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Research Article

EVALUATION OF ENERGY CONSUMPTION IN AGRO-INDUSTRIAL WASTEWATER TREATMENT PLANT

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ABSTRACT
Energy consumption during waste water treatment is a very important factor affecting food industry plants. Apart from highly efficient treatment of dairy and meat sewage, a low energy consumption is required in order to lower its costs. During the research period, parameters of raw and treated sewage were tested (BOD,COD, N-total, P-total). Also, the energy consumption from selected processes as well as total consumption were measured. Indicators of energy consumption per m^3 and removed load were calculated. It was found that biological treatment and aeration played the main role in energy consumption in both objects. It was respectively 40 and 47% for Bielmlek and JBB plants. The second biggest energy consuming stage of treatment in both objects was sludge processing. Energy required to process excessive sludge equaled 30% of the total energy usage in both plants. Energy consumption factors related to hydraulic flow gave results in the range from 2.05 to 3.3 $kWhm^{-3}$and from 2.72 to 3.23 $kWhm^{-3}$ for Bielmlek and JBB plants respectively. The research will be continued in order to optimize energy consumption, while retaining high efficiency treatment in food industry WWTPs. Finally, a mathematical model will be prepared for optimizing energy consumption in food industry WWTPs.

Keywords: dairy industry, meat industry, wastewater, energy efficiency

INTRODUCTION

Food production is one of the most important branches of industry. Dairy and meat products are crucial elements of human diet. According to statistics, meat and dairy production are both placed among the top three sub-sectors of Polish food and drink sector. This trend is also visible in most of the EU-member countries. A significant increase in meat and dairy production in Poland between 2012 and 2014 was also observed (GUS 2015; Food Drink Europe 2015). Higher production levels are causing an increase of industrial wastewater amounts in Poland (GUS 2015). Industrial wastewater is more concentrated than municipal wastewater, therefore, the treatment is much more energy-consuming. Dairy and meat industry wastewater has high oxygen demand (BOD, COD) and nutrient concentration that requires advanced technologies of removal which in turn generate costs, mainly from the usage of electrical energy (Bustillo-Lecompte and Mehrvar 2015). In order to keep the companies competitive, scientists and engineers have been working to come up with solutions to reduce the energy usage of industrial wastewater treatment plants. This paper presents the results of a research carried out in two WWTP's: Bielmlek Dairy Cooperative localized in Podlaskie Voivodeship, Bielsk Podlaski, Poland and JBB Meat Processing Plant localized in Mazowieckie Voivodeship. In both locations five measuring series were carried out, during which wastewater was characterized in terms of Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Nitrogen (TN) and Total Phosphorus (TP). Also, energy consumption and flow were measured, which let the authors determine the energy consumption factors related to the removed pollution loads. This article gives an insight into the energy usage in the treatment of wastewater from two agro – industrial wastewater treatment plants.

MATERIALS AND METHODS

Bielmlek and JBB WWTPs characteristics

Bielmlek Dairy Cooperative is localized in Bielsk Podlaski, Podlaskie Voivodeship, Poland. The plant is one of the most modern dairy plants in eastern Poland. It has production capability up to 500 m^3 of milk a day and it exports its merchandise to Middle-Eastern, African and EU countries. The wastewater treatment plant is localized near the dairy plant so the site's sewer system is gravitational. The plant's average hydraulic capacity is 750 m^3d^{-1} and the maximum capacity is 1200 m^3d^{-1}. A 6 mm diameter screen bar is the first element of the technology line. It removes large, floating objects from the wastewater. The next object is the main pump station which is localized in the same building as the steering room. From the pump station, wastewater goes to a grit chamber. Following the grit chamber there is a buffer tank equipped with two stirrers and a primary aeration system. The tank allows the inconstant pH and pollution loads to equalize. Dissolved Air Flotation system (DAF) is next in the process. The DAF system can remove up to 80% of fat, TSS (Total Suspended Solids), BOD, COD and TN loads from the wastewater (Babatola et al. 2011). During the DAF process a variety of chemicals are used, including PIX and PAX coagulants and polymers. DAF cell parameters can be changed so the activated sludge load is maintained at a required level. The wastewater without fat goes to Sequencing Batch Reactors (SBR) where biological treatment is carried out. The treated wastewater is discharged into the receiving Biała river. Excessive sludge is gravitationally thickened, aerobically stabilized, mechanically dewatered and agriculturally used.

