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SUSTAINABLE WASTEWATER TREATMENT

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ABSTRACT
In order to develop sustainable wastewater treatment it is needed to view the wastewater treatment systems in a broad sense. In addition to cost and treatment performance energy aspects, recycling and social issues are important when evaluating sustainability of a wastewater treatment system and selecting an appropriate system for a given condition. This requires a multidisciplinary approach where engineers cooperate with social scientists, economists, biologists, health officials and the public.

Wastewater contains organic matter and the three main nutrients for plant production: nitrogen, phosphorus and potassium. Theoretically speaking, the nutrients in domestic wastewater and organic household waste are nearly sufficient to produce enough food for the world population. Nitrogen fertilizer is energy consuming to produce and phosphorus is a limited mineral resource. Recycling and energy aspects are thus important factors of sustainable system design.

Scandinavia is pioneering sustainable solutions to wastewater treatment. Energy efficient moving bed reactors are developed for tertiary treatment in traditional "end of pipe" wastewater collection and treatment systems. A variety of watersaving and urine diverting toilets can nearly halve water consumption. Toilet waste (blackwater) or urin can be collected separately. Cotreatment of blackwater and organic household waste yield both energy and hygienic fertilizer and handles all organic waste from the household in one waste stream. Water from showers, sinks and kitchen (greywater) can be treated in a variety of systems. Treated greywater is suitable for irrigation, groundwater recharge or as a source of potable water production. Utilizing the latter more than 90% water saving is possible. Source separation (blackwater/greywater) systems produce near zero emissions and open up for exiting urban applications.

INTRODUCTION

In order to develop sustainable wastewater treatment it is needed to view the wastewater treatment systems using a holistic approach. A holistic approach implies considering the primary and secondary environmental effects and costs that the systems produce. Examples are the pollution produced at the power plant (generating electricity for wastewater treatment) and the energy cost of producing treatment chemicals. Designing or selecting a treatment system based on sustainability criteria involves a multidisciplinary approach where engineers cooperate with social scientists, economists, biologists, health officials and the public.

Over the last decade sustainable wastewater treatment has been an issue at several conferences (Ødegaard 1991, Henze et al. 1997, Graf 1999). The first international conferences of "Ecological engineering for wastewater treatment", was held in Sweden in 1991 (Etnier and Guterstam 1991), addressing sustainable wastewater treatment systems. The focus was on natural or ecologically engineered systems, that optimize resource gains and minimized resource use, hence, recycling and energy aspects, were in focus. Later several conferences have been held regarding ecological sanitation (Staudenmann et al. 1996, Kløve et al. 1999, Jana et al. 2000, Werner et al. 2004). The year 2008 which had been declared the "Year of Sanitation" by the United Nations to bring more focus to sanitation because the Millenium goals for sanitation is far behind schedule to fulfill the goals. To promote sustainable sanitation systems toward 2008 a Sustainable Sanitation Alliance (SSA 2007) was formed. The SSA unites forces of universities working with sustainable sanitation with major world organizations as UNDP and the world bank national donor organizations and NGOs.

One of the first attempts to look at energy aspects of wastewater treatment was Antonucci and Schaumburg (1975). They documented the energy and chemical use at South Lake Tahoe tertiary treatment plant and concluded that it was impossible to say whether the plant was an environmental benefit or liability.

The European union (EU) has launched a 5-year project COST C8 "Best Practise for Sustainable Infrastructure" and is developing a handbook for assessing the degree of sustainability for infrastructure of water supply and sewerage systems. In this project 15 countries are co-operating to make a push for more sustainable infrastructure.

In Norway the national research program "Natural systems for wastewater treatment 93-98" (Jenssen 1995) had a main focus on development of sustainable systems for rural areas. Simple wetland systems that meet tertiary standards and decentralized systems with near complete recycling of nutrients, possibilities for large water savings and energy production were developed (Jenssen and Etnier 1997, Mæhlum 1998, Zhu 1998, Jenssen 1999, Jenssen and Krogstad 2002, Jenssen et al. 2005)**.** Some of these systems are also suited in urban areas.

