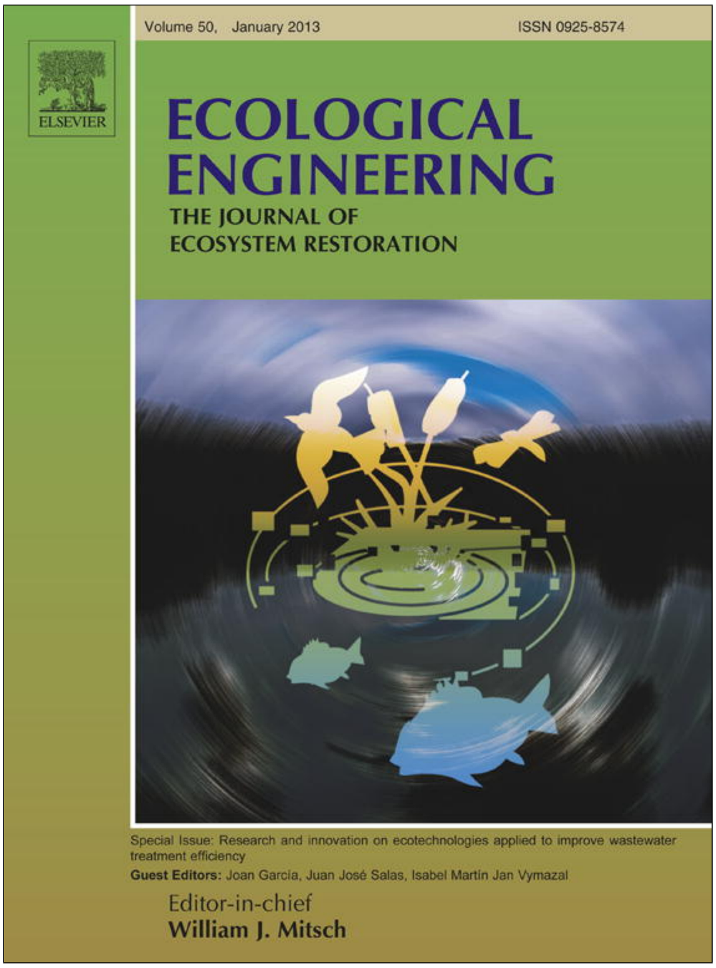
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A review of wastewater handling in the Arctic with special reference to pharmaceuticals and personal care products (PPCPs) and microbial pollution

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ABSTRACT

Treatment of wastewater is often inadequate or completely lacking in Arctic regions. Wastewater contains different kinds of substances that can be harmful for the environment and human health, including residues of pharmaceuticals and personal care products. Bioaccumulation and biomagnifications of chemicals in the food web are of concern. This can affect fishery that is a significant industry in many Arctic coastal regions. Wastewater from human settlements may also contain antibiotic resistant bacteria and pathogens that can cause negative impacts on human health and the environment. In the Arctic, especially, the direct release of untreated sewage may have severe consequences for the receiving environment due to low biological diversity, low ambient temperatures and consequently high vulnerability of the Arctic ecosystem to environmental contaminants.

Bucket toilets are common in remote settlements but are also used in towns. In settlements having inadequate sanitary facilities the risk of contracting diseases, such as hepatitis A, is unacceptably high. Conventional centralized wastewater collection systems and treatment plants are a challenge to build in the Arctic and expensive to operate. Thus alternative methods are needed. Possible solutions are improved dry or low flush toilets with collection of toilet waste at the household level and subsequent centralized treatment by dry composting or anaerobic digestion. Both treatment methods facilitate co-treatment of wastewater along with other organic waste fractions and provide a by-product that is environmentally safe and easy to handle. Combining the above with decentralized greywater treatment will reduce the costs for expensive infrastructure.

1. Introduction

It is challenging to design, construct and operate wastewater collection systems in the Arctic because of permafrost conditions, hard rock surfaces, freezing, flooding in the spring, limited quantity of water, high costs of electricity, fuel and transportation, as well as a settlement pattern with limited accessibility, especially in the rural parts of the Arctic. The cold climate influences the efficiency of biological treatment processes in particular, but also chemical processes (Smith and Low, 1996). The most important present types of wastewater collection systems in the Arctic are listed in Fig. 1 (Smith and Low, 1996).

