CASE STUDY REPORT:

Advanced Technology for Phosphorus Recovery and Recycling from Manure Wastewater

Blue Spruce Farm, Bridport, VT

STUDY PREPARED BY:
Mark Stoermann
Newtrient Technology Advancement Team

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OVERVIEW

Blue Spruce Farm is owned and operated by the Audet family. Beginning in 1958 with 35 cows, the dairy steadily grew to become one of Vermont's largest producers. Today the dairy milks about 1,500 cows and produces over 40 million pounds (4.7million gallons) of milk per year. Blue Spruce Farm is committed to environmental sustainability and was awarded the "Outstanding Dairy Farm Sustainability" in 2012 presented by the Innovation Center for U.S. Dairy.

As a sustainability dairy leader, Blue Spruce Farm was the first dairy in Vermont to have a manure digester integrated with a DVO Phosphorus Recovery System to capture and separate and phosphorus from recycled manure wastewater. The Audet's implemented the new technology to capture valuable nutrients and test the economic viability of manure-based products and environmental benefits.

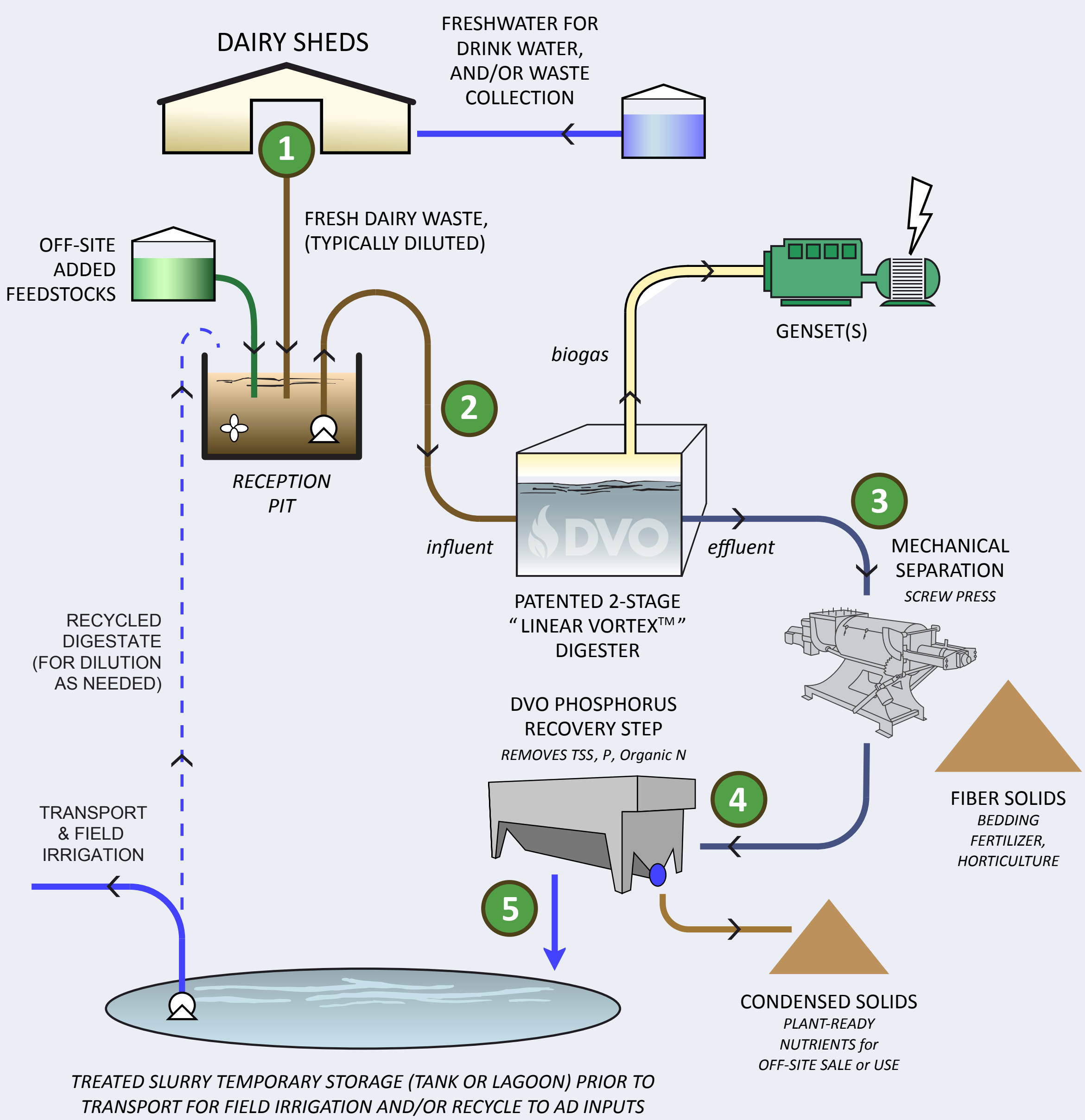
BACKGROUND

DVO Phosphorus Recovery System captures 75-85% of the fine solids and phosphorus in the manure stream for reuse on the farm or for sale off-site as soil amendment products.

In 2018, Blue Spruce Farm partnered with DVO on the installation and use of an advanced Phosphorus Recovery System scaled to process 400,000 gallons/week of the dairy's entire manure wastewater. In addition, the Vermont Agency of Agriculture, Food