In Sweden a large national research program (Urban water 2001) involving all major Swedish universities was launched at the turn of the Millenium. This 6-year project, finances 15 doctoral candidates working only within sustainable wasterwater systems. It is expected that this program will bring Sweden in the forefront in the world concerning the design, analysis and operation of sustainable wastewater alternatives.

This paper briefly mentions sustainability analysis of wastewater treatment systems. The main focus is on sustainable technologies for wastewater treatment developed in Norway. This includes optimization of conventional technologies for nitrogen removal based on moving bed and fixed film reactors and ammonia stripping. In addition recycling systems based on separate treatment of the blackwater (toilet waste) and greywater (all except toilet waste, shower, kitchen and washing) is described (Jenssen et al. 2003). Such systems can be utilized both in rural and urban settings.

SUSTAINABILITY ANALYSIS OF WASTEWATER TREATMENT SYSTEMS

In earlier times and even to day, engineers and politicians nearly always use a simple cost/benefit analysis when choosing a wastewater system. This means that, for instance, only the discharge of organic matter (BOD) or phosphorus and the cost is looked upon. However, the quest for sustainability is necessary because we see *many* problems are coming like global warming, acidification, diminishing ozone layer, micro-organic pollutants and other toxic chemical matters, eutrophication, diminishing important resources like phosphorus, potassium and oil and other threats to mankind, flora and fauna. This shows that many indicators must be used when deciding what type of wastewater systems we should implement. And we should choose the wastewater system that contributes most to an overall sustainable future.

The notion sustainability should include ecology, economy and sociological aspects and the sustainability must also perform on three different stages:

1. Local, where hygienic and health aspects are of concern in time scales of hours or days.
2. Regional, where classic environmental problems operate in time scales of months or years.
3. Global, where sustainability matters in a time scale of decades or centuries.

To compare two wastewater alternatives the following indicators may be considered as relevant for a sustainability analysis (Lindholm and Nordeide 2000):

- Discharge of pollution to local recipients and major recipients. For instance: phosphorus, nitrogen and organic matter (BOD).
- The amount of micro-organic pollutants and heavy metals in the sludge going to agriculture.
- Amount of phosphorus, potassium and nitrogen recirculated for plant production.
- Discharge of climate gases like methane and CO_2.
- Use of electric energy and fossil energy.
- Use of products with hazardous components.
- Use of finite or critical resources.
- Costs as present value of investments, operation and maintenance.
- The use of area, influence on the landscape, aesthetic- and recreational values.
- The service levels like clogging of sewers and flooding of basements.
- Noise, smell, insects and other disturbances in the operation and construction period.
- Safety for children.

Indicators that are approximately the same for both alternatives may be eliminated.

The system borders for the analysis of the sustainability of a wastewater system are very important for the assessment. A wider or narrower definition of the system studied may alter the result of the assessment completely. The assessment may be studied on a global scale, on a regional/city scale or on a block/neighbourhood scale. The two last ones are appropriate for studies of infrastructure systems, even if the global context should be considered at all times. The system borders should be large enough to include not only the infrastructure itself (the hardware of the system), but also the city area it serves and the productive land and waters that enable the cycles of nutrients to be closed (the extended system).

However, up to now we have realised that the municipalities nearly always choose the well known, and cheapest alternative that complies with the minimum regulations and absolute demands from the authorities. We must hope that in the future this will change. The municipalities should achieve a minimum acceptable level of sustainability for their wastewater systems.

RESOURCES IN DOMESTIC WASTEWATER AND ORGANIC HOUSEHOLD WASTE

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). This, however, requires that people turn to a vegetarian diet. It also requires that appropriate technologies are available for safe recycling of the wastewater resources. 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.