Bucket toilets are still widely used in many of the northern communities, such as in Canada's northern areas and some parts of Alaska and Greenland. This particular toilet solution has been considered a problem for many years with respect to uncontrolled spreading of nutrients, diseases and potential pollution issues. As indicated in Fig. 1 the hauling of waste from bucket toilets is either done individually or collectively. The health and convenience level is considered being low when hauling is done individually due to limited water usage and varying individual disposal practices (Smith and Low, 1996). Those factors are improved when the hauling is done collectively by municipal or private organized operators. The initial construction costs of sanitation systems consisting of bucket toilets are low whatever hauling system is selected, and so is the operational cost of individual hauling, while the cost of collective hauling can be high, dependant on the usage rates. Flush toilets provide high inhouse health and convenience level. The selection of sewer pipe system depends on i.a. the topography; gravity systems can be used in gently sloping terrain, while vacuum systems can be

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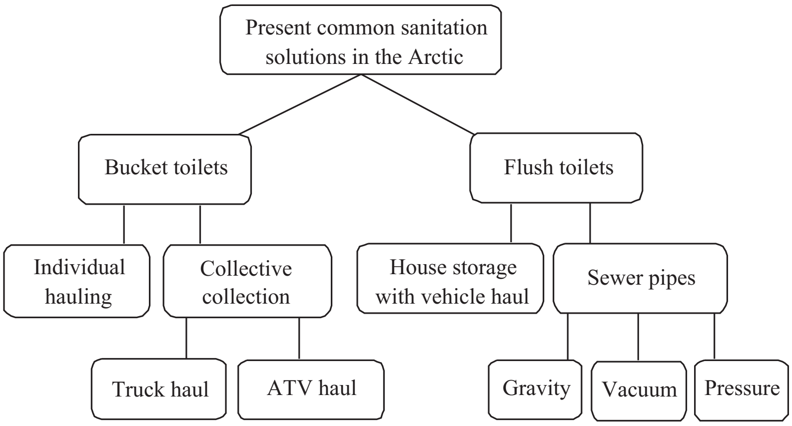

Fig. 1. The main types of wastewater collection systems in the Arctic. *Abbreviation*: ATV: All Terrain Vehicle.

used in level to gently sloping terrain. The advantage of pressure sewer is that it can be used under every topographical situation. The gravity systems require the least maintenance but flushing of low-use lines may be required. The pressure and vacuum systems use smaller diameter pipes and the water requirement is low for the latter one (Smith and Low, 1996).

The main options for drinking water systems in cold regions are (Smith and Low, 1996):

- Self-haul systems
- Vehicle-haul systems
- Piped systems

The volume of wastewater from each dwelling depends on the water supply system; i.e. households with self-haul drinking water systems produce much less wastewater than those on piped water.

In many Arctic regions wastewater treatment is inadequate or even completely lacking. Greenland is an example of an Arctic region where no treatment of industrial or domestic wastewater exists. In the Greenlandic towns the residents have pressurized in-home drinking water. The dwellings have either traditional water flush toilets or bucket toilets. Those who have water flush toilets in the larger towns are either connected to a sewer or the blackwater (wastewater from toilets) is stored in a holding tank outside the residence while the greywater is led out directly to the terrain. In the small settlements of Greenland some dwellings have pressurized in-home drinking water while other residents have self-hauled water, typically obtained from a community water point. Bucket toilets are used in almost all settlements in Greenland where approx. 8500 out of a total population of approx. 57,000 inhabitants lived in 2012 (Statistics Greenland, 2012). Routine collection of the bags from the bucket toilets and pumping of the holding tanks is organized by the municipalities or local companies, but individual haul is also done in some settlements. Handling of wastewater from tourist huts in Greenland is another challenge since they do not have running water supply and are often remotely located.

In indigenous people's communities in Alaska five levels of service have been established to categorize the different methods to dispose of human sewage (U.S. Congress, 1994). These are summarized in Table 1.

Level A is the most rudimentary service, and the health and convenience level of this service is considered low due to limited water use and different individual disposal practices (Smith and Low, 1996). Regarding level D septic tanks only work in regions with well-drained soil above the seasonal water table. Level E is considered to provide the highest technical and safety level and includes flush toilets and piped sewerage. However, construction of these systems is often difficult and expensive due to the remoteness of the villages and the harsh environment. For levels D and E a year round water supply for flushing must be supplied (U.S. Congress, 1994).