and Markets (VAAFM) provided support to develop a case study on this innovative phosphorus reduction technology. VAAFM was particularly interested in how the system could help Vermont dairy farms reduce phosphorus and help the state meet clean water goals, while at the same time deliver new sources of revenue to farmers from the value of manure-based products. Marie Audet said, "the main opportunity for this project is to implement a new phosphorus recovery technology that can be used on other dairies, while developing new products and markets — all while improving water quality and farm viability".

The system, shown in **Figure 1,** on the next page starts with manure wastewater collected from a combination of alley-scrapers in the barn, milking parlor wash water and the youngstock barn. The manure wastewater (approximately 8–12% total solids) is blended in a reception pit with 10,000 to 12,000 gallons/week of off-site organic feedstock. The blended feedstock and manure wastewater are

FIGURE 1: Blue Spruce's Annaerobic Digester and Phosphorus Recovery Flowplan



Flowplan description:

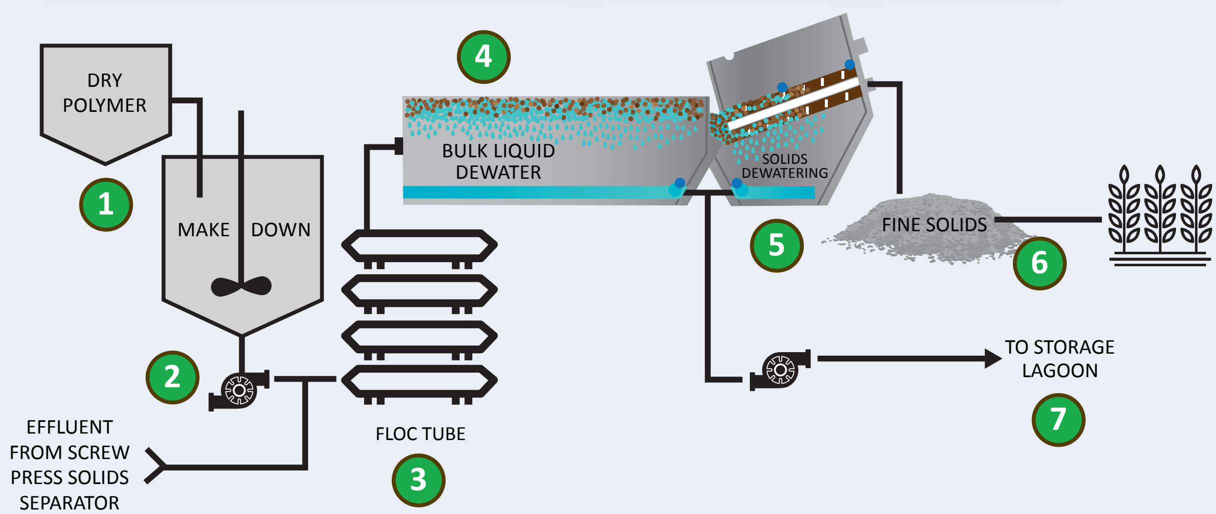
1. Fresh dairy waste is pumped to a reception pit and mixed with off-site feedstock
2. The manure/feedstock slurry is then processed in a anaerobic digester
3. Digester effluent is pumped to a screw press to remove fibrous solids
4. Separated screw press liquids are pumped to the Phosphorus Recovery System
5. Separated PR slurry is temporarily stored in a lagoon for field irrigation and condensed soilds are used for crop fertilizer or sold