JBB Meat Processing Plant is localized in Łyse, Mazowieckie Voivodeship, Poland. The plant specializes mainly in meat processing, not in slaughtering. The company has its own sewers system and a wastewater treatment plant. The sewer system is divided into industrial, storm water and sanitary sub – systems. The JBB wastewater treatment plant's average hydraulic capacity is 2500 m^3d^{-1}. The treatment is conducted in two phases: mechanical treatment with the DAF process and biological treatment with two-stage activated sludge process. The first element of the sewage line is a two-stage screen bar. The next step is the DAF system and a buffer tank. The role of the buffer tank is similar to that used in dairy wastewater treatment. According to literature, the DAF system can remove up to 78% and 79% of BOD and COD respectively and 89 % of TSS from meat processing wastewater (de Sena et al. 2008). After the buffer tank, the wastewater goes to the biological stage of the treatment. In contrast with Bielmlek, the biological treatment is carried out in flow two-stage activated sludge system. A high-loaded activated sludge reactor is followed by a low-loaded reactor. Every reactor is divided into three parts with different aerobic regimes so that biological dephosphatation, denitrification and nitrification can be carried out. The recirculation of the return sludge is also guaranteed. Activated sludge is separated from the treated wastewater in a settling tank. The treated wastewater is discharged to a receiving drainage ditch. Excessive sludge is gravitationally thickened, aerobically stabilized, mechanically dewatered and agriculturally used.

Samples collection, measurement method and installed powers characteristics

Bielmlek WWTP. The samples were taken from three spots at the plant: the grit chamber (raw wastewater), the outlet of the DAF device (mechanically treated wastewater) and the outlet of the SBR reactors (biologically treated wastewater). The samples were collected as average from 8 hour (eight-hour) shift of dairy plant operation. Five measurement series were conducted. The analyses were conducted at Bielmlek Dairy Cooperative Laboratory. The samples were characterized in terms of BOD, COD, TN and TP. Electric energy usage was measured on-line with three phase power analyzers connected with each three-phase device at the plant. The data from the analyzers was sent to the SCADA system where it could be processed and analyzed. Wastewater flow was also monitored on-line via ultrasonic flow meters.

JBB WWTP. The samples were taken from three spots at the plant: the outlet of the screen

Table 1. Bielmlek and JBB WWTP's powers installed

Item	Unit	Bielmlek WWTP	JBB WWTP
Mechanical treatment	kW	74	111
Biological treatment	kW	105	346
in which aeration system only	kW	*88*	*296*
Sludge processing	kW	57	213
Total	kW	235	670

bar (raw wastewater), the outlet of a buffer tank (mechanically treated wastewater) and the outlet of a settler tank (biologically treated wastewater). The samples were collected as average from 24-hour of meat processing plant operation. Five measurement series were conducted. The analyses were carried out at JBB Meat Processing Plant Laboratory and VIEP Ciechanów Laboratory. The samples were characterized in terms of BOD, COD, TN and TP. Energy usage of the whole object was determined by the reading from the main transformer and recorded by the SCADA system. Energy usage of individual devices was defined by operation time and installed power. Wastewater flow was monitored on-line via ultrasonic flow meters.

Table 1 presents power installed on both considered WWTPs. The JBB WWTP installed power is almost three times higher than Bielmlek's WWTP. It is accurate due to higher loads of pollution and hydraulic capacity of the meat processing plant. The installed power of aeration system only in Bielmlek and JBB plants is respectively 37% and 44%, which makes biological treatment the most energy-consuming stage of the treatment. This phenomenon is commonly observed in industrial and municipal WWTPs as well (Singh et al. 2012, Dąbrowski et al. 1997, Zaborowska 2013). Mechanical treatment and sludge processing share in total installed power is respectively 31% and 24% for Bielmlek plant and 17% and 32% for JBB plant.

