

Piggery Slurry Composting Using Batch Operating Autothermal Thermophilic Aerobic Digestion System

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ABSTRACT : The performance of an autothermal thermophilic aerobic digestion (ATAD) system was studied to determine if nitrogen loss, as ammonia, was affected by an exhaust gas condenser. The system was run with and without a condenser while treating 8 m³ of piggery slurry for 8 days. The system with a condenser (SWC) maintained the reactor temperatures above 40°C for 2 days during the 8 days run, while the system without a condenser (SWOC) remained above 40°C for 6 days. The SWC maintained the reactor temperatures mostly at mesophilic conditions while the SWOC at thermophilic conditions. Differences in operation conditions for the two runs were mainly caused by differences in atmospheric temperatures. Soluble chemical oxygen demand (SCOD) and volatile solids (VS) removal efficiencies of the SWC (SCOD: 62%, VS: 41%) were higher than those of the SWOC (SCOD: 40%, VS: 20%). The total Kjeldal nitrogen (TKN) removal efficiency of the SWC (7%) was less than that of the SWOC (25%). The concentration of total volatile fatty acids (VFA) in the SWC was observed to be lower than the threshold value of 0.23 g total VFA/L after 6 days, while the SWOC progressed below the threshold value after 3 days. No offensive odor emissions were observed in either run, which suggest that the use of the ATAD system may be a good odor removal strategy. (*Asian-Aust. J. Anim. Sci.* 2006. Vol 19, No. 2 : 273-279)

Key Words : ATAD, Nitrogen Loss, Ammonia Loss, Condenser, Odor, VFA

INTRODUCTION

During the last few decades pig production has intensified in Korea. Development of pit gravity drain systems for livestock waste collection has led to an increase in the number of pigs per unit of production area. Pit gravity drain systems collect feces and urine together under a slatted floor, which was mainly designed to reduce labor requirements. Pig farming in S. Korea produces about 25.8 million metric tons of waste each year, mostly as slurry (MAF, 2000). The high moisture content of slurry makes handling and transportation difficult. In addition, its various concentrations of organic matters and pollutants limit higher treatment efficiencies of engineered systems developed for treating industrial and municipal wastes. Improper management of piggery slurry, high in organic matter, can result in pollution of streams, lakes, and groundwater. It is believed that the rapid decrease of water quality in water bodies in S. Korea is attributed to improper pig waste treatment and intensification of pig production in recent years. Therefore, the effluent standard of livestock wastewater has been reinforced and the Korean Government has imposed new legislation, the Odor Control Law, to abate odor emissions from concentrated livestock operation facilities. Because of the great number of complaints filed by neighbors of these livestock facilities

the odor prevention law has been extended to livestock producers.

Many kinds of livestock waste treatment systems have been applied to pig farms in Korea in last two decades, such as anaerobic digestion, activated sludge process, advanced treatment processes, and composting systems. Jung and Kim (1999) reported that 89% of animal farms in S. Korea were equipped with at least one of these animal waste treatment systems and only 17% of purification and 74% of composting facilities were being operated properly. The comparatively low rate of operation may be attributed to higher labor and management requirements to maintain high operational efficiencies. Livestock waste treatment systems should require simplified operation and cost-effectiveness for farmers to implement them effectively.

Land application of manure to cropland, which is the most popular practice in US and EU, can be considered as one of alternative for livestock waste treatment systems in S. Korea. However, limited cropland, application time, and environmental risks, such as odor emission and water pollution, may jeopardize this practice. Improper application of manure can lead to nitrate leaching into groundwater, phosphorus runoff into surface water, and a variety of other water pollution problems. Along with water pollution problems, odor nuisance is also of concern and is the single most serious complaints filed in local governments in S. Korea at the present.

The autothermal thermophilic aerobic digestion (ATAD) system has some attractive advantages to circumvent the aforementioned limitations of land application. The ATAD has demonstrated faster degradation rates of organic matters,

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Table 1. The compositional properties of feed slurries

	TS ³ (%)	VS ⁴ (%)	TCOD (g/L)	SCOD (g/L)	TKN (g/L)	NH ₄ -N (g/L)	Total VFA (g/L)
SWC ¹	2.9	69.7	43.0	27.1	3.9	2.3	13.1
SWOC ²	3.2	63.8	44.1	25.6	4.5	3.4	9.8

¹ System with a condenser, ² System without a condenser.