Source: DVO

pumped to a DVO anaerobic digester, producing methane gas, electricity and heat for on-farm use. Effluent from the anaerobic digester is then sent to a screw press for separation of fibrous coarse solids (25% volume). The separated solids are used for cow bedding and are sold as a soil amendment product. The remaining screw press liquid faction (75% volume), containing large amounts of suspended solids and associated nutrients, is then processed through the DVO Phosphorous Recovery System for fine solids separation. These fine solids contain condensed plant-ready nutrients that can be used on-farm or sold off-site as a soil amendment product. Unfortunately, these high-quality nutrients do not yet qualify as Organic due to the use of polymer. The final low-nutrient liquid effluent from the system is stored in a lagoon for eventual use as crop fertilizer.

The DVO Phosphorus Recovery System, as shown in **Figure 2,** below is a modified Dissolved Air Flotation (DAF) system comprising several key components: a polymer mixing and dosing system, a micro-air compression and injection system,

FIGURE 2: Blue Spruce Farm DVO Phosphorus Recovery System Operation



The Phosphorus Recovery System key components:

1. Polymer mixing and dosing system
2. Micro-air compression and injection system
3. Manure-polymer-air mixing tube
4. DAF vessel for separation solids
5. Dewatering moving disc presses for recovery of fine solids
6. Recovered fine solids (p-cake)
7. Final effluent (tea-water)

Source: DVO

a proprietary manure-polymer-air mixing tube for optimal treatment, the DAF vessel itself for separation, rise and skimming of solids, and lastly dewatering moving disc presses for production of a semi-stackable solid under continuous flow conditions. The system is placed at an elevation to allow gravity to feed of the manure slurry from mechanical (screw press) solids/fiber separators to an equalization pit for mixing. The slurry is then pumped from the pit to the Phosphorus Recovery System. After treatment in the system both outputs are gravity-fed to the next stage: produced solids (P-cake) is conveyed to a concrete pad and treated liquid (tea-water) to a storage lagoon pump transfer pit.

The entire system is semi-automated for continuous operation, only turning off when float valves on the equalization pit determines the need to temporarily stop due to low manure volume. The system restarts operations automatically when more manure is available. Ernie Audet said, “Regular operations and maintenance is a daily walk-through and completion of a monitoring checklist with a morning filling of solid polymer to a feed hopper.”

The entire system is placed within a portion of an existing processing building. The P-cake is stacked in a covered portion of the building until it can be transported to fields for application. The farm is currently working to identify alternative storage sites for this material. The next steps for the project are to further improve the process to produce a dry, manageable P-cake, to engage other stakeholders who have interest in the P-cake product, and to work toward integrating this system as a valuable part of a sustainable operation.

KEY ISSUES AND CHALLENGES

The Phosphorus Recovery System was installed and commissioned at Blue Spruce Farm in September 2018. The facility was procured as a “design-build” project with the dairy assuming responsibility for ongoing system operations and maintenance. During the first months of full operation, several key operational issues and challenges were identified and addressed as described below.

Consistent Feedstock — The Blue Spruce Dairy system was designed as a scalable, semi-continuous flow process to treat the dairy’s daily manure flow of 400,000 gallons/week. In addition to the manure stream, 10,000 to 12,000 gallons/ week of off-site liquid organic substrates (sweet whey) are delivered to the farm and mixed with the manure for processing in the anaerobic digester. The organic feedstock is added to the digester upon delivery which increases the flow on that day and can create changes in the physical and chemical makeup of the input stream. This is not uncommon with digesters that take outside organic feedstock, but it can make it more difficult determining the proper Dissolved Air Flotation (DAF) polymer dosage and system flow rate when setting up the system.

