# Planning a Solid-Liquid Separation System to Meet Manure Treatment and Management Goals

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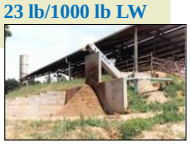
## What is Solid-Liquid Separation?

- Manure is a mixture of organic solids, plant nutrients, minerals and water.
- Solid-liquid separation is a process that divides the manure into two fractions. One that is mostly solids and the other is mostly liquid.
- So when we say a process removes total solids, nitrogen, phosphorous, or some other component from manure we simply mean that a portion of one of these components is moved to the part that is mostly solids.

## Example: This flighted conveyor screen repackaged components of flushed dairy manure into solids.

| | High Bedding (SC) | Moderate Bedding (MO) |
|---|---|---|
| TS Removed | **61%** | **45%** |
| TN Removed | **49%** | **17%** |
| Org-N Removed | **52%** | **19%** |
| TP Removed | **51%** | **10%** |
| Separated Solids Prod./day | **51 lb/1000 lb LW** | **23 lb/1000 lb LW** |

Screen size = 0.059 inches



## Purpose

- Provide a summary of liquid-solid separation options
- Discuss how these options fit or do not fit for manure treatment. (Dairy & Swine)
- Share some system layouts to help with planning.

## Why you may *not need* solid-liquid separation on your farm. (1)

- If the animal operation is fully integrated with crop production in such a way that all plant nutrients are being used to grow grains or valuable crops. (Soil-test P not a problem.)
- Typically means you farm enough to spread manure to meet $P_2O_5$ or $K_2O$ needs, proper credit for available manure N.
- Apply the needed fertilizer N a optimum rates and times.

## Why you may *not need* solid-liquid separation on your farm. (2)

- Dairy manure is currently handled and stored as a slurry.
- Manure forms a reliable crust. (Odor control most of the time.)
- Plenty of land is available close by to use the plant nutrients.

## Why you may *not need* solid-liquid separation on your farm. (3)

- You remove manure from barns as a slurry and use anaerobic digestion to destroy as many solids (VS) as possible to generate methane for bioenergy.
- Solid-liquid separation prior to the digester will reduce loading rate and biogas production.
- Plenty of land is available close by to use the valuable plant nutrients in treated slurry.

## Why you may *not need* solid-liquid separation on your farm. (4)

- You animal operation is small and cannot realize a benefit from the cost of equipment and maintenance.
- You cannot define an economic or environmental benefit from the added expense.

## Why Use Solid-Liquid Separation?

- Remove solids to facilitate pumping.
- Reduce organic loading prior to biological treatment (e.g. lagoon)
- Remove *liquid* from flushed manure prior to anaerobic digestion
- Remove solids & plant nutrients *after* digestion.
- Generate separated solids to make compost or stall bedding
- Move excess P from manure to solids to facilitate transport to remote fields
- Improve uniformity of solids & plant nutrients in larger liquid part.
- First step in treatment

## Liquid-Solid Separation Options

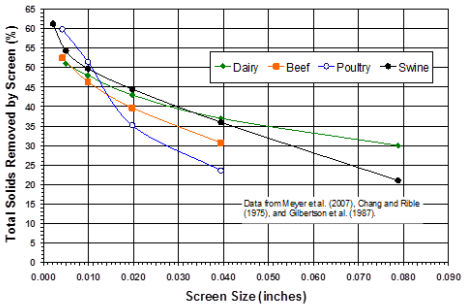
1. Separation based on **particle size** – *screens & presses.*
2. Separation based on **density of the manure** – *gravity settling, centrifuges & cyclones*
3. *All data are from a literature review in a publication that will be available from NRCS.*

## Some screen type separators

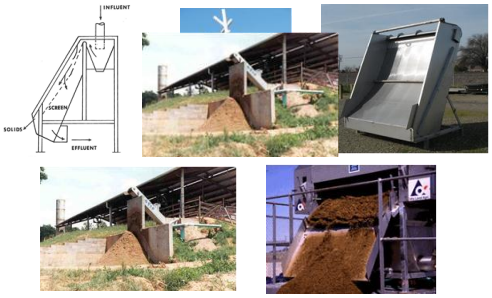
## Mechanical Separation – Screens

- Liquid manure flows through a screen.
- Particles that are captured by the screen are removed from the liquid manure stream.
- The liquids that flow through the screen go on to a storage structure, lagoon or other treatment method.
- Only pressure to drive separation comes from gravity or the flow of the manure.

