TOWARDS ZERO WASTE SWINE PRODUCTION

Theo van Kempen
Department of Animal Science
North Carolina State University
Raleigh, NC 27695
E-mail: t_vankempen@ncsu.edu

ABSTRACT

A novel swine production system was developed that has the potential to be profitable while substantially reducing waste streams. At the basis of this system is a modified housing system. Instead of mixing urine and feces in a pit, they are collected separately using an inclined conveyor belt placed in the pit. Due to a slope of 4%, urine runs off the belt into a collection gutter, which takes it out of the building into a closed storage container. As a result of separating urine and feces, ammonia and odor emission from the house is substantially reduced. Urine collected can be used as a fertilizer, its nitrogen can be converted to harmless N_2 gas, or it can be recovered through chemisorption for use as a pure fertilizer. Feces are passively dried while on the belt, and can be harvested daily at 6 a.m. with a dry matter of approximately 50%. Dried feces can be used as an energy source, for example in a gasifier. Simple gasifiers seem to be the best fit for the industry, although these units have a limited range of end products, including heat, steam, or electricity when implemented on a large scale. Ash remaining after gasification is a good source of minerals for swine feed, but can also be used as a fertilizer or concrete amendment. The economics of the system depend strongly on the value of the energy produced; where other (expensive) energy sources can be replaced it is a viable alternative. In summary, the RE-Cycle system addresses environmental concerns that face the swine industry while generating a green energy supply.

INTRODUCTION

The production of manure is invariably a consequence of swine production. Historically, this material was used as a valuable fertilizer for crop production. However, intensification of swine production and the geographical separation between crop and swine production has resulted in difficulties applying manure to cropland as a fertilizer. As a result, manure is sometimes treated as a waste product.

Swine manure contains several compounds that, when not managed properly, can lead to pollution. Nitrogen has received a large amount of attention as it can affect water, soil, and air quality. Nitrogen is excreted in urine predominantly in the form of urea, and in feces predominantly in the form of protein. Urea is easily degraded into ammonia, which can volatilize and result in air pollution. Most nitrogen remaining in the manure is highly soluble, and after application can run off croplands into surface waters or penetrate to ground water reservoirs. Other compounds that are of environmental concern are listed in Table 1.

In order to solve the environmental challenges facing the swine industry, it is important that systems are developed that minimize the production of compounds of concern, or that produce value-added products in which these compounds are utilized in a sustainable matter. Table 1 can provide some guidance for this, as it lists the sources of several of these compounds. Thus, it provides insight into what a system needs to accomplish to be maximally sustainable. For example, odor is mainly derived from animal housing, while a substantial portion of ammonia and methane is from the animal housing. Thus, sustainable production systems need to start modifications in the house.

Table 1. Sources of compounds of concern at a typical swine farm, and effectiveness of treatment systems to deal with this compound. (0=not treated, +=partially treated, ++=fully treated)

	Main source	Digester	Bioreactor	RE-Cycle
Nitrogen	Urine, feces	0	+	++
Phosphorus	Feces	0[a]	0[a]	++
Copper, zinc	Feces	0	0	++
Organics	Feces	+	+	++
Odor	Swine housing	0	0	+
Odor	Manure	++	++	++
Ammonia	Swine housing	0	0	+
Methane	Swine housing	0	0	0
Methane	Manure storage	++	+	++
Microbes	Feces	+	+	++
Bio-active compounds	Feces	+	+	++

[a] Phosphorus is concentrated in microbial mass, which can be harvested as sludge.

