Experiences and suggestions for collection systems for source-separated urine and faeces

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Abstract This study collects experiences from existing systems with urine diversion and dry handling of faecal matter and presents design recommendations for improved function of new systems. Urine collection and piping systems were studied in four large residential areas in Scandinavia and South Africa where urine had been collected separately for 5–9 years and dry faeces collected for 4–15 years. We found that larger (>1 toilet) urine collection systems should have odour traps. Blockages in u-bend odour traps can be efficiently prevented by cleaning the u-bend 1–4 times per year with a sewage auger, caustic soda solution or strong acetic acid. A urine pipe diameter of 75 mm and a gradient of at least 1% are recommended. In small systems without a u-bend, a diameter of 25 mm can be used in combination with a gradient of at least 4%. For faecal collection, the most important factors for good function and high acceptability of the system are diversion of the urine, small collection bins (high emptying frequency) and easy access for emptying of bins.

Keywords Dry toilet systems; faecal collection; source separation; toilet design; urine-diverting toilets

Introduction
Sanitation systems using urine-diverting toilets allow separate collection of the urine in a fraction with small volume, high concentration and low pollution. Separating the urine from the faeces minimises the hygiene risk, as most pathogens are excreted with the faeces.

Separate collection of urine may appear simple as it is a liquid excreted in small volumes, 1–1.5 L per person and day (Vinnerås et al., 2006). Collection systems for source-separated urine can be small, collecting urine from only one toilet plus possibly a urinal, or large, collecting urine from more than one toilet. Urine collection systems can also be flushed or unflushed. However, many systems for separate collection of urine have problems. More knowledge is needed on how to construct robust and well-functioning collection systems for urine diverted at source, i.e. in the toilet.

At excretion, urine normally has a pH of 4.8–7.5 and a low odour, and some 75–90% of the nitrogen present is in the form of urea, the remainder mainly being ammonium and creatinine (Diem and Lentner, 1970). After excretion, bacterial enzymes rapidly degrade these compounds into ammonium and other nitrogen-containing compounds, many of them malodorous, raising the pH, usually to about 9.0–9.3 (Jönsson et al., 1997). At this elevated pH, the solubility of magnesium ammonium phosphate (MAP) and calcium phosphate is a small fraction of that at pH 7 (Lindquist et al., 2003). The urine becomes supersaturated and the compounds are quickly precipitated together with organic material (Udert et al., 2003; Vinnerås and Jönsson, 2007). It is this combination of odour and precipitation caused by the elevated pH that poses the main challenge in the construction of urine-diverting systems.
Several solutions are used to mitigate the odour, all of which involve eliminating contact between the degrading urine and the air in the toilet. Flushed toilets with u-bend odour traps are used, as are flushed toilets without any trap. With some waterless toilets, odour traps based on a one-way rubber membrane valve are used but waterless toilets without any odour trap are far more common. Many waterless urinals use u-bend odour traps with an organic liquid, often some vegetal oil, functioning as a floating odour seal. Irrespective of the type of solution used, many systems suffer from inadequate function of the odour trap regarding odours and blockages. More knowledge is thus needed on how to construct and maintain functional source-diverting systems for urine and faeces.

Collecting faecal matter dry is an attractive solution for on-site sanitation as the faecal volume is small compared with that of the other wastewater fractions. Generally, 100–200 g (wet weight) of faeces are excreted per person and day, and this material has a dry matter content of approximately 20–25% (Vinnerás et al., 2006). Furthermore, avoiding polluting the wastewater with the faecal matter reduces the risk of transmitting diseases via the wastewater, as most of the pathogens are excreted via the faecal matter.

Home-owners in Sweden who install dry sanitation systems are usually motivated by the environmental advantages of such systems, which were also confirmed in our study. Old dry sanitation systems, constructed more than 15 years ago, are mainly of the mixed-excreta type, handling the urine and the faecal matter together as latrine compost, while most of the systems constructed during the last 10 years are urine-diverting. For wider implementation of dry sanitation systems, important aspects of existing systems such as the technical function and the design need to be evaluated and improved.

The main objective of this study was thus to collect experiences from existing urine-diverting or faecal collection systems and to develop design and maintenance recommendations for improved function of new and old systems.

Methods

Data on urine collection and piping were collected in structured investigations in four large residential areas where urine diversion systems have been in use for some time: Understenshöjden, Sweden (44 apartments, urine diversion system in use for about 9 years); Palsternackan, Sweden (51 apartments, urine diversion system in use for about 9 years); Hyldeøjle, Denmark (10 apartments, urine diversion system in use for about 5 years); and Mosheshoeh, South Africa (11 apartments, urine diversion system in use for about 4.5 years). Understenshöjden, Palsternackan and Hyldeøjle all use water-flushed urine-diverting toilets with a u-bend odour trap in the urine pipe. Mosheshoe uses unflushed urine-diverting toilets, with dry faecal handling and without an odour trap. In addition, experiences were collected in an unstructured manner from small (one toilet) urine diversion systems around the world.

