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Research Article

ACTIVATED SLUDGE TECHNOLOGY COMBINED WITH HYDROPONIC LAGOON AS A TECHNOLOGY SUITABLE FOR TREATMENT OF WASTEWATER DELIVERED BY SLURRY TANKS

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ABSTRACT
The paper presents information related to the use of hydrophytic technology combined with traditional activated sludge solution for wastewater treatment in areas without central sewage system. The analyzed wastewater treatment plant (WWTP) was operated in activated sludge technology with a hybrid activated sludge reactor where biomass is kept in a settled and suspended form. Treatment system was completed with a hydroponic lagoon. Hydroponic lagoon has been used as tertiary treatment, in which the self-cleaning processes with the participation of the plant has come to an additional reduction of nutrients. The analyzed three-stage treatment plant is located in the municipality of Nowa Sól. Only domestic wastewater delivered by slurry tanks is treated there in the amount of 60 m^3/d. During the observation, high average concentrations of total nitrogen (201.0 mgN/dm^3) was observed and organic matter expressed by COD reaching 1341.5 mgO_2/dm^3 and BOD_5 on the level of 246.3 mgO_2/dm^3 were noted. A characteristic feature of the object designed for wastewater treatment delivered by slurry tanks is high irregularity of wastewater supply and high instantaneous loads of pollutants (the system does not provide expansion tank). The biggest inequality factor of the flow to the reactor was observed in December 2014 (Nd=3.9). During the observations days with no inflow of sewage also occurred. The study shows the dynamics of changes in the amount of delivered domestic wastewater and sewage flowing out of the treatment plant including inequality factor. Information about the quality of wastewater was used to determine the reduction of concentrations of pollutants such as organic matter, suspended solids, nitrogen and phosphorus.

Keywords: activated sludge technology, hydroponic lagoon, wastewater delivered by slurry tanks, wastewater treatment efficiency

INTRODUCTION

Due to the location of the entire territory of Poland in the basin of the Baltic Sea, which was recognized as sensitive to eutrophication, in the EU Accession Treaty Poland is committed to a 75% reduction in the load of nutrients (nitrogen and phosphorus) discharged into the surface water. This information is contained, inter alia, in the National Programme of Municipal Sewage Treatment, which at present is controversial as to write specific assumptions [Mikosz, Mucha 2014; Mucha, Mikosz 2014]. Activities that were performed to reduce the load of pollutants introduced with wastewater were numerous modernizations of existing treatment plants, construction of new facilities and building sewerage in the areas previously unequipped with sewer systems [Struk-Sokołowska 2012]. Doubts are raised about records specifying the reduction levels for selected size of the treatment plant which does not define the size of the agglomeration, from which wastewater is received, without reference to the capacity of the treatment plant. Still, achieving high reduction of biogenic compounds is a huge technological problem especially on greenfield sites. This is due to the inability to build central sewer systems completed with at least two-stage sewage treatment plant, for which constant control of the effects of work is possible. This would allow for a full control of the impact of such a facility on the environment and on early prevention of problems, e.g. breach of water permits and standards for wastewater discharge to the receiver.

