Anaerobic Diegestion: Applying Anaerobic Technology to Satisfy Livestock Waste Treatment Regulations.

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ABSTRACT

Anaerobic digestion has been proven to be a beneficial application for treating livestock wastes. Benefits of anaerobic digestion include; reduction of odors, renewable energy in the form of biogas, stabilization and pollutant removal, and retention of nutrients for land application. Conventional digesters have been an established method of anaerobic treatment for a long period of time. However, they have many unfavorable qualities such as large reactor volumes, high capital cost, high maintenance requirements, complex operations, high risks of failure, high solids waste, long hydraulic retention time and overall slow treatment. To improve conventional methods, highrate anaerobic digestion systems have been developed and new, innovative technology of these systems continues to improve the anaerobic digestion process. With increasing federal and statewide regulations for animal feeding operations and technological improvements, highrate anaerobic systems could prove to be an economical application for dairy and livestock wastewaters in Iowa. Research is being conducted to obtain information on how different processes effect characteristics of the waste for pre-treatment before digestion. Fixed film anaerobic digesters have been implemented and research continues for dairy flush system application in Florida. The Upflow Anaerobic Sludge Blanket and modifications have been widely implemented in Europe and the US, newer technologies such as the Sequencing Batch Reactor and Static Granular Bed Reactor have shown to be effective anaerobic technologies as well. Studies have been conducted to compare the SGBR to SBR and UASB processes.

KEYWORDS: Anaerobic Digestion, High rate systems, SGBR, UASB, FFAD, ASBR

INTRODUCTION

Animal feeding operations are regulated by the state Department of Natural Resources in Iowa. Larger feeding operations are required to have manure management plans for safe handling of waste. Anaerobic digestion could be incorporated into manure management plans with the primary benefits of odor reduction and energy production in the form of methane that can be used on-site. Anaerobic digestion is a three step process where soluble and particulate organic material is broken down by different groups of bacteria in the absence of oxygen to produce biogas. The biogas mostly consists of methane, CH_4 and carbon dioxide. High rate anaerobic systems separate the solids retention time and hydraulic retention time (HRT). The SRT can be increased giving microorganism a chance to grow and accumulate inside the reactor which can operate at significantly shorter HRTs than for traditional systems. Short HRTs allow for much smaller reaction volumes making high rate systems a faster and cheaper process. High rate systems can be categorized as attached or suspended growth. High rate systems have been successfully implemented in the US and throughout Europe for treating wastewaters that are typically dilute in nature, since high solids would clog and slow down many systems. This paper is an overview of anaerobic digestion for dairy farms and state of the art research on high rate anaerobic systems.

LIVESTOCK WASTE REGULATIONS

The majority of livestock farming systems in the US have evolved to confined feeding operations. Large numbers of animals concentrated in a small amount of space generate excessive waste that must be treated. Federal and state regulations have been established to protect against pollution of ground and surface water sources from such facilities. Animal feeding operations (AFOs) in the state of Iowa are regulated primarily by the Iowa Department of Natural Resources (DNR). The DNR regulates land-applied manure, construction of feeding operations and additions to existing operations. The regulations an AFO must comply with are determined by factors such

as capacity, feeding system type, operational procedures, topography and animal farmed. There are two main categories of AFO systems used in Iowa; confined feeding operations and open feedlots.
Open feedlots confine animals but are not completely covered. Below is a list of registered open feedlots in Iowa based on animal units.

	1-300 AU	301-1000 AU	1001 and up	Total
Northeast Iowa:	63	109	5	177
North Central Iowa:	64	72	6	142
Northwest Iowa:	185	333	96	614
Southwest Iowa:	151	202	49	402
South Central Iowa:	69	79	7	155
Southeast Iowa:	62	41	4	107

Figure 1: Iowa Open Feedlots as of Dec, 2005
(Iowa DNR)

These systems must comply with DNR regulations. Environmental regulations for open feed lots include: preventing discharge into public lakes and wells, not violating state water quality standards, preventing surface and ground water pollution, and operation permits when determined by IA Administrative Code. Operational permits fall under the Iowa DNR National Pollutant Discharge Elimination System (NPDES) issuing section. Operation permits are required for open feedlots if feedlot capacity is greater than 1,000 beef cattle, 2,500 swine, and 700 dairy cattle. Operation permits are required for less capacity if the feedlot discharges directly into state waters. (Iowa DNR, 2007).
Confined feeding operations are the most heavily regulated for the state. In confined feeding operations livestock are kept under completely covered structures. Environmental regulations for confined feed lots include: storing all manures onsite until land-application, reporting manure release to DNR within 6 hour, and incorporating a manure management plan (NPDES permit) for larger operations greater than 500 animal units. (Iowa DNR, 2007).
As of July 31, 2007 all livestock producers with NPDES permits are now required to submit a nutrient management plant (NMP) to the DNR before applying manure or releasing wastewater. As a result of new and future regulations, livestock operations continue to improve methods for handling waste in order to meet state regulations.

