Technical Article
August 2004

Membrane Filtration of Manure Wastewater

A Comparison of Conventional Treatment Methods and VSEP, a Vibratory RO Membrane System.

Greg Johnson[a], Dr. Brad Culkin Ph.D. [a], Larry Stowell[a]

[a]New Logic Research, Incorporated
1295 67th Street, Emeryville, CA 94608

Introduction

If constructed and managed properly, the age-old lagoon method of manure handling is a reliable method of storing and treating livestock waste. Lagoon storage followed by sprayfield application on local farms has proven to be a very symbiotic and effective method throughout the ages. However, the recent trend in the hog production and the cattle industry is towards larger centralized operations housing thousands of animals in a confined area. The problem that arises is that the local biosphere used for dispersing the waste is fixed in size and has limited capacity to absorb manure fertilizer. Nutrient overload, pathogen release, excessive odor emissions, and tributary eutrophication are potential threats when operating a manure production facility at or near the limits of the land.

Worries about liability and tightening regulations are driving changes in manure management practices. When you consider that for example there may be 4000 lagoons in North Carolina alone. The statistical probability of all 4000 lagoons being constructed and managed properly would be quite an accomplishment. Even if 100% successful in that endeavor, the liability is an overhang that can't be ignored.

New manure management technologies are in a development phase at present, with few technologies at the commercialization stage. There are dozens of new technologies currently vying for acceptability and in the end one or a few will be proven out and be accepted as the norm. For many technologies, there is a lack of available information and data to complete a full analysis of their effectiveness. The evaluation and research process is ongoing worldwide as industry groups, universities, and individual livestock producers begin the task of rank ordering new methods for the treatment of livestock manure.

VSEP Reverse Osmosis Treatment

New Logic Research has been installing membrane filtration systems since 1986, but has only recently launched its agricultural waste system. The system, VSEP (vibratory shear enhanced process), is capable of filtration of practically any type of wastewater including landfill leachate and municipal sludge. Hundreds of industrial wastewater VSEP systems are installed around the world. VSEP is a proven product that has been serving the industrial wastewater market for many years.

After realizing the benefits of VSEP when treating manure wastewater, New Logic installed its first hog farm wastewater system in Korea in May of 2000. Since then, there have been three other installations in Korea and three in Japan. New Logic is presently working on several potential manure system installations in North America and in Europe.

One of the advantages of VSEP is that it is a proven technology for which years of data exist. Rather than being an experimental technology with hidden problems or unknowns, VSEP has a track record of performance and has demonstrated economical and reliable operation on a full-scale basis. One other benefit is that VSEP can be either used as the complete solution for manure treatment or can be used in conjunction with other technologies, as this article will discuss.

Standard Lagoon Methods

Most hog and cow farmers use anaerobic ponds to treat manure effluent. These lagoons can be simple and effective and if operated correctly can contain odor problems. Anaerobic, (oxygen starved), ponds tend to malfunction when the loading rate is too high, or when heavy organic loads are added infrequently. When an anaerobic pond gets out of balance due to overloading or uneven loading, odors can result.

Facultative lagoons are often used as secondary treatment ponds in conjunction with anaerobic ponds. A facultative pond has an aerobic, (oxygen rich), layer over an anaerobic layer. If a “facultative” lagoon doesn't have enough surface area or is not sufficiently oxygenated it will behave like an anaerobic pond. This can be resolved by placing aerators on the lagoons and creating a stratified lagoon. Stratified lagoons are anaerobic ponds with shallow mechanical aerators installed to aerate the surface of the lagoon. Aeration is a proven odor control technology. However, it has high operating costs.

Aerated lagoons are sometimes used in conjunction with anaerobic and/or facultative lagoons to provide further polishing of effluent. Naturally aerated lagoons are less than 1.5 m deep to promote light penetration and oxygen transfer. The surface area of these ponds must be very large and they are rarely practical for treating intensive livestock effluent. Mechanical aerators can be used to promote aerobic conditions. However, this is very expensive.

Current Methods used for Manure Treatment

Anaerobic, Aerobic, or Facultative lagoons are the main part of most manure treatment process. However, there is no one single complete solution. Some of the methods that are currently employed include:

<u>Direct land application by tanker:</u>
Wastes are flushed from the barns into a collection sump. The manure slurry is pumped into a tanker and directly spread on agricultural land without treatment.

<u>Local irrigation with composting:</u>
Wastes are flushed from the barns into a collection sump through a mechanical screen. The collected solids are composted with a bulking agent (sawdust, straw) and sold off-site as fertilizer. The liquid component is irrigated daily and without treatment onto agricultural land.

<u>Anaerobic lagoon:</u>
Wastes are flushed into a conventional anaerobic pond. This pond overflows into a secondary holding pond from which effluent is irrigated onto agricultural land. Irrigation can be timed to match crop and weather conditions. Once in every ten years (or so), sludge is removed from the anaerobic pond, composted and sold as fertilizer.

<u>Anaerobic lagoon with flush water recycling:</u>
Treated effluent is recycled from the secondary pond back through the hog barns as flushing water. This reduces the requirement for clean water, reduces the irrigation requirements, and allows more frequent flushing and thus cleaner sheds.

<u>Mechanically-aerated lagoon:</u>
Wastes are flushed from the barns into a mechanically aerated basin. No solids are removed. After treatment, the effluent flows into a storage lagoon prior to irrigation. Treated effluent is recycled as flushing water. Accumulated sludge is removed, composted and sold off-site. Mechanically aerated treatment ponds are typical of sewage and food processing waste treatment systems. They are reliant on good management and maintenance. Problems rapidly develop if the aerators break down.

<u>Anaerobic Digester:</u>
Manure is anaerobically digested in a controlled system using digester tanks. Methane is produced and this generates electricity for sale to the local grid. This system is expensive and complex but eliminates odor and has the potential to generate income from sales of electricity and fertilizer.

Characteristics of Manure

Manure comprises both urine and feces. It consists of water, complex carbohydrates, and nutrients. Complex carbohydrates are broken down into simpler compounds such as carbon dioxide and water during effluent treatment. Manure also contains large quantities of nitrogen, phosphorus and potassium, as well as minor nutrients, trace elements and salts. A range of pathogens is also contained in pig manure.

Complex carbohydrates are mainly composed of carbon (C), hydrogen (H) and oxygen (O). They include starches, sugars, proteins and fats. In effluent treatment terms, the complex carbohydrates can be variously measured and expressed as biological oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC) or volatile solids (VS). Complex carbohydrates contain energy that can be released when they are broken down into simpler compounds such as CO_2 and H_20.

The nutrients in pig manure include the major nutrients found in commercially available fertilizer including nitrogen, phosphorus, and potassium. Other minor nutrients and trace elements are also present. In manure, nitrogen is usually in the ammonium form or organic nitrogen (NH_4). Ammonium is a water-soluble cation. During biological activity, the pH can be increase and this causes soluble ammonium to be converted to ammonia (NH_3) which is a gas and can contribute to odor problems. Salts found in manure mainly include Sodium (Na), Calcium (Ca), Magnesium (Mg), Chloride (Cl), Sulfate (SO_4) and Carbonate (CO_3). Although some salts are contained in the feed, most salt enters a manure system via its water supply.

Pig manure contains a wide range of bacteria, viruses and other pathogens. As soon as manure is produced, microorganisms start the breakdown process. The breakdown process will continue in an ad-hoc manner if no specific effluent treatment system is used, or can continue in a precise and optimal manner if a sophisticated effluent treatment system is used. Uncontrolled breakdown occurs in manure slurries. Simple anaerobic lagoons provide the next level of treatment where 60% to 90% of BOD can be removed. Complex treatment systems such as activated sludge units and sequence batch reactors can more completely breakdown BOD. If organic matter is broken down anaerobically, the end products are mainly methane (CH_4) and carbon dioxide (CO_2) but other odorous gases are also produced. Most treatment systems allow the gases to escape to the atmosphere. However, methane is a potential energy source and is a greenhouse gas. Methane has about 20 times the global warming potential of carbon dioxide. Treatment systems can be designed to collect the methane produced by the anaerobic breakdown. If organic matter is broken down aerobically, more CO_2 and less CH_4 is produced.

Odor Creation

In most cases, odors from farm operations are created by incomplete anaerobic breakdown of the organic matter in manure. Anaerobic breakdown occurs in the absence of free oxygen and uses microorganisms that thrive in these conditions. It is a two-stage process. In the first stage, organic matter is converted to volatile fatty acids (VFA's). In the second stages methane-forming bacteria convert these acids to methane (CH_4) and carbon dioxide (CO_2). The methane-forming bacteria can only survive in specific environments; for instance, they have a narrow pH range in which they can survive. Hence, incomplete anaerobic digestion may occur. Odors emanate from the release of VFA's and other compounds under these circumstances.

Simple Solids Removal Techniques

Typical Degritting Device

In addition to large amounts of dissolved organic matter and nutrients, manure also contains suspended matter that can easily be removed using screening techniques. Screens or screw presses are almost always used as a first step in any manure treatment process. The collected solids can be composted and sold as fertilizer. Vibrating or stationary screens are a simple and low cost method for removing solids from manure effluent. Mechanical screens remove about 10-35% of the total solids. Press screws can generally remove higher levels of suspended solids than screens. Press screws are less efficient if the effluent stream has an inconsistent or low TS content. Belt presses probably have similar performance to press screws. Presses are more expensive than screens, but are inexpensive relative to most of the other solids separation technologies.

Alternative Advanced Technologies

There are a number of treatment systems out there for hog manure. Very few if any of these are complete solutions with a single piece of equipment. Most still require large lagoons or simulate small-scale municipal wastewater treatment plants. One of the largest hog farms in the western United States actually produces as much waste as the entire county of Los Angeles. All of these still leave the risk of pollution to the water supply by nitrates and pathogens.

Typical Outdoor Aerobic Digester (Japan)

There are several technology offerings, which are similar to standard municipal sludge waste treatment plants. These will always have an image problem and require a very large footprint. Approval for these by the thousands will be problematic, as neighbor approval will be tepid. A tangential flow separator (TFS) is a sophisticated device that uses lime and polymer dosing and tangential flow to remove solids. It has very high capital, operating and maintenance costs. TFS can remove about 34% of TS and at least 90% of phosphorus. The separated solids have a TS content ranging from about 6-40%. While the Tangential Flow Separator is effective at getting Phosphorous, it is poor in removing TOC, Nitrogen, and COD. It also adds chlorides and Iron to the waste stream.

Conventional aerobic digestion is a process where bacteria that use Oxygen will biologically consume organic matter and convert it to carbon dioxide, water, and ammonia. Further processing converts the ammonia to nitrites and then finally to nitrates. There are several types of aerobic digesters including Sequencing Batch Reactors (SBRs), where the process occurs in one container in a sequence of steps. These steps include filling, aeration, reaction time, settling, drawing down, and idling. Conventional aerobic digestion would have the same steps but would occur in several tanks where each step would take place.

Sequencing Batch Reactor (SBR)

Anaerobic digestion is one of the oldest processes used for stabilization of sludges. In an anaerobic digester, complex carbohydrates are converted to methane and carbon dioxide. Only the anaerobic process can be used for methane recovery in order to generate electricity. The methane is burned to power a generator. This process occurs in a closed system and requires 30-60 days of retention time. The residual sludge will contain many of the nutrients for fertilizer, by much of the nitrogen escapes in the forms of methane. One benefit is that the remaining sludge is pathogen free and nonputrescible.

Limitations of These Technologies

As with the human stomach, digestion is very effective at consuming organic matter and converting it to carbon dioxide, water, and energy. Digesters can reduce some inorganic materials, but only those that can be settled. The problem is that manure contains much more than organic material and settlable solids. The remaining effluent is still potentially harmful if not treated in the proper manner. The digester will have little or no effect on things like chlorides, nitrates, phosphates, potassium, and sulfates. Digesters are also not capable of eliminating metals such as sodium, calcium, magnesium, iron, aluminum, copper, and zinc.

Also, with all of these methods large tanks, basins, or lagoons will remain. None of these is a complete solution by itself, which represents a technologically superior method. In each case, the remaining effluent water would need to be land applied or disposed of safely in some other way. Direct surface water discharge would not be possible. Some reuse of this water could be done when flushing, but there is the potential for accumulation and build up of salts and toxic metals in the system with no outlet for these. At best the water could be blended with fresh water to maintain a balance.

VSEP RO Filtration System

New Logic has developed a treatment system, which is technologically superior to other systems on the market. The Vibrating Membrane Filtration process employed provides many key advantages to the treatment of hog manure. Since VSEP uses reverse osmosis filtration as has been done in seawater desalination for many years, it is capable of concentrating all solids both suspended and dissolved and producing water that is clean enough for animal consumption, surface water discharge, or irrigation water. The VSEP system filtrate has 98% of the organic matter (BOD) and 95% of the ammonia removed. The remaining reject volume can be as little as 10% of the total volume and would now constitute a valuable concentrated organic fertilizer slurry.

VSEP can be used as a stand-alone treatment process with only a simple screen to remove large objects. The screen would first remove large particles for composting and the VSEP would concentrate the untreated raw manure to make clean animal drinking water and thickened fertilizer slurry. The VSEP reject can be pelletized or shipped and dispensed in a slurry spray truck as fertilizer.

VSEP System installed for Manure Treatment in Japan

When used in conjunction with an aerobic digester, all nutrients are recovered. The digester will break down the organic matter and have settled solids that can be recovered. The VSEP can be used to treat the effluent from the digester with the VSEP reject being returned to the digester and the VSEP filtrate being discarded or reused. The VSEP is able to concentrate many of the sparingly soluble metal salts like calcium carbonate and magnesium phosphate and return these nutrients for recovery in the digester. Using this method, nearly 98% of all nutrients are recovered from the manure.