In Canada municipal wastewater effluents are considered being one of the largest threats to the quality of the water (Environmental Signals, 2003). There is a great difference in the level of wastewater treatment between Canadian municipalities that discharge to coastal versus fresh inland waters. In 1999 most of the coastal municipalities served by sewers had primary or no wastewater treatment and only a minority had secondary treatment (Environmental Signals, 2003). On the contrary about 84% of the inland municipalities served by sewers received secondary or tertiary wastewater treatment while 15% received only primary treatment (Environmental Signals, 2003). In large urban areas in Canada, such as Victoria in British Columbia, wastewater is not treated before discharged into the Pacific Ocean (Colt et al., 2003).

In 1990 wastewater from approx. 5% of the inhabitants in Iceland was treated, while in 2002 that number had increased to over 60% (UST, 2003). However, this was mainly in the capital Reykjavík, where 62% of the inhabitants lived in 2002. In other parts of the country more than half of the wastewater was discharged untreated to the recipients. The treatment method mostly used outside the capital city was septic tanks (UST, 2003). Fig. 2 shows the division of treatment methods used in Iceland in 2002.

In Iceland one step treatment includes mechanical and/or chemical treatment to lower the content of suspended particles, e.g. by precipitation or filtration. Two step treatment includes an initial precipitation or filtration step and a second step that includes biological treatment of the wastewater, often succeeded by precipitation (UST, 2003). In Iceland it is allowed to use one-step treatment when discharging wastewater from 10,000 to 150,000 person equivalents (PE) in coastal areas categorized as being less sensitive, and from 2000 to 10,000 PE when discharging to estuaries (UST, 2003). However, it is allowed to use one-step treatment for more than 150,000 PE when discharging to less sensitive areas if it can be shown that more developed treatment methods do not improve the environmental status of the recipient. Sludge from septic tanks and treatment plants is landfilled in most cases as there is no tradition for using sludge in agriculture in Iceland. However, treatment plants for sludge have been built in certain parts of the country where the sludge is mixed with lime with the purpose of being used as fertilizer (UST, 2003).

Table 1
Five levels of service in indigenous people's communities in Alaska (U.S. Congress, 1994).

Level	Sanitary solution	Collection and discharge
A	Pit toilets, privies and bucket toilets	The buckets are carried by the residents to a disposal site, but in some cases they are emptied on the ground in the immediate vicinity of the residence or carried to nearby pit bunkers by residents.
B	Bucket toilets	Bucket toilets are hauled by a community employee. Individual residents haul the waste to bins at central collection points, and when filled the bins are hauled to the community sewage lagoon by snowmobile or truck.
C	Flush toilets	Holding tanks and hauling of wastes to a disposal area is done by a truck service. The tanks, which are emptied periodically by a pump or vacuum collection vehicle operated by the community, are either large insulated tanks located outside the residence or smaller containers located inside the home.
D	Flush toilets	Septic tanks and leach fields
E	Flush toilets	Piped sewerage

In other parts of Scandinavia simple mechanical treatment is also common, such as along the western and northern coast of Norway where that kind of treatment is found to dominate at small and medium sized wastewater treatment plants, primarily being used for the removal of particulate matter (Vogelsang et al., 2006).

The here presented comparison of national Arctic sewage and wastewater treatment strategies is only meant as an illustration and not to give an exhaustive comprehensive overview on the circum-Arctic situation.

Disposal of organic matter and nutrients (nitrogen and phosphorus) are not of great concern in Arctic regions when discharged directly to the sea, due to low population density and large receiving water bodies (Danish Environmental Protection Agency, 2005). If the water change in the recipient is poor those substances can however deteriorate the quality of the marine environment and even cause eutrophication. However, wastewater contains a variety of substances that can be harmful for the environment as well as human health. Those substances include anthropogenic pollutants like industrial chemicals, oil, grease (Eriksson et al., 2002), metals (Palmquist and Hanæus, 2005), residues of pharmaceuticals and personal care products (PPCPs) (Kallenborn et al., 2008; Vasskog et al., 2009), pathogenic microorganisms and parasites (Bitton, 2005) as well as antibiotic resistant bacteria (Batt and Aga, 2005). The Arctic nature is vulnerable to environmental contaminants because of low biological diversity, lack of nutrients and extreme seasonal variations in light (AMAP, 2009). Therefore the direct release of untreated sewage may have severe consequences for the receiving (aqueous) environment (Kallenborn et al., 2008; Bergheim et al., 2010; Bach et al., 2009, 2010). With increasing populations in the Arctic communities it becomes even more vital to improve the status of wastewater treatment in these regions.

