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Process analysis of manure collection systems at dairy farms and case study of LWR manure treatment system

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ABSTRACT Large manure production from concentrated animal feeding operation (CAFO) is posing pressure on not only our environment also farm operation such as sand lanes and lagoons. However, there is almost no well accepted technology available for manure treatment. One main reason is that most of available technologies do not consider farm manure collection systems during design and operation. In this study, process analysis of manure collection systems of flush dairy and flush flume dairy is first carried out to help identify root causes of difficulty in manure treatment. Then, an evaluation of LWR manure treatment system is presented by site data from full-scale LWR systems at 2 dairy farms in Wisconsin and Michigan.

Keywords: Manure; Dairy Farms; Treatment

INTRODUCTION Livestock industry is a key part of our society. It provides meat and milk for our daily life. With growing demand and world population, livestock farms are switching over to concentrated animal feeding operation (CAFO) to increase meat/milk production and to control operating cost. CAFO is now one main livestock farm operation type in developed countries/regions, especially in US, Canada and Western Europe (Burton & Turner, 2003; Shore & Pruden, 2009).

However, CAFO poses a big challenge to us. It produces much more manure than before. In 2006, the daily Canadian livestock manure reached half a million tons. It means over 180 million tons over the year (Hofmann, 2008). In US, the total number of milk cows, cattle and calves hit 102,988,100 in 2010 (US-Census, 2012). The estimated annual manure was over 1 billion tons, according to ASABE Standard on Manure Production and Characteristics (ASABE, 2005).

The large amount of livestock manure implies potential environmental issues. When not treated properly, livestock manure can cause water, air and soil contamination (Burkholder et al., 2007; Gerba & Smith, 2005; Heederik et al., 2007). Walkerton/Ontario Tragedy is a serious lesson Canadians learned in May 2000 (Hrudey et al., 2003). About 2300 people became seriously ill and 7 died. The drinking water was contaminated by bacteria. And, the primary bacteria source was cattle manure from a farm near a well.

Manure-related environmental issues in turn affect farm operation. CAFO farms have to safely store manure by building more lagoons if they cannot treat or truck it away. As such, CAFO farms see increasing capital cost on lagoons, decreasing available farm land for future expansion and accumulating manure on site. Conventional land application of liquid manure is no longer a good option. Besides negative environmental effects (Oenema, 2004), relatively low concentrations of ammonia/potassium with high concentration of phosphorous plus high trucking cost prevent crop farms applying liquid manure as fertilizer (Powell et al., 2005).

Current manure treatment technology available in market is mainly based on two purposes. First, it is to do liquid/solid separation (Hjorth et al., 2010; Zhang & Westerman, 1997). Phosphorous is related to eutrophication pollution and mainly in solid phase of manure (Christensen et al., 2009; Daniel et al., 1998; Masse et al., 2005; Peters et al., 2011). After liquid/solid separation, liquid manure has a lower concentration of phosphorous and then would be safe for land application (Sharpley et al., 1996). Typical equipment include mechanical screens (e.g slope screens and rotary screens), dissolved air flotation (DAF) and centrifuges (Møller et al., 2000). Second, it is to convert manure to value-added products. Anaerobic digestion is a well-known example. It converts part of organic content of manure to biogas for heat and electricity generation (Wilkie, 2005). Some other promising technologies are also proposed for manure treatment such as gasification, pyrolysis and hydrothermal conversion, but are still mainly under lab-scale research (Buckley & Schwarz, 2003; Ro et al., 2010; Yin et al., 2010).

However, almost no manure treatment technology/system has considered effect of farm operation, especially manure collection system, on manure treatment. Therefore, in this paper, we will start with process analysis of two popular manure collection systems for dairy farms (flush and flush flume). The goal is to identify fundamental causes of difficulty in manure treatment. Then, LWR manure treatment system, which is designed and operated based on the process analysis, will be introduced, followed by case study of full-scale LWR systems at two dairy farms in Wisconsin and Michigan.