If electrical energy is the goal, an anaerobic digester can be used with a VSEP to treat the resulting effluent. The efficiency of the digester is much better when the organic solids loading is elevated. By using VSEP to treat the effluent and return organic material to the digester thus raising the concentration of organic fuel, a much more efficient digester will result leading to higher yields of electricity. The recovered sludge would also have higher nutrient levels when recovered as with the aerobic digester.

The three main uses of VSEP for manure treatment as shown above represent technologically superior treatment methods. Maximum utilization and nutrient recovery is possible in each case. There is virtually no waste and all of the recovered materials, whether it is water, nutrients, or methane represent valuable products that can generate profit for the livestock farmer. In addition to proven technical feasibility, VSEP, most importantly, is also economically viable and well within the reach of most hog farmers and dairy operations.

Membrane Introduction

Membrane separation technology has been around for many years. Initially, the use of membranes was isolated to a laboratory scale. However, improvements over the past twenty years have made it possible to use membranes on an industrial level. A membrane is simply a synthetic barrier, which prevents the transport of certain components based on various characteristics. Membranes are very diverse in their nature with the one unifying theme to separate. Membranes can be either liquid or solid, homogeneous or heterogeneous and can range in thickness. They can be manufactured to be electrically neutral, positive, negative or bipolar. These different characteristics enable membranes to perform many different separations from reverse osmosis to microfiltration.

There are four main categories of membrane filtration. These are determined by the Pore size or Molecular Weight Cut off:

Filtration Type	Particle Size Rejection	Molecular Weight Cut-off
Reverse Osmosis	$\leq$ 0.001 micron	$\geq$ 100 daltons
Nanofiltration	0.001 to 0.01 micron	100 to 1000 daltons
Ultrafiltration	0.01 to 0.1 micron	1000 to 500,000 daltons
Microfiltration	$\geq$ 0.1 micron	$\geq$ 500,000 daltons

The first category of membranes is for Reverse Osmosis. These are the tightest membranes for separating materials. They are generally rated on the % of salts that they can remove from a feed stream. However, they can also be specified by Molecular Weight cutoff. Usually, the rejection of NaCl will be greater than 95% in order to be classed as an RO membrane. The molecular weight cutoff is shown in the above table. An example of their use would be for filtering seawater in order to remove the salt. They are also used to remove color, fragrance and flavor from water streams.

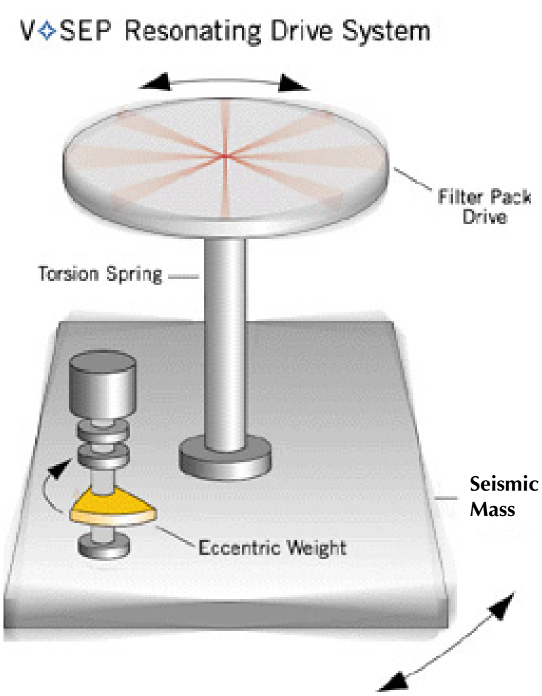
The advantage of the pure ionic separation of membranes has always held the interest of those wishing to treat wastewater. In the past, the limitations of conventional spiral membrane systems have prevented widespread use because of rapid fouling due to colloidal scale formation. Colloidal fouling obstructs the pores of the membrane and greatly reduces the throughput and increases the frequency and amount of cleaning required. To combat this problem, elaborate pretreatment is used to prevent scale formation inside the membrane system. In addition spiral membrane companies have developed membranes that are extremely hydrophilic so that organics are repelled. Even with these improvements, the limitations of conventional spiral membranes have not allowed their widespread use in wastewater treatment.

VSEP Advantages vs Conventional Membranes

A new membrane system know as VSEP, (vibratory shear enhanced process) employs torsional vibration of the membrane surface, which creates very high shearing energy at the surface and near the pores. The result is that colloidal fouling and polarization of the membrane due to concentration of rejected materials are greatly reduced. Since colloidal scale fouling is avoided because of the vibration, the use of pretreatment to prevent scale formation is not required. In addition, the throughput rates of VSEP are 5-15 times higher in terms of GFD (gallons per square foot per day). The sinusoidal shear waves propagating from the membrane surface act to hold suspended particles above the membrane surface allowing free transport of the liquid media through the membrane. This accounts for the increased performance of VSEP membrane filtration when compared to conventional spiral crossflow membrane filtration.

VSEP Technology Overview

Beyond the flow-induced shear of conventional crossflow filtration, VSEP can produce extremely high shear on the surface of the membrane because of the inherent oscillation at high frequency. This accomplished by the torsional vibration of a disk plate in resonance within a mass-spring-mass system. The membrane is attached to this plate and moves at an amplitude of 1/2" to 1" peak-to-peak displacement. The frequency at which the system vibrates is between 50 and 55 Hz. Much as in a laundry machine, the fluid in the stack remains fairly motionless creating a highly focused shear zone at the surface of the membrane. Retained solids at the membrane surface are removed by the shear allowing for higher operating pressures and increased permeate rates. Feed pressure is provided by a pump, which consistently circulates new fluid to the filter.



In general, a VSEP is simply two masses connected by a spring. This is a torsion spring and it is set to resonate at its natural frequency. One mass, the filter pack, is lighter and rides atop the torsion spring. This filter pack contains the membrane(s) and moves at high amplitude. The other mass, the seismic mass, moves with smaller amplitude, which is proportional to the ratio of the two masses. The use of two masses in this resonance scheme allows the entire system to resonate without attachment of the device to a rigid surface.

The resonance excitation is provided by an AC motor controlled by a variable frequency, solid-state speed controller. The motor spins and Eccentric Weight coupled to the seismic mass. Since the eccentricity of the weight (i.e., its center of mass lies heavily on one geometric side) induces a wobble, the Seismic Mass begins to move as the motor speed increases. This energy is transmitted up the torsion spring inducing the same wobble in the filter pack, however 180˚ out of phase. As the motor speed approaches the resonance frequency, the amplitude of the moving filter pack reaches a maximum, and greater motor speed will only decrease the amplitude. VSEP is run under operating conditions below the maximum amplitude to reduce spring stress and ensure infinite spring life.

To allow for free movement of the system, VSEP is mounted on isolators. Solid piping to the filter pack is attached to the Torsion Spring and is removed at the point of zero-amplitude (node). Flexible piping is used at the top of the filter pack. VSEP industrial and pilot systems *(Series i and L/P* can be operated in a single pass configuration, which makes them ideal for industrial scale applications consisting of upwards of hundreds of gallons per minute. During single-pass operation, the material enters the top of the filter pack, and is progressively dewatered by the membranes as the material passes down through the stack. This establishes a concentration gradient, where the material at the top of the stack is most similar to the feed material, and the material at the bottom of the stack is concentrated reject, having been dewatered as it passed through the filter pack. The concentrated material is essentially extruded from the bottom of the pack. The clear filtrate is removed through the center of the pack from a porous drainage cloth under each membrane sheet. The limit to concentration varies from feed material to feed material but essentially needs to remain flowing as a liquid which can be removed from to the outlet pipe.

Proposed VSEP Manure Process Description

VSEP can be used in many ways. Almost every VSEP manure installation thus far has been installed in a slightly different configuration. Since VSEP is compact, modular, versatile and can be used under very different operating conditions. It can handle very wide temperature swings from 5ºC to 60ºC instantaneously. There is improved performance with increased temperatures, but VSEP can operate at any normal ambient temperature needed. It can also tolerate large fluctuations in pH, solids loading, and changes in chemical composition of the wastewater. The VSEP works automatically and produces results immediately without reaction time or waiting for biological activity to develop.

VSEP can be used in the following ways:

1. As a single treatment method with just a mechanical screen to make clean water for reuse and a concentrated nutrient slurry for composting, land application, or portable slurry for off-site fertilization from a spray truck

2. As pre-treatment to either an aerobic or anaerobic digester. The clean water is produced ahead of the digester for reuse. The concentrate from the VSEP is then sent to the digester at a greatly reduced volume. This means a smaller digester system that is working on more concentrated material thus improving efficiency.

3. As post-treatment for a digester to treat the effluent produced. VSEP polishes the water to make it suitable for reuse or discharge. The reject from the VSEP can be either returned to the digester or blended with digester sludge or blended with screen reject composting.

VSEP Only Manure Treatment

The only pre-treatment required for the VSEP is a coarse mechanical screen to prevent beach sand sized particles from entering the system. It is not necessary to completely remove suspended solids, only the ones large enough to act as projectiles and possibly do damage to the membrane. Normally, 60 to 100 mesh screen size is sufficient.

This proposed process would take effluent from the settling basin or other primary holding tank, which has passed through a wire screen, and then filter this liquid using a reverse osmosis membrane. The filtrate from this would be sent to water storage holding structure of some kind. This clean water then becomes available for animal drinking water, flush water, or for irrigation. The concentrated reject from the filtration system would be returned to a batch process feed tank. This "Batch Concentration" process would continue until the % solids in the tank reaches 12% solids or greater. At that time the contents could be hauled and sold as slurry fertilizer. The clean filtrate from the water storage holding basin, now like a duck pond could be used for recharging of the trenches in the barn or for cooling cell operations. The trenches would continue to function as they do now, only with cleaner water as the charge.

There is a trade off between high % solids and throughput of clean filtrate. Higher % solids could be reached but at the expense of reduced throughput. The same is true in the opposite. More throughput could be handled but at the expense of lower % solids at the end of a batch concentration run. The optimum % solids and throughput have been determined to be approximately 12% solids, 80% recovery of filtrate, and 20 gpm per module. To illustrate the relationship between concentration and throughput, the VSEP can also produce 20% solids in the concentrate, but only at a rate of 10 gpm per module. Or, conversely, VSEP could produce 5% solids in the concentrate at a flow rate of 25 gpm. These numbers are approximately and may vary depending on the type of farm and the ambient temperature, but they show the correspondence of concentration and throughput. Modules are units within the system and the total system can be sized for any total flow rate.

VSEP System installed for Hog Manure Treatment in Korea

System Components

The liquid manure would be pulled out of the settling basin using a self priming sump pump or centrifugal pump which would be installed on a floating buoy to pull liquid from the top foot of tank level. The liquid will transfer into the VSEP treatment building and then pass through a degritting or pre-screening unit to remove large particles, (100 mesh). There are many types of mechanical screens that could be used.

Primary Settling Basin

The manure then flows into an equalization feed tank where it can be heated if needed to improve performance. This tank works on a demand basis and would be controlled by tank level. The transfer pump would activate to fill the tank based on the signal it gets from the tank level sensor. The manure is pulled out of the tank near the bottom and pumped through a protective bag filter and sent on to the VSEP machine itself. The bag filters and pumps are provided with the VSEP system and are skid mounted for easy installation.

VSEP Process Tanks

The VSEP system comes with a cleaning tank and many of the valves and other interface equipment. The system is "Plug and Play". The feed tank, degritting unit, heat exchangers, and boiler are not normally included, but can be provided as part of a complete process package. The VSEP system is automated and controlled by a PLC (Programmable Logic Controller). Operator interface is limited to monitoring the system and making periodic adjustment to parameter settings. The cleaning is automatic and controlled for degradation in flow rates.

VSEP as Pre-treatment to a Digester

VSEP can be used to pre-concentrate or thicken the manure prior to aerobic or anaerobic digestion. The main benefit to this is that the digester size and expense can be cut significantly. VSEP could be used to remove 50-85% of the liquid volume as clean water reducing the size of the needed digester by a proportional amount. Many digesters will be more efficient when the solids level is elevated. For this scenario, the VSEP would be configured as shown in the VSEP only scenario. In this case though, very high recovery would not be as critical and the VSEP would be used primarily to take the load off the digester. The VSEP could also be used as a redundant bypass should the digester require reaction time or other downtime maintenance. Again, the VSEP would take liquid manure out of the settling basing that has been pre-screened and then filter is using reverse osmosis. As before the clean water will be diverted to a water storage holding tank or basin for reuse. The thickened concentrate from the VSEP would be sent to the digester for processing.

The benefit to this over the VSEP alone scenario is that the sludge is stabilized in the digester. After being digested, it will not putrefy since all of the organic material has been converted to stable compounds. It can be pelletized, or dried to make bagged fertilizer and will remain stable. In the digestion process pathogens are also destroyed. The Volatile Fatty Acids have been broken down to carbon dioxide and water and the ammonia has been converted to nitrates so most of the odor associated with manure is neutralized.

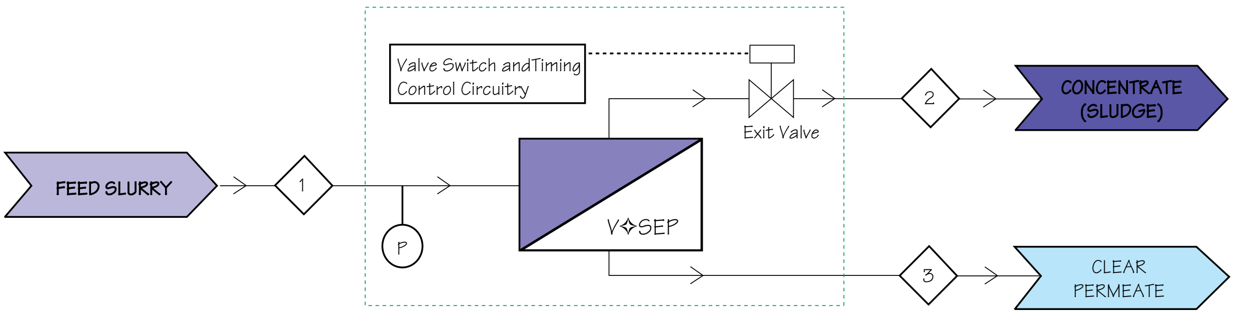
VSEP Post-Digester

This is the most common method of using the VSEP. Our first installation in Korea has a sequencing batch reactor (SBR) in front of the VSEP reverse osmosis filtration system. In these cases the purpose of the VSEP is to produce clean water from the digester effluent that can be discharged or reused and to capture any remaining nutrients in the digester effluent that may be dissolved or not captured by the digester. In the case above where the VSEP is used ahead of the digester to volume reduce the wastewater, the concentrate has one destination which is the digester. In the case of post-treatment with VSEP, there would be several possible destinations for the VSEP concentrate. It can be returned to the digester for additional biological degradation, it can be blended with the sludge removed from the digester, or it can be blended with the screen rejects for composting.

