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Polish Journal of Chemical Technology, 25, 3, 50—55, 10.2478/pjct-2023-0024

Influence of Effluent Quality from Sludge Dewatering on Electricity Consumption

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During the dewatering process, centrate is produced, which is returned to the beginning of the technological system. The quality of the resulting centrate, and therefore the size of the returned load of pollutants, affects the demand for electricity in the process of biological wastewater treatment. The following study presents the results of centrate quality tests at five wastewater treatment plants located in Poland. The dependence between suspended solids content and ammonia and COD concentrations in the centrate was determined. It was estimated that an increase in the overall suspended solids leads to an increase in COD by about 1.15 kgCOD/kgTSS. No correlation was found between TSS concentration and ammonia. It was calculated that the complete elimination of suspended solids from the sludge would reduce the electricity consumption for all five objects by about 535 MWh/y.

Keywords: wastewater, sludge dewatering, flocculant, energy savings.

INTRODUCTION

Sludge dewatering is an essential part of the wastewater treatment process, as it reduces the volume of sludge that must be disposed of or treated further. Sludge treatment and management are one of the main operating costs. The process of dewatering produces effluent, which can contain a significant load of pollutants. The efficiency of this process has a direct impact on the electricity consumption of the downstream biological wastewater treatment process, processing of dewatered sludge[1], and also affects greenhouse gas emissions in the final treatment processes[2]. In order to achieve full carbon neutrality and energy selfsufficiency of wastewater treatment plants, modernization and optimization of the applied technologies are necessary[3]. The current economic and environmental situation provides additional motivation to search for new technological solutions aimed at reducing energy indicators of the process. One popular direction of development is increasing the production of own energy using, for example, cofermentation[4], conditioning raw sludge before fermentation[5], building wind farms, solar power plants, and heat pumps[6]. The energy indicators can also be improved by reducing energy consumption at individual stages of the treatment process. About 74% of the electrical energy is used for biological treatment, about 8% for sludge processing, pumping sewage consumes 7%, and the rest of the electrical energy is wasted for other purposes[7]. It should be noted that in the case of small wastewater treatment plants, the share of energy consumption of each process may be significantly different[8]. Individual shares may also vary due to the characteristics of the sewage network and the quality of the incoming wastewater. The use of some technological solutions may also cause changes in electricity consumption, e.g. preprecipitation[9]. The area with significant potential for reducing electrical energy consumption is the process of sludge dewatering. There have been a number of studies that have investigated the relationship between quality of effluent and electricity consumption in wastewater treatment plants. A study by Boncescu et. al. found that the concentration of pollutants among others total suspended solids (TSS) in the sewage was a significant predictor of electricity consumption in the downstream biological treatment process[10]. Research by Mininni et. al. on WWTP with the designed capacity 500 000 p.e. (population equivalent) showed that the stream of recycled COD load in the effluents from the dewatering process is less than 2% of the incoming load[11]. It should be emphasized that the size of the recycled load of pollutants, as well as the energy consumption of the processes, may vary significantly in individual treatment plants. Currently, many technologies are being developed to pretreat effluent and reduce the returned load of contaminants to the beginning of the technological system. Much attention is paid to reducing the load and recovery of nitrogen compounds[12], especially in the form of ammonia[13]. The concentration of nitrogen depends on the sludge treatment technology used. Effluent from dewatering of digested sludge may contain up to 1500 mg/L of ammonia and constitute 25% of the total nitrogen load[14]. The hydrolysis of sludge before fermentation process may increase the concentration of ammonia in the discharge by two times[15, 16]. Iddya et. al. developed a method for removing nitrogen using electrically conducting gas stripping membranes[17] which has a lower energy consumption indicator per unit of nitrogen compared to traditional biological methods. Membrane methods are also being developed, including transmembrane chemical absorption[18] and membrane distillation[19]. Attempts are also being made to modify traditional biological treatment methods[20] and use bioelectrochemical systems[21]. Some researchers see great potential in the high concentration of free ammonia in the effluents. Research is being conducted on the use of ammonia from dewatering effluents to increase biogas production from primary and excess sludge up to 30%[22, 23]. Lackner et. al. presented the technology of centrate treatment in the sequencing batch reactor (SBR) from the dewatering of the wastewater treatment plant in Ingolstand Germany with a size of 275 000 p.e. The proposed technology allowed to achieve a 52% lower specific energy consumption compared to the classical method[24]. The effluents are also rich in phosphorus compounds[25]. Phosphorus may be recovered from the stream by precipitation as struvite (magnesium ammonium phosphate) and next may be used as a fertilizer. At the moment, high-efficiency recovery technologies have been developed[26]. Some of them allow the recovery of more than 90% of phosphorus. According to many authors, total suspension is a factor that reduces the efficiency of recovery. Quist-Jensen et. al. developed a membrane crystallization method that allows for the simultaneous recovery of phosphorus and ammonia[27]. In this case, the degree of phosphorus recovery was 60%. Many of the new technologies successfully developed on a laboratory scale are not suitable for full-scale implementation due to high investment costs or a negative energy balance[28]. The concentration of contaminants in the effluent is influenced by, among other things, the efficiency of the dewatering device[29]. Low efficiency of solid particle separation leads to the passage of significant amounts of suspended solids to the effluent, which is the main carrier of COD[30]. Wan. et. al. indicates that high efficiency of capturing COD is an important parameter affecting the energy selfsufficiency of the sewage treatment plant[31]. It has been shown that electricity consumption at sewage treatment plants is positively correlated with the incoming COD load[32]. The efficiency of capturing total suspended matter is described by the equation:

$$F = \left(1 - \frac{L_{out}}{L_{in}}\right) \cdot 100\% \tag{1}$$

where:

L_{out} – suspended solids load in the effluent (mg/L),

L_{in} – load of suspended solids in the influent (mg/L).

Recent studies have shown that the quality of the effluent from sludge dewatering can affect electricity consumption in several ways. Obtaining a better quality effluent requires the use of more electricity or a higher dose of chemicals. On the other hand, the better quality of the effluent reduces energy consumption in the biological treatment plant. Electricity consumption depends on the type of dewatering device used. Currently, there are many devices for dewatering sewage sludge available on the market. Examples of such devices are belt filter press, chamber-membrane filter press, disc press, and screw press decanter centrifuge. The optimal dose of flocculant, as well as the degree of dewatered, will be different for each type of device due to, for example, the presence of shear forces, and the difference in pressure exerted on the sludge. The researchers found that the energy consumption of the plant was lower when the sludge was dewatered using a centrifuge, compared to other dewatering methods such as belt filter presses[32, 33]. They also found that the energy consumption increased with the total solids content of the sludge, indicating that higher quality effluent can lead to lower energy costs. Overall, these studies suggest that the quality of the effluent produced during sludge dewatering can have a significant impact on the electricity consumption of a wastewater treatment plant. Proper management of sludge dewatering can help to minimize energy costs and improve the overall efficiency of the treatment process.

There is a lack of literature data on the effectiveness of solid particle separation on the volume of returned contamination load, which became the basis for extensive research, the results of which are presented in this article. In this study, we aim to further investigate the relationship between effluent quality and electricity consumption in wastewater treatment plants. By understanding the factors that influence electricity consumption in this context, it may be possible to identify opportunities for improving energy efficiency and reducing the environmental impact of wastewater treatment. The aim of the research was to determine the correlation between the effectiveness of suspended solids separation and the contamination load in the effluent. The obtained data allowed the authors to estimate the potential energy savings resulting from improving the degree of separation.