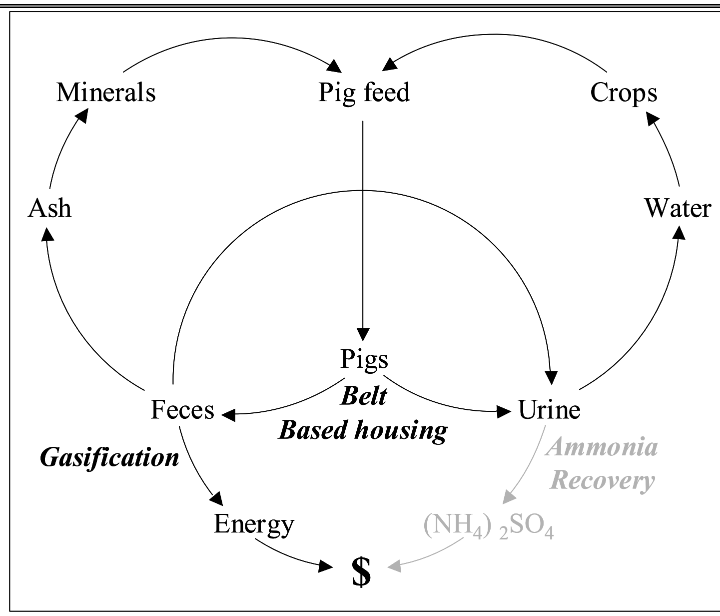
Thus far, most research projects with as objective a sustainable production system have focused on a specific problem and typically they have started with the waste as it comes out the swine house. This means that odor, ammonia, and methane from the house are not addressed. It also means that the starting material had a given composition; swine manure with a dry matter content of less than 10%, limiting what can be done with the material. Examples of such systems include digesters that focus on recovering energy from biomass, and bioreactors that focus on conversion of nitrogen into harmless nitrogen gas.

Although these systems are effective given their objectives, they do not address the range of concerns that face the animal industry. For example, a digester can produce methane for use as an energy source, but the total volume of waste as well as its nitrogen and phosphorus content is not changed. Thus, the need for land application or further processing of the waste has not changed, making this a method to recover value from manure but not for improving sustainability. Worse, the manure has actually lost fertilizer value as organics have been reduced. Bioreactors that convert nitrogen into nitrogen gas are even more challenging. First, they derive no value-added compounds and thus only constitute a cost for the farm. Second, they do not affect waste volume and leave phosphorus and other minerals in the waste, making land application of the residual much more problematic than for the original manure as it now has lost fertilizer value for N.

The RE-Cycle system was designed with the objectives of recycling or prevention of waste without negative effects on the profitability of an operation. From Table 1 it follows that we had to start with modifying the swine housing system to address all the issues that we were facing. The change made in the housing system is actually pretty simple: urine and feces are *collected separately*. This can be achieved with a fairly simple belt collection system that is placed in existing manure pits. Such a system prevents the mixing of urine and feces, which results in a major reduction in ammonia and odor emission. The resulting waste streams, urine and partially dried feces, each have unique attributes. Feces can be passively dried and used as an energy source, leaving only minerals as a co-product. These minerals can be used as an animal feed, fertilizer, or building product. Urine can be denitrified, the nitrogen can be extracted, or it can be used as a fertilizer.

Schematic overviews of the RE-Cycle system are shown in Figure 1 and Figure 2, and a more detailed description of the modified housing system and processing of feces is provided below.

