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Full Paper

A comparative study of sequencing batch reactor and moving-bed sequencing batch reactor for piggery wastewater treatment

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Abstract: This research aims to comparatively study the efficiency of piggery wastewater treatment by the moving-bed sequencing batch reactor (moving-bed SBR) system with held medium, and the conventional sequencing batch reactor (SBR) system, by varying the organic load from 0.59 to 2.36 kgCOD/m^3.d. The COD treatment efficiency of the SBR and moving-bed SBR was higher than 60% at an organic load of 0.59 kgCOD/m^3.d and higher than 80% at the organic loads of 1.18-2.36 kgCOD/m^3.d. The BOD removal efficiency was greater than 90% at high organic loads of 1.18-2.36 kgCOD/m^3.d**.** The moving-bed SBR gave TKN removal efficiency of 86-93%, whereas the SBR system exhibited the removal efficiency of 75-87% at all organic loads. The amount of effluent suspended solids for SBR systems exceeded the piggery wastewater limit of 200 mg/L at the organic load of 2.36 kgCOD/m^3.d while that for the moving-bed SBR system did not. When the organic load was increased, the moving-bed SBR system yielded better treatment efficiency than that of the SBR system. The wastewater treated by the moving-bed SBR system met the criteria of wastewater standard for pig farms at all organic loads, while that treated by the SBR system was not satisfactory at a high organic load of 2.36 kgCOD/m^3.d.

Keywords: sequencing batch reactor (SBR), moving-bed SBR, moving-bed biofilm reactor, piggery wastewater treatment

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INTRODUCTION

Piggery wastewater is high in organic matter and consists of pig manure (urine and faeces), food waste and water from cleaning living quarters. Piggery wastewater is very difficult to treat because it contains a considerable amount of unstabilised organic matter and a high ammonia concentration. In Thailand, the average volume of piggery wastewater is in the range of 10-20 L/pig/day [1]. Generally, its average biochemical oxygen demand (BOD) value is in the range of 1,500-3,000 mg/L, and its average chemical oxygen demand (COD) value is in the range of 4,000-7,000 mg/L [1]. The Ministry of Natural Resources and Environment (Thailand) has recently introduced regulations for livestock wastewater control including effluent standards for pig farms, which states that the effluent from small- and medium-size pig farms must contain not more than 100 mg/L of BOD, 400 mg/L of COD, 200 mg/L of suspended solids and 200 mg/L of total Kjeldahl nitrogen (TKN) [2]. In order to comply with these regulations, an effective wastewater treatment system for both organic and nitrogen removal is required.

The biological process appears to be the method of choice for organic and nitrogen removal from animal waste because the chemicals for the process are relatively inexpensive and the treatment efficiency is relatively high [3-4]. The organic matter in piggery wastewater can be initially treated with anaerobic digestion. This process achieves an effective reduction of organic matter and pathogens and generates biogas, a valuable energy [5]. However, the effluent from anaerobic digestion of piggery wastewater contains a high amount of ammonia, which requires further removal by such methods as air stripping and coagulation-flocculation (physicochemical method) [6-7], treatment in a biofilm air-lift reactor or membrane bioreactor (physicobiological method) [4], and/or treatment in a sequencing batch reactor (biological method) in order to meet the quality standard for discharged effluent. The sequencing batch reactor (SBR) with the ability to remove nitrogen and organic matter in limited space has recently been used for piggery wastewater treatment [3, 8-10], either in aerobic/anoxic condition or in anaerobic digestion [8-10]. From the economical point of view, the biological treatment is preferred since its relative cost is lower than other physicochemical or physicobiological methods [11]. The SBR system can also be used to treat wastewater with high nitrogen content through nitrification-denitrification [12-13].

Over the last decade, there has been growing interest in the moving-bed biofilm reactor process for both municipal and industrial wastewater treatments, as compared to conventional biological processes and biofilter process, due to their greater compactness and need for less space, high tolerance to load impact, no sludge bulking problem as well as less dependence on final sludge separation and utilisation owing to the lack of sludge return [14-17]. At present, there are about 400 large-scale wastewater treatment plants from 22 different countries all over the world using the moving-bed process [18]. The development on the attached growth bioreactor by addition of a moving-bed medium in the case of high biomass concentration has created great interest [13, 15-16]. Due to its high removal efficiency and stable operation at high organic loads, some researchers [13,15-19] have employed the moving-bed bioreactor in treating slaughterhouse wastewater [13], phenolic wastewater [20], pesticide wastewater [21] and municipal wastewater [13-16,19].

As mentioned earlier, the piggery wastewater from the anaerobic digestion still contains high amounts of organic matter and ammonia and thus requires further treatment. Therefore, it is the

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aim of this work to apply the SBR system with a moving-bed medium to the treatment and to compare the results with those obtained from the ordinary SBR system. Recent literature [13-21] has clearly indicated that such comparative study of moving-bed SBR and ordinary SBR systems, especially that utilising piggery wastewater, has been limited. This then becomes the main interest in our present work.

