2.1 Solid–liquid separation systems

Solids separation systems are becoming an increasingly important component of effluent management systems, particularly for larger herds. Removing solids from the effluent stream offers improved system reliability and reduces sludge accumulation in effluent ponds.

Why install a solids separation system?

Solids separation systems offer the following advantages:

- They minimise the need for agitation in sumps and reduce the likelihood of blockages in pumps and pipes.
- They reduce the rate of sludge accumulation in ponds. Together with the reduction in volatile solids (VS) loading to the pond, this allows smaller ponds to be built or extends the life of existing ponds.
- They allow the use of conventional irrigation equipment for distribution of effluent from adequately sized single ponds (although high salinity levels are not reduced, and some equipment, for example centre pivots, may require additional protection).
- They concentrate organic matter (and nutrients to a limited extent) for direct application to pasture, composting or cost-effective transportation off-site.

However, installing a solids separator may also introduce some additional requirements:

- A solids handling system (separator, impermeable storage pad, front-end loader, spreader etc.) will be needed in addition to the existing liquid handling system, introducing additional energy, labour, repair and maintenance costs.
- Separated solids will generally have a total solids (TS) content of 10% to 30%. Effluent may drain from wetter storage piles and, along with any rainfall runoff from the pad, must be collected to drain back into the effluent management system.
- Separated solids will become anaerobic and may emit odours unless composted or dried to a moisture content of <60% (40% TS). The dry crust on stockpiles limits odour emissions until the stockpile is disturbed.

As most of the precursors to odour generation (carbon compounds, proteins and nutrients) are contained in the finer particle fraction, which is not removed by gravity or mechanical systems, solids separation has only a limited capacity to reduce odour generation. The reduction in VS loading may reduce odour generation in an existing pond, but quantitative data is lacking. During the design phase for new ponds, a reduction in VS loading rate may result in a smaller pond surface area which will reduce expected odour emissions. If significant reduction of odours and nutrients is an objective, additional chemical treatment may be necessary (see chapter 5 'Odour emissions and control').

Types of solids separation systems

Solids separation systems can generally be divided into two broad categories:

- those that rely on gravity (trafficable solids traps, sedimentation basins and ponds)
- mechanical systems using screening (inclined stationary screens, elevating stationary screens, vibrating screens, rotating screens), centrifugation (centrifuges, hydrocyclones) or pressing (roller press, belt press, screw press).

Gravity sedimentation systems

Settling or sedimentation of solids by gravity is the most effective method for separating solids from dilute effluent streams such as dairy shed effluent, loafing pad or feedpad runoff, and manure flushed from freestalls). Sedimentation systems can consistently remove more solids and nutrients from effluent than mechanical methods when the TS content is low, and remain the favoured approach for the dilute effluent typical of Australian dairies. Sedimentation systems are not suited to effluents with a TS content exceeding 3% (Mukhtar *et al.* 1999), and settling rates may become hindered when TS > 1% (Sobel 1966).

Sedimentation basins are typically shallow structures designed to achieve a low through-flow velocity and accommodate the accumulated settled material between periodic clean-outs. Trafficable solids traps, now common on many dairy farms, are a form of sedimentation basin using a concrete base for regular clean-out by front-end loader. Earthen sedimentation basins are a more suitable option where the catchment area (holding yards, loafing pads or feedpads) will generate a significant volume of runoff during storms. Sedimentation ponds are deeper structures that do not drain before clean-out.