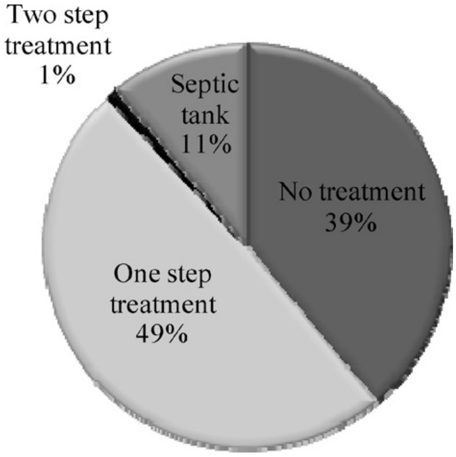

Fig. 2. Wastewater treatment methods for all inhabitants in Iceland in 2002 (UST, 2003).

In addition, future projections show that the continuous loss of permafrost expected in the next two decades will add additional challenges to technological solutions chosen for sewage treatment (AMAP, 2011).

This article will discuss challenges and possible solutions of wastewater treatment in the Arctic with focus on pharmaceutical residues as well as pathogens and antibiotic resistant bacteria.

2. Methods

Standard literature search was performed in a selection of available bibliographic databases including ISI Web of Science, the DTU Library (Technical Information Center of Denmark), PubMed databases and the open accessible Scholar Google database. Relevant research papers were identified using scientific key word search procedures by combining scientific terms like "Arctic", "cold climate", "wastewater", "public health", "composting", "anaerobic digestion", "antibiotic resistant bacteria", "pathogens", "pharmaceutical residues", covering the subjects and chapters identified as relevant for the here performed review. Relevant secondary references within each paper were also reviewed and included. In addition, important information (including reports of limited availability) was identified by approaching and discussing with colleagues as well as direct requests to networks of Arctic experts.

3. Results

Discharging of untreated wastewater to fresh inland waters or the sea can have various impacts on the environment, such as biomagnifications and bioaccumulation of chemicals in the food chain, chronic and acute toxicity to aquatic life from chemical pollutants, as well as increased nutrient levels. In the Arctic there are periods of ice cover on lakes, rivers and the sea. During those periods the concentration of dissolved oxygen gradually decreases (Smith and Low, 1996). In the spring Arctic waters may therefore be especially vulnerable to discharge of nutrient rich effluents.

3.1. Pharmaceuticals in the marine environment

Pharmaceuticals in the environment are becoming a subject of global concern, potentially having environmental consequences (Zuccato et al., 2006). One concern is the risk of exposure to and uptake in the food web with the potential for hazardous effects on human health and the environment. As fishery is a significant industry in many Arctic coastal regions, pollutant contamination of marine species exploited for human consumption is a major concern. Some pharmaceuticals such as anti-inflammatory drugs, antidepressants and antibiotics are not completely eliminated in the human body and can therefore enter the sewage system as the parent compound and their biologically active metabolites (Vasskog et al., 2009). In the Arctic where wastewater treatment is lacking these compounds enter the receiving water often as the parent compound and their biologically active metabolites. Some of the chemicals identified as pharmaceuticals and personal care products (PPCP) can increase the risk of development of antibiotic resistant microorganisms (Büyüksönmez and Şekeroğlu, 2005; Kallenborn et al., 2008) and it has been shown that extended exposure to low doses of antibiotics leads to the selective propagation of resistant bacteria which can transfer the resistance genes to other bacteria, even other species (Batt and Aga, 2005; Kallenborn et al., 2008; Bergheim et al., 2010). Kallenborn et al. (2008) concluded that pharmaceutical residues are degraded significantly slower in the cold Nordic aquatic environment compared to release scenarios on lower latitude. Removal of medicine residues by photodegradation is limited during the winter in the Arctic when sunlight is limited, and the cold climate in the Arctic slows down the rate of degradation of medicine residues in the environment (Kallenborn et al., 2008). The biodegradation and non-biotic elimination of the antibiotic benzyl-penicillin was studied at different temperatures (5, 12.5 and 20 °C). The degradation process followed similar pathways at the three different temperatures. What differed significantly was the degradation velocity, which was shown to be temperature dependent (Bergheim et al., 2010). In this way a threefold reduction of the transformation velocity was found when lowering the ambient experimental temperature from 20 to 5 °C (Bergheim et al., 2010).