Figures for the amount of mineral fertilizer that can be substituted for organic fertilizer sources vary and depend on several factors, one being whether a country has a net import or export of food. In countries belonging to the Organisation for Economic Cooperation and Development (OECD) the nutrients in wastewater average 8 % of the applied mineral fertilizer and the nutrients in household and yard waste constitute another 7 % (Gardner 1997). If all the nitrogen and phosphorous in Norwegian wastewater was reclaimed and recycled into agriculture, application of mineral fertilizer could be reduced 15-20 % (Jenssen and Vatn 1991). The corresponding figures for Sweden are 16-17 % (Guterstam 1991). In most developing countries these levels are higher (Gardner 1997), and according to Etnier and Jenssen (1997) more than 40 % of the nutrients present in chemical fertilizers could, theoretically, be substituted with nutrients from wastewater. Organic matter accounts for one third of the input to landfills in industrialized countries and as much as two thirds, in developing countries (Gardner 1997).

While recycling domestic organic waste can not replace mineral fertilizer entirely, it can reduce pollution from domestic waste, reduce excessive fertilizer use and develop healthier soils.

Tertiary treatment facilities can be designed to remove both nitrogen and phosphorous, but recycling of the nitrogen is difficult unless nitrogen is precipitated as struvite or removed using ammonia stripping with adsorption. The most common method of nitrogen removal in conventional treatment plants today are biological processes. However, with these methods most of the removed nitrogen is discharged to atmosphere. Phosphorus is most commonly removed by chemical precipitation using either Fe- or Al-salts as precipitating agents. However, the plant availability of phosphorus precipitated as Fe- or Al-phosphates can be very limited due to very low solubility under normal soil conditions whereas with lime precipitation the phosphates are easier dissolved and available to the plants (Krogstad et al. 2005). Since industries, households, and street runoff discharge to the same sewer system, there is a risk of heavy metals and other contaminants. In Scandinavia, this threat has reduced the farmer«s motivation to recycle sewage sludge.

LARGE CONVENTIONAL TREATMENT SYSTEMS

Sustainability aspects of nutrient removal (tertiary treatment)

The Norwegian Institute for Water Research (NIVA), showed in the 60`s and the 70`s, that it was important to remove phosphorus from wastewater in Norway, because phosphorus is the main limiting factor for algal blooms in rivers, lakes and narrow fjords (Holtan 1976).

Phosphorus removal by chemical precipitation has been refined in Norway, Sweden and Finland over the last 30 years. The concentration of phosphorus is easily reduced down to 0,50 mg P/l in the effluent, measured as total phosphorus and a net removal of 95 % or more is achieved. The cost and energy consumption in the chemical precipitation process is low compared to biological P-removal methods**,** because adding and mixing chemicals to the wastewater is far more energy efficient than the aeration needed for biological treatment processes. Chemical precipitation also removes other wastewater constituents than phosphorus (Table 1).

Table 1. Reduction of wastewater constituents other than phosphorus by chemical precipitation (Vråle and Olsen 1994).

Wastewater constituent	Removal %
Organic matter expressed as BOD_7	75-80
Suspended solids	85-90
Dissolved organic	30-55
Total nitrogen*	15-40

* *If the sludge from a chemical treatment plant is digested and the sludge is dewatered and the water is sent back to the inlet the percent removal of nitrogen is reduced to approximately 5 %.*

The energy consumption for chemical precipitation in Norway is only 0,23 kWh/m^3 treated water for larger treatment plants (Ødegaard 1992). Most of this energy consumption is used for heating and ventilation of the buildings over the treatment basins. For biological treatment (activated sludge with only 30 % phosphorus removal) the energy use is in the order of 0,37 kWh/m3 (O`Brien, J.K. 1986) showing that from an energy aspect chemical precipitation is more sustainable than a biological process.

Nitrogen removal

Removal of nitrogen in Norway was triggered by The North Sea Agreement in 1988. For countries having direct discharge to the ocean, it is believed that nitrogen is the main limiting factor for algae growth in the marine environment. According to the North Sea Treaty, countries bordering the North Sea have agreed to reduce the input of nutrients (nitrogen and phosphorus) by 50 % within year 2005, using emissions in 1985 as a baseline (SFT 1991).