Trafficable solids traps

Guidelines for the construction and management of trafficable solids traps are provided in existing guides (DairyCatch 2006, Haughton 2006, NSW Dairy Effluent Subcommittee 1999, Skerman 2004) and via the Target 10 website at www.nre.vic.gov.au/cgi-bin/exsysweb.exe?KBNAME=fer03. In summary, the design of trafficable solids traps should include the following provisions:

- The trap must have enough capacity for the solids that accumulate between cleanouts (see Table 4), plus the volume used in yard washing each milking (critical when floodwashing), plus freeboard of 200 mm to avoid spills upon clean-out of wetter-than-normal settled solids.
- The ramp slope must not exceed 10:1 (horizontal to vertical) even at sites where a 4WD tractor is used.
- The trap must have a minimum width of 3 m (or tractor width plus 0.6 m).
- The trap must have a liquid depth of no more than 900 mm.
- The permeable weir must be placed so that the drainage ‘path’ to discharge is no more than 12 m (Harner *et al.* 2003); large-capacity traps may need the permeable weir to extend along the side of the structure.
- The area of the permeable weir should be as large as the structure allows.
- The spacing between boards (or other permeable weir members) should be adjustable from 10 to 25 mm.
- Where boards are used, orientate them vertically if possible (as straw floats horizontally); see Figure 1.
- Locate the point of entry of effluent into the trap towards the ramp end (as entry near the weir may resuspend settled solids). Heavier material such as sand may be removed first and handled separately if effluent enters at the ramp end.
- Wastewater from the milk room or pit may enter the trap behind the permeable weir (or bypass the trap completely).
- Where the effluent passing through the trap must be pumped out, the sump should be designed so that the pump cut-in level avoids backing water into the settled solids.
- Align the outlet pipe towards the pond to avoid bends.

- Any grooves formed during construction to assist with traction on the ramp must not have raised protrusions that may catch the leading edge of the tractor bucket, and should be oriented at an angle to the slope.
- Fence off solids traps to exclude people, especially children, and stock.
- A drying and storage pad may be required for the solids removed; the pad should drain back into the trap.

Generally, the larger the trafficable solids trap the more effective it will be at removing solids. It is possible to remove 50% of total solids from the effluent stream (see ‘Earthen sedimentation basins and ponds’ below), but to do so, trafficable solids traps should have a capacity of 1.0 m^3 per cow y^{-1} for cows producing 16 L of milk, and 1.2 m^3 for cows producing 36 L (see chapter 1.2 ‘Characteristics of effluent and manure’) and assuming that 10% of manure is collected (Table 4). As existing Australian guidelines range from 0.2 to 0.9 m^3 per cow y^{-1}, either an increase in capacity is needed or farmers must clean traps frequently to be effective. Guidelines from the USA (Fulhage 2003, Harner *et al.* 2003, Midwest Plan Service 1985) suggest designing traps with a volume of 0.9 to 1.6 m^3 per cow y^{-1} if 10% of manure is collected. These values exclude any allowance for freestall bedding, which may contribute another 8 to 11 m^3 per cow y^{-1} where 100% of the waste bedding is collected.

Smaller traps may be appropriate where the objective is to separate only the gravel and sand from the effluent stream. In such case, a ‘weeping weir’ arrangement (where effluent seeps between the horizontal or vertical members of a drainage wall) is not necessary.

Table 4. Solids accumulation rate ($m^3 \cdot week^{-1}$) per 100 cows based on removal of 50% of solids.

Time held (h)	Milk yield ($L \cdot day^{-1}$)						
	16	20	24	28	32	36	40
1.5	1.2	1.3	1.3	1.4	1.4	1.5	1.5
2	1.6	1.7	1.8	1.9	1.9	2.0	2.1
2.4 (10%)	2.0	2.0	2.1	2.2	2.3	2.4	2.5
3	2.5	2.6	2.7	2.8	2.9	3.0	3.1
4	3.3	3.4	3.6	3.7	3.8	4.0	4.1
5	4.1	4.3	4.4	4.6	4.8	5.0	5.2
6	4.9	5.1	5.3	5.6	5.8	6.0	6.2
8	6.5	6.8	7.1	7.4	7.7	8.0	8.3
10	8.2	8.5	8.9	9.3	9.6	10.0	10.3
12	9.8	10.2	10.7	11.1	11.5	12.0	12.4
18	14.7	15.4	16.0	16.7	17.3	17.9	18.6
24	19.6	20.5	21.3	22.2	23.1	23.9	24.8

The table assumes a density of 1000 $kg \cdot m^{-3}$.