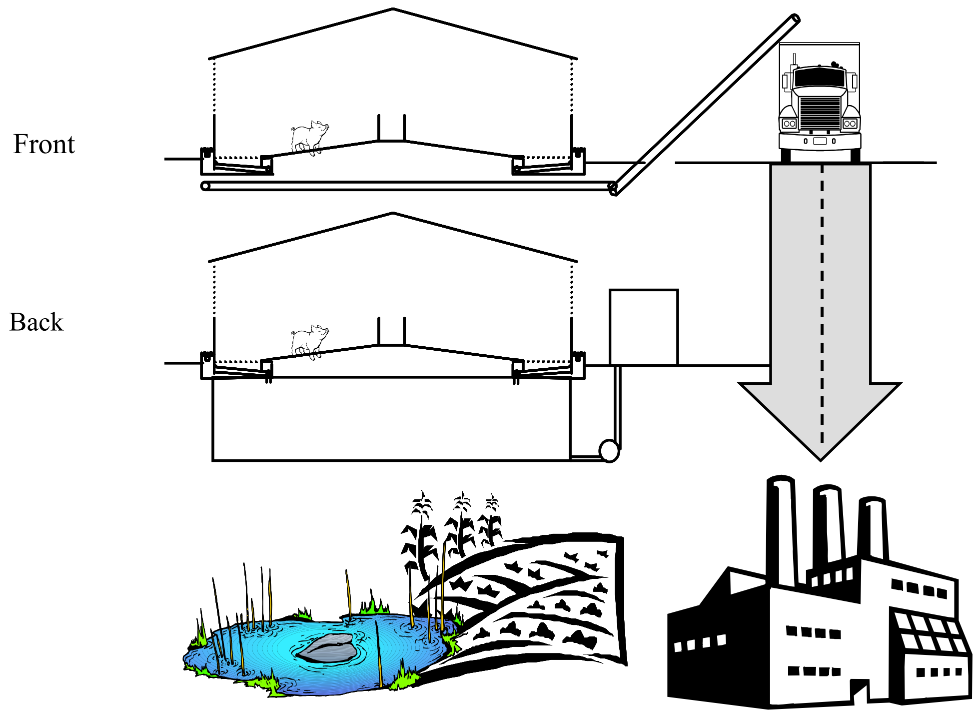
Figure 1. Fate of nutrients in the RE-Cycle system.



CONVEYOR-BELT BASED SWINE HOUSING

Conveyor belts have been used in the laying hen industry for approximately 30 years with good success. They require minimal intervention, last 8 to 10 years, and allow the poultry manure to be collected in a dry form with minimal ammonia and odor emission. The major challenge with pigs is that pigs produce a large volume of urine, which has to be separated from the feces. To achieve this, the belt should be placed at an angle so that the urine runs away from the feces.

Figure 2. Overview of the RE-Cycle system. Top: Swine feces are collected on a belt system placed in the barn and are harvested in a dry state. These feces are transported to a gasification plant where they are used as an energy source. Bottom: Urine is continuously removed from the building by gravity. Urine is either used as a fertilizer, treated on farm to convert the nitrogen to N_2 gas, or it is processed through a system that can recover the nitrogen in usable form. Remaining water is used for irrigation.



Typical behavior of pigs is to defecate against the back walls of pens or against open partitions between pens, and this behavior can be utilized in constructing a belt-based housing system. Using a partially slatted housing system as a starting point, belts that cover the width of the flush-gutter are placed in the existing flush-gutter such that the highest end of the belt is against the back wall, sloping inward at approximately 4° (Figure 3). At the low end of the belt, a gutter is installed below the belt or the belt is bent back upwards to generate a urine gutter. The advantage of a separate gutter is that ammonia emission can be maximally reduced as this gutter can be covered, but the disadvantage is that solids (especially spilled feed) can settle in the gutter leading to clogs and odor. The advantage of the gutter integrated in the belt is that the gutter is cleaned whenever the belt operates. However, the gutter residue can lower the dry matter content of the feces collected and the exposed urine in the gutter can augment ammonia emission.

For an optimal air quality in the swine barn, it is paramount that the urine be removed from the barn as soon as possible. This is because fecal contamination of urine results in the breakdown of urea to form ammonia, which can volatize. Ammonia has a negative effect on animal and worker health and well-being and has been implicated in eutrophication (nutrient enrichment of the environment). In buildings that are placed on a slope and that use the above belt design, the urine continuously flows out of the building. Research has shown reductions in ammonia of 65 to 80% depending on the extent of pen fouling. Actual ammonia concentrations measured in a facility with a ventilation rate of approximately 50 m^3/h/pig place were 2-3 ppm. Total ammonia emission was found to be equivalent to 6.5±0.6% of the feed nitrogen (Table 2).

