BUL 991

Estimating the Efficiency and Cost of an On-Farm Centrifuge Separator

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Introduction

WITH ROUGHLY 437 DAIRIES in operation generating about 15.1 billion pounds of milk in 2018 (Idaho Dairymen's Association 2019), dairy production is Idaho's largest agricultural category. The state also ranks third nationally in milk production. As a by-product of milk production, huge amounts of manure are generated each year in Idaho, which demand efficient manure management. Bigger dairies prefer to use flushing systems because of their ease of mechanization and low labor requirements. A number of dairies in the Magic Valley of southern Idaho employ manure-handling flushing systems that result in large amounts of lagoon water that are applied via irrigation systems to adjacent cropland during the growing season.

Solids and nutrient components in liquid manure complicate manure-handling processes. They present at least four concerns:

1. **Reduced lagoon capacity**. Some of the solids in liquid manure that flow into a storage lagoon settle on the lagoon floor. Eventually, they need to be removed to increase lagoon capacity. However, their removal is costly, an added financial burden for operators.
2. **Limited land application rate**. Liquid manure with high solids and nutrients (especially phosphorus [P]) limits the land application rate, which means that larger areas are needed to apply the same amount of liquid manure. Consequently, operators must transport large volumes of liquid manure longer distances, steadily increasing costs.
3. **Clogged equipment**. Liquid manure with high solids will more likely plug pumps, transfer pipes, and sprinkler nozzles. Their presence requires more power to pump the same volume and creates higher pressure

at the pump, thus increasing the risk of ruptured seals and manure spills.

4. **Impermeable cropland**. Liquid manure with high solids seals the surface of croplands, preventing water from penetrating the soil.

Creating effective solid-liquid separation (removing a substantial amount of organic solids from fresh liquid) thus poses an ongoing challenge for Idaho dairy producers, but once solved, its benefits can be enormous: the production of nutrient-rich organic solids, reduction of odors in liquid-manure storage lagoons, and improved treatment-process economics due to reduced organic loading rates each year. Furthermore, it diversifies the uses of separated solids—operators can apply them on farms near animal operations or export them to other areas as fertilizer or other soil-conditioning products.

Many dairy producers in Idaho, familiar with these benefits, have incorporated solid-liquid separation processes in their manure management systems. Most of them use primary solid-liquid separation technologies such as settling ponds, inclined screens, rotary screens, and screw presses. Inclined screens are simple and effective for capturing larger particles, but their removal efficiencies are generally less than 40% of total solids—10%–20% of total nitrogen (TN) and 10%–20% of total phosphorous (TP) (Powers et al. 1995).

Centrifuges, however, offer a more efficient system. Thus, we've taken a closer look at the centrifuge separator by measuring the efficiency and cost of running one on a commercial Idaho dairy. Hopefully, the data we've gathered will encourage dairy producers to use centrifuges to improve manure management on their farms.

The Study

The yearlong manure sampling and sample analysis we conducted in 2017 involved the collection of a wealth of other vital data too, including financial investment information; maintenance, routine operation, and labor expenditures; added nutrient values; and other centrifuge-related costs, to determine the annual capital and operating costs associated with a centrifuge application.

The dairy host site, located in the Magic Valley of southern Idaho, consisted of about 4,000 milk cows in both open lots and free stall barns. Operators flushed sixteen manure lanes three times each day. See Figure 1 for a schematic flowchart of the flushed manure path. It is worth mentioning that the centrifuge monitored in this case study was the first and only one used on Idaho dairies at the time of this study.