LIVESTOCK WASTE TREATMENT BY ANAEROBIC DIGESTION

Anaerobic digestion is the decomposition of organic material by microorganisms in an oxygen free environment. The end products are methane gas (CH_4), carbon dioxide (CO_2), stabilized organic matter, and a small fraction of additional gasses, mainly hydrogen sulfide.
Improvements to anaerobic technology show it has potential for treatment of livestock waste with the bonus of harvesting methane gas. The methane gas can be used to produce energy and reduce polluting emission. Other benefits of anaerobic digestion include; odor reduction, pathogen reduction, water pollution control, and green technology appeal, while retaining nutrients for fertilization.
The anaerobic process can be summarized in three stages according to active bacteria functions; hydrolysis, acid formation (acidogenesis), and biogas production. The first step of anaerobic digestion is hydrolysis. During hydrolysis liquefying bacteria convert part of the organics into liquefied soluble organic material. For livestock waste these organics consist of lipids, polysaccharides, protein, and nucleic acids. The intact inorganic and insoluble organic materials along with water pass through to the effluent. Since it can take some time for solid organics to hydrolyze this is usually the rate limiting step. The second step is acidogenesis, also known as

fermentation. During this process acid forming bacteria further degrade soluble, organic material into short-chain organic acids. The organic reactants serve as the required electron acceptors and donors. In this step acetic acid is converted into acetate. Propionate and butyrate are two intermediates that can be further degraded to acetate, hydrogen, and carbon dioxide when hydrogen is maintained at a low concentration.

In the last step, biogas production, methanogenic bacteria convert the short-chain organic acids into methane and CO2. Methanogens in anaerobic digesters are similar to bacteria naturally found in the digestive tracts of cattle. They can be dived into two different groups of bacteria based on substrates consumed. Aceticlastic methanogens utilize acetate to convert into methane and carbon dioxide while hydrogen-oxidizing methanogens utilize hydrogen as the electron donor and carbon dioxide as the electron acceptor to produce methane. Aceticlastic bacteria reactions account for about 70% of the total methane produced. Hydrogen-reducing bacteria account for about 30% of methane production. Methane can also be produced by acetogens that use carbon dioxide to oxidize hydrogen and form acetic acid that is converted into methane. However, this an insignificant amount compared to other dominating reactions. Methanogens are pH and temperature dependant. Methenogenic bacteria are able to grow under phycophilic, mesophilic, and thermophilic temperatures at increasing rates with increasing in temperatures. The mesophilic temperature range (30-35°C) is most common and preferred for anaerobic digestion. At this range methanogens produce sufficient conversion of organic acid to end products and operations can be controlled. Biogas reactions at the phycophilic temperature range (around 15°C) are inefficient and only common in covered lagoons existing in northern regions. Most anaerobic processes avoid thermophilic temperature ranges (50-60°C) due to difficulties with operational control and energy input expense. Digestion at thermophilic temperatures is currently being researched for its pathogen reduction and stabilized sludge benefits in wastewater treatment.

Livestock waste can be harvested for energy production from methane in biogas when appropriate anaerobic technology is applied. According to the EPA, dairy cows have a high estimated yield of 40,000 Btu biogas production per animal on average. Swine have a high estimated yield of 300 Btu average per animal (EPA 2005). This shows potential for making anaerobic digestion an economical application in animal operations waste treatment.

PARAMETERS

Total solids (TS) is a measure of the solid material in a sample by weight after drying. The TS consists of soluble and suspended solids that are either volatile or fixed. Volatile solids (VS) are determined by calculating the weight of solids that are burned at high temperatures (550°C). VS can be useful in calculating methane potential. For high rate systems is it desirable to have a high fraction of solids in soluble and volatile form.

Volatile fatty acids (VFAs) can be a good indication of an anaerobic digestion process. Fermentation and methanogenesis reactions take place in sequence and are dependent upon each other. When a system is treating a large amount of soluble organics the preceding step reacts quickly and can cause a build up of hydrogen and intermediate acids indicated by VFA. This can have a reducing effect on pH and inhibit methane conversion from intermediates.

Chemical oxygen demand (COD) tests for the influent and effluent are critical for analyzing wastewater treatment. The COD test indirectly measures the amount of organic material and gives the removal efficiencies of organic pollutants from anaerobic digestion. Also, higher COD concentrations will yield greater amounts of methane per volume influent. Hence the COD can be used to calculate theoretical methane yield from anaerobic digestion. High chemical oxygen demands (CODs) of 1,300 to 50,000 mg/L are required for anaerobic digestion to be feasible. Sufficient levels of COD will produce enough methane to heat the wastewater to mesophilic temperatures without requiring an external source. When COD is lower than 1,300 mg/L aerobic digestion is favored. (Metcalf and Eddy, 2004).