Figure 3. **Belt setup in a conventional, partially slatted, swine house. A polypropylene belt is placed at a 4° angle in the pit such that urine runs off into a gutter, while feces stay on the belt and dry passively. Feces are collected daily at 6 am at a dry matter content of approximately 50%. Benefits of separating urine and feces are a dry fecal waste stream and substantially reduced ammonia and odor emission.**

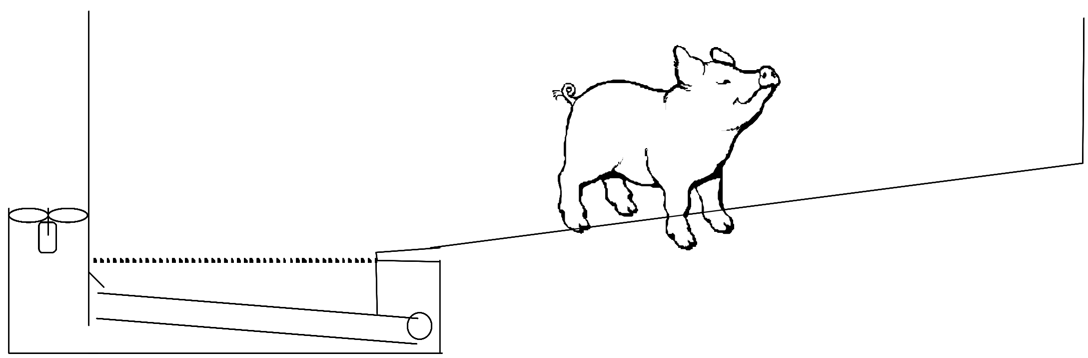


Table 2. **Summary of animal and environmental performance data obtained with the belt housing system over five trials.**

Pigs per trial	80 to 100
Weight range, kg	25 to 55
Average daily gain, kg	0.84±0.08
Average daily feed intake, kg	1.67±0.20
Gain to feed	0.50±0.01
Water intake, l/d	4.1±0.5
Urine collected, l/d	1.3±0.2
Feces collected, kg DM/d	0.26±0.05
Feces dry matter, %	48±6.3
Ammonia emission, kg/year/pigplace	1.23±0.10
Methane emission, kg/year/pigplace	1.05±0.29

Possibly because of the lower ammonia levels in the building, excellent animal performance was observed. Gain to feed for five groups of pigs raised from 25 to 55 kg averaged 0.50±0.01, a 5 to 10% improvement over the gain to feed observed of similar pigs in commercial buildings. Another benefit of removing urine from the building is a marked reduction in odor as odor is linked to aging urine. The urine that is collected contains only minimal contamination from fecal material, as judged by appearance and mineral composition.

Methane emission was equivalent to 0.41±0.13% of the feed energy intake. Data from this and other trials in our lab show that methane emission from the building is mainly derived from the animal (through flatulence and possibly through respiration). Reducing this source of methane emission is possible through dietary manipulations. The manure itself, unless stored in a deep pit, does not seem to contribute to methane emission.

To harvest the feces with the highest dry matter content possible, it was originally believed that the residence time on the belt was of importance. The longer the feces sat on the belt, the more time it had to dry. This assumption turned out to be false. After a day, feces accumulate on the belt to a point that urine does not run through freely, trapping the urine and creating puddles. What was observed, however, was that the time of collection was of major importance. Feces collected late in the afternoon were the wettest; those collected early in the morning, the driest. The reason for this is that pigs are asleep most of the night and thus do not urinate, allowing the feces to dry. During the day, the pigs' urination decreases the dry matter content of the feces. Harvesting feces at 6 am has proven very effective, with dry matters averaging 48±6.3%. At this point the feces are dry to the touch, don't clump, and are stable when stored. In a commercial setting, these feces can be conveyed to a truck bed for collection or to a composting shed.

