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ORIGINAL ARTICLE

Wastewater treatment in an integrated laboratory system

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Abstract

Integrated laboratory system consisted of three stages - activated sludge reactor, biofilter and subsurface vertical flow wetland was used to treat two types of wastewaters differed in their generation and pollution. Wastewaters from a pig farm as well as from a landfill site for domestic wastes were used in the experiments. The BOD/COD ratio of the wastewaters from a pig farm and from the landfill leachate was 0.5 and 0.07, respectively. In the first stage of the integrated system was achieved COD removal (48 % for the piggery wastewater for 3 days and 62.3 % for the landfill leachate after 4 days). BOD removal (55.6 %) for the piggery wastewater was achieved in 3 days and 24.9 % - for the landfill leachate after 4 days. The decreasing of organics at aerobic conditions was accompanied with the ammonium ions decreasing - 1.5 times for the piggery wastewater and 4 times for the leachate. In the second stage - biofilter without aeration, an additional organic loading decreasing was achieved. The COD decreased from 820.9 mg/dm^3 to 274.3 mg/dm^3 for piggery wastewater and for the leachate - from 869.5 mg/dm^3 to 423.6 mg/dm^3. The BOD values decreased from 384.1 mg/dm^3 to 106.8 mg/dm^3 for the piggery wastewater and for leachate - from 117.8 mg/dm^3 to 57.4 mg/dm^3. The ammonium ions were eliminated from both types of wastewaters. In the third stage (subsurface vertical flow wetland) the emission standards for discharge into the sewage collection systems or into the water bodies are met.

Keywords: piggery wastewater, landfill leachate, activated sludge reactor, biofilter, vertical-flow wetland

1. Introduction

The point source of pollution of the surface and groundwater, such as landfills and pig farms, can discharge wastewater if their quality is responsive to the emission standards for discharge into the sewage collection systems or into the water bodies. The high concentrations of chemical oxygen demand (COD), biochemical oxygen demand (BOD), ammonium nitrogen and odour are typical for this kind of wastewaters. The quality of the piggery wastewater varies depending on whether the solid fraction is preliminary separated prior to further treatment (Li et al. 2016). In comparison with landfill leachates, the piggery wastewaters contain high concentrations of easily biodegradable compounds. The composition of the landfill leachates is more complex. They also contain various toxic and nonbiodegradable compounds. The quality of the leachates varies during the landfill exploitation

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(Bhalla et al. 2013). The discharge of the piggery wastewater and landfill leachate into aquatic environment without preliminary treatment will cause serious eutrophication and other unfavourable effects (Melnyk et al. 2014, Yamamoto et al. 2008).

The main purpose for treatment of such kind of wastewaters is the nitrogenous compounds removal accompanied with a significant decrease of COD and BOD values. There are different biological (aerobic and anaerobic) methods for this kind of compounds removing (Jetten et al. 1999, Joo et al.2006, Kim et al. 2016, Lavrova and Koumanova 2007, Lavrova and Koumanova 2014, Limoli et al. 2016, Mojiri et al. 2016, Renou et al. 2008, Sheridan et al. 2002, Strous et al. 1997, Wang et al. 2016, Zhang et al. 2008). Air stripping of ammonia, coagulation, flocculation and precipitation for preliminary treatment of the wastewater are also used. These techniques require large capital investments, greater energy consumption, application of additional quantities of reagents, etc. (Wiszniowski et al. 2006). Other methods such as reverse osmosis and adsorption only convert pollutants and do not solve the environmental problem. Recently advanced oxidation methods like UV/H_2O_2, UV/O_3, UV/TiO_2 are used for mineralization of recalcitrant organics but they are not economically acceptable for large-scale application. A significant decrease of overall high organic loaded wastewater treatment cost could be obtained by the combination of different biological processes.

The aim of this study was to compare the treatment efficiency of integrated laboratory system, consisted of an aerobic activated sludge reactor, a biofilter and a reactor type subsurface vertical flow wetland for two types of wastewaters - piggery wastewater and landfill leachate.

2. Materials and Methods

2.1. Wastewater characteristics

Two different types of wastewater were used in the experiments – piggery wastewater and landfill leachate.

