Extension
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Nutrient Recovery System for Dairy Farms: Dissolved Air Flotation and Multi-Disk Press

A manure management plan consists of balancing the use and/or reuse of organic material but, more importantly, nutrients — primarily nitrogen and phosphorous — and water. Water and nutrients are intertwined because water is the primary means by which nutrients are conveyed across and away from farms. On-farm nutrient and water management have become increasingly important in recent years. Nutrient losses reduce land productivity and/or increase operational cost for replenishment of lost nutrients. Nutrients in runoff degrade water quality in receiving bodies of water and have resulted in nearly $1 billion in negative economic impact every year just from tourism reductions across the U.S. Studies suggest that agriculture's non-point source contribution to nutrient loads into the nation's lakes, streams and rivers not only represents a large fraction of the overall load but is also one of the most difficult to address ("Agriculture | Chesapeake Bay Program," 2020).

Addressing the challenges of decreased water quality resulting from nutrient loads requires a holistic approach that includes manure treatment technology innovation, advances in feed science and nutrition, optimization of soil and crop management, and creation of secondary markets that can drive revenue generation for manure-based, value-added products such as biogas and pelletized fertilizer. While all these aspects must be addressed, the separation and treatment technologies used at the point of generation can have the greatest impact. Individuals and organizations, both public and private, have accepted the challenge to develop innovative ways to address nutrient separation, removal and reuse.

One system that has recently gained popularity because of its effectiveness is the combination of dissolved air flotation (DAF) and a multi-disk (MD) press to produce a nutrient-rich cake from a waste stream that has been conditioned by pre-screening coarse material (Figure 1). The DAF/MD combination is a physical/chemical process to separate solids and nutrients, primarily phosphorous and organic nitrogen, from impaired water.

The smallest of these systems is capable of processing several hundred thousand gallons of water per day and currently is intended primarily for medium- to large-scale dairies, generally producers with about 250 or more milking cows. One of these smaller systems could cost between $300,000–$400,000 (CapEx) and $30,000–$35,000 per year to operate (OpEx). The output of this size of system would include tea water that is high in ammonia and approximately 1,800 metric tons per year of phosphorous- and nitrogen-rich cake with approximately 25% solids content ("Evaluation of Nutrient Recovery Technologies," n.d.).

Trident Nutrient Recovery System

While there are several commercial providers for this type of system, this case study focused on the Nutrient Recovery System (NRS) designed and sold by Trident Processes LLC, in Sumas, Washington, and Abbotsford, British Columbia. Trident's history and success in adapting this system for manure nutrient management dates to at least 2014 and is demonstrated by the number of their installations across North America.

The NRS is suited to process a variety of manure waste stream compositions. Figures 1a and 1b show process diagrams for NRS systems that treat manure from fiber bedding and sand bedding, respectively. It should be noted that Figures 1a and 1b are representative of the systems visited by the authors. The precise configuration and use of final process effluent water can vary from facility to facility depending on existing infrastructure and farm management practices. It should be noted that an equalization (EQ) tank is used to provide a more constant flow to the drum screens and dissolved air flotation (DAF) systems.

The primary difference between the fiber and sand bedding systems is the need for a sand removal system

