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EVOLVING OF HIGHLY EFFICIENT METHOD OF WASTEWATER TREATMENT WITHIN THE LANDSCAPE PARK AREAS

There is presented an advanced technology of wastewater treatment which guarantees an efficient removal of organic carbon, total nitrogen and phosphorus and suspended solids. Such a technology can be very attractive when applied in landscape parks where quantities of discharged wastewater vary seasonally and daily and high quality of purified wastewater is required. The first wastewater treatment plant designed according to the presented concept is now built for the Popielno community situated within the area of landscape park, the Large Mazurian Lakes (north-eastern part of Poland).

1. INTRODUCTION

In Poland, we can find the areas very appreciated for theirs natural and landscape features, i.e. landscape parks. These areas are specially protected in order to avoid their degradation and to keep natural environment properties as well as to preserve their scientific, aesthetic and tourist quality. The protection of landscape park areas excludes any industrial activity and other actions, which can contaminate soil, surface water and air. In Poland there are 82 landscape parks (1992) of the total surface area approaching 1 565 000 hectares.

The purity of water in Polish lakes can be considered as alarming. Of 817 lakes investigated by 1993, only 5% possessed water of very high quality – the so-called "1st purity class" [1]. Surface water, especially lake water, is a very unstable element of environment that undergoes irreversible and quick physicochemical and biological transformations due to discharging pollutants of different origin. Because of municipal, industrial and agricultural activities about 224 000 t of nitrogen and 30 200 t of phosphorus per year – nutrients being responsible for eutrophication of lakes and water reservoirs – are discharged in Poland into surface water. The consequences of an extended development of tourism and recreation cannot be likewise negligible in causing threats to the environment.

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The worsening quality of surface water is not without importance in the subsequent development of tourist, recreation and agricultural activities and the condition of landscape parks. Especially untreated or wrongly treated wastewater causes serious hazards when is discharged into lakes and rivers. In many cases the areas with landscape parks are lacking wastewater treatment plants, or if they exist, they are frequently disused and cannot keep treatment standards. It concerns e.g. the relevant degree of nutrient removal. For that reason it is advisable to develop a unified, highly efficient method of treating wastewater discharged in the areas of landscape parks. This method should guarantee high degree of removal of organic carbon, total nitrogen and phosphorus as well as suspended solids. Moreover, it should be reliable and flexible in order to enable an effective wastewater treatment in the case of large fluctuations in the quantity and quality of inlet wastewater. Distinguishing variations of wastewater characteristic can result from a seasonal increase in the number of inhabitants.

In this paper, it was presented the solution which would meet the above-mentioned requirements. The first wastewater treatment plant designed according to the presented concept is now built for the Popielno community situated in the area of landscape park within the Large Mazurian Lakes (north-eastern part of Poland). The Large Mazurian Lakes due to their natural, tourist and scientific features are the important region in Poland under special protection. The lakes occurring in that area and in the 19th century connected with watercourses formed a large water system of the surface area approaching 300 km^2 (a total water area occupies about 30% of the region). In 1977, the Mazurian Landscape Park came into being in the southern part of the Large Mazurian Lakes region comprising among others the largest lake in Poland, i.e. Śniardwy Lake. Within its area there are many nature reserves mainly of waterfowl species. At Łuknajno Lake there is a known in the world reserve of biosphere applying an international convention, whose area is the greatest colony of silent swan (*Cygnus olor*) in Europe.

2. SELECTION OF WASTEWATER TREATMENT TECHNOLOGY

Nitrogen and phosphorus removal from wastewater has become important because it allows us to protect water bodies from eutrophication, especially lakes and highly enclosed bays, where water stagnates. Considering the fact that the wastewater treatment plant designed for the Popielno community will be situated in the area of landscape park, the choice of a proper wastewater treatment technology must be preceded by taking into account many aspects, first of all the following ones:

- reliability of wastewater treatment process,
- high efficiency of wastewater treatment with reference to organic carbon, total nitrogen and phosphorus as well as suspended solids, independently of the season,
- flexibility of wastewater treatment plant that enables an immediate adaptation of technological parameters in the case of distinguishing fluctuations in quantity or quality of wastewater,

- limited area occupied by wastewater treatment plant,
- moderate treatment costs,
- minimum harmfulness for environment,
- possibility of introducing the wastewater treatment plant into a landscape composition.