The equivalent of 17.5±2.1% of the dry matter feed intake was recovered as fecal dry matter. This value is in good agreement with the dry matter digestibility of a typical corn soybean meal diet, suggesting that feces were completely recovered with the belt. This fecal material, on a dry matter basis, has an energy content of 19.7 kJ/g, and contains 45% carbon and 12% ash. These values make it well suited as a fuel when harvested dry.

As wet-dry feeders are used that minimize water wastage, and as the entire system has been set up to stimulate evaporation, the equivalent of only 33±6.3% of the water intake is recovered as urine. Total waste production with the belt is less than 2 kg per animal per day, substantially less than in conventional facilities. This difference is believed to be related to reduced drinking water waste, and increased evaporation of water from the waste streams.

The costs of retrofitting existing barns with a belt are estimated at US $7 to $8 per pig place per year. This is based on individual farms with 4 barns each holding 1200 pigs and includes the costs of urine processing (using a sequential batch reactor) and feces storage. This cost picture does not take into consideration any improvement in animal health and performance that may occur. It also does not take into consideration that waste disposal, under current conditions, has a cost associated with it that can be avoided.

GASIFICATION

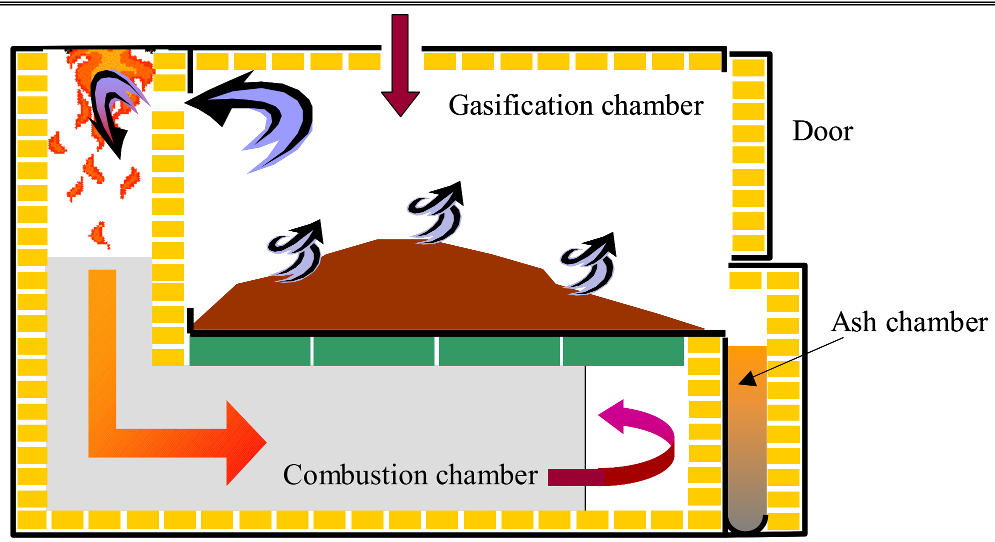
Gasification is a form of thermal decomposition in an environment with limited or no oxygen. The concept is that material is indirectly heated to very high temperatures, for example, 800°C, at which point organic material decomposes into gases such as H_2, CO, CO_2, CH_4, and ash containing minerals. These flammable gasses can then be used as an energy source or as chemical building blocks for the production of value-added compounds such as ethanol.
Gasifier designs range from very simple, where heat is the main end product, to complicated systems with high-value end products such as ethanol or diesel. Initially, for the RE-Cycle project, a very complicated gasifier was evaluated that was designed for the production of liquid fuels. The liquid fuel we were focusing on was ethanol, for which we thought commercially viable catalysts were a reality. The complexity of the gasifier, however, turned out to be a major stumbling block, requiring highly trained people for running the equipment. Even then down-time as a result of system failure was substantial. Similarly, the catalysts for the production of ethanol (and diesel) currently available still suffer from poor efficiencies and they result in the production of byproducts, which would require clean-up processes or further processing of end materials. Although this technology holds promise, our evaluation suggests that neither the complicated gasifiers nor the catalysts for converting product gas into liquid fuels are ready for commercial application in animal agriculture.