Human exposure to endocrine disrupters in the environment is also of critical concern and the long-term impacts are still unknown (Liu et al., 2009). Compounds with potential endocrine disrupting effects enter the environment via long range transport (AMAP, 2009) and direct emissions from landfills, agricultural runoff and various effluent discharge pathways (Salste et al., 2007). Aquatic ecosystems have been studied for the effect of endocrine disrupters from wastewater discharged continuously to the recipients, directly linking steroidal estrogen concentrations in wastewater treatment plant effluents with the production of vitellogenin (female specific egg-yolk protein) in fish downstream of the plants (Routledge et al., 1998; Larsson et al., 1999; Rodgers-Gray et al., 2000). Purdom et al. (1994) showed that concentrations of the synthetic birth-control pharmaceutical ethinylestradiol as low as 0.1 ng/L caused elevated levels of vitellogenin in male rainbow trout. Lorenzen et al. (2005) examined the persistence and pathways of dissipation of testosterone in agricultural soils at different temperatures, showing that the rates of testosterone dissipation and metabolite appearance and subsequent dissipation were temperature dependent with rates decreasing with decreasing temperatures.

In those parts of the Arctic where treatment of domestic and hospital wastewater is absent e.g. in Sisimut, Greenland (Bach et al., 2009, 2010), discarded and excreted pharmaceuticals are discharged without any elimination. Concentrations of antibiotics in hospital effluents are typically higher by a factor of 100 compared to municipal sewage and what is found in sewage treatment plants (Kümmerer, 2009). Weigel et al. (2004) studied the prevalence of selected pharmaceuticals in different sewage samples from Tromsø (~68,000 inhabitants) in Norway as well as in seawater from Tromsø-Sound, the recipient of the wastewater. The selected pharmaceuticals were, among others, the analgesic, antipyretic and non-steroidal anti-inflammatory drug ibuprofen and its metabolites, and the insect repellent *N,N*-diethyl-3-toluamide (DEET) as well as caffeine, which was included as a tracer for domestic sewage. It was concluded that regardless of the strong tidal current in the Tromsø-sound, and dilution with the presumably non-polluted North Atlantic water, caffeine and DEET were detected in all seawater samples. Furthermore ibuprofen and/or its metabolites were detected in most seawater samples. It has previously been shown that ibuprofen and its metabolites are easily eliminated in sewage treatment plants and under limnic conditions, so apparently low temperatures and low biological activity in the Tromsø-Sound hindered their rapid transformation (Weigel et al., 2004).

3.2. Pathogens

Wastewater contains numerous pathogenic microorganisms and parasites. There are three categories of pathogens found in the environment (Leclerc et al., 2002):

- Bacterial pathogens: Some of these pathogens are enteric bacteria, such as *Salmonella* and *Shigella*, while others, e.g. *Legionella*, *Mycobacterium avium*, *Aeromona*, are indigenous aquatic bacteria.
- Viral pathogens: These pathogens are released into the aquatic environments but are unable to multiply outside the host cells. The infective dose is generally lower than for bacterial pathogens.
- Protozoan parasites: The parasites are released into the aquatic environments as oocysts and cysts and they are quite resistant to environmental stress and disinfection. They do not multiply outside their hosts.

Other pathogens transmitted via the feco-oral route are the human polio-virus (Ghendon and Robertson, 1994), the bacteria *Clostridium tetani* that causes tetanus (Edlich et al., 2003), as well as the virus causing hepatitis A that can be transmitted through water and food and is associated with poor sanitation (WHO, 2008). E.g. it has been reported that the potential for Natives in Alaska to contract hepatitis A and other diseases is unacceptably high in villages where bucket toilets are still used and water supply (for excrement processing as well as for human consumption) is limited (U.S. Congress, 1994). The relationship between inadequate sanitation and higher rates of respiratory tract infections (Gessner, 2008; Hennessy et al., 2008; U.S. Department of Health and Human Services, 2006), skin, and gastrointestinal tract infections has also been documented among rural Alaska natives (Hennessy et al., 2008). Outbreak of epidemics of other diseases, such as impetigo, bronchitis, serious ear infection, meningitis as well as hepatitis A and B in remote Alaskan communities is often ascribed to poor sanitary facilities (U.S. Congress, 1994). More than 70% of all hepatitis A cases reported throughout the State of Alaska in 1988 occurred in Native villages with honey bucket systems (U.S. Congress, 1994). Throughout parts of the Arctic regions and rural Alaska, the outbreak of disease, such as chronic influenza-like symptoms to hepatitis and enteric diseases, is often a result of exposure to human waste and deficient personal hygiene (U.S. Congress, 1994). When transporting the human waste to disposal sites or lagoons, spillage occurs on community roads and boardwalks. The exposure of residents in rural Alaska, particularly children, is therefore frequent (U.S. Congress, 1994). In some of the agricultural parts of Iceland severe incidences of *Salmonella* infections in animals have occurred and it is believed that they were caused by installation of septic tanks without usage of secondary treatment, i.e. a drain field (UST, 2003). Zoonotic pathogens (i.e. pathogens transmissible from vertebrate animals to humans, and vice versa) have been found in mammals and marine birds from the Northwestern Atlantic (Bogomolni et al., 2008). The pathogens may have been acquired via contamination of coastal water by sewage, run-off and medical waste. The findings indicate that vertebrates in the Northwest Atlantic are reservoirs for potentially zoonotic pathogens that may be transmitted to humans.