2.1. SYSTEMS OF BIOLOGICAL NUTRIENT REMOVAL

The above-mentioned concept of wastewater treatment based on activated sludge process has been recognised as advisable. There are many different technologies that utilise activated sludge to combined removal of nitrogen, phosphorus and organic carbon. Such technologies are frequently named the biological nutrient removal (BNR). Within the BNR technologies the following ones are of great importance: Phoredox, Bardenpho, A_2O, UCT (University of Cape Town), MUCT (modified UCT) and SBR (sequencing batch reactor). Nowadays there are up to 20 different systems for wastewater treatment plants originated from the Phoredox process every individually named [2].

After making a preliminary analysis of the BNR systems applied in practice, a special attention has been paid to SBR reactors which can be applied to solve the problem. The SBR systems are at present one of the most recommended solutions for treating small amounts of wastewater, though at the same time there are built, based on the SBR technology, larger wastewater treatment plants of 100 000 $m^3 \cdot d^{-1}$ capacity. In Poland, the largest SBR wastewater treatment plant works in Nowy Targ (24 000 $m^3 \cdot d^{-1}$). According to EPA (Environment Protection Agency) in the USA at present there are exploited about 170 of SBR reactors [3]. Approximately 40 SBR reactors have been designed for biological nutrient removal.

2.2. SYSTEMS OF SEQUENCING BATCH REACTOR

SBR systems are simple and more flexible than conventional activated sludge systems. A cycle period can be easily changed, hence the fluctuations in quantity and quality of inlet wastewater do not disturb the process and therefore significant treatment effects can be observed. Moreover, batch processes are characterized by an equalized flow and balanced organic loading. The SBR system can be controlled in such a way as to guarantee either a constant low substrate concentration in the reactor or a sequential high/low substrate concentration through making changes at the fill phase. Such a solution enables us to take advantage of the selector mechanism in order to limit the growth of filamentous microorganisms and to avoid a sludge bulking. If we adopt the operating strategy of anoxic filling, the significant improvement of sedimentation properties of activated sludge is observed compared to the operating strategy of filling under aerobic conditions [4]. The active volume of a reactor can vary, depending on the wastewater type, expected degree of treatment, sedimentation properties of activated sludge, etc. The time from starting the fill phase to completion the decant phase is named the work cycle of a reactor. The operating strategy of reactor exploitation, which means the system, partition and duration of each process phase within one cycle, depends on the assumed degree of wastewater treatment. The exemplary work cycles of the SBR reactor have been presented in figure 1.

