SOURCE SEPARATION OF HUMAN URINE - SEPARATION EFFICIENCY AND EFFECTS ON WATER EMISSIONS, CROP YIELD, ENERGY USAGE AND RELIABILITY

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Urine is the waste fraction from households which contains the largest amounts of nutrients. In Sweden it contains approximately 70% of the nitrogen and 50% of the phosphorous and potassium in all household waste and wastewater fractions. During the 1990-ies, urine separation has been thoroughly investigated in waterborne systems in Sweden. Measurements have shown that between 50% and 85% of the urine has been source separated, depending on the motivation and dedication of the inhabitants.

In horizontal urine pipes, magnesium and calcium phosphates precipitate forming sludge and, if the pipe slopes backward or its diameter is too small, sometimes stoppages. Therefore, the length of the urine pipes should be kept at a minimum, and they should be easy to inspect and clean. Horizontal pipes should slope at least 1% and their diameter should preferably be 75 mm or more.

The urine is sanitised by enclosed storage and recommendations for this have been developed. The storage period recommended depends on which crops that are to be fertilised, storage conditions and type of system.

The fertilising effect of urine to cereals has for nitrogen been found to be close to that of chemical fertiliser (~90%) and for phosphorous to equal that of chemical fertiliser. The measured ammonia emission after fertilisation has been 5%±5%. If the system is correctly designed, the ammonia emission from collection, transport and storage is insignificant (<1%).

The environmental effects of urine separation have been investigated in several studies. All have concluded that compared to a conventional waterborne sewage system, a urine separation system recycles much more plant nutrients, especially nitrogen and potassium and emits less waterborne nutrients. Generally, a urine separation system also saves energy. Urine separation systems have in all studies been found preferable to conventional waterborne systems form an environmental point of view.

Urine separation is now well documented and can be recommended under most conditions. The advantages of urine separation are larger in dry sanitation system than in waterborne systems and therefore for dry systems urine separation is strongly recommended.

Introduction

Urine is the household waste fraction, which contains the largest amounts of nutrients. In Sweden, the urine contains approximately 70% of the nitrogen and 50% of the phosphorous and potassium in all household waste and wastewater fractions, while the volume flow of urine is comparatively small, 1-1.5 litres per person and day (Figure 1).

This means that it is interesting to separate the urine at the source, i.e. in the toilet. From the toilet the urine is piped to a collection tank, stored and then used as a fertiliser for agricultural and horticultural crops.

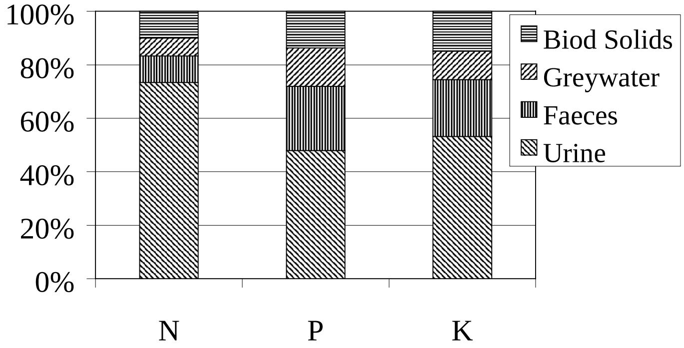

Figure 1. Relative distribution of nitrogen (N), phosphorous (P) and potassium (K) flows between the different household waste and wastewater fractions, i.e. biodegradable solid waste, greywater, faeces and urine in Sweden (SEPA, 1995; Sonesson & Jönsson, 1996; Kärrman et al., 1999).

Results

The results presented below are presented in more detail by Jönsson et al (2000), Höglund (2001), Jönsson et al. (1997), Jönsson et al. (1999) and Johansson et. al. (2001), Lindgren (1999) and Vinnerås (2001).

Hygiene

The hygienic aspects of a sanitation system are very important and they are presented in depth in several other presentations at this conference.

Toilet - degree of separation

In five different housing districts, with a total of 315 inhabitants, the function of the toilet and the percentage of urine being separated have been studied (Table 1). Most of the measurements have lasted around 30 consecutive days. The apartments in most of the districts were rented, but those in the eco-village Understenshöjden were tenant owned. The inhabitants in Understenshöjden had decided themselves that they wanted a urine separating sewage system. In the other districts, the property owner had installed urine separation without asking the tenants. Thus, the inhabitants of Understenshöjden were better informed, motivated and dedicated than the inhabitants in the other districts. The tenants in Miljöhuset, on they other hand, were ill informed about urine separation. One important reason for this is that they on average moved much more frequently than the tenants in the other houses. As is seen in Table 1, the motivation and dedication of the inhabitants have a profound impact on the percentage of urine actually being source separated.