Course Fiber Separation — The system is a modified DAF system that removes fine solids from the preprocessed manure stream. DAF systems function on the small electrical charges that are present on the solids, polymer and microscopic air bubbles that combine to form the P-cake. These systems work optimally with the course fibers removed from the manure, but the quality of the P-cake and the clarity of the effluent is often benefited by a small amount of these solids being present in the infeed. Blue Spruce does an excellent job of removing almost all the course fiber from their manure stream, but this may hinder the performance of the DAF to some extent and increase polymer dosage and reduce effluent clarity.

Polymer Dosing — The first step in a DAF system is a flocculant dosing process that feeds polymer into the incoming liquid. This liquid is then combined with air and fed into equipment designed to efficiently separate the flocculated solids and water. These solids are subsequently dewatered. In addition to the above-mentioned challenges of determining the optimum chemical form and dosing amount and excellent fiber separation, there were also issues with delivering the polymer into the system caused by the failure of the dosing pump. About two-thirds of the way through the monitoring period (June 25th), a faulty pump was discovered in the portion of the system responsible for injecting polymer into the DAF vessel. Once this pump was repaired, system performance immediately improved. Prior to repair of the pump, several other corrections were made. The system began performing as expected once the polymer pump was repaired.

Storage — The system uses a conventional dewatering technology, a moving disc press, that produces a stackable solid product with approximately 75-80% water content (20-25% total solids). The logistics of storing and transporting this material, though significantly improved over raw manure, still presented challenges. These challenges were heightened, particularly during the long, wet spring given the large volume of material that had to be dealt with. There were times when the system was not running during the testing period due to the lack of storage space for solids. DVO continues to research advanced de-watering technologies and other solids drying and storage options to improve overall system efficiency and performance.

SAMPLING PROGRAM AND RESULTS

The University of Vermont (UVM) monitored the Blue Spruce system and was scheduled to collect P inflows and outflows three times per week for fifteen weeks to report solids and nutrient partitioning performance and solids product characteristics. **Figure 3** below shows the physical by-products and co-products sampled over a fifteen-week period. Samples were collected approximately three

FIGURE 3: Phosphorus Recovery System Monitoring Samples

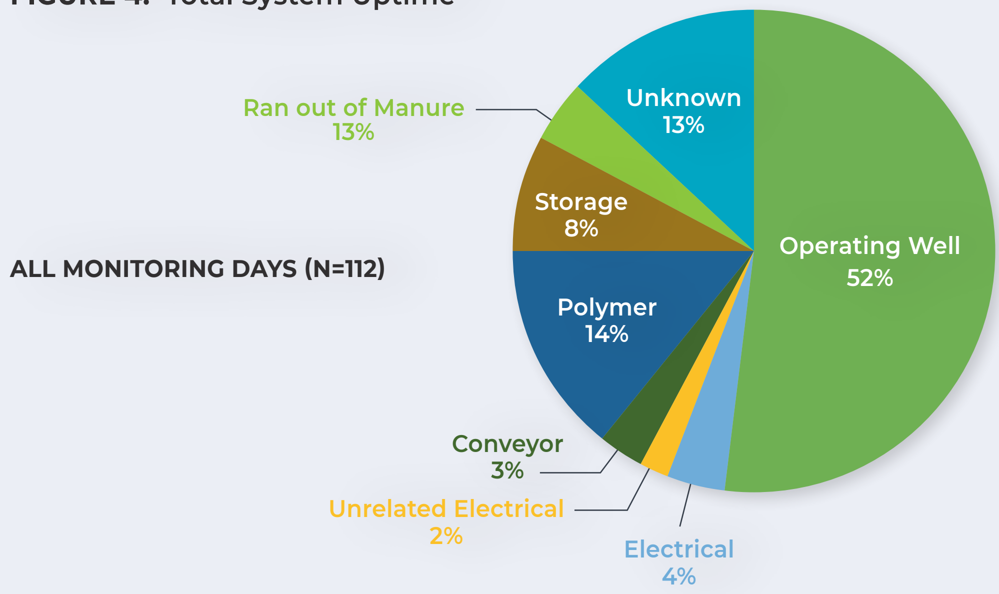
Screw Press Liquid (Input to the system)	**Polymer Water**	**Disk Press Effluent** (Tea-water)	**Phosphorus Solids** (P-cake)

