DESIGN AND PERFORMANCE OF ECOLOGICAL SANITATION SYSTEMS IN NORWAY

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Abstract
Over the last decade ecological sanitation has made a leap forward in Norway. At present municipalities as well as the Agricultural University of Norway is considering conversion to a fully recycling and watersaving sanitation system. This interest has been rised through successful demonstration projects where both the toilet and the greywater fraction is treated. In Oslo, the capital of Norway, greywater from 33 apartment homes is treated in beautifully landscaped compact natural system in the courtyard of the building. At the agricultural university of Norway 24 student apartments has a complete recycling system based on aerobic hygienization of blackwater, collected using a vacuum toilet system and rendering an odourless and hygienized fertilizer slurry. The system can also handle the organic household waste. The greywater is treated to swimming water quality. New energy efficient equipment for fertilizer application is developed and the yields using liquid organic fertilizer is comparable to the yields using mineral fertilizer.

Introduction
Substantial amounts of plant nutrients and organic matter are present in household waste and waste from food processing industries (Jenssen and Skjelhaugen 1994). Theoretically speaking, the nutrients in domestic wastewater and organic waste are nearly sufficient to fertilize crops to feed the world population(Wolgast 1992). Practically speaking 20-40% of the water consumption in sewered cities is used to flush toilets (Gardner 1997). In order to evolve towards a sustainable society we need to recycle nutrients, reduce the water consumption, and minimize the energy needed to operate waste treatment processes.

Blackwater (toilet wastewater) contains 90% of the nitrogen and 80% of the phosphorus if phosphate free detergens are used. In addition 30 – 75% of the organic matter in the wastewater is in the toilet waste (Jenssen & Skjelhaugen 1994). By the use of urine separating, composting, or extremely water saving toilets, nutrients can be collected and recycling facilitated (Jenssen 1999). Concentrated toilet and organic household waste can also produce energy via aerobic or anaerobic processes. In Norway the main focus has been on the use of extreme water saving (e.g. vacuum) and composting toilets. Substantial efforts are also devoted to the development of simple greywater treatment systems as wetlands, biofilters or soil infiltration systems or a combination of such.

Greywater treatment is an important part of a complete ecological sanitation system. Greywater treatment options was considered by Rasmussen et al. (1996). In Norway greywater treatment systems using simple LWA biofilter systems or a combination of LWA biofilters and subsurface flow LWA constructed wetlands have emerged (Westlie 1997, Guldbrandsen 1999, Larsen 2000 and Heistad et al. 2001, Jenssen and Krogstad 2001). The principle of a source separating fully recycling system is shown in Fig. 1.

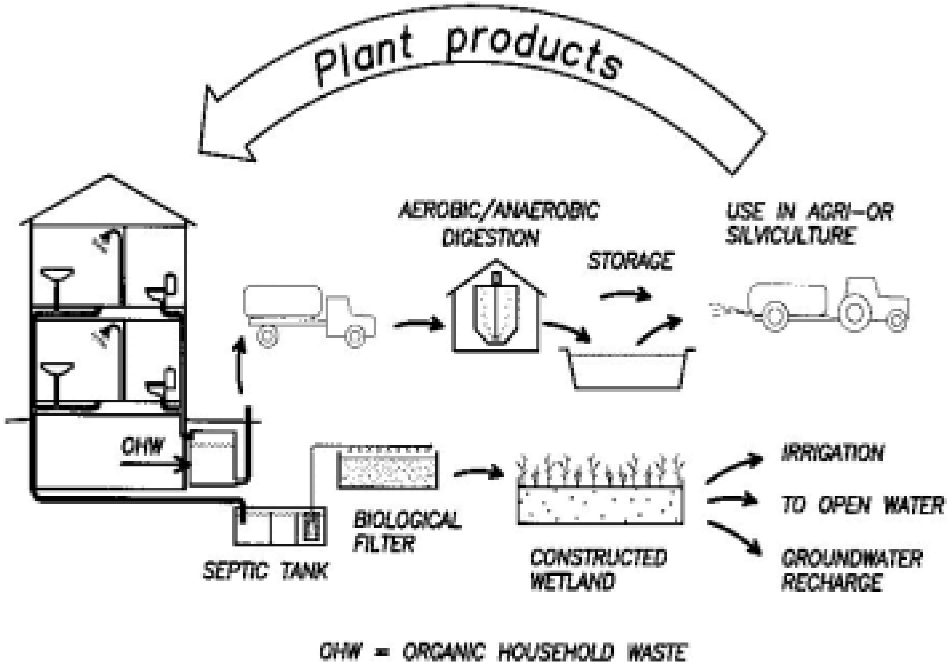

Fig. 1. A fully recycling system using separate treatment of blackwater and greywater.