PROCESS ANALYSIS OF MANURE COLLECTION SYSTEMS

Flush manure system Flush manure system is shown in Figure 1. It mainly consists of sand lane, screens and lagoons. In barns, as-excreted manure is flushed out by lagoon water. Then, the flushed manure flows through a sand lane and screens to separate sand and fibers, respectively. Subsequently, the screen filtrate flows to several lagoons which help fine solids settle. The top liquid of the last lagoon is then reused and pumped to flush manure again.

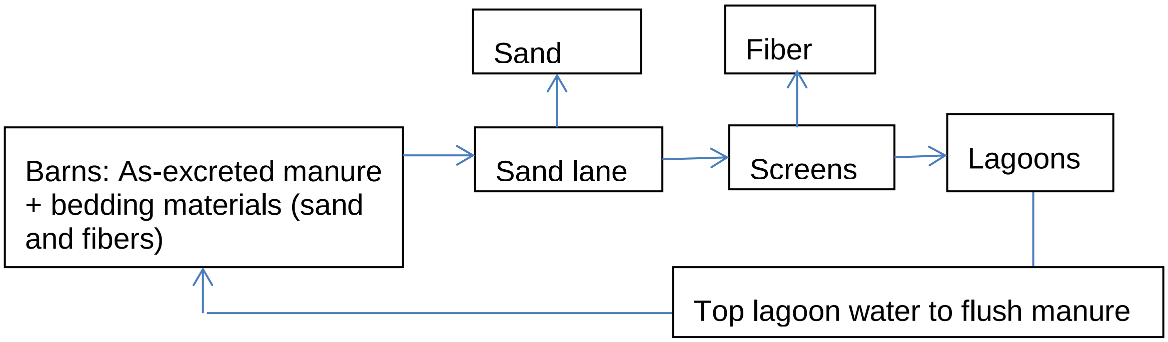

Figure 1. Flush manure collection system

Flush flume manure system Flush flume manure system is similar to flush manure system. But, there are two main differences. As shown in Figure 2, first, as-excreted manure is not flushed out by lagoon water. Instead, the manure is usually scraped into liquid called flume. The flume carries manure to sand lane and screens. Second, the flume is screen filtrate, not lagoon water. Flush flume system has several advantages over flush system. It requires less water to collect manure, and the flume does not freeze in winters because of its relatively high salt concentration.

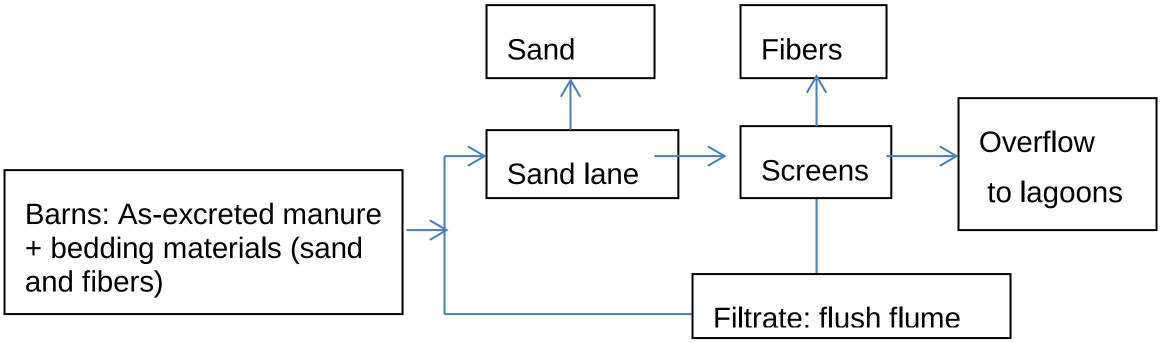

Figure 2. Flush flume manure collection system

Fundamental problems with flush and flush flume manure systems Flush and flush flume systems help farms recycle bedding materials of sand and fibers, however, they have two main fundamental problems. First, they don't reduce manure volume. Second, they are not sustainable operation for farms.