Nitrogen removal is performed mostly by biological methods in large scale treatment systems. Adding a nitrogen removal step with pre- or post-denitrification more than doubles the energy consumption of the treatment plant if the original plant is based on chemical precipitation. At the Lillehammer wastewater treatment plant (Table 2) adding nitrogen removal increased the energy use by a total of 2,2 million kWh per year or by additional 0,23 kWh/m^3 (Moen and Lien 2000).

In Norway nitrogen removal has been a challenge due to low wastewater temperatures in the winter and a very dilute sewage because of combined sewers and infiltration water.

Two methods of nitrogen removal have been developed with success in Norway; 1) the moving bed Kaldnes system (KMT™) and 2) the fixed bed biological filter by Degremont. The latter process has been improved based on new types of expanded clay aggregates (Filtralite HC™ and -HR™) developed by Maxit of Norway.

Table 2. The major treatment plants with nitrogen removal in Norway (Moen and Lien 2000).

Treatment plant	Start of N-removal	Hydraulic design cap. (PE)	Qdim m^3/h	Treatment process before N-removal	N-removal process
Lillehammer	1994	70 000	1200	Mechanical/chemical	KMT pre and post denitrification
VEAS Oslo	1993/95	700 000	6m^3/s	Mechanical/chemical	DegrŽmont /Maxitc and ammonia stripping
Groos	1995	16 000	750	Pre-sedimentation	Activated sludge biological P and N-removal
N. Follo	1997	40 000	1125	Mechanical/chemical	KMT pre and post denitrification
Gardermoen	1998	50 000	1300	Mechanical/chemical	KMT pre and post denitrification
Bekkelaget Oslo	2001	280 000	3m^3/s	Mechanical/chemical	Activated sludge pre-denitrification

All the plants except Groos uses a mechanical/chemical precipitation process prior to the N-removal process. The table shows that 5 out of 6 plants for nitrogen removal built in Norway have found it most economical and efficient to use a chemical precipitation process in front of the N-removal process step. All the treatment plants have had individual investigations before decisions have been made.
The reason for this combination, is that large amounts of organic matter and some particulate nitrogen are coprecipitated with the phosphorus (Table 1). This reduction

reduces the needed areas and volumes for the nitrification and denitrification, and gives an overall more efficient and economic process.

The Groos and Bekkelaget plants are based on an activated sludge process more typical for the plants in Denmark and continental Europe. Based on a general evaluation of the process these plants seem to be less sustainable at least from an energy aspect.

New nitrogen removal processes

The KMT™ process

The KMT™ system is the most frequently used system (Table 2 and Fig. 1). The KMT™ system uses three plastic biomedia with a specific surface area from 310–500 m^2/m^3. The biomedia enhances the efficiency of the system so that smaller volumes are needed compared to a traditional activated sludge process, thus the energy process is also improved. Other advantages are robustness to load variations and low sensitivity to the tank shape and flexibility to operation.

