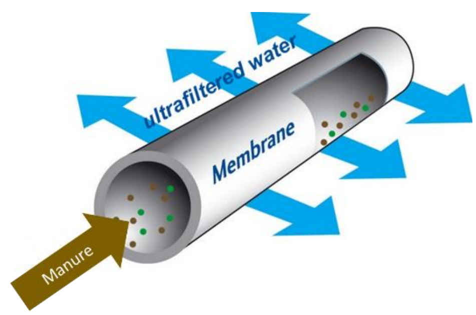
Ultrafiltration Testing Report

Digested Organics carried out onsite testing of our manure filtration system during the week of December 12th, 2016 at the Brad Schwieterman Farm in Celina, Ohio. This testing was arranged by Theresa Dirksen, Ag Solutions Coordinator, with the goal of demonstrating how ultrafiltration can be used to remove phosphorus, suspended solids, organic nitrogen, and pathogens from swine manure. **This project was not intended to treat a large volume of manure; rather it was a small-scale demonstration of the technology.**

Digested Organics utilizes a patented ultrafiltration system made of porous stainless steel tubes with holes about 0.02 microns in diameter, which is equivalent to sterile filtration used in laboratories. This means the ultrafiltration system can remove all suspended solids, which includes bacteria and most of the phosphorus and organic nitrogen. A pump is used to push the manure through parallel tubes fast enough to keep them clean, and the filtered manure, which we call permeate, is collected outside of the tubes in the shell. The manure inside the tube, which we call concentrate, becomes thicker and thicker as we remove more permeate. During our demonstration, we utilized a system that contained about 5.6 square feet of surface area along a 20' length of porous tube. This system is unique in that the filter contains no moving parts besides a single centrifugal pump (easily serviced) and uses no polymers or fancy chemicals that must be routinely purchased.



We setup our ultrafiltration system connected to a tank full of swine manure. We performed two separate batches to concentrate the manure and generate as much permeate as possible. The first batch used raw swine manure from the farm's pit after 45 minutes of agitation and the second batch used raw manure collected from near the top of the pit without agitation. Since there were lots of larger solid particles in the agitated manure that settled quickly, the second batch is more representative of manure after using a screw-press to remove large solids. We recommend using a screw-press before the ultrafiltration system because this will protect the system from damage due to rocks or other large particles, improve performance, and increase longevity. Plus, the solids removed by the press contain high amounts of phosphorus and are easy to transport off the farm.

For both batches, we measured the flow rate of the permeate in gallons per minute (GPM) as the manure thickened in the tank. Initially, the permeate flows faster because the manure is thinner, but as we remove the permeate and only the solids remain, the ultrafiltration system has to work harder and the permeate flow rate declines. Our goal is to remove about 80-90% of the manure volume as permeate, so it's important to understand how the system will perform as the material thickens. We convert the permeate flow rate in gallons per minute into a flux rate, which describes the permeate flow rate on a per square foot basis. The flux rate is measured in gallons of permeate produced per square foot of membrane per day and is abbreviated GFD.

Results—Batch 1

Batch 1 started with 75 gallons of raw manure from the agitated pit. As shown in the table below, this raw manure contained about 6.4% total dry matter with 36 lbs/1000 gal total nitrogen (TN), 20 lbs/1000 gal phosphorus (P2O5) and 24 lbs/1000 gal potassium (K2O). We collected two permeate samples for analysis, one on 12/12/16 near the start of the run and one on 12/13/16 near the end of the run. As expected, both permeate samples were similar but the sample collected later in the batch on 12/13/16 had slightly higher amounts of NPK and minerals. This happens because the material has been circulating for longer through the system. As a result, this later sample is more representative of the permeate quality we would see from a commercial-scale facility.