The task of wastewater treatment plant is to remove contaminants present in the form of carbon, nitrogen and phosphorus from sewage. The methods used for these purposes are primarily mechanical methods which deprive thicker sewage pollution and biological methods helpful in reduction of nutrients (nitrogen and phosphorus) [Klaczyński, Ratajczak 2013]. Among the available technology activated sludge technology is used on a global scale. It was developed as early as in 1914 [Ardern, Lockett 1914] and improved throughout the years. The proper course of wastewater treatment is provided by constant supply of wastewater with known characteristics, rich in easily decomposable carbon compounds and nitrogen compounds. According to Bever et al. [1997], to ensure the removal of nitrogen and phosphorus from wastewater at a high level, the ratio of N:BOD_5 no greater 0.2 and the ratio P:BOD_5 not exceeding 0.04 should be provided. Łomotowski and Szpindor [1999] and also Pirsaheb et al. [2015] indicate that the process of denitrification is also conditioned by an appropriate ratio of organic carbon to nitrogen, which should exceed 3.5 g BOD_5/g N. A necessary condition must also ensure an adequate oxygen concentration in the aerobic chamber in reactor for the growth of microorganisms that "work" for the reduction of the pollutant load in wastewater [Sikora, Miksch 2012]. The biggest technological problem is the lack of a constant inflow of wastewater, whose operators try to compensate by delivering sewage from septic tanks. This becomes a problem for wastewater treatment plant at a time when the physicochemical composition of the wastewater is far from the composition of sewage widely adopted for design purposes. Domestic wastewater from septic tanks due to its composition and the state in which they are anaerobically decomposed may cause difficulties in cleaning them in conventional systems [Karczmarczyk 2013; Richards et all. 2016]. In wastewater delivered from septic tanks a high concentration of pollutants occurs, mainly organic matter. Particular hazard may result from a high concentration of ammonium, which can cause poisoning of activated sludge [Kucharski 2000; Im, Gil 2015]. As a result of processes of anaerobic decomposition of pollutants in the septic tank occurs gases, among which the most toxic effect has hydrogen sulfide [Piaskowski, Terlecka 2012]. Its moderate concentrations in effluent flowing into the chambers of activated sludge may slow down the growth of microorganisms, but increased levels of H_2S are the cause of technological problems and increased oxygen consumption, which stems from the need to oxidize delivered pollutants before O_2 is used in the processes of nitrification [Sikora, Miksch 2012]. Additional problems in wastewater treatment plants in the areas without sewer system are also caused by delivering of sludge from local sewage treatment plants and mixing them with sewage. Impact flow of this type of mixture to the reactor could lead to anaerobic conditions and the extinction of activated sludge organisms [Powley et al. 2016]. Therefore, the design assumes a partial share of sewage delivered by slurry tanks in relation to the wastewater inflow from sewerage systems. Usually the 10% as the maximum amount of delivered sewage in relation to the influent is accepted [Bugajski, Satora 2009]. Wastewater treatment plants, which function as facilities for the treatment of sewage delivered by slurry tanks are rare [Lam et al. 2015]. They represent mainly transient condition before connecting the area to the sewage system and directing a constant flow of wastewater into a proper facility [Sadecka et al., 2012].

Wastewater from the septic tanks is mainly characterized by "hard" physical and chemical composition and high irregularity of delivery, which certainly presents a challenge for any conventional technology. The aim of the study was to assess the legitimacy of the use of hydroponic lagoon working in conjunction with the two-stage mechanical-biological wastewater treatment plant as the right technology for the treatment of domestic sewage delivered by slurry tanks.

MATERIALS AND METHODS

Samples of wastewater were used to define the possibility of delivered wastewater treatment in traditional activated sludge technology with additional third stage treatment in hydroponic lagoon. Samples of raw wastewater were taken from tank for delivered wastewater. Purified wastewater were taken from the outflow from WWTP – the outflow from hydroponic lagoon. Tests of the quality of raw and purified wastewater were made in Water and Wastewater Laboratory of Faculty of Environmental Engineering and Geodesy in Wrocław University of Environmental and Life Sciences with use of current standards. BOD_5, COD, total suspended solids, total nitrogen and total phosphorus concentrations were determined with methods showed in Table 1.

Samples of raw and treated wastewater were taken from three stage (mechanical-biological-hydroponic) treatment plant, located in the municipality of Nowa Sól. The object purifies only sewage delivered by slurry tanks in average amount of 60 m^3/d. The analyzed object consist of a technical block, which includes a tank for delivered wastewater, whose task is to collect and averaging sewage inflow. After averaging tank, sewage flows through the pumping system on a vertical screen, where larger parts are separated and then to the grit chamber to remove mineral particles. Next, the sewage flows into a primary settling tank, which ends the mechanical block. Specifications of the equipment installed in hydroponic wastewater treatment plant are presented in Table 2. After the primary settling tank sewage is subject to biological treatment in a hybrid circulating reactor of activated sludge. The reactor is built on the outer cover of the secondary settling tank and has the shape of a radial flow chamber. It is divided into oxygenated and anoxic chambers, with one anaerobic chamber, to whom the wastewater flows after mechanical cleaning. Individual chambers are separated by plastic panels covered with bacterial biofilm which are the trophic and oxygen barrier. The purpose of the reactor is to remove carbon compounds as well as the reduction of nitrogen (nitrification and denitrification) and phosphorus (biological dephosphatation). After the activated sludge reactor, wastewater is directed to the secondary settling tank located in the central part of the building, where wastewater is clarified. The final stage of wastewater treatment in this system is a hydroponic lagoon. Location of the lagoon inside the building provides insulation from unfavourable thermal conditions, and windows built-in wall and roof provide a supply of solar energy required for the processes of photosynthesis of plants planted on the lagoon. About 50% of the lagoon is covered with panels made of plastic, which is a support for milfoils whorled (*Myriophyllum verticillatum*) that was introduced into the lagoon (Figure 1). WWTP is also equipped with a station of sludge dewatering.