A pH value around 7 is ideal for anaerobic digestion. Since a significant portion of the gas produced is CO_2, a high alkalinity is required to maintain a close to neutral pH. Typical alkalinity ranges from 2,000 to 4,000 mg/L as CaCO3. It may be necessary to supplement wastewater with additional alkalinity to ensure process effectiveness. Anaerobic bacteria are dependent on pH to be reactive; methanogens are among the most sensitive and require a pH around neutral to produce methane.

Toxic Compounds
Ammonia toxicity can be a concern to anaerobic digestion especially with livestock manure operations which contain high amounts of protein and amino acids that can be degraded to ammonium. Methanogenic activity is inhibited by high concentrations of free ammonia which is a function of temperature and pH. Ammonia thresholds measured in NH_3-N were found to be from 100-500 mg/L depending on adjustment time. (Metcalf and Eddy, 2004).
Hydrogen sulfide can be a detrimental byproduct in anaerobic digestion processes. High concentrations of sulfide are toxic to methanogenic bacteria. Combustion of sulfur compounds causes air pollution. It is also odorous and corrosive. Sulfide problems occur when there are high levels of sulfate coming into the digester with sulfate-reducing bacteria present. The sulfate-reducing bacteria use sulfur compounds as electron acceptors and consume COD to produced harmful hydrogen sulfide gas. The sulfate-reducing bacteria compete with the methanogens for COD which reduces the amount of methane produced when hydrogen sulfide is produced instead.

AEROBIC DIGESTERS

Common digesters include traditional and newer high rate systems. A graph of agricultural digestion methods used in 2005 for the US is shown below.

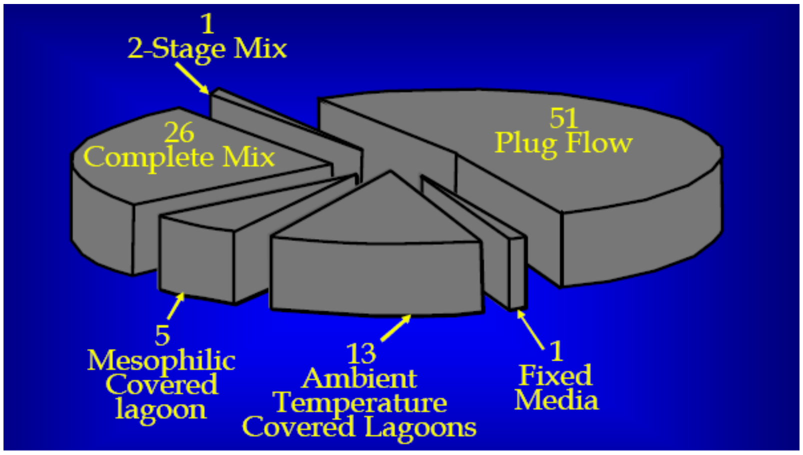

Figure 2: US Agricultural Digesters
(EPA, 2005)

Traditional Systems
Traditional anaerobic digestion systems have been used for many years. Traditional digesters can be categorized as complete-mix or plug flow. Plug flow method is where waste is input into the digester and remains unmixed until sufficient time for the anaerobic process to occur. This typically requires long retention times of 20-50 days. The complete-mix process has equal solids and hydraulic retention times. The influent is completely mixed in a tank through various mixing techniques. The retention time is usually 15 to 30 days for adequate reaction to take place. Traditional systems have many unattractive features that make it unfavorable. Some problems with the traditional systems are long hydraulic retention times, solid retention dependant on hydraulic retention, large reactor volumes, may require external heat source, complicated operations, high maintenance, and large occurrence of past failures. These problems provide opportunities for technological improvements. High rate systems are improvements to traditional anaerobic digestion processes. In high rate anaerobic digestion the hydraulic retention time is separated from solids retention time. Biomass is recycled in the system and has a 10% lower

yield. Advantages of high rate processes are: greatly reduced hydraulic retention time, increased organic loading rate, increased solids retention time due to less biomass wasted, smaller reaction volume, faster treatment at high removal efficiencies and biogas production. However, high rate anaerobic digestion is not suitable for livestock waste high in total suspended and undegradable solids. The high rate systems are capable of treating the soluble fraction of waste and risk becoming clogged by particulates.

High Rate Systems

This section provides an overview of high rate anaerobic digestion processes and their applications. There are well known high rate technologies currently used as well as many modifications and new developments being researched. The high rate anaerobic processes can be divided based on suspended or attached bacteria growth. Suspended growth systems have the biomass unattached to filter media. The earliest application of anaerobic digestion in wastewater treatment was suspended growth systems (Metcalf and Eddy). Anaerobic suspended growth processes include complete-mix, Anaerobic Contact Process, Horizontal baffled reactor, anaerobic sequencing bath reactors (ASBR), Upflow Anaerobic Sludge Blanket (UASB), and the The anaerobic contact process is similar to the complete-mix but incorporates a settling tank used for biomass recycling to extend solids retention time longer than hydraulic retention time. This allows the reactor volume to be significantly reduced and more economical. Sludge is settled typically by gravity before recycling. Like the complete-mix process, the anaerobic contact has been modified and less preferable to new technologies.

