Engineering an Innovative Bioreactor with Existing Lagoon System for Dairy Wastewater Treatment/Reuse – A Pilot Plant Study

Eulsaeng Cho, Piyalerg Kangsil and P.Y. Yang

Graduate Program in Bioengineering, Department of Molecular Biosciences and Bioengineering, University of Hawaii at Manoa **Corresponding author:** P.Y. Yang, Department of Molecular Biosciences and Bioengineering, University of Hawaii at Manoa, Honolulu, HI 96822; phone: 808-956-8459; fax: 808-956-9269; email:pingyi@hawaii.edu

ABSTRACT *One of a large dairy farm (60 acres of land with 1,600 livestock) located on the island of Oahu, Hawaii is investigated for potential integration of the existing lagoon system with cost effective pretreatment unit process. Based on the laboratory study, a pilot plant has been installed two 10 m^3 of anaerobic bioreactor. Two layers of media "Bio-nest" providing void volume of 98% are placed into each anaerobic bioreactor at 19% based on the bioreactor water volume. For better performance and reduction of shock load, the equalization/settling tank is employed prior to the first anaerobic Bio-nest reactor. The installation of an intermediate holding tank follows the second anaerobic Bio-nest reactor. It is for settling of effluent suspended solids from the Bio-nest reactor and adjustment of loading rate in order to improve the performance of aerobic EMMC (Entrapped Mixed Microbial Cell) bioreactors. At this time, the installation of EMMC reactor is under progress. During 25 days operation of the Bio-nest system at organic loading rate of about 1.5 g/l/d, the production rate of biogas from the first and second Bio-nest reactors is 0.69 l/l/d and 0.17 l/l/d, respectively. Methane production rate is 0.43 l/l/d in the first Bio-nest reactor and non detectable in the second reactor. This indicates that anaerobic degradation of organics occurred mainly in the first Bio-nest reactor due to the low loading rate. The effluent from the Bio-nest system shows TCOD removal of 78% and SCOD removal of 67%. Further investigation is undergoing with increasing organic loading rate, and the EMMC reactor will be integrated to reuse the treated wastewater for floor washing/flushing.*

Keywords. *Bio-nest, Entrapped Mixed Microbial Cell, biogas, Methane, anaerobic degradation*

Introduction

Anaerobic lagoon system has been applied in many livestock farms for years in the managing wastewater (US EPA, 1983). Although the lagoon system is considered as low cost, less maintenance and easy operation system (Pearson et al., 1987; Mara et al., 1992; Maynard et al., 1999), it still has many problems involved, such as odor generation, groundwater contamination, surface water pollution and lagoon sludge clean-out. These problems will be more obvious when the intensifying livestock operation is practiced. It will be expected the poor treatment performance if the design lagoon volume is under the increased organic loading rate applied. In order to relieve listed weakness for the existing lagoon system, an appropriate cost-effective pretreatment unit process needs to be developed.

One of large dairy farms (60 acres of land with 1,600 livestock) located on the island of Oahu, Hawaii is investigated for potential integration of the existing lagoon system with cost effective pretreatment unit process. The wastewater of 1,136 m^3/day generated from the milk parlor is currently discharged to the existing lagoon systems (72.6 x 15.2 x 1.83 m^3 for each volume). The wastewater generated from milking center mainly composed of milk waste produced by washing milking equipment, walking way flushing waste and manure flushing waste. Because of the under designed lagoon, the effluent from the existing lagoon system is not allowed to be reused for flushing the milk parlor. Also, lagoon sludge clean-out is posed as another maintenance problem. Apparently, a pre-treatment unit process to be integrated to this lagoon system is required for possible reuse of treated wastewater and protection of environmental quality.

A series of laboratory scale of the innovative biological pretreatment unit process including anaerobic "Bio-nest"- a special prepared media- and aerobic "EMMC" (Entrapped Mixed Microbial Cell) bioreactors were investigated for the potential treatment of this wastewater. The final effluent qualities after these series of treatment are TCOD of 650-750 mg/l, TBOD5 of 15-22 mg/l, TN of 90 mg/l, TP of 9 mg/l and SS of 50 mg/l (Dong, 2003). This effluent quality is considered to be suitable for holding in the lagoon system for further reuse/disposal.

Currently, a pilot plant including two 10m^3 of anaerobic Bio-nest reactors with a 3.8 m^3 of aerobic EMMC reactor has been installed and operated in this dairy farm in order to determine a set of design and operation criteria for potential integration of existing wastewater treatment/reuse systems.