For further information on estimating TS, see chapter 1.2 ‘Characteristics of effluent and manure’.

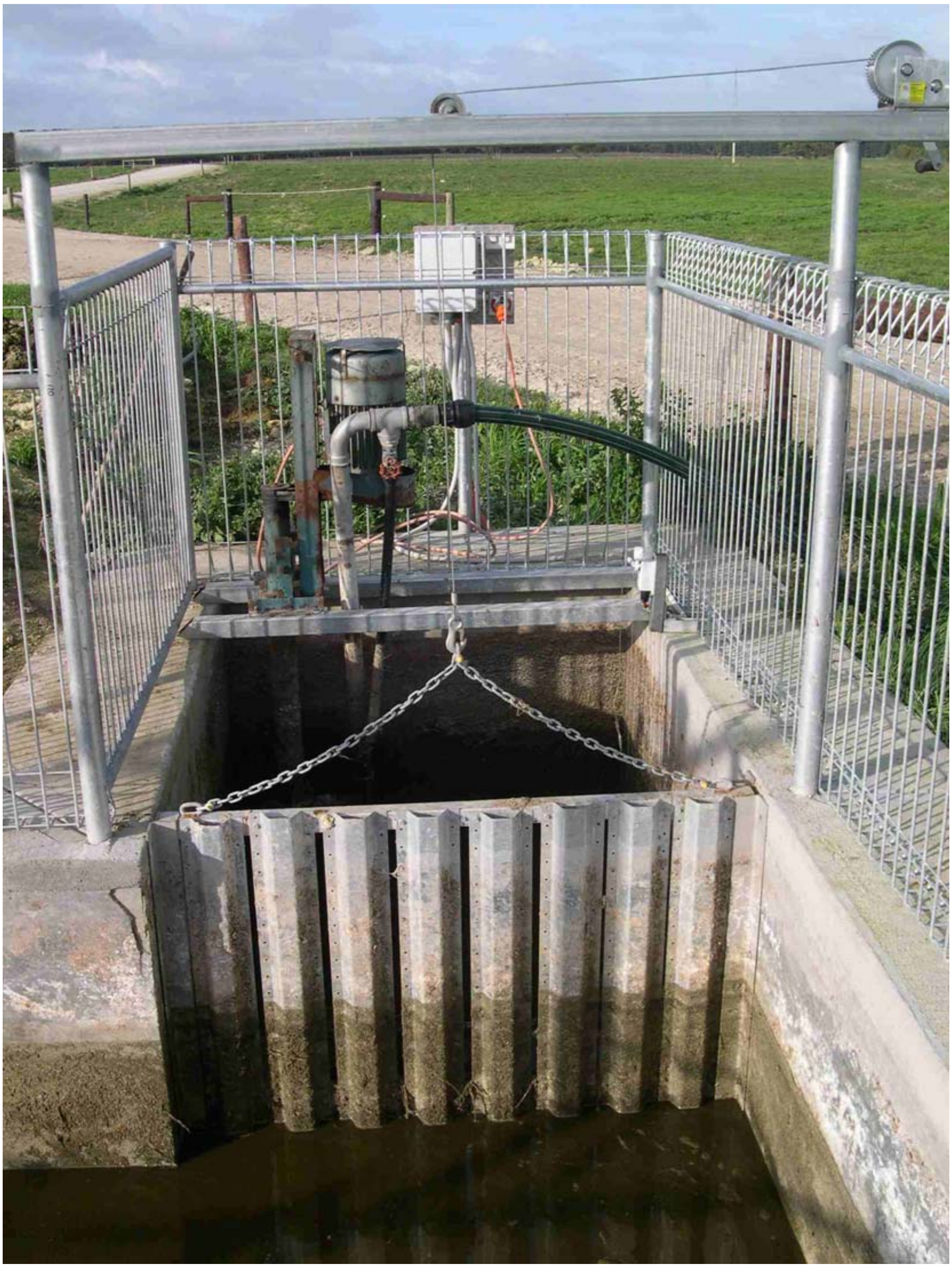

Figure 1. Vertical weir in trafficable solids traps (courtesy of Rural Solutions SA).