Large particles in dairy can be easily removed by simple screens as compared with other species.




These are mostly used for dairy manure because they use relatively large openings.




## Screen-Type Separators: Dairy Manure

**Separated solids stacked well (19% - 23% solids)**

| Screen Size | TS of Manure | TS Removed | N Removed | P Removed |
|---|---|---|---|---|
| 0.020” | ? | 55 - 74% | 33 - 52% | ? |
| 0.022” | 2.8% | 68% | ? | ? |
| 0.059” | ≈ 2% | 46% | 17% | 11% |
| **0.059”*** | **3.8%** | **61%** | **49%** | **53%** |
| 0.066” | 4.6% | 49% | ? | ? |
| **0.066”**** | **1% or less** | **10 - 20%** | **VL?** | **VL?** |

*** Heavy organic bedding use caused extra high removal**.
** Dilute flushed manure little to no organic bedding

Removal of solids, N, & P from **dairy manure** using a 0.030" (0.75 mm) ***rotating screen***.

| Influent TS | Total Solids Removed | Volatile Solids Removed | Nitrogen Removed | P Removed |
|---|---|---|---|---|
| 0.5% | 0% | 3% | VL | VL |
| 3% | 14% | 4% | VL | VL |

Manure solids removed by rotating screen had a solids content of 6% to 11%. Too wet to handle as a solid. (Hegg et al.,1981)

## Issues with using simple screen separators

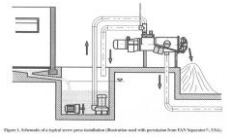
- Large screen sizes needed to keep up with manure flow from barns. Flow matching is needed.
- Small screens for high capture requires low processing flow rates.
- Fine screens turn liquid manure into slurry and liquid manure. Separated solids are often too wet for optimal storage and handling as a solid. (Odor, flies)

## Mechanical Separation – Presses

- Applies pressure to force more liquids through a small screen.
- Pressing can be provided by a screw, perforated belts, or filter plates.
- Can be used with smaller screens than stationary screens.
- Separated solids can be piled and handled as a solid. (Less odor and flies)

## Screw & Belt Press Separators



## Screw Press Separator: **Dairy Manure**

| Screen Size | TS of Manure | TS Removed | N Removed | P Removed |
|---|---|---|---|---|
| 0.020” | 2.6% | 25% | 8% | 6% |
| 0.029” | 10% | 71% | 24% | 24% |
| 0.094” | 2% | 16% | ? | 9% |
| 0.094” | 4.9% | 33% | 13% | 10% |
| 0.094” | 10% | 47% | ? | 29% |

**Separated solids had TS of 25% to 29% and stacked well**.

## Presses have also been used to remove solids from anaerobically treated manure – lagoon sludge and digester solids.


## Screw Press Separator: **Anaerobically Digested Dairy Manure**

| Screen Size | TS of Manure | TS Removed | N Removed | P Removed |
|---|---|---|---|---|
| 0.020” | 7.5% | 50% | 16% | 24% |
| 0.029” | 8.3% | 47% | 17% | 20% |
| 0.089” | 5.5% | 4% | 1% | 1% |

(Gooch et al., 2005).

**Separated solids had TS of 24% to 29% and stacked well**.

## Belt Press: **Dairy & Swine Manure**

| Screen Size | TS of Manure | TS Removed | N Removed | P Removed |
|---|---|---|---|---|
| **Dairy** | | | | |
| 0.039”– 0.079” | 7% | 32% | 10% | 15% |
| **Swine** | | | | |
| 0.0039” | 3.0% | 47% | 32% | 18% |
| 0.0039” | 8.0% | 59% | 35% | 21% |
| 0.039”– 0.079” | 5.7% | 22% | 10% | 20% |

**Separated solids had TS of 14% to 19% and were to wet to stack well**.

## Issues with using press separators

- High pressure provides dry solids, but forces some large particles through screen.
- Trade-off between particle capture and dryness of pressed cake.
- Low process flow rate.
- Tight tolerances can lead to screen replacement & higher maintenance costs.

