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SINGLE SBR REACTOR'S ENERGY USAGE IN COMPARISON WITH TOTAL ENERGY CONSUMPTION OF MEDIUM WASTEWATER TREATMENT PLANT

PORÓWNANIE ZUŻYCIA ENERGII PRZEZ POJEDYNCZY REAKTOR TYPU SBR W ODNIESIENIU DO CAŁKOWITEGO ZUŻYCIA ENERGII PRZEZ OCZYSZCZALNIE ŚCIEKÓW ŚREDNIEJ WIELKOŚCI

Abstract

The paper analyses the share of single SBR in total energy consumption of studied wastewater treatment plant. The analysis is based on a two sets of data: measurements, gathered by automated measuring installation and data archived manually by plant's operator. Energy consumption was also analysed with reference to archive data of daily flows.

Keywords: energy consumption, wastewater treatment plant, SBR

Streszczenie

W artykule zestawiono zużycie energii elektrycznej pojedyńczego reaktora typu SBR w odniesieniu do całkowitego zużycia energii przez badaną oczyszczalnię ścieków. Porównania dokonano w oparciu o dwa zestawy danych: pomiary, zgromadzone przez automatyczną instalacje pomiarową oraz dane eksploatacyjne archiwizowane przez operatora oczyszczalni. Analizę zużycia energii odniesiono również do zarejestrowanych przepływów dobowych przez oczyszczalnię.

Słowa kluczowe: zużycie energii, oczyszczalnia ścieków, SBR

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1. Introduction

In recent decades, more and more efforts are undertaken in order to increase energy efficiency in industry and everyday life. This trend will continue despite potential changes in political, ideological, economical and cultural trends. The reason is simple – higher efficiency is profitable. Part of the human nature is minimizing costs and maximizing profits, therefore, searches for improvements will continue. However, not all branches of industry are equally improving their efficiency. In Poland, the problem of energy efficiency, in small and medium wastewater treatment plants, is still not well examined in comparison to bigger facilities, or other countries [1]. Overall the situation is improving due to newer and more efficient equipment, but there is little coordinated effort in that area. Intentional optimization cannot be performed without solid data on current situation. Such data can be obtained by creating measuring grid similar to installation installed in the studied treatment plant. Built measuring grid is fully operational, although it is a pilot installation. Gathered data supplemented with plant`s archive were used to investigate the amount of energy used by single SBR in comparison to plant's total energy consumption and daily flow.

2. Basic information

2.1. Plant's description

The studied plant is located near Kraków. The plant consists of two independent technological lines, 2 SBRs and 1 sludge stabilization chamber each. The plant's capacity is 1250 m^3/d and PE 14 950. However, due to incomplete municipal sewerage, real daily flows usually are below 700 m^3/d. That is why usually only 2 reactors are operational, and if there is need to treat higher amount of sewage, one of the two remaining reactors is actuated. Sometimes the 3rd reactor is activated intentionally by the operator to avoid period of inactivity that is too long. With only two reactors operational, the plant's capacity is: 720 m^3/d and 7300 PE. Plant's main devices list (1.5 kW of power and above) [2]:

- sludge truck's discharge station 3.5 kW,
- vertical sieve 1.5 kW,
- stage 1 pumping station 4.7 kW (1+1 in reserve, working interchangeably),
- grit & grease removal 4.0 kW,
- retention tanks' blowers 5.5 kW (1+1 in reserve, working interchangeably),
- stage 2 pumping station 7.5 kW (1+1 in reserve, working interchangeably),
- 2 x 2 SBRs (no 1.2 – older tech-line, no 3.4 – newer tech-line):
  – 2 x 3 blowers 30.0 kW each (2x 2+1 in reserve, working interchangeably),
  – 2 x 2 excess sludge pumps 5.5 kW each (1 pump per reactor),
  – 2 x 2 internal turbines 11.0/7.5 kW (2 gears) (1 turbine per reactor),
- 2 x 1 sludge stabilization chamber (1 chamber per 2 reactors):
  – 2 x 1 blower 11.0 kW each (1 blower per chamber),
  – 2 x 1 internal turbines 5.5 kW (1 turbine per chamber),
- stabilized sludge pump 2.2 kW,

–   centrifuge (sludge dewatering) 17.2 kW,
–   dewatered sludge auger 1.5 kW.

