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Teatment of Work Camp Wastewater Using a Sequencing Batch Reactor Followed by a Sand Filter

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Abstract: Work camps, have to be established quickly, are a transient nature and located in environmentally sensitive areas. Wastewater treatment systems located in the work camps often perform poorly. In response to these deficiencies and the need to provide for reliable, cost effective, high efficiency wastewater treatment, the research team designed a sequence batch reactor (SBR)/ sand filter system that is simple, compact, robust, easy to operate and produces a high quality effluent. The SBR/sand filter system is operated with varying organic loading rates and process performance is assessed by monitoring COD, BOD_5, pH, volatile suspended solids, suspended solids and nitrate during the cycle operation. The process described, is a flexible, biologic, suspended growth system that can be operated in the conventional activated sludge or extended aeration mode.

Key words: Wastewater treatment, sequencing batch reactor, nutrient removal, work camp, sand filter

INTRODUCTION

The design and operation of small wastewater treatment plants are a challenge to wastewater engineers. Conventional suspended growth activated sludge processes, which have been used successfully and widely to treat municipal wastewater during the last hundred years, are not always suitable for treating small wastewater flows[1]. Factors that should be taken into account when designing small wastewater treatment plants include land requirement, construction cost, operation cost, maintenance and landscape[2]. Therefore, the facilities for small wastewater treatment have to be not only environmentally sound but also human friendly. In this study, a pilot-scale system designed for small wastewater flows was constructed and studied. The system comprised a SBR and a sand filter. Sequencing batch reactor technology has been developed on the basic scientific assumption that periodic exposure of the microorganisms to defined process conditions is effectively achieved in a fed batch system in which exposure time, frequency of exposure and amplitude of the respective concentration can be set independently of any inflow condition[3-7]. SBR technology differs in various ways from conventional technologies used in biological treatment of wastewater. The most obvious difference is that the reactor volume varies with time, whereas it remains constant in the traditional continuous flow system. From the process engineering point of view, the SBR system is distinguished by the enforcement of controlled short term unsteady state conditions leading in the long run to a stable steady state with respect to composition and metabolic properties of the microbial population growing in the reactor by controlling the distribution and physiological state of the microorganisms. The success of SBR technology depends upon the great potential provided by the possibilities of influencing the microbial system in the SBR and also upon the fact that SBRs are comparatively easy to operate and are cost efficient[8,9]. The SBR processes are known to save more than 60% of expenses required for conventional activated sludge process in operating cost. Interest has been growing worldwide both in scientific research and in practical application of SBR technology. The system with various reactor configurations for nutrient removal have been studied extensively [10-12]. In the other hand, recent attention has focused on the use of sand filters for tertiary wastewater treatment[13]. The sand filter was operated in wastewater and drinking water treatment for removal of carbon, pathogenic bacteria, protozoan parasite and suspended solids. Sand filtration is a simple to operate, low cost, efficient and reliable technique and used successfully to remove microorganisms in drinking water since 1900. Sand

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filters work through the formation of a gelatinous layer or biofilm called the hypogeal layer in the top few millimeters of the fine sand layer. This layer consists of bacteria, fungi, protozoa, rotifera and a range of aquatic insect larvae. The biofilm is the layer that provides the effective purification in potable water treatment, the underlying sand providing the support medium for this biological treatment layer. As water passes through the biofilm, particles of foreign matter are trapped in the matrix and dissolved organic material is adsorbed, absorbed and metabolised by the bacteria, fungi and protozoa. The water produced from a sand filter can be of exceptionally good quality with no detectable bacterial content. Sand filters slowly lose their performance as the biofilm grows and thereby reduces the rate of flow through the filter. Eventually it is necessary to refurbish the filter. Two methods are commonly used to do this. In the first, the top few millimeters of fine sand is very carefully scraped off using mechanical plant and this exposes a new layer of clean sand. Water is then decanted back into the filter and recirculated for a few h to allow a new biofilm to develop. The filter is then filled to full depth and brought back into service. The second method, sometimes called wet method, involves lowering the water level to just above the biofilm, stirring the sand and thereby suspending any solids held in that layer and then running the water to waste. The filter is then filled to full depth and brought back into service. Wet method can allow the filter to be brought back into service more quickly[14-17]. In this study, a sand filter was used to remove bacteria and suspended solids from the effluent from the SBR unit before it was allowed to percolate into the environment. The objectives of this research were to test the performance of the combined SBR and sand filter system in work camp wastewater treatment.

