IFAS MEDIA IN A SEQUENCING BATCH REACTOR FOR NITRIFICATION AND DENITRIFICATION OF HIGH STRENGTH WASTEWATER

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ABSTRACT

In 1996 a study group identified pig farm waste as one of Asia's foremost environmental problems. So in 1999 a US AEP led effort established the Environmental Center for Livestock Waste Management (ECLWM) on the campus of the National Pingtung University of Science and Technology (NPUST), Taiwan. The ECLWM constructed a state-of-the-art prototype swine manure wastewater treatment system. A vertical, glass lined steel tank fitted with three banks of manufactured fixed-film synthetic media is being operated as a biofilm sequencing batch reactor (BSBR) to treat the liquid wastes flushed from several confinement pig buildings at the located on the campus of the NPUST. The treatment unit handles approximately 63 m^3 of the waste flow from six different buildings housing a total of approximately 540 head or a total weight of approximately 45,000 kg. Effluent from this treatment unit is decanted to a large aboveground storage tank prior to reuse as flushing water. Excess treated water is applied to grassland in the area at agronomic rates. The flush water being treated in this system has an average biochemical oxygen demand (BOD) of approximately 1,600 mg/l. The treated water has a BOD generally less than 50 mg/l and consistently less than 100 mg/l. Total Kjeldahl nitrogen concentrations are reduced from 60 to 90 percent depending upon the loading rate and the operating schedule.

KEYWORDS

IFAS, Fixed-Film, Agricultural waste, SBR, Hog farming, anaerobic, BSBR

INTRODUCTION

The discharge of untreated or partially treated wastewater from confinement pig production is an environmental and economic challenge wherever intensive pig production is established. The Environmental Center for Livestock Waste Management (ECLWM) located on the campus of National Pingtung University of Science and Technology, Taiwan, is dedicated to the development, evaluation, and dissemination of alternate livestock waste management technologies in response to the needs of livestock producers throughout Asia. The sequencing batch reactor (SBR) was selected as one of the options to be evaluated based on the need to devote a minimal land area to the treatment system.

The treatment alternative evaluated in this study was selected after previous SBR experiences on the ECLWM farm. The concept was to construct a single vessel treatment scheme that would produce an effluent that could be used as flush water thereby reducing effluent discharge to near zero. In order to be judged satisfactory, the treatment system had to operate without the release of objectionable odors and require a minimum of operator attention. In addition, the system had to be one that has a high degree of reliability and operate with a cost that can be borne without undue stress on the enterprise.

Manufacturers located in the United States contributed the equipment used in this study to demonstrate the most effective technologies currently available. Installation, operation and evaluation of the system was the responsibility of NPUST faculty with the cooperation and technical support of the U.S. ECLWM faculty team.

LITERATURE REVIEW

Both municipal and industrial wastewaters containing organic materials and nutrients have been commonly treated using typical processes such as the aerobic activated sludge process, anaerobic upflow sludge blanket process, and others. Similarly agricultural wastewater treatment has moved from traditional lagoon systems to more engineered systems due to the need to produce discharge quality effluent water which can be reused, removal of nutrients such as N and P, and to have compact systems with minimal land area requirements and odor-free operations. Although aerobic processes such as the activated sludge process can effectively remove BOD and also convert ammonia nitrogen to nitrate, yet will not be able to remove N and P effectively. The combination of both aerobic and anaerobic treatment in a single tank has been reported to remove BOD and reduce aeration costs while at the same time achieve nitrogen removal (Argaman, 1991). The nitrogen removal is achieved by promoting nitrification of dissolved ammonia to nitrate ions and then the nitrate ions are denitrified to nitrogen gas. Nitrification is performed by nitrifying bacteria, which are obligate aerobes, whereas denitrification is conducted by heterotrophic bacteria, which can utilize nitrate in place of oxygen under anaerobic/anoxic conditions. Hence, provision of anaerobic-aerobic conditions in a treatment system is critical for nitrogen removal from wastewater. Typical continuous flow treatment systems use aerobic and anaerobic/anoxic stages to achieve nitrification and denitrification, and batch systems such as SBRs use alternating aerobic and anaerobic sequencing conditions to achieve nitrogen removal. The more recent method of achieving nitrogen removal in a single tank involves use of biofilm media in a traditional activated sludge process or an SBR. These systems are commonly known as integrated fixed film activated sludge (IFAS) processes. The suspended growth portion of the process is aerobic and the biofilm portion of the process serves as anaerobic/anoxic zone, thereby allowing nitrification and denitrification in the respective zones. Phosphorus removal is also possible in an anaerobic/aerobic cyclic system based on luxury uptake by the sludge in the aerobic phase through enhanced biological phosphorus removal (EBPR) mechanism (Rittmann and McCarty, 2001).