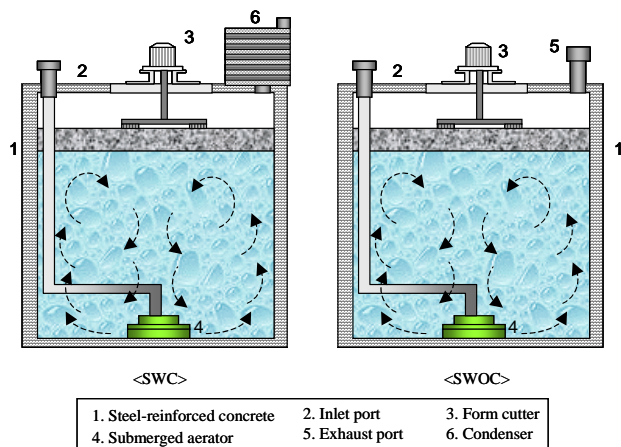


Figure 1. Schematic view of a pilot ATAD system (SWC: system with a condenser, SWOC: system without a condenser).

rapid inactivation of pathogenic microorganisms due to the thermophilic range of the slurry temperature, and effective reduction of odorous compounds. In addition, treated slurry can be utilized as a liquid fertilizer for crops and fruit trees.

Thermophilic aerobic digestion has been proven to be an effective process for higher organic waste treatment by many researchers since the late 1960s. High levels of off-gas ammonia releases are commonly observed in thermophilic aerobic systems. Recovery of nitrogen lost in the form of ammonia is important to raise the fertilizer value of slurry by trapping emitted ammonia during ATAD operation.

A condenser with exhaust pipe may be an alternative solution to reduce ammonia emissions in thermophilic aerobic systems. For this reason, the influence of a condenser on the efficiency of nitrogen recovery and odor abatement in an ATAD was investigated in this study.

MATERIALS AND METHODS

Feed slurry

The experimental pig house, located at Collegiate Livestock Experiment Station, housed 200 pigs, which are raised from a weight of 30 to 105 kg. Pig slurry was stored in the pit, beneath the concrete-slat floor, and drained into an underground concreted-walled storage tank by gravity. The slurry was mixed with a submersible mechanical aerator to prevent sludge deposition on the bottom of the storage tank and separated by a 100-mesh and 200-mesh

two-layer screen vibrator. Coarse solids were removed from the slurry and the liquid fraction was discharged into the MultiFunctional Storage (MIFS). The compositional properties of the feed slurry after separation are shown in Table 1.

Thermophilic aerobic digestion process

General schematics of the SWC and SWOC are shown in Figure 1. The reactor had a total volume of 10.5 m³, with the working volume limited to 8 m³ to allow head space for the build-up and collapse of foam. The walls of the reactor were made of a 200 mm thick reinforced concrete with 100 mm insulation materials (Styrofoam plate) placed inside the wall, except on top and bottom walls.

Normally foam is produced during aerobic treatment. To combat this, the reactor has a foam cutter, which runs on and off in 20-min intervals, to break down the foam bubbles into a liquid. The foam cutter was driven by a 0.75 kW electric motor installed at the top of the reactor. If the foam cutter does not work properly, the aerator automatically stops to avoid over-foaming. Air in the headspace was exhausted through an 80-mm diameter pipe. The incoming air is drawn through a 40 mm diameter plastic pipe by a 1.5 kW submersible aerator to supply fresh air (2.2 m³/m³/h) to aerobic bacteria and to mix the slurry in the reactor to prevent sludge deposition. Two different experiments for the SWC and the SWOC were implemented in this study. The SWC equipped with a condenser was evaluated to investigate the influence of its function on the treatment efficiency of the thermophilic aerobic digestion process. The water vapor in the exhaust gas was condensed and flowed back into the reactor. The condenser was constructed from 15-mm diameter hose wound around the outside of a 100 L cylindrical tank and was cooled by tap water. The system was run in a batch-operating mode. The reactor was initially filled with 8 m³ of piggery slurry and continually aerated for 8 days.