MATERIALS AND METHODS

Influent characteristics: There was a need to establish that the characteristics of the influent wastewater used in this study were similar to the effluent from a work camp. Table 1 shows the wastewater characteristics. A set of experiments were carried out, using the same operational conditions of work camps. pH, temperature and DO of the nutrient medium were continuously monitored.

SBR configuration: A cylindirical aeration tank with a total volume of 20 l was used throughout the study. The wastewater was collected in feed tank and was pumped

Table 1: Physico-chemical characteristics of wastewater

Parameter	Concentration
pH	7.5-8.2
Alkalinity (mg L^{-1} as CaCO3)	230-300
SS (mg L^{-1})	300-450
VSS (mg L^{-1})	240-382
BOD (mg L^{-1})	200-300
COD (mg L^{-1})	350-450
COD:N:P ratio	100:10:1
NO3-N	45-65
Sulphate (mg L^{-1})	60-100

Table 2: Cycle period and phase details of SBR

Phase	Cycle period	Air supply	Condition
Filling (h)	1	Off	Anoxic
Reaction with recirculation (h)	18	On	Aerobic
Settling (h)	4	Off	Anoxic
Withdrawal (h)	1	Off	Anoxic

in the reactor. The contents of reactor was aerated vigorously by using an air pump and diffusers to keep dissolved oxygen (DO) concentration above 2 mg L^{-1} in the oxic phase. The initial volume of the culture in the tank was 3l which was completed to 15l with the addition of wastewater at the beginning of each cycle. The reactor was operated in suspended growth configuration in sequencing batch mode at a constant temperature of 20±2°C. The total cycle period of 12 h consisting of 60 min of filling phase, 18 h of reaction (aerobic) phase with recycling, 4 h of settling phase and 60 min of withdrawal phase was employed throughout (Table 2). During the anaerobic phase, in order to avoid oxygen transfer through the surface, mixing was achieved with a recirculation pump. Aeration was provided with a diffuser. Sludge was wasted during every cycle from the mixed liquor min before the settling phase. The sequence of the SBR operation was controlled by pre-programmed timers (feeding, aeration, recycling and withdrawal). At the beginning of each cycle, immediately after withdrawal (earlier sequence), a pre-defined feed volume was pumped into the system and the reactor volume was recirculated with aeration during the reaction phase. At the end of the cycle, suspended biomass (VSS) settled and effluent was withdrawn from the reactor. When the system was considered stable under the different organic loading rates, samples were taken every 4 h for analyses. The following temperatures were tested: 10, 15, 20, 25 and 30°C to determine the effect of this parameter on wastewater treatment. Temperature was maintained at the desired level by means of a thermostatic system. Recirculation was maintained throughout the investigation to achieve a homogeneous distribution of substrate as well as uniform distribution of suspended biomass along the reactor depth. Recirculation also facilitates linear velocity, which restricts the existence of a concentration gradient during the reaction phase of the SBR operation. The reactor can be considered as completely mixed during the reaction phase of the sequence. The SBR was inoculated with biomass (aerobic) acquired from an operating laboratory scale activated sludge process unit, which had been operated continuously for long time. The mixed liquor from the aerobic chamber was acquired and was fed to the SBR reactor at a ratio of 1:5 with reactor volume as inoculum.