Flush and flush flume manure systems are closed- loop systems. As shown in Figure 1 and Figure 2, the input of flush and flush flume system is as-excreted manure with bedding materials of sand and fibers. After sand and fibers are removed by sand lane and screens, there is no output of manure. As such, manure volume is not reduced, but accumulating in the systems and at farms. With increasing manure volume, farms have to build more lagoons. Given no manure volume reduction, manure is not treated in fact.

Besides no manure volume reduction, the dissolved solid contents of these two systems keep increasing. Dissolved solids refer to dissolved salts and dissolved organics (Rice et al., 2012). They are not separated from manure by sand lane and by mechanical screen. Moreover, due to the closed-loop system design, the liquid in flush/flush flume systems will eventually become as heavy as as-excreted manure in terms of dissolved salts and organics. The high concentration of dissolved salts further indicates that lagoon water is not suitable for plant as fertilizer due to high salinity (Bauder et al., 2011) and that coagulation and flocculation will become less efficient or completely inhibited if there is a down-stream chemical treatment step for manure (Christensen et al., 2009). On the other hand, the high concentration of dissolved organics would negatively affect sand lane operation. Organics would increase liquid viscosity, then resulting in less efficient separation for sands. Moreover, organics would deposit onto sand surface (Wedel, 2013). The separated sand becomes dirtier, not ready for reuse. To deal with the above problems, the option that farms have now is to use external natural clean water sources such as well water and ground water to dilute liquid to keep flush and flush flume systems running. However, flush and flush flume systems are not capable of removing dissolved solids. The problem will happen again and again like cycles. Therefore, current flush and flush flume systems need improvements, especially, on manure volume reduction and sustainable operation.

LWR MANURE TREATMENT SYSTEM LWR manure treatment system can be a good solution to the above problems of increasing manure volume and increasing dissolved salt/organics level in flush and flush flume systems. LWR system is able to reduce manure volume by about 60 % by making solid/organics-free clean water, and to control/stabilize dissolved solid level in manure by applying the produced clean water to the flush or the flush flume.

LWR system mainly consists of two treatment trains. The first train is based on coagulation and flocculation. It removes from manure > 98 % suspended solids and > 90 % phosphorus, producing phosphorus-rich solids. The volume of the solid is about 10 % of input manure. The second train is to remove remaining dissolved organics and salts from manure by microfiltration and reverse osmosis. It produces RO clean water (dry matter < 0.01 %) and liquid nutrient (RO concentrate). RO clean water accounts for about 60 % of input manure volume and liquid nutrient for about 30 %.

LWR systems can be easily integrated into flush and flush flume manure systems. For flush manure system (

Figure 3), the lagoon overflow is introduced into LWR system. Based on mass balance, the overflow volume is the same as as-excreted manure. As such, LWR system converts about 60 % of the as-excreted manure volume to clean water, 30 % to liquid nutrient and 10 % to solids.

Moreover, the clean water is immediately available for other uses. For example, it can replace part of dirty flush water to stabilize dissolved solid/organics level. As such, sand lane and screen operation won't suffer. Similarly, for flush flume system (

Figure 4), LWR system treats the overflow of screen filtrate, making about 60 % clean water, 30 % liquid nutrient and 10 % solids from manure.