A mechanical screen, screw press, or centrifuge is normally used ahead of the digester to remove the large solids that would take a long time to deteriorate in the digester. After the degritting and screening step, an air stripper can be used to remove some of the ammonia and VFAs to make it more comfortable for the workers operating the digester. SBRs are operated indoors so odor from manure can be a problem even though SBRs are aerobic. Also, sulfide gas can be a health concern and is also removed via air stripping. Outdoor conventional digesters may not need air stripping. After degritting, the manure is feed to the digester in a batch method. The digester is first filled and then allowed to react and then settle. After settling and sufficient time for digestion, the water is drawn down and this effluent is then sent to the VSEP equalization tank. VSEP can be used on demand and can start and stop based on tank level. VSEP then filters the effluent to create clean water for discharge or reuse.

VSEP Performance

New Logic has many installed manure applications and so the performance results of the VSEP are quite well known. There may however, be slight variations from location to location. Pilot testing is always a good idea to confirm estimated results. There can be many differences from farm to farm. Cow manure is different than hog manure and there are even different kinds of hog manure depending on whether the manure is from sows or feeder pigs. Cow manure typically has higher suspended solids and lower dissolved solids than hog manure. Each animal also processes nutrients and minerals differently. Also, the nutrients, salts, and minerals that end up in the manure are a function of the water used and the feed material that is given to the animals.



In general, the VSEP is able to produce slightly higher throughputs on digester effluent than on raw manure. This is not true in all case though, but on average is true. The following table illustrates performance throughput on several manure scenarios. Membranes are rated based on their throughput per square foot of membrane. The value given to the is GFD which stands for gallons of permeate produced per square foot of membrane per day.

Averages	Single Stage Reverse Osmosis			
	Untreated Raw Hog Manure	**Aerobic Digester Hog Manure**	**Untreated Raw Cow Manure**	**Aerobic Digester Cow Manure**
Permeate Flux Rate	18 GFD	28 GFD	19 GFD	24 GFD
Filtrate Recovery	78%	88%	82%	85%
Temperature	25ºC	25ºC	25ºC	25ºC
Membrane Used	LFC 1	LFC 1	LFC 1	LFC 1
Pressure Used	575 psi	600 psi	600 psi	500 psi

Ambient temperature and pH also can affect the VSEP system performance. With so many variables that can affect the make up of the manure, it's hard to generalize about the VSEP performance, but some estimates can be made. The following table shows the results from a recent trial conducted on cow manure after it had been treated with an aerobic digester.

Aerated Cow Manure/Reverse Osmosis

		VSEP Feed	VSEP Concentrate Estimate	VSEP RO Permeate	% Reduction
		Feed	Concentrate	Permeate	% Reduction
Total Solids	TS	1.88%	9.28%	0.03%	98.6%
Total Suspended Solids	TSS	8,000	40,000	0	100.0%
Total Nitrogen	TN	2,210	10,734	79	96.4%
Ammonia	NH4	1,200	5,736	66	94.5%
Sulfates	SO4	950	4,498	63	93.4%
Calcium	Ca	146	726	1	99.3%
Chloride	Cl	2,420	11,988	28	98.8%
Copper	Cu	0.7	3.5	0	100.0%
Iron	Fe	2.5	12.5	0	100.0%
Magnesium	Mg	42	210	0	100.0%
Manganese	Mn	0.3	1.5	0	100.0%
Phosphorous	P	211	1,039	4	98.1%
Potassium	K	2,730	13,530	30	98.9%
Sodium	Na	868	4,340	0	100.0%
Zinc	Zn	1.7	8.5	0	100.0%

VSEP Analytical Results from Pilot Trials on Cow Manure

When compared to other treatment methods, the VSEP has the ability to produce the highest quality water and is effective on all of the dissolved solids rather than only being effective on a few or some of the solids. For example, digesters and biofilters are poor at removing phosphorous, potassium, and chlorides. Tangential flow separators are good at phosphorous but actually increase the amounts of chlorides, calcium, and iron in the effluent due to addition of lime and ferric chloride. The following table illustrates the relative performance.

Technology Comparisons		VSEP Filtration System	Sequencing Batch Reactor	Tangential Flow Separator	Biofilter Treatment
Total Suspended Solids	TSS	100%	98%	82%	82%
Chemical Oxygen	COD	94%	93%	49%	75%
Total Nitrogen	T-N	96%	60%	22%	61%
Total Phosphorous	T-P	98%	15%	90%	24%
Chlorides	Cl	99%	0%	-210%	0%
Copper	Cu	100%	10%	87%	5%
Calcium	Ca	100%	10%	-60%	5%

Comparisons of VSEP Results compared to other technologies

VSEP Throughput Factors

VSEP can operate at almost any ambient temperature. However, throughput can be increased with increasing temperature. The limit for polymeric RO membranes is 60ºC. The VSEP can be operated at any temperature up to that. The reason for this is that increasing temperature reduces the viscosity of the manure. Viscosity can act as a rate-limiting variable when it comes to filtration. The effects of this are very dramatic. For example the throughput of a VSEP could be twice as much at 45ºC as it is at 20ºC. While heating the manure is not mandatory, it can make for a more economical system design. It will slightly increase the operating costs, but will reduce the capital cost.

Another factor affecting the throughput is the percentage of water that is removed from the total volume of manure wastewater. This is known as % recovery. As the manure becomes more concentrated, there are more dissolved solid ions competed for space with the water at the membrane surface. In addition, the highly concentrated reject water near the membrane can cause osmotic pressure, which is the natural tendency for two liquids separated by a membrane barrier to want to equalize concentrations. In order to overcome the clean water's need to flow backward through the membrane higher pressure is need to drive the flow in the right direction. At lower recoveries like 50%, the osmotic pressure is very low. At high recoveries like 90%, the osmotic pressure is very high and will reduce the rate of mass transport through the membrane. Increasing or decreasing the recovery can have an inverse effect on throughput.

pH is also a very effect tool for manipulating the throughput and rejection of the membrane. Lower pH helps to solubilize mineral salts that can slow down performance. pH also has one other very important effect as shown below.

Effects of pH and Temperature on Ammonia

Free ammonia (NH3-N) and ionized-ammonium (NH4+-N) represent two forms of reduced inorganic nitrogen which exist in equilibrium depending upon the pH and temperature of the waters in which they are found. Free ammonia is a gaseous chemical, whereas the NH4+ form of reduced nitrogen is an ionized form, which remains soluble in water.

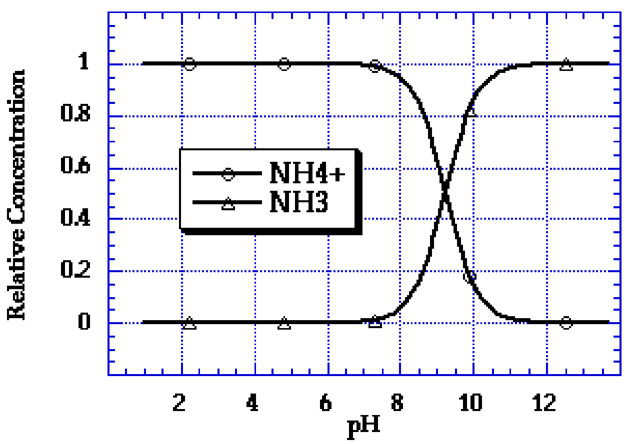
A factor affecting the magnitude of ammonia volatilization is pH. NH3 (gaseous ammonia) and NH4+ (aqueous ammonium ion) are in equilibrium at a pH of about 9. The equilibrium relationship is defined by the following equation.

$$NH_4^+ \longleftrightarrow NH_3 + H^+$$

$$\frac{\left[NH_3\right]\left[H^+\right]}{\left[NH_4^+\right]} = 5.7\times10^{-10}$$

Ammonium is ionized, (it has a plus charge), and is very soluble in water. Very large amounts of dissolved ammonium can exist in water if the conditions are right. Because the ammonium is ionized it will associate with a negatively charged anion such as carbonate or nitrate. This attraction keeps and holds the ammonium in solution. Even if concentrated, the ammonium will remain in solution. Ammonia, however, is non-charged and has a limited solubility in water as a gas. If the pH or temperature changes or the solution is concentrated shifting the concentrations of ammonia past its solubility, then it will evolve as a gas and leave the liquid rather than convert to ammonium.

Ammonia and ammonium exist in equilibrium depending on the pH. A solution pH above 7 begins to reduce the concentration of the ammonium ion, since the equilibrium between the mono-valent ammonium ion and the uncharged ammonia molecule shifts toward ammonia as the pH approaches the basic range. Since the ammonia gas has a limited solubility, raising pH will shift ammonium to ammonia and in doing so drive ammonia out of solution as an evolved gas, which leaves the system to the atmosphere. The graph below shows the relationship between ammonium and ammonia concentrations with regard to pH.



As you can see, at pH 6, nearly all of the Ammonical Nitrogen is in the form of the ionized ammonium, which will be soluble in water in high quantities. At a pH of 11, there is no ammonium and any ammonical nitrogen present would be in the form of ammonia, Since this has a limited solubility, any excess would evolve and leave the liquid as a gas. If the objective were to keep the ammonical nitrogen in the system, operation at pH 7 or less would be required.

When it comes to ammonia rejection using RO membranes, with little ionic charge to enhance rejection, the very small non-charged ammonia molecule readily permeates RO membranes. When pH is raised from 5.0 to 8.5 the ammonia rejection of an RO system drops from 95% to 62%. The fact that ammonium has a plus charge makes it less likely to diffuse through an RO membrane. Since ammonia has no charge and is very small, it has an easier time diffusing through the membrane.

Therefore, operating an RO system at a pH of less than 7 will result in the best rejection/concentration of ammonical nitrogen. If the objective was to get rid of ammonical nitrogen, the pH should be raised to pH 11 and then the solution should be sent through an air stripper to evolve the ammonia gas. Then the pH can be dropped to 6 and filtered using an RO membrane. This will result in very dramatic reductions in ammonical nitrogen in the resulting filtrate.

Temperature also affects solubility of ammonia/ammonium, but to a lesser degree. As with most gases, raising the temperature makes ammonia less soluble. If the objective is to recover nitrogen for its nutrient value, the ammonia must be kept as ammonium as much as possible. To do this, the pH of the sample should be kept at pH 6

Benefits of VSEP

Local acreage is not required for sprayfields.
Treated water can be reused over and over
Nearly 100% of valuable nutrients can be recovered and sold as a commodity
Can be used to compliment bioreactors and reduce loading on lagoons or replace them
Reused water is safe animal drinking water
Footprint required is about 100 Square feet
System consumes about 15 horsepower and no chemicals are needed

Since the beginning of time, farming has always been about nutrient recycling. Our system is the ultimate in the capture of nutrients and the best option for preventing pollution by seepage, volatilization, spills, or airborne transmission of pathogens. Also, the most valuable resource of all, Water, is recycled. This can reduce the load on Aquifers or Municipal Water Districts.

Company Profile

New Logic is a privately held corporation located in Emeryville, CA approximately 10 miles from San Francisco. New Logic markets, engineers, and manufactures a membrane dewatering and filtration systems used for chemical processing, waste streams, pulp & paper processing, mining operations, and drinking water applications. The VSEP technology was invented by Dr. Brad Culkin in 1985. Dr. Culkin holds a Ph. D. in Chemical Engineering and was formerly a senior scientist with Dorr-Oliver Corporation.

About the Author: Greg Johnson, Chief Operating Officer, has been with New Logic Research since 1992 and has a Chemical Engineering background. He is responsible for engineering and design of the patented VSEP Vibratory Membrane System.

New Logic Research
1295 67th Street
Emeryville, CA 94608
510-655-7305 tel
510-655-7307 fax
www.vsep.com
info@vsep.com

BIBLIOGRAPHY

The following Publications or Articles were used for preparation of this study:

Metcalf & Eddy , 1991, Wastewater Engineering 3rd Edition, Boston: McGraw-Hill, 1334 p.

American Society of Civil Engineers, 1997, Water Treatment Plant Design 3rd Edition, New York: McGraw-Hill, 806 p.

J. Morris, R. Fleming, M. MacAlpine, Pigs Accept Drinking Separated Water from Liquid Manure, University of Guelph, Ridgetown College Research Note, 2004

G. Johnson, VSEP Industrial Strength Filtration, Chemical Processing Magazine Article, 2003

G. Johnson, Kinetics of Mineral Scale Membrane Fouling, Desalination Article, 2003

New Logic Research, VSEP Case Study, Treatment of Hog Farm Liquid Manure Wastewater, 2001

R. Fleming, M. MacAlpine, Evaluation of Mechanical Liquid/Solid Manure Separators, University of Guelph, Ridgetown College Research prepared for Ontario Pork, 2003

K. Zering, How to Select an Alternative Manure Treatment System, North Carolina Pork Conference Paper, 2000

L. Jackson, Water Quality, University of Northern Iowa Article, 2001

J.G. Pieters, G. G. Neukermans, M. Colanbeen, Farm-Scale Filtration of Sow Slurry, University of Ghent Article, 1999

E. Warnemuende, R. Kanwar, The Effect of Swine Manure Application on Bacterial Quality of Leachate from Intact Soil Columns. 2001

United States Environmental Protection Agency (EPA), 2003, 40 CFR 141 & 143, National Primary Drinking Water Standards, 5 p.