Piggery wastewater

The piggery wastewater was taken from a pig farm located in the south-western part of Bulgaria. After collection, the raw slurry was settled overnight because untreated effluent typically contains high concentrations of solids, organic matter, and nutrients. Table 1 summarizes the characteristics of the influent piggery wastewater.

Landfill leachate

The landfill leachate was taken from a 15 years old landfill situated in the north-western part of Bulgaria. The characteristics of the landfill leachate used in the experiments are presented in Table 2.

Tab. 1 Piggery wastewater characteristics.

Parameter	Value (mean ± SD)
COD (mg/dm^3)	2049 ± 40.9
BOD (mg/dm^3)	1037 ± 32.9
NH_4-N (mg/dm^3)	406 ± 22.4
NO_3-N (mg/dm^3)	0
pH	7.3 – 8.3

Tab. 2 Landfill leachate characteristics.

Parameter	Value (mean ± SD)
COD (mg/dm^3)	2867 ± 47.8
BOD (mg/dm^3)	207 ± 9.3
NH_4-N (mg/dm^3)	232 ± 40.6
NO_3-N (mg/dm^3)	1.6 ± 0.5
pH	7.5 – 8.1

The COD value in the piggery wastewater was significantly lower than that in the landfill leachate, while BOD value in the piggery wastewater was fivefold higher than that in the landfill leachate. The BOD/COD ratio of the piggery wastewater and of the landfill leachate was 0.5 and 0.07, respectively. Obviously, the easy biodegradable substances in the piggery wastewater are predominant in comparison with those in the landfill leachate. Typically piggery wastewater has extremely high concentration of the ammonium nitrogen, which is result of the animals' vital activity. In the wastewater used for the experiments the NH_4-N concentration was 406 ± 22.4 mg/dm^3. In the landfill leachate their concentration was almost twice lower (232 ± 40.6 mg/dm^3) because of the landfill age. It is well known that with the development of the operational period of the landfill, the NH_4-N concentration is decreasing. It is also believed that ammonia is mainly released during the organic matter decomposition (Burton and Watson-Craik 1998). Thus ammonia appears to be a good indicator for organic nitrogen in the leachate (Lee et al. 2010). The piggery wastewater has not contained nitrate nitrogen because it was taken soon after its generation and without preliminary treatment. Because of oxidation of ammonium ions in the reservoir, where it was collected for a longer period of time, the landfill leachate contained nitrate nitrogen. The pH of the piggery wastewater and the landfill leachate was without significant difference.

2.2. Integrated laboratory system

The integrated laboratory system used in the experiments is shown in Fig. 1. It is consisted of three main treatment units – an activated sludge reactor, a biofilter and a reactor type subsurface vertical-flow wetland. The laboratory reactors were made of Plexiglas.

Activated sludge reactor (ASR). The dimensions of the activated sludge reactor are 195 mm in diameter and 650 mm in height. The air was blown into the system through three diffusers, situated at the bottom of the ASR. The aerobic activated sludge (AS) was taken from a municipal wastewater treatment plant.

Biofilter

The dimensions of the biofilter are 123 mm in diameter and 900 mm in height. It was filled with 800 mm layer of 7 ÷ 15 mm round gravel.

Constructed wetland

The reactor type subsurface vertical-flow wetland (SVFW) was planted with *Phragmites australis* and its dimensions are 123 mm in diameter and 900 mm in height. The reactor column was filled with 300 mm height bottom layer of 35 ÷ 55 mm round gravel and top layer with a height of 500 mm of 5 ÷ 25 mm gravel thus providing a media porosity of 31.5 %.

