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POLISHING OF AEROBICALLY TREATED WASTEWATER IN A CONSTRUCTED WETLAND SYSTEM

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ABSTRACT

The intensive human activity significantly increases the emission of biogenous substances, which cause the eutrofication of the natural aquatic systems. The situation can not be improved in hypertrophic watercourses without radical activities in the prime source of the pollution. The wastewater from confined animal operations, milkhouse wastewater, sewage, surface runoff, silage and landfill leachate, mine drainage, etc., have to be compulsory purifying from the organic pollutants before their discharging in the water reservoirs.

The aim of this study is to investigate the aerobic purification followed by polishing in a constructed vertical flow wetland system of piggery wastewater. The water samples have been examined by physicochemical analysis to determine their characteristics: Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD_5), Ammonium Nitrogen (NH_4^+ - N), Nitrate Nitrogen (NO_3^- - N), pH, etc. It was established the significant COD, BOD_5 and (NH_4^+ - N) removal in in the activated sludge reactor and (NO_3^- - N) in the vertical flow constructed wetland system.

Keywords: *piggery wastewater, activated sludge process, vertical flow constructed wetland, Phragmites australis.*

INTRODUCTION

The intensive human activity significantly increases the emissions of biogenous substances, which cause the eutrofication of the natural aquatic systems. As a result the water transparency is reduced, the production of organic substances increases, the sedimentation increases, the oxygen concentration decreases, the composition of species changes (perennial algae are replaced by annuals, such as blue-green algae and green algae, the composition of benthic species is depleted, the food base for fish changes and correspondingly so does the composition of fish species), and rapid choking of water courses with vegetation takes place. The situation will not be improved in hypertrophic watercourses without radical activities in the prime source of the pollution. The wastewater from confined animal operations, milkhouse wastewater, sewage, surface runoff, silage and landfill leachate, mine drainage, etc., have to be compulsory purifying from the organic pollutants before their discharging in the water reservoirs.

Wastewater treatment falls into three main categories: primary treatment (e.g. removal of floating and settleable solids); secondary treatment (e.g. removal of most organic matter); and tertiary treatment (e.g. removal of nutrients, suspended solids, etc.) [1].

The objective of the primary treatment is the reduction of suspended solids and biochemical oxygen demand (BOD_5) loads to subsequent unit processes.

The objective of the secondary treatment is the reduction of BOD_5 through the removal of organic matter, primarily in the form of soluble organic compounds, remaining after primary treatment. Biological treatment involves the use of microorganisms to remove dissolved nutrients from a discharge [2]. Aerobic wastewater treatment processes can be broadly divided into suspended and attached growth processes. Activated sludge process like conventional, extended aeration, oxidation ditches, and sequencing batch reactors (SBRs) are examples of suspended growth processes; trickling filters and rotating biological contactors (RBCs) are examples of attached growth processes. The microorganisms involved in aerobic treatment process require free dissolved oxygen to reduce the biomass in the wastewater [3]. The activated sludge process is capable of 95 % reduction of BOD_5 and suspended solids [4]. In addition, reductions in ammonia nitrogen in excess of 95 % are possible at temperatures above 10°C and dissolved oxygen concentrations above 2 mg dm^{-3} [5]. Advantages of using aerobic wastewater treatment processes include low odour production, fast biological growth rate, no elevated operation temperature requirements and quick adjustments to temperature and loading rate changes.

Tertiary wastewater treatment can have one or several objectives. One common objective is further reduction in suspended solids concentration after secondary clarification. Nitrogen and phosphorus removal also are common tertiary wastewater treatment objectives. Tertiary wastewater treatment may be used to remove soluble refractory, toxic, and dissolved inorganic substances. One of the used systems for tertiary wastewater treatment is the constructed wetland. The treatment processes of constructed wetlands are based on ecological systems found in natural wetlands [6]. There are various types of those systems. Vertical flow constructed wetlands (vegetated submerged beds) possess greater oxygen transport ability than horizontal flow systems. They are more effective for the removal of organic matter and ammonia-nitrogen from wastewaters through aerobic microbial activities [7-9]. That subsurface flow constructed wetlands act as fixed-film bioreactors [10]. The wetland systems are filled with different media types typically planted with the same species of emergent vegetation present in the marshes. Kadlec and Knight [11] listed 37 families of vascular plants that have been used in water quality treatment. The primary role of vegetation in a wetland treatment system is to recycle nutrients in the waste into a harvestable crop, but vegetation plays a distinct role in each treatment process. The vegetation is the support media for biological activity as well as for erosion protection. It can play a role in stabilization of the soil matrix and can maintain long-term infiltration rates. The vegetation is facilitator of nitrification/denitrification [12].