MATERIALS AND METHODS

Experimental Set-up

The SBR and moving-bed SBR systems each consisted of an acrylic reactor 40 cm high, 0.5 cm thick and 16 cm in diameter with a working volume of 6 L. One air pump system (Yamano AP-10, Japan) was used for supplying the air to the two reactors. The flow-in and flow-out rates of piggery wastewater were controlled by a level control (Omron, Japan) and solenoid valve (AirTac-2W025-08, China). The operational sequence of the SBR systems and the movements of all mechanical devices including the air pump system, solenoid valve and level control were controlled by a programmable logic controller (Omron ZEN-10C3AR-A-V2, Japan). The SBR and moving-bed SBR systems were installed and assembled as shown in Figure 1.

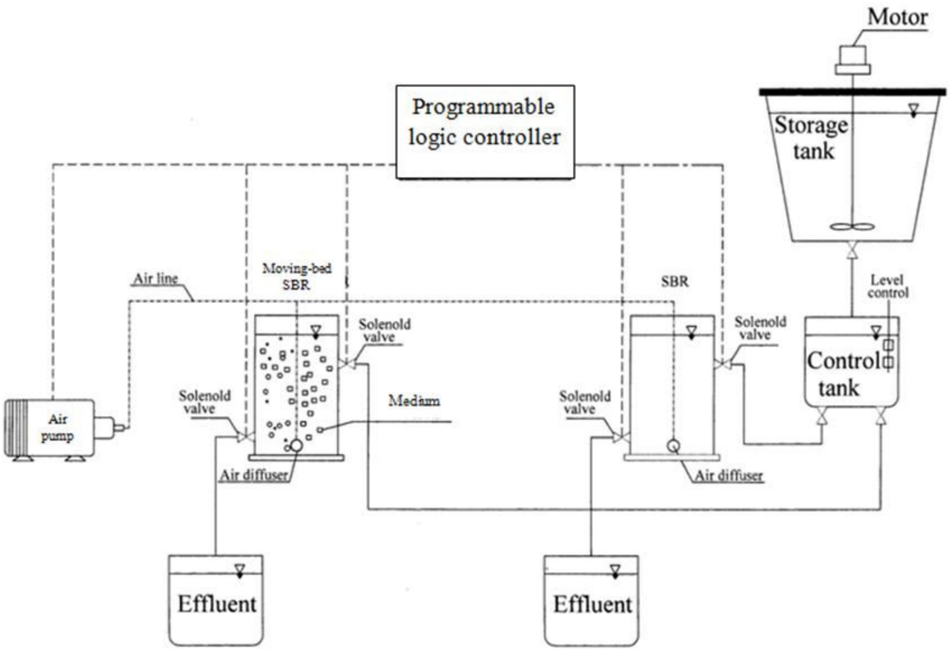

Figure 1. Schematic diagram of SBR and moving-bed SBR systems

Before starting each batch reactor, the piggery wastewater was fed into the reactor containing activated sludge. The activated sludge culture was obtained from Bangkok central wastewater treatment plant. The volatile suspended solids to suspended solids ratio of the activated sludge was 0.89. The activated sludge microorganisms was adapted to the piggery wastewater by cultivating in an aeration tank. The SBR and moving-bed SBR systems were operated batchwise for 10 days with aeration and mixing to obtain a dense culture of the activated sludge for use as inocula

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for the two systems, which, after cultivating, had a mixed liquor suspended solids (MLSS) concentration of about 3,000 mg/L. Both systems worked 2 cycles per day. One cycle comprised the following stages: 1 h for filling, 8 h for reacting, 2 h for settling and 1 h for drawing and idling. During the drawing phase, the supernatant wastewater was decanted until the liquid volume in the reactor decreased to 2 L. Both systems were operated at a sludge retention time (SRT) of 10 days by wasting a certain amount of mixed liquor from the reactors everyday just before the settling period. The piggery wastewater was treated at 8 L/day for each system, and the hydraulic retention time (HRT) was 0.75 day. The dissolved oxygen (DO) concentration in each reactor was maintained by an air flow rate of 1.0 L/min. Throughout the study, the pH and ambient temperature were approximately 7.5±0.5 and 27±2^{o}C respectively. Poly(vinyl chloride) sponge, which was cut in 1.5-cm cubes, was used as the floating medium in the moving-bed reactor. The sponge cubes were circulated in the reactor by air without any additional mixing equipment. The moving medium had a specific surface area of 400 m^2/m^3 and a density of 0.0145 g/cm^3 and was used at 20% fill fraction [% fill fraction = 100 × (volume occupied by medium / reactor volume)].