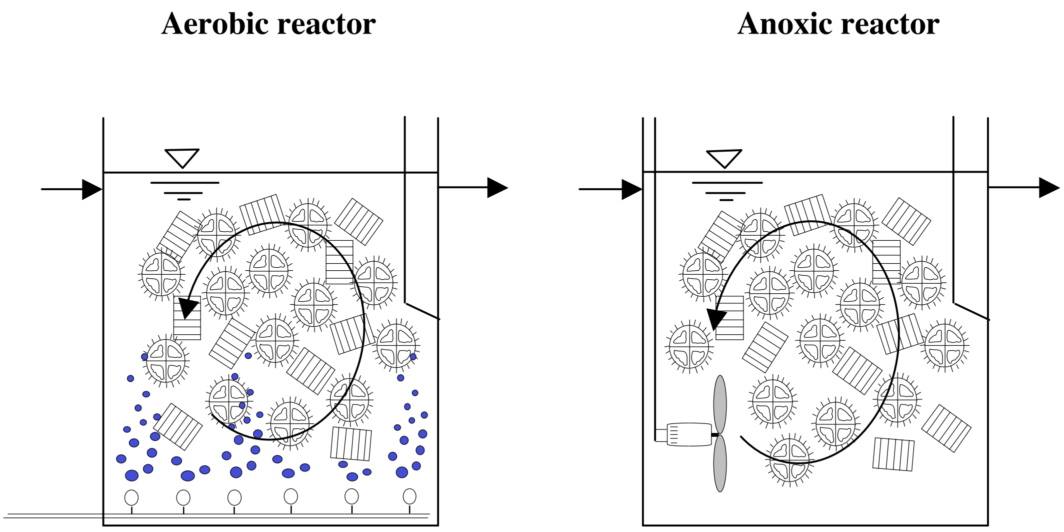

Fig 1. The Kaldnes process (principle) in a nitrification denitrification system. The tanks are filled approximately 67% with biomedia. The media is kept moving by air diffusers in the aerobic stage and by a mixer in the anaerobic stage.

The plants have a requirement to remove 70 % of the total nitrogen and this is normally achieved.

The Degremont/Maxit process using Filtralite™

The VEAS plant is the largest in Norway and is based on the Degremont process for N-removal (Sagberg and Berg 1999 a). There are 24 upflow nitrification filters each with a surface 87 m^2 and the media depth of 4 m. The biofilter consists of crushed expanded clay aggregates developed in collaboration with the French company Degremont and the Norwegian company Optiroc. The aggregate size is 3-6 mm. The surface area of the round FiltraliteHR media is 3000-5000 m^2/m^3, which is larger than for the KMT plastic biomedia. The crushed FiltraliteHC exposes the inner surface of the porous aggregates and increases the available surface for biofilm development compared to round or uncrushed aggregates.

At the bottom of the filters, heterotrophs degrade the carbonacious material. The amount of carbon oxidized is this way only 9 % of the inlet carbon amount. In the upper parts of the nitrification filters, the pH can drop as far down as to pH 5,5 at temperatures down to 6 °C (Sagberg and Berg 1999a). The capacity of the nitrification process is mainly oxygen limited.

After nitrification the water enters an upstream denitrification filter each having a surface of 65 m^2 and a total of 24 filters. The filtermedia has a depth of 3 m of 2,5-6 mm expanded clay aggregates. A carbon source is added to the water before it enters the denitrification filter. The denitrification operates well at temperatures down to 10°C. At lower temperatures it is necessary to add small amounts of phosphoric acid to maintain high rates of denitrification. This may also be necessary for the KMT process, especially when post denitrification is used**.**

The overall removal of total-N at VEAS is 74 %; of this 61 % is removed as nitrogen gas, 22 % is removed with the dewatered sludge (biosolids) and 17 % is removed as adsorbed nitrogen from ammonia stripping (Sagberg and Berg 1999 a).

<u>Ammonia stripping from filtrate water</u>
The VEAS plant has built a closed loop ammonia stripping system, treating the effluent from the sludge dewatering unit. The sludge from the digesters is conditioned with lime before dewatering to rise the pH. The increase in pH results in free ammonia, which is absorbed using nitric acid in an adsorption tower trapping the ammonia rich air. The result is a 55 % solution of ammonium nitrate. The ammonium nitrate is sold to a factory producing mineral fertilizer.

The cost efficiency of the ammonia stripping process, is described by Sagberg and Berg (1999 b). This study concluded that the closed loop ammonia stripping from filtrate water gives significant savings including capital costs at normal methanol prices. It was also demonstrated that a duplication of the stripping facility, under slightly higher methanol prices than historical average, would also be cost efficient and probably one of the first choices if the N-removal capacity of the plant should be increased.