MATERIALS AND METHODS

Wastewater treatment plants (WWTP) are facilities that are designed to treat and purify wastewater before it is released back into the environment. These plants play a vital role in protecting public health and the environment by removing contaminants and pollutants from sewage and other types of wastewater. There are various types of WWTPs, ranging from small, decentralized systems that serve a single building or community, to large, centralized plants that serve entire cities or regions. Regardless of size or type, all WWTPs follow a similar treatment process, which typically involves the following steps: collection, treatment, and discharge. During the collection phase, wastewater is transported to the WWTP through a network of pipes or channels. The treatment phase involves a series of physical, chemical, and biological processes that are used to remove contaminants and pollutants from the wastewater. Finally, in the discharge phase, the treated wastewater is released back into the environment, either through a natural body of water or through an irrigation system. The research was conducted at five municipal wastewater treatment plants located in Greater Poland province in Poland. Objects 1 and 2 are large wastewater treatment plants with the process of mesophilic fermentation of sludge and pe. > 100 000. The pe. of rest WWTPs (3 – 5) are less than 60 000. The characterization of the treatment process at the studied facilities is described in the next chapters below.

Characteristics of the WWTP 1 – 2

In the first stage, the sewage is filtered through bar screen (1), and then dewatered in a sand trap (2). In the primary settiling tank (3), organic sludge is separated and sent to the gravitational thickener (6). The treated sewage is then directed to the biological reactor (4), and then to the secondary settiling tank (5). Excess sludge is thickened in the mechanical thickener (8) and mixed with the preliminary sludge before being sent to the mesophilic fermentation chamber (9). The fermented sludge is dewatered in the decantation centrifuge (10). The sludge dewatering process is assisted by flocculant. Effluent from dewatering and thickening processes is returned to the beginning of the technological system. Figure 1 shows a simplified diagram of objects 1 – 2.

Characteristics of the WWTP 3 – 5

In the first stage, the wastewater is screened on bar screen (1), and then the mineral suspended solids are removed in the sand trap (2). The clarified wastewater is then sent to the biological reactor (4) and then to the secondary sedimentation tank (5). Excess sludge is thic-

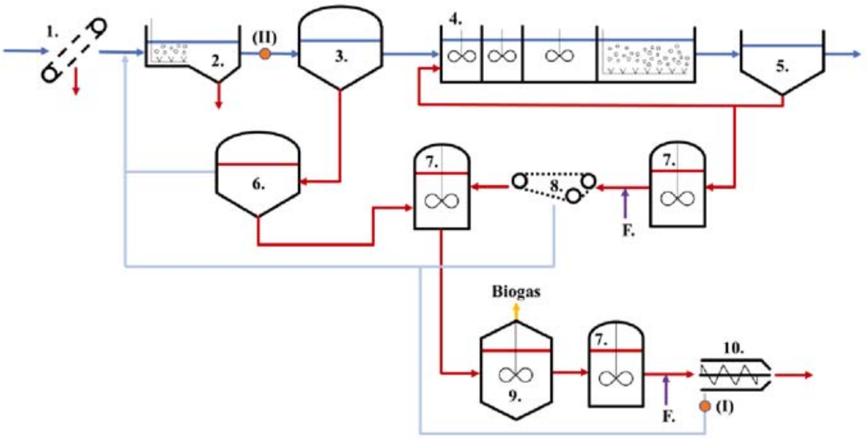

Figure 1. Scheme of WWTP 1 – 2; 1. Bar screen; 2. Girt chamber; 3. Primary Settling Tank; 4. Bioreactor; 5. Secondary Settling Tank; 6. Gravity Thickener; 7. Holding Tank; 8. Belt Thickener; 9. Digester; 10. Decanter centrifuge; F. Flocculant; (I) & (II) samplings point

kened in the gravity thickener (6). The thickened sludge is then dewatered on the decantation centrifuge (10). The sludge dewatering process is aided by a flocculant. Effluent from the dewatering and thickening processes is returned to the beginning of the technological system. The wastewater clarified in the secondary sedimentation tank is sent to the receiving body. Figure 2 shows a simplified scheme of objects 3 – 5.

Samples and Analyses

Samples of effluent were taken directly from the outflow of the dewatering device (I). Samples of raw wastewater were taken for WWTP 1 – 2 before the primary sedimentation tanks (II) and for WWTP 3 – 5 before the biological reactors (III). Wastewater parameters (BOD_5, COD, TN, TP) were determined in accordance with the procedures set out in the Regulations of the Maritime Economy and Inland Navigation Minister[17] i.e. chemical oxygen demand - PN-ISO 6060:2006; total suspended solids - PN-EN 872:2007+Ap1:2007; ammonia PN-EN ISO 14911:2002; total phosphorous - PN-EN ISO 6878:2006+Ap1+Ap2/2010; pH - PN-EN ISO 10523:2012; alkalinity - PN-EN ISO 9963-1:2001/Ap1:2004. At the same time, the inflow to the facilities and the hydraulic load on the dewatering equipment was also recorded. The intensity of effluent was calculated based on a mass balance.