The piggery wastewater used in this experiment was taken from an anaerobic system of a pig farm in Nontaburi province. It was allowed to settle for 1 h and then filtered through a 1-mm mesh screen to remove any large particles. The wastewater in the influent tank was prepared daily by mixing the raw piggery wastewater with tap water to provide the feed wastewater with COD concentrations of 500, 1000, 1500 and 2000 mg/L, and organic loads of 0.59, 1.18, 1.77 and 2.36 kgCOD/m^3.d respectively. The characteristics of a typical piggery wastewater sample from the anaerobic digestion are given in Table 1.

Table 1. Characteristics of raw piggery wastewater

Parameter	Unit	Concentration	Standard value for pig-farm effluent (Thailand) [2]
BOD	mg/L	1500-2300	100
COD	mg/L	4700-5900	400
Suspended Solids	mg/L	4000-8000	200
TKN	mg/L	300-500	200
NH_3-N	mg/L	210-380	-
pH	-	7.5-8.5	5.5-9.0

Analytical Methods

The samples collected from the influent and effluent wastewaters were analysed in terms of chemical oxygen demand (COD), biochemical oxygen demand (BOD), total Kjedahl nitrogen (TKN), ammonia-N and suspended solids according to “Standard Methods for the Examination of Water and Wastewater” [22]. The per cent removal efficiency of COD, BOD and TKN was defined as: [(influent value – effluent value) / influent value] × 100 .

Dissolved oxygen (DO) and pH measurements were monitored by a DO meter (Oxi 340i, WTW, Germany) and a pH meter (pH 340i, WTW, Germany) respectively. The sludge volume

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index (SVI), the volume in millilitre occupied by 1 g of a suspension after 30 min settling, was determined in 1-L graduated cylinders with the mixed liquor samples taken directly from the reactors at the end of the reaction period. SVI is typically used to monitor settling characteristics of activated sludge and other biological suspensions [22].

The attached biofilm on the medium was determined as biofilm mass after extraction from the medium. The experimental method for determining the attached biofilm followed the work of Andreottola et al [19]. The average errors for all experimental data were ±5%.

RESULTS AND DISCUSSION

COD and BOD Removal Efficiency

A set of experiments were performed at four different organic loads varying from 0.59 to 2.36 kgCOD/m^3.d while the HRT was fixed at 0.75 day. Figure 2 shows the effluent COD in the two systems as a function of organic load. The results clearly show that as the organic load increased, so did the effluent COD, whose values were similar in both systems at the organic loads of 0.59 and 1.18 kgCOD/m^3.d, whereas they were higher in the SBR system at the organic loads of 1.77 and 2.36 kgCOD/m^3.d. At 2.36 kgCOD/m^3.d the effluent COD in the SBR system did not pass the standard for piggery wastewater (COD of 400 mg/L) [2], while the piggery wastewater treated by the moving-bed SBR satisfied the standard criteria at all organic loads. The moving-bed SBR system was thus apparently more effective at a high organic load than the SBR system. This might be related to the fact that the circulating medium in the moving-bed SBR enhanced distribution of liquid flow and oxygen transfer. This then would enable the unsettled waste to be treated directly [15]. The relationship between COD removal efficiency and organic load for the two systems is shown in Figure 3. It can be seen that as the organic load increased the removal efficiency of the moving-bed SBR also increased or remained unchanged while that of the SBR gradually decreased at high organic loads.