days per week between April 2nd, 2019 and July 18th, 2019 for a total of forty-five days sampled. Materials were collected from five sample ports connected to the DAF: inflow, primary liquid outflow, moving disk press (MDP) liquid outflow, the liquid outflow to storage (not used for calculations) and the separated fine solids outflow.

Operational parameters were monitored throughout the course of the study period using a manhour log. The Blue Spruce Farm employee managing the DAF system submitted daily entries in the log to track manhours spent on normal maintenance, manhours spent on abnormal conditions, unplanned shutdowns and their suspected causes. UVM also recorded observational notes during each sampling event.

According to the manhour log, the DAF system experienced an abnormal or unplanned shutdown on 49 of the 112 days monitored **(Figure 4)**. The cause of the shutdown was not always related to the DAF system. On two occasions, the DAF system was shut down because of unrelated electrical issues. On nine occasions, the DAF system was shut down because of limited space to store the recovered fine solids. This was partially an effect of the uncharacteristically wet spring, which made it difficult to take spreading equipment onto the fields. On five occasions, the DAF system was shut down because it ran out of manure. These are not considered abnormal shutdowns because the DAF system is designed to shut down when manure levels in the equalization pit fall below a certain level. Other unplanned shutdowns can be directly linked to issues with the DAF system,

FIGURE 4: Total System Uptime



including the solids conveyor belt (three instances) and electrical issues (five instances). At least sixteen unplanned shutdowns appear to be linked in some way to the polymer dosing. There were about fourteen unplanned shutdowns recorded where the primary cause was not clear.

As referenced earlier, a faulty pump was discovered about two-thirds of the way through the monitoring period which may have been affecting the delivery of polymer to the DAF vessel. Though it is impossible to say how much of the variability in P recovery performance can be attributed to this one factor, the operators and UVM personnel did observe a marked improvement in the consistency of the recovered solids after the polymer pump was fixed. This was evidenced by observed qualitative changes in the recovered solids, including improved ability to stack the material and a crumbly texture indicative of higher total solids content. There were only two shutdowns reported after the polymer pump was fixed (June 25 and July 20), both due to low manure levels in the equalization pit which is part of normal operation.

The polymer issue also affects the quality and quantity of both liquid outflows. This issue likely played a role in the wide range of sample observed before the polymer pump was repaired. For this reason, the investigators have reported the results of the system in two groups. The first is a data set of all samples and the second is a data set that has been analyzed for statistically significant outliers based on the results obtained after the polymer pump was repaired.

PHOSPHORUS RECOVERY SYSTEM PERFORMANCE RESULTS (TOTAL SAMPLES)

Table 1 displays the system solids and nutrient content of each stream based on the data from the entire sampling set.

Table 1 **SOLIDS AND NUTRIENT PORTIONING PERFORMANCE (TOTAL SAMPLES)**

SAMPLE PORT	TOTAL SOLIDS (%)	TOTAL N (% DM)	P_2O_5 (% DM)	K_2O (% DM)
Inflow	4.1 ± 0.3	9.4 ± 1.1	3.0 ± 0.3	8.4 ± 0.9
Primary Liquid Outflow	2.2 ± 0.5	14.0 ± 2.3	2.0 ± 0.4	15.6 ± 2.9
MDP Liquid Outflow	1.8 ± 0.1	14.7 ± 1.2	1.4 ± 0.4	18.4 ± 2.2
Solids Outflow	20.4 ± 3.0	5.0 ± 0.5	3.7 ± 0.5	1.6 ± 0.4

Table 2 displays the flow data for each stream that was used for the mass balance calculations. Because of the substantial variation in outflow rates measured day to day, a constant value for all outflow rates was used to calculate nutrient flows, recovery rates and loss/gains for each day sampled. The calculated constant solids outflow rate was determined by averaging seven flow rates measured over longer time intervals (50.4 lbs./min) these were confirmed during daily sampling by using a shorter duration measurement. The primary liquid outflow rate and MDP liquid outflow rate were both calculated by averaging the ten flow measurements made (281.7 and 107.4 lbs./min, respectively).