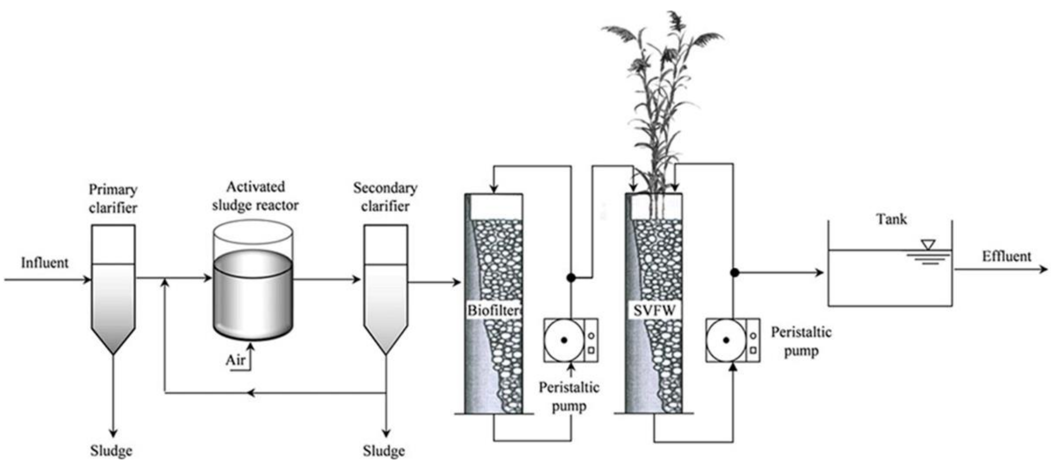

Fig. 1 Flow diagramme of the lab-scale integrated system.

2.3. Analytical methods and chemicals

The parameters Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Ammonium Nitrogen [NH_4-N] and Nitrate Nitrogen [NO_3-N] were determined by standard methods, using pure reagents for analysis (American Public Health Association et al. 1992).

2.4. Treatment of wastewater by integrated laboratory system

First stage

After sedimentation in the primary sedimentation tank the wastewater flows into activated sludge reactor, using volume ratio of mixed liquid "activated sludge : wastewater" (AS:PS) = 1:1. The air was blown into the system through three diffusers, situated at the bottom of the ASR. Water samples were taken for determination of the COD, BOD, NH_4-N and NO_3-N values. After some decreasing of the initial values of the analyzed physicochemical parameters, wastewater flows into secondary sedimentation tank for clarifying.

Second stage

After clarifying the wastewater flows into the biofilter without aeration. Peristaltic pump ensures the water movement through the reactor with flow rate 45 cm^3/min. The system operated continuously in recirculation regime. The recirculation was performed at ratio of 1:2, giving 1 h water movement through the filter media and 2 h resting period of the water into the reactor (contact between the wastewater and the bed matrix). Water samples were taken daily for determination of the COD, BOD, NH_4-N and NO_3-N values. After reaching half COD decreasing, the wastewater flows into the next reactor.

Third stage

Young *Phragmites australis*, obtained from comparatively clean area, was planted in the reactor type subsurface vertical-flow wetland (SVFW). The SVFW operated continuously in recirculation regime too. The recirculation was performed at ratio of 1:2, giving 1 h water movement through the filter media and 2 h resting period of the water in the reactor (contact between the wastewater and the bed matrix). The flow rate of the system was 45 cm^3/min and hydraulic loading was 0.38 cm^3/cm.min. Effluent samples were taken daily for analyses of the COD, BOD, NH_4-N and NO_3-N.

2.5. Removal efficiency

The removal efficiency was determined using the formula Eq. 1:

$$R = 100 - \left(\frac{C_t}{C_O}\right) * 100 \qquad (\%) \qquad \textit{Eq. 1}$$

where C_t is the concentration at time t and C_o is the initial concentration in mg/dm^3.

3. Results and discussion

Figure 2 shows the variation of the analysed parameters (COD, BOD, NH4-N and NO3-N), characterizing the wastewater quality during the experiments with piggery wastewater and landfill leachate. The piggery wastewater was treated in each stage as follows: 2 days in the activated sludge reactor, 3 days in the biofilter and 4 days in the subsurface vertical-flow wetland. The landfill leachate was treated in each stage as follows: 3 days in the activated sludge reactor, 5 days in the biofilter and 7 days in the subsurface vertical-flow wetland. The reason was to obtain gradual reduction of the initial concentrations of the parameters of interest.

The BOD/COD ratio is an indicator of the proportion of biochemically degradable organic matter to total organic matter (Lee and Nikraz 2014). This ratio of the piggery wastewater and the landfill leachate was 0.5 and 0.07, respectively. As a whole the pH values are closed to neutral zone which is important for the nitrifying bacteria.