Sequencing batch reactors (SBR) have been incorporated in systems for removing biochemical oxygen demand (BOD) and nutrients from both municipal and industrial wastewater. (Irvine et al., 1987; Goronszy, 1992; Surampalli et al., 1997). Performance of a system of this design is dependent upon proper sizing of the reactor as well as proper scheduling of the aerobic and anaerobic portions of the treatment cycle. At the beginning of the cycle, untreated waste is introduced to the treatment unit under anaerobic conditions where organic matter is utilized by denitrifying bacteria in the presence of nitrate. During the aerobic portion of the cycle, blowers provide sufficient oxygen to achieve aerobic conditions. During this phase the aerobic heterotrophic bacteria oxidize the residual organic matter to CO_2, and autotrophic nitrifying bacteria convert the ammonia to nitrate. During the anaerobic portion of the cycle, the blowers are turned off and the residual organic material utilizes the available dissolved oxygen and nitrate and creates an environment to support denitrification. This technology was initially intended for small communities and high strength industrial wastes (U.S. EPA, 1986) but more recently there has been widespread application with other dilute waste sources.

An SBR incorporated with biofilm media (BSBR) used to treat dilute pig wastewater is being reported in this paper. In the BSBR system, the biofilm media zones provided in the SBR serve as anoxic zones and the bulk liquid containing oxygen becomes the aerobic nitrification zone. Therefore in the suspended sludge, both BOD and ammonia are oxidized, and in the biofilm sludge, nitrate is denitrified to nitrogen gas. If phosphorus removal is desired, then anaerobic-aerobic sequencing conditions during the react phase of the SBR operation will be able to perform EBPR by the bulk suspended sludge.

SYSTEM DESCRIPTION

This wastewater treatment unit was designed to treat the wastes from a group of pig confinement buildings located on the farm located immediately south of the National Pingtung University of Science and Technology (NPUST) campus. Manure waste from six buildings is collected by a common sewer and flows by gravity to a collection sump at the lower end of the research/teaching farm. The buildings, the typical animal inventory, and the projected waste load are shown in Table 1. About 80% of this waste flow is pumped to the BSBR, the remainder flows to a conventional “Red Mud” anaerobic digester. Considerable water is used in flushing and cleaning these buildings so the total solids concentration is typically low, about 0.3% solids.