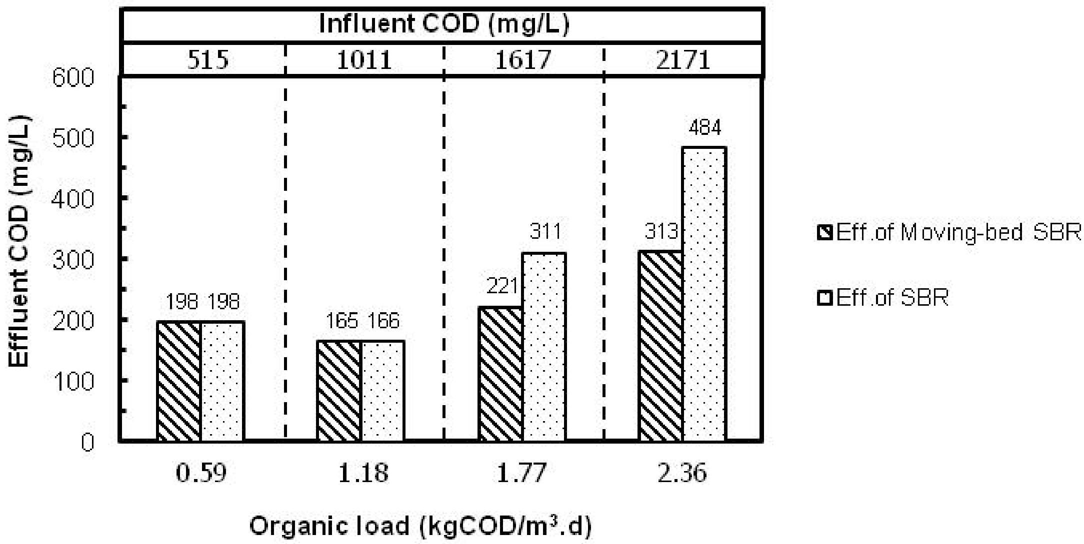

Figure 2. Relationship between effluent COD and organic load

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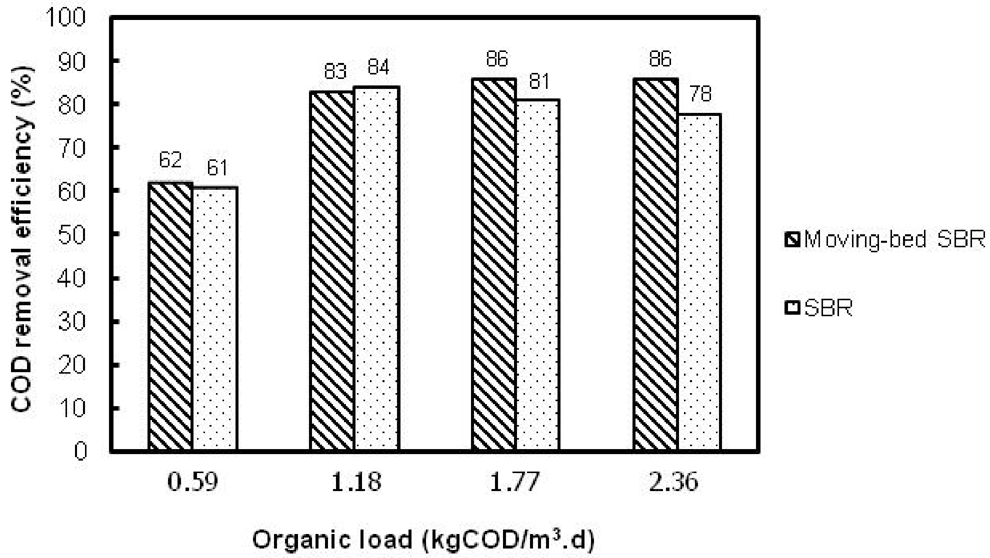

Figure 3. Removal efficiency of COD as a function of organic load

The values of DO in the effluents at different organic loads are given in Figure 4. The DO concentrations at all organic loads in the moving-bed SBR were greater than those in the SBR. These results substantiate the hypothesis that the moving-bed medium can assist in oxygen transfer and liquid distribution in the moving-bed SBR system.

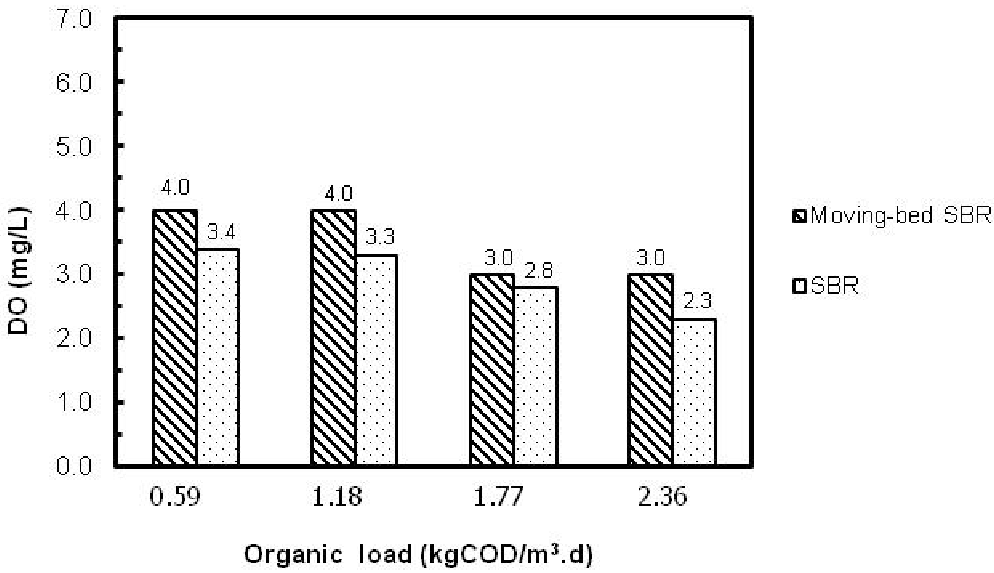

Figure 4. DO of effluents at different organic loads

The quality of the effluents from the two reactors in terms of BOD at different organic loads are shown in Figure 5. The BOD trends were similar with those of COD in Figures 3-4. The effluent BOD in the SBR system at the organic load of 2.36 kgCOD/m^3.d did not pass the standard criterion (BOD of 100 mg/L), whereas the piggery wastewater treated with the moving-bed SBR satisfied the standard criterion at all organic loads. It can be seen from Figure 6 that the BOD removal efficiency

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was greater than 90% at high organic loads (1.18-2.36 kgCOD/m^3.d), which in this study were 2-4 times higher than those used by Sirianuntapiboon and Yommee [13], who reported that the moving-bed aerobic SBR gave higher than 95% COD and BOD removal efficiency when the system was operated to treat synthetic wastewater with an organic load of 0.528 kgBOD/m^3.d. Thus, the moving-bed SBR seemed to effectively handle a high organic load and consistently provide a high BOD removal efficiency. The biofilm on the medium surface apparently facilitated more biodegradation in the system, thus accounting for the improved BOD removal.

