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THE IMPACT OF MILK PROCESSING PLANT PRODUCTION PROFILE ON DAIRY SEWAGE COMPOSITION

Abstract
Dairy industry is one of the biggest sources of industrial wastewater in Europe. The problem of dairy sewage treatment is not completely solved. Dairy wastewater is characterized by high load of COD and BOD_5. This includes fats, sugars and protein and shares of these substances can vary. Nitrogen in dairy sewage occurs in the form of organic nitrogen and NH_4^+, NO_2^- and NO_3^- ions and its main source are milk proteins. Susceptibility to biological degradation of substances contained in dairy wastewater depends on the type of wastewater generated in a particular milk processing plant. The purpose of this work was to determine the variability of wastewater composition in milk processing plants depending on their production profile. Polish milk production was characterized based on geographical division into regions around the country. The share of Polish milk production in the European and global economy was also determined. The region of Podlasie, which is the national milk production center and the Mazowieckie and Warminsko-Mazurskie had special focus. The results of research carried out between 2014 and 2018 were analyzed for fourmill milk processing plants. Dependencies between indicators of organic and biogenic contamination were analyzed in the wastewater generated from those plants. It was determined that dairy sewage discharged from differing production profile plants varied also in the physico-chemical composition. The composition of dairy sewage is primarily influenced by the plant production profile but also by specific technologies used. An example of such a technology is a closed circuit economy which allows for a substantial reduction of water and energy consumption. Regardless of production profile dairy sewage is characterized by a high COD/N_{tot} ratio which classifies it as susceptible to highly effective biological purification. Biological removal of phosphorus from dairy sewage should proceed with high efficiency without the need for chemical precipitation. Only in dairy wastewater from Olecko (curd, cottage cheese and yogurt not produced) the lower value of the ratio BOD/P_{tot} and COD/P_{tot} makes it impossible to achieve high biological effectiveness of phosphorus removal and an additional process of chemical phosphorus precipitation should be applied in WWTP.

Keywords
dairy, industrial, milk processing plant, wastewater, production profile

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1. INTRODUCTION

Dairy industry is one of the biggest sources of industrial wastewater in Europe. In 2017 milk production in the European Union amounts to 156 mln t which accounts for approximately 31% of world production [1, 2]. Annual milk production in the leading European countries is shown in Figure 1.

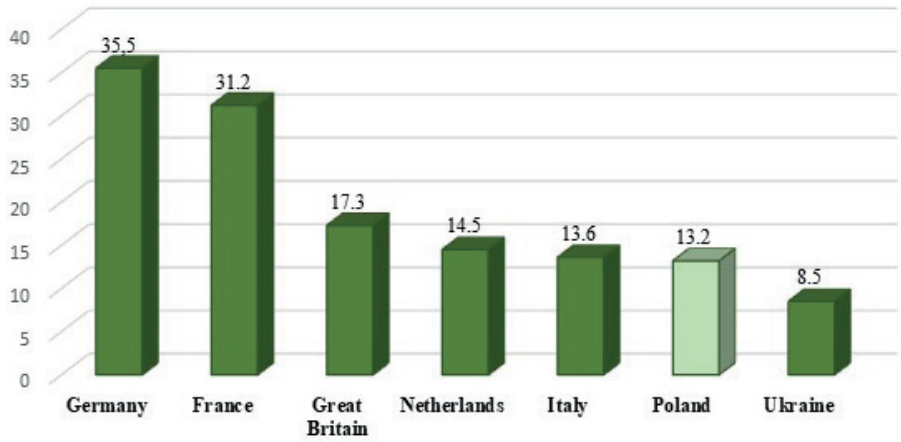

Fig. 1. Milk production in Europe in 2016 (mln t) [3]

The annual production of cow's milk in Poland in 2017 increased by 4.5% compared to 2016. Milk production from 2016 classifies our country as sixth in Europe. The highest share in milk production in 2016 was recorded in the following regions – Mazowieckie (20.9%), Podlaskie (20.1%), Wielkopolskie (13.6%) and Warminsko-Mazurskie (7.9%) and the lowest in Lubuskie (0.7%), Zachodniopomorskie (1.1%) and Dolnośląskie (1.4%). Comparing milk production per one hectare of agricultural land in Poland the decisive leader is Podlaskie region where the amount of milk per one hectare in 2016 was 2,362 l, almost three times more than the Polish average of 885 l. Mazowieckie region is second with production at the level of 1402 l [4].