The horizontal baffled reactor is distinguished by its horizontal flow configuration. It functions similar to the Upflow Anaerobic Sludge Blanket reactor with a large population of small anaerobic bacteria. (Burke, 2001).The biomass remains to the bottom of the reactor by gravity. Flow is directed through baffles that prevent solids from traveling through to the effluent.

The Anaerobic Sequencing Batch Reactor (ASBR) is a batch fed system divided into four steps. The first step is feeding the reactor, followed by a reaction step where solids and substrates are periodically mixed to give uniform distribution. The third step is settling of sludge and last, decant of treated effluent. The four step process has been performed at hydraulic retention times as low as 3 to 24 hours. (in class hand-out).

The Upflow Anaerobic Sludge Blanket (UASB) is the most common sludge blanket process capable of treating a variety of wastewaters. The USAB has an upflow configuration where screened influent enters the bottom and travels through a sludge blanket which consists of high settling circular granules. Treatment takes place in the blanket layer at the bottom of the reactor. A liquid-gas separation apparatus is attached at the top to collect biogas and effluent separately. The UASB can treat high volume COD wastewaters with low solids. One downfall of the UASB is the risk of losing reactive solids with the effluent due to buoyancy and process imbalance. Modifications to solve this problem include installing an external solids capture system or implementing packing material at the top of the digester.

The Static Granular Bed Reactor (SGBR) is similar to an attached growth anaerobic fluidized bed reactor utilizing suspended bacteria to treat waste water as it passes through suspended bacteria inside the reactor. The SGBR consists of active anaerobic granules that are whole ecosystems of microorganisms. The SGBR operates in a downflow manner, a distinct difference to popular high rate anaerobic systems such as the UASB. Benefits of the SGBR include: active granules do not waste space, downflow configuration prevents buoyancy problems, relatively cheap and simple technology. The technology was developed at Iowa State University. Research has been done with SGBR application to swine slaughterhouse, synthetic, and municipal wastewaters as well as landfill leachate. A side view of the SGBR is shown in figure 3.

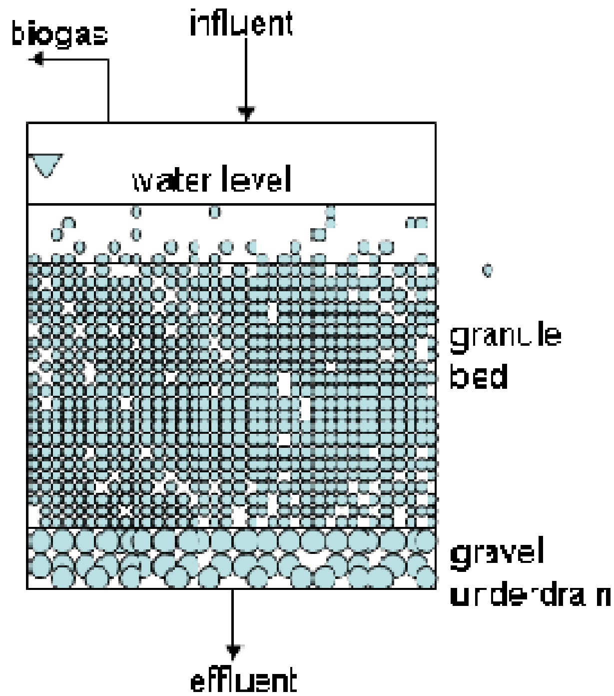

Figure 3. Static Granular Bed Reactor schematic
(Ellis and Evans, 2007)

Anaerobic attached growth systems include anaerobic filters, fluidized bed reactors, and fixed film processes. The anaerobic filter is usually an upflow digestion process where influent flows from the bottom through packing material. The packing material typically consists of some variety of plastic media placed either throughout the entire volume or a fraction of the upper height in hybrid filters. The influent flowrate is reduced to prevent washing out of accumulated biomass. When biomass reaches its solids retention time it must be removed by flushing or draining to prevent clogging on packing material. The anaerobic attached growth filter can handle a high organic loading within a small reactor volume as long as the concentration of suspended solids is low. The main concern is packing material cost and clogging due to solids build up.
The Fluidized Bed Reactor (FBR) is a continuously fed upflow reactor that can be classified as an attached or suspended growth process. The FBR operates at high velocities to expand the sand packing material into suspension. Bacteria attach to the fluidized sand particles and are then capable of treating the wastewater while it passes. As biomass continues to accumulate on the sand, the particles decrease in density and rise to the top of the reactor. These lighter particles need to be periodically removed to prevent high suspended solids release in the effluent. Like other high rate processes, the FBR is most effective for wastewaters with higher soluble COD concentrations. The main disadvantages with this system are its long startup time and cost of packing material and pumping power.
The fixed film anaerobic digester (FFAD) is an attached growth method that can be used as either upflow or downflow configuration. The fixed film digester is a large volume tank filled with plastic media that allow bacteria to attach to and grow forming a biofilm. The fully submerged media utilizes the anaerobic bacteria to treat wastewater as it passes through the tank. A schematic of the fixed film digester is shown in Figure 4.