During the studied period, WWTP operated flawlessly and easily met the administrative requirements [3, 4].

2.2. Measuring grid's description

Measuring grid consists of (main elements only):
•   1 central unit (notebook) with specialized software,
•   1 signal converter,
•   5 automated energy counters.

The software installed on the central unit controls work of the installation. Notebook functions also as data archive. Signal converter translates data from meters to a form that is acceptable by the computer. Automated counters measure the total energy used by selected devices in 5 minutes intervals (current settings). Counters are installed on the following devices:
•   Blowers (D4, D5, D6),
•   SBR internal mixing-aerating turbine (Tr4),
•   Excess sludge pump (P11).

To measure energy usage of one reactor, an installation of meters on all devices directly connected with this reactor is needed. This means SBR internal turbine, excess sludge pump, and oxygen source. Because of reliability reasons, all three blowers are connected into one oxygen supply system for both reactors [5]. All other devices are not directly connected with reactor's work. For example, stage 2 pumping station supplies all 4 reactors, and without very specific data, unfortunately not recorded by WWTP's systems, it is impossible to define how much energy was used to supply reactor no 4 with sewage. During the measuring period, SBR4 worked only with blower no 5, however, due to long-term character of measurements, the change of blower is highly probable. Secondly, the installation is scheduled to be expanded at least on the SBR3, also supplied by blowers no 4, 5 and 6, therefore all 3 blowers must had been equipped with meters.

Installation was launched and calibrated in April 2015. Since then, it worked stable with one exception, there are no records from 26 May 6:40 to 1 June 00:00. After launch, even before identifying the problem of missing data, the installation was scheduled for potential recalibration after two-three months of measurements. It was accepted that, after 60–90 days period, it will become clear if current measurement settings are sufficient. Observed lack of records added one more variable that needs to be assessed before scheduled recalibration. Several reasons probably responsible for this data gap are being investigated, however, for the time being, nothing has been confirmed yet. Fortunately rest of the data is valid and can be analysed.

3. Data

Data analysed in this paper came from two sources: automated measurements provided by measuring grid and plant's journal of the exploitation provided by WWTP's operator. Data recorded by installation had been registered with 5 minutes intervals. Data archived

by plant's operator have daily intervals, except Saturdays, Sundays and statutory holidays. After consultation with the WWTP operator, in regard to average daily flows and total energy consumption, it became clear that extrapolation of missing data with simple arithmetic average will be sufficient. Extrapolated flows and energy consumption are bit lower than recorded ones; however, during weekends, no additional wastewater is delivered by sludge trucks, hence smaller results are plausible. Please note that these averages were based on data received from an effluent meter, therefore, the total flow within studied period wasn`t extrapolated. Only missing daily flows are a result of extrapolation. The exact same situation was with WWTPs total energy consumption. All vital data used for analyses are presented in Table 1.

Table 1

SBR4 energy consumption compared to WWTP's total energy usage

Date/Active SBRs	SBR4 total energy consumption [kW]	WWTP total energy consumption [kW]	SBR4 % of WWTP's total energy consumption	Daily flow [m³/d]
30–04/2	430	*1185*	36.26%	268
01–05/2	430	*1185*	36.26%	268
02–05/2	383	*1185*	32.31%	268
03–05/2	355	*1185*	29.98%	268
04–05/2	368	1380	26.65%	405
05–05/2	405	1200	33.72%	406
06–05/2	389	1440	27.00%	624
07–05/2	390	1320	29.52%	470
08–05/2	441	*1240*	35.59%	358
09–05/2	454	*1240*	36.62%	358
10–05/2	427	*1240*	34.46%	358
11–05/3	424	1620	26.18%	467
12–05/3	425	1020	41.67%	504
13–05/3	441	1380	31.94%	409
14–05/3	432	1380	31.29%	405
15–05/3	444	*1280*	34.68%	272
16–05/3	464	*1280*	36.22%	272
17–05/3	414	*1280*	32.37%	272
18–05/3	427	1140	37.45%	405