Milk production in Poland has been growing systematically and ranges from 11.6 bn l in 2006 to 12.9 bn l in 2016 [5].

In milk processing plants across the country raw milk is processed into cheese (maturing, blue, etc.), cottage cheese (natural, with fruit, vegetables, honey), drinking milk (0–3.2% fat, lactose free, organic), cream (10–42% fat), curd (natural, with vegetables and spices), yogurt (natural, with fruit, Greek and Icelandic type), mascarpone, feta type cheese, butter, kefir (0–2% fat), sour milk, etc. Dairy wastewater is generated during production of milk products and is characterized by a high load of COD and BOD_5. This includes dissolved and crystallized fats (glycerol, triglycerides), sugars (lactose) and protein (casein) in colloidal form and as clots; shares of these substances can vary. Nitrogen in dairy sewage occurs in

the form of organic nitrogen (proteins, urea, and nucleic acids) and NH_4^+, NO_2^- and NO_3^- ions and its main source are milk proteins. Some fats like casein are resistant to biodegradation and thus require properly adapted microorganisms for biological degradation [6]. The dairy industry is one of the most polluting industries, not only in terms of the volume of effluent generated, but also in terms of its characteristics. This industry generates about 0.2–10.0 l of effluent per litre of processed milk [7, 8].

The purpose of this work was to determine the variability of wastewater composition in milk processing plants depending on their production profile. The Food and Agriculture Organization of the United Nations (FAO) and the Organization for Economic Co-operation and Development estimate global milk production in 2024 to increase by 23% compared to 2012–2014, namely by ca. 175 mln t [9, 10]. The growth in milk production and processing rates will further lead to a substantial increase in the volume of generated dairy wastewater. This confirms the validity and the advisability of the dairy wastewater subject. In literature [7, 8, 11] dairy sewage is characterized by a holistic approach, i.e. without diversification due to the plant's production profile. Many articles relate to research using statistical models and not real dairy sewage. It is clearly worth to examine the composition of wastewater from milk processing plants and indicate the differences. This data may be relevant to other researchers involved in the treatment of dairy sewage by various methods.

2. MATERIALS AND METHODS

The study was conducted in 2014–2018 in four milk processing plants, located in East-North Poland in the following regions – the Podlaskie and the Warminsko-Mazurskie.

2.1. AREA OF STUDY

Area of the study is shown in Figure 2.

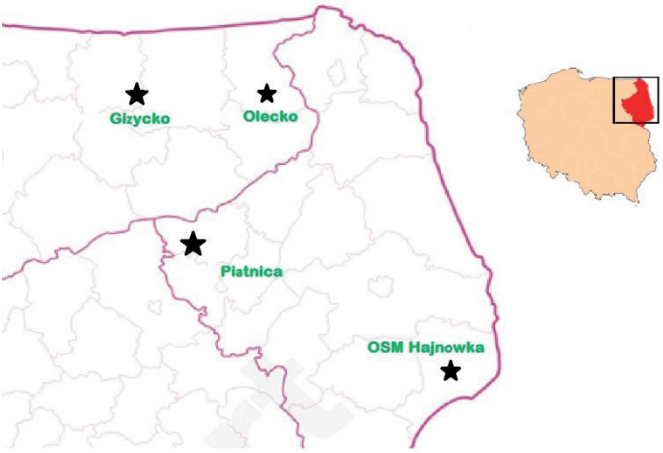

Fig. 2. Milk processing plants selected for analysis

Piatnica Milk Processing Plant

The Regional Dairy Cooperative in Piatnica annually purchases 333 mln l of milk and is the largest producer of cottage cheese in the world. Drinking milk production (ecological) is based on a method of microfiltration and pasteurization at 74°C/20 s. In recent years Piatnica has continued to expand and modernize with investments including the launch of new cottage cheese production line as well as a fully automated and climate controlled high storage 5,000 pallet warehouse, the first of its type in Polish dairy plants. A line for the production of innovative 0% fat and double protein Greek yoghurt was launched in 2015. Piatnica was the first Dairy Cooperative in the country to implement IMS – Integrated Management System, including: Quality management system ISO 9001, food safety system according to HACCP, ISO 14001 environmental management system. A system for the purification and reuse of process water has been implemented which allowed for a significant reduction of water consumption by as much as 240 $m^3 \cdot day^{-1}$. The water consumption index is currently 2.7 l per each litre of processed milk. Dairy sewage generated in production processes flows into the industrial wastewater treatment plant [12].