As an alternative, BGP Inc. of Scarborough, Ontario, provided a much simpler gasifier. The design of this gasifier is based on years of experience, with the primary objective being the destruction of waste without causing air pollution. The original design contained no moving parts other than a door for loading and unloading, and a downdraft blower. However, to better fit this technology into animal agriculture the unit is being re-engineered to allow for simple but automatic loading and unloading of the unit, thus allowing for unattended processing of waste. A diagram of the re-engineered unit is provided in Figure 4.

Experiments with a non-automated version of the BGP gasifier have shown that the unit is indeed easy to operate and that it operates fail-safe. Batches of manure can be gasified in approximately 4 hours. Ash remaining is of high quality (see next section). However, the unit upon delivery contained an oversized burner. Even at a low setting, the size of this burner caused an escalation of the gasifier temperature when combustible gasses were formed from the fecal material. In addition, the current unit has not been designed to recycle energy in order to minimize fuel consumption. This could be achieved with a relatively simple heat exchanger. Realistic fuel consumption data, however, could not be determined. Extrapolating from current data it is estimated that the fuel consumption is such that for each unit of fuel energy three units of heat are produced, two of them derived from the feedstock. How far this can be improved by optimizing the design of the gasifier is not currently known.

Using such a system on a farm with 5,000 grow/finish pigs would result in a total heat output of approximately 0.55 MW. A portion of this heat can be harvested in the form of hot water, or it can be converted to electricity. The latter, although technically possible, is not the best solution as such systems increase in efficiency with size, with an on-farm system probably not being economical. Using the heat as hot water would allow for heating of buildings, which can result in cost savings. Other uses of heat may exist as well. One possibility is to use it to evaporate water from the liquid waste stream to concentrate it such that the remainder can be used as a concentrated fertilizer.

Figure 4. Schematic diagram of the gasifier. A downdraft burner is used to heat the L-shaped combustion chamber to, eg., 800°C. Heat transfers from the combustion chamber into the gasification chamber through heat-conducting tiles (the rest of the unit is lined with insulating fire-bricks). Feces are introduced in batches into the gasification chamber through a hatch located on the top of the unit. Inside, the feces are heated up causing the material to gasify. Gasses formed during this process escape from the gasification chamber into the combustion chamber, where they are burned and fuel the system. Ashes remaining after gasification of the feces are dumped using a tilting floor in the gasification chamber into an ash chamber, where any carbon remaining is burned off. Ash is removed from the bottom of the ash chamber using an auger.