Earthen sedimentation basins and ponds

Large, shallow sedimentation basins with an earthen floor are widely used for removing settleable solids from runoff in beef feedlots. The larger treatment volumes afforded by sedimentation basins and ponds also makes them suitable for handling the storm discharge from holding yards, loafing pads and feedpads.

Sedimentation basins are typically designed to drain completely so that the material removed during clean-out can be handled as a solid. A pair (or more) of sedimentation basins with provision to divert flows to one while the other dries provides the opportunity to maximise the solids content of the material removed. Sedimentation ponds are usually overflow-type structures from which the solids are removed as a slurry with an excavator or specialist slurry pumping equipment following agitation.

The design of sedimentation basins with an earthen floor must take into account equipment requirements for clean-out. As the floor of the structure is unlikely to dry enough to support vehicular traffic, earthen basins should be narrow enough for an excavator to reach to the centre line of the floor, with a width limited to around 15 m for a 1-m-deep basin (and 13 m for a depth of 2 m). Longer-reach excavators are available but are not usually suitable for frequent desludging. It is also important that any compacted liner on the floor and walls of the basin be protected from damage during clean-out. Options include a 150-mm layer of sand or gravel, and recycled tyres placed horizontally across the surface.

Where agitation and pumps are to be used, stable machinery access points must be incorporated into the design (see chapter 6 'Occupational health and safety').

Laboratory research has demonstrated that the majority of settling in static water occurs within 30 to 60 min, typically removing 40% to 60% of TS, 45% to 65% of VS, 30% to 50% of total phosphorus (TP) and 20% to 40% of total Kjeldahl nitrogen (TKN). Settling has little effect on the soluble nutrients ammonium (NH_4^+) and potassium (K) (5%–20%). The solids content of the material recovered typically ranges from 10% to 25% in published results.

Sedimentation and evaporation ponds (SEPs)

Long, narrow sedimentation basins and ponds have been used on dairies in the past and, more recently, have been constructed at larger dairies and freestall developments where large volumes are generated by floodwashing of yards and alleys. Some of these are deep (1.8 m), have no drainage and retain liquid upon clean-out; others use only one or two ponds and are difficult to manage.

Recent research from the pig industry has identified that SEPs offer significant improvements in the recovery of solids removed from effluent (Payne *et al.* 2008). Anecdotal evidence also suggests that SEPs reduce odour when conventional anaerobic ponds are replaced.

The standard SEP system developed by the pig industry comprises three parallel ponds, typically 6 m wide (5–10 m) and 0.8 m deep (0.7–1.0 m). Each pond must be separated by sufficient distance to accommodate an excavator and truck during clean-out (minimum 10 m). Their length depends on the sludge volume and may range up to 600 m. Larger volumes can be achieved by building in multiples of three.

Effluent is directed to one of the three ponds. Once that pond is full of solids, it is taken out of use and allowed to dry out over summer. On account of its narrow, shallow structure, the sludge dries readily and can be removed by an excavator and truck. At any point in time, one of the ponds is filling, one is full and drying, and one is ready to be, or has been, cleaned out.

The equivalent design volume for a dairy cow is approximately 0.6 to 0.9 m^3 per cow (producing 6 kg VS day^{-1}; 10% to 15% collected) for 6 months of operation. Therefore, a 200-cow herd with 15% of excreta collected would require three 30-m-long structures, or approximately 0.6 ha after allowance of 10 m for access between structures. An 800-cow dairy with a feedpad (say, 40% collected) would require three 300-m-long structures.

Payne *et al.* (2008) showed that SEPs give similar results in terms of effluent treatment to conventional anaerobic ponds, with a reducing TS by 79%, VS by 82%, P by 89%, TKN by 36%, and K by 4%. The cost of removing the solids recovered ranged from \$4 to \$6·t^{-1} for large piggeries, compared with \$21 to \$60·t^{-1} for other approaches (sludge pumping, excavating slurry).