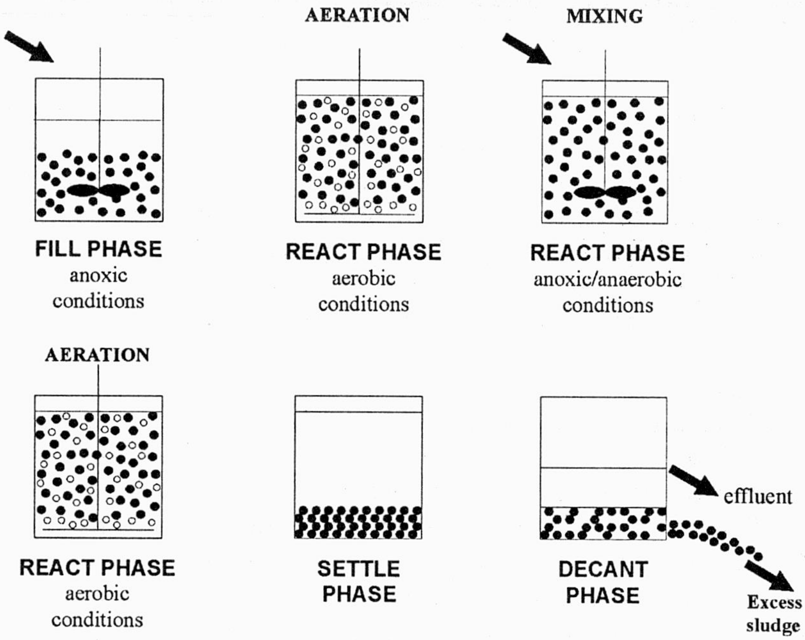

Fig. 1. Operating strategy of SBR reactor

The six-phase work cycle of the SBR reactor (figure 1) for the most frequent cycle duration of 6 hours provides good effects of wastewater treatment in terms of BOD_5 and nutrient removal (compare to Polish Standards [5]).

In the case of SBR reactor, the activated sludge process can be carried out as:

• process with simultaneous sludge stabilization when the sludge age is 25 or more days;

• process with nitrification when the sludge age is 12–15 days.

In the case of combined removal of nitrogen and phosphorus in sequencing batch reactors, the following general criteria have to be taken into account:

• in each work cycle, anaerobic, aerobic and anoxic conditions should be created;

• Bio-P bacteria (accumulating phosphorus) require volatile fatty acids (VFA) under anaerobic conditions;

• denitrifying bacteria need an organic carbon under anoxic conditions.

In addition to the facts mentioned previously, we can state that the SBR technology satisfies all above requirements.

In the case of high requirements for the total phosphorus removal from wastewater (total P ≤ 1.0 g·m^{-3}), an application of biological methods, including enhanced phosphorus removal, can be insufficient when stable and very high degree of phosphorus removal is required. For that reason in such cases the methods of chemical phosphorus precipitation followed by subsequent filtration should be taken into account. The aim of biological phosphorus removal is to develop aerobic/anaerobic conditions that enable accumulation of phosphorus in cells of bacteria, e.g., *Acinetobacter.* If such bacteria connected with activated sludge flocs enter effluent, phosphorus removal is better. Therefore in enhanced phosphorus removal systems it is very important to secure a high efficiency of secondary settlers and in many cases also a final filtration of wastewater. In the case analysed, we have decided to apply the modern continuous DynaSand® filter (presented in figure 2).

2.3. DYNASAND FILTER

DynaSand® is a continuous filter. This means that the bed material is cleaned without interruption. The material is lifted up by means of an air-lift pump to a washing device in which it is cleaned before being returned to the bed. The bed material in the filter is in a state of continuous movement downwards. The water flows through the bed from the bottom upwards. DynaSand® filters have long been used for "tertiary filtration" in sewage treatment plants. This means that the filter is connected with the secondary sedimentation tank in order to improve the separation of particles and to lower the phosphorus content.