Table 1. Methods used for determining the physico-chemical composition of wastewater

Parameter	Unit	Methods	Standards
BOD_5	mgO_2/dm^3	specific method	PN-EN 1899–1:2002
COD	mgO_2/dm^3	non-specific spectrophotometric method	ISO 6060:1989
Total suspended solids	mg/dm^3	Potassium dichromate titration	PN-EN 872:2002
Total nitrogen	mgN/dm^3	specific method	PN-EN 25663:2001
Total phosphorus	mgP/dm^3	Spectrophotometric method with mineralization with HNO_3	PN-EN 1189–2000

Table 2. Specification of hydroponic wastewater treatment plant in the municipality of Nowa Sól

Characteristics	Type of device/size of parameter	Task / Comments
Q_{dav}	60 m^3/d	Only wastewater delivered by slurry tanks (eventually after sewerage 250 m^3/d)
	Tank of delivered wastewater	Collecting of wastewater and averaging composition
Mechanical Block	Vertical screen EKOFINN 1.5kW	Preliminary reduction of pollutants
	Vertical grit EKOFINN	Securing of biological area from the inlet of solids endangering proper operation of WWTP
	Primary settling tank	
Biological Block	Chamber of activated sludge (capacity 180 m^3)	Biological treatment of organic carbon, nitrogen and phosphorus by activated sludge
	Aeration grids with blowers	Providing oxygen conditions necessary for the occurrence of the process
	Secondary settling tank	Separation of activated sludge from treated wastewater
	Hydroponic lagoon with aeration diffusers	Reduction of biogenes in wastewater additional reduction of suspended solids flowing out of the secondary settling tank
Sludge block	Chamber of sludge stabilization	Dewatering and stabilization of sewage sludge
	Belt press with thickener	

Figure 1. Plastic panels with plants (*Myriophyllum verticillatum*) (phot. A. Bawiec)

Dehydration takes place on a belt press with the use of polyelectrolytes, and then also on press, sludge is subjected to compaction. Dehydrated sludge goes into drying and then is stored in the warehouse of sludge.

Designed hydroponic wastewater treatment plant uses a hybrid method of activated sludge consisting in conjunction suspended in the depths of sewage biomass and the biomass attached to the packages that are placed on the border of the individual oxygen – anaerobic zones. Wastewater without thicker parts of pollutants that were removed on mechanical block flow successively through the anaerobic zone (Figure 2) to the anoxic and aerobic zones.

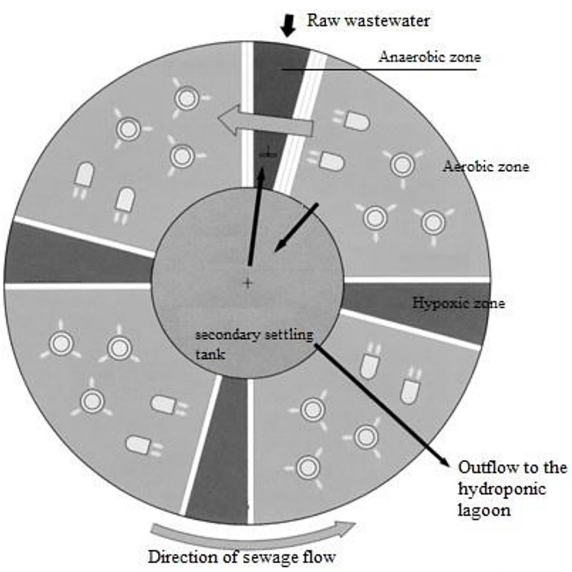

Figure 2. Functional diagram of a circulating reactor [Sadecka, Waś 2007]