Sand filter unit: The sand filter experimental set up consisted of a cylindrical plexiglass biological reactor, with 50 cm of inner diameter and 100 cm of hight, completely submerged and operating in down flow mode. The filter was equipped with the effluent of SBR. When the pressure drop exceeds the maximum available of water layer of the sand filter, the upper layer of the sand was scrapped out. The sand was washed several times to remove impurities before packing the filter. The outer surfaces of the containers and tubes were wrapped with aluminum foil to prevent algal growth. A peristaltic pump was used to transfer the synthetic medium solutions to the sand filter. Transfer tubes were washed with acidic solution weekly to prevent microbial growth.

Analytical methods: Samples were withdrawn from the different times of each treatment period. Analyses of chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), alkalinity, total nitrogen, total suspended solids (TSS), volatile suspended solids (VSS), total solids (TS) and volatile solids (VS) were performed following standard methods[18]. Samples were analyzed in triplicates and average values were reported. Biomass concentrations (MLSS) were determined by filtering the samples through 0.45 μm millipore filter and drying in an oven at 105°C until constant weight. Sludge volume index was measured by sedimenting 1 l of the wastewater in an Imhoff cone for 30 min and measuring the biomass concentration at the bottom sediment.

RESULTS AND DISCUSSION

SBR/sand filter performance: SBR was operated in sequencing batch mode with a total 24 h period using a low organic loading rate to assess the suitability of the reactor for treating the wastewater under study. Initially after the start up of the reactor, the reactor was operated with a higher organic loading and the reactor performance was assessed by monitoring mainly carbon removal (COD and BOD_5) during the sequence (cycle)

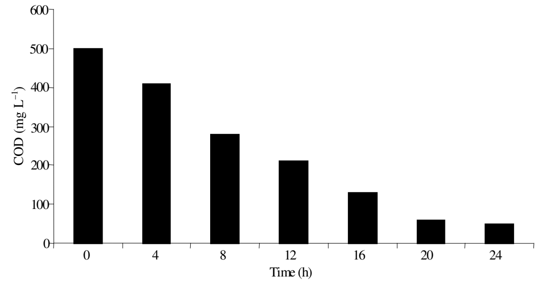

Fig. 1: COD values after filling, end of the aerobic phase and effluent

operation and also throughout the reactor operation. The variation of COD removal with the function of the cycle time is depicted in Fig. 1. The COD removal rate was slow during the initial phase of sequence operation. With an increase of sequence time a relatively rapid removal was noticed at the end of the reaction phase. The initial low COD removal may be due to the relatively high concentration gradient of the substrate. With an increase in sequence time, the native suspended biofilm might have become acclimatized to the new substrate conditions facilitating rapid removal of the organic substrate through mineralization. The BOD profile during the sequence operation (reaction phase) showed comparably the same pattern as the COD profile. The high performance BOD removal was observed after the reactor attained stability. It can be concluded from the reactor performance data obtained that SBR showed relatively better performance with respect to COD removal. With continued operation, the reactor showed enhanced performance with respect to COD and BOD removal and attained stable conditions after feeding and remained more or less constant thereafter. Sequencing batch reactors have been widely used for wastewater treatment in the past. A number of studies are reported in the literature on nutrient removal from wastewaters by SBR operation[3]. Umble and Ketchum investigated the effect of total cycle time on system performance[19]. BOD_5, total suspended solids (TSS) and NH_4-N removals of 98, 90 and 89% have been obtained, respectively with a 12 h cycle time. Chang and Hao studied the effects of important process variables on nutrient removal in an SBR system and obtained COD, total nitrogen, phosphate removals of 91, 98, 98%, respectively with a sludge age of 10 days and total cycle time of 6 h[20]. Chang *et al*. carried out experimental studies on nutrient removal in a small scale SBR[21]. Maximum nitrogen and phosphate removals have been obtained of anaerobic/aerobic/anoxic phases. Nakhla and Farooq studied the impact of filtration rates in the range of