United States Environmental Protection Agency (EPA), 2003, 40 CFR 141 & 143, National Secondary Drinking Water Standards, 5 p.

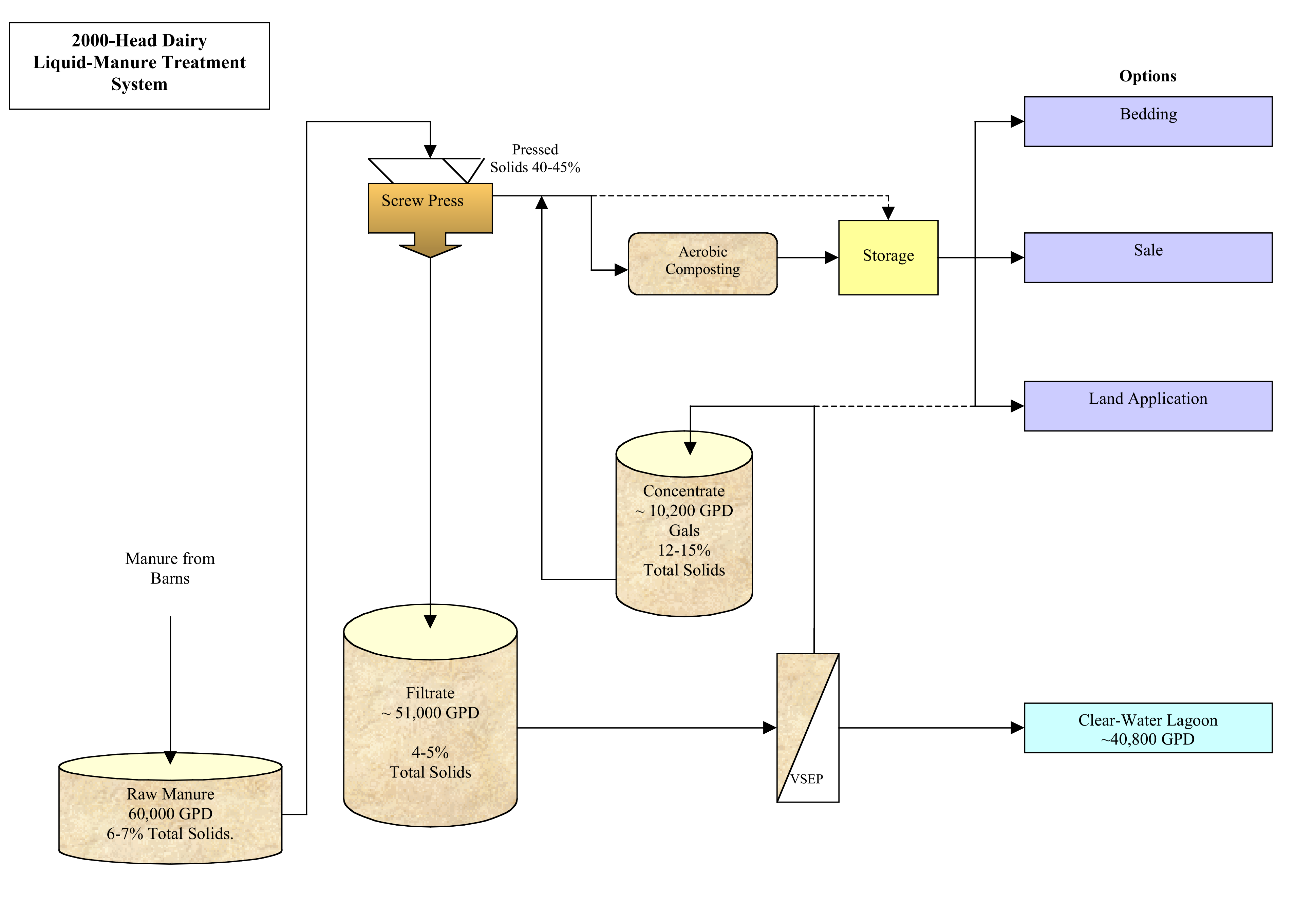
United States Environmental Protection Agency (EPA), Environmental Regulation & Location of Hog Production, Agricultural Outlook Newsletter, 2000

ATTACHMENTS

Figures

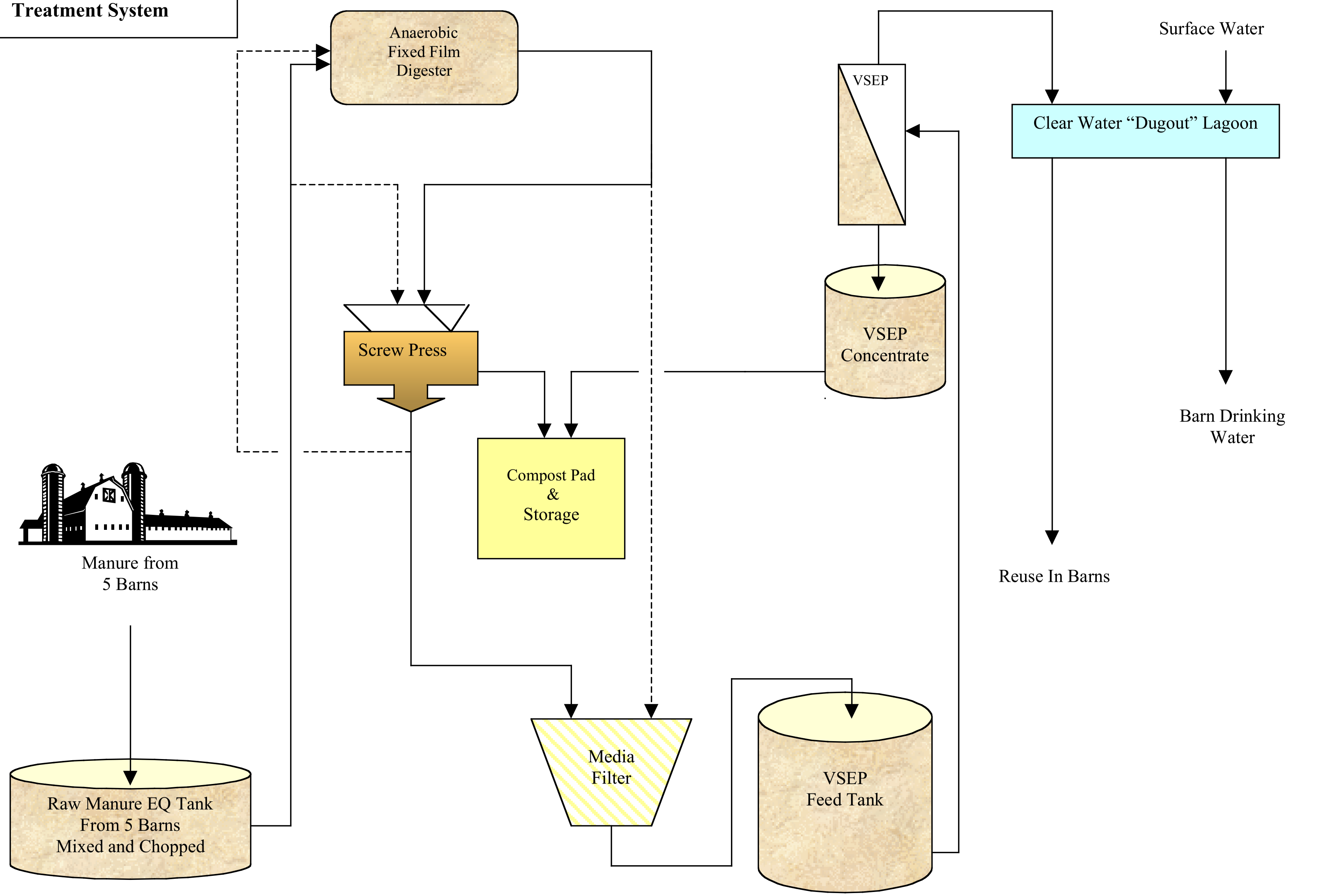
Images

Charts



Screw Press/VSEP	New Logic Research, Inc. 1295 67th Street, Emeryville, CA 94608 Atlanta Office : 770-421-9205	Flow Schematic #1 VSEP Membrane Filtration

Hog Farm
Liquid Manure
Treatment System



Anaerobic Fixed Film Digester/VSEP

New Logic Research, Inc.