tab. 1

19–05/3	432	1200	36.00%	406
20–05/3	439	1260	34.86%	572
21–05/3	416	1260	33.00%	576
22–05/3	410	*1220*	33.57%	328
23–05/3	370	*1220*	30.36%	328
24–05/3	380	*1220*	31.18%	328
25–05/3	344	1200	28.64%	489
Sum:	10 733	32 760	–	10 080
Average:	413	1260	32.76%	388

Presented data are part of long-term experiment. These data covers the first 26 days of operation of fully calibrated measuring grid. Therefore, all conclusions are true only to these 26 days. All other observed regularities, or anomalies will have to be confirmed by next sets of data. However, almost a month of observations reveals potential directions on which further researches should focus.

For the first 10 days of studied period, only two SBRs were active (whole newer tech-line). On the eleventh day of May, reactor no 1 was reactivated, after 8 days, SBR1 was turned off again, but SBR2 was reactivated instead. Dates of switching on or off the reactors are marked in Table 1 by bolding. Data extrapolated is in *italics*.

4. Analysis

4.1. Dependence between total energy consumption and daily flow

According to previous researches [6], there is a direct connection between average daily flow and total energy consumption. Creating a chart identifying a nature of relation between daily flows and energy usage helps in verification of data correctness. As can be seen in the Fig. 1, such dependency exists and is consistent with the assumptions.

However, few inconsistencies may be observed. Given the cyclical nature of the work of SBRs, some drops in the energy consumption, similar to one observed at 4–5th May, are acceptable. On the other hand, sudden spike and drop, observed on 11–12th May, is unusual. One of the possible explanations for this spike is reactivation of SBR1, therefore, reactivation of whole 2nd technological-line. If this was the case similar spike should be observed on 18–19th May when SBR1 was turned off, and SBR2 was turned on. There was an increase in energy consumption during switching SBR 1 and 2 as well, however, not as drastic as during reactivation of the SBR1 (only 60 kW increase in comparison to 380 kW). It may be also only a simple human error, made during writing down value from meter. For now, there is not enough data to decide if this spike was a one-time anomaly, and what caused it.
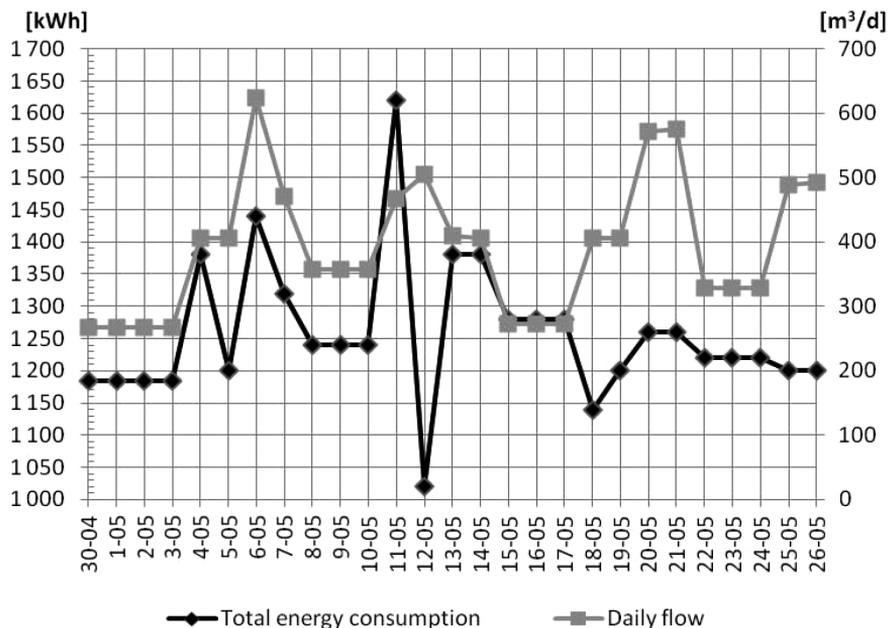
Fig. 1. Comparison of daily flow and plant's total daily energy consumption