## Trade offs to consider when using mechanical separators

- *Presses* can remove more total and volatile solids, N and P than screens, but work best with slurry manure and small screen openings.
- *Presses* can yield drier solids than screens.
- *Presses* are slower than screens.
- *Screens* with small openings can remove a significant amount of solids & plant nutrients but yield wet separated solids (slurry) at high process flow rates.
- *Screens* with large openings can handle high flow rates but only remove large solids. Solids pile easily.

Combination of an in-channel flighted conveyor screen with a small screw press helped to provide additional dewatering. But **separated swine solids** were still too wet to stack well.

Screw Press

Side-discharge spreader used to catch and apply solids. ➔

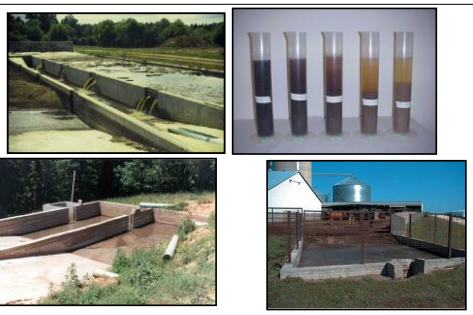
Liquid-solid separator that employs three techniques: fine stationary incline screen (0.020 in), screw press, and an inclined fighted conveyor screen (courtesy of US FARM Systems, Tulare, CA).

Removal of solids, N, & P from dairy manure using *a combination machine* (US FARM Systems).

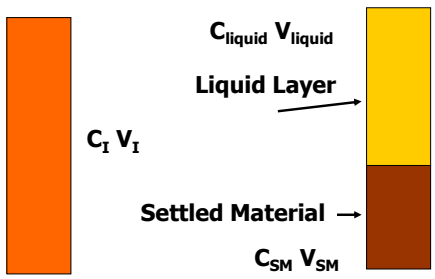
| Influent TS | Total Solids Removed | Volatile Solids Removed | Nitrogen Removed | P Removed |
|---|---|---|---|---|
| < 1.5% | 50% | 56% | 23% | 20% |

Flushed manure, stalls bedded with dried dairy solids, separated solids TS = 23% (Chastain, 2009).

## Liquid-Solid Separation by Settling



**During gravity settling liquid manure separates into liquid and settled material layers.**




Before Settling After Settling

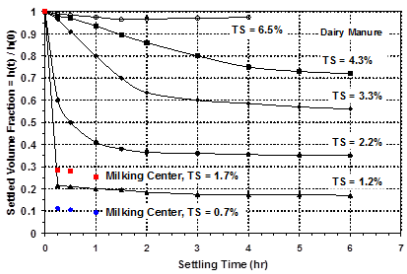
## Factors that determine the effectiveness settling

1. Particles must be heavier than water.
2. There must be enough water in the mixture for the solids to settled and form a large liquid layer.
3. Want to provide sufficient settling conditions.
   - very low flow velocity
   - Long enough detentions time for solids to be captured.

## Gravity settling can be used for…

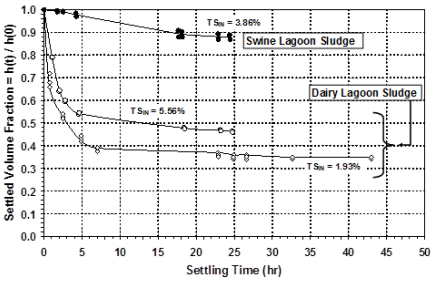
- Removing solids & nutrients from runoff from outdoor lots.
- Flushed manure from freestall buildings, and milking centers, and flushed swine facilities.