Ammonia stripping is thus an interesting method from a sustainability aspect because recycling of nitrogen is possible. However, ammonia stripping is to this date only used in small scale and laboratory systems and not as the main N-removal method. Investigations by Vråle (1992) showed very promising results, but ammonia stripping has not been used in large scale applications due to fear of practical problems when upscaling. At VEAS ammonia stripping is used in a sidestream and has not given problems with scaling (Sagberg and Berg 1999 b).

SOURCE SEPARATING - RECYCLING SYSTEMS

Blackwater (toilet wastewater) contains , 90% of the nitrogen, 74% of the phosphorus, 79% of the potassium (Vinnerås 2002). In addition 30–75 % of the organic matter in the wastewater is in the toilet waste (Jenssen and Skjelhaugen 1994). By the use of urine separating, composting, or extremely water saving toilets, nutrients can be collected and recycling facilitated (Jenssen 1999). Urine is an excellent fertilizer and needs only 6 months of storage to obtain hygienic safety for agricultural use (Höglund 2001, Johansson et al. 2001). Concentrated toilet and organic household waste can also produce energy via aerobic or anaerobic processes (Jenssen et al. 2003). 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 were 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 been developed (Jenssen and Krogstad 2001, Jenssen and Vråle 2004). The principle of a source separating fully recycling system is shown in Fig. 2.

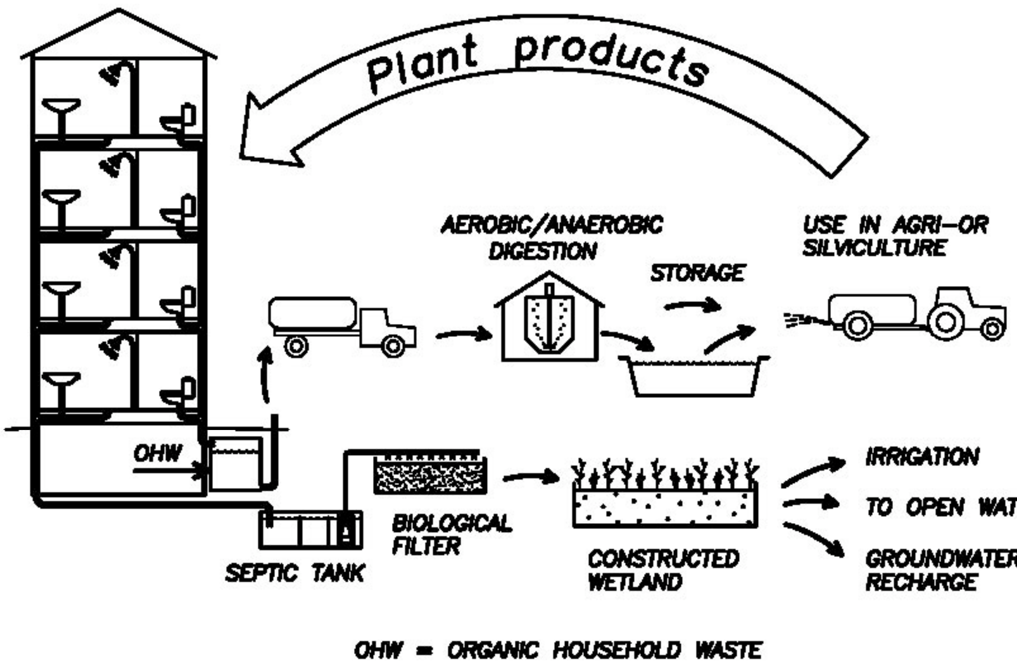

Figure 2. A fully recycling system using separate treatment of blackwater and greywater. Blackwater from watersaving toilets (e.g. vacuum) is collected and treated together with organic household waste.

Treatment and recycling of blackwater and organic waste
Vacuum and gravity operated toilets using 0,5-1,5 liter per flush are commercially 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 one liter toilet an average Norwegian family would produce 6-9 m^3 blackwater per year and 15 families would produce about 10 m^3 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 treat the blackwater successfully 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 hygienized and odorless. 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 being superior to heat and less energy is 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 (DGI) 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 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 present in large numbers (Ottosen 2003). 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. 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 sand filter or a combination of a biofilter and a subsurface flow constructed wetland (Fig 3 and Table 3). Biofilters and constructed wetlands using lightweight expanded clay aggregates (LWA) or similar porous media are pioneered in Norway (Jenssen et al. 2005).