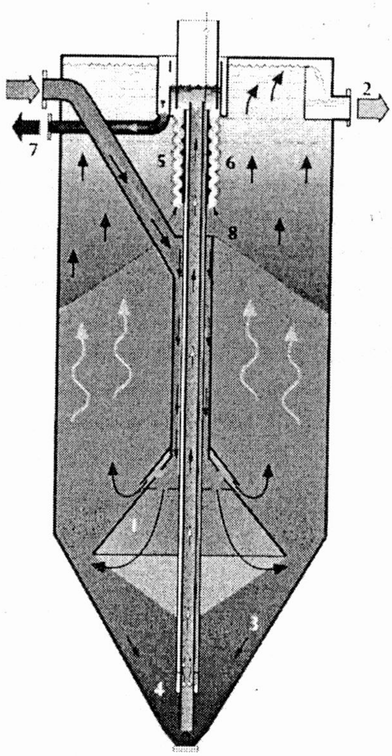

Fig. 2. Principle of DynaSand® filter operation

The DynaSand® filter works on the upstream principle. The water that is to be treated is admitted to the inlet distributor (*1*) in the bottom section of the filter. The water flows up through the sand bed, where it is cleaned and then leaves the filter through the filtrate outlet (*2*) at the extreme top. The pollutants remain in the sand bed. The contaminated sand is transported from the bottom cone (*3*) by means of the air-lift pump (*4*) to the sand washer (*5*) at the top of the filter. Cleaning of the filter sand begins in the air-lift pump, in which an intense stirring action releases the dirt particles from the grains of sand. The contaminated sand flows out of the pump outlet and drops down into the washing labyrinth (*6*), where it is washed by a moderate flow of cleaned water. The contaminants are entrained upwards to the washing water outlet (*7*). The grains of sand, which are heavier than the contaminants, drop down towards the sand bed (*8*) which is thus in a state of constant downward movement through the filter [6].

The operation of the filter – both cleaning of the water and cleaning of the sand – is continuous. As a result, the filter need never be shut down.

3. TECHNOLOGICAL PARAMETERS OF SBR REACTOR FOR THE POPIELNO COMMUNITY

The Popielno community is a small settlement of about 200 inhabitants. Research Station of Ecological Agriculture of Polish Academy of Sciences is also placed in the community area together with a recreation centre for about 100 persons. Designer assumes to build a sewerage system conveying wastewater to the wastewater treatment plant. Some buildings are very scattered (e.g., forester's lodges) and for that reason it is not reasonable to build a sewerage system for all of them. In such a case, wastewater will be delivered to the receiving chamber by sewage disposal automotive transport.

3.1. INITIAL ASSUMPTIONS

Based on earlier studies, it is fixed that the amount of wastewater to be treated in the designed wastewater treatment plant will be on the level of 60 m^3 per day, except the summer season. In the summer season, the amount of wastewater will increase up to 120 m^3 per day. Approximated concentrations of inlet basic pollutants and required parameters of purified wastewater according to the Regulation of the Minister of Environmental Protection, Natural Resources and Forestry (Poland) are presented in table 1.

Table 1

Concentrations ($mg \cdot dm^{-3}$) of inlet basic pollutants and required parameters of purified wastewater

Parameter	Inlet wastewater	Purified wastewater
BOD_5	456	15
Suspended solids	350	25
Total nitrogen	80	30
Ammonia nitrogen	65	6
Total phosphorus	20	1

In the future, these parameters can be restricted. Therefore before calculating and selecting SBR reactors the following assumptions have been accepted:

- Wastewater treatment plant has to guarantee an appropriate degree of nutrient removal (nitrogen and phosphorus) besides reduction of organic compounds. For this end biological treatment should consist of the following processes: biological phosphorus removal, nitrification and denitrification.
- Because a very high degree of suspended solids removal is necessary, a plant has to be equipped with devices for final filtration of wastewater.
- Due to very strict regulations applied to the total phosphorus removal and due to the fact that in the process of biological phosphorus removal the concentration of total phosphorus in effluent below 1.5–2.0 $mg \cdot dm^{-3}$ is difficult to obtain, we assume that this nutrient should be additionally precipitated by the PIX coagulant (40–45% solution of iron sulphate). The PIX will be dosed before the filter, but accidentally it will be possible to dose the coagulant also directly into the SBR reactors.
- Sludge age, which limits its degree of stabilization and conditions of nitrification occurrence, should not be shorter than 25 days.

3.2. BASES OF CALCULATIONS

The volumes of reactors have been calculated based on following assumptions:

- sludge age – 25 days;
- activated sludge concentration – 4.0–4.5 kg $MLSS \cdot m^{-3}$;
- removal efficiency of BOD_5 in mechanical part of wastewater treatment plant (sieve) – 40%, therefore BOD_5 in the inlet to biological part reaches 0.274 $kg \cdot m^{-3}$; the assumed value is 0.3 $kg \cdot m^{-3}$;
- unit sludge growth – 0.7 $kg \cdot kg\ BOD_5^{-1} \cdot d^{-1}$.