## Gravity settling cannot be used to treat dairy manure with a TS greater than 3%.




**Gravity settling cannot be used to treat slurry manure.**

## Gravity settling also does not work well for thick lagoon water and sludge mixtures.




## Removal of solids, N, and P from liquid dairy manure by gravity settling. (Inflow TS = 1.7%)

| Total Solids Removed | Volatile Solids Removed | Nitrogen Removed | $P_2O_5$ Removed | $K_2O$ Removed |
|---|---|---|---|---|
| 61% | 66% | 41% | 45% | 25% |

Gravity settling can greatly reduce the loading of solids and phosphorus on a storage or lagoon. Volume of settled solids was 25% of flush volume (SVF = 0.25)

## Solids and Nutrient Content of Liquid Dairy Manure Before & After Settling for 1 hour.

| | Flushed Manure | Liquid From Settling | Settled Solids |
|---|---|---|---|
| TS | 1.7% | 0.9% | 4.1% |
| | Pounds / 1000 gallons | | |
| VS | 111.6 | 50.5 | 290.7 |
| Org-N | 3.8 | 1.4 | 10.7 |
| TAN | 6.3 | 6.5 | 6.4 |
| $P_2O_5$ | 3.4 | 2.5 | 6.0 |
| $K_2O$ | 7.6 | 8.0 | 7.8 |

Dairy: Change in ratio of PAN and $P_2O_5$

| | Flushed Manure | Liquid From Settling | Settled Solids |
|---|---|---|---|
| | Pounds / 1000 gallons | | |
| Org-N | 3.8 | 1.4 | 10.7 |
| TAN | 6.3 | 6.5 | 6.4 |
| PAN- incorp | 7.3 | 6.0 | 11.5 |
| $P_2O_5$ | 3.4 | 2.5 | 6.0 |
| PAN:$P_2O_5$ | 2.1 | 2.4 | 1.9 |

Most grain crops want PAN:$P_2O_5$ = 2.2 to 2.5.

| | Flushed Manure | Liquid From Settling | Settled Solids |
|---|---|---|---|
| PAN:$P_2O_5$ | 2.1 | 2.4 | 1.9 |

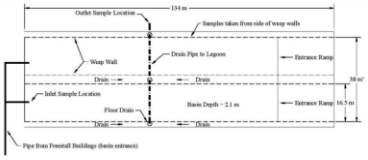
Gravity settling of dairy manure improves the balance of N to $P_2O_5$ for many crops for the liquid part while increasing the relative $P_2O_5$ content in the separated solids.

Removal of solids, N, and P from flushed swine manure by gravity settling. (Inflow TS = 1.0%)

| Total Solids Removed | Volatile Solids Removed | Nitrogen Removed | $P_2O_5$ Removed | $K_2O$ Removed |
|---|---|---|---|---|
| 53% | 58% | 33% | 68% | 17% |

Gravity settling can greatly reduce the loading of solids and phosphorus on a storage or lagoon.

## Weeping-wall, drain dry settling basins combine treatment & storage. How big do you want?




## Weeping Wall Settling Basin: **Dairy Manure**

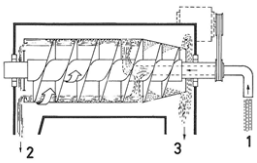
| | TS of Manure | TS Removed | N Removed | P Removed |
|---|---|---|---|---|
| **Meyer et al. (2004)** | | | | |
| | 1.1 – 1.8% | 49-63% | ? | ? |
| **Mukhtar et al. (2011)** | | | | |
| Two-stage | 3.0% | 88% | 84% | 86% |

**Separated solids had TS of 30% to 36%.**
**Must be sized based on number of cows & storage period.**
**1.67 $ft^3$/cow/day – manure solids**
**2.22 $ft^3$/cow/day – manure solids + sand bedding (Fulhage, 2003)**

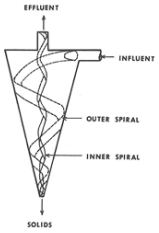
## Main issues with gravity settling to take into account are…

- Cost and permitting of settling basin or pond (large foot print)
- Potential for increase in odor if too wet.
- Cost of permeable cover that can greatly reduce odor. (Settling ponds)
- Purchase and maintenance cost of agitation and pumping equipment.
- Requires transport to fields with different equipment than the liquid part.