Advantages of SEPs:

- Ponds are easily desludged.
- Total odour emissions are reduced compared with conventional anaerobic ponds.
- nutrients contained in sludge are recovered more frequently (6-monthly to yearly).
- Nutrient reuse can be decoupled from treatment where off-site use is necessary.

Disadvantages of SEPs:

- Their shallow depth means a large land area is required.
- The soil must be suitable for the construction of a low-permeability clay liner (or an artificial liner must be used).

The summer drying period is important to produce a low-moisture-content solid, so the use of SEPs may not be appropriate for summer-dominant rainfall areas, and is not appropriate for high-rainfall areas owing to the large surface area. Rainfall–evaporation modelling may be needed for those sites where effluent is to be reused for yard and feedpad washdown.

Designing for settling velocity

The size of sedimentation basins, particularly those receiving storm runoff, is determined by settling characteristics, not detention time. Although some organic solids will start settling as the horizontal velocity of the liquid drops to $<0.3\ m{\cdot}s^{-1}$ (as opposed to sand, which will settle below $0.6\ m{\cdot}s^{-1}$), the horizontal velocity should be reduced to less than the suspended solids' vertical settling velocity if maximum removal is to be achieved (the velocity at which sediments are re-entrained is about equal to the their settling velocity).

Settling velocity is influenced by the size, density, shape, and roughness of the particles. Using beef cattle faeces and feedlot manure, Lott and Skerman (1995) established that 60% to 85% of settleable solids will be removed at a horizontal velocity of $6\ mm{\cdot}s^{-1}$ ($22\ m{\cdot}h^{-1}$). In the absence of head–discharge curves for permeable weirs, where discharge is restricted by manure, maintaining a flow depth of 100 mm in a 3-m-wide trafficable trap would be sufficient at uniform flow and a discharge of $2\ L{\cdot}s^{-1}$ (50% of a typical washdown hose flow rate). Trafficable solids traps should therefore be cleaned out before the accumulated solids encroach within 100 mm of full.

Where sedimentation basins receive larger flows—such as floodwash or storm runoff from large catchment areas such as loafing pads and feedpads—sizing must account for the expected flow rate. The National Guidelines for Beef Cattle Feedlots in Australia (ARMCANZ 1997) stipulate designing sedimentation basins for a 1-in-20-year design storm using a coefficient of runoff of 0.8 and show an example calculation. Australian Rainfall and Runoff (IEAust 1987) and chapter 2.6 'Effluent storage requirement' of this database outline methods to determine the design storm and resulting runoff volume. An overflow weir or spillway will be necessary to handle events larger than the design storm volume.

Note that the flows from floodwash systems, particularly from the long alleys in freestalls, will be much less at the sedimentation basin inlet than at the floodwash valve. However, little data is available to assist with developing typical design parameters at this stage.

Mechanical separation systems

Inclined stationary screens

Inclined stationary screens have a header tank at the top edge of an inclined screen; as the effluent overflows the tank and runs down over the full width of the screen, liquid passes through the screen openings, leaving solids behind on the screen. The solids are washed downwards and drop onto a storage and draining pad. The lack of moving parts means maintenance and power requirements are low. However, regular washdown is necessary, and acid-washing to remove struvite may be needed to prevent blinding of the screen. A wash with disinfectant may be necessary if a biological film begins forming.

Inclined stationary screens are suited to a higher-solids-content effluent than sedimentation basins are suited to, but are limited to a TS content, in inflow, of <5% (Zhang and Westerman 1997). Separation efficiency (the capacity of the system to separate effluent into a 'solid' fraction and a liquid fraction) must be not be considered in isolation from the recovered solids content, as high separation efficiencies can be obtained with larger screen openings producing 'solids' with a dry matter content of <5%; that is, still liquid. Separation efficiencies of 20% to 30% TS and up to 10% N and 15% P are possible when solids with a dry matter content of 12% to 23% are produced.