RESULTS AND DISCUSSION

The analysis of raw and purified wastewater included the determination of the content of organic matter in the wastewater expressed by BOD_5 and COD, total suspended solids, total nitrogen and total phosphorus. All the analyses were made by current standards listed in Table 2. Qualitative characteristics of wastewater delivered to WWTP assumed by designers and the results of the analysis made in the laboratory are presented in Table 3.

Design values presented in Table 3 formed the basis for the design of WWTP. Designers did not take into account that wastewater quality may be characterized by high variability. The results of the laboratory analysis showed that the concentrations of pollutants in sewage delivered by slurry tanks are sometimes even almost three times higher than the expected values. Organic matter concentration expressed by COD reached the level of 3234.8 mgO_2/dm^3, where the design value is 1243.0 mgO_2/dm^3. Real values of pollutants concentrations were even more than three times lower than those adopted for the purposes of design, as is the case of BOD_5, Laboratory analyzes showed that BOD_5 levels were lower than design values during the whole research period and varied from 2.3 to 480.0 mgO_2/dm^3. Such a wide range of changes in the concentrations of the basic parameters was closely associated with the place of sewage origin (septic tanks, local sewage treatment plants) and had a direct impact on the nature of the processes occurring in devices of treatment blocks [Ścisłowska, Wolny 2010; Piaskowski, Kołacz 2011; Siwiec 2012].

Table 3. Characteristics of quality of delivered wastewater and intervals of design values estimated for WWTP

Parameter	Unit	Design value	Real value*
COD	mgO_2/dm^3	1243.0	74.3 – 3234.8
BOD_5	mgO_2/dm^3	746.0	2.3 – 480.0
Suspended solids	mg/dm^3	870.4	90.0 – 2200.0
Total nitrogen	mgN/dm^3	136.8	62.1 – 333.3
Total phosphorus	mgP/dm^3	22.4	6.1 – 49.2

Table 4 shows designed, obtained and recommended in the literature relative shares of individual parameters characterizing the raw sewage in order to provide appropriate conditions for the removal of nitrogen and phosphorus in biological processes.

The values of the relative shares of $N:BOD_5$ and $P:BOD_5$ presented in Table 4 indicate that the composition of delivered wastewater does not provide adequate conditions for proper overlap of the biological treatment process. At the design stage the quality of wastewater necessary for correct treatment and maintenance high removal efficiency of nitrogen and phosphorus was estimated. Assumptive values of contaminants concentrations are not corresponding to the actual quality of sewage supplied to the treatment plant. Analysis of the ratio of nitrogen to organic matter expressed in BOD_5 ($N:C > 0.2$) showed that the wastewater treated in described plant does reach the value that guarantees high reduction of N and P (required N:C ratio should be lower than 0.2). In each of the analyzed samples during measurement, the concentration of BOD_5 in relation to the concentration of the nitrogen was at least twice as low in comparison to the required minimum. The ratio of phosphorus to organic matter in inflow sewage also did not show values required for normal biological process of purification. The analysis of P to BOD_5 ratio of showed that in the wastewater there is insufficient organic matter, which can be used by the microorganisms in the processes of nitrification, denitrification and phosphorus removal [Piaskowski 2015; Zhi, Ji 2014]. In the case of failure to provide adequate C:N ratio, it may be necessary to introduce an external carbon source to the processes taking place in the chambers of the bioreactor to provide the correct parameters of sewage into the occurrence of effective wastewater treatment processes [Łomotowski, Szpindor 1999; Isaacs, Henze 1995].

On the basis of the analysis of pollutants concentration in wastewater delivered and flowing out of the plant after the three stages of the purification (mechanical treatment, bioreactor with activated sludge, hydroponic lagoon), the efficiency of contaminants removal in the analyzed WWTP was calculated (Table 5).