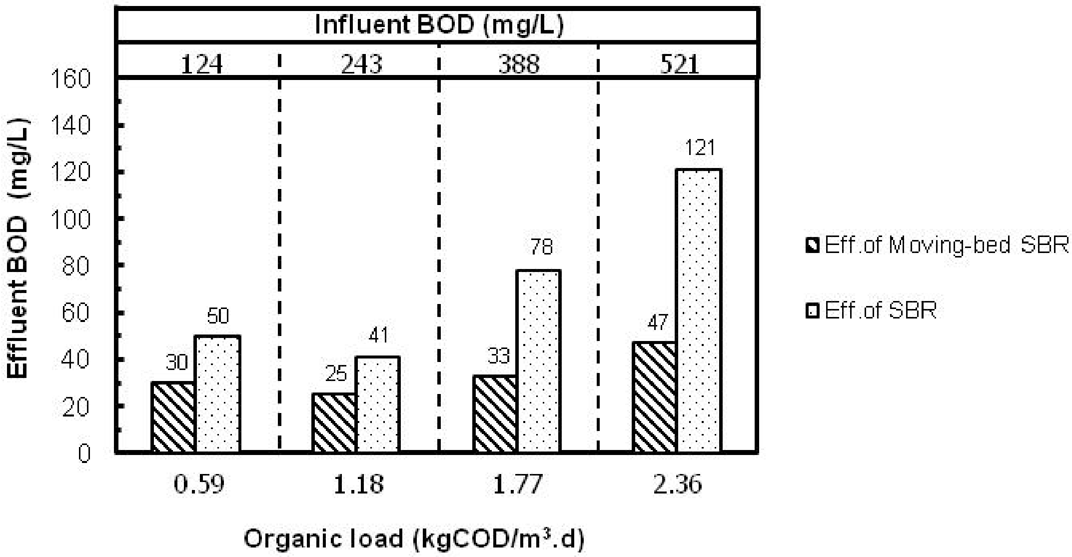

Figure 5. Effluent BOD at different organic loads

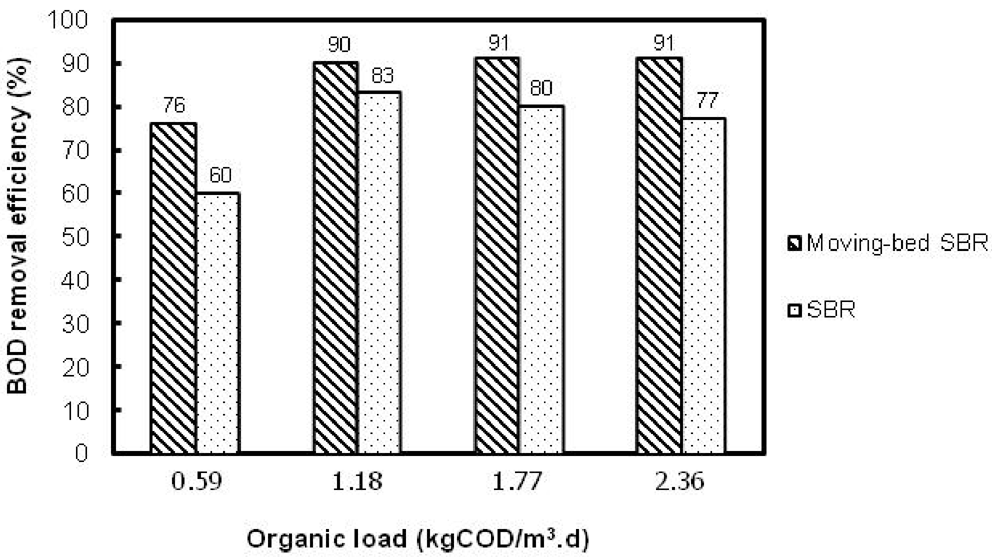

Figure 6. Relationship between BOD removal efficiency and organic load

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TKN and Ammonia Removal Efficiency

Figure 7 shows the relationship between TKN and organic load for the SBR and moving-bed SBR systems. It can be seen that influent and effluent TKN increased with increasing organic load for both systems, although the TKN effluents in both the SBR and moving-bed SBR satisfied the standard criterion at all organic loadings. Figure 8 presents relationship between TKN removal efficiency and organic load; the efficiency of the moving-bed SBR (86-93%) was better than that of the SBR (75-87%). The biofilm formation on the moving-bed medium, which led to a more efficient nitrification/denitrification process, could account for the increasing nitrogen removal [13,16]. As shown in Figure 9, the ammonia-N in the effluent of the moving-bed SBR was also lower than that of the SBR at all organic loads. This indicates that ammonium oxidation by oxygen occurred more efficiently in the moving-bed SBR, in agreement with the DO data presented in Figure 4.