Treatment and recycling of blackwater and organic waste

Vacuum and gravity operated toilets using 0.5 - 1,5 liter per flush are comercially available. Using these toilets experience shows that 5-7 liters of blackwater is produced per person and day (Gulbrandsen 1999). Using conventional flush toilets the daily per capita production of blackwater would be 6 – 15 times higher. Using a 1 liter toilet an average Norwegian family would produce 6 - 9 m3 blackwater per year and 15 families would produce about 10 m3 of blackwater per month. Such volumes are possible to handle separate. Even when the amount of flushwater is only 1 liter the dry matter content (DM) is usually below 1%. In order to successfully treat the blackwater by liquid composting, which is the most common process in Norway, organic matter must be added (Jenssen and Skjelhaugen 1994). Grinded organic household waste, animal manure or residues from various food processing industries are all additives that bring the DM content up to a level where the composting process is successful. An energy efficient liquid composting unit is developed (Jenssen and Skjelhaugen 1994). The effluent from the liquid composting unit is hygienised and odourless. The unit is running with a positive energy balance if the heat generated by the composting process is utilized.

Anaerobic treatment in small decentralized units has been considered uneconomical in Norway. This is partly due to safety regulations, but also the climate that demands better insulation and more sophisticated systems than in warm climates. Nevertheless anaerobic processes are attractive due to the energy quality of gas beeing superior to heat and less energy needed to operate an anaerobic process. Work has therefore started investigating the use of small scale anaerobic reactors for cold climates.

A special direct ground injection system was developed for injection of liquid organic fertilizers (Morken 1998). This equipment does not penetrate the ground, rather the fertilizer is injected under pressure. Immediate soil contact secures ammonia adsorption and good plant accessability of the fertilizer. This reduces the ammonia loss to 15 – 20% as compared to to traditional surface spreading methods where the loss is 70 – 80%. The equipment also makes it possible to sow at the same time as the fertilizer is injected. The yields using injection of liquid organic fertilizer compare well to conventional methods using mineral fertilizer.

Greywater treatment

Greywater contains minor amounts of nitrogen and phosphorus, but substantial amounts of organic matter (Rasmussen et al. 1996). Indicator bacteria are also present in large numbers (Rasmussen et al. 1996, Gulbrandsen 1999, Larsen 2000). The need for treatment of the greywater depends upon its final discharge or use. For discharge to the sea no or primary treatment is sufficient. When the discharge is to inland lakes or rivers the authors recommend secondary treatment. This may be achieved using a simple biofilter system as developed by Westli (1997) or Heistad et al. (2001). In order to be able to discharge the greywater to small local streams or use it for irrigation or groundwater recharge, reduction of the hygienic parameters as bacteria is important. This can be obtained using a sandfilter or a combination of a biofilter and a subsurface flow constructed wetland (Fig 3 and Table 1).

Where natural conditions are favorable, soil infiltration is a cost effective option that gives excellent greywater treatment (Westby et al. 1997). Norway has developed its own set of sizing and design criteria for soil infiltration and sandfilter systems that includes greywater (Jenssen 1986, Jenssen and Siegrist 1991, MD 1992).

Biofilters and constructed wetlands using light weight aggregates (LWA) or similar porous media are pioneered in Norway (Heistad et al. 2001, Jenssen and Krogstad 2001).

A single pass biofilter aerates the wastewater and reduces BOD and bacteria, thus, higher loading rates can be used for a subsequent infiltration system (Heistad et al. 2001). The use of a single pass biofilter also provides new designs of onsite natural systems (Fig. 1). In sloping terrain such filters can be operated by the use of a siphon. Using such filters a 70% BOD reduction and 2-5 log reduction of indicator bacteria has been obtained at a loading rate for greywater of 115 cm/d. Assuming a greywater production of 100 liters/person/day (Table 2) a biofilter of 1 m2 surface area can treat greywater from about 10 persons, hence, very compact biofilters can be made. The key to sucessful operation of the biofilter is uniform distribution of the liquid over the filter media and intermittent dosing.