Dairy wastes and animal wastewaters may cause severe environmental pollution due to their high organic and nutrient concentrations. Discharging these wastes to conventional wastewater treatment facilities may cause serious overloading problems. Raw, untreated effluent typically contains concentrations of solids, organic matter, and nutrients high enough to kill most wetland plants. Wastewater from all confined animal feeding operations must be treated before it is discharged to a constructed wetland to protect the plant community. Green et al. [13] took the row manure which diluted with water to enable the separation of the suspended solids and to reduce the COD and BOD concentrations and after that the wastewater flew into reactor with gravel medium and passive aeration without vegetation. Preliminary their experiments showed that feeding the reactor with COD concentration higher than about 5000 mg dm^{-1} caused the formation of foam which hampered reactor operation. They achieved 67 % COD and 47 % BOD reduction. Felde and Kunst [14] investigated COD degradation and N-conversion within unplanted vertical flow system. They took sewage from a farm multicompartment septic tank and intermittently brought onto the columns. In general a sufficient oxygen supply in vertical flow bed leads to 90 % COD and NH_4^+ decreasing. To increase the purification capacity some scientists use an effluent recirculation [15-17]. They investigate strong agricultural wastewater, preliminary settled and diluted with tap water, which passes through vegetated with ***Phragmites australis*** four-stage reed bed system and final effluent recirculation at ratio 1:1. The values of COD, BOD and NH_4^+ were decreased by 77 %, 78 % and 62 %, respectively.

In the aim of the present paper is to investigate two stage process for the piggery wastewater purification. The first stage consists in biodegradation in an activated sludge bioreactor and the second stage – polishing in the vertical flow constructed wetland system planted with ***Phragmites australis***.

EXPERIMENTAL

The treatment system consisted of a primary sedimentation tank, activated sludge reactor, secondary clarifier and constructed vertical flow wetland system (Fig. 1).

Both the activated sludge reactor (ASR) and the constructed wetland (CW) were made of Plexiglas. ASR of 195 mm i.d. and 650 mm in height was used. The air was introduced into the system through three diffusers, situated on the bottom of the ASR. The aerobic activated sludge (AS) was taken from a municipal wastewater treatment plant.

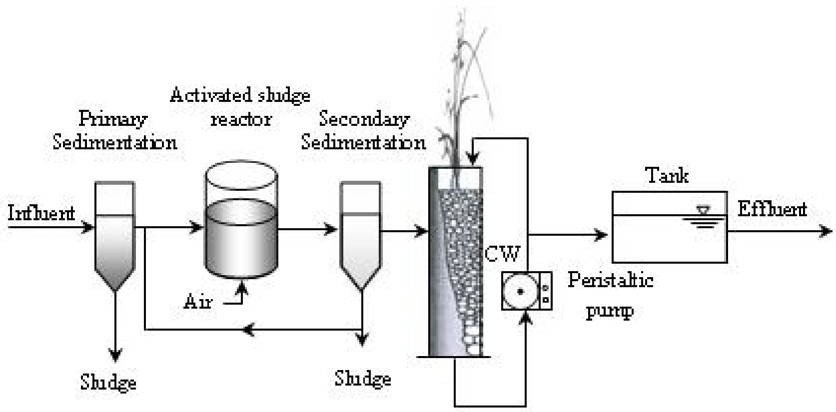

Fig. 1. Flow diagramme of the wastewater treatment system.

CW was a cylinder with dimensions 123 mm i.d. and 900 mm in height. The CW column was filled with round gravel divided into two layers: the bottom layer consisted of 35-55 mm fraction (300 mm height); and the top layer of 5-25 mm gravel (500 mm height). Young ***Phragmites australis***, obtained from comparatively clean area, was planted in the top layer of the CW. The CW was operated continuously in recirculation regime. The recirculation was employed at ratio of 1:1, giving CW 1 h of wastewater – bed matrix contact and 1 h of effluent recirculation. The flow rate of the system was 82 cm^3 min^{-1}.

Wastewater was taken from a pig farm located in south-western part of Bulgaria. After collection, the raw slurry was allowed to settle overnight and then the supernatant was treated. Table 1 summarizes the characteristics of the influent piggery slurry.