## Liquid-Solid Separation by Centrifuge & Hydrocyclones (Works for Dairy & Swine)




Decanter Centrifuge




Hydrocyclone

## Removal of solids, N, and P from liquid swine manure using a *centrifuge*. (Inflow TS = 1.5%)

| Total Solids Removed | Volatile Solids Removed | Nitrogen Removed | $P_2O_5$ Removed | $K_2O$ Removed |
|---|---|---|---|---|
| 38% | 44% | 21% | 61% | 14% |

A centrifuge provides removal similar to settling in much less space and yields a pile of solids (Westerman and Ogejo, 2005).

## Removal of solids, N, and P from swine lagoon sludge mixture using a *centrifuge*. (Inflow TS = 1.6%)

| Total Solids Removed | Volatile Solids Removed | Nitrogen Removed | $P_2O_5$ Removed | $K_2O$ Removed |
|---|---|---|---|---|
| 32% | 25% | 26% | 63% | 11% |

A centrifuge can be used to process dillute swine lagoon sludge mixtures (Westerman and Ogejo, 2005).

## Addition of Polymers (PAM) and Metal Salts – works for dairy & swine manure

- These chemicals can be used to improve the performance of any method of liquid-solid separation.
- Solids and P removals of 70% to 90% can be obtained.
- Requires TS less than 6%
- PAM, Alum, Iron Chloride, and others can be used alone or in combination *at proper dose*.

## Effect of adding alum or iron chloride to dilute swine manure prior to settling (TS in = 0.24%).

| | Coagulant Concentration | | | | | |
|---|---|---|---|---|---|---|
| | 40 mg/L | | 250 mg/L | | 625 mg/L | |
| | TSR (%) | PR (%) | TSR (%) | PR (%) | TSR (%) | PR (%) |
| **Control** | 52.6 | 19.0 | 50.1 | 17.8 | 50.2 | 14.6 |
| **Alum** | 53.6 | 21.0 | 86.5 | 73.9 | 92.8 | 90.9 |
| **Iron Chloride** | 62.2 | 30.0 | 90.9 | 82.7 | 91.9 | 78.2 |

TSR = Total Solids Removal and PR = Phosphorous Removal (adapted from Powers and Flatow, 2002).

## Treatment of liquid swine manure (TS = 1.5%) using a settling pond with and without addition of alum (UGA, Worley & Das, 2000)

| | Settling Pond – No Alum | Settling Pond – 2900 mg Alum/L |
|---|---|---|
| TS - Removed | 60% | 70% |
| P - Removed | 38% | 75% |
| N - Removed | 20% | 20% |
| K- Removed | 8% | 8% |

Disadvantage of alum or iron salts is that it makes the soluble P unavailable to plants.

Treatment of pit-recharge swine manure by addition of PAM followed by screening (0.039) (Vanotti et al., 2002)

| | No PAM | 60 mg PAM/L | 120 mg PAM/L |
|---|---|---|---|
| TS - Removed | 9% | 39% | 54% |
| TSS - Removed | 15% | 68% | 93% |
| VSS - Removed | 17% | 69% | 93% |
| P - Removed | 10% | 53% | 74% |
| N - Removed | 7% | 23% | 33% |

Treatment of dilute swine lagoon sludge mixture using a centrifuge with and without chemicals (Westerman and Ogejo, 2005)

| | No Chemicals | C + F | C+F+L |
|---|---|---|---|
| TS - Removed | 32% | 51% | 76% |
| TSS - Removed | 41% | 73% | 88% |
| VS - Removed | 25% | 55% | 79% |
| P - Removed | 63% | 54% | 82% |
| N - Removed | 26% | 40% | 48% |

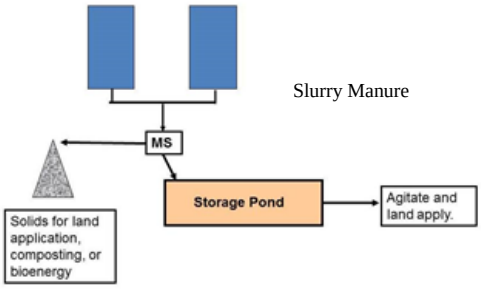
C = coagulant, F = flocculent, L = lime

Chemicals can be used to remove 70% to 90% of the solids and P for most methods of liquid-solid separation