Table 2 FLOW RATE DATA (TOTAL SAMPLES)

Range and mean ± 1 standard deviation of flow rates from DAF ports.

SAMPLE PORT	FLOW RATE RANGE (LBS./MIN)	MEAN ± 1 SD FLOW RATE (LBS./MIN)	FLOW RATE RANGE (KG/MIN)	MEAN ± 1 SD FLOW RATE (KG/MIN)
Inflow	387.0 – 440.2[a]	426.1 ± 9.7[a]	175.6 – 200.0[a]	193.3 ± 4.4[a]
Primary Liquid Outflow	121.7 – 362.8[b]	281.7 ± 72.7[b]	55.2 – 164.5[b]	127.7 ± 33.0[b]
MDP Liquid Outflow	43.7 – 165.6[b]	107.4 ± 42.8[b]	19.8 – 75.1[b]	48.7 ± 19.4[b]
Solids Outflow	15.4 – 88.6[a]	53.9 ± 16.6[a]	7.0 – 40.0[a]	24.4 ± 7.5[a]

[a] *n* = 45 [b] *n* = 10

The nutrient partitioning accomplished by the system was calculated utilizing a mass balance calculation based on the full data set of samples using the data from Table 1 and the flow rates from Table 2. The mass balance calculations indicate that 75.2% of phosphorus and 31.4% of the total nitrogen in the anaerobic digestion manure slurry after course solids separation is partitioned with the P-cake.

PHOSPHORUS RECOVERY SYSTEM PERFORMANCE RESULTS (OUTLIERS REMOVED)

Because there was a known issue related to the polymer pump repaired on June 25th, further analysis was done on a data set with outliers removed. Outliers were defined as points more than three standard deviations outside the mean of the data obtained from the samples after the polymer pump repair. This resulted in removing five points from the total data set.

P_2O_5 REMOVAL IN SOLIDS

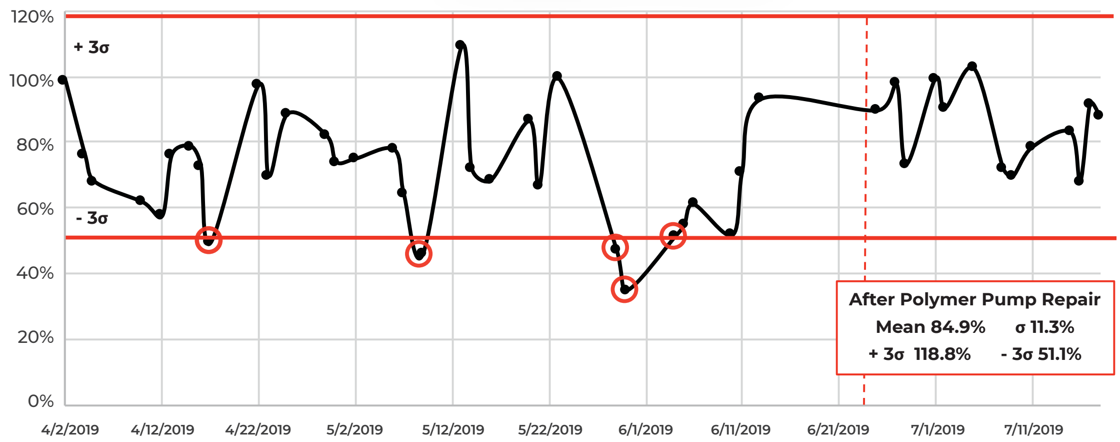


Table 3 displays the system solids and nutrient partitioning performance based on the data once outliers were removed based on the performance after the polymer pump was repaired.