This case will be re-investigated after gathering more data in the following months. During the studied period, average daily flow was 388 m³/d, and excluding data from 11 and 12th May, the average total energy consumption was 1255 kWh. Max flow was recorded on 6.05 (624 m³/d) followed by highest total energy consumption (1440 kWh). Recorded minimal flow was on the 4, 14, 18th May (405 m³/d) however, smallest total energy consumption was recorded 12.05 (1020 kWh).

Despite minor inconsistencies, similarity of the chart in the Fig 1 to other examples confirms correctness of WWTP data archive. This allowed further analyses.

4.2. Relation between total energy consumption and daily flow

Despite visible dependency between total daily energy usage and daily flow, the relation itself is not as strong as was expected. Correlation coefficient was calculated in order to determine the degree of dependency between energy consumption and daily flow. As expected, there was a weak positive correlation between daily total energy consumption and daily flow ($R = 0.2775$). Distribution of points on the Fig. 2 is consistent with R value. The relation hardly can be called linear. However, at the time being, there is not enough data to make final statement about exact nature of this dependency, also due to a small amount of data, the calculated correlation coefficient should be treated only as a guide value for the further researches.
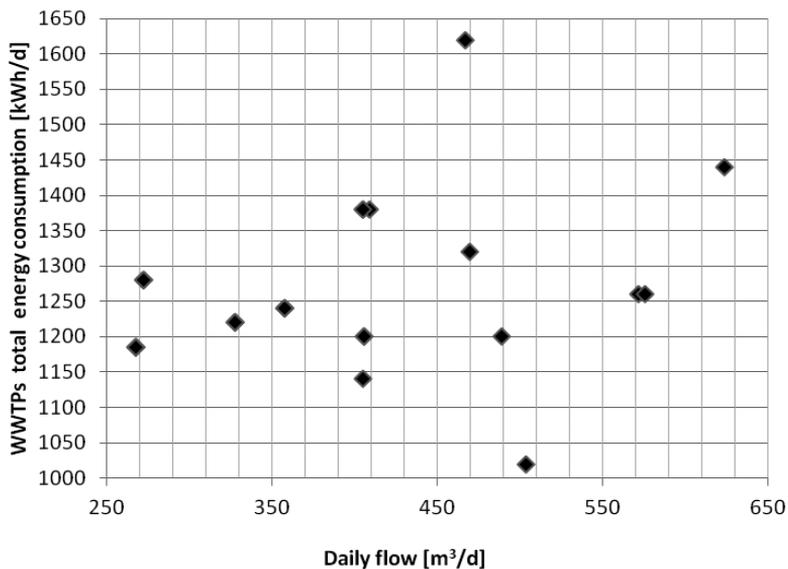
Fig. 2. Correlation of daily flow and plant's total daily energy consumption