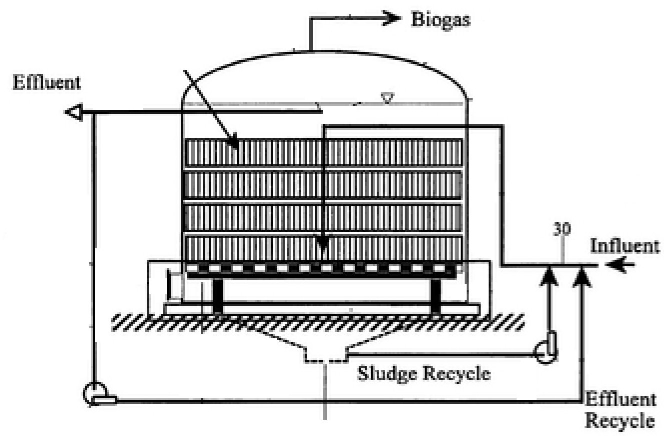

Figure 4: Fixed Film Digester schematic
(EPA, 2007)

Extensive research is currently being done in at the University of Florida's Institute of Food and Agricultural Sciences Dairy Research Unity (DRU) for dairy wastewater treatment.

RESEARCH

This year Wen et al published results from anaerobic digestion of dairy wastewater in the Journal of Chemical Technology and Biotechnology. Three main objectives of the conducted research were to determine impacts of organic strength and loading rate parameters on anaerobic digestion efficiency, and observe phase separation effects. The dairy source used a hydraulically flushed system that separated solids from the manure using a belt screen separator. The solids were used for composting while the liquid was discharged into a lagoon for storage. Originally the water was taken from the lagoon and used as recycled flushwater. The experimental set up consisted of five continuously stirred tanks arranged in sequence. The five 4.5 liter tanks were set at 35°C temperature and stirred at 30rpm.
Three different influent streams were compared; the first stream (A) was taken directly from the lagoon. The second stream (B) was made from fresh manure mixed with four parts water by weight. The third stream (C) was made from fresh manure mixed with two parts water by weight. The purpose of streams B and C were to simulate slurry taken from the flush system prior to lagoon settling. The three influents were tested for COD, TS, VS, VFA, total nitrogen, ammonia nitrogen, alkalinity, and pH. Characteristics of the three waste streams are summarized in table 1 below:

Parameter	Stream A	Stream B	Stream C
COD (mg/ L)	10,530	19,350	30,870
TS (mg/ L)	8,180	17,860	27,610
VS (mg/ L)	5,560	13,430	20,880
VFA (mg/ L)	313.2	801.3	1,475.8
Total nitrogen (mg N / L)	724	410	543
Ammonia nitrogen (mg N / L)	447	109	183
Alkalinity (mg CaCO3 / L)	1,286	2,051	3,691
pH	7.28	7.39	7.22

Table 1: Parameters of Three Waste Streams
(Wen et al, 2007)

Stream A had the lowest original COD, TS, VS, and VFA concentrations due to the natural degradation that took place during lagoon setting and flush water recycling. The reuse of lagoon water for flushing allowed solid organic nitrogen to become soluble and mix into wastestream. This accounts for the high total and ammonia nitrogen in stream A (Wen et al.). The three influent streams were tested at loading rates of 2L/d at 2 L working volume and 1.5 L/d at 3 L working volume. Results are summarized in table 2 below.

	Stream A	Stream B	Stream C
Q = 2 L/d V = 2 L			
Biogas (L/d)	2.21	4.86	8.10
Methane (L/d)	1.24	3.28	5.78
TS removal (%)	26.73	39.73	45.82
VS removal (%)	25.90	37.90	43.52
COD removal (%)	24.04	34.22	41.82

Table 2: Efficiencies for Each Wastestream
(Wen et al, 2007)

Results suggest that wastewater streams with higher organic strength will have greater COD and solid removal efficiencies as well as greater biogas and methane production (Wen et al, 2007). Tests to determine phase separation effects were simply done by observing biogas production and taking pH and VFA measurements. The system showed no signs that phase separation of anaerobic digestion was taking place. This was accounted for by the high concentration of VFA and buffering capability from sufficient alkalinity in the influent. The estimated alkalinity required for 35*C with values of 1,500 to 2,400 mg/L as $CaCO_3$ supports this (Metcalf and Eddy, 2004).