Manure sampling. We started the manure sampling from January 9, 2017, until November 14, 2017. (We were unable to collect samples in December

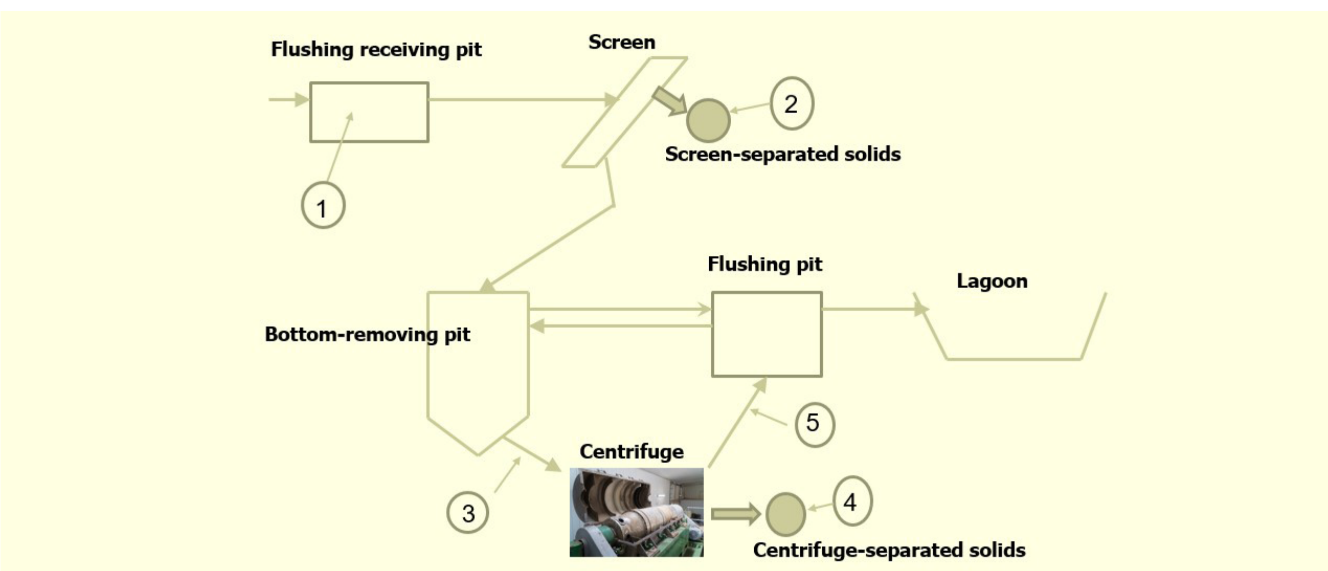

Figure 1. A schematic flow chart of the flushed manure path. Note: arrows show the liquid flow directions; numbers indicate sampling locations (1, 3, and 5 are liquid sampling locations; 2 and 4 are solid sampling locations).

2017 because foam covered the flushing receive pit.) Each month, we collected three samples from the flushing receiving pit (location #1 in Figure 1), the before-centrifuge location (#3), and the after-centrifuge location (#5) and three samples from the two screen–separated solids location (#2) and the centrifuge-separated solids location (#4), respectively. The samples were immediately sent to a commercial lab for nutrient analysis based on standard methods of practice. Information regarding how many tons of solids from the two screen separators and the centrifuge separator, as well as costs associated with the centrifuge, were obtained directly from the dairy owner. The collected information along with other local costs were used to estimate expenditures associated with the centrifuge's use.

Cost analysis. Costs associated with the purchase and use of the centrifuge were partitioned into annual capital costs and annual operating costs, following Møller et al. (2000). Capital costs are calculated based on the following equation:

$$C = \frac{I \times r/100}{1-(1+r/100)^{-n}}$$

where C (\$) indicates the capital costs in annual terms, I (\$) the purchase cost of the centrifuge, r (%) the interest rate considered, and n (years) the depreciation period. Table 1 shows the values of each variable and the resulting annual capital costs from comparing a centrifuge with two inclined screens. Results indicate a relative higher annual capital cost of $8,827.85 for the centrifuge when considering seven years of depreciation at an annual interest rate of 3%.

The comparison of annual operating costs are shown in Table 2, which separately takes into account the cost of maintenance and repair, fuel and lubrication, removal of solids, cleaning the lagoon, electricity, transportation of liquid manure, and cleaning the "settling cell." The settling cell is replaced by the use of a centrifuge.

Table 1. Annual capital costs for a centrifuge and for two inclined screens.