Measurements made during the experiment

During the experiments, the ATAD system was comprehensively monitored. The temperatures of the reactor slurry and the exhaust and ambient air were recorded with a data logger (Angus Electronics Company, USA). The samples of feed and treated slurry were taken every day or every other day at sampling spots, the feed slurry pump, inlet pipe, and the submersible pump outlet

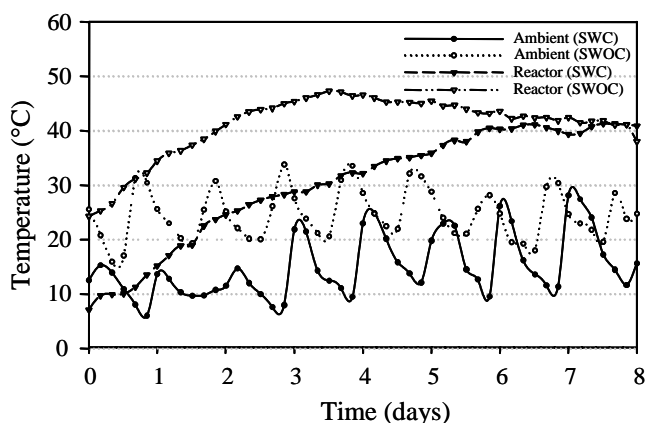


Figure 2. Temperatures of slurry and ambient air (SWC: system with a condenser, SWOC: system without a condenser).

pipe. Five liters of sample slurry was taken, homogenized, and 1 L used for analysis to ensure the sample to be a representative. The pH and ORP measurements (InoLab pH Level1, DO-2F/KRK, and Hanna instruments) were taken immediately after sampling. Soluble chemical oxygen demand (SCOD), total solids (TS), and volatile solids (VS) were determined according to standard methods (APHA, 1998). Total Kjeldal Nitrogen (TKN) was determined by the auto-kjeltec system. Ammonia nitrogen ($\text{NH}_4\text{-N}$) and nitrate nitrogen ($\text{NO}_3\text{-N}$) were analyzed using an ion chromatography. The volatile fatty acids (VFA) were determined using a gas chromatograph (HP 6890, Hewlette-Packard Inc., Avon-dael, PA) with a flame ionization detector (FID).

RESULTS

Variation of temperatures

Although both systems used similar feed slurry and operated under the same condition the SWOC showed higher temperatures than the SWC (Figure 2). The SWC reached a reactor temperature of approximately 40°C after six days, and maintained a similar level until the experiment end. The temperature of the SWOC system reached roughly 40°C in a two days, rose to a maximum temperature of 47°C at day 4, and then steadily decreased with time. The mean temperature of feed slurry in the SWOC was observed to be 18°C higher than that in the SWC. This may be caused by 10°C higher atmospheric temperatures during the entire period of experiment for SWOC than the time for the SWC.

The temperature of the pig slurry gradually increased with time because of exothermic oxidation of pig slurry. Heat liberated by the organisms through endogenous metabolism was responsible for the 10-30°C higher than ambient temperature achieved in this system without addition of external energy (Gould et al., 1978; Mohaibes and Heinonen-Tanski, 2004). This heat may play an

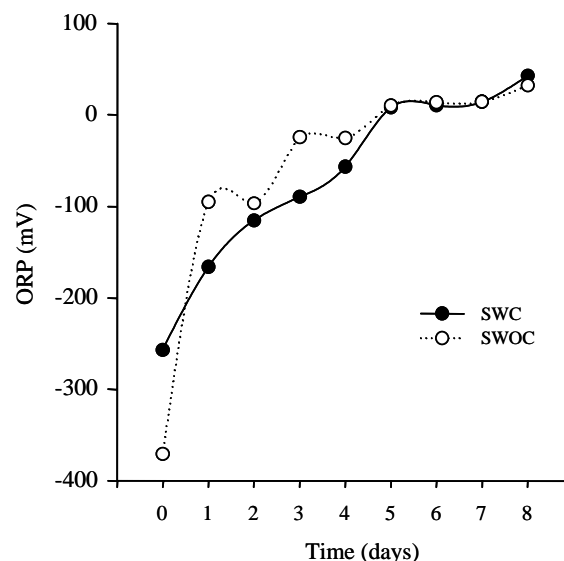


Figure 3. Temporal variation of ORP (SWC: system with a condenser, SWOC: system without a condenser).