A single pass biofilter aerates the wastewater and reduces oxygen demand (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. 3). 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 4) a biofilter of 1 m^2 surface area can treat greywater from about 10 persons, hence, very compact biofilters can be made. The key to successful operation of the biofilter is uniform distribution of the liquid over the filter media and intermittent dosing (Fig. 3).

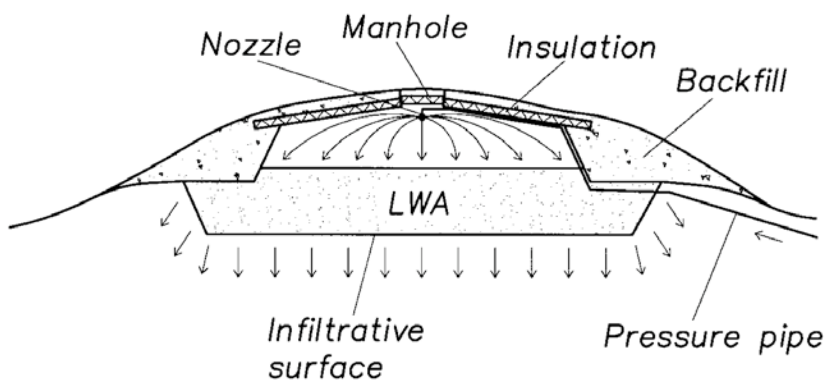

Figure 3. A soil infiltration system with pretreatment in a lightweight expanded clay aggregate (LWA) biofilter (from Heistad et al. 2001).

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. 3 and 4). For cities a biofilter preceding a subsurface flow constructed wetland has been used with success (Jenssen and Vråle 2004).