Capital Cost	Centrifuge ($)	Inclined Screen(s) ($)
Purchase Cost	250,000	120,000 (60,000 x 2)
Installation Costs	50,000	125,000 (concrete slabs + building elements)
Interest Rate	3%	3%
Years of Depreciation	7	7
Totals	**48,151.91**	**39,324.06**

Table 2. Annual operating costs for a centrifuge and for two inclined screens.

Operating Cost	Centrifuge ($)	Inclined Screen(s) ($)
1. Maintenance and Repair	5,000	2,500
2. Fuel and lubrication (+labor)	1,300	650
3. Solid removal	9,125	36,500
4. Clean lagoon	3,000	17,500
5. Electricity[a]	21,024	3,504
6. Transportation of liquid manure[b]	2,500	5,000
7. Clean "Settling Cell" (replaced by Centrifuge)	---	20,800
Total	41,949	86,454 (if without centrifuge)
Total		43,154 (if with centrifuge. Here, costs 4, 6, and 7 are already covered.)
Total (centrifuge + inclined screens)		**85,103**

[a] uses 50 amps or 24 kWatt-hr at $0.10/kW-hr for $57.60/day. Inclined screens use 4 kW-hr at $0.10/kW-hr for $9.60/day.

[b] Assuming 1.5 million gal at $0.01/gal; centrifuge assumes transport every six years (conservative estimate, which has not currently been reached) and for inclined screens.

As noted from Table 2, the resulting annual operating costs for the centrifuge are $41,949. Moreover, the alternative inclined screens indicate two results. The first considers the annual operating costs solely for two inclined screens at $86,454; while the second accounts for the annual operating costs of the two inclined screens at $43,154, assuming the existence of the operating centrifuge after these, as seen in points 3 and 4 from Figure 1.

In summary and observing Figure 1, the resulting annual operating costs for the inclined screens only (at point #2) is $86,454 while the resulting total annual operating costs for the inclined screens and the centrifuge (at point #5) is $85,103 ($43,154 + $41,949). Thus, using a centrifuge results in annual operating net savings of $1,351 ($86,454 - $85,103).

Findings

Separated solid particle size. Seven loads (one load equals about 25 yd^3 or 12–15 tons) of solids were separated by the two screens while about three loads of solids were separated by the centrifuge each day. Centrifuge-separated solids and screen-separated solids are shown in Figure 2, respectively. It is noticeable that the screen-separated solids are mostly undigested fibers while the centrifuge-separated solids are finer particles.

Figure 2. Centrifuge-separated solids (left) and screen-separated solids (right).

Nutrients in separated solids. Phosphorus (P, as P_2O_5) concentrations in the screen-separated and the centrifuge-separated solids are shown in Figure 3.

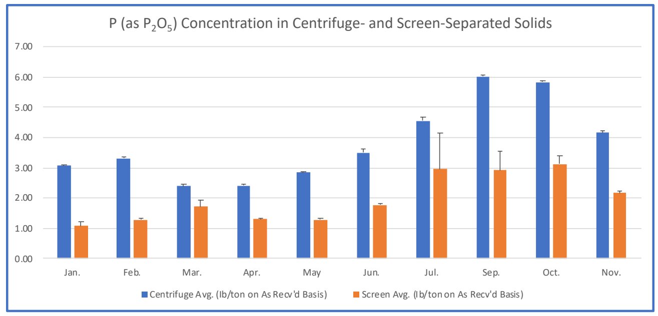

Figure 3. Phosphorus (as P_2O_5) concentration in both centrifuge- and screen-separated solids.

The concentration of P in the centrifuge-separated solids is much higher than that in the screen-separated solids. A yearlong average of P concentration in the centrifuge-separated solids was 3.81 lb/ton as the received basis compared to 1.96 lb/ton which constituted the screen-separated solids.

Based on a rate of 7 screen-separated loads/day, we found that 60,096–75,117 lb/year of P (as P_2O_5) were removed by the two screen separators. In addition to the screen-separated P, we estimated that the centrifuge separated 50,063–62,579 lb/year of P (as P_2O_5) from the liquid stream.