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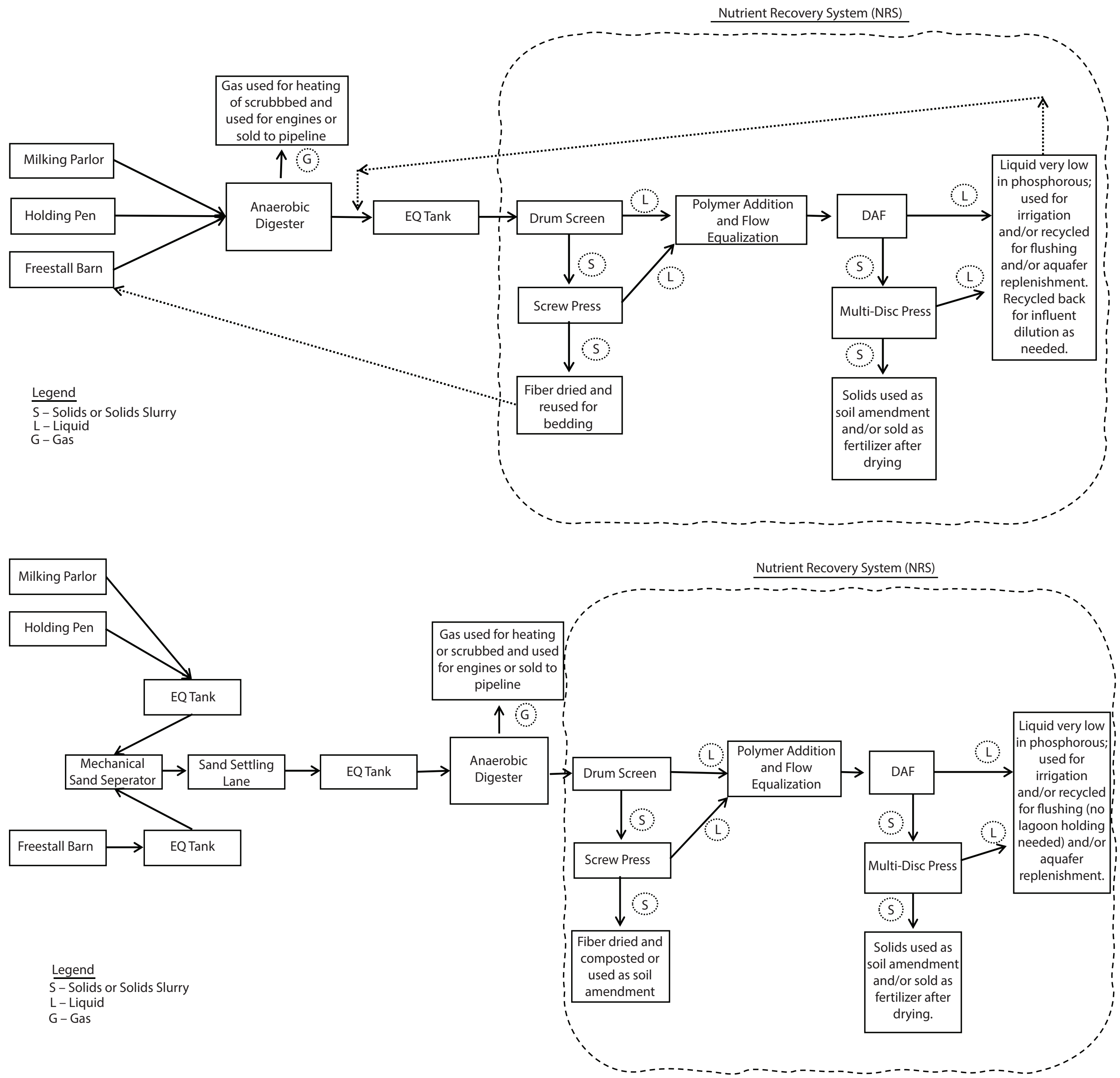

Figure 1. Processes sketches of the Trident NRS system when applied to fiber- and sand-bedded daries (top and bottom, respectively).

upstream of the anaerobic digester. The Trident Bedding Recovery System (BRS), consisting of a rotary drum screen and screw press, is incorporated into the Trident NRS system when the NRS is employed. Removal of coarse fiber from either bedding or animal rations reduces downstream solids load, decreases overall costs and acts as a conditioning step prior to the DAF. Although any screening technology with a nominal pore size of ¼-inch would sufficiently pre-treat the manure stream, Trident based their system design around the screw press for low-moisture fiber recovery and the rotary drum screens integrate easily by sitting directly above the presses.

Dissolved air flotation, or DAF, is a solids/liquid separation process that has existed for more than 50 years. Typically employed in industries where wastewater streams have a high concentration of fats, oils, and greases, DAFs use micro-bubbles to increase the buoyancy of particles in the water. The particles float to the surface and form a floating sludge layer before being skimmed off the top with a set of moving baffles that are commonly referred to as rake assembly flights.