RESULTS AND DISCUSSION

The range and average values of BOD, COD, TN and TP during the tests are shown in Table 2. Also, the daily sewage flow in the days when the tests were conducted is shown. High fluctuation in the values of BOD, COD and flow can be seen. It is a typical feature of any industrial waste water treatment plant (Martín-Rilo et al. 2015, Kushwaha et al. 2013). A required removal rate of all indicators was kept during the tests in both WWTPs.

In the Bielmlek WWTP case the total removed pollution load yielded results in the range from 488.4 to 1272.2 $kg_{rem}d^{-1}$, from 651.1 to 1770.8 $kg_{rem}d^{-1}$, from 1.1 to 33.7 $kg_{rem}d^{-1}$, and from 6.6 to 17.8 $kg_{rem}d^{-1}$ for BOD, COD, TN and TP respectively. The mechanical stage of treatment along with the DAF system was removing approximately 54.9%, 54.6%, 57.3% and 33.7% of BOD, COD, TN and TP loads respectively.

Table 2. Wastewater parameters during the tests

Item	Flow	BOD			COD			TN			TP		
	m^3d^{-1}	mgO_2dm^{-3}			mgO_2dm^{-3}			$mgdm^{-3}$			$mgdm^{-3}$		
		1	2	3	1	2	3	1	2	3	1	2	3
Bielmlek WWTP													
Min	337	1150	440	3	1415	566	12,1	13	10	1,8	17,1	12	0,23
Max	881	2000	1250	6	2655	1728	54,1	108	55	22,1	25	17,3	0,66
Mean	519	1470	690	4,6	1927,2	928,8	28,4	55,6	30,4	10,6	21,6	14,4	0,38
JBB WWTP													
Min	2250	1650	927	16	3123	1752	58,4	98	76	5,4	29	19	1,8
Max	2403	2897	1308	27	4521	2420	75,9	172	137	9,8	41	36	2,4
Mean	2321	2187,2	1063,2	22,2	3758,2	2075,2	68,9	140	103,6	7,1	34,8	26,2	2

1 – inlet (raw wastewater), 2 – wastewater after DAF process, 3 – outlet (treated wastewater)

The biological stage was removing approximately 45.1%, 45.4%, 42.7% and 66.3% of BOD, COD, TN and TP loads respectively. In the JBB WWTP case the total removed pollution load yielded results in range from 3810.4 to 6664.9 $kg_{rem}d^{-1}$, from 6995.3 to 10700.4 $kg_{rem}d^{-1}$, from 217.0 to 372.2 $kg_{rem}d^{-1}$, and from 64.7 to 89.3 $kg_{rem}d^{-1}$ for BOD, COD, TN and TP respectively. The mechanical stage of treatment along with the DAF system was removing approximately 51%, 45.4%, 27.4% and 27.4% of BOD, COD, TN and TP loads respectively. The biological stage was removing from 49.0%, 54.6%, 72,6% and 72.6% of BOD, COD, TN and TP loads respectively. Figures 1 and 2 present the average total pollution loads of BOD, COD, TN and TP removed during the tests for both of the considered objects.

Energy usage characteristics of both plants is presented in Figures 3 and 4. Biological treatment and aeration play the main role in energy consumption of both objects. It is respectively 40% and 47% of total use for Bielmlek and JBB plants. The second biggest energy consuming stage of treatment in both objects is sludge processing. The energy required to process excessive sludge equals 30% of the total energy usage in both plants. Also the energy consumption by the mechanical treatment with the DAF system is equal in both cases and it constitutes 17% of the total energy usage. Other usage presented in Figures 3 and 4 must be understood as lighting, power supply for the monitoring and steering equipment, heating, video surveillance etc.