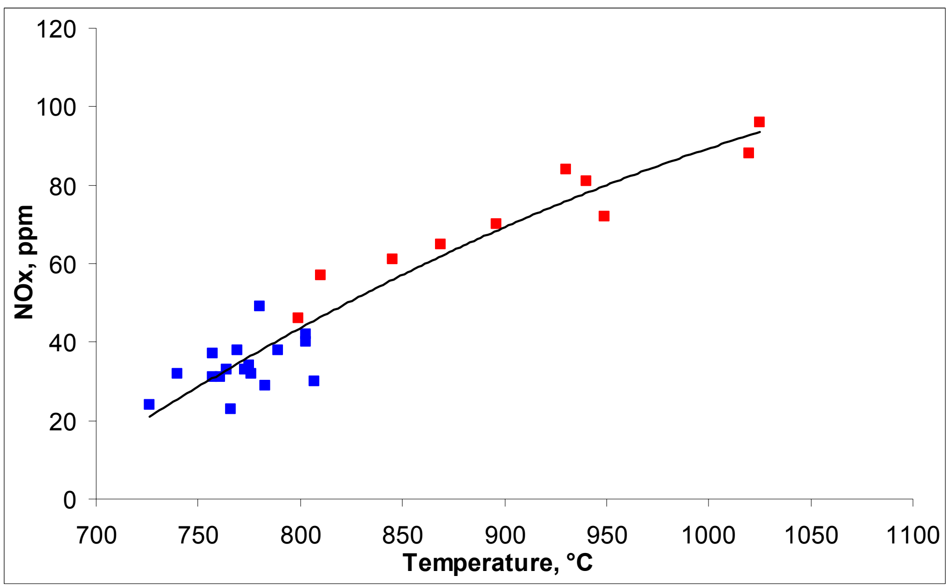


Another possibility is to gasify the feces in a central location such that much larger scale operations can be built. In that case, heat could be used more efficiently for electricity production. If a profitable market for electricity does not exist, then the heat could be used for the production of steam for a feed mill or rendering plant.

Utilization of the heat generated remains a major challenge in practice given that electricity production with the intent to sell is not economically attractive without a form of green energy credits. An 'outside the box' concept would be to use the heat as an energy source for a process that requires a large amount of heat. Ideally such a process would be relatively simple, would result in products that are easy to market, and would be profitable. Some ideas include the production of bricks and glass. Production of a nitrogen fertilizer is an intriguing but likely controversial prospect. Nitrogen could be harvested from the air using the Haber-Bosch process, a process that otherwise only consumes energy. So far the most appealing idea is to use the heat for the production of cement. Cement is made by exposing limestone to very high temperatures, followed by some grinding and mixing. Overall, this process is relatively simple, limestone is a ubiquitous resource, and marketing cement should not be a major challenge.

One of the reasons that gasification technology is appealing is that it is deemed more environmentally friendly than regular combustion processes. Although gasification is a combustion process, during gasification both temperature and oxygen availability can be controlled. This control is responsible for the lower levels of pollutants. For example, dioxins are formed at temperatures well above 1000°C. NOx emissions are also temperature dependent (Figure 5), with production becoming pronounced at temperatures over 700°C and becoming of concern over 1000°C.

Figure 5. NOx emissions observed during the gasification of swine feces as a function of the operating conditions of the gasifier. NOx emissions increased with increasing temperature. However, all temperatures tested resulted in NOx emissions below EPA emission guidelines.



One major benefit of gasification of fecal material is that any bioactive compound in it is destroyed. This would include antibiotic residues, bacteria, viruses, and prions. Although there is little proof at this point that any of these form a real concern for public health, such destruction would be welcomed by the general public.

RECYCLING OF ASH

Using grower feed as a starting point, approximately 17.5% of the dry feed mass is converted to dry swine feces. Upon gasification, approximately 12% of the fecal mass is converted to ash. Thus, per kg of grower feed 20 grams of ash is produced, or 2%. This ash contains most of the minerals that were in the swine feces in either oxide or carbonate form. The ash (composition in parenthesis) is rich in elements such as Ca (11.5%), P (13.3%), and Mg (5.8%) as these minerals are predominantly excreted in the feces. The ash recovered from the gasifier has been exposed to temperatures of 800°C and is thus sterile. Therefore, from a disease perspective it is perfectly safe to feed this ash back to pigs.

The mineral digestibility of the ash has been evaluated both in pigs and under lab conditions. Results of both assays were in agreement and showed that the digestibility of minerals in ash was practically equivalent to the mineral digestibility in commercial sources of these minerals (for example, limestone and dicalcium phosphate). This means that the ash becomes a value-added product in the RE-Cycle system.

Formulating a diet based on this ash composition showed that, for grower pigs, the inclusion in the diet of 2% ash (treated with hydrochloric acid to reduce the pH and provide chloride), 0.15% salt, and 0.6% limestone provided all the macro and micro minerals needed by the pig. At this inclusion rate, a nearly perfect balance exists between ash production and ash utilization. Other uses for the ash exist as well, for example, as a fertilizer and liming agent (providing Ca and P), or as a concrete amendment. Thus, minerals remaining after gasification can be easily used as a value-added product.