Reactor system of Pilot plant

A pilot plant for treating milk parlor wastewater and reuse consists of a primary settling/equalization tank, two anaerobic reactors, an intermediate holding tank and an aerobic reactor. The pilot plant layout and configurations of the reactors are depicted in Figures 1 and 2, respectively.

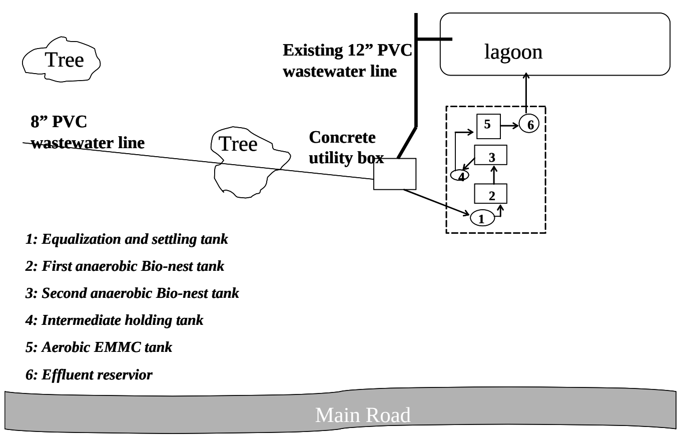


Figure 1 Layout of pilot plant process

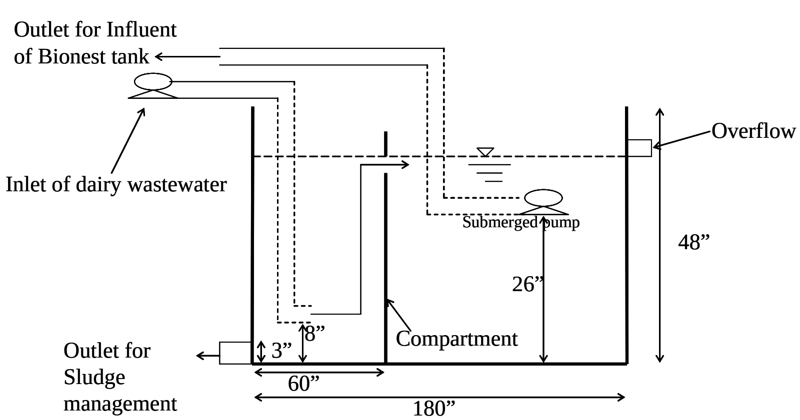
The primary settling/equalization tank of 16.7 m^3 is used to overcome the operational problems and to improve the performance of the downstream process by pre-removal of high solids concentration and reduction of shock loading caused by variations in the influent wastewater strength. As shown in Figure 2(a), this tank is compartmentalized into two zones for better solids settling. Raw wastewater goes into the first zone that allows grit/heavy solids to settle to the bottom and then it goes into the second zone. The submerged pump for providing wastewater to the anaerobic reactor is placed at 0.7m high from the bottom in the second zone

Two anaerobic reactors are made of isophthalic polyester (Harrington Industrial Plastics LLC). Each reactor has a volume of 10 m^3 with a 182.88cm inside diameter and 381 cm depth. The water volume of each reactor is about 8.4 m^3. In order to distribute influent wastewater evenly to the Bio-nest reactor, 12 feed holes of ¾" diameter are made on the both side of inlet feeding PVC pipe that is placed at the bottom of tank. Two layers of "plastic string" (referred as Bio-nest) as media are placed into the each anaerobic reactor in order to increase the retention time of biomass (Figure 2(b)). The Bio-nest media of 19% based on the water volume is occupied in each reactor. It is made of PVC and provides a void volume of 98.6%. Each reactor has three sampling ports at 0.38m, 1.6m and 3.2m height from the reactor bottom. If necessary, sludge can be discarded through the sludge wasting outlet at the bottom of reactor. On the top of each reactor, there is a vent for gas collection and a safety valve. Two gas meters (Measurement Control Systems, AM-250) are installed to measure the biogas from each Bio-nest anaerobic reactor to separately collect gas and analyze its composition. Besides, the separation of gas can enhance the bioreactor stability since it can protect syntrophic bacteria from the elevated levels of hydrogen that are produced mostly in the first anaerobic Bio-nest bioreactor. In order to protect corrosion of gas meter, iron sponge is placed inside of pipe line prior to the gas meter.