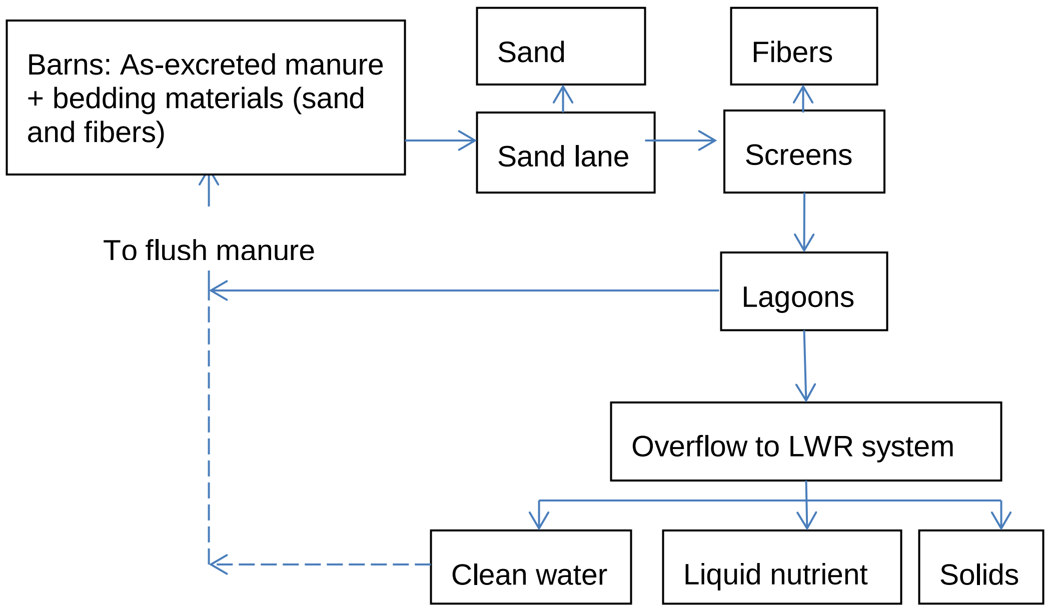

Figure 3. Integration of LWR system into flush manure system

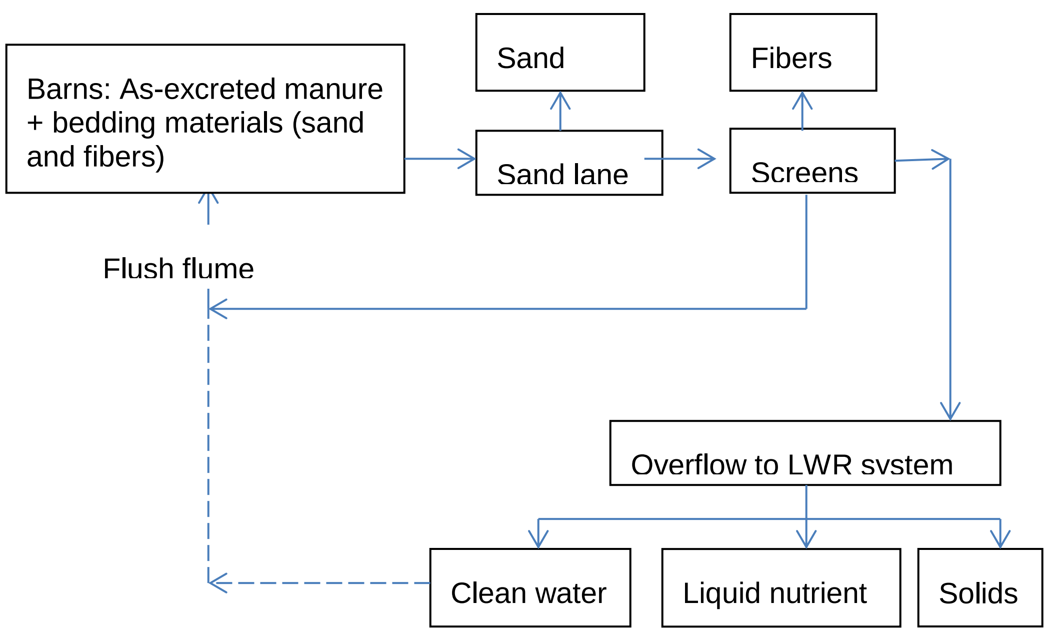

Figure 4. Integration of LWR system into flush flume manure system

CASE STUDTIES Currently 6 US livestock farms are running LWR systems. And, this summer (2015), two more farms will join and start LWR systems. They are mainly located in Wisconsin, Michigan and New York. The following are two case studies of LWR systems.