The permeate collected on 12/13/16 contained 1.42% total dry matter, a reduction of about 78% relative to the raw manure. As expected, there was very little reduction in the ammonia-nitrogen (since ammonia-nitrogen is water soluble and passes through the filter), but the system did remove about 92% of the organic nitrogen, for a removal efficiency of about 30% of total nitrogen. **Most importantly, the permeate contained just 0.93 lbs/1000gal P2O5, which was a 95% reduction compared to the raw manure.** Finally, while the lab results shown below indicate that the permeate contained slightly more potassium than the raw manure, this is highly unlikely and is probably a result of minor sampling or analytical error. This table also presents information on the mineral content of the raw manure and the permeate. The ultrafiltration system removes about 70-80% of the calcium and magnesium, along with about 20% of the sulfur and nearly all of the iron, manganese, copper, and zinc.

Unfortunately, due to an electrical problem that developed overnight when the system was running unattended, the recirculation pump on our system shut down and this batch could not be completed. Hence, no concentrate sample was collected.

Parameter	Units	Raw Manure 1 (12/12/16)	UF Permeate (12/12/16)	Percent Removal	UF Permeate (12/13/16)	Percent Removal	Average Percent Removal
Moisture	% wet basis	93.60	98.70	N/A	98.58	N/A	N/A
Dry Matter (Mineral)	% wet basis	1.36	0.78	42.6%	0.87	36.0%	39.3%
Dry Matter (Organic)	% wet basis	5.04	0.52	89.7%	0.55	89.1%	89.4%
Total Dry Matter	% wet basis	6.4	1.3	79.7%	1.42	77.8%	78.8%
Total Nitrogen	lbs/1000gal	35.96	21.57	40.0%	25.2	29.9%	35.0%
Ammonium-N	lbs/1000gal	24.73	20.14	18.6%	24.27	1.9%	10.2%
Nitrate-N	lbs/1000gal	ND	ND	N/A	ND	N/A	N/A
Organic-N	lbs/1000gal	11.23	1.43	87.3%	0.93	91.7%	89.5%
Phosphorus (P2O5)	**lbs/1000gal**	**19.92**	**0.59**	**97.0%**	**0.93**	**95.3%**	**96.2%**
Potassium (K2O)	lbs/1000gal	23.8	24.34	-2.3%	27.23	-14.4%	-8.3%
Calcium	lbs/1000gal	10.13	1.51	85.1%	1.69	83.3%	84.2%
Magnesium	lbs/1000gal	7.34	1.68	77.1%	1.94	73.6%	75.3%
Sodium	lbs/1000gal	6.67	6.97	-4.5%	7.78	-16.6%	-10.6%
Sulfur	lbs/1000gal	10.3	7.05	31.6%	8.12	21.2%	26.4%
Boron	lbs/1000gal	0.032	0.028	12.5%	0.032	0.0%	6.3%
Iron	lbs/1000gal	0.726	ND	98.9%	ND	98.9%	98.9%
Manganese	lbs/1000gal	0.184	0.008	95.7%	0.014	92.4%	94.0%
Copper	lbs/1000gal	0.279	ND	98.6%	ND	98.6%	98.6%
Zinc	lbs/1000gal	0.471	ND	99.7%	ND	99.7%	99.7%