Olecko Milk Processing Plant

The Regional Dairy Cooperative in Olecko annually purchases 36.5 mln l of milk. In 2003 the HACCP quality control system was introduced. In 2004 whey compaction equipment was put into operation. In 2005 the entire refrigeration installation was replaced. In 2007 the extension of cheese ripening was started. In 2011 the salt works department was built and equipped. In 2013–2015 foam washing in the production departments and the apparatus department were modernized and a self-cleaning centrifuge for milk with an ice-water subcooler was purchased. In 2017 modernization of whey concentration, production of fudge and cottage cheese making rooms was started. Dairy sewage generated in production processes flows into the municipal wastewater treatment plant in Olecko without pre-treatment and load averaging. The average daily volume of dairy wastewater reaches 510 $m^3 \cdot day^{-1}$, which constitutes ca. 9% of the total volume of wastewater inflowing to the MWTP. Contribution of BOD_5 load in dairy wastewater is ca. 19%, whereas its COD load constitutes on average 21% of the total contaminants load.

Hajnowka Milk Processing Plant

The Regional Dairy Cooperative in Hajnowka annually purchases 58.4 mln l of milk and has implemented a HACCP quality control system. In 2009 a fully automated maturing cheese department was commissioned. In the powder section (nanofiltration) – a device for the recovery of water from NF permeate and evaporative condensate with a technological installation for the distribution of recovered water to selected facilities in the plant was installed. In 2012 a production line for ripening cheeses was opened. Dairy wastewater inflows to an aerated retention-averaging tank from where it is passed into the municipal wastewater treatment plant. The average daily volume of dairy wastewater reaches 500 $m^3 \cdot day^{-1}$, which constitutes ca. 8% of the total volume of wastewater inflowing to the MWTP. Contribution of BOD_5 load to dairy wastewater is ca. 32%, whereas its COD load constitutes on average 21% of the total contaminants load.

Gizycko Milk Processing Plant

The Regional Dairy Cooperative in Gizycko annually purchases 145 mln l of milk and introduced standard of Good Manufacturing Practice (GMP) and HACCP system. The most important investments included: installation of modern milk processing and milk collection facilities and a modern cheese brewery with a milk processing of approx. 450,000 l a day. In 2015 a modern maturing room was opened for use, which can hold approx. 4,000 t of ripening cheese at the same time. Dairy sewage generated in production processes flows into the municipal wastewater treatment plant in Bystre.

The Production Profile in Milk Processing Plants

The Production Profile in Milk Processing Plants is shown in Table 1.

Table 1. The production profile in milk processing plants

Product	Piatnica	Olecko	Hajnowka	Gizycko
Cheese		×	×	××
Drinking milk	×	×	×	
Whey powder			×	×
Cream	×	×	×	
Curd cheese	×		×	×
Fudge		×		
Buttermilk		×		
Butter		×		
Cottage cheese	×			
Yogurt	×			
Kefir	×			
Mozzarella type cheese				×

2.2. ANALYTICAL METHODS AND CALCULATIONS

Samples were collected at a monthly basis from equalization tanks from dairy industries. The scope of analytical determinations in samples of raw dairy wastewater included analysis of the following indicators: pH, BOD_5, COD_{Cr}, TSS, N_{tot}, P_{tot}. Analyses were carried out in accordance with APHA (2012) [13]. Based on the study results, ratio of organic compounds (BOD_5, COD) for biogenic compounds (N_{tot}, P_{tot}) were carried out. The various statistical parameters such as minimum, maximum, arithmetic mean, median, standard deviation have also been established.

3. RESULTS

Table 2 summarizes the characteristics of dairy wastewater from four milk processing plants in 2014 and 2018.