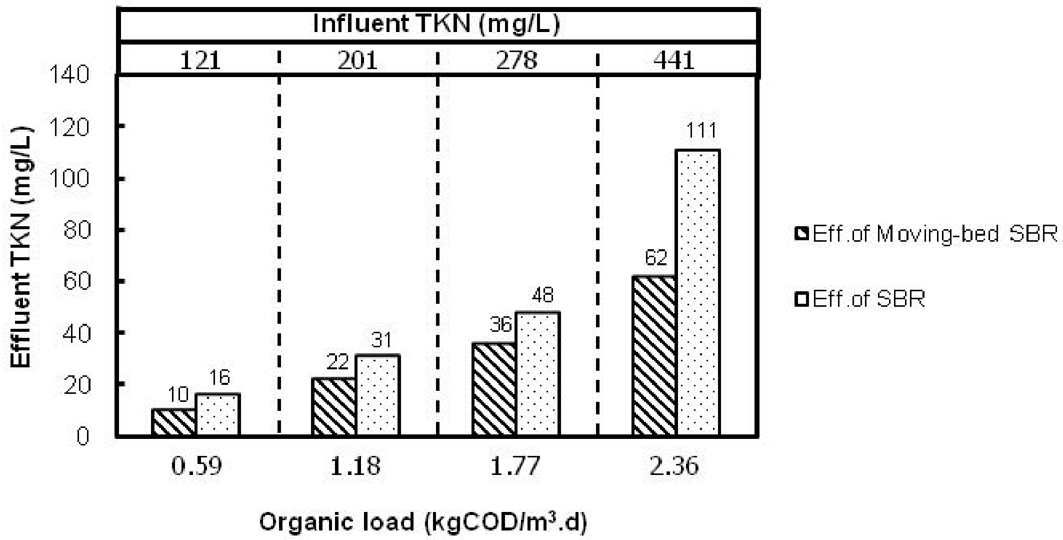

Figure 7. Relationship between TKN and organic load

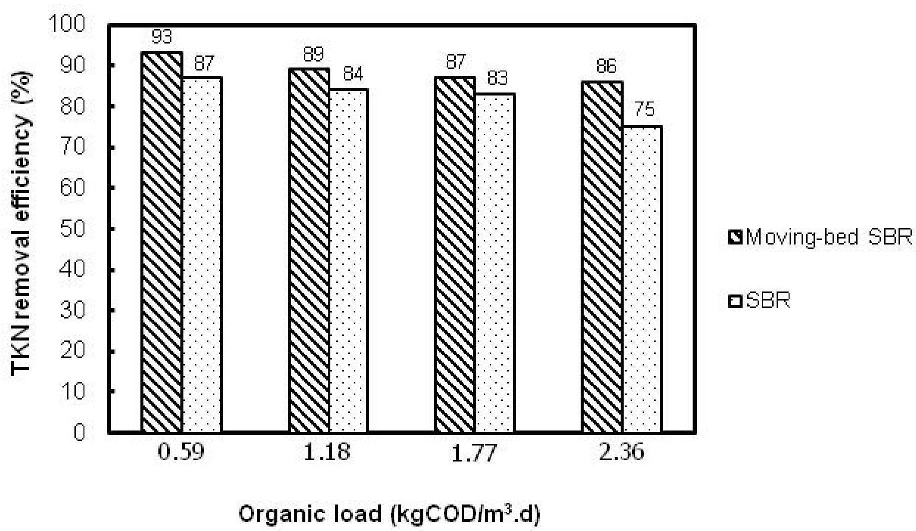

Figure 8. Relationship between TKN removal efficiency and organic load

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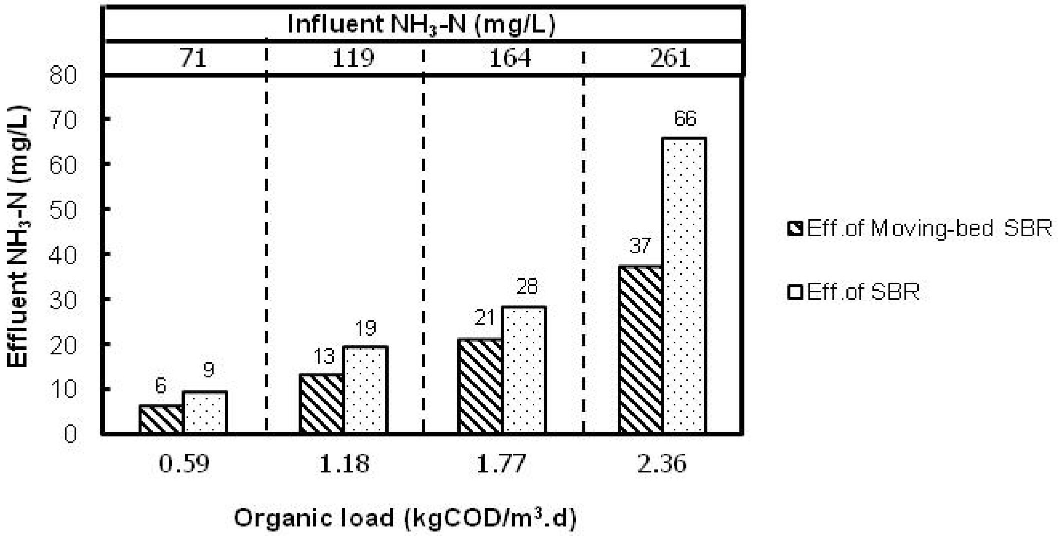