The data presented in Table 5 for the efficiency of pollutants removal in the three-stage wastewater treatment plant show a very high percentage of their removal despite working only with sewage delivered by slurry tanks. Reducing the concentration of total nitrogen was approaching almost 95% during the research period (reduction from 333.3 mgN/dm^3 to 17.0 mgN/dm^3). The removal of phosphorus in research period reached almost 95%, but in one month the concentration of phosphorus in the treated wastewater (7.2 mgP/dm^3) was higher than in raw sewage (6.1 mgP/dm^3). Organic matter, expressed in COD was often removed with the efficiency exceeding 95% (COD in raw wastewater – 3234.8 mgO_2/dm^3 and in treated wastewater – 56.2 mgO_2/dm^3). BOD_5 levels were usually reduced by 99%, for example in June 2015 the BOD level in raw wastewater was 480 mgO_2/dm^3 where it reached the level of 0.3 mgO_2/dm^3 in the treated wastewater. Similar removal efficiency was observed for total suspended solids. In samples taken in December 2014 sewage enrichment in phosphorus and or-

Table 4. Summary of shares of nitrogen and phosphorus relative to the organic matter (design and preferred values)

$N:BOD_5$ / Date	Designed ratio $N:BOD_5$	Obtained ratio $N:BOD_5$	Preffered ratio $N:BOD_5$	Designed ratio $P:BOD_5$	Obtained ratio $P:BOD_5$	Preffered ratio $P:BOD_5$
04.11.2014	0.18	0.50	< 0.2	0.03	0.13	< 0.04
09.12.2014		27.0			2.67	
03.02.2015		0.69			0.04	
18.03.2015		0.88			0.18	
24.04.2015		2.16			0.23	
14.05.2015		0.84			0.12	
19.06.2015		0.61			0.06	

Table 5. Efficiency of contaminants removal [%] in wastewater treatment plant in Nowa Sol municipality

Indicator	COD	BOD_5	Suspended solids	Total nitrogen	Total phosphorus
Efficiency [%] $\frac{\text{min– max}}{average}$	$\frac{15.1-98.3}{80.7}$	$\frac{-21.7-99.9}{75.0}$	$\frac{61.9-98.5}{89.6}$	$\frac{43.4-94.9}{74.1}$	$\frac{-16.6-94.2}{56.1}$
Number of samples (n)	5	5	5	5	5
Number of exceedances according to water permit	-	-	2	-*	-*

* negative values of reduction indicate the secondary contamination of sewage
-* not required by the water permit

ganic matter (BOD_5) was observed, as indicated by the negative values shown in the table 5. The reason may be decomposition of plants growing on hydroponic lagoon caused by low temperatures and lack of sunlight which are necessary for plants vegetation. In February and March 2015, there was no outflow from the plant, what made it impossible to determine the quality of treated wastewater and thus – to calculate the removal efficiency. Inflow to the WWTP was so small that all wastewater were collected in the tanks of sewage treatment facilities as well as in the hydroponic lagoon. Reducing the outflow and, consequently, periods without any outflow were due to the lack of sewage delivered to the plant resulting in a lagoon worked as a buffer (additional secondary sedimentation tank) [Zawałek, 2012].

According to the legal status (Regulation of the Minister of the Environment) [Rozporządzenie Ministra Środowiska…], on the outflow WWTP should provide a reduction of 3 basic parameters BOD_5, COD and TSS, whose concentration should not be higher than : 25 mgO_2/dm^3, 125 mgO_2/dm^3, 35 mg/dm^3 accordingly. Research on sewage quality flowing into the plant showed, that during the period of observation the maximum permissible concentrations of BOD_5 and COD on the outflow from the plant were not overrun, but has twice exceeded the maximum permissible concentration of total suspended solids, which reached 50 mg/dm^3. The attention should be paid also to the fact that in February and March 2015 during the sampling did not occur the outflow of sewage from the plant and hydroponic lagoon worked as a tank for biologically treated wastewater. Using hydroponic lagoon as a sedimentation tank caused formation of sewage sludge which, at the time of increasing the wastewater inflow, was flowing out of WWTP. The flocs of sludge picked up by flowing wastewater from the bottom of the lagoon increased the concentration of total suspended solids in the outflow.