Total nitrogen (TN) concentrations in the screen-separated and the centrifuge-separated solids are shown in Figure 4. A yearlong average of TN concentration in the centrifuge-separated solids was 8.99 lb/ton compared to the concentration of 7.68 lb/ton in the screen-separated solids.

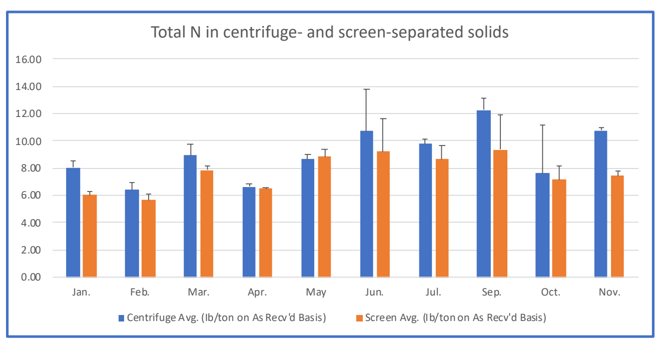

Figure 4. Total nitrogen (TN) concentrations in centrifuge- and screen-separated solids.

Based on a rate of 7 loads/day of screen-separated solids, we found that 235,469–294,336 lb/year of TN were removed by the two screen separators [7 loads/day × 365 days/year × (12–15) tons/load × 7.68 lb/ton]. In addition to the screen-separated TN, we estimated that the centrifuge separated 118,129–147,661 lb/year of TN from the liquid stream [3 loads/day × 365 days/year × (12–15) tons/load × 8.99 lb/ton].

Potassium (K, as K_2O) concentrations in the screen- and the centrifuge-separated solids are shown in Figure 5. A yearlong average of K concentration in the centrifuge-separated solids was 4.42 lb/ton compared to the concentration of 4.20 lb/ton in the screen-separated solids.

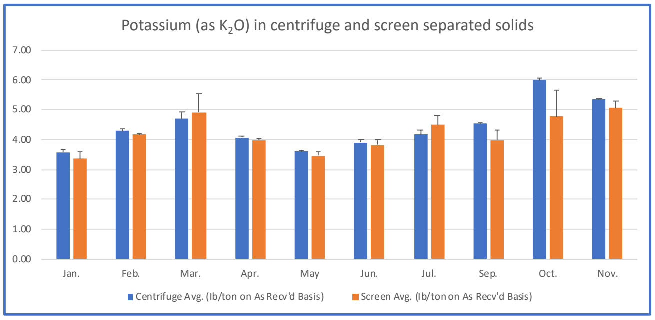

Figure 5. Potassium (as K_2O) concentration in centrifuge- and screen-separated solids.

Based on a rate of 7 loads/day of screen-separated solids, we found that 128,772–160,965 lb/year of K (as K_2O) were removed by the two screen separators [7 loads/day × 365 days/year × (12–15) tons/load × 4.2 lb/ton]. In addition to the the screen-separated K, we estimated that the centrifuge separated 58,079–72,599 lb/year of K (as K_2O) from the liquid stream [3 loads/day × 365 days/year × (12–15) tons/load × 4.42 lb/ton].

A summary of solids and nutrients (P, N, and K) removed by both the screens and centrifuge is shown in Table 3.

Table 3. Solids and nutrients (P, N, and K) removed by both the screens and centrifuge.

	Screen-Separated Each Year	(Screen + Centrifuge)-Separated Each Year
Solid (ton)	34,493[a]	49,276[b]
Total P (as P_2O_5, ton)	34	62
Total N (TN, ton)	133	199
Potassium (as K_2O, ton)	72	105

[a] Based on 7 loads/day and 13.5 ton/load.

[b] Based on 3 loads/day and 13.5 ton/load.