The aerobic process has been carried out using two volume ratios of activated sludge : piggery wastewater (AS : WW = 1 : 1 and AS : WW = 1 : 1,5). After the treatment in the activated sludge reactor the piggery wastewater flows into the secondary sedimentation tank to clarify and after that flows into the constructed wetland system.

Table 1. Characteristics of the influent piggery slurry.

Parameter	Influent
COD, mg dm^{-3}	1041,6
BOD_5, mg dm^{-3}	192
Ammonical-nitrogen, (NH_4^+- N), mg dm^{-3}	34,6
Nitrate-nitrogen, (NO_3^-- N), mg dm^{-3}	0
pH	6,3

The water samples were taken every day till the elimination of the (NH_4^+- N). The water samples have been examined for pH, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD_5), Ammonium Nitrogen (NH_4^+ - N), Nitrate Nitrogen (NO_3^- - N) [18].

RESULTS AND DISCUSSION

Activated sludge process

Fig. 2 to Fig. 6 illustrate the comparison of the water characteristics for both influents studied (AS:WW = 1:1 and AS:WW = 1:1,5).

As shown on Figs. 2 and 3 the COD and BOD_5 values of the wastewater in the first case (AS:WW = 1:1) decrease without significant diversions in comparison with those of wastewater in the second case (AS:WW = 1:1,5), where the organic loading of the system is higher. Nevertheless there are not significant gaps between curves because of the slight difference of the influents loading. In general, considerable removal of COD and BOD_5 was achieved in both cases. The percentage removal of COD and BOD_5 is 84 % and 90 %, respectively for AS:WW = 1:1 and 83 % and 93 %, respectively, for AS:WW = 1:1,5. In the second case the percentage removal of BOD_5 is greater because of the longer process duration. Decreases of the COD and BOD_5 values are steepening during the first twenty-four hours. The reduction of COD and BOD_5 for AS:WW = 1:1 is about 50 % and 42%, respectively, and that of COD and BOD_5 is 50 % and 35 % for AS:WW = 1:1,5, respectively. In that time easier chemically oxidizable organic matter and biodegradable organic matter undergoes changes under the influence of the microbial activity.

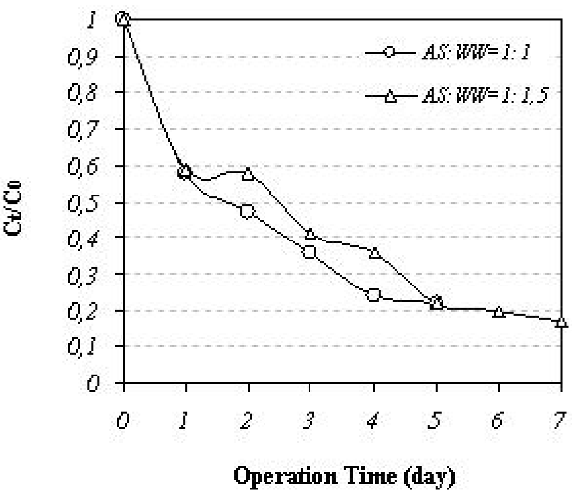

Fig. 2. Variation of COD during the activated sludge process in both cases.

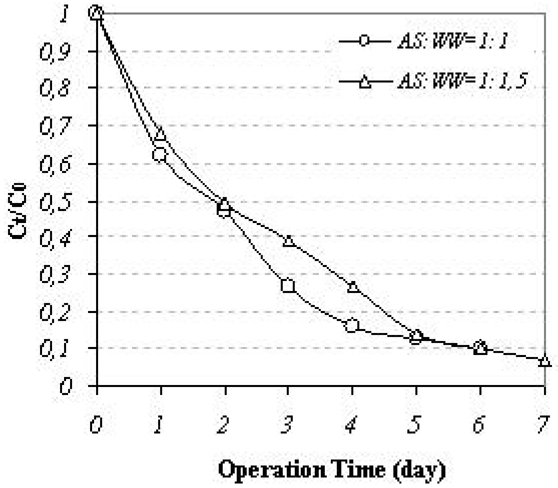

Fig. 3. Variation of BOD_5 during the activated sludge process in both cases.