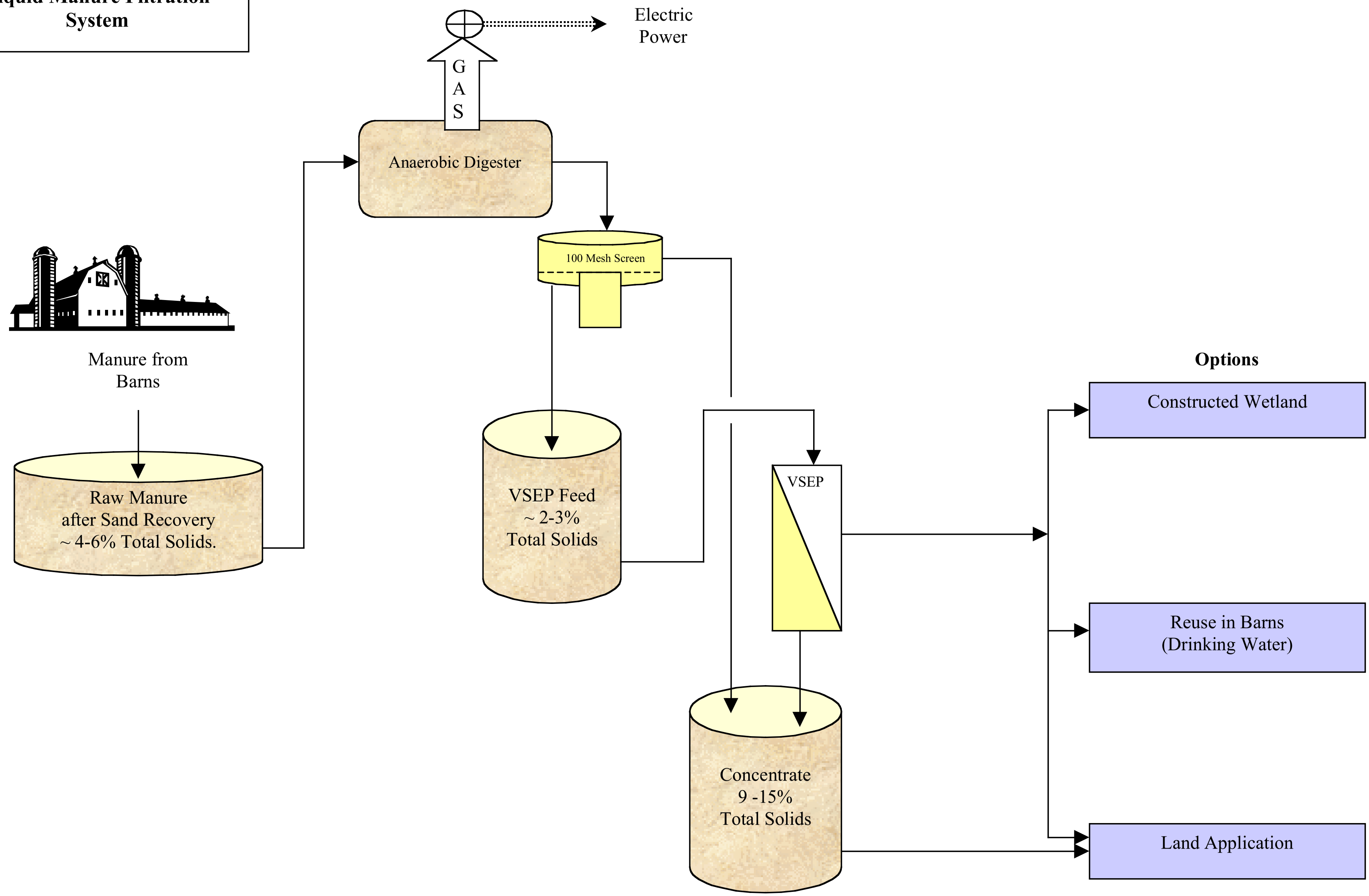
1295 67th Street, Emeryville, CA 94608

Atlanta Office : 770-421-9205

Flow Schematic #2
VSEP Membrane Filtration

2600 - Head Dairy Farm

Liquid Manure Filtration System

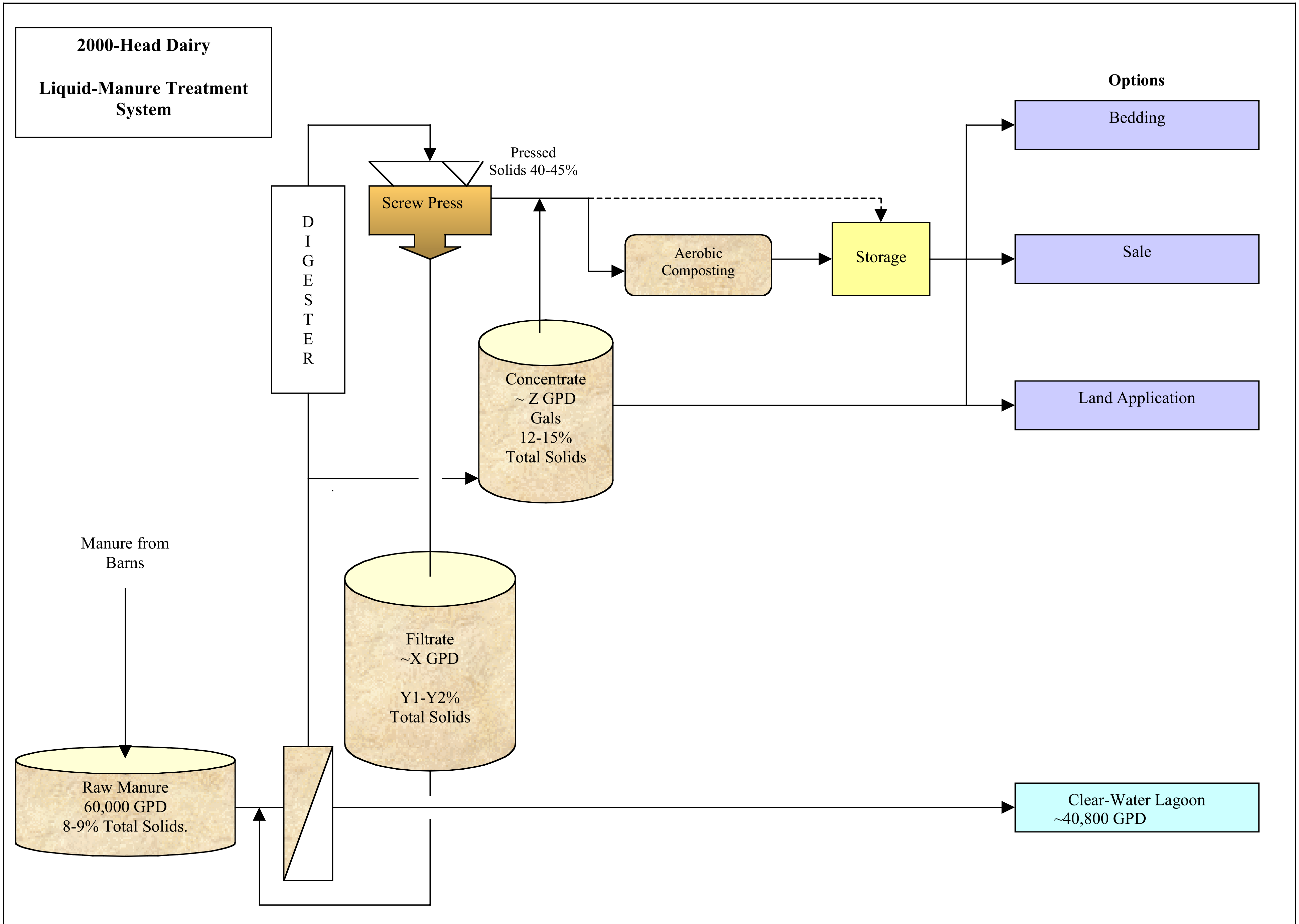


Anaerobic Power Generation/VSEP

New Logic Research, Inc.

1295 67th Street, Emeryville, CA 94608 **Atlanta Office : 770-421-9205**

Figure 3
VSEP Membrane Filtration



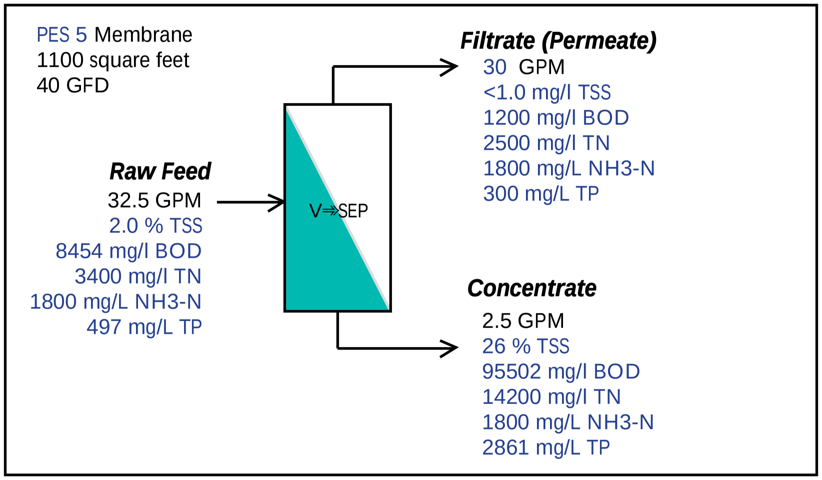
VSEP /Aerobic Digester

New Logic Research, Inc.
1295 67th Street, Emeryville, CA 94608
Atlanta Office : 770-421-9205

Flow Schematic #4
VSEP Membrane Filtration

Hog Manure Ultrafiltration

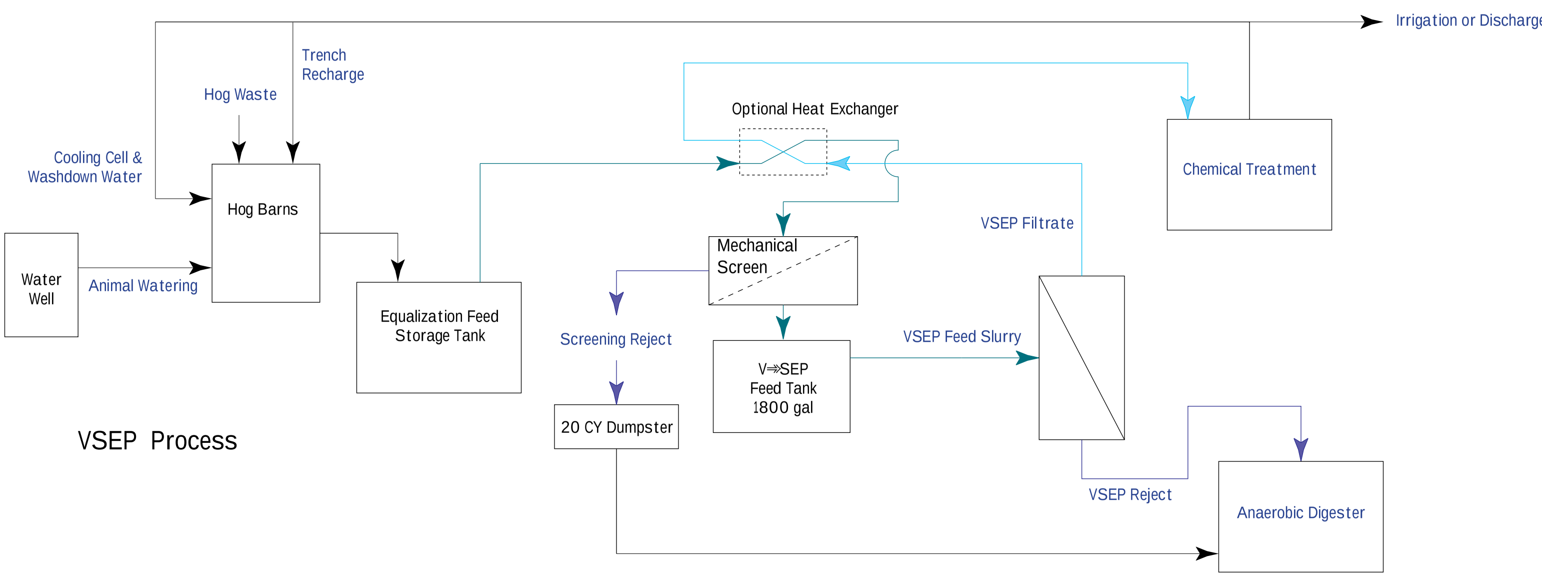
Typical Installation



VSEP Process Objectives:

To volume reduce the manure to be treated by an anaerobic Digester. The VSEP filtrate will be used as irrigation water

20% Concentrate Solids
Suspended Solids Free Permeate
Recover solids for the digester
Nutrient Recovery
High throughput
92% recovery of filtrate



VSEP Process

NEW LOGIC Research
1295 67th Street, Emeryville, CA 94608 (510) 655-7305

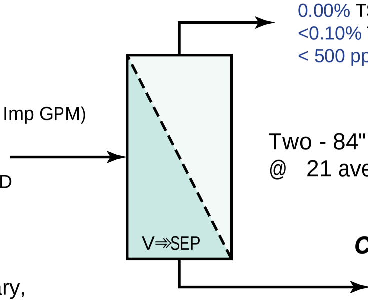
Figure 5	VSEP Series i System	7/15/04
Manure Ultrafiltration Process Flow Diagram		

Anaerobic Digested Hog Manure Wastewater
Contaminent Removal by RO Filtration

LFC 1 Membrane

Permeate
38 GPM (31.5 Imp GPM)
0.00% TSS
<0.10% TDS
< 500 ppm BOD

Feed
48 GPM (40 Imp GPM)
1.83% TSS
0.80% TDS
7680 ppm BOD



Two - 84" V⇛SEPs (1300 SF ea)
@ 21 ave GFD

Concentrate
10 GPM (8.5 Imp GPM)
8.78% TSS
36.2% TDS
34,964 ppm BOD

80% Recovery Shown
Feed Composition will vary,
so numbers shown are estimates only

Operational 22/24 hours to process 63,554 US GPD (52,910 Imp GPD)

Process Objectives:
63,554 US Gallons per day (Feed) (52,910 Imp Gal)
Filtrate to be used for drinking water
Concnentrate to be composted
Need BOD < 100-500 ppm

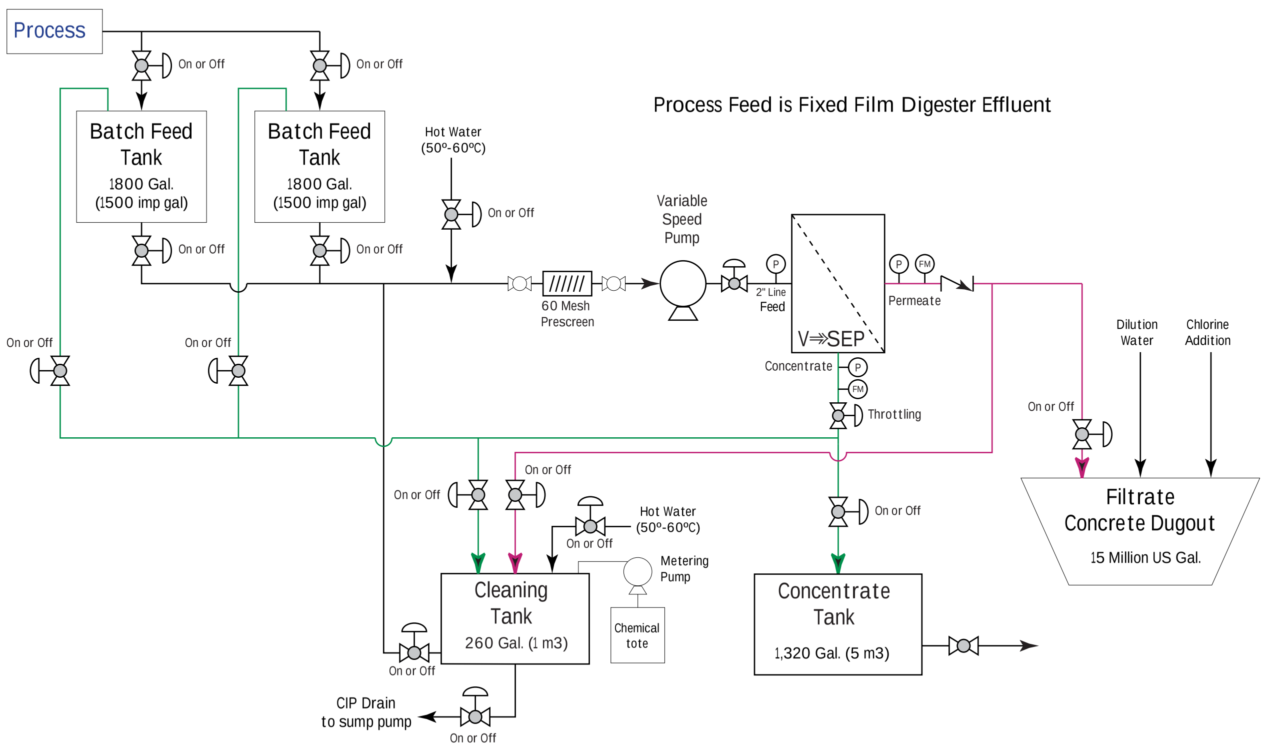
V⇛SEP Advantages:
Simplicity and easy to use
Small Footprint
Energy Efficient
High % recovery as filtrate

Membrane: LFC-1
Cleaning: NLR 404 and 505

Desired V⇛SEP Performance:

	Feed	Permeate
Dissolved Solids	8,000 mg/L	<1,000 mg/L
Total BOD	7,680 mg/L	< 500 mg/L
Nitrite & Nitrate		<100 mg/L
Sulfate		<500 mg/L
Calcium		<1,000 mg/L
Magnesium		<300 mg/L
Sodium		<400 mg/L
Hardness		<500 mg/L
Total Coliform		<2 mg/L