Figure 3 below shows pictures of effluent samples with different total suspended solids concentrations. The samples come from the process of dewatering digested sludge from WWTP 1. The lower the total suspension content, the more yellow the colour of the sample. Increasing the concentration of the suspension darkens the sample.

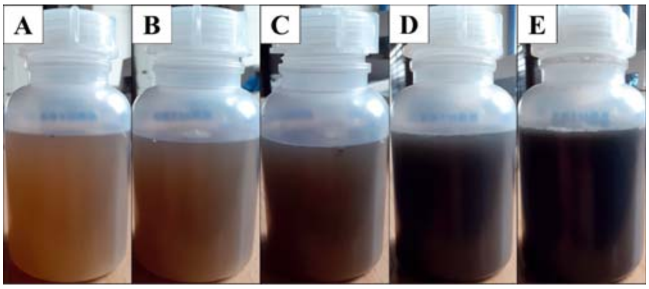

Figure 3. Photos of effluent samples with different concentrations of total suspended solids: A – 100 mg/L; B – 500 mg/L; C – 800 mg/L; D – 1400 mg/L; E – 3100 mg/L

RESULTS

The results of effluent quality for each wastewater treatment plant are presented in Table 1. Effluents from mesophilic digestion sludge (MD) dewatering had significantly higher concentrations of ammonia compared to effluents from waste activated sludge (WAS). Higher pH and alkalinity values were also observed for MD than WAS. The best quality of centrate was obtained at WWTP 4. The lowest values of each of the tested pollutants were recorded.

There was a demonstrated increase in COD from 1.0 to 1.3 mg/L in relation to the increase in total suspended

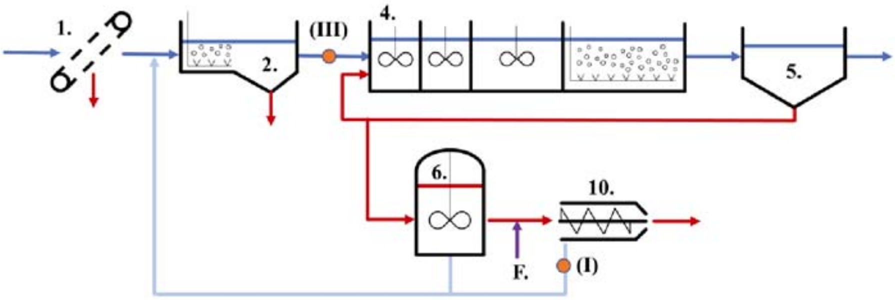

Figure 2. Scheme of WWTP 3 – 5; 1. Bar screen; 2. Girt chamber; 4. Bioreactor; 5. Secondary Settling Tank; 6. Gravity Thickener; 10. Decanter centrifuge; F. Flocculant; (I) & (III) samplings point