4.3. Dependence between SBR4 energy consumption and daily flow

Second analysis made was similar to the first, but only energy consumption of SBR4 was taken into account. Results of comparison of SBR4 energy usage and daily flows are shown in the Fig. 3.
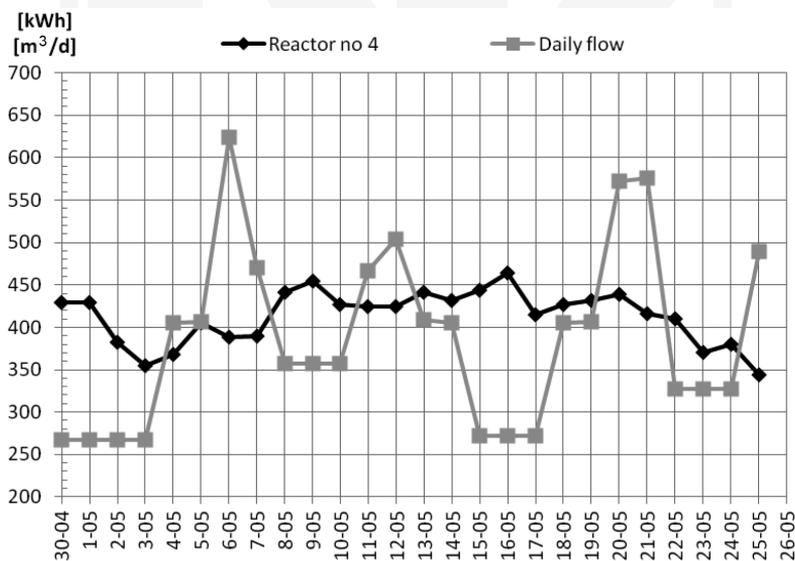

Fig. 3. Comparison of daily flow and reactor no 4 daily energy consumption

On the first look, the chart of the SBR4 changes less dynamically than of the total energy consumption (TEC) and looks also less correlated with daily flows. Nevertheless, changes in reactor no 4 energy usage are also connected with changes of the daily flows. Delay visible in the graph comes from the small inertia of treatment processes in WWTP with SBRs. Increases and decreases are of course smaller than for whole WWTP, but follow the same pattern. There is a second factor influencing energy consumption of single reactor – sewage distribution between SBRs. Reactors are rarely evenly loaded, hence energy consumption's dependence on daily flow may not be as obvious for single reactor as for the whole facility. Average daily energy consumption for SBR4 during studied period was 413 kWh. Maximum 464 kWh, recorded on 16.05 – day with the smallest daily flow. Lowest energy consumption (EC) was recorded on 25.05 with flow 101 m^3/d higher than the average, but not the highest. As mentioned before, inertia of the treatment processes and unequal load of the reactors reflects in SBR4 min-max energy consumption occurrence.

4.4. Relation between SBR4 energy consumption and daily flow

Unfortunately, there are no records on daily flow distribution between active SBRs, therefore, proper correlation coefficient cannot be calculated. It is only possible to check the relation between energy consumption of SBR no4 and total daily flow. Taking into account distribution of points on the Fig. 4 and very small dependency observed in the Fig. 3 it becomes quite obvious that, in May, there were no relation between the amount of energy
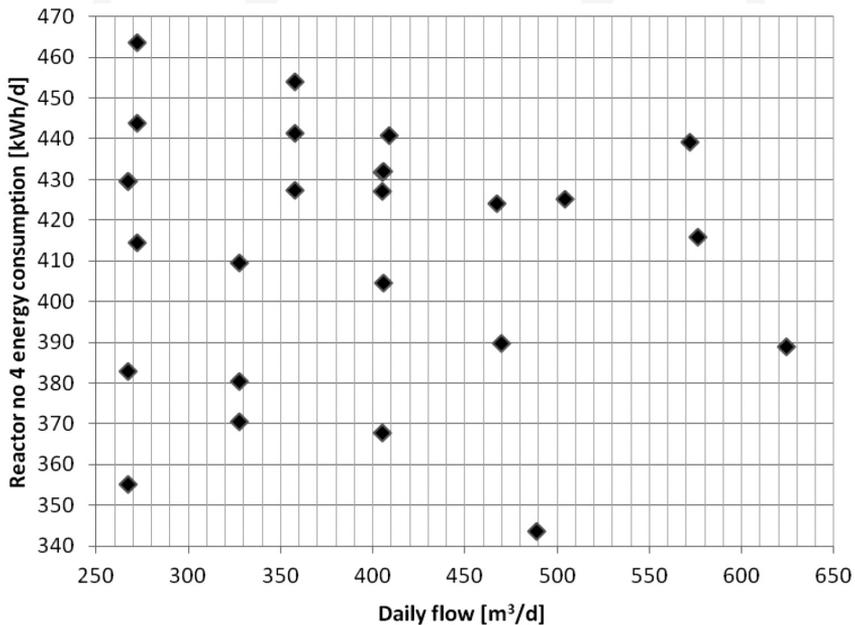
Fig. 4. Correlation of daily flow and reactor no 4 daily energy consumption