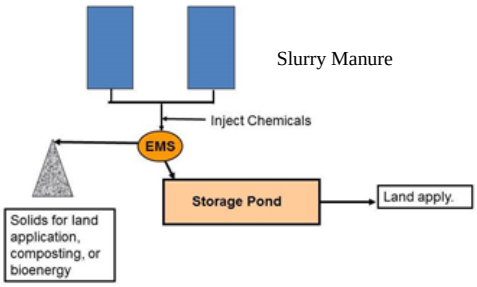
- Need proper dose
- Need proper mixing
- Need proper dilution
- Need $$$

## Some systems layouts to consider…

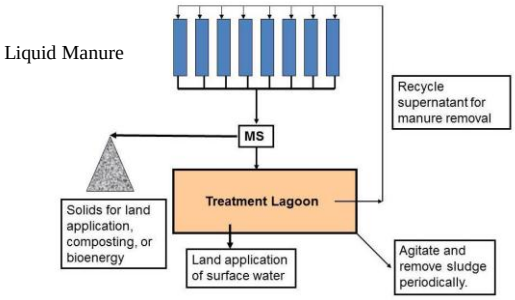
Using mechanical separation (MS) to reduce solids in storage to improve pumping and to provide solids for bedding or remote land application.



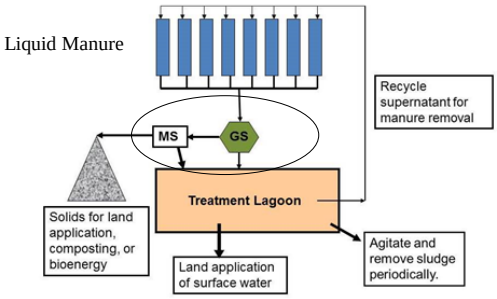

Chemically enhanced mechanical separation (EMS) to remove large amounts of solids & P.



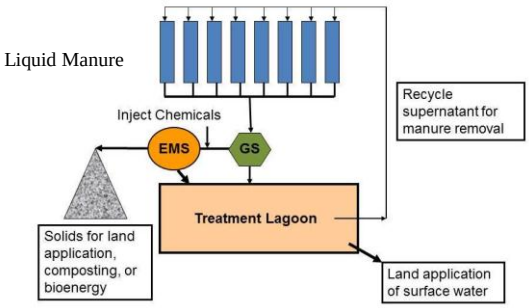
## Use of a mechanical separator (MS) to reduce loading on a lagoon or storage. Flow rate?



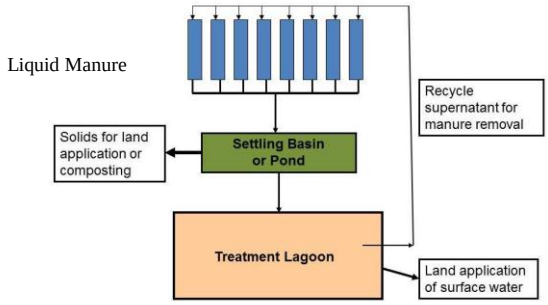

## Gravity settling (GS) prior to mechanical separation (MS) can allow small screens to be used with high manure flow rates associated with flush systems.



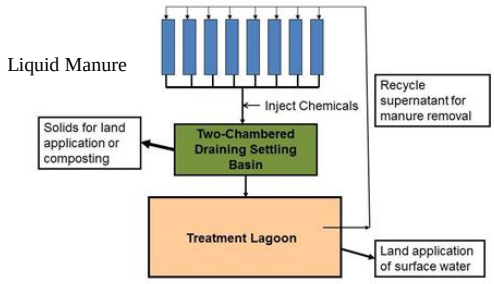

## Gravity settling can be used to make high-rate mechanical separation easier – also reduces chemical costs.



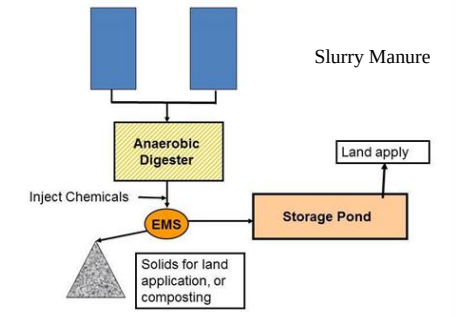
## Add a settling basin or pond before a lagoon or storage – basins drain dry, ponds do not.