RECYCLING OF NITROGEN

Pigs excrete approximately 50 to 70% of waste nitrogen in urine, mainly in the form of urea. It is this urea that is broken down quickly to result in ammonia emission in conventional swine housing systems. By minimizing contact between the urine and the feces and by removing the urine from the house as soon as possible, ammonia emission can be prevented.

This urine is a good source of nitrogen fertilizer, but as collected it is rather dilute (1% N, approximately 4% solids), unstable, and smelly (after short-term storage), making land application not an ideal solution except when using an injection system under dry weather conditions. Ideally, a method for concentrating and stabilizing urine is developed which would yield a product well suited for fertilization purposes. Possibly, waste heat from an on-site gasifier can be used for this purpose. An alternative method for managing the nitrogen is to nitrify/denitrify it, as is done in many municipal waste-treatment plants. In such a system bacteria first oxidize the ammonia to form nitrates, and then, in a second step, reduce the nitrate to N_2 gas. Nitrogen gas makes up 80% of the atmosphere and can be safely released. Although technically a good option, this process does not produce any value-added products and results in the loss of a valuable resource, fertilizer N. Examples of such systems are sequential batch reactors or constructed wetlands.

An alternative solution is to trap the ammonia from urine using, for example, a reversible chemisorption system such as the Ammonia Recovery Process or ARP. This ARP consists of a column containing a zinc-based resin that reversibly binds ammonia. When urine passes through this column, nearly all of the ammonia (up to 99.7%) binds to the column, and the remaining 'urine' can be used as irrigation water since it is virtually free of nitrogen and phosphorus. Ammonia that is bound to the column is periodically removed by flushing the column with a strong acid solution. The resulting solution of zinc-ammonium-sulfate is transported to a centralized processing facility and converted to, eg., ammonium sulfate or anhydrous ammonia fertilizer. The economics of this process, however, are unknown, and the utilization of urine remains a challenge for the RE-Cycle system.

CONCLUSIONS

Using a belt system for separately harvesting urine and feces provides many advantages. Ammonia and odor emission are substantially reduced, resulting in better air quality both inside (possibly resulting in improved animal performance) and outside the building. Feces can be harvested at 50% dry matter making them suitable as an energy source. They can also be used for the production of compost or for land application as a fertilizer.

Gasification is a possible method for recovering value from the fecal waste stream while destroying all bioactive compounds excreted with the feces. Although it is technically possible to produce high-value products such as ethanol, technical and economical challenges suggest that this is not yet a viable option. Currently available technology allows for the production of heat or steam, and on large scale, electricity. The economics of this system depend on the value of energy that can be realized, something that needs to be investigated for each individual site.

Minerals remaining after gasification are well suited for use as an animal feed ingredient as they contain high levels of calcium and phosphorus, both with excellent digestibility. As alternative, they can be used as a fertilizer or building material.

Urine can be used as a nitrogen fertilizer, or the nitrogen can be removed from it through nitrification/denitrification resulting in a loss of value. Alternatively, the nitrogen can be extracted using chemisorption.

The economics of the entire RE-Cycle system depends on

- the value that can be realized for the end products, especially energy
- the avoided cost for manure disposal using conventional methods
- avoided penalties for exceeding emissions (eg., ammonia)
- the improvements in animal performance.

Combining the different technologies described, the RE-Cycle system has the potential to yield a waste-free, profitable swine production system (see Table 1). The key technology for the system is the belt housing system, as it improves air quality in the house, reduces emissions from the house, and results in waste streams that are much more flexible in their use. Already, commercial houses using this system are being used with good results.

SUGGESTED FURTHER READING

Kaspers, B., P. Burnette, J. Koger, M. van Kempen, and T. van Kempen. 2002. Separating urine and feces may be key to flexibility. Feedstuffs 74: 11-13.

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