3.1. Piggery wastewater treatment

Significant removal efficiency was achieved in the aerobic activated sludge reactor during the 2 days treatment of piggery wastewater. The COD and BOD values decreased with 48 % and 55.6 %, respectively. The organics reduction in aerobic conditions was accompanied with the ammonium ions concentration decreasing (77.8 %) as well as their nitrification to nitrates. Significant increasing of the NO_3-N concentration in this treatment stage was observed due to the intensive aeration in activated sludge reactor. Then the water flows to the bioreactor for three-day treatment.

During this period of time the COD concentration of the piggery wastewater decreased 3.9 times and high removal efficiency (86.6 %) was achieved with respect to the initial COD of the raw piggery wastewater. BOD values decreased 4.3 times and removal efficiency of 89.7 % with respect to its initial concentration of the raw wastewater was achieved.

Less pronounced reduction of ammonium ion in the biofilter was observed. The concentration of NH_4-N decreased 1.5 times. The nitrates concentration was reduced from 8.9 mg/dm^3 to 7.3 mg/dm^3. No significant denitrification was observed probably because the developed anoxic conditions in the biofilter are not sufficient in this case. Obviously, the addition of carbon source will be needed. The third stage of the integrated laboratory system is a subsurface vertical-flow wetland (SVFW) which was used for the wastewater polishing. There the COD values of the piggery wastewater decreased 3.6 times after 4 days of treatment. It was achieved 96.3 % COD removal efficiency and 97.6 % BOD removal efficiency with respect to the initial COD and BOD. Total elimination of ammonium ions from the piggery wastewater was achieved in the subsurface vertical-flow wetland for 3 days, but the total denitrification was not achieved.

3.2. Landfill leachate treatment

During the 3 days treatment of the landfill leachate in the activated sludge reactor the removal efficiency was 62.3 % for COD and 24.9 % for BOD, respectively. This minor efficiency according to BOD is probably due to the lower BOD/COD ratio (0.07) of the landfill leachate. Presumably the non-biodegradable substances are those that inhibit the aerobic microorganisms' activity which leads to the lower treatment efficiency. The NH_4-N concentration decreased with 73.3 %, which was accompanied with sharply increasing of the nitrate concentration. The initial NO_3-N concentration in the landfill leachate was 1.6 ± 0.5 mg/dm^3 and for three days of oxidation their concentration increased up to 7.9 mg/dm^3. After initial reduction of the leachate pollution in the aerobic reactor, it enters the biofilter for further treatment, where the COD decreased 2.6 times for 5 days, and high removal efficiency of 85 % was achieved with respect to the initial COD. The treatment of the landfill leachate in the biofilter leads to 2.7 times BOD deceasing and 71.9 % removal efficiency with respect to the initial BOD of the raw landfill leachate. Less pronounced reduction of ammonium ion, contained in the landfill leachate, in the biofilter was also observed. The concentration of the NH_4-N decreased 1.5 times also and in parallel with this was observed minimal nitrates reduction from 9.4 mg/dm^3 to 7.5 mg/dm^3. In the final stage of the integrated laboratory system – SVFW, the COD of the landfill leachate decreased 5.7 times after 7 days of treatment. It was achieved 97.4 % removal efficiency with respect to the initial COD of the raw landfill leachate. 88.5 % BOD removal efficiency was achieved in the SVFW for 4 days.

Total elimination of ammonium ions from the piggery wastewater and the landfill leachate was achieved in the subsurface vertical-flow wetland for 7 days. In the SVFW total denitrification was not achieved.