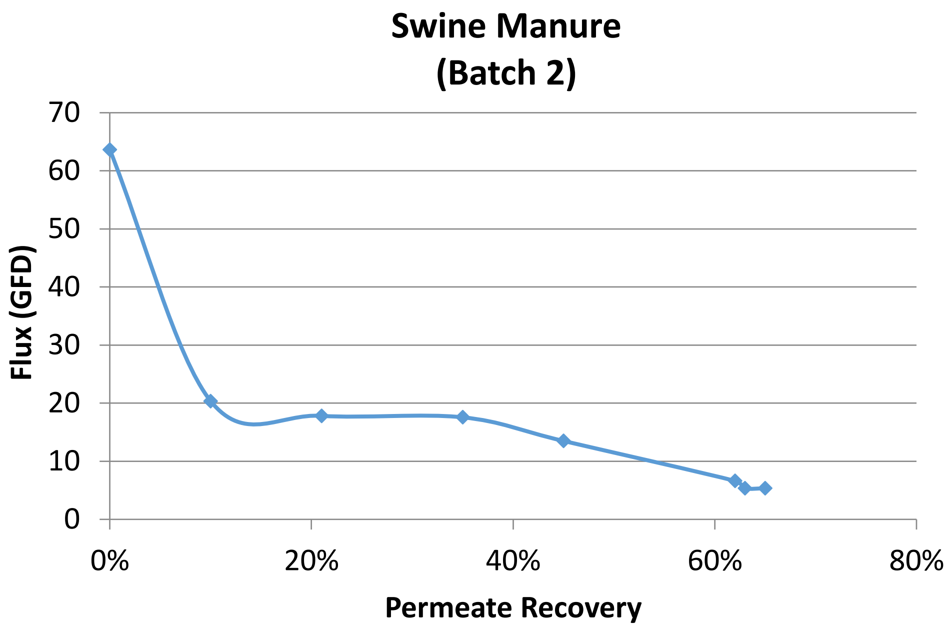
Results—Batch 2

Batch 2 started with 100 gallons of raw manure from the pit without agitation. As shown in the table below, this raw manure contained about 4.3% total dry matter with 34 lbs/1000 gal TN, 14 lbs/1000 gal P2O5 and 24 lbs/1000 gal K2O. This composition is similar to the raw manure used in Batch 1 except it contains less dry matter and less phosphorus, which was expected because we allowed the heavy particles that settle to remain on the bottom of the pit. This also supports the idea that if a screw-press were used, the coarse solids it removed would be rich in phosphorus.

A single permeate sample was collected near the middle of the batch. Similar to Batch 1, the permeate contained very little organic N (a 93% reduction compared to the raw manure). A higher level of ammonia removal was found but this may have been due to sample collection and handling (some ammonia could have volatilized from the manure in the tank). Again, **the phosphorus removal was high with the permeate containing just 0.92 lbs/1000gal for a reduction of about 94%.** A similar amount of removal of potassium and minerals was found in this second batch and the first.

This batch was concentrated for about 25 hours until we produced 65 gallons of permeate, equivalent to a recovery of 65% or a concentration factor of 2.9. In a commercial installation, we would design the system to achieve 80 to 90% recovery as permeate, but our onsite testing was limited by the size of our equipment, the cold weather, and time. As shown in the table below, the concentrated manure contained 10.5% total dry matter with about 60 lbs/1000 gal TN, 41 lbs/1000 gal P2O5 and 23 lbs/1000 gal potassium K2O. As you can see in the rightmost column, when the concentration factor for a single nutrient matched closely to the volumetric concentration factor (which was 2.9), the percent removal in the permeate was very high (e.g., for organic nitrogen and phosphorus). This means we could expect these nutrients to be even more concentrated if we removed more permeate.

Parameter	Units	Raw Manure 2 (12/13/16)	UF Permeate 2 (12/13/16)	Percent Removal	UF Concentrate Run 2 (12/14/16)	Concentration Factor
Moisture	% wet basis	95.67	98.66	N/A	89.43	
Dry Matter (Mineral)	% wet basis	1.21	0.83	31.4%	2.05	1.7
Dry Matter (Organic)	% wet basis	3.12	0.51	83.7%	8.52	2.7
Total Dry Matter	% wet basis	4.33	1.34	69.1%	10.57	2.4
Total Nitrogen	lbs/1000gal	34.43	18.92	45.0%	59.87	1.7
Ammonium-N	lbs/1000gal	24.45	18.25	25.4%	27.81	1.1
Nitrate-N	lbs/1000gal	ND	ND	N/A	ND	N/A
Organic-N	lbs/1000gal	9.98	0.67	93.3%	32.06	3.2
Phosphorus (P2O5)	**lbs/1000gal**	**14.13**	**0.92**	**93.5%**	**41.39**	**2.9**
Potassium (K2O)	lbs/1000gal	23.52	25.44	-8.2%	23.47	1.0
Calcium	lbs/1000gal	8.54	1.59	81.4%	22.66	2.7
Magnesium	lbs/1000gal	5.41	1.84	66.0%	13.09	2.4
Sodium	lbs/1000gal	6.68	7.45	-11.5%	6.38	1.0
Sulfur	lbs/1000gal	9.05	7.62	15.8%	11.45	1.3
Boron	lbs/1000gal	0.029	0.029	0.0%	0.035	1.2
Iron	lbs/1000gal	0.519	ND	98.5%	1.529	2.9
Manganese	lbs/1000gal	0.151	0.013	91.4%	0.413	2.7
Copper	lbs/1000gal	0.256	ND	98.4%	0.726	2.8
Zinc	lbs/1000gal	0.36	ND	99.6%	1.022	2.8