Elevating stationary screens

Elevating stationary screens, or flighted conveyor screens, have a narrow inclined screen with its lower end in the effluent collection channel. A series of paddles move the effluent up the screen, allowing liquids to pass through the screen before discharging the remaining solids from the upper end onto a draining pad. Reported efficiencies are similar to that of inclined stationary screens. Although the elevating stationary screen overcomes the need for regular cleaning associated with the inclined stationary screen, it has a high maintenance requirement owing to its moving parts and to abrasion between paddles and screen.

Rotating screens

Rotating screens have a drum-type screen, the surface of which rotates past a fixed scraper to dislodge solids after the liquid drains through. Reported efficiencies are similar to that of inclined stationary screens.

Screw press separators

Screw press separators use a straight or tapered screw (auger) to compress solids within a perforated or slotted cylinder. Liquid is forced out through the screen openings by pump pressure and the rotating screw. Solids are pushed out the end of the barrel through an adjustable retainer.

Presses can operate at a higher TS content than can stationary inclined screens. Separation efficiency can be poor for dilute effluent but increases with solids concentration. Presses produce a drier solid than most mechanical devices—around 30% dry matter. Capital costs and power requirements are substantially higher than for stationary inclined screens.

Centrifuges

Limited results for centrifuges suggest good separation efficiency and dry matter content of recovered solids (>20% TS), but their use is limited by low throughput, high energy consumption and high capital expense.

Performance measures

The range in different types of solids separation systems available, not to mention suppliers, means that separation efficiency is a key criteria for comparing the performance offered by different types of separation systems. However, before doing so, it is important to note the following:

- Variability in particle size distribution (with manure type), TS content and flow rate make it difficult to draw anything other than general conclusions about the suitability of separator types for a particular farm. Results can vary greatly for any given device; take care in extrapolating results from published studies to individual farms.
- There is currently no standard for testing and reporting separator performance. Reported results must be scrutinised carefully to determine the method used to calculate efficiency, and whether the characteristics of the tested effluent are relevant. Published results come mainly from the USA, where rations are fed to housed or lot-fed cows and effluent may include readily separable organic bedding and waste feed.

Separation efficiency is the capacity of the system to separate effluent into a 'solid' fraction with high organic matter and nutrient concentrations and a liquid fraction with low concentrations. Solids separation systems will generally remove a good proportion of the total suspended solids (TSS) but only a small amount of total dissolved solids (TDS) with the separable suspended solids. As 62% to 83% of the TS is present as TSS (Loehr 1984), a TS separation efficiency of 60% is considered very good. Researchers have been attempting to increase the removal of solids by the use of chemical treatment to remove some of the TDS that comprises the remaining 15% to 40% of TS in raw effluent. Although separation efficiencies of 85% or more can be achieved by combining chemical treatment with gravity or mechanical approaches, the improved performance incurs a much higher cost (see chapter 5 'Odour emissions and control').

Separation efficiency is usually reported using one of two measures: the reduction in concentration (approximate) or (dry) mass balance. The difference in the calculated efficiencies can be substantial and, if the method used is not specified, this omission can lead to costly misrepresentation of equipment suitability.

Reduction in concentration (approximate) method

This is a commonly used measure as it does not require the measurement of volumetric or wet-mass flow rates in influent, liquid or solids streams. Other parameters can be substituted for TS concentration (e.g. VS, TKN, TP) to calculate the respective separation efficiencies.

$$E_{approx} = \frac{C_{\inf luent} - C_{liquid}}{C_{\inf luent}} \qquad (1)$$

where E_{approx} = separation efficiency

$C_{influent}$ = concentration of TS (or VS, TKN, TP etc.) in influent

C_{liquid} = concentration in liquid or effluent fraction.