Table 1. Influent wastewater projected daily load from confinement pig barns

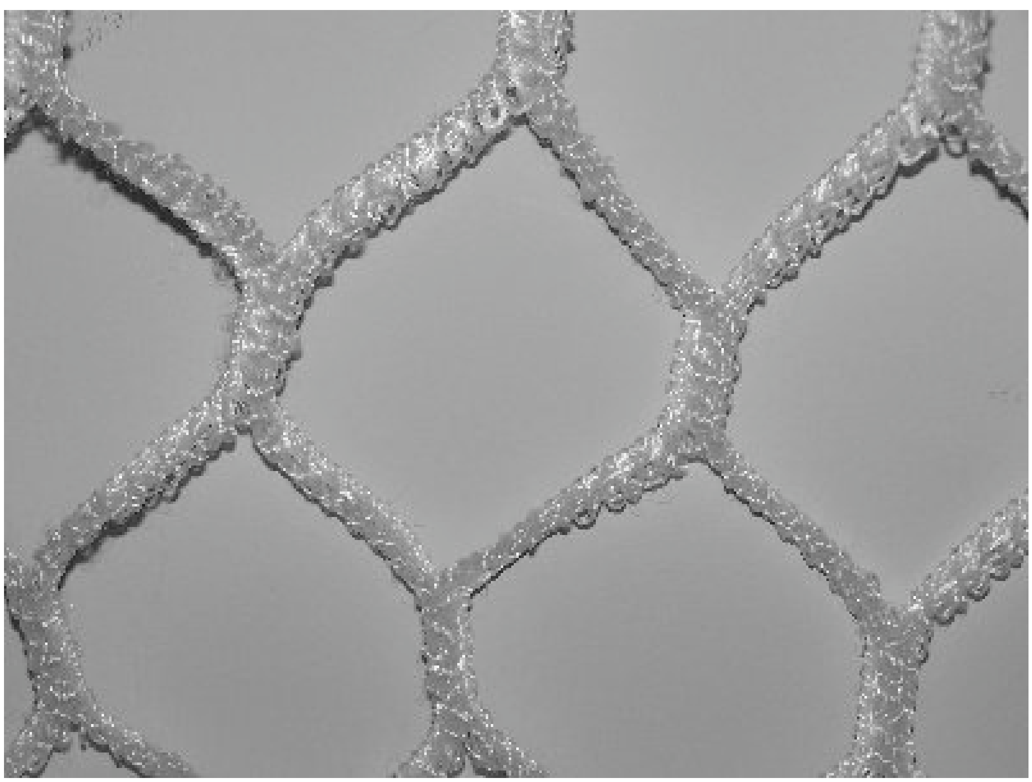
Building	Normal population	Total live weight, kg	Total solids, kg/d	Volatile solids, kg/d	BOD, kg/d	Nitrogen, kg/d
Grower-finisher	48 @ 90 kg	4,320	27.3	23.0	8.8	1.8
Farrowing	10 sows @185 kg 10 sows @ 115	3000	18	15.3	5.8	1.4
Nursery	159 @26 kg	4355	36	30	11.5	2.6
Dry sow	70 @ 170 kg	12,920	32.3	27.4	10.4	2.5
Grower	76 gilts @110 kg	8360	27.4	23.3	8.8	2.0
Grower – finisher	43 gilts @ 110 kg 51 mixed @ 75kg 67 whites @ 90 kg	12,435	78.8	67	25.5	5.2
Total	540 head	45,290	220	186	70.8	15.5

The BSBR reactor tank is a glass-lined cylindrical tank with conical bottom, and the pertinent dimensions of the tank are presented in Table 2. The reactor tank was fitted with three BioWeb (looped hexagonal polyester fibers) racks each with dimensions of 1.8 m x 1.9 m 1.5 m with 0.3 m leg supports. The Bio-Web material at 1.5 m tensioned width was looped over and under top and bottom cross members (3 cm tubular stainless steel) with centerline to centerline spacing of 15 cm. The three racks were spaced equidistant from the tank center and 30 cm tangential to the tank outer wall. The three racks provided 1000 m^2 of attached growth surface area in the BSBR tank.

Figure 1: The Biofilm Sequencing Batch Reactor

Figure 2: Three BioWeb synthetic media racks in the BSBR

Figure 3: Close up of the BioWeb fixed-film media



Aeration was supplied by two 3 hp compressors gauged at 0.4 kg/cm^2 . Separate manifold lines (52 cm diameter) were run to the bio-racks and to the open zones in the tank center and between the bio-racks. This layout provides for variable or intermittent aeration options for the biorack zones. Stainless steel diffusers (61 cm length, 0.2 to 0.6 m^3 / minute air transfer) were attached to the manifold lines at offset spacing of 0.6 m. The manifold line to the bio-racks was fitted with two diffusers below each rack. (Diffusers supplied by AeroMix, Minneapolis, MN). The fill and decant levels in the BSBR tank are controlled by timed high-low sensors with the decant volume transferred to the effluent storage tank by a 1 hp fixed position decant pump.