Table 3 SOLIDS AND NUTRIENT CONTENT (OUTLIERS REMOVED)

Range and mean ± 1 standard deviation of flow rates from DAF ports.

SAMPLE PORT	TOTAL SOLIDS (%)	TOTAL N (% DM)	P_2O_5 (% DM)	K_2O (% DM)
Inflow	4.1 ± 0.3	9.4 ± 1.0	2.9 ± 0.2	8.4 ± 0.9
Primary Liquid Outflow	2.2 ± 0.5	14.2 ± 2.3	1.9 ± 0.4	16.0 ± 2.7
MDP Liquid Outflow	1.8 ± 0.1	14.7 ± 1.2	1.3 ± 0.3	18.7 ± 2.2
Solids Outflow	21.1 ± 2.3	4.9 ± 0.4	3.8 ± 0.5	1.5 ± 0.3

The nutrient partitioning accomplished by the system was calculated utilizing a mass balance calculation based on the full data set of samples using the data from Table 3 and the flow rates from Table 2. The mass balance calculations based on this data set indicate that 78.9% of phosphorus and 32.1% of the total nitrogen in the anaerobic digestion manure slurry after course solids separation is partitioned with the P-cake.

It should also be noted that, based on only the samples taken after the polymer pump was repaired, the mass balance calculation indicates 84.9% of phosphorus and 36.2% of the total nitrogen in the anaerobic digestion manure slurry after course solids separation is partitioned with the P-cake.

SYSTEM ECONOMICS

The total system cost including capital equipment and installation is estimated to be $400,000 including design, permitting, engineering, groundwork, pads, pumps/mixers and conveyors. These costs are considered estimates because the system was installed in an existing building and much of the installation was done by Blue Spruce Dairy. The optimal system performance was achieved while dosing polymer at 115 parts per million after the polymer pump was repaired. The dairy has not had a great deal of time to evaluate if lower dosing rates adversely affect performance. At this polymer dosing, the estimated operating costs including electrical, chemical, labor and maintenance are $120,000 per year. The system installed at Blue Spruce Dairy received a grant from the Vermont Agency of Agriculture Food and Markets, this grant was not factored in for the calculations below in order to show the cost per pound for nutrients recovered into the P-Cake.

System Capital Installed	• $400,000 • $193 per cow • $30,634.55 Annual CapEx payments @ 6% for 10 years	
System O&M	• 115 ppm polymer dosing • 40 kWh/h electrical • 40 minutes/day labor	• 3% capital parts • $120,000 Annual cost O&M • $55-60 per cow per year
System Solids	• 270,000 lbs. N per year • $0.555 cost/lb. N (Total Annual Cost/Total lbs. N) • 201,000 lbs. P_2O_5 per year • $0.743 cost/lb. P_2O_5 (Total Annual Cost/Total lbs. P_2O_5) • 83,000 lbs. K_2O per year • $1.798 cost/lb. K_2O (Total Annual Cost/Total lbs. K_2O)	

KEY LEARNINGS

1. The phosphorus recovery system produces both low solids irrigation water and a stackable nutrient-rich phosphorus solid.
2. The technology produces a solid product that is about 75% water, making it significantly easier to store and transport when compared to raw manure but which still requires significant space for storage.
3. Phosphorus-rich solids generated by the system can be marketed as a soil amendment, fertilizer or potting soil ingredient and sold off farm the size of this market is currently unknown.
4. Operating costs of the phosphorus recovery system averages just over one-half cent per gallon of liquid process.
5. Additional training for operators and remote equipment monitoring is helpful to ensure a smooth transition and avoid delays in addressing issues.

KEY BENEFITS

Production of a low nutrient irrigation water — DAF systems are effective in removing nearly all suspended solids and a large fraction of total solids, from the effluent stream producing a tea-water that is highly suitable for use in irrigation systems. Due to this significant removal of solids, there is a reduced need for costly lagoon agitation and dredging prior to irrigation of fields. Removal of solids from the anaerobic lagoon also reduces the production of methane gas and lowers the greenhouse gas footprint of the dairy beyond what is already accomplished by the digester.