important role in killing pathogenic bacteria and weed seeds in piggery slurry and may be able to be utilized as a supplemental heat source for greenhouses and livestock houses.

Oxidation-reduction potential (ORP)

Dissolved oxygen (DO) concentration is generally used to monitor and control the aeration level in a wastewater treatment reactor, but a level below 0.9 mg/L is quite difficult to measure at high temperatures (Burton, 1992). ORP can be used as a surrogate indicator of DO for high organic concentration wastewater at high temperatures. McIntosh and Oleszkiewicz (1997) defined anaerobic conditions as ORP values of less than -300 mV and anoxic conditions in the range of -225~0 mV.

Figure 3 shows the ORP variations with HRT (Hydraulic Retention Time) for the SWC and the SWOC. An aeration rate of 2.2 m³/h/m³ produced ORP values which ranged between -257 mV and +43 mV in the SWC and -371 mV and +32 mV in the SWOC. ORP values increased with HRT in batch operating mode. From this data it is assumed that the reactor was operated in anoxic conditions during the first four days. This indicates that the aeration strategy applied in this study was not suitable for supplying a sufficient amount of oxygen into the biomass. The aeration flow rate is generally designed according to the concentration of organic matter in the substrate. Researchers have suggested very wide ranges of aeration rates. The EPA (1990) suggested that an air input value of 4 m³/h/m³ of active reactor volume is appropriate. Skjelhaugen (1999) applied a low aeration flow rate (0.2-0.5 m³/h/m³ of active reactor volume) to his system and reported high performance. Even when a high aeration rate

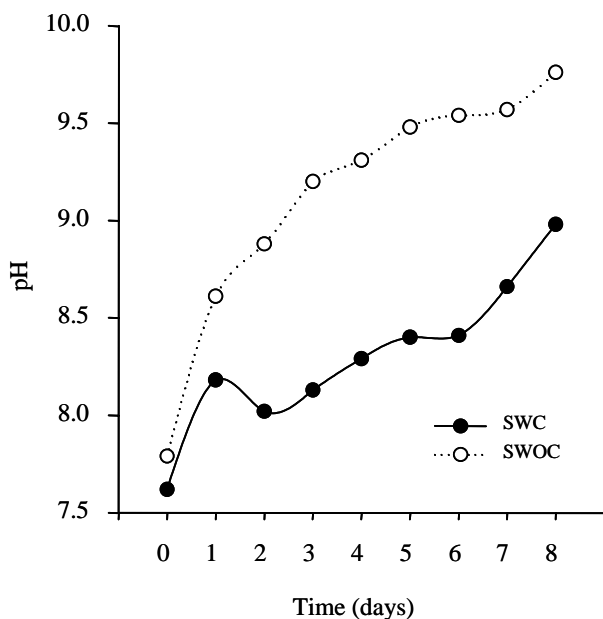


Figure 4. Temporal variation of pH (SWC: system with a condenser, SWOC: system without a condenser).

($2.2 \text{ m}^3/\text{h}/\text{m}^3$) was applied in this study, low ORP values were measured. This indicates that it is necessary to increase the aeration rate to increase biodegradability.

Variations of pH

The pH levels typically observed in ATAD systems tend to be slightly above 8.0 (U.S. EPA, 1990). Similar to the results of the preceding report, pH levels were measured between 8.0 and 9.7 in this study, as shown in Figure 4. The pH rose from 7.6 to 9.0 for the SWC and from 7.8 to 9.8 for the SWOC. The pH increase is mainly attributed to the ammonification of proteinaceous matter, transformed from amine groups (deamination process) to ammonia in the feed slurry. When ammonia is released into the pig slurry it creates alkalinity by forming a weak base.