Thus, to reach a high percentage of separation, it is very important to inform and motivate the users of the toilet about why the urine is source separated. The consequences of a low separation percentage are more serious in systems where the faeces are handled dry than in waterborne systems. The unsorted urine increases the water content of the faecal fraction and thus makes dehydration or composting more difficult. Thus, in systems where the faecal fraction is handled dry, it is especially important to inform and motivate the user. To increase separation, it is a good idea to also install urinals.

It should be stressed that not even the inhabitants of the eco-village Understenshöjden were very well informed about the benefits of urine separation, since the advantages of urine separation had not been thoroughly investigated at that time. Had they been better informed, probably their separation would have been even better.

Table 1. Investigated housing districts, and the measured percentage of source separated urine in each district (Jönsson et al, 2000, Lindgren, 1999, Vinnerås, 2001)

	Understens-höjden	Palster-nackan	Hus-hagen	Eko-porten	Miljöhuset
Inhabitants, no	160	50	8	35	62
Toilet	BB Dn	BB Dn	WM DS	BB Dn	BB Dn
Apartment type	Tenant owned eco-village	Rented	Rented	Rented	Rented
Motivation	High-medium	Medium-low	Medium-low	Medium-low	Very low
Urine separated, %	82	63	62	71	48

The conclusions from these measurements were:

- Motivation, information and feedback are important for the amount of urine actually being source separated!
- Normally 60-90% of the urine produced is source separated, but higher percentages can probably be reached.
- Many men want to urinate while standing up. The toilet should enable these men to source separate their urine, otherwise the percentage of urine actually separated will drop. Installation of urinals is recommended.
- Avoid contact between urine and metals in the toilet and in the whole system. Urine is very corrosive and at excretion its concentration of heavy metals is very low. Metals in contact with urine will corrode and thus contaminate the urine. Furthermore, corrosion will also decrease the lifetime of the metal parts.
- In waterborne systems, urine separation saves flush water. The amount of flush water saved depends on motivation. Savings of 80% are possible, but so far only up to 50% has been measured.

Toilets, pipes and tanks

The function of the toilets were studied in two questionnaires, one to 96 households in 1997 and another one to 73 households in 1999. The two toilets studied were Dubbletten and WM DS. The most important problem found was that stoppages normally appeared in the u-bend of the toilet after a short time. Initially these stoppages were a big problem, since the users did not know how to clear them. Studies of the stoppages showed that 76% of them mainly consisted of hairs, fibres, and precipitation forming on them. The precipitation consisted mainly of calcium and magnesium ammonium phosphates. These stoppages could easily be cleared with a mechanical snake or with caustic soda. The remaining 24% of the stoppages consisted of precipitation, which had formed on the pipe wall. These stoppages could efficiently be cleared with caustic soda. Now, when the users know how to clear the stoppages, they are not a problem any more.

The precipitation is due to the urine pH rapidly increasing from around 7 to around 9. This happens in the u-bend of the toilet and as the urine slowly flows in horizontal pipes. In the pipes a biologically active sludge is formed, which rapidly degrades the urea of the urine to ammonium and thus increases the urine pH to around 9. At this pH, the magnesium, ammonium, calcium and phosphate ions of the urine naturally form calcium phosphate and magnesium-ammonium phosphate and these precipitate.

This means that stoppages due to precipitation can form wherever the urine pipe has a backward slope, especially if the toilet has no u-bend.

Measurements and observations by video and by naked eye have been made of pipes and tanks. Sludge is formed in all horizontal urine pipes, which therefore should have a large enough diameter and a slope of at least 1%. The sludge can easily be flushed away with water and it is important than the pipes are equipped with adequate facilities for inspection and cleaning. Experience also stresses the importance of the pipes being 100% watertight. A common problem has been ground and/or surface water leaking into the system and filling the urine tank.

Based on the studies and experiences so far the following recommendations are given:

- Keep the piping system to a minimum, especially horizontal piping. This is probably more important if the urine pipe has no u-bend at the toilet.
- The pipe systems should have adequate facilities for inspection and cleaning (flushing). It should be possible to use a mechanical snake and caustic soda.
- Installations in the ground must be 100% watertight. Ground water leaking into the system and filling the urine tanks has been a frequent problem!
- Horizontal pipes should have a slope of at least 1% and a diameter of at least 75 mm (preferably 110 mm), because sludge continuously forms from the urine mixture. The sludge is easy to flush away, but this should only be needed about once every 10 years, if the recommendations are followed. If a diameter of 50 mm or less is used for horizontal pipes, these may need flushing every year.
- The urine system should not be ventilated. If it is correctly constructed the total ammonia emission from collection, transport and storage usually is less than 1%.
- It is an advantage if the tanks are filled from the bottom and have the manhole close to the incoming pipe.