Table 2

Basic parameters of SBR reactors for the Popielno community

Parameter	Unit	$V_{SBR} = 160\ m^3$	
		4.0 kg $MLSS \cdot m^{-3}$	4.5 kg $MLSS \cdot m^{-3}$
Sludge age	day	25	28.5
Sludge loading	$kg \cdot kg\ O_2^{-1} \cdot d^{-1}$	0.056	0.050
No. of cycles	cycle per day	4	4
Sludge mass in SBR	kg MLSS	640	720
Reactor active volume	m^3	96	88
Oxygen consumption	$kg\ O_2 \cdot kg\ BOD_5^{-1}$	2.1	2.1
Excess sludge	$kg \cdot d^{-1}$	25.2	25.2
Volume of excess sludge	$m^3 \cdot d^{-1}$	2.52 $m^3 \cdot d^{-1}$	2.52 $m^3 \cdot d^{-1}$

The calculated active volume of reactors V_{SBR} compatible with the above data is equal to 160 m^3. It is assumed that two SBR reactors, each of the volume of 80 m^3, will be necessary. The basic parameters of SBR reactors for the Popielno community are presented in table 2.

4. TECHNOLOGICAL SCHEME OF WASTEWATER TREATMENT

Technology of wastewater treatment in Popielno is based on the method of activated sludge with applying the SBR reactors. In order to assure high degree of phosphorus and suspended solids' removal, the phosphorus chemical precipitation and filtration through the DynaSand® filter will complete the biological process of wastewater treatment. The technological scheme of wastewater treatment plant is presented in figure 3.