Dairy Manure Characteristics
It is useful to understand the difference between characteristics of the liquid and solid manure fractions. High rate anaerobic technology utilizes the liquid fraction of manure for methane production and waste treatment. High rate digesters effectively degrade only the soluble matter due to lower HRTs for microorganisms to act. Hence, it is desirable for the waste streams to have organic matter primarily in soluble form and high biodegradable chemical oxygen demand (COD_{BD}) or most of the total COD be in the soluble form (SCOD). Rico et al researched characteristics of manure components based on phase. Tests were performed after screening the manure through a 1mm sieve then further separation with coagulation-flocculation and settling which achieves a better solid-liquid separation than mechanical devices. The objectives were to retain the total solids (TS), total Kjeldahl nitrogen (TKN), and phosphorus (P_2O_5) in the solid fraction while obtaining organic matter of mostly soluble form in liquid fraction.
After separation the wastes were analyzed. The solids fraction was found to be 30.7% of the final mass and contained 60, 72, 82, and 89% of the total TKN, TS, VS, and P in the manure respectively. In the liquid fraction 86.3% of the total COD was in soluble form. (Rico et al). Methane production was measured as total accumulation and specific production. Methane accumulation was greatest for unscreened manure before solid-liquid separation and least for the liquid portion. When converted to specific methane production by dividing accumulation by VS the values were greatest for the liquid and least for the unscreened. The liquid manure took eight days to produce 90% methane expressed as percent of final production. While the screened and unscreened manure achieved only 46 and 38% methane production. The manure required a minimum of 18 and 24 days to reach 90% production. (Rico et al, 2007). For this type of separation to be implemented large-scale it would require a large separating mechanism such as a belt filter press after coagulation-flocculation. This would be an additionally significant cost.

Dairy Wastewater Characteristics and Fixed Film Digestion
One of the most important aspects of anaerobic digestion is the influent characteristics. High rates systems require particular influent parameters that must be within certain ranges in order to be functional, efficient, and economically feasible. Continuous research has been performed to characterize influent streams from dairy manure wastewaters. Many variables such as animal

diet, facility size, flush systems, pretreatment (solid separation), and temperature have been measured in attempt to understand effects on wastewater characteristics and how it will effect anaerobic digestion performance.
A market has been found in Florida for anaerobic digestion with fixed film technology since the majority of Florida dairies use large amounts of water in a flush system that is later used for land irrigation. High rate digestion is a solution for odor control of incompletely digested waste and has the economical benefit for energy production. A 100,000 gallon digester is being studied at a HRT of 3 days at DRU. Results have shown a biogas production of 6,000 ft^3/day. Of this about 80% is methane and 20% carbon dioxide. The biogas production has not been tested throughout winter months and reliability with lower temperatures is currently unknown. Purposed uses for the methane gas include refrigeration for milk cooling, on-site (farm) energy use, hot water for the milking parlor, or automotive fuel. (U.S. Environmental Protection Agency, 2007).
The University of Florida DRU conducted a year-long analysis on wastewater from a dairy flush system for possible anaerobic treatment using Fixed Film digestion. An average of 359 cows contributed to the 502 m^3/day wastewater from flushing two free stall barns and a milking parlor. Measurements of the amount and type of diet fed to the cows, amount and frequency of milking, weight and number of cows, frequency and water volume used in flushing, and the path of the flushwater. Water was flushed from the barns and parlor down collection channels into a sand trap that removed material reused for bedding, through a mechanical separator with bar screen, to a sedimentation basin, and into a sampling pit before storage ponds. Wastewater was pre-treated to remove the amount of fibrous, non-degradable solids which cause scum formation, media clogging, and active volume reduction in the reactor. Characteristics of the wastewater were TS of 3,250 mg/L, VS of 2210 mg/L, COD of 3530 mg/L prior to screening. Wastewater samples were taken after the sedimentation basin to observe effects of the solids separation on wastewater characteristics. It was found that 47% TS, 60% VS, and 42% COD were removed during screening and sedimentation. The COD:VS ratio increased which shows a larger portion of the removed solids were non-degradable and would not be anaerobically digested. COD was decided to be a better indicator of methane potential and used to develop a relationship between predicted COD as a function of flushwater usage based on animal units (AU) as a fundamental design parameter for anaerobic fixed-film digestion. Figure 6 shows COD vs. water use per animal unit per day.