0.15-0.38, on nitrogen elimination in slow sand filter[22]. Although NO_3-N removal efficiency was more than 95% at the filtration rate of 0.05 m H^{-1} in this study, Nakhla and Farooq achieved about 80% denitrification efficiency in raw wastewater including average 3.2 mg TKN L^{-1} at the same depth of 80 cm. It was assumed that the slowly biodegradable soluble COD in the wastewater might hinder the denitrification process and the high contact time positively affects the NO_3-N elimination in the biodenitrification process; therefore higher NO_3-N elimination was observed in this experiment. In many work camps, wastewater is pre-treated by a septic tank. By assuming 35 % of the total influent BOD_5 is settleable and 90% of the settleable BOD_5 is removed by settling in the septic tank; that 60 % of the influent SS is settleable and again 90% of the settleable SS is removed, the characteristics of such a pre-treated wastewater will be in the order of 277 mg L^{-1} BOD_5 and 223 mg L^{-1} SS, respectively.

pH and alkalinity: The work camp wastewater was slightly alkaline in nature due to presence of detergents, soaps etc. It was observed that during the treatment, the reactor had developed acidic conditions causing a drop in pH values of the reactor content and the treated effluent. However, this happened for a very short period; therefore there was no need to supply extra alkalinity. During the study period the pH values of the influent were used to be in the range of 6.8-7.6. The influent alkalinity (as CaCO3) was observed to be in the range of 230-300mg L^{-1} whereas, the effluent alkalinity varied between 178 and 400mg L^{-1}. At the daily treatment, the effluent alkalinity was noticed to be 25-33% more than the influent alkalinity due to formation of carbonates and bicarbonates in the reactor.

Effect of temperature: Temperature often imposes some limitations for wastewater treatment. To establish the temperature limits of this step in the operation of a SBR, a series of experiments were carried out using the same operational conditions, but using different temperatures, ranging from 15 to 30°C. At the lower temperatures tested, there was a substantial reduction in the removal percentage. This decrease was especially noticeable below 15°C. As a conclusion it can be said that SBR operation, at operational conditions of experiment, can be carried out without any special concern at temperatures higher than 15°C.

Suspended solids removal: Effect of the treatment on removal efficiency of suspended solids (SS) and volatile suspended solids (VSS) seemed to be significant. It was observed that influent SS concentration varied in the range of 300-450 mg L^{-1} whereas, the effluent SS concentration was less than 25 mg L^{-1} most of the times during study period. The SS reduction efficiency was 95% at HRT of 24 h and was around 90% at nearly all the lower HRTs considered in this study. During the study period the problem of clogging of sand filter was not observed. Such long term operation without cleaning saves cost of operation and maintenance.

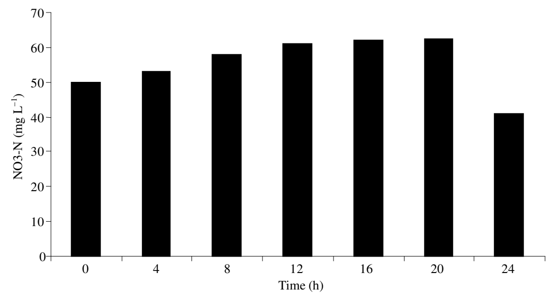

Fig. 2: NO3-N cincentration after filling, end of thr aerobic phase and at the end of the cycle

Nitrate-N removal efficiency: Although high nitrate was not present in the effluent, it was produced as a result of nitrification of NH_4-N during the oxic (aerobic) phase and converted to N_2 during the anoxic phase (Fig. 2).

CONCLUSIONS

The SBR/sand filter showed relatively efficient performance compared to a conventional system in treating work camp effluent. It is concluded that SBR/sand filter needs a relatively short period for start up and stabilization of reactor was achieved compared to a conventional system. The performance of SBR/sand filter is dependent on organic loading rate and the system can withstand its performance up to high loading rate. Enforced short term unsteady state conditions coupled with periodic exposure of the microorganisms to defined process conditions which can control the physiological state in SBR/sand filter have resulted in comparatively efficient performance over the conventional suspended growth systems for the treatment of work camps effluents.

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