DAF performance is highly dependent on the buoyancy, or floatability, of the solids. Flocculation of particles prior to the DAF is critical in achieving greater floatability. Flocculation occurs in a flocculation tank where dosing pumps add flocculant at a rate that is dependent on the type of solids and flowrate through the system. The importance of this step cannot be overstated and, as such, Trident uses a real-time automated system to monitor and dose the flocculant to achieve optimal performance from the DAF. There are many different manufacturers and types of flocculant available to agricultural producers. Commercial flocculants are designed to bind to specific types of solids, and a system designed around a specific brand and/or type of flocculant may need to be recalibrated if the flocculant type is changed.

The floating sludge from the DAF is directed to one or more multi-disc (MD) presses. The MD press is very similar to a screw press insomuch as solids are compressed against a screen by an internal auger as they are conveyed from the inlet to the outlet. The difference between a screw press and a MD press is the design of the screen against which the solids are compressed. A screw press features a perforated stainless-steel tube whereas the MD press features an assembly of fixed and moving rings or disks that are allowed to slightly undulate with the compressive force of the auger. The result is a press that, although slightly more intricate and costly, is less likely to shear and damage the fragile flocs leaving the DAF. High shear from a screw press would break up the flocculated solids and reduce overall nutrient recovery.

Water rejected by the MD presses, also called pressate, is either collected and sent back to the flocculation tank for reprocessing through the DAF or directed to a holding basin where it is stored until land application occurs. Dewatered solids discharged from the MD press fall to a conveyor that carry the dewatered cake out of the NRS room for further drying, collection, composting, conversion to a value-added product (like pelletization), or used as a soil amendment.

The NRS by Trident Processes features sophisticated process control consisting of Allen-Bradley CompactLogix programmable logic controllers (PLCs) and PanelView Plus human machine interfaces (HMIs) for control of flocculation, DAFs and MD presses. The process control provides a supervisory control and data acquisition system (SCADA) platform. This allows the owner/operator to set various alarms and notifications and even allows the operator to view and control all unit processes in real time for advanced troubleshooting, maintenance and system tuning.

Advantages of the DAF/MD press

- Provides better control over the farm's processes and operation by increasing flexibility in terms of on-farm water and nutrient management.
  - Provides greater water inventory management flexibility by removing large amounts of nutrients, particularly phosphorous.
  - Separates waste stream into phosphorous-rich cake and nitrogen-rich water, allowing for better agronomic management of nutrient ratios.
- Allows for development of value-added products from dewatered, nutrient-dense cake such as pelletized fertilizer.
- No clogging potential for membranes or filters.
- Primarily mechanical maintenance (e.g., electric motors); no chemical cleaning, etc.

Disadvantages of DAF/MD press

- Performance dependent on flocculant effectiveness.
  - Potential variability due to changes in feedstock (e.g., pH, feed type and ratio, etc.)
- Multiple mechanical components subject to maintenance and repair.
- Little to no removal of ammonia-nitrogen and potassium from liquid effluent.
- The technology may be cost-prohibitive for operations with herds less than 250 head.

Requirements for success

- A pre-screening system capable of removing grit and fibrous material greater than ¼-inch.
- Minimum herd size of 250 lactating cows.
- Adequate space for a process equipment building.
  - A building for 1,000 cows requires a footprint of approximately 50-by-25 feet.

Design considerations

The design of the DAF and associated flocculation system relies on a number of factors that are unique to both the industry and the individual farm. The performance of the DAF depends primarily on the ratio of the volume of air to the mass of solids required to achieve a given degree of removal. The volume of air required is dependent on the solubility of the air in the liquid that will be treated; this in turn is dependent on pressure (elevation), temperature and composition of the liquid stream—dissolved solids concentration, fats/oils, etc. The mass of solids aspect of the ratio can vary depending on the type, and expected effect, of the polymer used for flocculation (Tchobanoglous et al., 2003).