For the study of faecal collection systems, interviews were performed with 75 Swedish users of a source-separation system that collected faecal matter dry, i.e. without any flush water. The survey covered nine housing areas and an additional 15 separate households. The questions were divided into three categories: technical description; experiences of the system; and degree of user satisfaction with the system.

Of the 75 systems investigated, 30 had urine-diverting toilets with dry faecal collection, four had urine diversion by use of a separate toilet for urine collection combined with a non-urine diverting toilet for the faeces and 41 collected the urine and faeces mixed, as latrine compost. Of the mixed systems, three systems collected the faecal material in a container directly below the toilet and treated the collected material in a separate location, 34 systems composted the material directly below the toilet in the collection chamber, while the question was left unanswered for four systems. The collection
Results and discussion

Odours in urine-diverting systems

Users reported that the odour level with urine-diverting toilets equipped with a u-bend on the urine pipe was similar to that with ordinary, non-diverting water flushed toilets (Lindgren, 1999), whereas seven of the 11 households in Moshoeshoe with urine-diverting toilets without an odour trap on the urine pipe experienced odour problems from the system. On the other hand, many small (one toilet) urine-diverting systems without an odour trap are in use around the world without any odour problems. This is probably because the urine in well-designed small urine-diverting systems without an odour trap rapidly flows to the collection vessel. It reaches the collection vessel before there is time for it to degrade significantly. The odours from the degraded urine only slowly diffuse back to the toilet, provided that there is no gas flow in the urine pipe to the toilet. Such gas flow can be avoided by having the incoming urine pipe extend to close to the bottom of the collection vessel (Kvarnström et al., 2006). Any diffusing odours can then be eliminated by efficient ventilation. However, in large systems such as that in Moshoeshoe, air will flow in the urine pipe from toilets with higher air pressure to toilets with lower air pressure. A gentle wind or a difference in temperature is sufficient to generate a difference in air pressure between different toilets. Our conclusion therefore is that odour traps should always be used in large (>1 toilet) urine-diverting systems.

Blockages in urine collection systems

Users of urine collection systems with a u-bend reported the majority of blockages (Jönsson et al., 2000). However, 5–9 years of experience from Understenshöjden and Palstermackan show that these blockages can be efficiently removed by cleaning with a sewage auger and/or with a caustic soda solution (1 part soda dissolved in 2 parts of water), which is poured into the u-bend and allowed to stand overnight, before being flushed away by 2–5 L of water vigorously poured into the urine pipe in the morning. At Hyldespælet, the recommendation is to carry out preventive cleaning once a month using strong (32%) acetic acid and complementing this with thorough cleaning with a sewage auger. Our experiments have shown that caustic soda is far more efficient in clearing urine precipitates than citric acid (Jönsson et al. 2000). Therefore, our conclusion is that blockages in the urine pipe u-bend can be eliminated by preventive cleaning 1–4 times per year using a sewage auger and caustic soda solution (1:2; soda:water). The caustic soda removes the organic matrix, which is hydrolysed by the high pH. This enables simple removal by flushing of the precipitated phosphate compounds. On alternate occasions, the caustic soda solution can be replaced by strong (>32%) acetic acid, which instead attacks the mineral matrix of the structure. Thus, alternating alkaline and acid treatment targets both the organic and the mineral components of any build-up.

In Understenshöjden, Hyldespældet and Moshoeshoe, blockages were also reported in the urine pipes further down in the system. In Understenshöjden, one blockage had occurred in a 75-mm pipe with a negative gradient, while in Hyldespældet blockages had occurred in the 40–50-mm pipes behind the toilet in seven or eight of the 10 apartments. These blockages normally occurred in the 90° bend immediately behind the toilet. The 35-mm pipes in Moshoeshoe were joined by many 90° bends, and blockages also occurred here. In Palstermackan, no documented blockage of the pipes had occurred. The pipes were inspected visually through 14 inspection hatches after 9 years of operation and this inspection normally showed a thick, syrupy sludge layer at the bottom with a
thin liquid layer on top. As long as the gradient of the pipe was sufficiently large (≥1%) and the bends not too sharp, the sludge slowly flowed along the pipe without blocking it, even in 50-mm pipes and after 9 years. However, when the gradient was too small sludge accumulated, risking eventual pipe blockage. In small systems without a u-bend and with short pipes of good gradient, blockages due to precipitation were unheard of, while they rapidly occurred whenever the gradient of the urine pipe was too small. In small systems, precipitation and blockage seem to be prevented by the urine flowing so rapidly through the pipes that there is not enough time for degradation and the associated pH increase, even if this occurs rapidly (Udert et al., 2003a, 2003b). Thus, no sludge is precipitated and therefore the pipe can be thinner, down to 25 mm in small systems, provided that its gradient is good and that the pipe is not too long. Our tentative recommendation is that the gradient should be ≥4% and the pipe length ≤10 m to ensure this. In very small systems with good gradient and easily accessible pipes, i.e. a few metres and mainly vertical, the diameter can be even smaller, 12–15 mm.

