, heating installations and hot water lines.

6.2 After receiving PhD

In the years 2012-2018, I published 15 scientific papers, including nine publications in the JCR-listed journals (Att. no. 5 II.A.II); five papers are the part of the summary of my scientific accomplishments (Att. no. 5 I.B). Moreover, I co-authored two books (Att. no. 5, II.E.2, items 3 & 4).

I participated in 23 conferences (Att. no. 5, III.B.2); during 10 of these conferences, I delivered the oral presentations (Att. no. 5, II.L.2).

Also, I am the co-author of patent application no. 44/15 titled 'Method for the sulfide removal from wastewater characterized by reducing properties' (Att. no. 5, II.C.2).

I acted as the manager of two research projects (Att. no. 5, II.J.2.3 and 4) as well as managed three projects (Att. no. 5, II.J.2 items 1, 2 & 5), including one international project (Att. no. 5, II.J.2 item 1).

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I jointly participated in the preparation of 13 expert opinions for solid waste treatment plants and companies responsible for trans-shipment of fuels as well as in the elaboration of technologies for biofuel purification and the contamination reduction in wastewater received from cruise ships in the Gdynia Harbor (Att. no. 5, II.F.2).

My activities were awarded with four awards and one award of distinction (Att. no. 5, II.K.2). In 2015, I received the title of Pomeranian Master of Techniques that is awarded by the Pomeranian Council of the Polish Federation of Engineering Associations, Central Technical Organization in Gdansk for the innovative technical solution titled Method for the removal of sulfide and hydrogen sulfide from permeate originating in the reverse osmosis process of landfill leachate (Att. no. 5, II.K.2 item 4).

6.3 Statistics of scientific publications

The pooled Impact Factor (IF) for all scientific papers published by me, according to the Journal Citation Reports (JCR), is **IF = 39.257** (after receiving PhD, **IF** = **28.978**), which includes **IF = 20.928** for scientific accomplishments, and **IF = 8.05** for the remaining accomplishments.

The points assigned by the Ministry of Science and Higher Education (PM), taking into account the percentage share for co-authoring, amounted to the following values:

PM = 228.8 (after receiving PhD, **PM = 215.75**), which includes **PM = 128.5** for scientific accomplishments, and **PM = 100.3** for the remaining accomplishments.

The number of citations according to the Web of Science (WoS) is **143** (133 without self-citations), while the WoS h-index (Hirsch index) is **H = 6**.

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7. DIDACTIC ACTIVITIES

Since starting my doctoral studies in 2005, I have conducted lectures for the students attending stationary and non-stationary studies of the 1st and 2nd degree in the following fields of studies: Environmental Biology, Technology of Water and Wastewater, Heating Industry, Heating Installations, Ventilation and Air-conditioning, Sewage Systems (Att. no. 5. III.J.1 and 2)

Within the framework of my didactic activities and in cooperation with Viessmann and Venture Industries, I organize laboratories for the students of the stationary studies of 2nd degree which consists of practical skills in using the renewable sources of heat in the heating industry and installations, ventilation and air-conditioning. To make the didactic activities more attractive to students, I also closely cooperate with other leading companies in the field of heat industry, heat installations, and ventilation and air-conditioning, e.g. Smay, Dimplex and Klima-Therm. In the years 2018-2017, I organized trips for the students of the stationary studies of 1st degree annual to the annual International Trade Fair of Environmental Protection POL-ECO SYSTEM in Poznan. In addition, in the years 2008, 2010, 2012, 2014 and 2016, I also organized student trips to International Trade Fair of Installation INSTALACJE in Poznan (Att. no. 5. III.J.1 and 2). I jointly organized as well as participated in a one-week didactic tour of EDF atomic plants in France, Belgium and Germany.

Since 2012, I have promoted 68 engineering theses and 35 Master theses as well as reviewed 55 engineering theses and 40 Master theses (Att. no. 5, III.J.2 items 2 and 3). I also act as the promoter of Weronika Jasnoch who conducts the Master's thesis research titled „Charakterystyka ścieków powstających na składowisku odpadów w aspekcie metody ich utylizacji". Ms. W. Jasnoch is a recipient of the stipend granted within the framework of competition „Konkurs dla magistrantów" organized by Voivodship Fund for Environmental Protection and Water Management in Gdansk for the academic year 2012/2013 (Att. no. 5, III.J.3). I was also the promoter of Martyna Magdalena Konopińska whose Master's thesis titled „Koncepcja modernizacji kolektora sanitarnego „Morena" na odcinku Kokoszki – przepompownia ścieków Motława wraz z uwzględnieniem trendu rozwojowego miasta Gdańska i gmin sąsiednich" received the Rector's award of 1st degree in the 'Dyplom Roku' competition in the academic year 2015/2016 as well as the award of distinction in the competition organized by Pomorska Okręgowa Izba Inżynierów Budownictwa in Gdansk for the best MSc thesis in the academic year 2015/2016 (Att. no. 5, III.J.3).

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I also organize training sessions for various groups interested in exploring the wastewater treatment plants (Att. no. 5, III.I.2, items 2, 3, 4 and 5).

In 2014, I received the 2nd degree team award of the Rector of the Gdansk University of Technology for distinctive didactic activities (Att. no. 5, II.K.2, item 2) for publishing the book titled Zaopatrzenie w wodę. Suligowski Z., Fudala-Książek S. 2014. Wydawnictwo Seidel Przywecki Sp. z o.o., str. 256; ISBN: 978-83-60956-35-9 (Att. no. 5, II.E.2, item 3).