Table 2. Dimensions and volumes of the BSBR

Characteristic	Dimension
Diameter	7.62 m
Total height	4.3 m
Height to the fill level	3.9 m
Height to the decant level	2.5 m
Total tank operating volume	177 m^3
Tank volume below the decant level	114 m^3
Tank volume between decant level and the operating level	63 m^3

OPERATION

The operation of the BSBR waste treatment unit during this three-month evaluation period was devised to provide a high quality water for decant transfer into the effluent storage tank that can be used for recycling, or if necessary, applied to grassland with a very low nutrient load. Operating conditions can be modified in the future to reduce costs and evaluate alternative nitrogen and phosphorus removal strategies. The treatment system was operated according to the schedule outlined in Table 3.

Table 3. Daily BSBR operating schedule

Time	Activity
0730	Turn off the supply switch to the storage tank
1030	Mix remaining BSBR contents and collect sludge inventory sample. Begin pumping from the collection basin to the effluent tank
1230	Begin aeration; collect sample of mixed manure and sludge
2030	Stop aeration and begin settling period

2100	Collect sample of clarified water
2230	Begin decanting clarified water to effluent storage tank until reach 240 cm height of effluent tank, then stop pumping automatically
2235 to 0730	Waste sludge and idle the reactor with no aeration

MONITORING PLAN

The monitoring strategy was devised to establish a material balance on the treatment system based on biological oxygen demand (BOD), chemical oxygen demand (COD), suspended solids, and total Kjeldahl nitrogen (TKN). TKN includes both dissolved ammonia and organic nitrogen. Settleability of sludge, water temperature and weather conditions were also recorded. Samples were collected from three locations. The source of the samples and the logic of these choices are provided in Table 4.

Table 4. Sampling locations to evaluate the performance of the BSBR

Sample designation	**Location and significance**
Mixed manure and sludge	As soon as the flush water has flowed to the collection sump and has been pumped to the treatment unit, the treatment tank is mixed by operation of the aerator for five minutes to create a homogeneous mixture. The sample represents the constituent concentrations in the BSBR, the retained sludge and the fresh manure. This concentration multiplied by the tank volume minus the concentrations in the other two samplings times their respective volumes allows for calculation of the manure load.
Effluent	Following the aeration phase of the BSBR tank, the contents are allowed to stand for two hours before beginning to decant effluent to the effluent storage tank. The decanting process continues for three hours. This sample is collected from the top of the treatment tank. Constituent concentrations in this material multiplied by the effluent volume (63.7 m^3) calculates the mass of a constituent that was not removed by the treatment.

Sludge inventory	After the flush water is decanted, the material remaining in the tank is the bacterial sludge that provides the treatment. It is agitated to a homogeneous mixture and sampled for analysis. The constituent concentrations multiplied by the volume below the decant pipe is the mass of constituent in the sludge inventory.

ANALYTICAL PROCEDURES

Water temperature, weather and sludge settleability were measured in the field according to a protocol established by the research team. Settleability is measured by pouring a representative sample into a one liter graduated cylinder and recording the volume of settled sludge after 30 min of quiescent settling. The BOD, COD, Kjeldahl nitrogen and suspended solids determinations were made in the ECLWM analytical laboratory using procedures approved by the Taiwan Environmental Quality Regulatory Agency and are largely based on Standard Methods (1992).

RESULTS AND INTERPRETATION

The system was activated during the early part of September 1999. The first samples were collected on September 24. Sampling continued on a twice a week basis. The results of sampling through December 3 are summarized in Table 5. The results include constituent concentrations of BOD, COD, SS, TKN, and settleability (SVI) in the influent pig manure waste, sludge, mixed manure and sludge, and the effluent water to the storage tank. It can be seem from the results that the BSBR is able to reduce the BOD of the influent pig manure waste from a weighted average of about 1830 mg/L to about 39 mg/L, 98% removal in a single tank. The effluent BOD levels reflected the trends in the influent levels. The breakthrough of BOD to high as 103 mg/L indicates conditions of excessive organic loading to the BSBR. The COD values in the influent reflect the same trends observed with respect to BOD, and the average effluent COD was 128 mg/L when the influent average COD was 5370 mg/L. The average BOD and COD removals by the BSBR are about 98%. The average BOD/COD ratio of the influent was about 0.34, whereas that of the effluent was about 0.30.