Table 2. Characteristic of dairy wastewater from four milk processing plants (2014–2018)

Indicator	Piatnica*	Olecko*	Hajnowka*	Gizycko*
pH**	3.3–12.2	3.2–12.6	6.6–8.9	7.2–7.8
BOD_5 $gO_2 \cdot m^{-3}$	1407.9/1425.0/556.4 1127.3–1632.5	270.8/283.6/187.8 242.4–586.3	1609.6/1790.0/342.8 1180.0–1912.0	665.2/682.0/102.2 506.0–820.0
COD_{Cr} $gO_2 \cdot m^{-3}$	2930.3/2967.6/1077.1 2222.5–3555.0	1015.5/562.8/838.4 500.8–983.0	2099.0/2310.0/422.4 1546.0–2420.0	1197.7/1120.0/227.1 939.0–1630.0
TSS $g \cdot m^{-3}$	628.6/626.2/289.1 472.5–830.0	211.5/228.5/91.9 122.4–283.7	296.40/298.0/92.5 176.00–432.0	159.4/160.0/25.4 110.0–197.0
N_{tot} $gN \cdot m^{-3}$	130.9/127.8/58.1 96.1–198.1	32.6/19.3/32.9 8.37/70.15	54.00/61.1/15.0 29.2–66.2	87.6/89.9/17.1 57.4–112.0
P_{tot} $gP \cdot m^{-3}$	21.5/20.6/8.8 17.9–27.6	20.9/19.7/3.8 17.9–25.2	26.3/25.6/1.3 25.4–28.6	18.8/18.6/4.9 12.0–27.3

* arithmetic mean / median / standard deviation min – max
** min – max

Based on the results of the study (Tab. 2) it was found that the variability of wastewater composition in milk processing plants depends on their production profile. The largest differences in the composition of dairy sewage were recorded in Olecko. The comparison of production profiles of all plants shows that the production of fudge, butter and buttermilk has the greatest impact on the characteristics of dairy sewage. In addition, it was found that dairy effluents form plants selected for analysis are not highly volatile throughout research period (Tab. 2) which may positively affect the treatment process in wastewater treatment plants (industrial or municipal).

The factor affecting the efficiency of pollutant removal from wastewater is their composition. Based on the results presented in Figure 3 and literature data [12, 14] it was found that dairy wastewater from Hajnowka and Gizycko is readily biodegradable (the ratio $COD/BOD_5 < 2.0$), from Piatnica – average biodegradable (the ratio COD/BOD_5 2.0–2.5) and from Olecko – slowly biodegradable (the ratio COD/BOD_5 2.5–5.0). For a detailed analysis of the composition of dairy sewage in the future, research on the COD fraction should be performed.

The amount of easily decomposed organic compounds found in sewage in relation to the nitrogen and phosphorus compounds directly affects the efficiency of nitrate nitrogen and phosphorus removal [15] and are shown in Table 3.

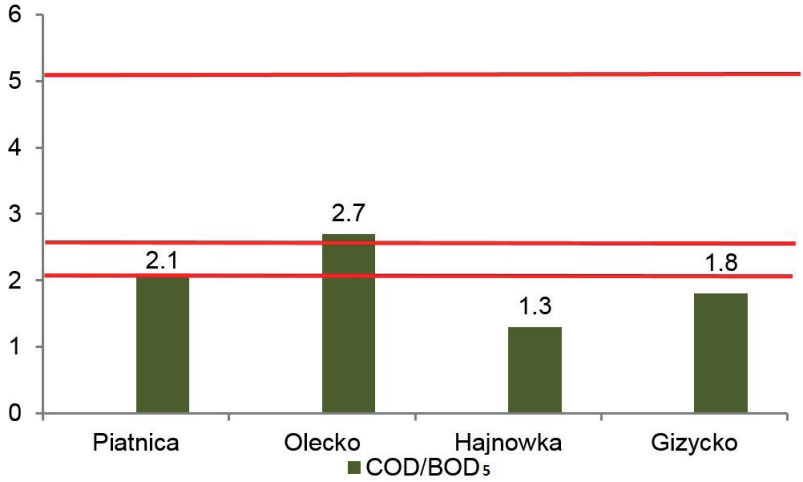

Fig. 3. A comparison of the ratio COD/BOD_5 in dairy wastewater from 4 milk processing plants (average value in 2014–2018)