Table 1. Characteristics of the centrate

Parameter or pollution	No. WWTPs	1	2	3	4	5
Design population equivalent	$\frac{\mathrm{BOD}\left(\frac{kg}{d}\right)}{0{,}06\left(\frac{\mathrm{kg}}{\mathrm{inhab}\cdot \mathrm{d}}\right)}$	958 000	350 000	51 465	44 650	28 500
Type of sludge		MD	MD	WAS	WAS	WAS
Total suspended solids	mg/L	626.9	291.7	707.9	213.9	738.1
	SD	658.6	293.0	478.0	207.6	416.7
	n	272	48	98	139	57
Ammonia	mg/L	1004.5	1090.4	62.7	8.1	77.5
	SD	234.4	236.1	36.0	8.0	30.5
	n	272	48	97	117	36
Chemical oxygen demand	mg/L	1287.1	834.1	1740.1	428.7	1896.2
	SD	992.4	347.8	778.3	361.2	747.2
	n	272	48	98	139	57
Total phosphorous	mg/L	159.5	67.2	364.2	5.2	345.8
	SD	73.7	37.3	103.4	7.9	123.6
	n	272	48	98	119	37
pH		7.8	7.9	6.6	6.7	6.5
	SD	0.2	0.2	0.3	0.6	0.3
	n	225	33	90	129	48
Alkalinity	mmol/L	83.1	89.3	11.0	5.2	13.0
	SD	16.5	15.2	1.8	2.2	2.9
	n	189	33	51	85	36
Solids capture efficiency	%	97.0	98.9	97.6	99.3	97.8

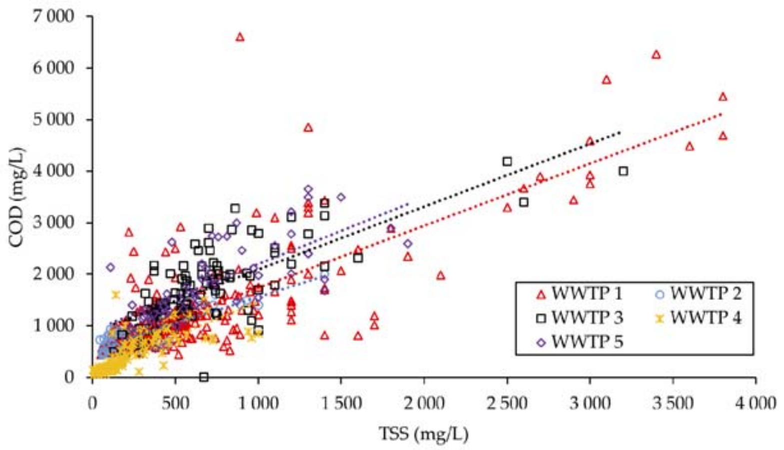

Figure 4. COD dependence on the total suspended solids concentration in the centrate

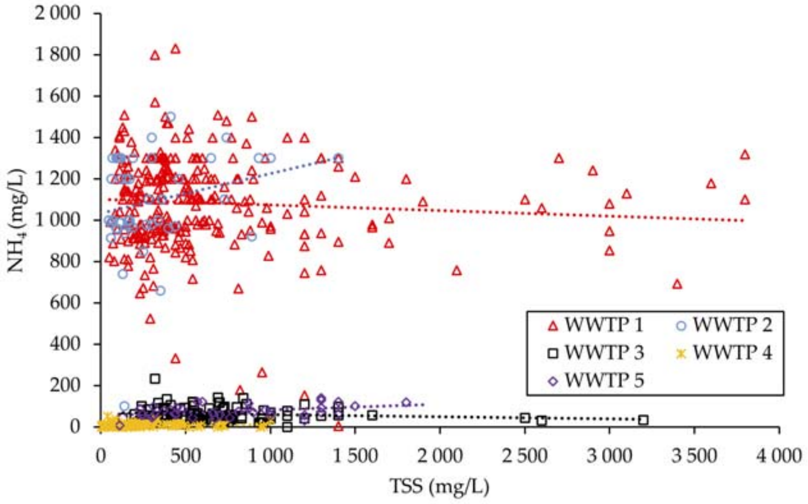

Figure 5. Ammonia dependence on the total suspended solids concentration in the centrate

solids, regardless of the type of sludge being dewatered. No significant correlation was observed between the concentration of TSS and the concentration of ammonia in the effluent. The relationship between the concentration of ammonia and COD and TSS is shown in Figures 4 and 5.