The average SS concentration in the effluent was 67 mg/L, and generally it has increased with increasing SVI or decreasing settleability. It is possible that at higher SVIs, the sludge blanket during the decant phase may be higher, and thus leading to higher solids in the effluent. This can be mitigated during the optimization phase either by having a lower effluent withdrawal flow rate during the decant phase or longer settle phase to lower the sludge blanket levels. The TKN levels in the influent ranged from about 220 mg/L to about 2800 mg/L, whereas they were about 31 to 140 mg/L in the effluent. The high variability in the influent TKN levels are currently being investigated. Despite the high variability in influent TKN concentrations, the BSBR was able to reduce the effluent TKN concentrations by an average of about 85%. Furthermore, the success of the treatment is confirmed by the observation of the research team that there were no discernable manure odors detected at the top of the treatment unit. The treated effluent from the system flows by gravity to a large above ground storage tank. From the effluent storage tank, the water can be reused as flush water or land applied using the irrigation equipment available to the farm. Because of the dilute wastewater entering the system to date, no sludge wasting has been necessary.

The data in Table 5 document the capability of the system to remove nitrogen, BOD, COD and suspended solids from the liquid manure. The information presented in Table 6 was generated by calculating the mass of the various constituents present in the three important components of the system. For example, the quantity of the constituent in the mixed sludge inventory is calculated by multiplying by the volume of the tank below the effluent decant pipe (114 m^3) by each specific analysis based constituent concentration. A similar process is used to calculate the mass of the constituents in the effluent water. The calculation of the mass of input by the liquid manure is a bit more complex. In this case the concentration in the mixed manure and sludge is multiplied by the total volume of the tank then the mass in the resident sludge is subtracted leaving the mass of constituent contributed by the incoming manure.

On an average, the BOD, COD and suspended solids were reduced more than 97%.The concentration of total Kjeldahl nitrogen (ammonia plus organic nitrogen compounds) in the treated effluent was measured as 100 mg/l or less throughout the data collection period. This degree of nitrogen removal suggests that nitrification and de-nitrification were being accomplished. The long aeration period was sufficient to convert ammonia N to nitrate N which was subsequently converted to elemental nitrogen gas and discharged harmlessly to the atmosphere during the entire monitoring period. The accumulation of total Kjeldahl nitrogen in the sludge during the final thirty days of the trial suggests an inadequate period of anaerobic/anoxic treatment during that phase of operation. Modification of the operational protocol will be tested in future research to alleviate this situation.

Table 5. Average concentrations of measured constituents in influent and effluent of BSBR

Constituent and time	Number of samples	Influent to BSBR	Sludge inventory	Mixed manure and sludge	Effluent to the storage tank

BOD, mg/l					
Sep. 24 - 30	2	1,300	520	790	50
Oct. 1 – 15	5	1,240	590	820	17
Oct. 16 – 31	3	1,100	980	1,120	3
Nov. 1 – 15	3	2,350	1,300	1,720	40
Nov. 15 – 30	5	2,430	1,130	1,600	65
Dec. 1 – 5	1	3,560	1,360	2,150	103
Weighted average		1,830	940	1,280	39
COD, mg/l					
Sep. 24 - 30	2	5,200	2,130	2,360	80
Oct. 1 – 15	5	3,800	2,200	3,000	56
Oct. 16 – 31	3	2,700	2,610	2950	40
Nov. 1 – 15	3	6,500	4,520	5,740	140
Nov. 15 – 30	5	6,900	3,782	5,320	220
Dec. 1 – 5	1	10,500	4,530	7,170	340
Weighted average		5,370	3,160	4,190	128
SS, mg/l					
Sep. 24 - 30	2	3,900	1,530	2,380	24
Oct. 1 – 15	5	4,700	1,990	2,960	3
Oct. 16 – 31	3	4,100	3,180	3,510	14
Nov. 1 – 15	3	6,800	2,920	4,290	85
Nov. 15 – 30	5	5,100	2,640	3,520	140
Dec. 1 – 5	1	6,000	3,020	4,080	210
Weighted average		5,000	2,500	3,400	67
TKN, mg/l					
Sep. 24 - 30	2	500	180	290	140
Oct. 1 – 15	5	390	470	290	90
Oct. 16 – 31	3	220	270	250	90
Nov. 1 – 15	3	250	590	800	100
Nov. 15 – 30	5	1,070	540	730	107
Dec. 1 – 5	1	2,800	1,060	1,720	31
Weighted average		660	476	382	98
Settleability,					
ml/l (SVI)	2		52 (34)		
Sep. 24 - 30	5		100 (50)		
Oct. 1 – 15	3		140 (44)		