For locations where traditional soil infiltration is not possible a simple biofilter alone or a biofilter prior to soil infiltration or a constructed wetland system may be used (Fig. 2 and 3). For cities a biofilter preceeding a subsurface flow constructed wetland has been used with success (Fig 3, Table 2).

For greywater a LWA biofilter/constructed wetland system (Fig. 3) can be designed very compact. This facilitates urban applications. With an integrated biofilter the total surface area about 2m2/person. The depth of the wetland is minimum 1 meter and the biofilter 0.6m. With this configuration very high effluent quality is achieved (Table 1).

In Oslo, the capital of Norway, greywater from 33 apartment homes (Klosterenga) is treated to swimming water quality (Table 1) in the courtyard of the building. The area requirement for the total system is about 1m2/person. The area covering the biofilter is used as a playground. Additional aeration, in the summer, is provided by a flowform system (Wilkes 1980) and it is planned to discharge the treated greywater to a local stream that will be reopened. With effluent qualities as shown in Table 1 the need for an elaborate secondary sewer system is reduced because local streams or water bodies can be used for receiving the treated water.

Table 1 also shows effluent values for two other full scale greywater treatment systems; one at the Agricultural University of Norway treating greywater from student dormitories (Kaja) and the other treating greywater from 43 condominiums in Bergen the second largest city in Norway (Torvetua). All three systems have the same principal design as shown in Fig. 3.

Table 1. Greywater septic tank effluent (GSTE) and effluent values of three biofilter/constructed wetland systems, average values.

System	Built year	Persons served	BOD/ COD GSTE	BOD/ COD effluent	TotN GSTE	TotN effluent	Tot-P GSTE	Tot-P effluent	TCB** effluent
Kaja	1997	48	88	6	8,8	2,4	1,0	0,1	<1000
Torvetua	1999	130	346*	44*	5,5	2,2	0,89	0,19	<1000
Kloster-enga	2000	100	ND	22*	ND	2,5	ND	0,02	0

* COD, ** TCB=Termotolerant coliform bacteria

Both the influent and the effluent values of these systems meet the WHO drinking water standards with respect to nitrogen (<10 mg/l). The phosphorus concentrations are also extremely low and the influent concentrations meet the Norwegian requirement for small treatment plants that discharge to freshwater (< 1mg/l). The TCB concentration in the GSTE is in the order of 104 – 106/100 ml. The bacteria concentration in the effluent (Table 2) meets the European standards for bathing water (<1000 TCB/100 ml). All samples at Klosterenga, that utilizes the last generation of the high phosphorus sorbing LWA termed Filtralite-PTM, have consistently shown 0 TCB/100 ml. After treatment of greywater in a biofilter followed by a constructed wetland the effluent can be discharged to local streams, irrigation, or groundwater.

Water consumption

The traditional water toilet accounts for 20 – 40% of the per capita water use (Gardner 1997). Table 2 shows that the per capita greywater production varies from 81 to 133 liters. The lowest greywater production displayed in Table 2 is from a Norwegian ecovillage project and shows what is possible to achieve if the people are focussed on water conservation. At the student dormitories (Kaja) the greywater production is higher despite water saving showerheads. Without water saving showerheads the greywater production was 156 liters per student per day. This shows that the showers account for a major part of the greywater production in the student dormitories. In Norway young people (15 – 25 years) generally take more frequent and longer showers than the rest of the population and thus it can be expected that the avrage greywater production for the population as a whole is lower. Compared to the average normal per capita water use in Norway the students at Kaja has a 27% lower total water consumption when they use vacuum toilets (1 liter/flush) and water saving showerheads. The people of the ecovillage where composting toilets were used had a 50% lower water use.

Table 2. Water use in households liters/person and day.

	Norway[1]	USA[2]	Ecovillage Norway[3]	Kaja[4]
Blackwater	40	57	0	7
Greywater	120	133	81	112
Total	160	180	81	117

[1] Vråle 1987, [2] Tchobanoglous 1998, [3] Kristiansen and Skaarer 1979, [4] Søyland 1998

Conclusions

Experience from Norway shows that separate treatment of blackwater and greywater nearly achieves "zero emission" and almost complete recycling. Organic household waste can be treated in the same process as the blackwater and yield a fertilizer/soil amendment and energy. The water consumption can be reduced by up to 50%. Compact technically simple greywater treatment systems facilitates decentralized treatment even in urban areas, thus the need for a secondary piping and pumping system for transport of untreated wastewater is reduced.

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