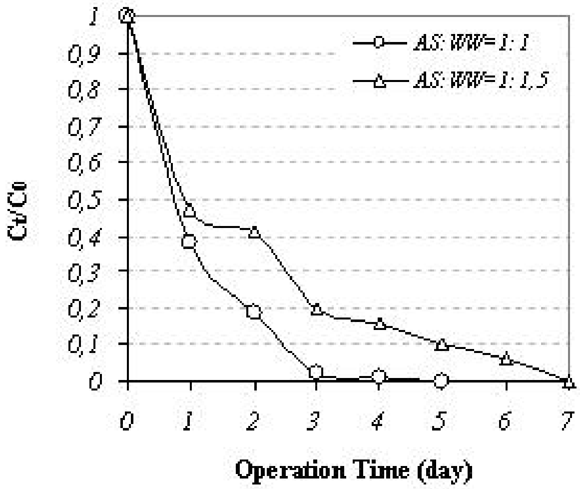

Fig. 4. Variation of NH_4^+-N during the activated sludge process in both cases.

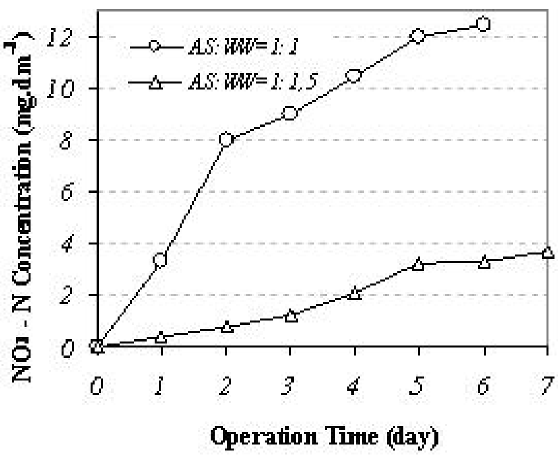

Fig. 5. Variation of NO_3^--N during the activated sludge process in both cases.

The values of (NH_4^+-N) and (NO_3^--N) are shown in Figs. 4 and 5. Completely elimination of (NH_4^+-N) was achieved during the both cases studied. The decreasing of the (NH_4^+-N) values are steepening during the first twenty-four hours like that of COD and BOD_5 where the reduction is about 62 % for AS:WW = 1:1 and 53 % for AS:WW = 1:1,5. In the first case (AS:WW = 1:1) (NH_4^+-N) elimination was attained for five days, in the second case (AS:WW = 1:1,5) - for seven days. Slower reduction of ammonium-nitrogen in the second case is a result of the comparatively higher organic loading of the system. Ammonia in treated wastewater undergoes volatilization and biological oxidation (nitrification). The nitrification is chemoautotrophic process. The nitrifying bacteria derive energy from the ammonia oxidation and carbon dioxide is used as a carbon source for synthesis of new cells. These organisms require O_2 during the ammonium-nitrogen oxidation to nitrate [19]. In the end of the experiment was established that the final volume of the activated sludge increased 1,4 times compared to the initial volume. As a result of the nitrification the levels of the (NO_3^-- N) increases from 0 to 12,5 mg dm^{-3} for the first case study (AS:WW = 1:1) and from 0 to 3,7 mg dm^{-3} for the second case study (AS:WW = 1:1,5).

As a whole the pH values are close to neutral zone which is important for the nitrifying bacteria (Fig. 6). A reduction of the total alkalinity may accompany the nitrification because of the significant amount of bicarbonate consumption during the conversion of ammonia to nitrite and synthesis of new cells.

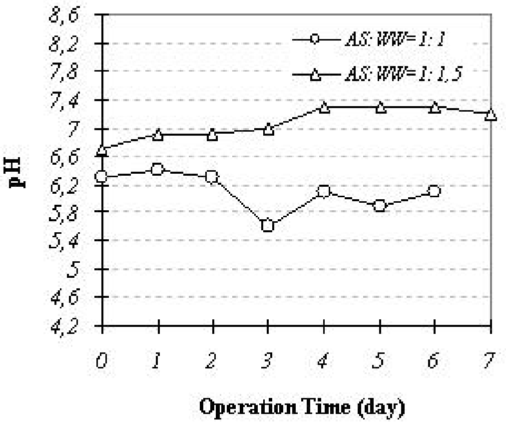

Fig. 6. Variation of pH during the activated sludge process in both cases.