3.3. Antibiotic resistant bacteria

Bacteria that have previously been exposed to antibiotics enter sewage from private households and hospitals, and sewage is therefore considered being a hotspot for antibiotic resistance genes (Zhang et al., 2009). A broad range of bacteria resistant to multiple antibiotics have been found in mammals and marine birds from the Northwestern Atlantic (Bogomolni et al., 2008). Marine vertebrates can act as vectors for pathogens and resistant bacteria globally (Bogomolni et al., 2008). Inadequate wastewater treatment in the Arctic is therefore not only a local problem but potentially a global one as well. Antibiotic resistance has been found in marine bacteria (Neela et al., 2007) as well as in bacteria living in coastal waters or estuaries polluted with sewage water (Kümmerer, 2004; Kimiran-Erdem et al., 2007). Antibiotic resistant *Escherichia coli* isolates, originating from Arctic birds, have even been found in remote places such as the Arctic Sea (Sjölund et al., 2008). Resistance genes can therefore be found in regions where no selection pressure exists. Engemann et al. (2006) showed that light exposure in the receiving waters of wastewater effluents is important and should be maximized in order to maximize the loss rate of the resistance genes tet(W), tet(M), tet(Q) and tet(O) after release. Other antibiotic resistance genes are similar in chemical nature so it can be expected that they are sensitive to light as well. It is therefore likely that the Arctic winter with limited sunlight is unfavorable regarding removal of resistance genes.

4. Discussion

The out-phasing of bucket toilets would help to reduce wastewater related diseases and improve the living conditions of northern communities (Heinke and Prasad, 1979; U.S. Congress, 1994), and treatment of wastewater would help reducing damage to the ecosystem. Considering suitable treatment methods, the low temperatures influence the efficiency of biological treatment processes in particular (Ekama and Wentzel, 2008). This makes it challenging and sometimes expensive to implement conventional treatment methods used in temperate zones. Septic tanks are a common conventional on-site treatment method where floatable and deposited material from the wastewater is removed while the liquid and solid components are treated anaerobically. The tanks can be installed in the ground outside the residences if the soil conditions permit. However, in cold regions permafrost and surface bedrock complicates installation and due to the cold climate, it is necessary to insulate the tanks. In areas with permafrost or deep frost penetrations the septic tanks may even have to be installed in a heated area under the house or a heated shed.

Another on-site treatment opportunity is aerobic systems or package treatment plants that are widely used in Scandinavia. The package plants include variations of the activated sludge process, aeration, trickling filters with or without chemical precipitation (USEPA, 2000; Johannessen, 2012). Even though secondary or tertiary treatment is achieved in theory, practical experience from Norway and Sweden show that this is not the case (Yri et al., 2007; Hübinette, 2009; Johannessen, 2012). The systems cannot perform without regular maintenance (Johannessen, 2012), and quality of operation, varying loads and loss of solids are the major factors causing poor performance (Smith and Low, 1996; Johannessen, 2012). Trials in Greenland observed by the authors show that package treatment plants are vulnerable to freezing and may require both good insulation and heating. This makes the systems expensive in extremely cold climate. Due to temperature vulnerability, cost, varying performance and maintenance need, traditional package treatment systems are not recommended in the Arctic. In parts of Scandinavia mechanical/chemical methods are preferred over biological (UST, 2003; Vogelsang et al., 2006). One reason for this is that mechanical and chemical processes are less dependent of temperature of the incoming wastewater. Mechanical and chemical methods also require less space than biological methods and this affects the cost of treatment plants when they have to be covered. If conventional treatment is selected in the Arctic, mechanical and chemical unit processes are probably more suited than biological.