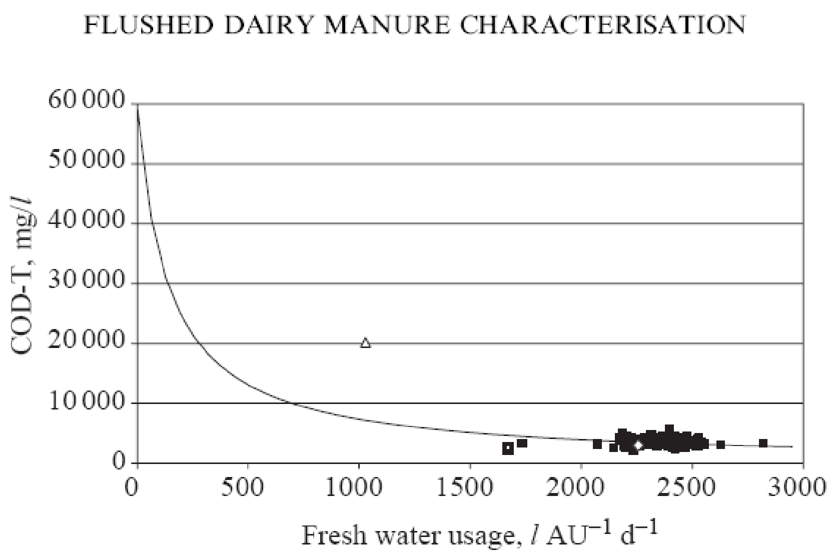

Figure 6: COD and Water User per AU
(Wilkie, Castro, et al, 2004)

Lagoon Effluent Characteristics
Ullman et al. performed research to determined lagoon characteristics of 16 different dairy facilities in Texas. The goal of research was to determine the differences between dry-lot and hybrid dairy operation facilities. Dry lot facilities are where the cows inhabit an open coral area

with no vegetation. Hybrid facilities have smaller dry lot areas along with free stall areas or bedded areas that consist of sand or composted manure material. The environmental effects of these systems were compared by measuring physiochemical characteristics of their lagoon effluents. Samples were taken for a composite of each lagoon profile. The lagoon waste influent came from feed alleys, milking parlors, holding pens, and open lots.

The study found that hybrid dairy facilities have an increasing effect on organic load, NH_4-N concentration, and salt concentrations compared to dry lots. In hybrid systems the cows tend to crowd near flush alleys in free stall areas that also provide attractive conditions such as food, bedding, and cooling. This leads to greater defecation rates and faster waste transport to lagoons via the flush alleys. (Ullman et al 2007). Excessive release of ammonia is an environmental concern since it can run off into and pollute receiving water bodies, causing eutrophication and soil acidification. High salt levels are detrimental to dairy operations by inhibiting bacterial reactions in lagoons and reduce plant productivity from high soil concentrations. There was little difference in pH and TKN values between the two systems. A summary of the dairy lagoon parameters is given in table 4.

Parameter	**Dry lot (*n* = 20)**		**Hybrid (*n* = 29)**	
	Mean	**St. Dev.**	**Mean**	**St. Dev.**
TS (%)	3.5	2.1	4.6	2.7
VS (%)	1.9	1.3	2.6	1.3
pH	7.4	0.1	7.6	0.2
TKN (ppm)	1630	687	2049	775
NH_4-N (ppm)‡	234	116	373	128
P (ppm)*	376	197	547	241
K (ppm)‡	894	191	1727	332
Ca (ppm)	0.16	0.10	0.19	0.18
Mg (ppm)‡	0.03	0.01	0.04	0.01
Na (ppm)‡	260	60	425	104
Zn (ppm)	18.9	10.0	19.5	10.6
Fe (ppm)	13.2	5.4	16.2	10.6
Cu (ppm)†	19.2	20.7	8.1	6.1
Mn (ppm)*	12.9	6.7	19.3	10.5
EC (µS/cm)‡	5604	1107	9121	2714

Table 4: Summary Statistics of Dairy Lagoon Parameters
(Ullman et al, 2007)

High seasonal variations in NH4-N have been found; NH3 emissions were measured to be eight times greater in the summer due to changes in feeding regimen. (Misselbrook et al 1998).

System Comparisons

Comparing different anaerobic processes can be difficult with the numerous variable that are hard to account for. For the purpose of system comparison it is good to conduct multiple reactors using the same methods and minimizing variation. The Upflow Anaerobic Sludge Blanket and Static Granular Bed Reactor performance were tested for comparison of wastewater treatment from a paper and pulp plant. Two 12 liter pilot scale reactors were built at Iowa State University for an UASB and SGBR reactor. The reactors were seeded with granules obtained from the Cedar Rapids Wastewater Treatment Plant. The UASB had 9 liters volume with granules while the SGBR had 8 liters occupied. The testing was conducted in four stages over a four month period. Hydraulic retention time was kept at a constant 24hours during the startup of the experiment. Once stead state was reached the HRT was lowered to 9, 6, and 4 hours. Trace nutrients and alkalinity were added to the wastewater. pH and temperature was measured daily. Total suspended solids (TSS), volatile suspended solids (VSS), and volatile fatty acids (VFA) were measured weekly. COD and gas composition were measured biweekly. It was found that the SGBR had higher COD% removal efficiencies for every HRT except at 9 hour. For the 24, 6, and 4 hour HRTs the SGBR achieved removals of 92, 67, and 73% respectfully. The UASB reached lower efficiencies of 90, 61, and 60% respectfully. COD removal efficiencies were shown to be dependant on HRT and organic loading rate (OLR). Graphed results for COD removal are shown below. Methane production was found to be higher over the 4 month test period for UASB. The UASB had an accumulative methane production of 180 L where the SGBR had a methane production of 163 L. For treatment purposes of industry wastewaters reduction of organics and other pollutants has higher priority over energy production. Both processes had overall low VFA concentrations and low VFA to alkalinity ratios indicating no acid build up and sufficient alkalinity to maintain a pH around neutral. The solids removal was lower for the SGBR which contradicts previous SGBR results where it was found to have high solids removal. The SGBR had a lower calculated biomass yield which could indicate less solids wasted and a higher SRT. Overall both systems performed well and were very comparable on most accounts.