Variations of SCOD

The SCOD reduction was 62% and 40% of the feed slurry in the SWC and the SWOC, respectively (Figure 5). The removal efficiency of SCOD in the SWOC was lower than that in the SWC. This result indicates that high temperature conditions may not be suitable to maintain optimum performance. Many researchers have reported contrary conclusions on the effect of temperature on biodegradation efficiency. Duke et al. (1981) reported the best performance was observed at 35°C for treating combined municipal and industrial wastewater, for the experimental temperature range of $35\text{--}52^\circ\text{C}$. Lapara et al. (2001) reported the SCOD removal efficiency declined as temperature increased from 30°C (62%) to 60°C (38%). Visvanathan and Nhien (1995) treated a modified municipal

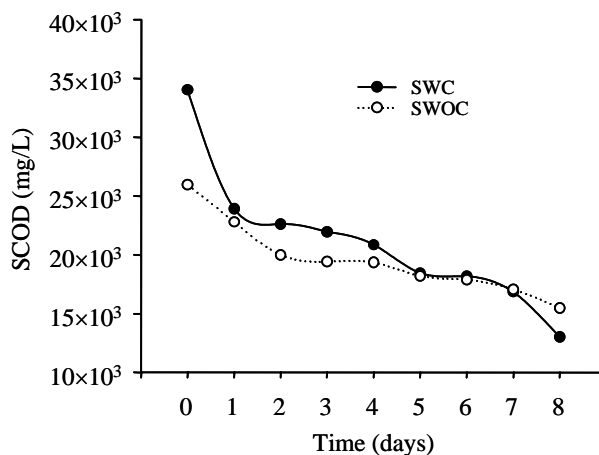


Figure 5. Temporal variation of SCOD (SWC: system with a condenser, SWOC: system without a condenser).

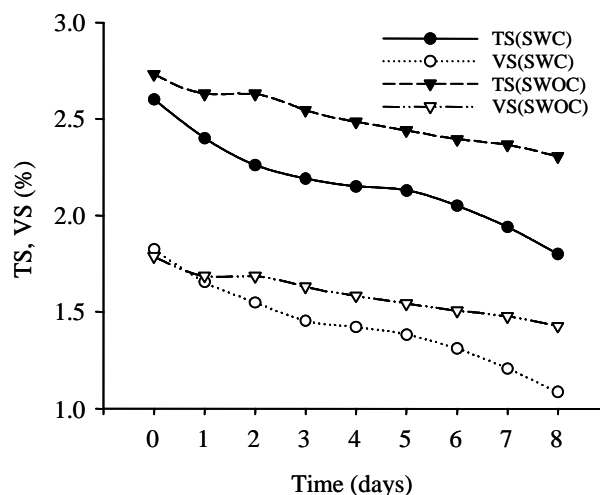


Figure 6. Temporal variation of TS and VS (SWC: system with a condenser, SWOC: system without a condenser).

wastewater at $30\text{--}55^\circ\text{C}$ in a submerged aerated biofilter and observed that the process performance declined as temperature increased. Their reports are in accordance with the results acquired from this study. However, Gould et al. (1978) and Matsch and Drnevich (1977) reported the biodegradation rate increased considerably with increasing temperature, which contradicts the latter reports. Further research is needed to clarify this ambiguity.