Table 3. The efficiency of nitrogen and phosphorus removal based on organic compounds in relation to the nitrogen and phosphorus compounds

The ratio	Value	Efficiency of the treatment process	References
BOD_5/N_{tot}	> 4	high effective denitrification	[12, 16, 17]
BOD_5/P_{tot}	> 20	high effective dephosphatation	[15, 17, 18]
COD/N_{tot}	> 9	high effective nitrogen removal	[12, 15, 18]
COD/P_{tot}	> 40	high effective dephosphatation	[12, 15, 17–20]
	< 36	the efficiency of phosphorus removal decreases	
	> 50	very high effective biological dephosphattion	

Figure 4 presents characteristics of dairy wastewater from four milk processing plants with different production profile.

Based on the results presented in Figure 4 and literature data [12, 15–20] it was found that the ratio between the amount of organic compounds and nutrients in the dairy effluent from four milk processing plants selected for analysis indicate the possibility of highly efficient biological removal processes of nitrogen and phosphorus from wastewater during treatment. Only in dairy wastewater from Olecko the lower value of the ratio BOD/P_{tot} and COD/P_{tot} makes it impossible to achieve high biological effectiveness of phosphorus removal and an additional process of chemical phosphorus precipitation should be applied in WWTP.

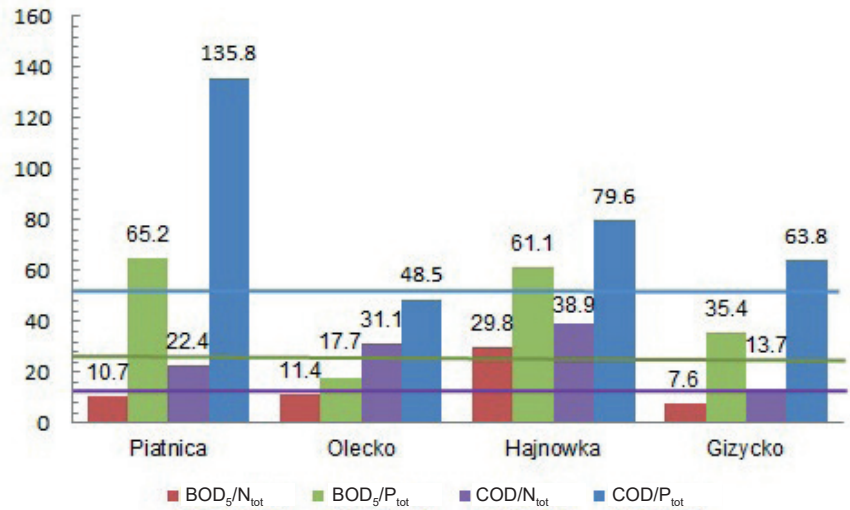

Fig. 4. A comparison of the ratio BOD_5/N_{tot}, BOD_5/P_{tot}, COD/N_{tot}, COD/P_{tot} in dairy wastewater from four milk processing plants (average value in 2014–2018)

4. CONCLUSIONS

- In milk processing plant in Piatnica recycled water is used for washing. The reduction in volume of dairy wastewater produced is linked to increased contaminant loads. In this plant loads of pollutants in dairy sewage are the highest.
- It can be concluded that dairy processing plants produce stable wastewater streams with variable pH values, high COD, BOD, N and P concentrations. Certainly wastewater also contains inhibiting cleaning agents and strong fluctuations in all factors but research should be extended to confirm this.
- The production of fudge, butter and buttermilk has the greatest impact on the characteristics of dairy sewage.
- The plant's production profile has no impact on the susceptibility to biological degradation of substances contained in dairy wastewater. The dairy wastewater from plants selected for analysis is amenable to biological treatment – either aerobic or anaerobic.
- The value of the ratio $COD/P_{tot} < 50$ g COD/gP in dairy wastewater in Olecko makes it impossible to achieve high biological effectiveness of phosphorus removal in activated sludge and an additional process of chemical phosphorus precipitation should be applied.