Fertilising effect

The fertilising effect of source separated urine to cereals has in Sweden been investigated in two pot experiments, a three year field experiment and a one year field demonstration. These investigations have shown that source separated urine is a well-balanced complete fertiliser and its nutrients are readily available to plants. The nitrogen effect was found to be close (~90%) to that of ammonium-nitrate fertiliser. It varied between 70% and more than 100% between different years (Johansson et al., 2001). The phosphorous effect was equal to that of chemical fertiliser (Kirchmann & Pettersson, 1995).

In the experiments, the ammonia emission after spreading varied between less than 1% and almost 10%. It averaged around 5%. No toxic effects have been observed in these or other experiments with the cereals barley, oats and wheat. The urine has been spread on the soil or in the growing crop. However, the nitrogen in stored urine is mainly found as ammonium/ammonia and it is well known that ammonia is toxic to some crops, if it is applied on the plants themselves.

The concentrations of heavy metals in source separated urine are very low. For example the Cd/P ratio was around 2 mg Cd per kg of P.

Emissions and resource usage

The computer package ORWARE was used to model and simulate the urine separating waterborne sewage system of Palsternackan, where the faecal water (faeces, paper and flush water) and greywater were treated in the central sewage treatment plant in Stockholm. The simulated environmental effects and resource usage of this

system were compared to those simulated for a conventional sewage system, using conventional toilets and treating all wastewater, including the urine, in the central treatment plant, which removed 98% of the phosphorous and 80% of the nitrogen. In both systems 50% of the generated sewage sludge was spread on arable land and 50% was landfilled.
Urine separation decreased the emissions of nitrogen and phosphorus to water by 55% and 33%, respectively (Figure 2). Sensitivity analysis showed that the reduction expressed in percent would be approximately the same also if the nitrogen and phosphorous reductions in the sewage treatment plant were less. This means that the absolute reduction, i.e. in kg/person and year, of the waterborne nitrogen and phosphorous emissions will be larger where the sewage treatment is poorer. Thus, in this situation the advantages of urine separation are larger.

A large fraction of the plant nutrients were recycled to agriculture as source separated urine instead of being led to the wastewater treatment plant. Thus, the urine separating system, compared to the conventional system, recycled 27 times more plant available nitrogen, 35% more phosphorus and 25 times more potassium. Approximately 1.6 kg of nitrogen and 0.15 kg of phosphorous were recycled per person and year, enough to fertilise 160 m^2 at 100 kg of nitrogen per hectare (10 000 m^2).

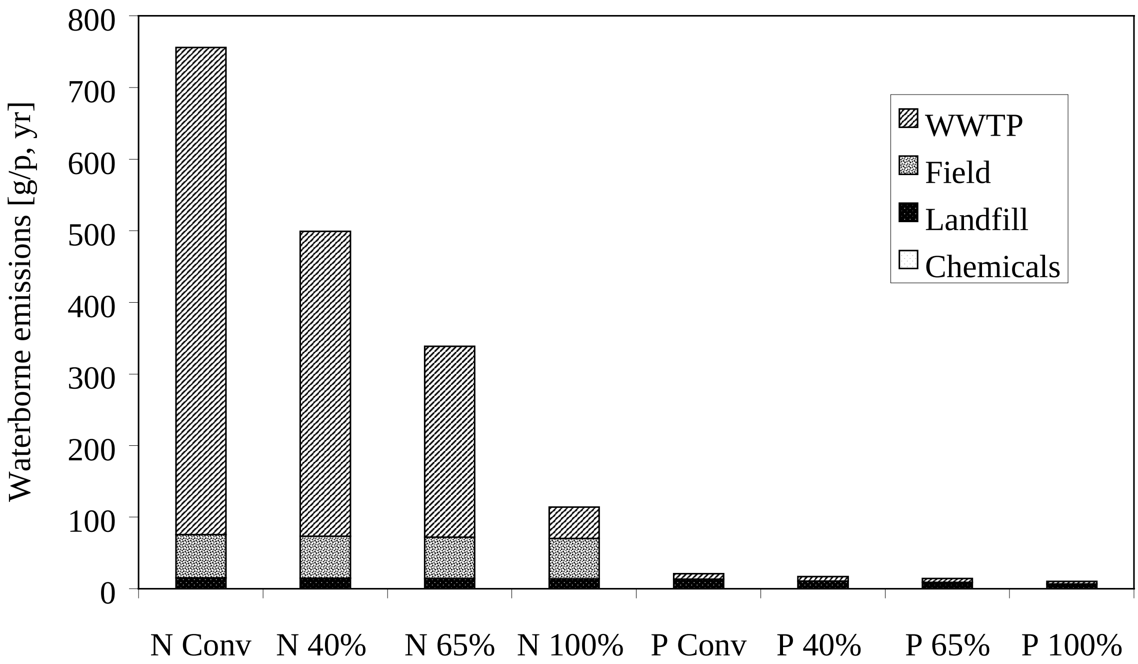

Figure 2. Waterborne emissions of nitrogen and phosphorous caused by wastewater from Palsternackan for the conventional system and for the urine separating system at different percentages actually being separated. In Palsternackan 65% of the urine was separated.