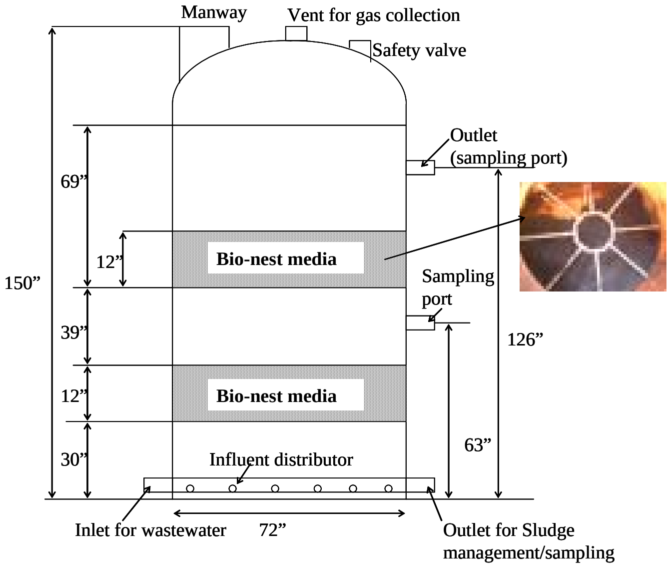
For the intermediated holding tank, the dome vertical tank of 1.89 m3 (Mr. Sandman, Inc., Model#JS-120) with 119.38 cm inside diameter and 182.88 cm depth is placed between the second "Bio-nest" reactor and the aerobic EMMC reactor. The overflow can be discharged to the lagoon. The part of effluent suspended solids from the Bio-nest reactor will be settled in the intermediate tank before going to the aerobic EMMC reactor.

The fabrication of EMMC reactor (sandman #TC7272IA, 3.8 m^3) is under progress with 30% packing ratio of EMMC carriers. In order to provide air to the tank, an air blower (Ametek Rotron Inc. model# DR523K58, 3HP) and 5units of membrane disc diffuser (Sanitaire, model #2261-LP9, 9" LP diffuser with 3/8"ø orifice) will be installed. For further high oxygen transfer efficiency, a well will be placed in the center of the tank as shown in Figure 2(d). The circulation of water containing dissolved oxygen through the center well can accomplish better mixing and oxygen transfer.

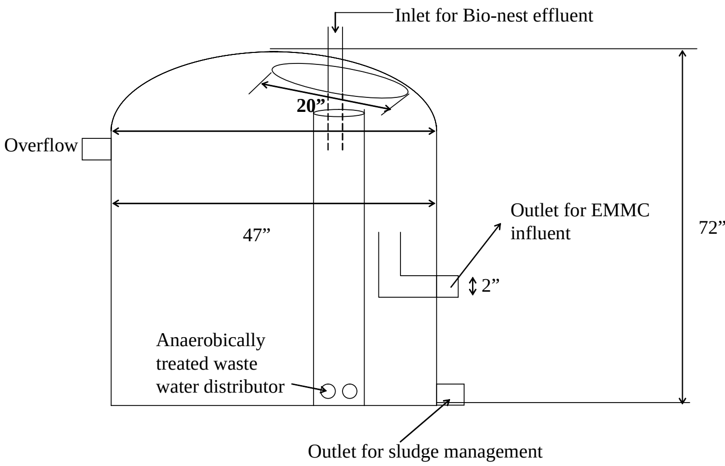
Sludge produced from each unit process is proposed to be further processed by an existing composting plant for the dairy cow manure generated from this farm.