The size of the DAF is determined once the amount of air required is derived from industry experience and, possibly, empirical data and jar tests. The required area for the DAF is determined by considering the rise velocity of the solids; this can be anywhere from 0.2 to 3.9 gallons per square foot per minute (8 to 160 liters per square meter per minute), depending on the solids concentration, degree of thickening and solids loading rate. Hydraulic loading per surface area (gallons per square foot) is also a key design parameter.

The MD presses are relatively simple to select once the DAF is designed since the output of the DAF design represents the design parameters, like solids concentration and flow rate, for the MD presses. The pressate from the MD presses is combined with the effluent discharge from the DAF, and a portion of the combined flow may be used for dilution of the incoming manure. Therefore, an iterative design process will be needed to model nutrient concentrations through the system before a final design can be completed.

The modeling and design of a DAF/MD system is inherently complex and requires the professional expertise of a design engineer whom is familiar with DAF systems implemented in the dairy and/or swine industry. It is highly recommended the producer interview multiple design professionals and select the person or entity that: (a) has a track record of success in the industry and (b) is willing to incorporate site-specific data into their design—even if that means the designer must make one or more trips to the site. Putting the time, effort and resources into the design process will ensure a more effective system for less cost.

Management of a DAF/MD pPress

The DAF and MD systems are monitored using a PLC and one or more HMIs depending on the size of the system. An active data link (land line, cellular, etc.) can allow the operator of the system to monitor operation in real time and the manufacturer can provide troubleshooting assistance as needed. A functioning data link can also provide greater operational flexibility by allowing a user to interface with the system from satellite computers and mobile devices.

Remote monitoring and automated process control provide convenience; but, daily in-person observation and periodic maintenance are still required. Owners can expect to dedicate a little less than an hour per day (300 to 350 hours each year) for inspections, blower and pump maintenance, polymer management and time to correct for alarms due to system disruptions such as clogging, part breakage, etc.

The polymer dosing system into the flocculation tank may be the most sensitive aspect of the overall process. Polymer addition must be balanced with flow rate and solids loading for performance of the overall system. Proper functionality requires harmony and precision between multiple components including flow meters and dosing pumps, managed by the automated control system. The level of the polymer must be monitored so additional chemical can be ready and on site when needed. Third party studies have suggested that polymer system issues represented 29% of system interruptions.

The precise nature of polymer dosing requires influent with consistent characteristics for optimal performance. Owners and operators of the DAF/MD system must be mindful of present or future upstream changes. Changes to animal rations rarely affect the chemical composition of the manure or negatively affect system performance. However, co-digestion modifications – changes to the digester feedstock – can have a significant effect on performance and may require recalibration of polymer dosing.

Sizing approach notes for DAF and MD components only

- DAF sizing is one square foot of surface area for every one gallon per minute of flow through the system.
- Flow rate should consider a recycle flow of up to 100% for dilution of digester effluent.
- General design for 1,000 cows would include one 50 square foot DAF and two 310-series MD presses.
- General design for 1,500 cows would include one 100 square foot DAF, and either three 310-series or two 410-series MD presses.
- Each rotary drum/screw combination can treat manure from a maximum of approximately 1,500 cows.

Note: These design parameters are for general sizing purposes only and will be different for each operation.

Installation focus: North America, USA

Sand Dairy and Fiber Dairy are two farms in the continental United States that recently selected a DAF/MD Press for their manure management. Fiber Dairy milks approximately 7,000 cows in scraped freestalls using fiber bedding. Sand Dairy milks approximately 3,000 milking cows in scraped freestalls using sand bedding. Both dairies selected Trident's NRS as part of their manure management system and both have found success implementing the NRS with the source feed coming from a digester. A comparison of the two helps illustrate how the NRS can be integrated into two very different operations.

Sand dairy

The manure management process at Sand Dairy begins when sand-laden manure is brought into a raw manure pit (Figure 2) with a belly-scraper tanker with vacuum suction. A piston pump (Figure 3) conveys the raw manure to a set of two McClanahan sand separators (Figure 4) where it is diluted with flush water, from the milking parlor and holding pen as collected in an agitated tank (Figure 5), to create “make-down” water.

Figure 2. Raw manure pit.

Figure 3. Piston pump.