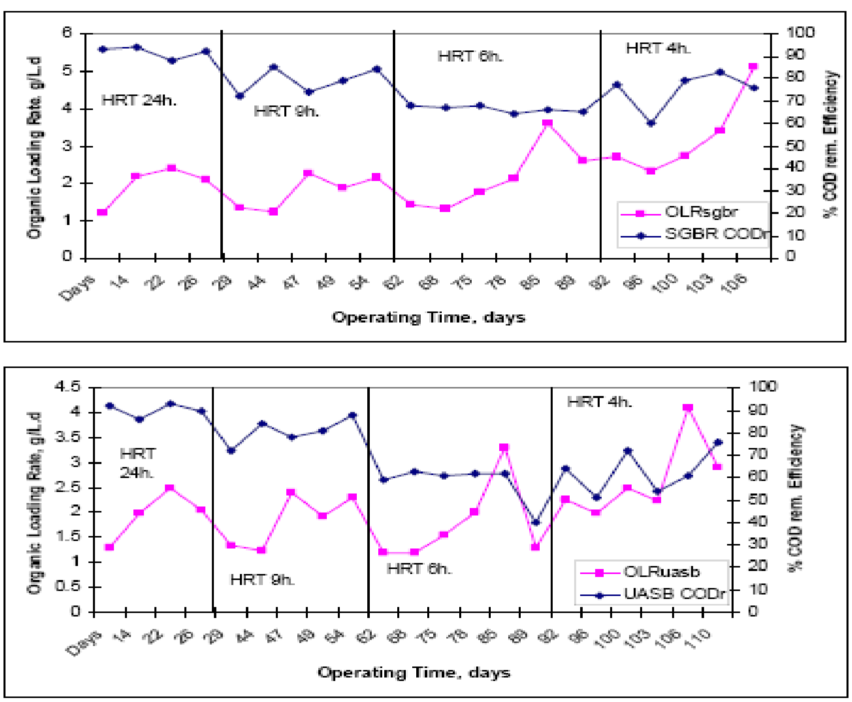

Figure 5: Organic Loading and COD removal for SGBR and UASB Reactors
(Aydinol et al, 2007)

In 2004 a comparative study of the Static Granular Bed Reactor (SGBR) to the Anaerobic Sequencing Bath Reactor (ASBR) was conducted at Iowa State University for the treatment performance of Hormel Foods wastewater. Average wastewater characteristics were: COD of 1,912 mg/L, VFA of 480 mg/L, and SS of 534 mg/L. (Jung et al, 2002). The hydraulic retention times and organic loading rates were controlled as the main variables. HRTs ranged from 48 to 4 hours. Through the experiment and different HRTs, the SGBR had a superior performance compared to the ASBR which failed due to biomass washout at 8hour HRT. The SGBR was then used as an on-site pilot study to treat slaughterhouse wastewater from Hormel Foods. The SGBR showed excellent performance with consistently high COD removal efficiency of over 90% for different HRTs and OLRs. Also the system could go long periods of time without feeding without the delaying reaction rates when restarted.

CONCLUSION

Before choosing an anaerobic digestion method it is essential to know the source and processes of the waste to be treated. Different operations of livestock such as animal type, housing facilities, location of farm, waste storage, and cleaning systems have an important role on the characteristics of the waste produced. It is also important to understand the parameters that characterize the wastewater such as solids, organics, fatty acids, pH, and nutrients. Once these are understood connections can be made between the processes of waste sources and alterations that can be made to produce a desirable waste for anaerobic digestion. One pre-treatment method that may improve waste characteristics is mechanical solid-liquid separation. Highrate anaerobic digesters have many benefits over traditional methods including faster treatment, smaller reaction volumes, and longer solid retention time leading to lower sludge waste. Highrate methods have been proven applicable for wastestreams low in suspended solids, high in soluble COD, and high in biodegradable COD. These highrate systems are able to efficiently reduce COD and solids while producing energy in the form of methane gas. Types of highrate digesters that are currently being used include the Upflow Anaerobic Sludge Blanket (UASB), Fixed Film Digester, and Static Granular Bed Reactor (SGBR). It is difficult to directly compare these methods since performance is dependant on the many types of highly variable wastestreams. These reactors along with other highrate systems mentioned have been shown to achieve excellent treatment and methane production efficiencies. However, no system is perfect and there is still extensive research needed to understand process details in order to make further improvements and work out problems.

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