used by reactor no4 and daily flow. It is an indication that sewage distribution between active reactors is more important than total daily flow in case of WWTPs subsystems energy consumption. It is quite reasonable to assume that, if 2 or 3 SBRs are active, sewage will not be distributed equally between them, therefore, the amount of energy used should be distributed unequally between reactors. However, these are just preliminary reports and all noticed tendencies will be investigated further.

4.5. SBR4 share in total energy consumption

The final analysis – comparison of SBR4 EC with TEC is presented in the Fig. 3. Due to wide range of values a bar-diagram was the best option.
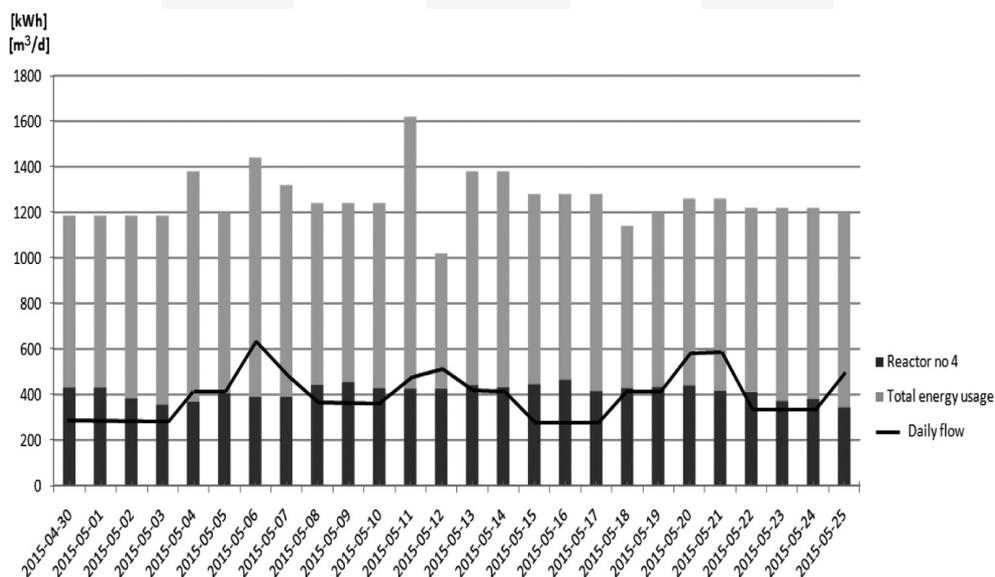

Fig. 5. Reactor no 4 participation in total energy consumption, with outlined daily flows

SBR4 Energy usage was rather stable and close to its average, TEC was more diverse, although SBR4 share in TEC was roughly the same during studied period. It ranged from 26.65% to 37.45% (values from 11 and 12th May were excluded). Average participation of studied SBR in total energy consumption is illustrated in the Fig. 4. During 26 days of measurements SBR4 was using ~ 32.76% of total energy used by WWTP.

This value is not surprising. What is surprising, however, it is that this value is not affected by activation of 3rd SBR. Average participation between 30.04 and 10.05 is 32.40 % (only two reactors were active during that period). Looking only on that short period of time, it could be assumed that twin reactor no 3 should have had similar participation, about 30 %. Using previous assumptions, it could be theorized that bioreactors share in total energy consumption is around 60% and after activation of 3rd reactor each, of them should use ~20%