Production of a stackable pile of nutrient rich solids — The partitioned suspended solids and total solids form a high-nutrient, dewatered, stackable pile with approximately 80% of phosphorus and 35% of nitrogen and appreciable amounts of secondary and micro-nutrients from the influent. These solids can be either sold off-farm or applied to dairy fields as a plant-ready organic fertilizer.

Savings in both energy and manure management costs — The partitioned solids, as noted above, can generate significant savings in both energy and manure management costs. Specifically, reduced energy to mix, dredge, pump and haul raw untreated manure; greater flexibility in targeting specific fractions and types of nutrients to meet on-farm soil management and crop requirements in accordance with the dairy's nutrient management plan. Additionally, the potential to export off the farm can provide significant phosphorus reductions necessary to meet the state's clean water goals.

Sale of partitioned manure solids and nutrients off-farm — The dairy is working to identify interested parties to sell a portion (amount varies season-by-season) of the screw press solids for marketing nationally as a retail bagged potting soil (raised bed and/or garden soil). Extracted nutrients in the partitioned system are also being used to develop various other horticultural products, including plant foods, soil amendments and soil conditioners; all being mixed with other natural ingredients. In unison, these systems can remove virtually all nutrients in the dairy's manure and wastewater stream and repurpose them into commercially viable horticultural products. There is potential with new products to achieve higher sales and revenues. Even without, significant benefits now exist for the dairy to reduce/ remove this nutrient load from their nutrient management plan accounting.

CONCLUSION

The DVO phosphorous recovery system installed at Blue Spruce dairy has demonstrated it can be very effective at removing phosphorous from the processed manure after the DVO digester and course solids separation. The system achieved 78.9% removal of phosphorous through the 15-week testing period despite start-up issues, shutdowns, inclement weather and failures of a key piece of equipment. Once the polymer pump was repaired the system ran consistently with no system shutdowns that were not part of normal operation. More importantly, during this period the system achieved nearly 85% removal of phosphorous.

There are certainly some challenges that remain. The solids produced at this time still require a significant amount of storage space and there are not yet markets available to make this type of system economically viable even with significant grant funding to reduce capital cost.

However, the demonstrated performance of the system and the cost per pound of phosphorous captured in the P-cake ($0.743/lb. P_2O_5) make this technology very attractive and a valuable tool in the State of Vermont's efforts to reduce the phosphorous loading to its lakes and rivers.

BLUE SPRUCE FARM PROJECT BY THE NUMBERS

Location	Blue Spruce Farm, Bridport, VT
Number of animals	2,063 milking cow equivalents
Type of bedding	Post AD Fiber
Manure collection	Combination of alley-scrapers, youngstock barn flush and parlor wash water
Daily flow	400,000 gallons/week mixed with 10,000 to 12,000 gallons/week of offsite organic substrates
System designed by	DVO, Inc.
Date operational	System commissioned in 2018
Energy produced/required	System requires 56 kWh/hour when operating
Ownership structure	Farmer owned

FINANCIAL INFORMATION

Capital investment	$400,000 (about $193/cow)
Annual operating and maintenance cost	$120,000 per year
Revenue	The system reduces manure handling cost and the solids can be sold. Operating costs for the system average just over one-half of a penny per gallon of liquid processed, a very small amount compared to the cost of transporting that gallon longer distances. The phosphorus-rich solids (P-cake) generated by the system can be transported from the area and are marketable as a soil amendment, fertilizer or potting soil ingredient.

ONGOING PRODUCT RESEARCH

The University of Vermont is leading a research study to identify potential commercial agricultural uses of the phosphorus solids produced by the system at Blue Spruce Farm. Specifically, research by UVM, Magic Dirt, and DVO is in progress that is focused on upcycling the raw P-cake to marketable plant food products.

Following peer-review the complete UVM report which includes all the information used in calculations for this report will be made available.

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NEWTRIENT
10255 W. Higgins Road
Suite 900
Rosemont, IL 60018
1.866.123.4567
info@newtrientllc.com

www.newtrient.com