Variations of TS and VS

Figure 6 shows the temporal variations in TS and VS concentrations for both treatments. The TS reduction in the SWC was 31% while only 16% in the SWOC. WEF (1998) reported VS reductions of 40% or greater in a German ATAD system with detention times longer than four days. The VS reduction rate of the SWC was observed to be 41%, which was similar to the WEF (1998). However, the VS reduction rate in the SWOC was only 20%. The removal

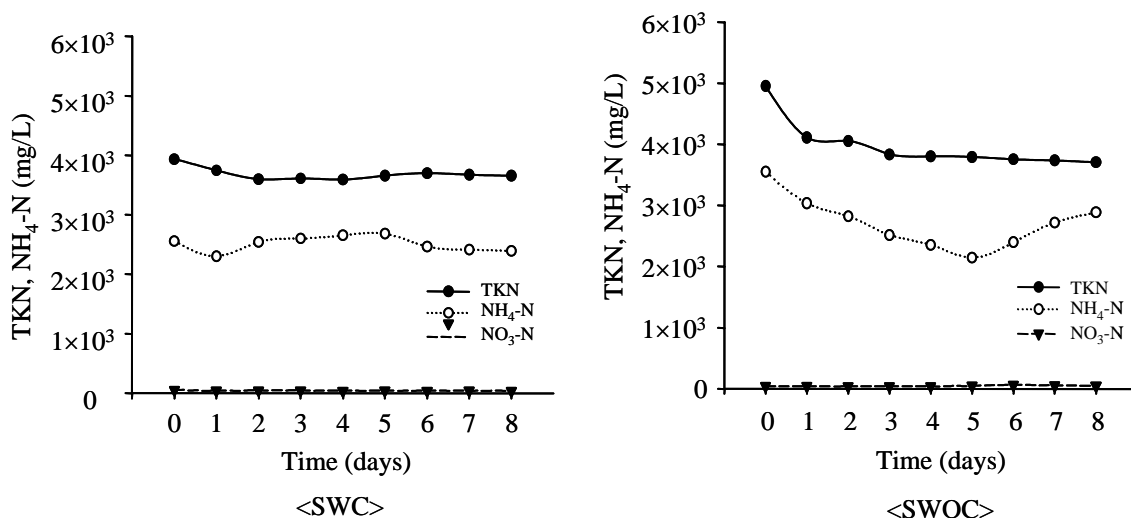


Figure 7. Temporal variation of nitrogen (SWC: system with a condenser, SWOC: system without a condenser).

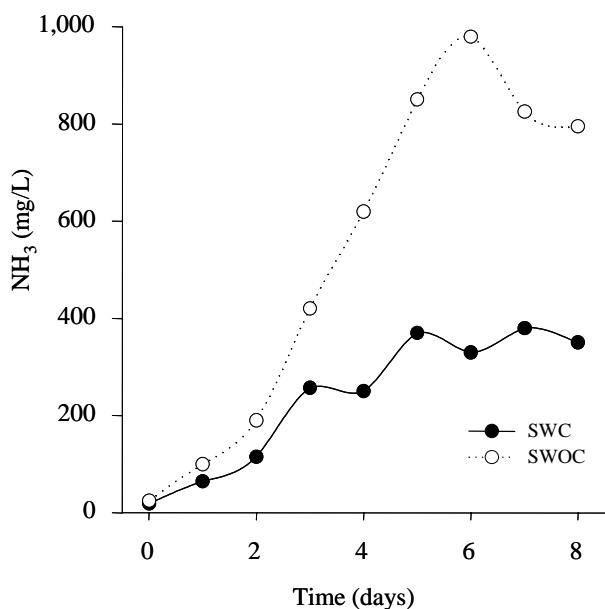


Figure 8. Temporal variation of NH₃ concentration measured at the exhaust port (SWC: system with a condenser, SWOC: system without a condenser).

efficiencies of TS and VS in the SWOC were observed to be lower than those in the SWC. This result indicates that high temperature conditions are not suitable for optimum removal efficiency (Duke et al., 1981; Visvanathan and Nhien, 1995; Lapara et al., 2001), which agreed with previous findings.