Energy consumption factors are presented in Table 3. The factors related to 1 kg of removed BOD yielded results in a range from 1,42 to 2.57 $kWhkg_{rem.}^{-1}$ and from 0.98 to 1.99 $kWhkg_{rem.}^{-1}$ for Bielmlek and JBB plants respectively. In the case of COD it was from 1.02 to 1.93 $kWhkg_{rem.}^{-1}$ and from 0.61 to 0.96 $kWhkg_{rem.}^{-1}$ for Bielmlek and JBB plants respectively. The removal of nutrients was more energy-consuming and its energy consumption factors yielded results in a range from 37.3 to 1099.3 $kWhkg_{rem.}^{-1}$ and from 17.2 to 34.9 $kWhkg_{rem.}^{-1}$ (TN) and from 97.6 to 167.9 $kWhkg_{rem.}^{-1}$ and from 73.5 to 101.2 $kWhkg_{rem.}^{-1}$ (TP) for Bielmlek and JBB plants respectively. Energy consumption factors related to the hydraulic flow gave results in a range from 2.05 to 3.3 $kWhm^{-3}$ and from 2.72 to 3.23 $kWhm^{-3}$ for Bielmlek and JBB plants respectively. Figures 5 and 6 present the average results of energy consumption factors of both plants. The presented data is related to the total treatment of both plants as well as to the mechanical and biological stages of the treatment. In both objects, the most energy-consuming stage of the treatment was the biological one.