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8. ORGANIZATIONAL ACTIVITIES

In the years 2013-2017, I was a member of the Faculty Admission Commission (Att. no. 5, III.Q.2, item 1). Since 2012, I have been a member of the Faculty Council at the Faculty of Civil and Environmental Engineering, Gdansk University of Technology.

Thanks to the project grants, that I had received and managed, and work contracts, new research work stations were created. These work stations were equipped with the lab-scale wastewater treatment systems, among others, A2O flow-through reactor, sequential biological reactor (SBR), system for advanced electrochemical oxidation of wastewater at the boron-doped diamond (BDD) electrodes. At present, these systems are used by the doctoral students (Att. no. 5, III.Q.3 items a, b and c).

I jointly organized five seminars (Att. no. 5, III.C.2), including two international ones (Att. no. 4, III.C.2, items 1 and 2). In 2015, I was the main organizer of national conference „Ścieki przemysłowe. Wyzwania Technologiczne i Ekonomiczne", whose honorary patronage was assumed by the Rector of the Gdansk University of Technology, the Rector of the University of Gdansk, and the Marshall of Pomorskie Voivodship (Att. no. 5, III.C.2 item 5). In 2018, I organized a seminar titled 'Improved energy consumption of a wastewater treatment plant as a result of changed steering system of the aeration process', with the patronage of Voivodship Fund for Environmental Protection and Water Management in Gdansk (Att. no. 5, II.C.2 item 6).

Since 2014, I have delivered 13 reviews for the international (JRC-listed) journals, including Environmental Science and Pollution Research, Environmental Technology, Chemical Engineering Journal (Att. no. 5, III.P.2).

Since 2005, I have been an active member of Polish Association of Sanitary Engineers and Technicians. In 2010, I joined the International Water Association (IWA) (Att. no. 5, III.I.1 and 2).

I was expanding my scientific competences by conducting international cooperation with Aalborg University (Denmark), Technological Educational Institute of Crete (Greece), and by participating in particularly valuable internships at the University of Strathclyde, Glasgow (Great Britain) and the University of Castile-La Mancha, Ciudad Real (Spain) (Att. no. 5, III.L1 and 2).

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I also participated in seven courses (Att. no. 5, III.L.1 and 2) to improve my professional qualifications, among others, Internal Auditor of Integrated Management System for Quality Management Systems, Environmental Management Systems and Occupational Health and Safety Management Systems (Att. no. 5, III.L1, item 1); 1-yr training titled 'Skuteczne zarządzanie projektem, zespół projektowy, techniki pracy w projekcie' at Gdańska Fundacja Kształcenia Menadżerów (Att. no. 5, III.L1, item 2). Moreover, in 2012, I took part in the DEX summer school titled 'Advanced course on wastewater treatment and drinking water' in Rottenbach (Austria), which was organized by the Vienna University of Technology, University of Natural Resources and Life Sciences in Vienna, Technische Universität Berlin, University of Kassel and the international company specializing in environmental protection, i.e. VTA Rottenbach (Austria) (Att. no. 5, III.L2, item 2).

After receiving a doctoral diploma, I attempted to closely cooperate with the industry where I could apply my scientific knowledge on the technology of municipal and industrial wastewater treatment to practical solutions. The outcome of this work was 13 expert opinions, implementations and technologies covering the wide spectrum of wastewater treatment (Att. no. 5, III. F.2) as well as a patent application titled 'Metoda usuwania siarczków ze ścieków o charakterze redukcyjnym' (Att. no. 5, III.C2, item 1). Moreover, I co-authored two academic books, i.e. „Zaopatrzenie w wodę." Suligowski Z., Fudala-Książek S. 2014. Wydawnictwo Seidel Przywecki Sp. z o.o., str. 256; ISBN: 978-83-60956-35-9 (Att. no. 5, II.E.2, item 3); and „Wykonanie i odbiór sieci kanalizacyjnych." Suligowski Z., Fudala-Książek S. 2016., Wydawnictwo Seidel Przywecki Sp. z o. o., str. 172, ISBN- 978-83-60956-47-2 (Att. nr 5, II.E.2, item 4). The aforementioned books are widely used by, *inter alia*, designers, contractors and users of water and sewage systems as well as students studying technical.

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9. SUMMARY OF THE ACHIEVEMENTS

No	Type of achievements	Number	
		After receiving the PhD degree	Before receiving the PhD degree
1	**Science publications, including:**	**23**	**45**
	journal with Impact Factor	5	9
	chapters in monograohs in the language of the national reach	1	3
	peer-reviewed journal and other periodicals	4	6
	industry books	0	2
	conference materials - reviewed	11	19
	professional magazines and conference materials - not reviewed	2	6
2	**Research projects, including:**	**6**	**5**
	international	1	1
	national	4	1
	WFOŚiGW in Gdansk	1	3
3	**Author and co-author presentations and posters at conferences and seminars, including:**	**13**	**25**
	international	10	13
	national	3	12
4	**The creative professional work, including:**	7	16
	patent applications	0	1
	implementation	0	4
	new technologies, equipment and research stations	1	2
	opinions and expertises	0	9
	conceptual and design works	6	0
5	**Auxiliary promoter in the Ph.D.**	**0**	**1**
6	**Supervisor of theses, including:**	**0**	**103**
	engineering works	0	68
	master's theses	0	35
7	**Reviewer of theses, including:**	**0**	**95**
	engineering works	0	55
	master's theses	0	40
8	**Citations (eithout self-citations)**	**0**	**132**
9	**h-index**	**0**	**6**

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