Figure 4. McClanahan sand separator.

Figure 5. Flush water pit (raw manure pit in background).

Figure 6. Sand settling lanes.

Figure 7. Digester surge pit, left; flush water pit, right.

The separator allows the sand to drop out of the water flow via gravity, and an auger conveys the sand out of the separator and onto a conveyor that transports it outside of the building. The water from the separator then flows through a sand separation lane to reduce the overall sand load (Figure 6). The separator removes the larger particles while the sand separation lane settles out the smaller particles. The operator had to try multiple sand sources to get the best combination of cow comfort and removal before finally settling on a mason sand. Sand is periodically scraped from the sand lane and the water flows to the digester influent pit (Figure 7).

Figure 8. Rotary drum screens and screw presses.

Water is pumped from the digester surge pit to the digester for stabilization of organics. Digestate leaves the digester and is sent to two rotary drum screens for fiber separation (top, Figure 8). It should be noted that a significant amount of fiber is removed from the digestate even though fiber is not used for bedding. Solids captured by the rotary drums drop into screw presses set directly below each rotary drum (bottom, Figure 8) for dewatering before being conveyed outside the building (Figure 9). The fiber is used as an organic soil amendment.

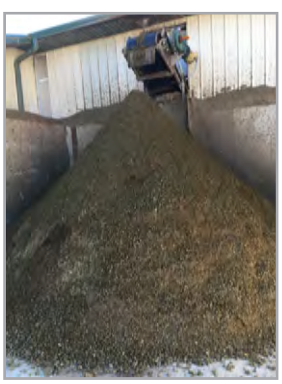

Figure 9. Dewatered fiber from screw presses.

Figure 10. Flocculation and EQ tank with DAF.

Figure 11. DAF with baffles pushing froth, or floating solids from aeration and flocculation processes.

The reject liquid from the rotary drums enters a flocculation tank where polymer is added before draining to an equalization (EQ) tank (Figure 10) and pumped to a single DAF (Figure 11).

Of the water flowing into the DAF, approximately 80% leaves as effluent (Figure 12) and flows to a storage basin. Approximately 20% is scraped off the top of the DAF with the froth (floating separated solids from aeration and flocculation processes) and sent to a set of four MD presses (Figure 13).

Figure 12. DAF effluent "tea" water.

Figure 13. DAF and MD presses.

MD presses are used for this stage because of the relatively low shear when compared to screw presses. Reject water from the MD presses is sent to the storage basin. The dewatered cake drops onto a conveyor (Figure 14) and is sent outside the building (Figure 15).

Figure 14. Cake conveyor.

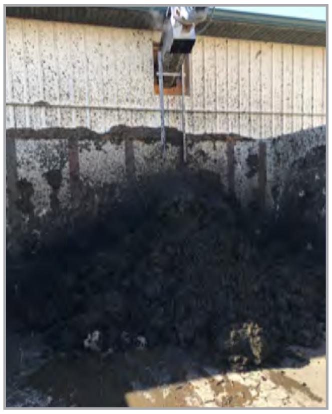

Figure 15. Cake pile.

Fiber dairy

Manure and fiber bedding at Fiber Dairy are collected via a scrape system and deposited directly into the digester. Digestate from the digester is pumped to an equalization tank (EQ tank, see Figure 16) where it is diluted from roughly 10% solids to approximately 6.5% solids using recycled process water. The solution then flows via gravity to five rotary drum screens (Figure 17).

The slurry enters the center of the rotary drum. Water falls through a screen while the solids are conveyed through the rotating internal cylinder using a spiral plate welded to the screen drum—a sort of reverse auger (Figure 18). As at Sand Dairy, the solids from the rotary drums fall into one screw press per drum for dewatering (Figure 19).

The screw press dewaters the fiber by compressing the solids against a stainless steel screen. The screen consists of an outer perforated shell (Figure 20a) providing structural support for an inner perforated screen that is removable to allow for modifiable pore sizes (Figure 20b). The fiber is pressed together by a compression auger (Figure 20c), and liquid is excreted through the screen.

Figure 16. EQ tank.