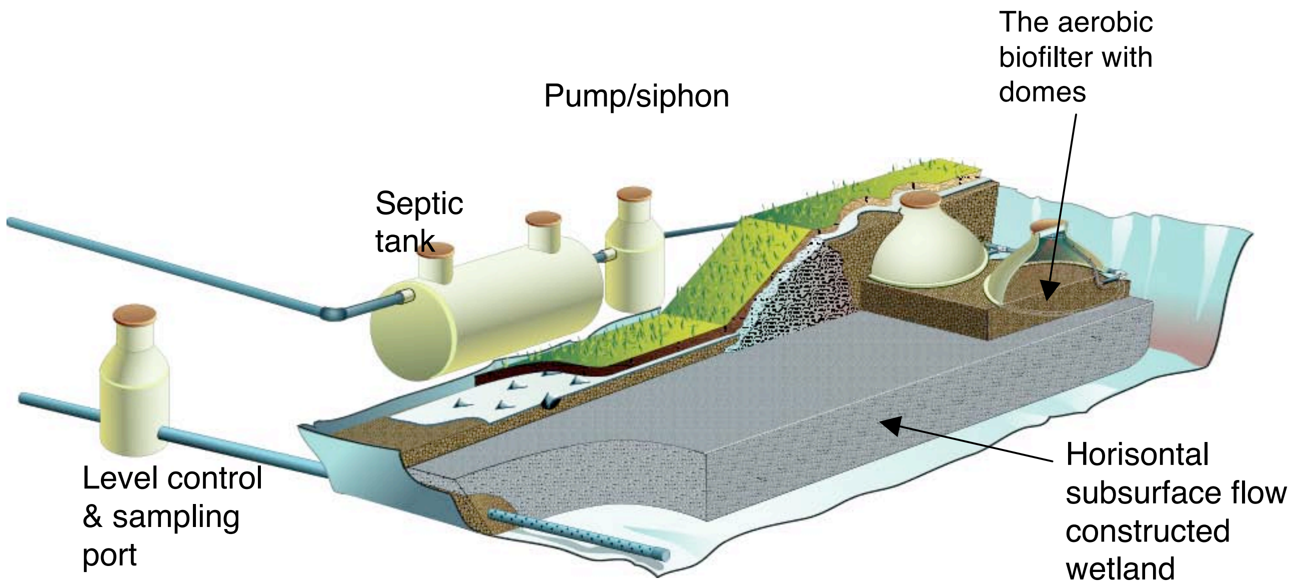

Figure 1. The latest generation of constructed wetlands for cold climate with integrated aerobic biofilter in Norway (Jenssen and Vråle 2004).

For greywater a LWA biofilter/constructed wetland system can be designed very compact (Jenssen and Vråle 2004, Jenssen 2005). With an integrated biofilter the total surface area is 1-2 m^2/person. This facilitates urban applications. The depth of the wetland is minimum 1 meter and the biofilter 0,6 m. With this configuration very high effluent quality is achieved (Table 3).

In Oslo the capital of Norway, greywater from 33 apartments (Klosterenga) is treated to swimming water quality (Table 3) in the courtyard of the building (Jenssen 2005). The area requirement for the total system is about 1 m^2/person. The area covering the biofilter is used as a playground. Additional aeration, in the summer, is provided by a flowform system (Wilkes 1980). With effluent qualities as shown in Table 3 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 3 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. 4.

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 reason for the low phosphorus influent concentrations are that phophate free detergents are used in Norway. The TCB concentration in the GSTE is in the order of 10^4–10^6/100 ml.

Table 3. Greywater septic tank effluent (GSTE) and effluent values of three biofilter/constructed wetland systems, average values (mg/l).

System	Built year	Persons served	BOD GSTE	BOD efflu-ent	Tot-N GSTE	Tot-N efflu -ent	Tot-P GSTE	Tot-P efflu-ent	TCB** efflu-ent
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	<100
Kloster-enga	2000	100	ND	22*	ND	2,5	ND	0,02	<10

* COD, ** TCB=Termotolerant coliform bacteria (per 100 ml).

The bacteria concentration in the effluent (Table 3) 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-P™, have consistently shown <10 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 4 shows that the per capita greywater production varies from 81 to 133 liters. The lowest greywater production displayed in Table 4 is from a Norwegian ecovillage project and shows what is possible to achieve if the people are focused 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 average 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 have 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.

The excellent effluent quality (table 3) facilitates reuse of the water for irrigation, groundwater recharge or for in-house applications. For flushing toilets and car wash it may be possible to use the effluent water (tab. 3) without further treatment. However, recent results show that greywater may contain virus and bacterial pathogens that are not represented by the indicator bacteria (Ottosen and Stenström 2002). This may call for further treatment before use as suggested above. In order to upgrade to drinking water quality or for washing, microfiltration, reverse osmosis or carbon filtration may be needed as a single step or in combination. If treated greywater is reused for in-house applications more than 90% reduction in water consumption is possible.

Table 4. 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] VrŒle 1987, [2] Crites and Tchobanoglous 1998, [3] Kristiansen and Skaarer 1979, [4] Søyland 1998.

Conclusions

Evaluation of sustainable wastewater treatment systems depends on a number of factors, energy use and recycling beeing two essential parameters. Chemical precipitation is more energy efficient than biological treatment methods and chemical precipitation prior to nitrogen removal reduces both space and energy need for the subsequent nitrogen removal step.

In Norway a moving bed reactor using plastic biomedia and a fixed film process using expanded clay aggregates are the two main methods for nitrogen removal. Both processes are robust and more efficient in terms of energy and space requirements than activated sludge processes. However, recycling is not possible using these biological methods. Ammonia stripping facilitates recycling, but is not yet developed for application as the main nitrogen removal process in large treatment plants.

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 % by using water saving toilets and water saving fixtures and by > 90% if treated greywater is recycled for in-house use. 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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