Simple mechanical treatment methods, such as screening, remove large objects from the sewerage stream. In smaller and less modern treatment plants manually cleaned screens may be used, but mechanical cleaning should be preferred to avoid the risk of disease spreading (Winther et al., 1998). Simple mechanical treatment may also include a primary sedimentation stage where the sewage flows through large tanks in which sludge is allowed to settle. The collected solids are later landfilled or burned at the wastewater treatment plant itself or in a solid waste incinerator. The collected sludge and screenings can also be treated further by e.g. anaerobic digestion (Hyaric et al., 2010) or composting.

Another interesting option is, however, to collect and handle the blackwater separate from the greywater. The approximately 1.5 L/day that a human excretes contribute with a considerable fraction of the PPCP (Winker et al., 2008), pathogens, organic matter and nutrients (Gallagher and Sharvelle, 2010) in wastewater. Composting and anaerobic digestion of blackwater are treatment methods that could be well suited for this material. Both processes may, however, be more challenging to run in cold climate than in more temperate zones, thus sufficient insulation and heating of reactors are needed. Both anaerobic digestion and dry composting methods open up for co-treatment of organic household waste and organic waste e.g. from food processing industries.

4.1. Composting

Composting is an aerobic, controlled self-heating, solid phase biodegradation process of organic material, comprising mesophilic and thermophilic phases which involves numerous microorganisms (Ryckeboer et al., 2003). Alternative sanitation technologies, such as composting toilets, appear to be an improvement over bucket toilets because they reduce the possibility of users in contact with fresh human waste and they may thus reduce overall, long-term health costs (U.S. Congress, 1994). Composting toilets eliminates the need for e.g. a sewage lagoon that is often used in north America (Smith and Low, 1996) to treat the wastewater containing human excreta and they may also provide a by-product that is more environmentally safe and easier to handle (U.S. Congress, 1994; Stenström, 2001).

Composting in cold climate is challenging, but it has been tested successfully at a Norwegian research station in the Antarctic (Hanssen et al., 2005). Solar heating of composting material could be a possibility in the Arctic, at least in the summer, while during winter material would accumulate and possibly freeze unless heated by other means. However, freezing has shown to reduce some pathogens and indicator bacteria in sludge and wastewater (Sanin et al., 1994; Torrella et al., 2003), and freezing also helps to dewater and improve the structure of the compost material (Hedström and Hanæus, 1999). It might therefore be beneficial when developing wastewater treatment methods for Arctic communities to utilize the cold climate and include freezing and thawing in the treatment processes. When human excrements are composted it is necessary to dewater the excrements since they contain 80–85% urine (Jennera et al., 2005). The effect of freezing and thawing on pathogen reduction in this type of material has not been investigated. Where possible the excess liquid can be disposed of by soil infiltration. This may be a challenge in some parts of the Arctic where thawed soil layers are scarce. This can be solved by using commercial biofilters of different materials. Systems for composting at household level as well as collection systems for professional centralized processing can be designed (Hanssen et al., 2005). The latter reduce the household level hygienic risk (Hanssen et al., 2005).

Removal of pharmaceutical compounds, which may be one of the key issues in wastewater treatment in the Arctic, show highly varying elimination rates for different compounds in traditional wastewater treatment plants (Vasskog et al., 2009). The potential for removal or breakdown of medicine residues or other organic chemicals is potentially larger in an intense thermophilic composting process than in traditional wastewater treatment. Vasskog et al. (2009) investigated the depletion of selective serotonin reuptake inhibitors (SSRIs) during sewage sludge composting and found that concentrations of all the SSRIs in question, as well as some of their metabolites, had a significant decrease during the composting process. Büyüksönmez and Şekeroğlu (2005) also tested the efficacy of the composting process to degrade 10 different PPCPs found in biosolids generated during municipal wastewater treatment. The results suggested that composting could be an effective treatment alternative for biosolids. Dolliver et al. (2008) studied degradation of the antibiotics chlortetracycline, monensin, sulfamethazine and tylosin in spiked turkey litter during managed composting compared to unmanaged composting. The results showed that some management of the composting, such as mixing to optimum water content and stockpiling, can reduce concentrations of antibiotics. After 35 days of thermophilic temperatures chlortetracycline showed >99% reduction, while monensin and tylosin reduction ranged from 54 to 76% (Dolliver et al., 2008). There was no degradation of sulfamethazine during the study. Other studies on antibiotic degradation during composting have shown >99% removal of oxytetracycline during 35 days of beef manure composting, compared to less than 15% reduction during incubation of the manure at room temperature (Arikan et al., 2007).