Figure 9. Variation in effluent ammonia-N with organic load

Suspended Solids, Sludge Volume Index and Microscopic Examination

As expected, the effluent suspended solids from the two systems increased with increasing organic load as shown in Figure 10. It was found that for both systems the effluent suspended solids were similar at organic loads of 0.59 and 1.18 kgCOD/m^3.d, while at organic loads of 1.77 and 2.36 kgCOD/m^3.d they differed. At the organic load of 2.36 kgCOD/m^3.d, the amount of effluent suspended solids from the SBR was 227 mg/L, which exceeded the limit of piggery wastewater standard of 200 mg/L, while the amount from the moving-bed SBR (169 mg/L) was still within the limit, thus again demonstrating a better performance of the moving-bed SBR over the conventional SBR system.

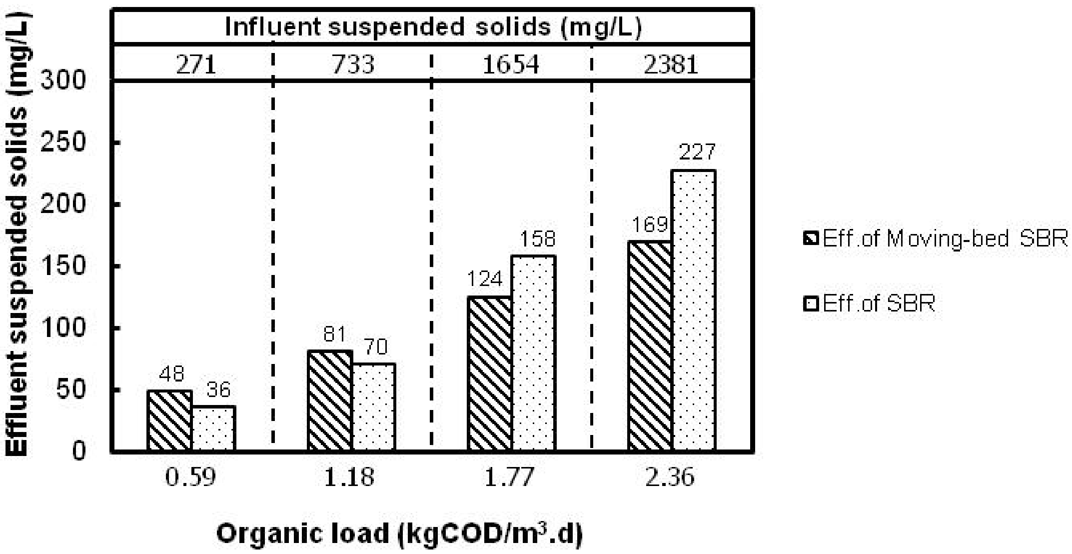

Figure 10. Variation in effluent suspended solids with organic load

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SVI is an important parameter affecting the performance of a wastewater treatment system. Low SVI values (<100 mL/g) indicate good sedimentation characteristics of the sludge yielding high biomass concentrations in the aeration tank, whereas high SVI values (>>100 mL/g) reflect bulky sludge and low biomass concentrations in the aeration tank [12]. Figure 11 shows SVI as a function of organic load. It can be seen that the SVI for both reactors ranged from 40 to 60 mL/g, indicating that the sludge had good settling capability.