Process Feed is Fixed Film Digester Effluent

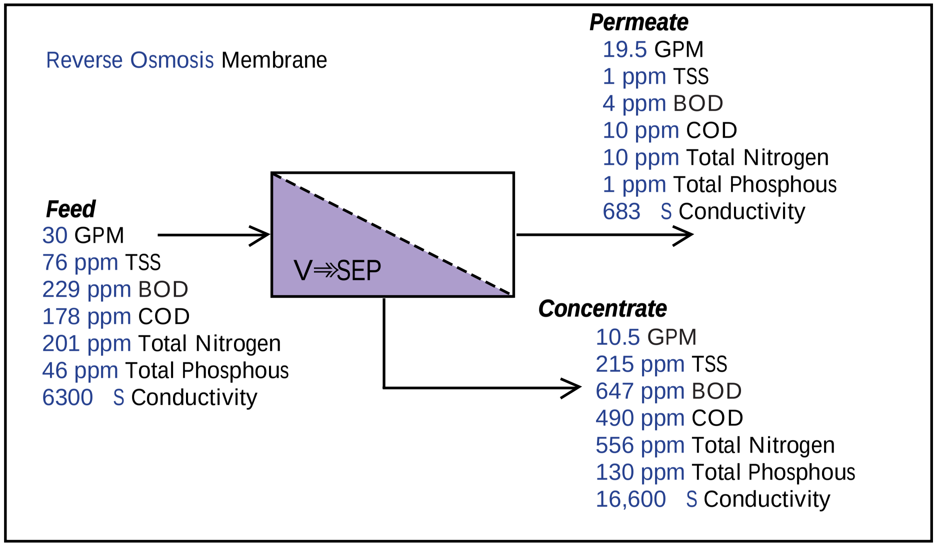


NEW LOGIC Research
1295 67th Street, Emeryville, CA 94608 (510) 655-7305

Figure 6	VSEP Series i System	7/15/04

Manure Reverse Osmosis Process Flow Diagram

SBR Aerobic Manure Wastewater



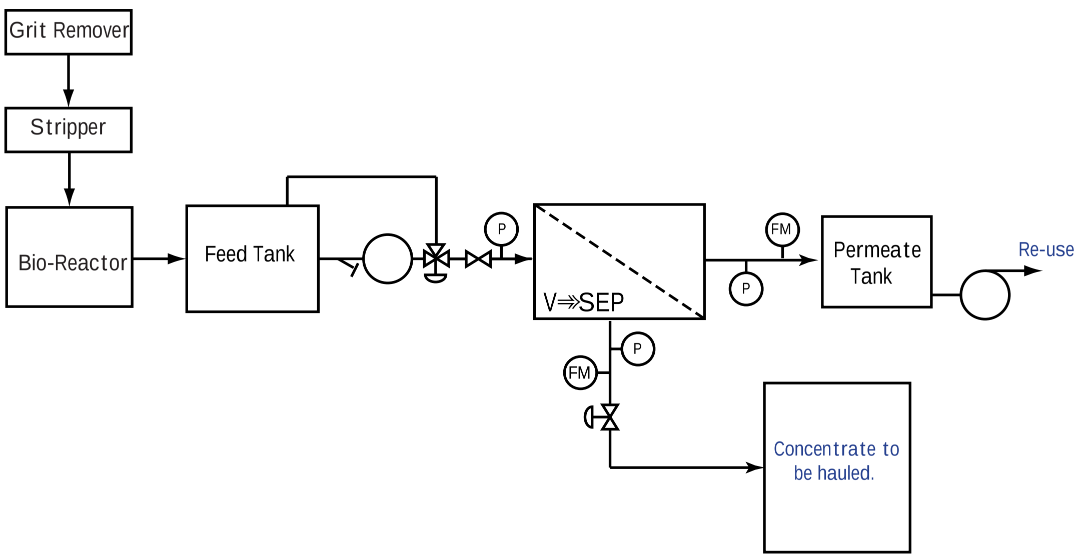
Process Objectives:

Reduce the COD, BOD and Total Nitrogen.
65% Recovery
Volume reduce waste
Permeate for re-use.

Process Description:
Wastewater from agriculture operations is treated biologically using a sequencing-batch reactor (SBR). The effluent from the SBR is treated in the VSEP to make permeate for water reuse purposes. The concentrate is hauled off for disposal.

Membrane: Reverse Osmosis

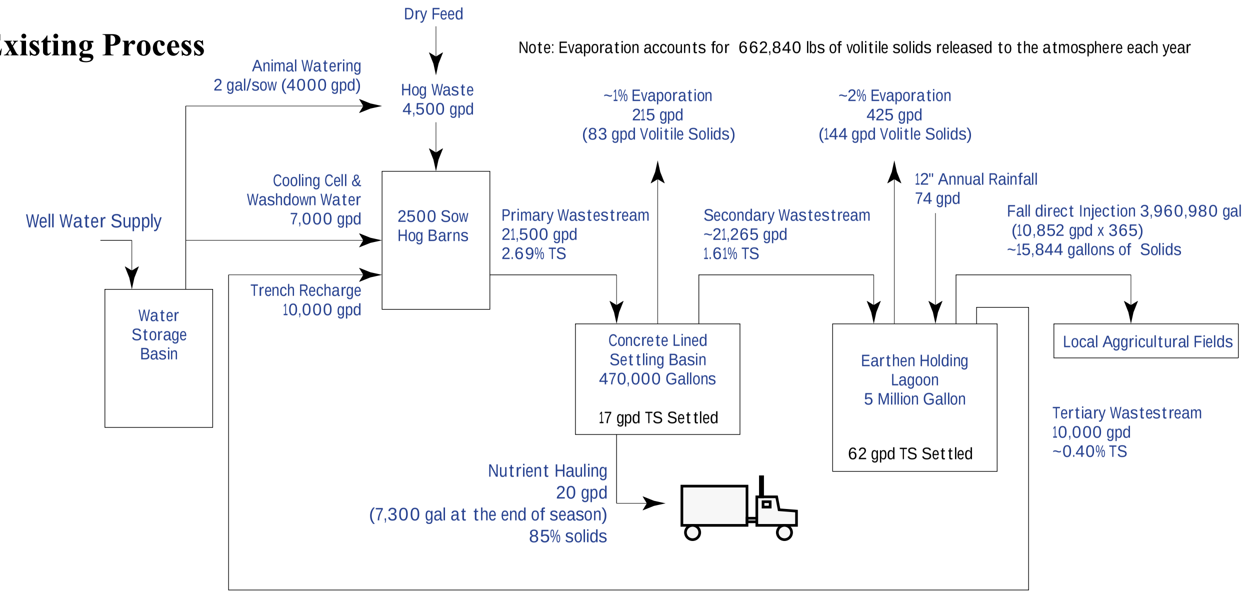
Conditions: pH 6.5 to 8.0
Temperature is 30-35^{0}C
Max Pressure is 500 psi



NEW LOGIC Research
1295 67th Street, Emeryville, CA 94608 (510) 655-7305

Figure 7	VSEP Series i System	7/15/04
Manure Reverse Osmosis Process Flow Diagram		

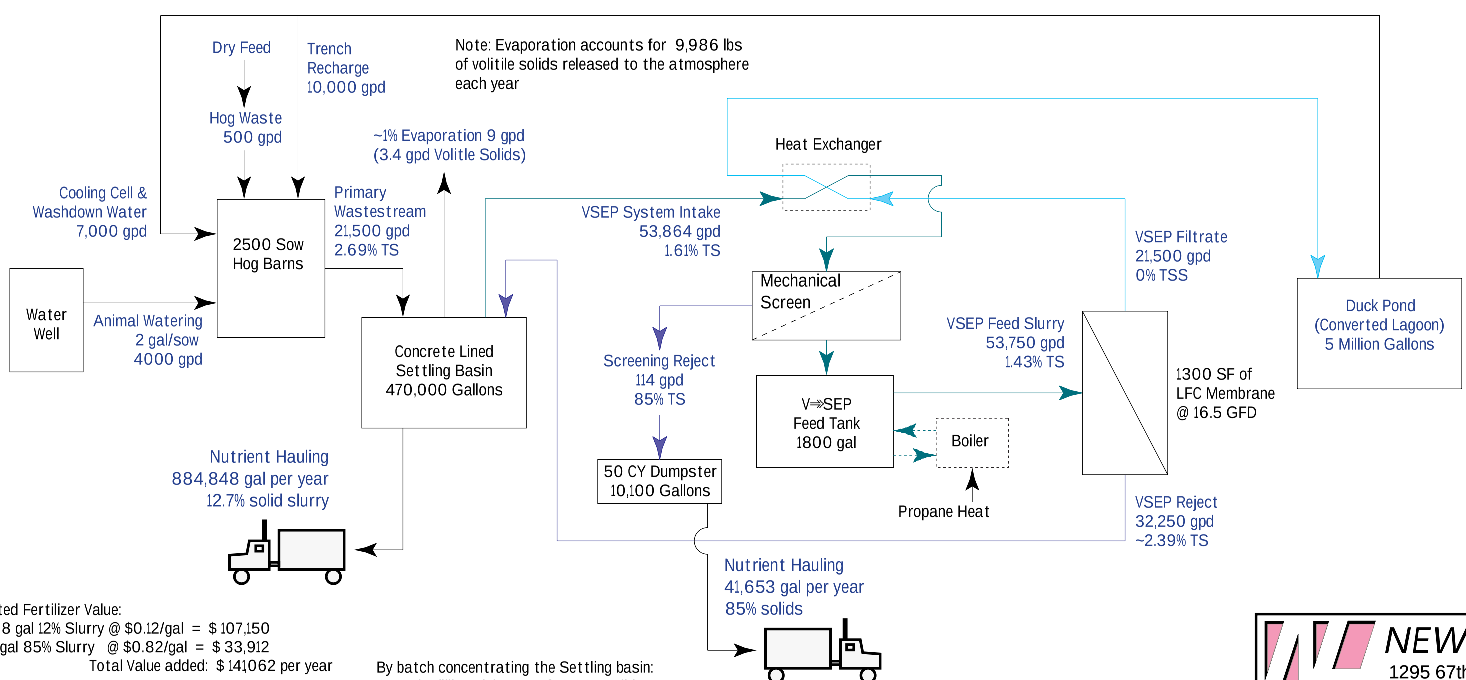
Existing Process



Typical V⇛SEP Performance:

	Feed	Permeate	Concentrate
% T Solids	1.16%	0.05 ppm	23.2%
BOD	7300 ppm	146 ppm	14.3%
T Nitrogen	0.23%	253 ppm	4.6%
Phosphorus	0.18%	450 ppm	3.6%
Potassium	0.19%	475 ppm	3.8%
Calcium	500 ppm	50 ppm	0.91%
Magnesium	324 ppm	16 ppm	6176 ppm
Sulfur	176 ppm	35 ppm	2855 ppm
Manganese	16 ppm	0.8 ppm	305 ppm
Copper	35 ppm	4 ppm	624 ppm
Zinc	38 ppm	0.6 ppm	749 ppm

VSEP Process



Note:
Boiler and Heat exchanger are shown dotted
These could be optional process design
features to boost production on demand.
This feature could be used for days with
heavier than normal washdowns or during
the winter when cold temperature would
decrease V⇛SEP performance

See the economics Calculations for Analysis

Estimated Fertilizer Value:
884,848 gal 12% Slurry @ $0.12/gal = $ 107,150
41,610 gal 85% Slurry @ $0.82/gal = $ 33,912
Total Value added: $ 141,062 per year

By batch concentrating the Settling basin:
Start by filling with waste@ 2.69% solids,
Then run V⇛SEP 105 days to reach 400,000 gal & 12.65% solids
Tank should be drained and hauled, then the process repeats
Annual hauling would require 1.4 million gallon tank capacity (6880 cubic yards)

NEW LOGIC Research
1295 67th Street, Emeryville, CA 94608 (510) 655-7305

Figure 8	VSEP Series i System	7/15/04

Nutirent Mass Balance Process Flow Diagram

V✧SEP Hog Manure Treatment System
as installed at Kimhae, South Korea

Sequencing Batch Reactor (Feed to V✧SEP)