However, Equation 1 assumes an insignificant flow rate in the solids fraction and that the volumetric or wet-mass flow rate of the influent stream is equal to that of the liquid fraction. This is not necessarily correct and can lead to significant errors. Separation efficiency should therefore be calculated on a dry mass basis where possible.

Mass balance

An exact measure of separation efficiency can be calculated as:

$$E = \frac{(C_{\inf luent} \times Q_{\inf luent}) - (C_{liquid} \times Q_{liquid})}{C_{\inf luent} \times Q_{\inf luent}} \qquad (2)$$

By substituting $M = CQ$, where Q = wet mass or volumetric flow rate and M = dry mass:

$$E = \frac{M_{\inf luent} - M_{liquid}}{M_{\inf luent}} \qquad (3)$$

or

$$E = \frac{M_{solids}}{M_{\inf luent}} \qquad (4)$$

Note that if using the mass balance approach to analyse sediment basin performance, use Equations 2 or 3, not Equation 4. As the wet mass in the separated solids can be measured only upon clean-out, a proportion of the VS will decompose in the interim period, leading to a significant reduction in the mass of the solid fraction recovered.

Worked examples

Using a stationary inclined screen with 1.3-mm openings for flushed effluent with 0.7% solids, Wright (2005) recorded the results in Table 1.

Table 1. Example 1: Flushed effluent with 0.7% solids was passed through a stationary inclined screen with 1.3-mm openings.

	Influent	Liquid fraction	Solid fraction
Concentration (g TS L^{-1})	6.95	2.87	43.3
Flow rate (L·min^{-1})	11 130	10 000	1120
Dry mass (kg·min^{-1})	77.4	28.7	48.5

The calculated separation efficiency is good by either measure (E_{approx} = 59%, E_{mass} = 63%); however, it is important to recognise that the solids stream is still a liquid (4.3% TS, compared to raw manure at 9% to 13% TS) and remains difficult to handle. Although this particular separator and manure combination may be suitable for concentration before a second separation, it does not produce a material that can be handled as a solid.

Conversely, although a screw press separator with 1.3-mm screen openings gave a low separation efficiency (E_{approx} = 10%, E_{mass} = 13%), it produced material with 22% TS that can be handled as a semi-solid (Table 2) Burns and Moody (2003).

Table 2. Example 2: Scraped manure was diluted to 1% and put through a screw press separator.

	Influent	Liquid fraction	Solid fraction
Concentration (g TS L^{-1})	10	9	216
Flow rate (kg·min^{-1})	185	183.9	1.1
Dry mass (kg·min^{-1})	1.9	1.7	0.2

Performance reported in the literature

Appendix A presents a summary of performance results taken from a range of published research on the solid–liquid separation of dairy effluent. Table 3 summarises those results for general system planning. Note that significant departures from the values shown in Table 3 have been reported, so the data should be considered only as a starting point for system planning.

A number of other mechanical separators have been considered for solid–liquid separation of livestock manure; Ford and Flemming (2002) (pig, beef and dairy manure) and Watts et al. (2002a) (pig manure) are useful references for those.

2.1 Solid-liquid separation systems

Any farmer considering a mechanical separator should ask the prospective supplier or manufacturer for actual data from effluent with characteristics similar to their own. If data are not available, a trial run based on a large sample of the farmer's effluent should be performed before system design and installation. Compare the data provided against the performance reported in Appendix A.

Table 3. Suggested separation efficiencies for initial system planning.

Separator [1]	TS (%)	VS (%)	N (%)	P (%)	K (%)	Dry matter (%)
Trafficable solids trap	50	55	30	35	15	19
Stationary inclined screen	25	25	10	15	5	18
Screw press	20	20	5	5	0	30
Screw press (pre-concentrated to 10% TS)	60	65	25	25	10	30

[1] All effluents assumed to have typical TS concentration of <1% unless otherwise noted.

Note that, along with performance, the choice of separation system must also consider capital and ongoing operation and maintenance costs, reliability, skill required and expected service life. No dairy-specific data on these important issues were available, although some detailed information on pig manure exists (Watts *et al.* 2002b).

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