1. Nutrients in the Liquid Stream

Phosphorus (as P_2O_5), TN, and K (as K_2O) concentrations in the liquid stream before screen use, after screen use, and after centrifuge use are shown in Figures 6–8, respectively. The yearlong

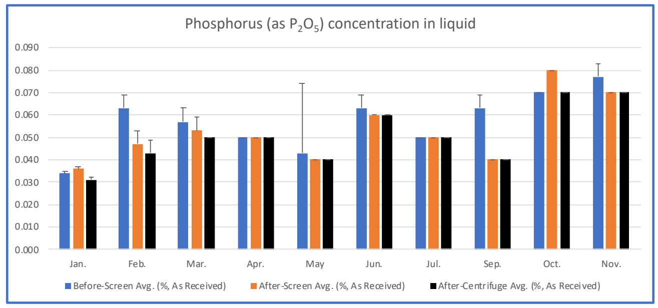

Figure 6. Phosphorus (as P_2O_5) concentration in the liquid stream.

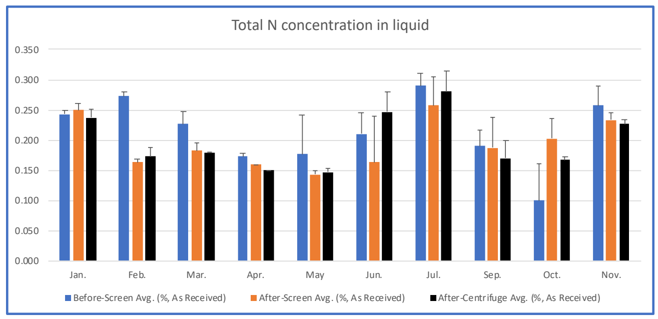

Figure 7. Total nitrogen (TN) concentration in the liquid stream.

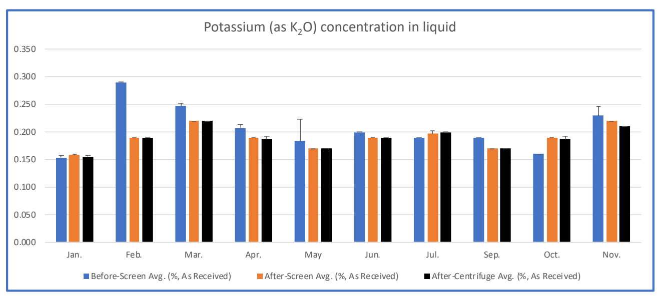

Figure 8. Potassium (as K_2O) concentration in the liquid stream.

average of P (as P_2O_5) in the liquid stream equaled 0.057% (before screen use) versus 0.053% (after screen use) versus 0.050% (after centrifuge use). The yearlong average of TN concentration in the liquid stream slightly fluctuated in comparison, equaling 0.214% (before screen use) versus 0.194% (after screen use) versus 0.198% (after centrifuge use). Lastly, the yearlong average of K (as K_2O) concentration in the liquid stream equaled 0.205% (before screen use) versus 0.190% (after screen use) versus 0.188% (after centrifuge use). Though the P, N, and K concentrations in liquids before and after the screen and centrifuge treatments did not differ by much, the amounts of P, N, and K removal were large because they were contained in huge amounts of liquid (i.e., 10 million gal).

2. Additional (Potential) Revenues

Considering the plausibility that separating liquid manure into solids can be done opens the door to potential commercial use. Separated solids can be converted into compost, biochar, hydrochar, or manure pellets, further concentrating the nutrients as marketable products. Yet further studies of their production and marketability as manure products are merited. In addition, prices for the N, P, and K nutrients may vary broadly: as an example, the United States Department of Agriculture (USDA) reported in 2020 that the average price in Illinois (early July) for urea (46% N) was $357/ton, diammonium phosphate (18% N, 46% P) $483/ton, and potash (potassium) $354/ton (USDA 2020).

Summary of Findings

The centrifuge separator tested in this study removes much finer particles and nutrients than the screens at a dairy:

- Centrifuge-separated solids have higher N, P, K concentrations than those from the screen-separated solids.
- The one-year average of P concentration in the centrifuge-separated solids is about two times that of the screen-separated solids.
- The added centrifuge not only reduces the land areas needed for lagoon water applications and the frequency and costs of cleaning storage lagoons, it also generates nutrient-rich solids, whose composting could be marketed as a value-added product, resulting in reduced overall manure-handling costs and better use of manure nutrient uses.

Further Reading

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