Figure 17. Rotary drum screen.

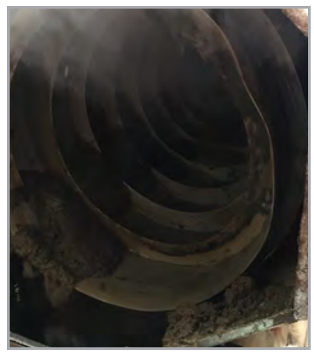

Figure 18. Inside of rotary drum.

Figure 19. Screw press excreting water.

Figure 20a. Outer shell.

Figure 20b. Inner screen.

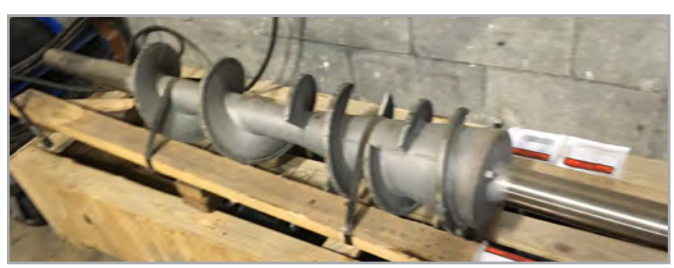

Figure 20c. Compression auger.

Figure 21. Fiber dropping onto conveyor.

The dewatered fiber is ejected from the end of the screw press and drops to a conveyor where it is conveyed (Figure 21) out to a drying area and is recycled for bedding (Figure 22).

Figure 22. Bedding drying and storage area.

The reject water from the drums and screws is collected and pumped to a flocculation tank (Figure 23) where the polymer is added and mixing occurs. The water then flows from the flocculation tank to an equalization tank (Figure 24).

Figure 23. Flocculation tank.

Figure 24. Equalization tank.

The slurry in the equalization tank is pumped to two DAFs of equal size (Figure 25). The DAF's aeration, necessary for flotation of flocculated solids, is produced by an aeration system (Figure 26). The system consists

Figure 25. Side-by-side DAFs.

of a pump pushing water through a pipe where it is oxygenated at high pressure by a compressor to a point of supersaturation (left, Figure 26). The water then flows into a decompression chamber (right, Figure 26) where bubbles nucleate in solution before flowing back into

Figure 26. Aeration system.

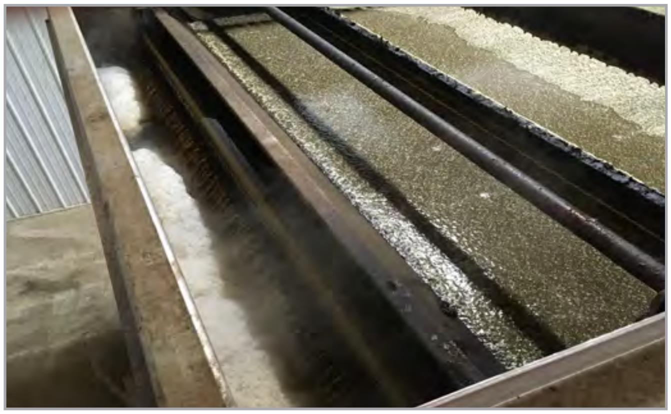

Figure 27. DAF effluent discharge to lagoon.

Figure 28. DAF froth discharge to MD presses.

Figure 29a. Bank of MD presses dewatering DAF froth (front veiw).

Figure 29b. Bank of MD presses dewatering DAF froth (side view).

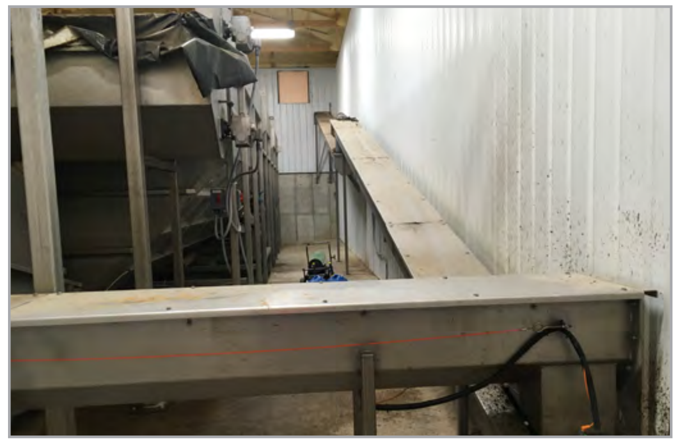

Figure 30. Cake conveyor from MD presses to drying pad.