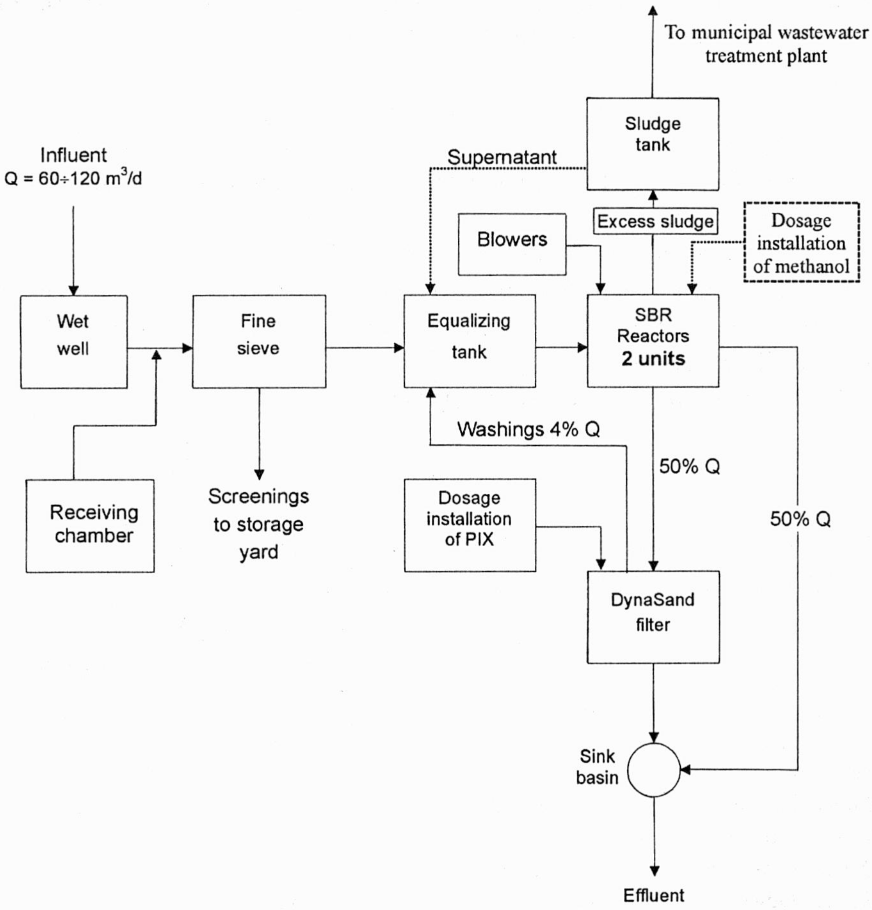

Fig. 3. Process scheme of the designed wastewater treatment plant

Wastewater incoming to the wastewater treatment plant will be introduced into a wet well and next into a fine sieve where it will be devoid of solids. After passing through a flowing part of the sieve (where solids are captured) screenings will be lifted to its upper part by means of a worm. A liquid extracted from screenings will pass through an outlet pipe to a channel, and the pressed and dewatered screenings will be transported to a special container. A worm sieve is designed to:

- separate mechanically solid pollutants;
- transport screenings;
- thicken and store screenings,
- protect the system against clogging.

A receiving chamber is installed in order to collect, control and record delivered wastewater. Such a solution enables us to identify suppliers, to measure the quantity of wastewater delivered by each supplier and to measure its total volume as well as to secure us against accidental discharges of wastewater by not authorised persons. The receiving chamber is equipped with an air-compressor, bar-code reader for quick identification of suppliers and a printer. It is also equipped with a pH, conductivity and temperature measurement unit. The construction of receiving chamber will enable us to close automatically an inlet valve in the case of exceeding amount of inflow wastewater. The receiving chamber will be placed in a building.

After collection wastewater will be supplied to an equalizing tank and pumped to 2 SBR reactors. In the reactors not only simultaneous sludge stabilization will take place, but also organic carbon, nitrogen and phosphorus removal that should be guaranteed by an appropriate sludge age, i.e. 25–28 days. The following phases of work cycle for SBR reactors are assumed:

- fill;
- fill with mixing (anaerobic conditions);
- aeration (aerobic conditions);
- mixing without aeration (anoxic conditions);
- aeration (aerobic conditions – re-aeration);
- settling;
- idle/waste.

SBR reactors do not require regular inspection and their maintenance is limited to periodic control of devices. The reactors will be specially covered in order to eliminate bioaerosols and odours harmful for environment and to reduce the negative impact of low temperature on the activated sludge biocenosis. The efficiency of biological processes occurring in activated sludge reactors heavily depends on temperature. Nitrification is especially sensitive to this factor, because it can be even completely inhibited in the case of significant drop in the temperature of inlet wastewater. The Popielno community is situated in the north-eastern part of Poland that is characterized, especially in the winter season, by the temperature lower than in other parts of the country. For that reason it is important to protect properly the SBR reactors as well as the tank equalizing inlet wastewater from the cold.

In order to enhance the rate of denitrification it is assumed to equip the designed wastewater treatment plant with an installation for dosing methanol into SBR reactors. The methanol-aided denitrification process would be applied if necessary.

The required degree of total phosphorus and suspended solid removal will be assured due to passing wastewater after the SBR reactors through the DynaSand® filter. About 50% of wastewater treated per day will be delivered onto the DynaSand® filter, the rest will by-pass the filter. The detailed proportion between filtered and not filtered wastewater will be fixed during the technological start-up of wastewater treatment plant. After collection of both streams wastewater will be discharged into Śniardwy Lake. It is possible to change the proportion of wastewater flowing onto the filter, but the maximum loading cannot exceed 15 $m^3 \cdot h^{-1}$. The filter can be effectively exploited if the concentration of suspended solids measured at the inlet is up to 100 $mg \cdot dm^{-3}$ or periodically higher, so it protects perfectly waters of the receiver against consequences of unexpected damages of biological reactors. Washings from the filter will be turned back to the biological reactors (3.5–4% Q_{av}). Phosphorus precipitation on the DynaSand® filter will make it possible to reduce the total phosphorus concentration in effluent to the level below 0.5 $mg \cdot dm^{-3}$.