The graph above shows the flux rate during the second batch of manure concentration. The manure temperature varied between 57°F (when the batch started) and 65°F (when the batch ended), even though the outside temperature was below freezing. A small amount of friction within the ultrafiltration system adds heat to the material, which will help it filter faster. As more permeate was removed, the manure got thicker and so the flux rate slowed down. We used these data to design the commercial facility estimates shown below.

These pictures show the UF permeate being collected in sample containers for shipment to the lab.

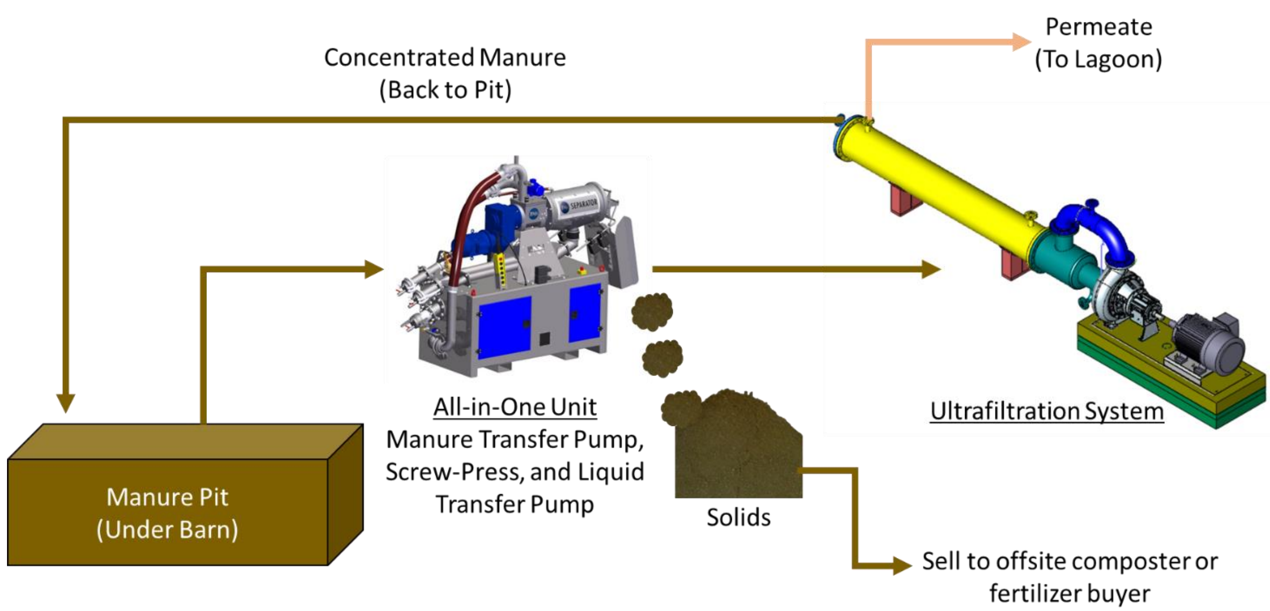
Commercial Facility Design

For this report, we have considered a simple commercial design to estimate the capital cost and operating cost of the facility. We assume roughly 300 gallons of manure per hog per year, so a facility with 7,500 hogs would produce about 2,250,000 gallons per year or 6,165 GPD manure. This design assumes a transfer pump moves material from the pit under the barn to a screw press and the liquids exiting the screw press are pumped through the ultrafiltration system continuously every day. The permeate (containing very little phosphorus) would then be stored in a nearby tank or lagoon while the concentrated material would remain in the pit or be stored in a separate tank. Most of the solids would be removed by the screw-press and transported off the farm, ideally when sold to a nearby composter or farmer out of the watershed. If needed, concentrated material in the pit could also be hauled offsite as a liquid slurry, but the goal is to keep transportation costs as low as possible and move material with as little water as possible. This system does not require any additional heating of the manure but will benefit from the use of hot water for cleaning (a small electric or propane water heater can be used to heat approximately 500 gallons of well water every week).