The occurrence of periods in which treated wastewater is not discharged from the plant is due to the high inequality of sewage inflow. It is a plant that receives only wastewater delivered by slurry tanks. Lack of central sewer and constant inflow of wastewater by pipes causes occurrence of periods without inflow, which has an unfavorable impact on the treatment processes that occur in the biological reactor and the hydroponic lagoon. Daily values of inflow and outflow of wastewater to the treatment plant and the maximum and minimum values in the analyzed period are shown in Figure 3.

The median for the observed values of the delivered wastewater was 45.5 m^3/d (Figure 4), and the amount of treated sewage due to the nature of the work of the object was characterized by a wide range of changes. Lagoon assuming partly the character of buffer tank regulated largely uneven inflow. For outflowing wastewater median had value of 37.2 m^3/d.

Technological system set only for the purification of wastewater delivered by slurry tanks has high flow imbalances which translates to varying hydraulic load as well as high and time-varying pollutants loads. The technology based on "live structures" as is the activated sludge flocs without continuous over time and stable in terms of physico-chemical composition inflow in the long term of time react with deterioration of the condition of activated sludge as well as a reduction in the quality of discharged wastewater. During the observations the amount of wastewater delivered into the plant showed an upward trend (Figure 3). However, despite a noticeable increase in the volume of sewage, high rates of inequality (2.0–3.9) were noted. The largest percentage in the amount of delivered wastewater had daily inflows in the range of 40–60 m^3/d (24% – Figure 5a). The amount of wastewater discharged from the facility is also characterized by a growing trend (Figure 3). The shift in the value of the daily outflow: 20–40 m^3/d (36% – Figure 5b) was noticeable. Despite of shifts in the class of the sewage inflow and outflow medians in both cases were similar to each other (Figure 4).

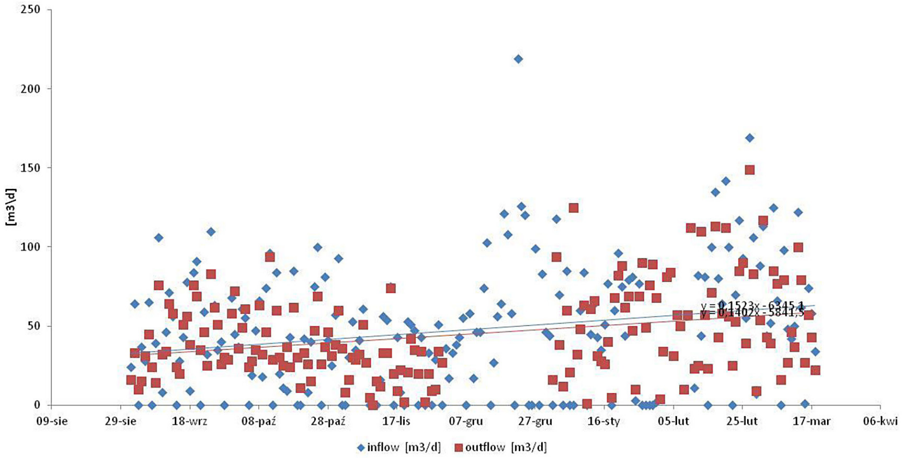

Figure 3. Dynamics of changes in the amount of sewage delivered to the plant and flowing out of it in the study period

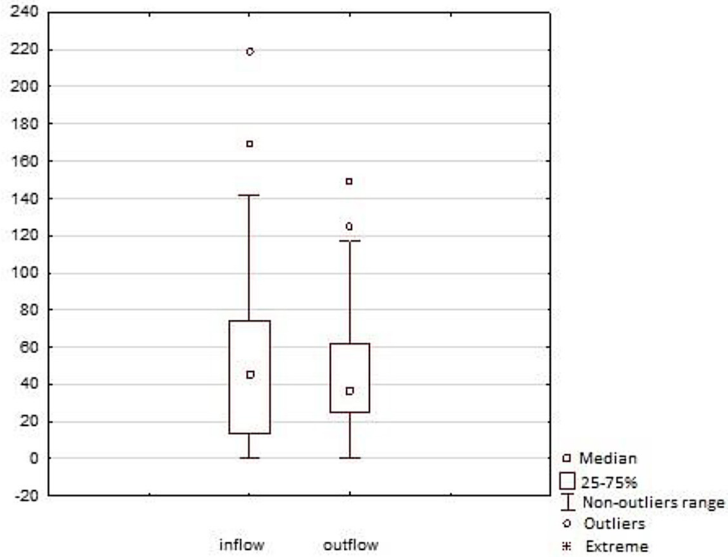

Figure 4. Distribution of the size of inflow and outflow of wastewater from treatment plant operating in the hydroponic technology