Degritting Unit

Gas Stripper

V✧SEP Hog Manure Treatment System
as installed at Kimhae, South Korea

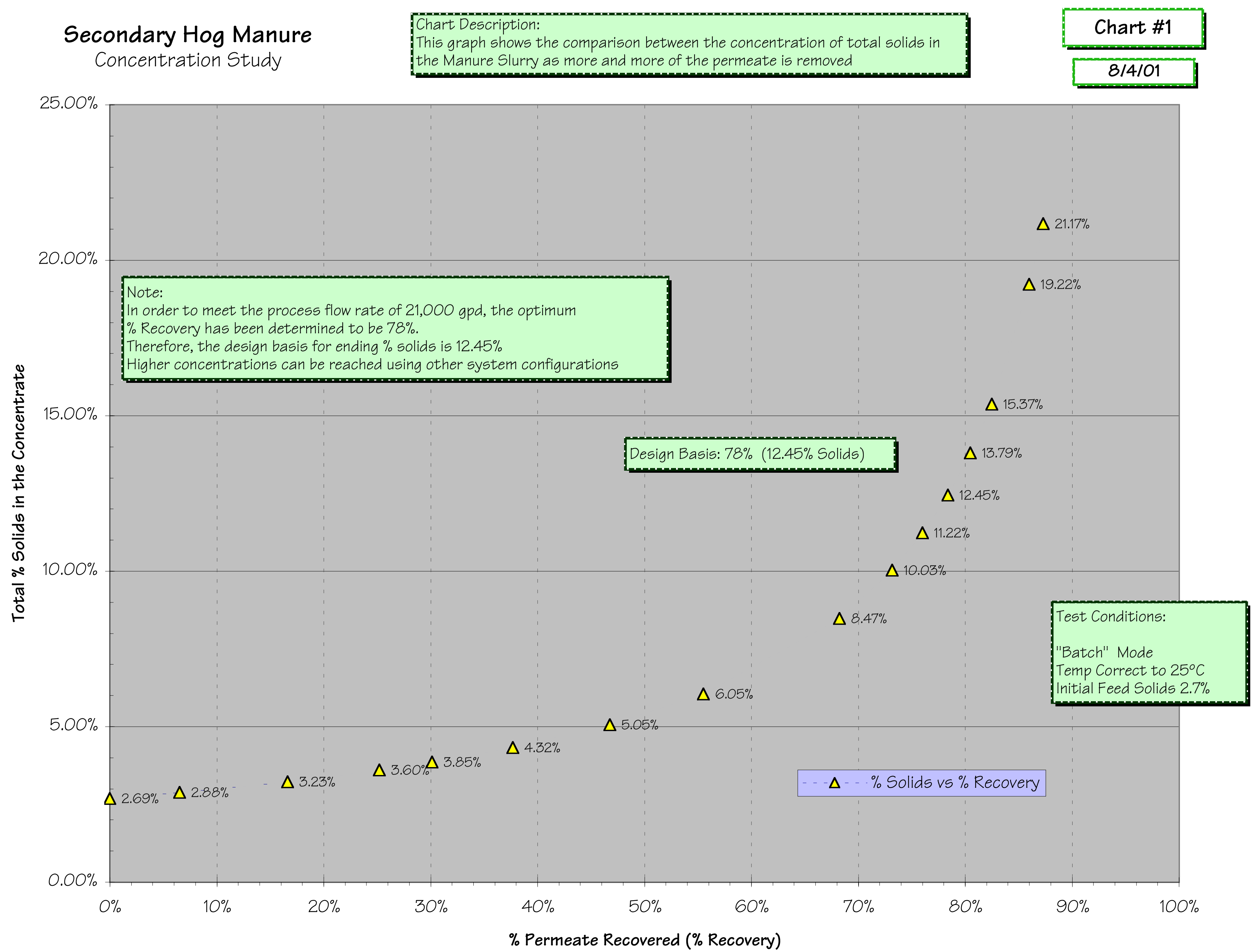
Kimhae 84" Seires i V✧SEP

Observation Deck

Pre-Screen Bag Filter

Concentrate Holding Tank

Fertilizer Spray Truck

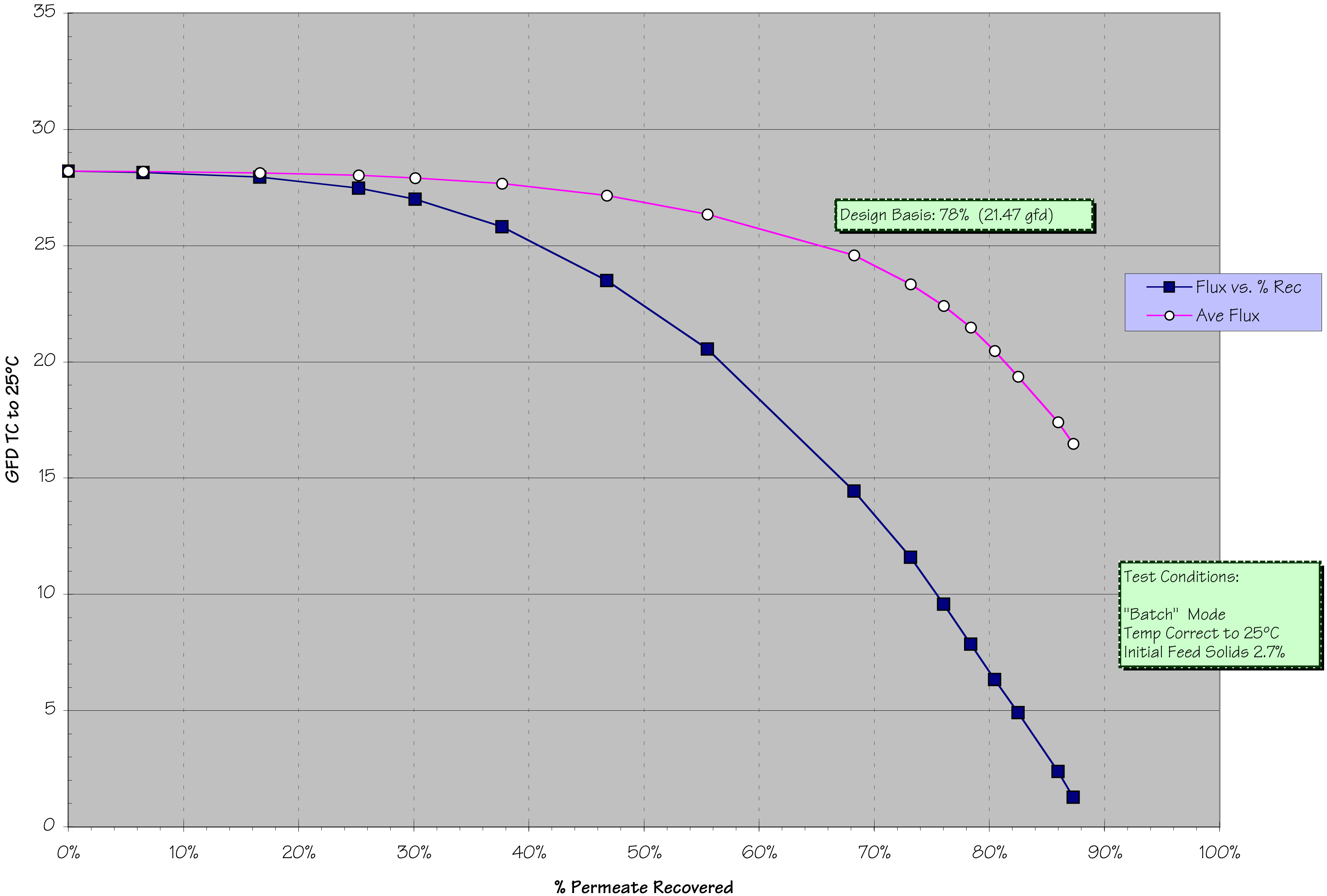

Secondary Hog Manure
Concentration Study
Chart Description:
This graph shows the comparison between the concentration of total solids in the Manure Slurry as more and more of the permeate is removed
Chart #1
8/4/01
Note:
In order to meet the process flow rate of 21,000 gpd, the optimum % Recovery has been determined to be 78%.
Therefore, the design basis for ending % solids is 12.45%
Higher concentrations can be reached using other system configurations
Design Basis: 78% (12.45% Solids)
Test Conditions:
"Batch" Mode
Temp Correct to 25°C
Initial Feed Solids 2.7%
% Solids vs % Recovery
2.69%
2.88%
3.23%
3.60%
3.85%
4.32%
5.05%
6.05%
8.47%
10.03%
11.22%
12.45%
13.79%
15.37%
19.22%
21.17%
Total % Solids in the Concentrate
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% Permeate Recovered (% Recovery)

Secondary Hog Manure
Concentration Study

Chart Description:
This graph shows the comparison between Permeate Flow and the Percentage of Permeate removed from the total volume. The average Flux is used for calculating performance

Chart #2

8/4/01

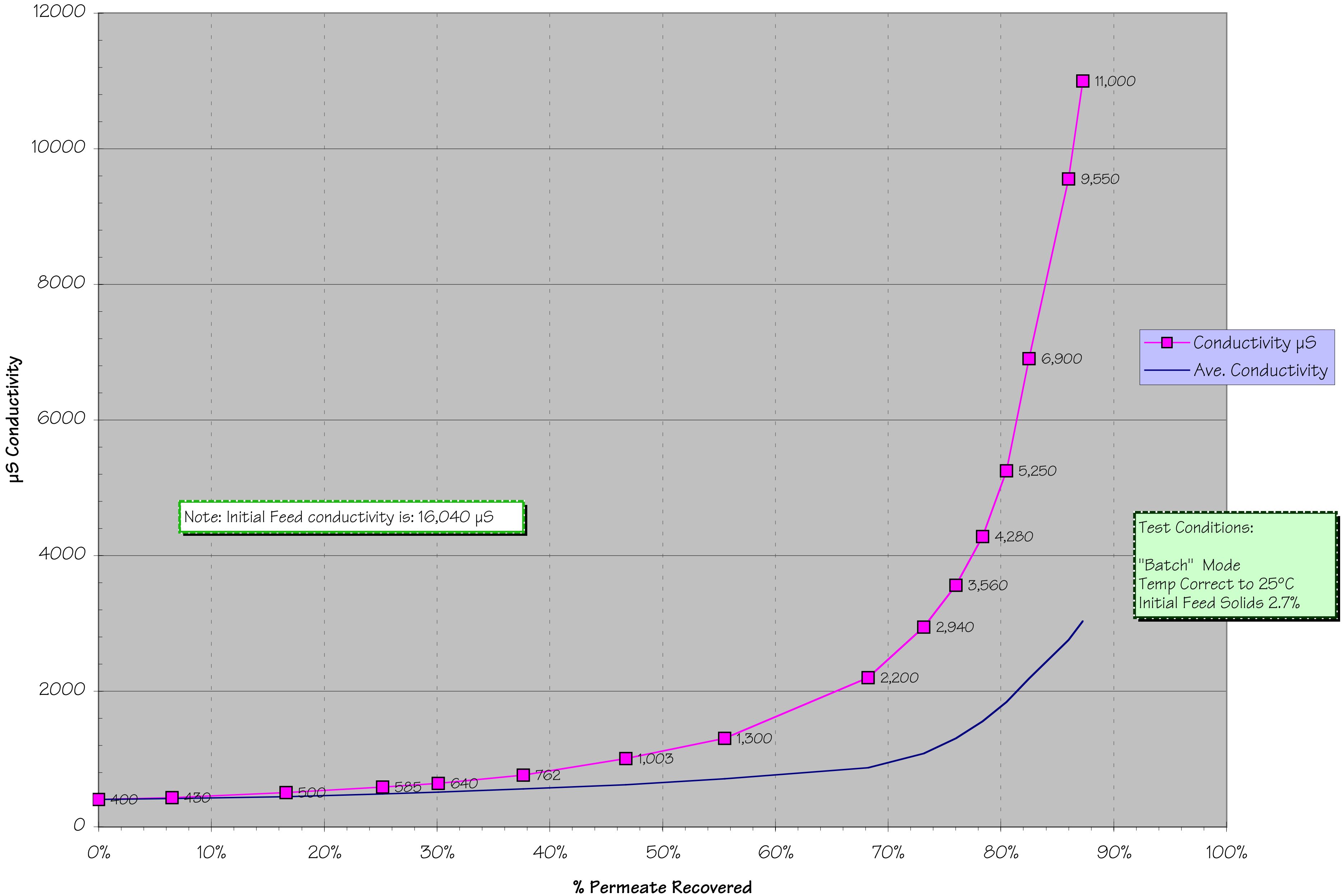


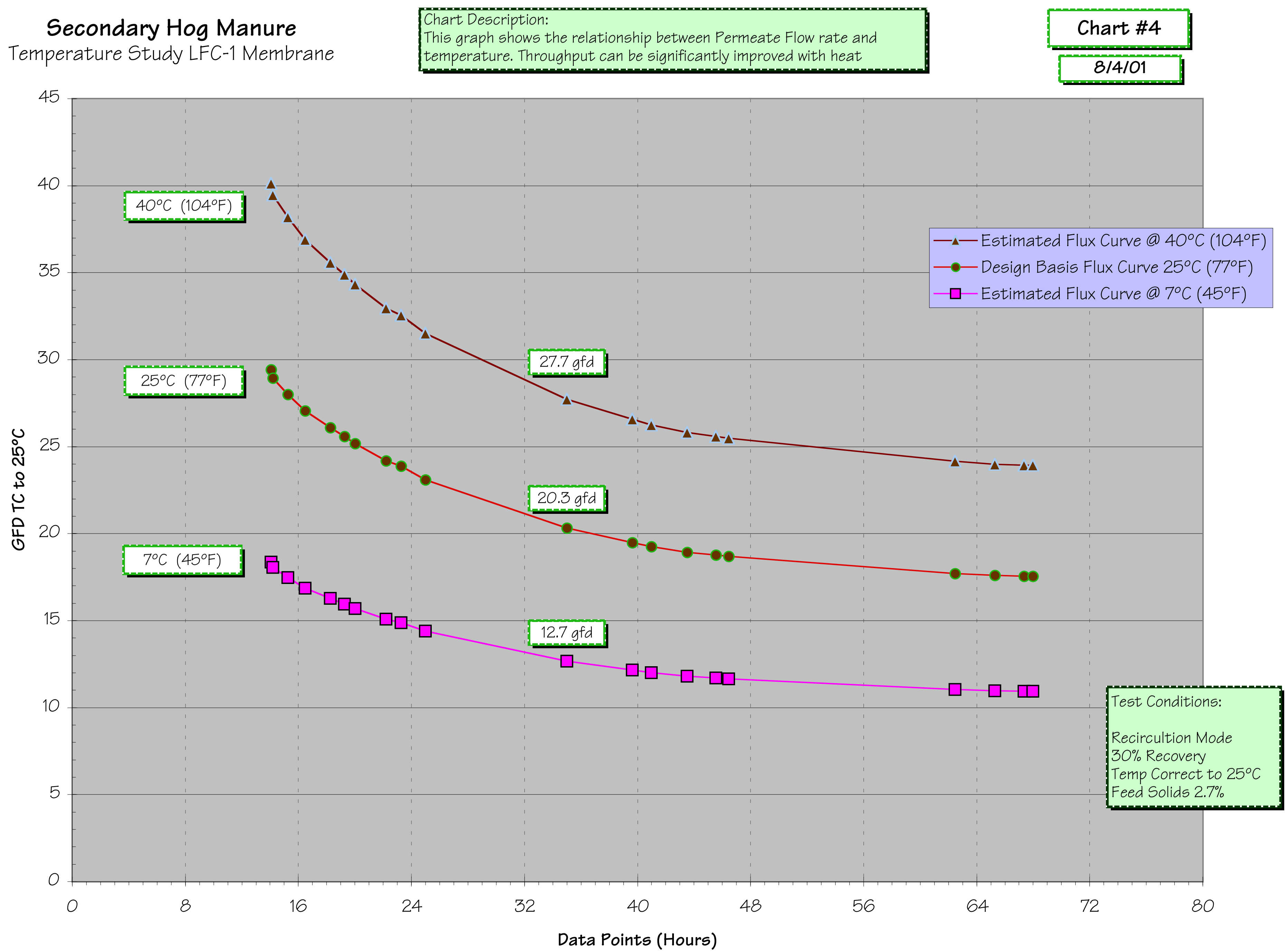
Secondary Hog Manure
Concentration Study