of plant's TEC. Yet nothing like that has happened. Average SBR4 participation in TEC from 11 to 18th May was ~33.40% and after switching reactors no1 and no2 from 19–25th May it was ~32.53%. All averages were gathered in Table 2 for greater transparency.
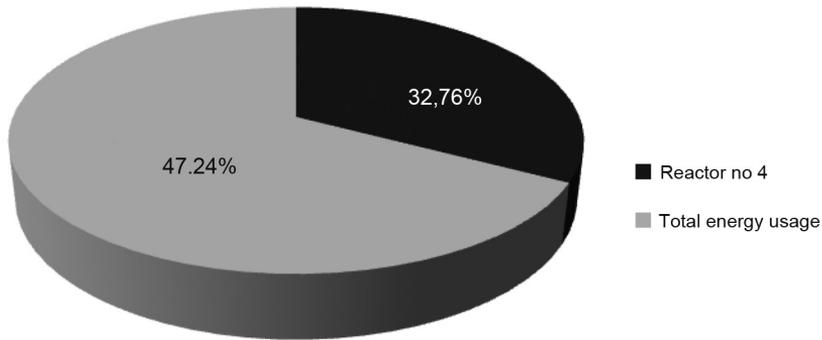

Fig. 6. Reactor no 4 average participation in total energy consumption during the analysed period

T a b l e 2

Average SBR4 share n Total Energy Consumption in different periods of time

Period of time	Active SBRs	Average SBR4 participation in TEC [%]
30.04–10.05	2	32.40
11.05–18.05	3	33.44
19.05–25.05	3	32.53
11.05–25.05	3	33.03
30.04–25.05	2–3	32.76

There was almost no difference between participation of SBR4 in TEC, whether there were two or three reactors active. Such results are unexpected and surprising. It was expected that share of single reactor will go down after activation of 3rd SBR. For the time being, these results are the most intriguing, but more data must be gathered before making any assumptions.

5. Conclusions

Impact of daily flows on WWTP's total energy consumptions had been observed and was consistent with previous researches. This allows to assume that data gathered by plant's operator are correct.

There were no major malfunctions or long-time blackouts during the studied period. However, a data gap occurred between 26.05 and 01.06. Potential reasons for this lack of data are being investigated.

Daily flows had an influence on single reactor's energy consumption, although it is noticeably weaker than the impact on the whole WWTP.

The collected data is of reasonable quality, but there is still room for improvement. It will require bigger involvement of the plant's crew in collecting data, but it is possible.

Contrary to expectation, SBR4 average share in total energy consumption stayed almost the same during whole studied period of time. It was expected that, after activation of 3rd reactor, each individual share should decrease a little bit, but no change was observed. This result is surprising and must be investigated when more data will be available.

All presented results and conclusions are preliminary and will be verified with next sets of data. These are long-term measurements, and some recalibrations of measuring grid may be required.

Despite few unexpected results, it is safe to assume that, after months of construction and initial calibration of the installation, it works as was expected.

R e f e r e n c e s

[1] Horne J. et al., *Energy Management Guidebook for Wastewater and Water Utilities*, Published by U.S. EPA 2008.

[2] Mucha Z., Mucha J., *Projekt budowlany: budowa oczyszczalni ścieków w Wołowicach*, Kraków 2008.

[3] SGS Polska Sp. z o.o. (laboratorium akredytowane), *Oczyszczalnia Ścieków Wołowice gm. Czernichów: Wylot ścieków z oczyszczalni – próbka średnia dobowa*.

[4] Regulation of the Minister of Environment of 16 December 2014 *on required parameters of treated wastewater and on substances that are particularly harmful to the aquatic environment*.

[5] Ciepliński J., *Budowa pilotażowej instalacji pomiarowej do określenia rzeczywistego zużycia energii przez reaktor typu SBR w małej oczyszczalni ścieków,* Podstawy Biotechnologii Środowiskowej – trendy, badania, implementacje, Gliwice 2015.

[6] Ciepliński J., Mucha Z., *Energy efficiency of wastewater treatment processes in small WWTPs*, Environmental Engineering – trough a young eye, Vol. 2, Białystok 2013.