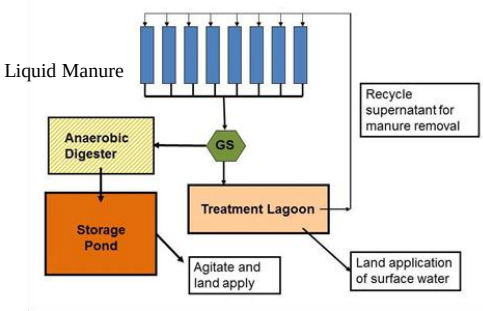

## Using chemicals to enhance gravity settling



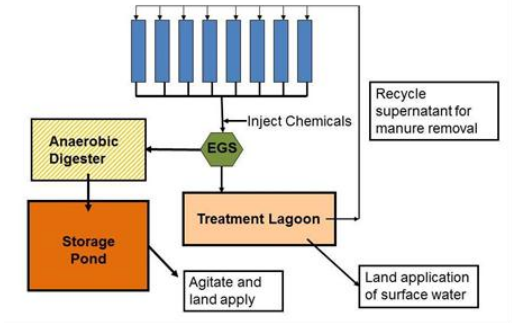

## Using enhanced mechanical separation (EMS) to treat digested slurry.



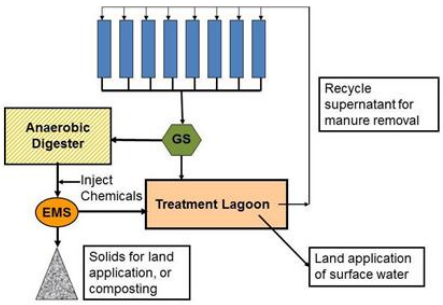
Use of gravity settling (GS) to concentrate volatile solids prior to loading an anaerobic digester.



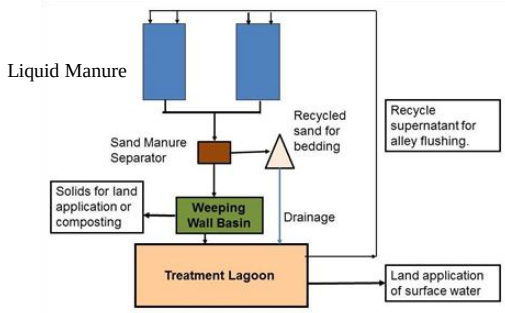

Chemically enhanced gravity settling (EGS) to concentrate 80% or more of the volatile solids prior to loading an anaerobic digester.




Settling to thicken liquid manure before digestion and enhanced mechanical separation after.



## Dairy: Gravity manure settling after sand separation.

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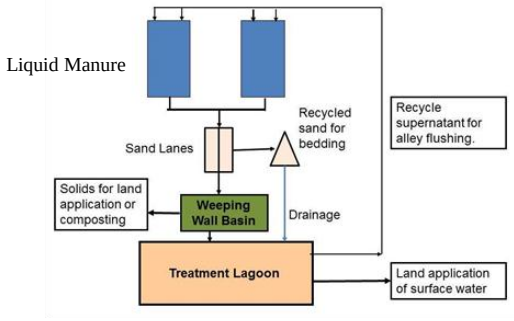


## Best Liquid-Solid Separation Options

- Presses: Slurry Systems
- Combo Systems: Liquid Systems
- Gravity Settling: Liquid Systems
- Centrifuge: Liquid Systems
- Use chemicals? How much solids & P removal do you need?
- Separation of lagoon sludge? Yes with right equipment and TS content.
- Is their an economic benefit?