The values of the directional coefficients, free terms, and R^2 for individual objects are listed in Table 2. Similar values of directional coefficients were obtained for COD. For wastewater treatment plants 1 – 2, the value of the constant b is very similar. This may be due to the fermentation process and the long retention time in

Table 2. Dependence of COD and ammonia on TSS in effluent

Pollution	No. WWTP	1	2	3	4	5
COD	a	1.2071	1.0224	1.2166	1.3211	1.2884
	b	530.42	535.93	878.86	146.12	907.74
	R^2	0.6417	0.7417	0.5583	0.5762	0.5161
Ammonia	a	–0.0027	0.1909	–0.0101	0.006	0.0279
	b	1100.4	1034.7	69.169	6.8222	55.842
	R^2	0.0057	0.0561	0.0174	0.0255	0.1623

Table 3. Average pollutant load in effluent from wastewater sludge dewatering

Parameters	WWTP	1	2	3	4	5
Load of TSS	kg/d	1153.4	71.6	60.1	17.3	42.0
Load of COD	kg/d	1975	205	145	35	108
Load COD without TSS	kg/d	579	132	72	12	54
E.E. consumption to remove COD	kWh/d	1678.8	174.3	210.3	50.8	156.6
E.E. consumption to remove COD without TSS	kWh/d	492.5	112.2	104,4	17.4	78.3
Theoretical electric energy savings	kWh/d	1186.6	62.1	105.9	33.1	78.3
Theoretical electric energy savings	MWh/y	433.1	22.6	38.6	12.2	28.6

digesters. In the case of WWTP 3 – 5, the difference in the value of b results from a different concentration of COD in the liquid phase.

In Table 3, the calculated average pollutant load returned to the beginning of the technological system is presented. Due to the fact that the concentration of ammonia is independent of TSS, only the COD load was taken into account for energy savings calculations. To calculate the theoretical electricity consumption needed to remove 1 kg of COD, indicators[34] were adopted, i.e. 1.45 kWh/kgCOD for plants with 10 000–100 000 PE and 0.85 kWh/kgCOD for plants >100 000 PE. Potential energy savings were calculated assuming all suspended solids were removed. The COD value was calculated by multiplying the suspension concentration by the obtained directional coefficients *a* (Table 2).

Understanding the influence of effluent quality from sludge dewatering on electricity consumption is important for a number of reasons. First and foremost, reducing the amount of energy consumed in the wastewater treatment process can help to lower the operating costs of these facilities, which can be significant. Additionally, improving energy efficiency in wastewater treatment plants can also help to reduce greenhouse gas emissions, as these facilities are often large consumers of electricity.

CONCLUSIONS

In this study, the results of effluent analyses from the sludge dewatering process at five different municipal wastewater treatment plants were examined. It was found that there is a positive correlation between the concentration of total suspended solids in the effluent and the concentration of chemical oxygen demand (COD). This means that as the concentration of total suspended solids increases, the concentration of COD also increases, ranging from 1.0 to 1.3 regardless of the type of sludge being dewatered. However, no correlation was found between the concentration of ammonia and the efficiency of suspended solids separation.

The researchers also found that improving the degree of separation in the dewatering process, either by increasing the control of dewatering equipment or changing the flocculant used, can lead to energy savings. It is estimated that complete elimination of suspended solids from effluent at the studied plants would result in a reduction of electrical energy consumption of approximately 535 MWh per year. These energy savings justify efforts to optimize the dewatering process, as it can be a simple and cost-effective way to improve the energy efficiency of wastewater treatment plants. The presented method can be used to assess potential savings at other wastewater treatment plants, and can help in the appropriate selection of the drainage device.

There are several directions that future research could take to further explore this issue. One possibility is to investigate the potential for using alternative energy sources, such as solar or wind power, to meet the energy needs of wastewater treatment plants. Another approach could be to develop new technologies or processes that are more energy efficient, such as advanced filtration systems or innovative methods for sludge dewatering. Overall, the importance of this research lies in the potential for improving the sustainability of wastewater treatment processes. By reducing the energy consumption of these facilities, we can not only save money and reduce greenhouse gas emissions, but we can also help to ensure that these essential services can be provided in a more environmentally responsible manner.

ACKNOWLEDGMENTS

The research was carried out under the Implementation Doctorate Program of the Ministry of Education and Science that was implemented in the years 2020-2024 (Agreement no. DWD/4/23/2020). This research was funded by the Ministry of Education and Science in Poland (SBAD)

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