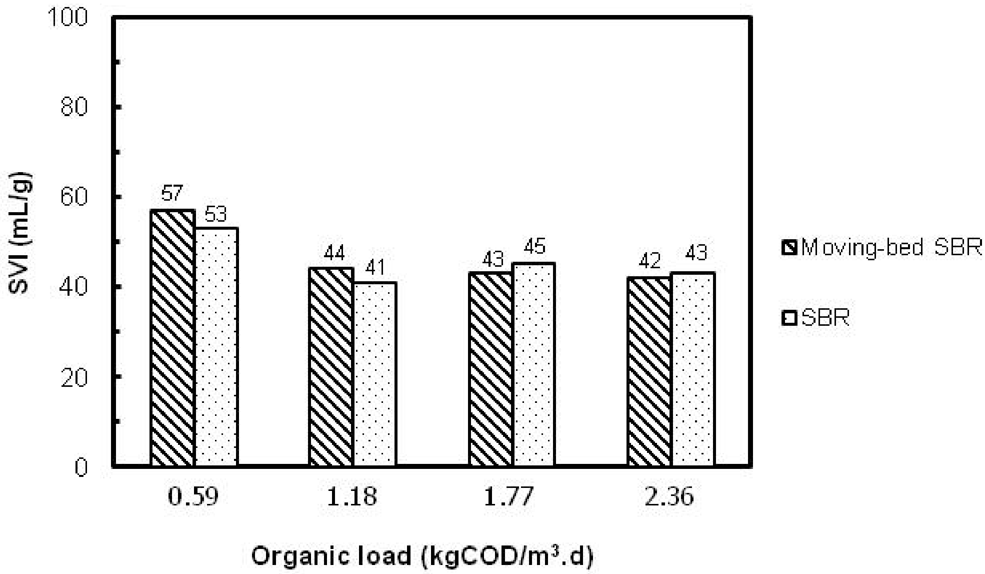

Figure 11. Variation in SVI with organic load

During the experiments, microscopic examination was carried out on samples of moving-bed medium taken from the moving-bed SBR. Typical results as in Figure 12 show that there was a large amount of biomass growing on the medium circulated in the reactor. This medium thus provided a large surface area for microbial growth during the operation. A large amount of the biofilm was found attached on the medium and could apparently handle a high organic load. The biofilm mass (mg MLSS/L) and biofilm mass of medium (mg/m^2) presented the sludge quantities in the moving-bed SBR (Table 2). It can also be seen that the bio-sludge quantity increased with increasing organic load.

Table 2. Bio-sludge quantities of the moving-bed SBR

Organic load (kgCOD/m^3.d)	Biofilm mass (mgMLSS/L)	Biofilm mass of medium (mg/m^2)
0.59	328	3.0
1.18	367	3.4
1.77	396	3.6
2.36	424	3.9

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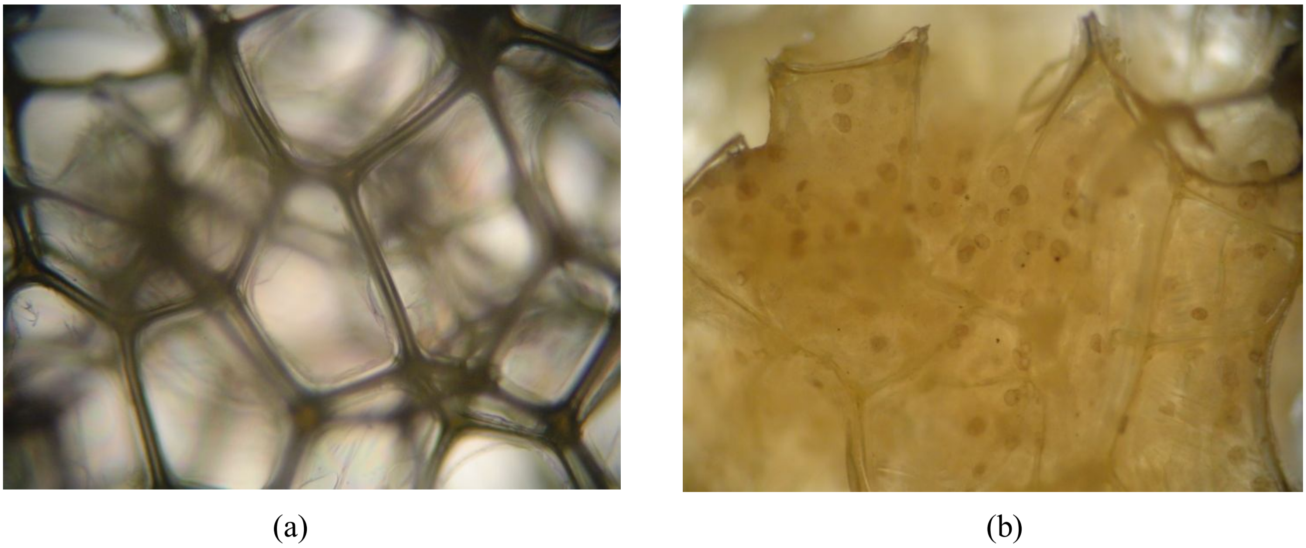

Figure 12. Photographs of sponge medium surface (×10 magnification): (a) without bio-sludge, (b) with bio-sludge

CONCLUSIONS

The moving-bed SBR system could be operated effectively at a high organic load. The quality of the effluent from the moving-bed SBR in terms of COD, BOD, TKN and suspended solids met the criteria of wastewater standards for pig farms at all organic loads used, whereas the SBR system was not satisfactory at a high organic load of 2.36 kgCOD/m^3.d. The moving-bed SBR thus seems to be an efficient system for treatment of piggery wastewater with a high nitrogen and organic content.

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