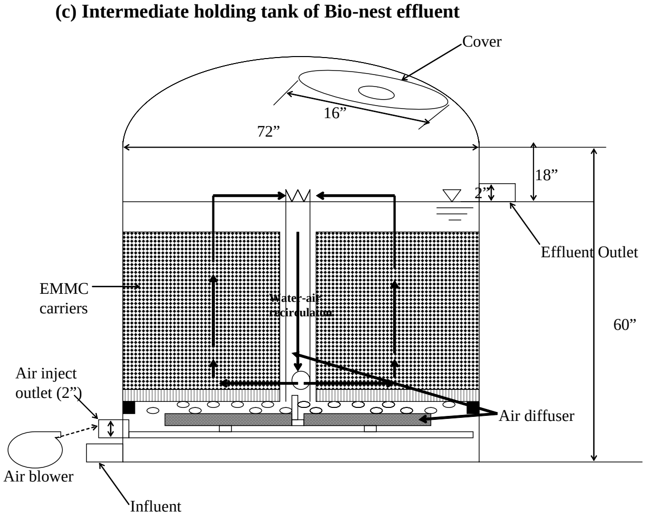
(a) Primary settling/Equalization tank



(b) Bio-nest reactor



(c) Intermediate holding tank of Bio-nest effluent



(d) EMMC reactor

Figure 2 Configuration of each reactor

Start-up and operation of anaerobic Bio-nest system

Two anaerobic Bio-nest reactors were seeded with the anaerobic sludge taken from an anaerobic digester at Hawaii-American Water Company in Honolulu, Hawaii. The Bio-nest reactors are allowed to acclimate at ambient temperature (25-30) without feeding for about 2 weeks and then wastewater of about 3.8 m^3 is fed in an upflow pattern to the Bio-nest reactors twice in a week, corresponding to a HRT of 15 days. After acclimation period, the Bio-nest system is started up at organic loading rate (OLR) of about 1.5 g/l/d, corresponding to the HRT of 2 days. Feeding is intermittently applied at schedule of 1h on/off to provide effective biomass and substrate mixing and to prevent biomass washing out. The equalization/settling tank removed TCOD and SS at about 28% and 30%, respectively. The operation results obtained for 25 days are shown in Table 1. The removal efficiency is calculated based on the effluent of the primary settling /equalization tank. Most of biogas is produced from the first Bio-nest reactor. This indicates that anaerobic degradation of organics involving hydrolysis/acidification and acetogenesis/methanogenesis mainly takes place in the first Bio-nest reactor due to the low organic loading rate. Increase of organic loading rate is in the progress.

Table 1 Performance of Bio-nest system at OLR of 1.5 g/l/d

	Primary Eff.	Bio-nest 1 Eff.	Bio-nest 2 Eff.	Removal, %
TCOD, mg/l	3178	1695	779	75.5
SCOD, mg/l	1207	596	443.3	63.3
Biogas, l/l/d	N/A	0.64	0.15	N/A
Methane, %	N/A	63.7	N/A	N/A

Conclusion

Pretreatment unit process consisting of a primary settling/equalization tank, two anaerobic Bio-nest reactors, an intermediate holding tank and an aerobic EMMC reactor is being installed and investigated in order to provide design/operation criteria for potential integration of existing wastewater treatment system. The start-up of anaerobic Bio-nest system accomplished TCOD removal of 76% with methane production of 0.2 L per 1 g of COD removed at organic loading rate of about 1.5 g/l/d. Due to low loading rate, the biogas is produced mainly from the first Bio-nest reactor. Further study will continue with increasing loading rate, and the EMMC reactor will be integrated to treat the effluent of Bio-nest aerobically for reuse. A proposed agricultural production and environmental protection system integrating with existing lagoon is shown in Figure 3.

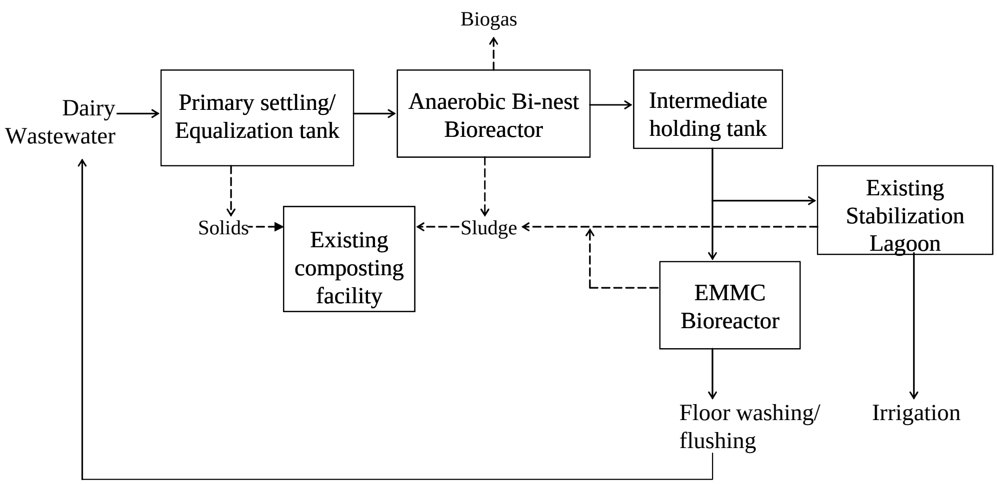


Figure 3 A proposed sustainable agricultural production and environmental protection system integrating with existing lagoon system

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