Figure 31. Cake drying pad.

the DAF. These tiny bubbles rise through the liquid and attach to small, low-density, flocculated solids—floating them to the surface to create the froth.

Once in the DAFs (two in total), the water is split about evenly, with approximately half leaving the DAFs as effluent (Figure 27) and flowing to a storage lagoon. Moving baffles push the froth, which contains the other half of the process water, to a collection weir (Figure 28).

The froth from the DAF tanks drops to a bank of nine MD presses (Figure 29a and b) that operate in a fashion very similar to the screw presses described above. The key difference between the screw presses and the MD presses is that the MDs utilize small rings that undulate approximately ¼- to ½-inch as the auger compresses the solids against them. The undulation gives the press the appearance of a snake's belly as the compression moves along the rings. The movement of the rings provides a self-cleaning mechanism for the press's filter, which is accompanied by periodic spraying to clean the outside of the rings.

Reject water from the presses either flows to the storage basin or is directed back to the front of the process for dilution of the digestate. The cake from the presses drops to a conveyor (Figure 30) and is sent to an outdoor pad (Figure 31) for additional drying and/or storage.

The owners of the fiber bedding system allowed Extension personnel to collect grab samples of liquid and solids throughout the process. Samples were taken during normal operation in late February of 2020. Figure 32 denotes where the grab samples were taken within the process. Sample numbers 1 to 6 in Figure 32 are related to the sample descriptions and content analysis seen in Table 1 (liquid samples) and Table 2 (solids samples). The nutrient recovery in the cake is similar to what Trident reports from other installations: 51% of organic nitrogen, 80% of phosphorous and 22% of potassium.

Operational insight

- Operator believes a piston pump is the most reliable type of pump for moving sand-laden manure.