This system could be installed in a new building onsite, an existing building, or delivered in a 8'x 40' shipping container and placed near the barn with access to the pit.

The estimated capital cost for this equipment and onsite installation is $535,000. This does not include the cost for a concrete pad, building, or container. **An insulated and containerized system ("plug-and-play" ready) would cost about $550,000.** Leasing and financing options are available through our partners.

The estimated operating cost for the system is approximately $22,500, or approximately 1 cents/gallon processed. This includes electricity ($15,000), cleaning chemicals ($2,500), and a contingency for repairs and/or replacement parts ($5,000). This electric cost assumes the site has 3-phase power that costs about 8 cents/kWh, though it is possible to use a single phase to three phase converter for sites without three phase power. This estimate excludes any labor costs by farm personnel, but the system is fully automated and should not require more than 2 hours per week of work.



Based on the manure analysis from Batch 1, which contained 19.9 lbs/1000gal P2O5, and the permeate analysis showing 0.93 lbs/1000 gal P2O5, if the facility recovered 85% of the manure volume as permeate, **we would expect this facility to remove approximately 43,000 lbs of P2O5 from the watershed each year. If valued at about $0.5/lb for P2O5,**

revenues from exporting phosphorus would cover about all of the system's operating costs. It will be important to work with local officials and businesses to ensure a reliable market of phosphorus-rich solids produced by this type of facility.

Picture of commercial ultrafiltration unit processing dairy manure in Sheboygan Falls, WI.

Agronomic Considerations

When applying the permeate to fields, nitrogen becomes the limiting factor. Based on a total nitrogen value of 22 lb/1000 gal, and assuming that the permeate is applied to a corn crop (180 bu/ac), one could apply between 8,000 gal/acre and 12,300 gal/acre depending on whether nitrogen losses to the atmosphere were considered. Most likely, the permeate would work well as a sidedress for corn or for topdressing wheat.

If one applied the permeate at 8,000 gal/acre, the field would receive the following approximate nutrient levels:

- 176 lbs of N per acre
- 7 lbs of P_2O_5 per acre
- 200 lbs of K_2O per acre

This would meet a crop's nitrogen needs while allowing phosphorus levels to be drawn down in the soil.

Conclusion

The pilot testing at the Schwieterman Farm was successful. We demonstrated that ultrafiltration is a simple, chemical-free and robust method to remove phosphorus, organic nitrogen, and pathogens from raw swine manure. We collected valuable data that will assist in the design of a commercial scale facility as well as support grant submissions that may help to cover the upfront capital costs. Some additional future work should be considered:

- Identify farms with lagoons that could implement this technology without needing to build additional storage for the permeate
- Identify farms with three phase power or investigate the cost to bring three phase power to interested farms or install single phase to three phase converters
- Work with local business and regulators to promote a market for exporting phosphorus-rich solids from the farm
- Investigate the most cost effective strategies for applying the UF permeate to crops to reduce the overall cost of manure processing

- Investigate the use of reverse osmosis to produce clean water suitable for feeding to the pigs, discharge to nearby waterways, or irrigation at very high volumes per acre close to the farm
- Consider hosting another demonstration with a screw-press to collect information about the composition of the screw-press solids or installing a screw-press (even without the ultrafiltration) on a farm to begin learning how to handle these solids, transport them, and sell them locally.
- Consider use of a larger mobile unit that would be able to process the manure in a farm's pit over the course of several days and then move on to the next farm. Such a system would require investment from a local business to own and operate the equipment, and farmers would have to be willing to pay a fee for the service of having their manure separated and filtered. Ideally, the mobile unit would be able to haul away the phosphorus-rich solids, leaving the farmer with filtered manure containing few solids and very little phosphorus.

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