Oct. 16 – 31	3	330 (113)
Nov. 1 – 15	5	390 (148)
Nov. 15 – 30	1	350 (116)
Dec. 1 – 5		227 (91)
Weighted average		

Table 6. Mass of various constituents based on the measured concentrations and the appropriate volumes

	Number of samples	Constituent present in the sludge, kg	Constituent added by the fresh waste, kg/day	Constituent present in the effluent flowing to the storage tank, kg/day
BOD				
Sep. 24 - 30	2	59	82	3
Oct. 1 – 15	5	67	79	1
Oct. 16 – 31	3	103	70	1
Nov. 1 – 15	3	148	150	5
Nov. 15 – 30	5	130	155	8
Dec. 1 - 5	1	154	227	12
COD				
Sep. 24 - 30	2	280	330	4
Oct. 1 – 15	5	295	240	4
Oct. 16 – 31	3	350	175	3
Nov. 1 – 15	3	610	415	9
Nov. 15 – 30	5	510	440	14
Dec. 1 - 5	1	610	670	22
Suspended solids				
Sep. 24 – 30	2	170	250	2
Oct. 1 – 15	5	230	300	1
Oct. 16 – 31	3	360	260	1
Nov. 1 – 15	3	330	430	5
Nov. 15 – 30	5	300	325	9
Dec. 1 – 5	1	340	380	14

TKN				
Sep. 24 - 30	2	20	32	9
Oct. 1 – 15	5	55	25	6
Oct. 16 – 31	3	31	14	6
Nov. 1 – 15	3	67	16	6
Nov. 15 – 30	5	61	68	7
Dec. 1 - 5	1	125	180	2

Based on the data in Table 6, it is clear that the mass of BOD, COD, suspended solids and Kjeldahl nitrogen in the flush water represents a reduction of over 95% when compared to the manure being flushed from the barn. Although this represents a very high degree of treatment, it does not achieve an effluent suitable for immediate discharge to most receiving streams. Additional treatment possibilities include a biofilter or pond storage to further lower the constituent concentrations. An alternative is to use the effluent as a replacement for fresh water in manure flushing.

CONCLUSIONS

This paper describes the evaluation of an alternating sequencing batch reactor incorporated with biofilm media as a part of a manure management system for a group of existing confinement pig barns that were designed on the basis of high water use. The SBR system involved an above ground vertically sided tank fitted with both aeration and with a solid medium to increase and maintain a high level of bacterial population under aerobic and anaerobic/anoxic conditions in the SBR tank. The system was evaluated based on its performance in removing organic matter and nitrogen.

The main conclusions are as follows:

1. The BSBR treatment system was able to reduce about 98% of the BOD, COD, and SS present in the influent pig manure waste.
2. The average TKN removal was 85% of the influent TKN concentration even under highly variable loading conditions.
3. The settleability of the sludge was very good as indicated by average SVI value of about 90 and values less than 150 at all times. This has significant implications for future processing of sludge through thickening and dewatering to convert it into useable product such as compost.
4. The system operated without any discernible odors at the top of the treatment tank.
5. The system has a very small “foot print” meaning that it did not require that a large land area be allocated to the waste treatment facility. The BSBR tank is 7.62 m in diameter.

The BSBR system is currently being operated to treat the waste from ECWLM animal facilities, and further research dealing with optimization of N removal is being conducted. Future research includes investigation of P removal to meet discharge requirements, and increasing cost effectiveness of the operation.

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