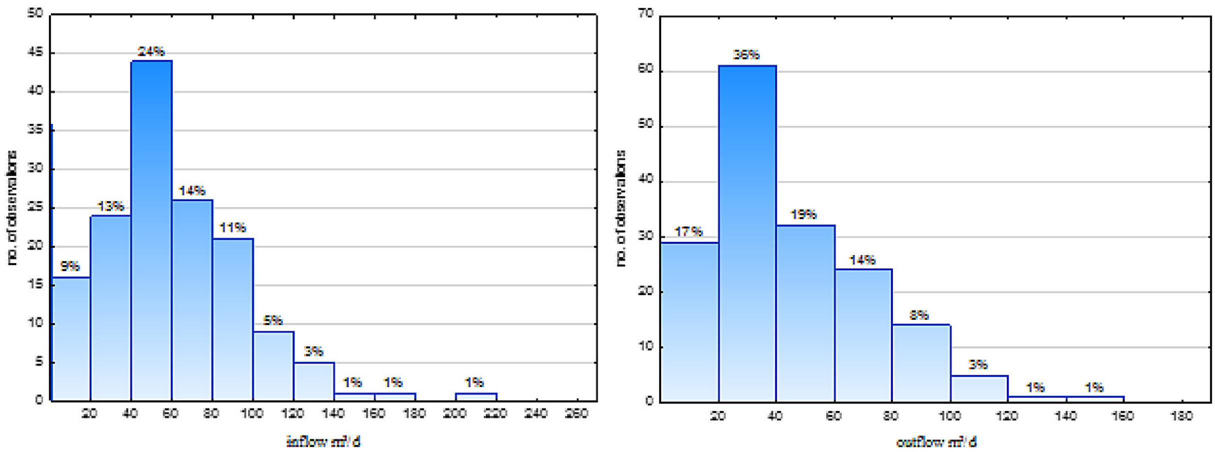

Figure 5. Histograms of the size of the inlet (s) and outflow (b) from wastewater treatment plant operating in the hydroponic technology

CONCLUSIONS

On the basis of the observations and laboratory analyzes the following conclusions were performed:

1. Maintaining the required quality parameters of wastewater outflow from the plant that treats only sewage delivered by slurry tanks (often anaerobically decomposed, with very high loads of pollutants) is demanding and difficult task from a technological point of view, however, feasible;
2. Facilities that use hybrid reactors in sewage treatment processes, although they are less sensitive to uneven conditions of flow and wide ranges of inflowing pollutants concentrations, show irregularities in the functioning with the absence of wastewater inflow and with deliver of anaerobically decomposed wastewater mixed with sludge coming from the local sewage treatment systems;
3. During the research time, high concentrations of organic matter expressed by COD and BOD_5 exceeded 2000 mgO_2/dm^3 which may have negative impact on the stability of wastewater treatment processes.
4. The observed values of the relative shares of N:BOD_5 (N:C > 0.2) and P:BOD_5 (P:C > 0.04) indicate that the composition of delivered wastewater does not provide adequate conditions for proper overlap of the biological treatment process.
5. In systems based on delivered wastewater it is possible to achieve high efficiency of wastewater treatment. In described facility when the inflow and outflow from WWTP occurred, it was possible to obtain even 99% reduction of BOD_5, COD and suspended solids, as well as 95% reduction of total nitrogen and phosphorus concentrations.
6. Wastewater collected in the lagoon where there is no wastewater flowing into WWTP cause sewage sludge disposal which, during high inflow of wastewater, can be picked up by flowing sewage from the bottom of the lagoon and increase the concentration of total suspended solids in the outflow.

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