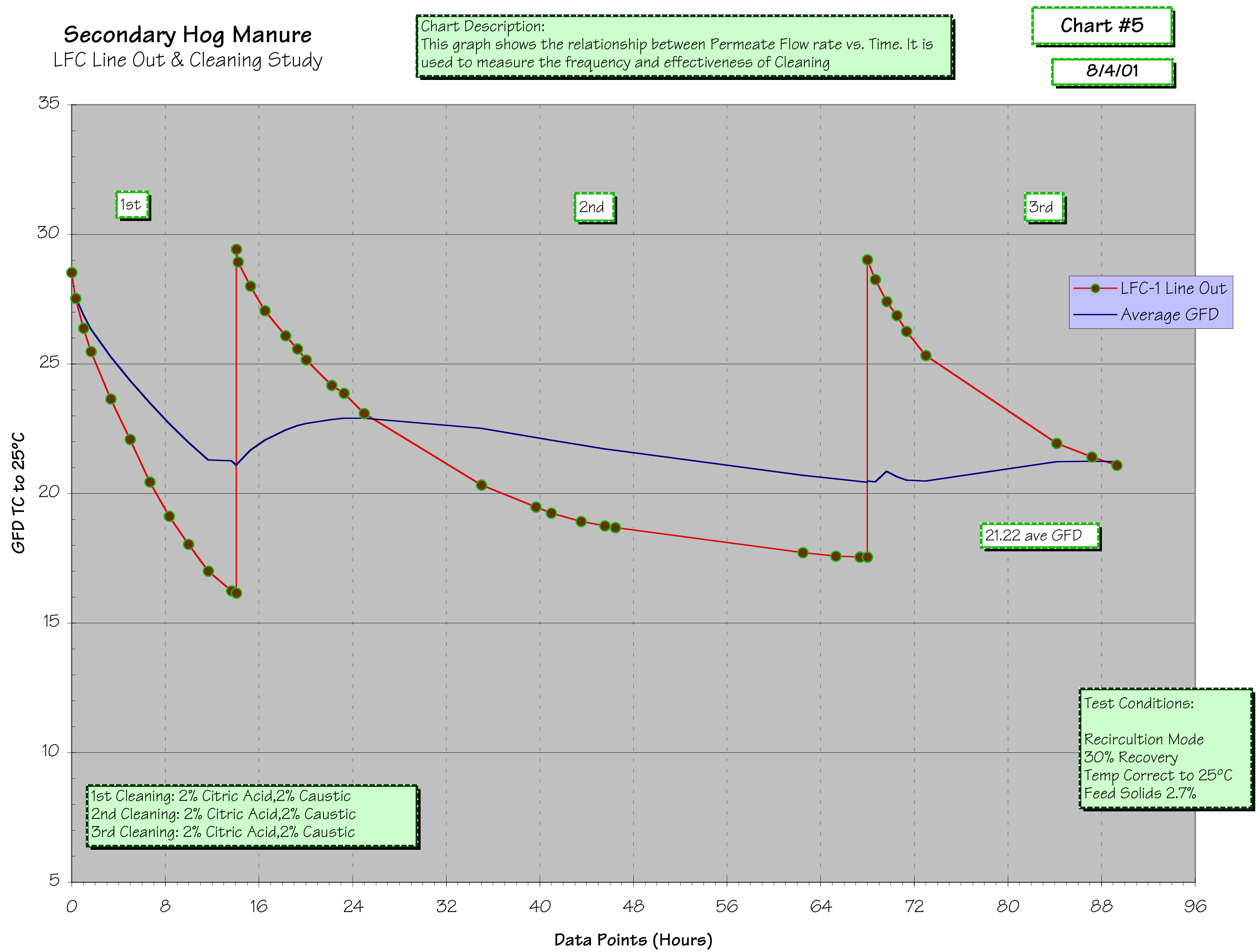
Chart Description:
This graph shows the compares Permeate Quality vs the Percentage of Permeate removed from the total volume. Since the membrane is seeing higher concnetrations at higher % recovery, permeate quality is decreased by high recoveries.

Chart #3

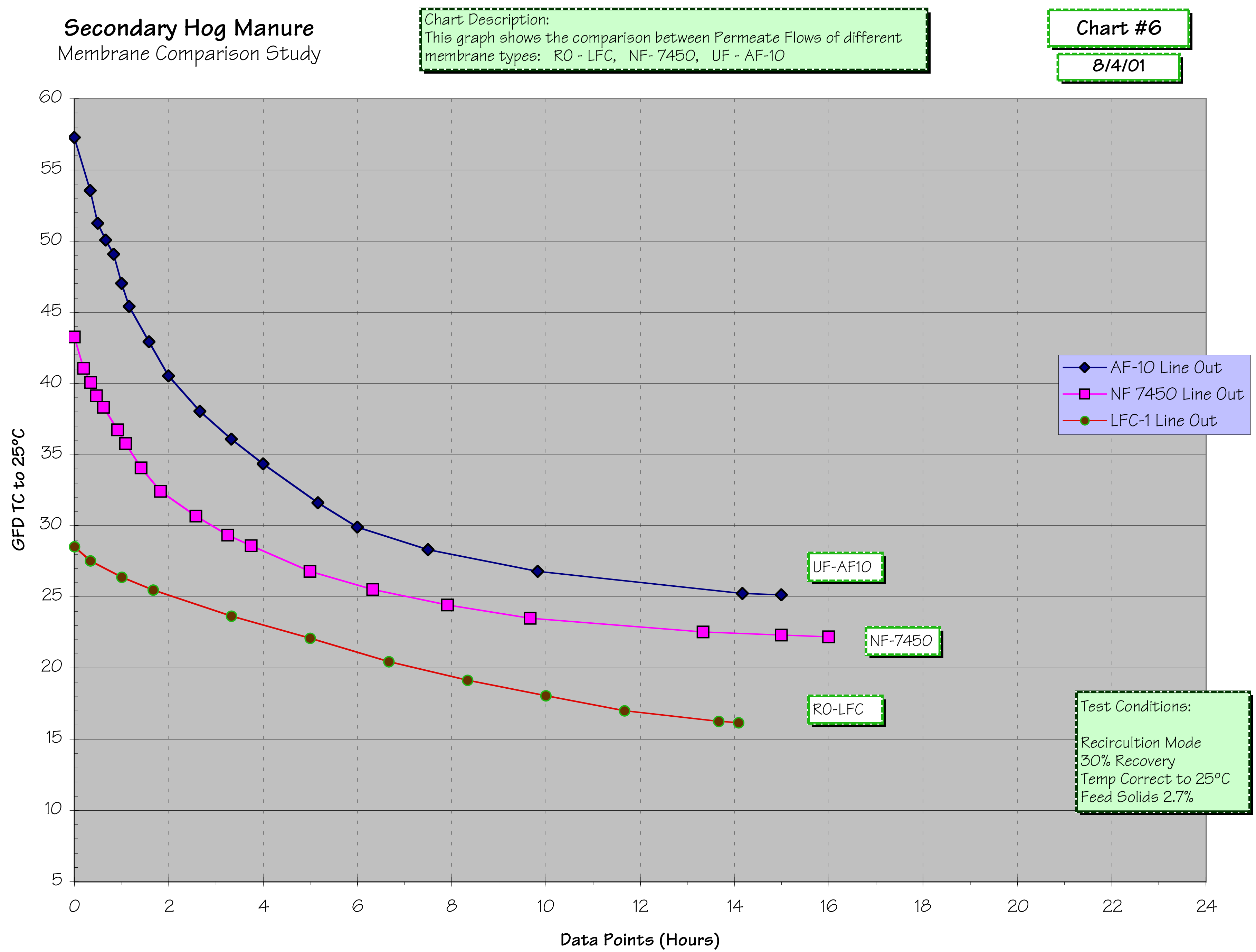
8/4/01

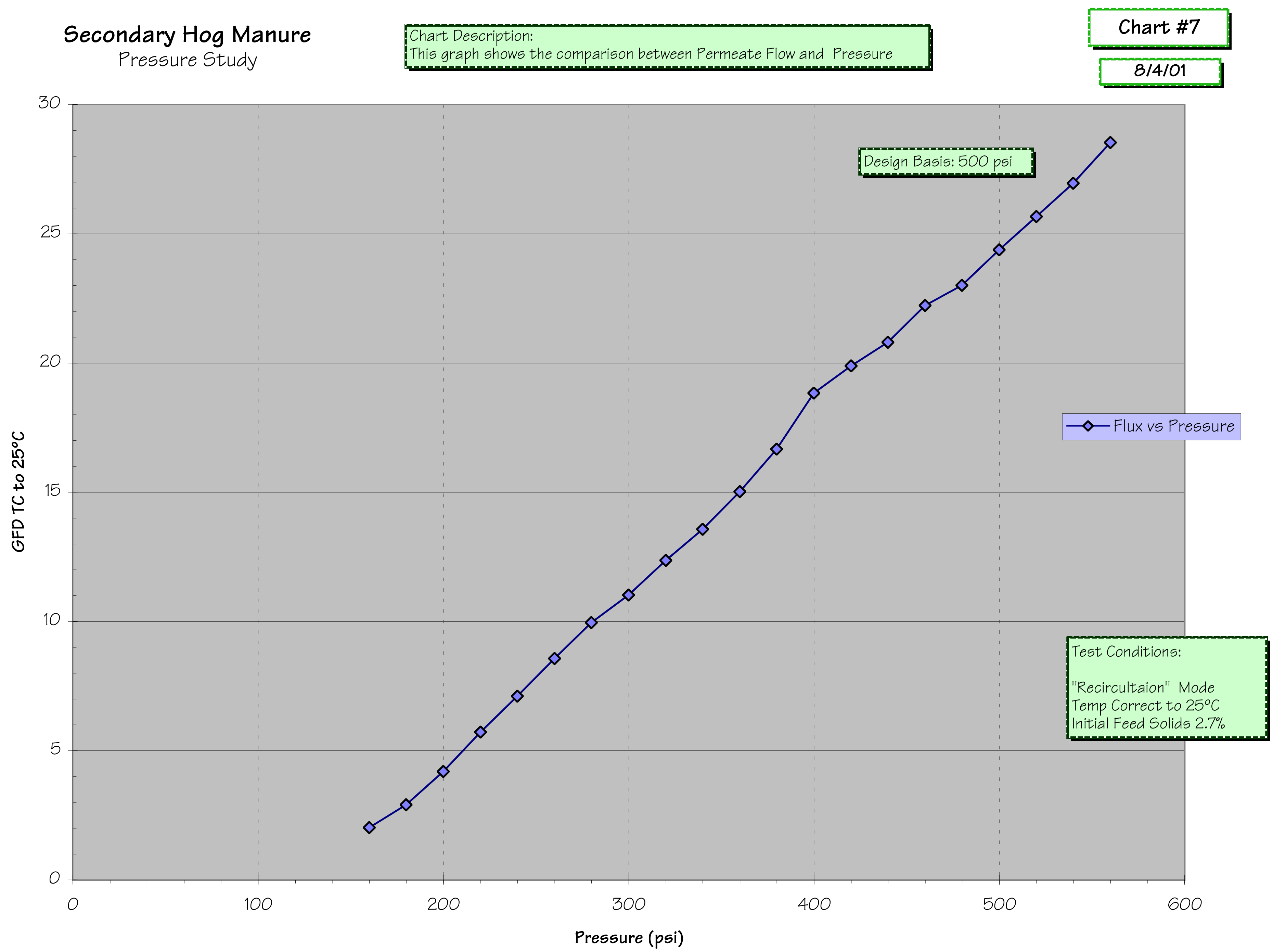



Secondary Hog Manure
Temperature Study LFC-1 Membrane
Chart Description:
This graph shows the relationship between Permeate Flow rate and temperature. Throughput can be significantly improved with heat
Chart #4
8/4/01
40°C (104°F)
25°C (77°F)
7°C (45°F)
27.7 gfd
20.3 gfd
12.7 gfd
Estimated Flux Curve @ 40°C (104°F)
Design Basis Flux Curve 25°C (77°F)
Estimated Flux Curve @ 7°C (45°F)
Test Conditions:
Recircultion Mode
30% Recovery
Temp Correct to 25°C
Feed Solids 2.7%
GFD TC to 25°C
Data Points (Hours)
0
5
10
15
20
25
30
35
40
45
0
8
16
24
32
40
48
56
64
72
80



Secondary Hog Manure
LFC Line Out & Cleaning Study
Chart Description:
This graph shows the relationship between Permeate Flow rate vs. Time. It is used to measure the frequency and effectiveness of Cleaning
Chart #5
8/4/01
1st
2nd
3rd
LFC-1 Line Out
Average GFD
21.22 ave GFD
Test Conditions:
Recirculation Mode
30% Recovery
Temp Correct to 25°C
Feed Solids 2.7%
1st Cleaning: 2% Citric Acid,2% Caustic
2nd Cleaning: 2% Citric Acid,2% Caustic
3rd Cleaning: 2% Citric Acid,2% Caustic
GFD TC to 25°C
35
30
25
20
15
10
5
0
8
16
24
32
40
48
56
64
72
80
88
96
Data Points (Hours)


Secondary Hog Manure
Membrane Comparison Study
Chart Description:
This graph shows the comparison between Permeate Flows of different membrane types: RO - LFC, NF- 7450, UF - AF-10
Chart #6
8/4/01
GFD TC to 25°C
Data Points (Hours)
AF-10 Line Out
NF 7450 Line Out
LFC-1 Line Out
UF-AF10
NF-7450
RO-LFC
Test Conditions:
Recircultion Mode
30% Recovery
Temp Correct to 25°C
Feed Solids 2.7%
60
55
50
45
40
35
30
25
20
15
10
5
0
2
4
6
8
10
12
14
16
18
20
22
24


Secondary Hog Manure
Pressure Study
Chart Description:
This graph shows the comparison between Permeate Flow and Pressure
Chart #7
8/4/01
Design Basis: 500 psi
Flux vs Pressure
Test Conditions:
"Recircultaion" Mode
Temp Correct to 25°C
Initial Feed Solids 2.7%
GFD TC to 25°C
Pressure (psi)
0
5
10
15
20
25
30
0
100
200
300
400
500
600