An excess sludge from SBR reactors will be periodically withdrawn and directed to a sludge tank and next to a municipal wastewater treatment plant located anywhere within ten to twenty kilometres and being in possession of an owner of a sludge utilisation system. It is also possible to periodically use in situ this sludge at the Research Station of Ecological Agriculture of PAN (Polish Academy of Sciences) in Popielno after carrying out necessary microbiological tests and determining heavy metal contents and, of course, if local authorities give the Station their permission to utilize sludge. In such a case and in order to protect the plant against damages (e.g., periodically sludge disposal in municipal wastewater treatment plant is impossible), the DRAIMAD® system will be installed. In this system an excess sludge can be preliminary dewatered (significant volume reduction) and next safely stored in special bags for further dewatering. A supernatant from the sludge tank will be directed to the equalizing tank, which allows us to supply the SBR reactors with VFA (volatile fatty acids) in order to increase the denitrification rate.

The basic technological equipment such as SBR reactors and DynaSand® filter has its own independent control-measurement systems enabling us to control pumps, blowers, etc. Moreover, the following parameters will be measured:

- level of wastewater in equalizing tank;
- flow of treated wastewater at outlet.

The wastewater treatment plant will be equipped with a measuring point which allows the wastewater control in terms of NH_4, NO_2, NO_3, total P, pH, O_2, BOD_5, COD and suspended solid contents.

4.1. OPERATING SYSTEM OF SBR REACTORS

Seasonal fluctuations in wastewater inflow will be the main problem arising in the operating system of wastewater treatment plant in Popielno. It is assumed that the amount of wastewater can increase even two times in summer. For that reason two SBR reactors will be installed though for such a small wastewater treatment plant usually one reactor is sufficient. Two reactors enable a significant operation flexibility of biological purification system. Depending on the quantity of wastewater in summer and in other seasons, the operation of SBR reactors can proceed in two ways:

• In the summer season both reactors operate, and out of the summer season one reactor is sufficient;

• Two reactors also operate when activated sludge concentration is reduced to about 2.5 $kg \cdot m^{-3}$ and the reactor active volume is decreased to app. 126 m^3 by changing the maximum height of reactor filling.

The second way is more advantageous because the inactive reactor does not require to be restarted before a new summer season. In this case, it is sufficient, for some time, not to carry off an excess sludge (in order to increase its concentration) and to elevate the maximum height of reactor filling with wastewater. Moreover, an application of two reactors assures continuous biological wastewater treatment even if one reactor suffers a serious damage or in the case when it is necessary to shut down one reactor because of, e.g., routine repair.

5. SUMMARY

The technology of wastewater treatment proposed for the Popielno community is fully professional, highly efficient, safe and flexible. The presented solution can be very attractive when applied in such areas as landscape parks, where the quantities of discharged wastewater vary seasonally and daily and, at the same time, high quality of purified wastewater has to be guaranteed.

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OPRACOWANIE WYSOKOEFEKTYWNEJ METODY OCZYSZCZANIA ŚCIEKÓW NA TERENIE PARKÓW KRAJOBRAZOWYCH

Zaprezentowano technologię oczyszczania ścieków gwarantującą wysoki stopień usunięcia z nich węgla organicznego, azotu ogólnego, fosforu oraz zawiesiny. Technologia ta może być bardzo przydatna na takich obszarach, jak np. parki krajobrazowe, gdzie ilość ścieków ulega istotnym zmianom sezonowym i dziennym, a jednocześnie wymaga się, aby jakość oczyszczonych ścieków była wysoka. Pierwsza oczyszczalnia ścieków według przedstawionego rozwiązania jest budowana dla gminy Popielno zlokalizowanej na terenie parku krajobrazowego w obrębie Wielkich Jezior Mazurskich (Polska północno-wschodnia).

oczyszczanie ścieków, usuwanie węgla organicznego, usuwanie azotu, usuwanie fosforu, parki krajobrazowe