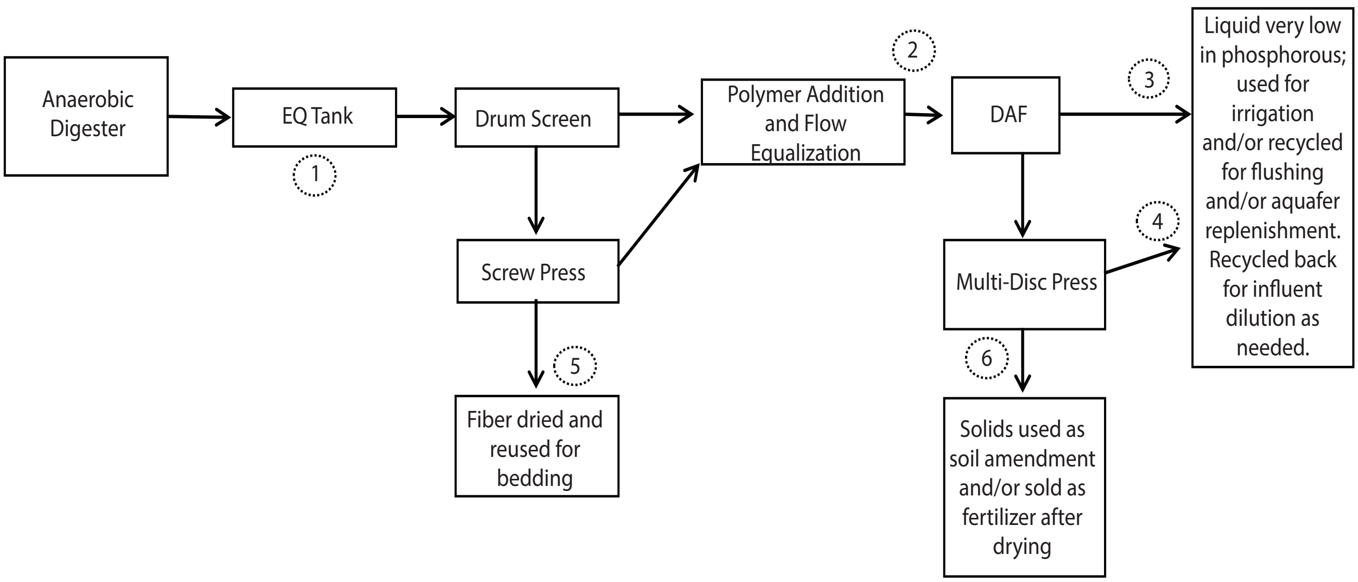

Figure 32. Sample locations refereced in Table 1 and Table 2.

Table 1. Nutrient concentrations and moisture content of liquid manure samples (references from Fig 32 provided).

		Combined influent, post-dilution (1)	DAF influent, after rotary drum screens and polymer addition (2)	DAF effluent (3)	MD reject water (4)
Total nitrogen	mg/L	3,931	2,521	2,106	1,789
	lbs/day	10,178	6,536	4,357	928
Ammonia-nitrogen	mg/L	2,567	1,978	1,998	1,751
	lbs/day	6,662	5,133	4,148	909
Total phosphorous	mg/L	640	293	91.2	446
	lbs/day	3,797	1,737	433	529
Total potassium	mg/L	2,368	2,032	1,956	1,676
	lbs/day	7,376	6,318	4,855	1,046
Moisture (%)		93.5	97.1	98.4	96.1
pH		7.88	8.19	8.22	8.21

Abbreviations: DAF = dissolved air flotation; MD = multi-disc press; mg = milligrams; L = liter; lbs = pound

Table 2. Nutrient percentages and moisture content of bedding and cake

		Bedding (5)	Cake (6)
Production	tons per day	50	193
Total nitrogen	percent	0.83	0.99
	pounds per day	830	3,819
Ammonia-nitrogen	percent	0.24	0.21
	pounds per day	235	818
Total phosphorous	percent	0.32	0.3
	pounds per day	740	2,662
Total potassium	percent	0.18	0.21
	pounds per day	212	980
Moisture	percent	63	81
pH		8.72	8.32

- Use of sand bedding still results in manure slurry with a significant amount of fibrous material excreted by the cows; this can be recovered and used as an organic soil amendment.
- The highly automated control system requires little operator input on a day-to-day basis. Bulk polymer addition every two to three days is the most intensive aspect that occurs on a regular schedule.
- Although day-to-day operator involvement is low, equipment or component failure may require someone with specialized knowledge to repair.
- The SCADA system allows owners/operators to work easily with the system provider to troubleshoot and recalibrate the system as needed.

Conclusion

Dissolved air flotation units and multi-disk presses are technologies that have been in use for decades in the municipal and industrial wastewater treatment industries. Their effectiveness and operational requirements are well known and they have gained wide acceptance as a result. Their application in the agricultural industry, while relatively new, does not detract from their history of solid performance. The ability of the equipment to perform as designed, provided all inputs to the system including the digester are accounted for, should not be a major concern.

It is highly recommended that anyone considering this system discuss operational requirements with current owners to understand the obligation of a highly mechanized process. Manufacturers are aware of the challenges facing adoption and use SCADA systems to provide as much support as possible. Nevertheless, owners should be prepared to maintain pumps, blowers, mixers, conveyance systems, and add polymer on a regular basis. It is also likely that systems treating herds larger than 1,000 could require 480 V, 3-phase electrical service. Operational planning around on-peak electrical demand times could offer significant cost savings over the life of the equipment.

The combination of the DAF/MD press, along with pre-screening for fiber removal, has shown excellent removal of particles from the liquid stream. The resulting water is high in ammonia, which accounts for 95% of the nitrogen, and relatively low in phosphorous. The resulting nitrogen-to-phosphorous ratio is approximately 10 to 1. This can provide operators who are phosphorous-limited with significant water management flexibility.

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