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REFERENCES

[1] EU-28: Milk production and population. Available from: https://www.clal.it/en/?section=produzioni_popolazione [accessed: 2018.07.26].
[2] The Statistics Portal. Available from: https://www.statista.com/statistics/263952/production-of-milk-worldwide/ [accessed: 2018.07.26].
[3] Mlekpol experience. 2017. Available from: https://www.miir.gov.pl/media/46634/Mlekpol_EFIS_08062017.pdf [accessed: 2018.07.26].
[4] Statistics Poland. Available from: https://stat.gov.pl/obszary-tematyczne/rolnictwo-lesnictwo/produkcja-zwierzeca-zwierzeta-gospodarskie/fizyczne-rozmiary-produkcji-zwierzecej-w-2016-roku,3,12.html [accessed: 2018.07.26]
[5] Olszewska M. Produkcja mleka w Polsce na tle świata i krajów Unii Europejskiej. 2015; LIII, 3: 150–157. Available from: http://www.izoo.krakow.pl/czasopisma/wiadzoot/2015/3/WZ_2015_3_art20.pdf [accessed: 2018.07.27].
[6] Struk-Sokołowska J., Mielcarek A., Wiater J., Rodziewicz J. Impacts of dairy wastewater and pre-aeration on the performance of SBR treating municipal sewage. Desalination and Water Treatment, 2018, 105, pp. 41–50. DOI: 10.5004/dwt.2018.22031.
[7] Lateef A., Chaudhry M.N., Ilyas S. Biological treatment of dairy wastewater using activated sludge. Science Asia, 2013, 39, pp. 179–185. DOI: 10.2306/scienceasia1513-1874.2013.39.179.
[8] Vourch M., Balannec B., Chaufer B., Dorange G. Treatment of dairy industry wastewater by reverse osmosis for water reuse. Desalination, 2008, 219, pp. 190–202. DOI: 10.1016/j.desal.2007.05.013.
[9] Prognoza światowej produkcji mleka do 2024 r. – Bydło i mleko. Available from: http://www.farmer.pl/produkcja-zwierzeca/bydlo-i-mleko/prognoza-swiatowej-produkcji-mleka-do-2024-r,58478.html [accessed: 2018.07.26].
[10] Struk-Sokołowska J., Rodziewicz J., Mielcarek A. Effect of dairy wastewater on changes in COD fractions in technical-scale SBR type reactors. Water Science & Technology, 2017, 1, pp. 156–169. DOI: 10.2166/wst.2018.099.
[11] Shete B.S., Shinkar N.P. Dairy industry wastewater sources, characteristics & its effects on environment. International Journal of Current Engineering and Technology, 2013, 3, 5, pp. 1611–1615.
[12] Struk-Sokołowska J. Variability of dairy wastewater characteristics in Piatnica – one of the largest and most advanced milk processing plants in Poland. E3S Web of Conferences, 2018, 44, 00169. DOI: 10.1051/e3sconf/20184400169.
[13] Rice E.W., Baird R.B., Eaton A.D., Clesceri L.S. Standard Methods for the Examination of Water and Wastewater. American Public Health Association (APHA), American Water Works Association (AWWA), Water Environment Federation (WEF), 22nd edition, 2012.
[14] Slavov K.A. General Characteristics and Treatment Possibilities of Dairy Wastewater – A Review. FTB Food Technology& Biotechnology, 2017, 55, 1, pp. 14–28. DOI: 10.17113/ftb.55.01.17.4520.

[15] Janczukowicz W., Zieliński M., Debowski M. Biodegradability evaluation of dairy effluents originated in selected sections of dairy production. Bioresour Technology, 2008, 99, pp. 4199–4205. DOI: 10.1016/j.biortech.2007.08.077.
[16] Kalinowska E., Bonar G., Duma J. Zasady i praktyka oczyszczania ścieków. Lemtech Konsulting, Kraków 2008.
[17] Wojnicz M., Anielak A.M. Kinetics of Dairy Wastewater Treatment in the SBR System. Archives Environmental Protection, 2010, 36, 3, pp. 27–37.
[18] Sadecka Z. Podstawy biologicznego oczyszczania ścieków. Seidel-Przywecki, Warszawa 2010.
[19] Fudala-Książek S. Wpływ zrzutu odcieków składowiskowych na efektywność pracy miejskiej oczyszczalni ścieków [PhD thesis]. Politechnika Gdańska, Gdańsk 2011.
[20] Miksch K., Sikora J. Biotechnologia ścieków. Wydawnictwo Naukowe PWN, Warszawa 2010.