Constructed wetland system

After the decreasing of the initial concentrations of the raw piggery wastewater in the ASR and the conversion of (NH_4^+-N) into (NO_3^--N), a portion of treated wastewater was introduced in the constructed wetland system for denitrification (Fig. 1). The characteristics of the influent to the constructed vertical flow wetland system are given in Table 2.

The process continues only two days, because of the faster elimination of the (NH_4^+-N) and (NO_3^--N) due to the denitrification and the consumption of the (NO_3^-- N) from the growing plants in the system. Fig. 7 illustrates the changes in the parameters COD and BOD_5. The COD and BOD_5 values were decreasing faster during the first twenty-four hours similarly as into the bioreactor. COD was decreased by 78 % and BOD_5 - by 82 %. The final levels of COD and BOD_5 are almost the same like those obtained in the activated sludge reactor.

The (NH_4^+-N) concentrations are decreasing faster in comparison with those of the (NO_3^-- N) during the first day (Fig. 8). Total (NH_4^+-N) and (NO_3^-- N) elimination was achieved because of several processes like nitrification, denitrification, volatilization and plants uptake. Rooted wetland macrophytes actively transport oxygen from the atmosphere to the media. Some oxygen leaks from the root hairs into the rhizosphere, supporting aerobic and facultative anaerobic microorganisms in the otherwise anaerobic media. Facultative anaerobic microorganisms are those that usually respire aerobically but can grow under anaerobic conditions [20]. In these conditions occurs the denitrification.

During the photosynthesis, plants consume carbon dioxide and release oxygen. Submerged aquatic plants growing within the water column raise the dissolved oxygen level in the wetland water and deplete the dissolved carbon dioxide, resulting in an increased pH [20].

Table 2. Characteristics of the treated piggery slurry flowed in the constructed vertical flow wetland system.

Parameters	Values
COD, mg dm^{-3}	487,86
BOD_5, mg dm^{-3}	91
Ammonical-nitrogen, (NH_4^+-N) , mg dm^{-3}	44,5
Nitrate-nitrogen, (NO_3^--N), mg dm^{-3}	8
pH	6,3

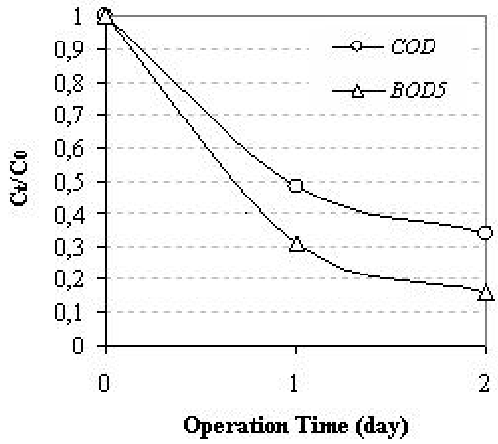

Fig. 7. Variation of COD and BOD_5 in the constructed wetland system.

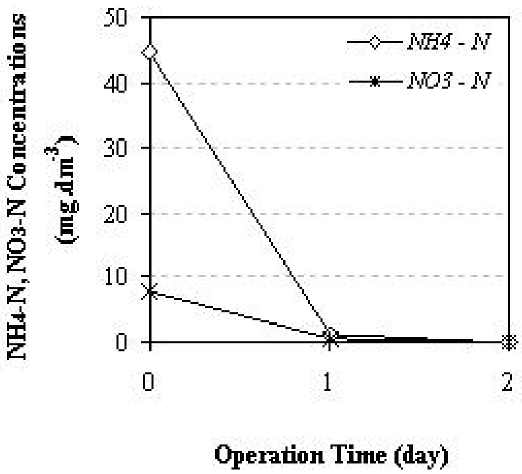

Fig. 8. Variation of NH_4^+-N and NO_3^-- N in the constructed wetland system.

CONCLUSIONS

Constructed vertical flow wetland system was studied for polishing of aerobically treated piggery wastewater. It was established that the values of the treated water characteristics are significantly decreased for comparatively short time accompanied with odour elimination.

Significant COD and BOD_5 decreasing was attained in both cases during the aerobic treatment of the piggery wastewater. (NH_4^+-N) was completely eliminated during the aerobic treatment because of the conversion into (NO_3^-- N). The elimination of (NO_3^-- N) in the constructed vertical flow wetland system was achieved due to the denitrification.

The investigations of the processes occurring in the constructed wetland system are useful because they imitate the processes occurring in the natural wetlands.

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