The concentrations of heavy metals were very low in the urine. Mercury, cadmium and lead were all below their detection limits, 0.0004, 0.0013 and 0.027 mg/l respectively. These values corresponded to: <1 mg Hg/kg P, <4 mg Cd/kg P and <89 mg Pb/kg P. In the measurements at Ekoporten, performed after this ORWARE study, the detection limit for cadmium was lowered and it was found that the Cd/P ratio was 2 mg Cd/kg P. Thus, urine is a very clean fertiliser.

Energy, 44 MJ/person and year, was required for transporting the urine mixture 33 km with a truck to a farm and for spreading it as a fertiliser. However, the decreased nutrient load on the sewage system meant that 32 MJ/person and year were saved in the sewage system. In addition, the source separated urine replaced mineral fertilisers, which would have required 75 MJ/person and year to produce. Thus, urine separation saved a total of 63 MJ/person and year (Figure 3). A sensitivity analysis showed that the urine mixture could be transported 220 km by truck and trailer before the urine separating system used as much energy as the conventional one.

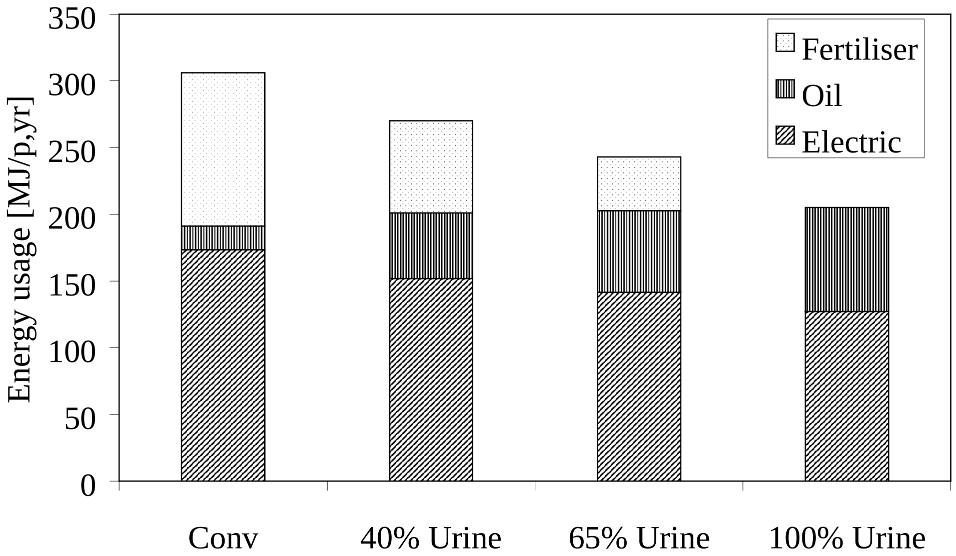

Figure 3. Total energy usage (electricity, oil and energy for production and distribution of fertiliser) for the conventional and the urine separating system at different separation percentages of the urine. The urine was transported 33 km with a truck and the degree of separation in Palsternackan was 65%.

Urine separation has also been investigated in a number of other environmental systems analyses using the methods life cycle assessment (LCA) and mass flow analysis(MFA). These studies have been using a variety of data and assumptions. Considering the environmental impacts and the use of natural resources, they have all concluded that urine separation is preferable to the conventional waterborne sewage system (Bengtsson et al., 1997; Bjuggren et. al., 1998; Kärrman et. al, 1999; Kärrman & Jönsson, 2001; Jernlid & Karlsson, 1997; Tidåker & Jönsson, 2001; Tillman et al., 1997). Therefore, the conclusion is that the sewage system is improved if it is supplemented with urine separation. This conclusion seems to hold under most conditions and assumptions, i.e. it is robust. Urine separation improves the sewage system more, where the sewage treatment is poor.

The advantages of an EcoSan system, separating the urine and handling the faeces dry, are larger than those of urine separation in a waterborne system. EcoSan systems emit no waterborne nutrients at all from urine or faeces. All nitrogen, phosphorous and potassium from urine and faeces can be recycled to agriculture, except for some small losses of nitrogen in the form of ammonia. A lot of energy is conserved since a lot of chemical fertilisers can be replaced by urine and faeces.

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