Case 1: Dairy Farm A is located in Wisconsin. It applies flush flume system to collect manure. The annual manure flow is about 25,000,000 US gallons. Table 1 summarizes LWR system operation at this farm. It shows that LWR system converts 55.3 % of manure to clean water, 32.8 % to liquid nutrient and 12 % to solids. Thus, the manure volume reduction is 55.3 %. Also, LWR clean water has good quality. Compared to raw manure, more than 90 % of nitrogen and potassium nutrients are removed. The removal % of phosphorous even reaches 99.99 %. The dry matter (total solids) is reduced by 99.8 %. The farm is applying LWR clean water to improve sand lane operation or to cool cows in summers.

Table 1. Overview of LWR system operation at Dairy Farm A

Dairy Farm A	Raw manure	LWR clean water	LWR liquid nutrient	LWR solids	LWR clean water – removal % compared to raw manure
Flow rate (GPM)	40.0	22.1	13.1	4.8	
Flow rate (%)	100.0	55.3	32.8	12.0	
Dry matter (%)	4.14	0.01	2.18	14.26	99.8 %
Ammonium nitrogen (ppm)	1600.0	40.0	1801.2	1000.0	97.5 %
Organic nitrogen (ppm)	789.0	80.0	390.0	5700.0	89.9 %
Phosphorous (ppm)	306.0	0.03	23.9	1483.6	99.99 %
Potassium (ppm)	1678.0	126.0	2742.0	1519.0	92.5 %

Case 2: Dairy Farm B is located in Michigan. It applies flush system to collect manure. Their annual manure flow is about 36,000,000 US gallons. Based on site data (Table 2), through LWR system, the manure volume reduction is 60.1 %. 60.1 % of manure is converted to clean water. Meanwhile, over 95.0 % of nitrogen, phosphorous and potassium is removed as well as 99.5% of dry matter when compared to raw manure.

Table 2. Overview of LWR system operation at Dairy Farm B

Dairy Farm B	Raw manure	LWR clean water	LWR liquid nutrient	LWR solids	LWR clean water - removal % compared to raw manure
Flow rate (GPM)	90.0	54.1	27.8	8.1	

Flow rate (%)	100.0	60.1	30.9	9.0	
Dry matter (%)	1.85	0.01	0.74	23.93	99.5 %
Ammonium nitrogen (ppm)	835.0	< 10.0	480.0	1440.0	> 98.8 %
Organic nitrogen (ppm)	465.0	< 10.0	90.0	7670.0	> 97.8 %
Phosphorous (ppm)	260.0	< 10.0	10.0	3950.0	> 96.2 %
Potassium (ppm)	970.0	10.0	630.0	930.0	99.0 %

CONCLUSION Current flush and flush flume manure systems are not able to reduce manure volume and to maintain sustainable operation. It is because they are closed-loop systems and the levels of dissolved organics and salt keep increasing due to internal recirculation of liquid (manure and water). They are also the root-causes of difficult operation of sand lanes of these two systems, especially after years of operation. A good solution is to integrate LWR manure treatment system into flush/flush flume systems. It reduces manure volume by making clean water, and the produced clean water can be further applied to control the level of dissolved organics and salts in flush and flush flume systems. Site data from two full-scale LWR systems show that 55~60 % manure volume is reduced/converted to clean water, about 30 % to liquid nutrient and about 10 % to solids. The liquid nutrient can be applied as nitrogen and potassium fertilizer because it is almost phosphorous-free. By comparison, the solids are rich in phosphorus. It can be a good phosphorus source for plants.

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