Our recommendation for pipes from toilets with a u-bend or with a gradient <4% is that the diameter of the urine pipe should be at least 75 mm (110 mm for underground pipes), the gradient should be at least 1% and they should be fitted with ample hatches for inspection and cleaning. A diameter as small as 50 mm can be feasible if the pipe has a gradient of at least 1%, has no sharp bends and is easy to inspect, clean and disassemble, as more maintenance and cleaning might be needed. To minimise the risk of odour and of blockage in vertical urine pipes, it is recommended that the pipes are not ventilated, just pressure equalised (Jönsson et al., 2000; Kvarnström et al., 2006).

**Dry faecal collection systems**

The interviews showed that three factors were especially important for user satisfaction with the dry faecal collection systems:

1. combination with urine diversion;
2. placement and design of the collection bin;
3. size of the collection bin.

The 34 users of systems with urine diversion were far more satisfied than the 41 users of composting toilet systems collecting latrine, i.e. urine and faeces together. This was shown, e.g., by the fact that 15 of the 41 latrine systems had been changed to another system, either to a urine-diverting dry system or to a conventional flushed toilet system. In addition, some users of latrine systems and some users of systems with separate toilets for urine and faeces expressed an interest in changing their system in the near future. The main complaints regarding the composting system concerned insects, too wet compost, unclean toilets and collection bins being over-filled.

The fraction of users that had experienced problems with flies was similar between the systems (93–96%). The major difference was in the frequency of fly incidents, which was much higher for the latrine system compared with the urine-diverting system. For the latter, the incidents were mainly described as single events. The most successful method of decreasing the frequency of fly events was to decrease the size of the collection vessel and thereby increase the frequency of emptying.

The complaints about odour from the faecal matter (40–42% of interviewees) were similar between the systems and were related to ventilation failures due to power cuts, but the general comment was that neither of the systems smelled. The frequency of complaints about unclean toilets was similar between the systems. Improved cleaning techniques have to be developed for dry toilets, as stains cannot be removed by just brushing and flushing as in flushed sewage systems.
The problems with inert and/or too wet compost were often experienced in the latrine system but hardly at all in the urine-diverting systems. This can be explained by the volume of urine, 1–1.5 L of urine per person and day, being very large compared with the small amount of faecal matter, 0.02–0.04 kg of faecal dry matter per person and day (Vinnerås et al., 2006). The wet material was in several cases also linked to the high frequency of flies in the toilet. The easiest way to remedy this is installation of a urine-diverting system.

Some cases of overfilled bins were also reported. The frequency of this was higher in latrine systems (44%) than in urine-diverting systems (28%). This was mainly due to inadequate maintenance, as the volume collected was not monitored. The problems with overfilled bins correlated to bins with a volume of more than 100 L, i.e. bins with a low emptying frequency.

Many users complained about the placement of the faecal collection bin and how to empty it. The manual emptying is a major difference compared with the flushing toilet system, which can be considered as a backwards development and thereby give a general negative attitude to the system (Quitzau, 2007). One common problem was that the opening used for emptying the collection bin was hard to reach, resulting in strained working postures. Additionally, the transport route of the bin itself or of the emptied material often included high lifts and steep ladders. Of the users with a latrine system, 85% experienced emptying as difficult, while the corresponding fraction was 33% for the users with urine diversion. One common comment was an uncertainty about the user’s ability to empty the bin in old age or infirmity. The users of small collection bins were generally more positive about the emptying compared with users of large bins. In designing systems for handing human excreta, one of the main factors to be considered is thus placement of the bin and access for emptying. This is even more important when planning larger systems with centralised emptying of the bins.

When users were asked whether they would recommend their system to others, a positive response was obtained from 20% of those with a latrine system. However, 71% of those with urine-diverting toilets and 62% of those with separate toilets for urine and faeces would recommend these systems.

**Conclusions**

Based on this study, we recommend two types of designs: (1) Toilets with a u-bend odour trap. These are recommended both for large and small systems. The urine pipe should have a diameter of at least 75 mm, its gradient should be at least 1% and frequent inspection and cleaning hatches should be provided. Preventive cleaning of the u-bend and the pipe immediately behind it by use of caustic soda, acetic acid and/or a drain auger 1–4 times per year is recommended. (2) Toilets without an odour trap. This design is at present only recommended for small, one-toilet, urine collection systems. Precipitation is prevented by minimising the time the urine stays in the pipe. In these systems, a thin pipe (diameter ≥ 25 mm) can be used, but its gradient must be good (≥ 4%) all the way, obstacles that could slow down the flow should be avoided and the pipe should be short, preferably <10 m. It is recommended that urine pipes are pressure equalised but not ventilated. Normally the urine pipe should extend down to close to the bottom of the urine tank.

The main factors for achieving high acceptance of a dry toilet system proved to be whether it had any problems with flies and whether difficulties were experienced when emptying the collected faecal material. To avoid these two problems, the design of dry faecal collection systems needs to be combined with urine diversion and the emptying...
interval should be short, preferably just a fortnight. For long-term acceptance the collected material has to be easy to remove and transport away.

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**References**