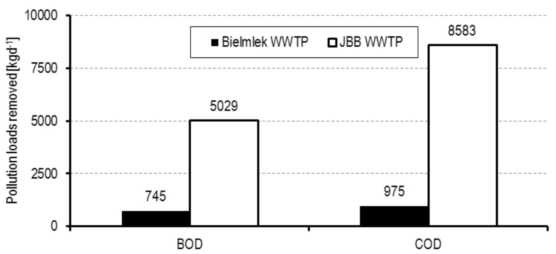

Figure 1. Average total removed loads of BOD and COD by considered objects

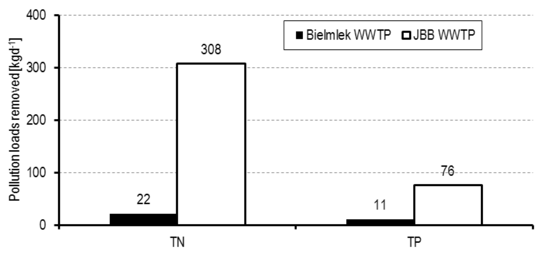

Figure 2. Average total removed loads of TN and TP by considered objects

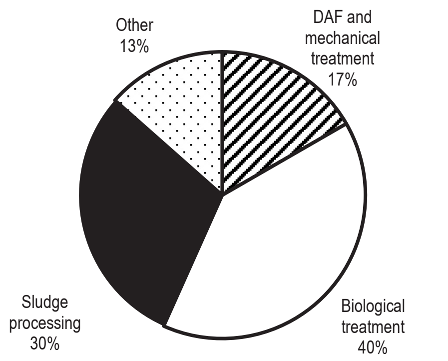

Figure 3. Energy usage characteristics of Bielmlek WWTP

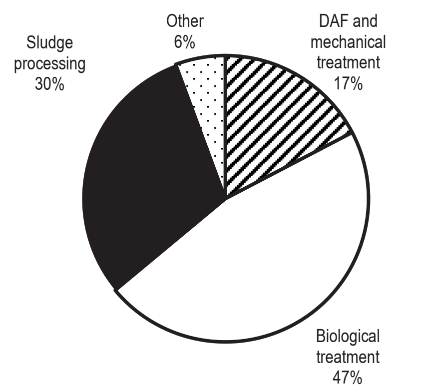

Figure 4. Energy usage characteristics of JBB WWTP

Table 3. Energy consumption factors

Series	BOD			COD			TN			TP			Flow		
	$kWhkgO_{2rem.}^{-1}$			$kWhkgO_{2rem.}^{-1}$			$kWhkg_{rem.}^{-1}$			$kWhkg_{rem.}^{-1}$			$kWhm^{-3}$		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Bielmlek WWTP															
I	0,6	0,9	1,7	0,4	0,7	1,3	208,5	1170,0	1099,3	77,2	82,2	167,9	0,42	1,2	3,3
II	0,8	1,4	1,4	0,6	1,0	1,0	55,9	124,4	112,5	67,4	85,7	101,4	0,56	1,0	2,0
III	0,5	2,3	2,1	0,4	1,8	1,7	13,2	32,5	42,5	44,5	58,7	97,5	0,34	1,0	2,4
IV	0,5	2,2	2,6	0,3	1,7	1,9	6,4	35,3	37,3	35,6	76,2	129,6	0,34	1,2	3,2
V	0,4	1,7	1,8	0,3	1,6	1,5	10,8	34,7	45,2	74,0	76,7	164,0	0,38	0,9	2,8
JBB WWTP															
I	0,6	1,4	1,6	0,4	0,8	0,9	10,3	12,8	18,8	45,1	69,5	94,7	0,50	1,3	2,9
II	0,4	1,2	1,1	0,2	0,5	0,6	11,0	15,0	21,3	47,2	75,1	101,2	0,47	1,3	2,7
III	0,8	1,6	2,0	0,3	0,9	1,0	25,5	21,3	34,9	140,2	48,5	92,1	0,56	1,5	3,2
IV	0,3	1,0	1,0	0,3	0,6	0,7	14,5	14,3	22,5	98,3	39,3	73,5	0,49	1,3	2,8
V	0,4	1,5	1,4	0,4	0,7	0,9	14,1	10,2	17,2	38,0	65,7	85,7	0,49	1,3	2,8

1 – mechanical treatment, 2 – biological treatment, 3 – whole object

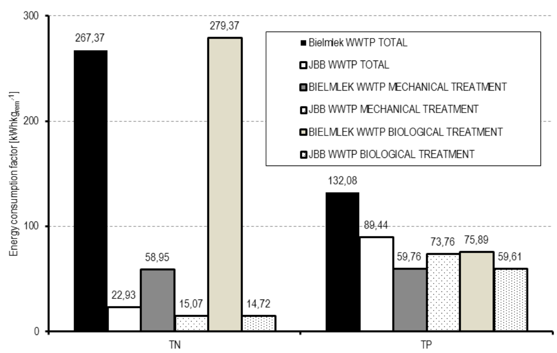

Figure 5. Average values of energy consumption factors related to BOD, COD and flow for Bielmlek and JBB plants' mechanical, biological and total treatment

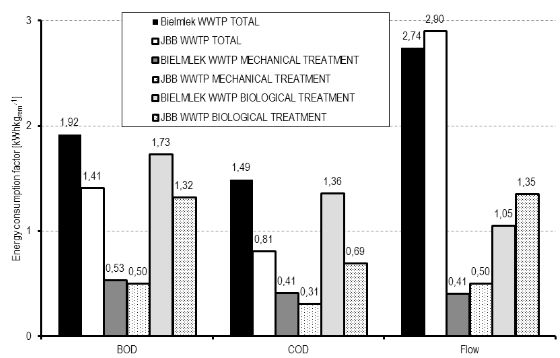

Figure 6. Average values of energy consumption factors related to TN and TP for Bielmlek and JBB plants' mechanical, biological and total treatment

CONCLUSIONS

Bielmlek and JBB plants proved to be effective systems in treating industrial wastewater. During the tests the required parameters of the treated wastewater were kept. The JBB plant is more loaded than the Bielmlek plant. Daily volumes of pollution and wastewater, as well as energy demand, are higher. At the same time, energy consumption factors related to removed pollution load are lower than in Bielmlek case. JBB plant energy consumption factors related to flow were slightly higher than those in the Bielmlek plant. On the other hand, the remaining factors were lower. It means that high loads of pollution translates into a considerable energy demand. The conducted research proved that the higher pollution loads decreased energy consumption factors. It suggests that it is more economically justified to keep the loads of a wastewater treatment plant at possibly high levels. The mechanical stage of the treatment was the least energy consuming part of the treatment in both plants. At the same time the mechanical treatment, mainly the DAF system, removal rates were higher than the biological stage. Therefore, more investment in mechanical treatment could prove itself to be the key to reduce the costs of industrial wastewater processing.

In order to save energy during industrial wastewater treatment, adequate measures must be taken. First of all, plants must be equipped with high-tech measurement equipment to localize the sources of the highest energy consumption and find ways to minimize them. Secondly, more research connected with energy consumption by industrial plants must be conducted so that the problem is well-understood. Finally, an optimizing program is being developed by the authors.

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