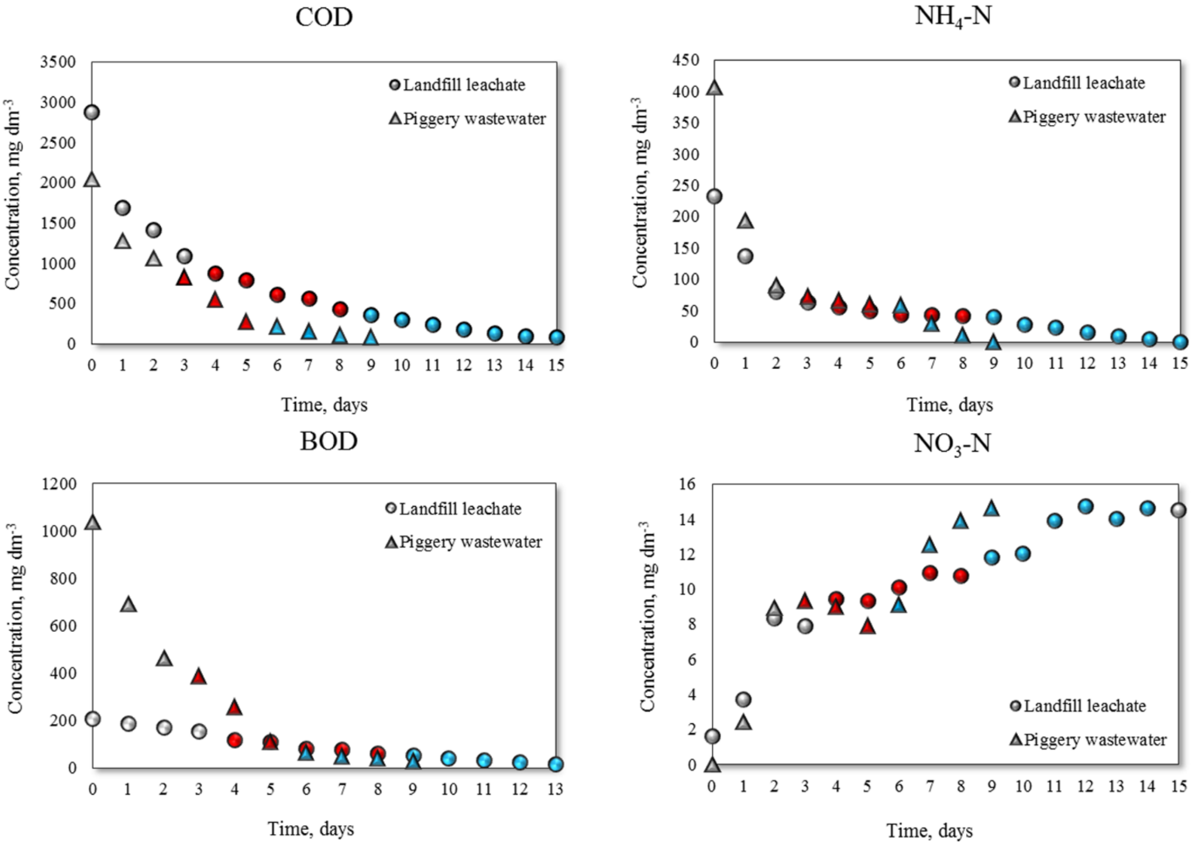

Fig. 2 Variation of COD, BOD, NH$_4$-N and NO$_3$-N.

As a whole, the treatment process of the piggery wastewater became faster than that of the landfill leachate. In a period of 9 and 15 days for piggery wastewater treatment and landfill leachate, respectively, were achieved the COD required limits according to the national legislation. The limits for BOD were reached during the wastewater treatment in the SVFW - of the 9th and 12th day for piggery wastewater and landfill leachate, respectively. The results show that the elimination of the ammonium ions, contained in the piggery wastewater, becomes easier than that in the landfill leachate although their higher initial concentration. This effect is probably due to the higher concentration of organics in the piggery wastewater (BOD/COD = 0.5). Total elimination of the NH$_4$-N contained in the piggery wastewater became for a nine days and in the landfill leachate – for fifteen days. In the SVFW denitrification was not achieved due to the greater depth of the *Phragmites australis* root system. It is well known, that the plant roots released oxygen in the rhizosphere, which makes the denitrification process impossible.

4. Conclusions

Integrated laboratory system was studied for treatment of two types of wastewater, differed in their generation and pollution - piggery wastewater and landfill leachate.

It was established that for both wastewaters studied the values of the characteristics of interest are significantly decreased accompanied with odour elimination.

Significantly higher value of the BOD/COD ratio in the piggery wastewater determines the more easily and faster purification of this type of water in the integrated laboratory system in comparison with the landfill leachate.

Complete nitrification of the NH_4-N was achieved while a negligible elimination of NO_3-N in biofilter was observed. In order to achieve total elimination of NO_3-N it will be useful to add carbon source to the biofilter as well as to use a vegetation with a shallow root system and a larger area of the subsurface vertical flow wetland system, to prevent the penetration of the roots to a greater depth.

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