Effect of treatment on nitrogen component

TKN reductions were 7 and 25% in the SWC and the SWOC, respectively. The removal efficiencies of TKN and NH₄-N in the SWC were much lower than those in the SWOC in Figure 7. Since the condensed water was recycled back into the reactor in the SWC, some of nitrogen was

recovered in the form of ammonia and ammonium ion was lost by aeration. However, ammonia was volatilized in the SWOC without recovery of nitrogen. In addition, the relatively high temperature of the SWOC caused higher levels of ammonia volatilization. Hence, TKN and NH₄-N concentrations in the SWC were much higher than those in the SWOC. The difference in TKN reduction between the SWC and the SWOC was found to be significant according to paired comparison t-test at a 99% confidence interval (p<0.01). This phenomenon agrees with ammonia concentration variations measured at the exhaust port in the SWC and the SWOC. The ammonia concentration of the SWC was remarkably lower than that of the SWOC, as shown in Figure 8. However, no significant change of NO₃-N concentration was measured between the treatments. Since nitrifying bacteria are inactive under high temperature conditions of above 40-45°C, there is a low possibility of nitrogen removal by nitrification in this system (Burton, 1992; Staton et al., 2001).

Variations of total VFA

VFA has been used as a suitable odor indicator for swine manure by many researchers (Barth and Plkowski, 1974; Schaefer, 1977; Spoelstra, 1980; Williams, 1984; Zahn et al., 1997). Burton and Sneath (1995) reported a total VFA concentration of 0.23 g/L corresponds to the beginning of offensive odors. As shown in Figure 9, VFA concentration progressed lower than 0.23 g VFA/L at the day 6 in the SWC and day 3 in the SWOC, which indicates no offensive odors were emitted. ATAD system may be considered an effective odor abatement method.

DISCUSSION

The temperature of the SWOC were 10-20°C higher

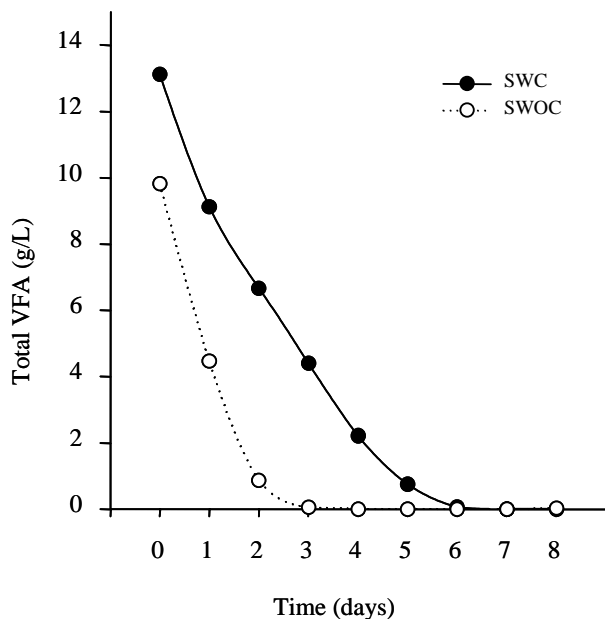


Figure 9. Temporal variation of total VFA concentration (SWC: system with a condenser, SWOC: system without a condenser).

than that of the SWC for the first 5 days, but both treatments reached similar temperature after 5 days. The SWC observed reactor temperatures above 40°C for the last 2 days of the 8-day run, while the SWOC stayed almost the same temperature for 6 days. The higher ambient temperatures and less heat lost in the SWOC may have caused the higher pig slurry temperatures.

The SCOD and VS removal efficiencies of the SWC were 22 and 21% higher than those of the SWOC, respectively. The effect of the temperature on the biodegradability of organic material is a controversial subject among researchers. It has been widely accepted that the pollutant removal efficiency of ATAD systems are proportional to temperature under 60°C. However, adverse effects of high temperature on ATAD process at the range of 50-60°C have been reported. Further research may need to be done to clarify the different observations.

The removal efficiency of TKN in the SWC was lower than that of the SWOC. The emitted ammonia was recovered in the SWC, and accumulated in the water trapped by the condenser. In addition, the higher temperature of the SWOC caused the higher ammonia emission rate.

VFA concentration progressed lower than 0.23 g VFA/L at the day 6 in the SWC and day 3 in the SWOC, which indicated no offensive odor was emitted. ATAD system may be considered an effective odor abatement strategy. It is concluded that SCOD and VS removal efficiencies can be improved and nitrogen loss as ammonia reduced by running an ATAD system with a condenser at a mesophilic temperature range.

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