Heat inactivation is considered to be one of the most reliable methods for sanitation (Sahlström, 2003). Studies have been conducted to assess the effectiveness of composting to destroy pathogens possibly present in raw sewage sludge. Wiley and Westerberg (1969) studied the survival of *Salmonella newport*, poliovirus type 1, *Ascaris lumbricoides* ova and *Candida albicans*, and found that after 43 h of composting, no viable indicator organisms could be detected. Their results indicated that aerobic composting of sewage sludge would destroy the indicator pathogens when a temperature of 60–70 °C is maintained for a period of 3 days (Wiley and Westerberg, 1969). To achieve thermophilic conditions in compost the containers have to be well insulated, especially under Arctic conditions. Tønner-Klank et al. (2007) found that it was only possible to ensure a homogeneous temperature in compost of fecal material when amendments were made and when composting containers were insulated. Vinnerås et al. (2003) studied a mixture of fecal matter, food waste and old compost matter, used as an amendment, mixed in a 90-L bin. The average surrounding temperature during the experiment was 10 °C. Thermal composting resulted in a temperature of over 65 °C. By using insulation and turning the compost it was possible to ensure a 5 $\log_{10}$ reduction of pathogens (Vinnerås et al., 2003). The relatively low ambient temperature in this particular experiment shows that it is possible during Arctic summers to reach thermophilic conditions.

One of the advantages of composting is the degradation of organic matter. A 50–60% reduction of volatile solids (VS) during anaerobic digestion due to liquefaction and gasification and a volume reduction of two-thirds have been reported (Finstein et al., 1980). Vinnerås et al. (2003) found that almost 75% of the organic matter in a compost of faeces and food waste during a pilot scale experiment had decomposed after 35 days, and Lopez Zavala et al. (2005) found a 56%, 70% and 75% reduction of total solids (TS), VS and chemical oxygen demand (COD), respectively, in experimental laboratory-scale bioreactors when testing the efficiency of bio-toilets.

4.2. Anaerobic digestion

Anaerobic digestion involves a series of biological processes where a number of microorganisms break down biodegradable material under anaerobic circumstances. During the process methane and carbon dioxide rich biogas is produced, suitable for energy production. After the digestion the nutrient-rich digestate can be used as fertilizer. Anaerobic digestion has been used for industrial and domestic purposes to treat waste and produce energy (Wang, 2010). The fishing industry is one of the most important industries in many Arctic coastal regions, such as in Greenland where it is the biggest one, generating about 14,000 tons of waste products each year whereof only 20% is utilized (Nielsen et al., 2006). This waste fraction could be used for biogas production along with other organic waste. In many settlements in the Arctic, municipal collection of blackwater is practiced. Instead of direct discharge to the sea it could be transported to a central anaerobic digester. In small remote settlements in the Arctic there is often a lack of technically skilled personnel and logistical problems can also occur during operational resupply (Smith and Low, 1996). It is therefore important to use technically simple digestion systems. Small anaerobic digesters have been proven to be successful in small villages but this has yet mainly been tested in warmer climate than in the Arctic (Bensah, 2009). Small anaerobic digesters are easier to run at mesophilic than thermophilic conditions because thermophilic digestion can be more sensitive to operational conditions such as the organic loading rate, temperature and the characteristics of the influent sludge (Kim et al., 2002; van Lier, 1996). Taking this, as well as the cold climate in the Arctic, into account it might be practical to run anaerobic digesters at mesophilic conditions, especially in the smaller settlements.

Information about breakdown and behavior of PPCPs during anaerobic sludge digestion is limited and even contradictory. Khan and Ongerth (2002) stated that most PPCPs persisted in the aqueous part of digested sludge. Another study showed that estrogens were not degraded substantially under methanogenic conditions (Andersen et al., 2003). In contrast Kreuzinger et al. (2004) indicated that the breakdown of natural estrogens was accelerated during anaerobic digestion. Holbrook et al. (2002) found that between 51% and 67% of the estrogenic activity contained in the influent wastewater was either biodegraded during the treatment of wastewater or biosolids, or was made unavailable to the extraction/detection procedure used during treatment.

The reducing effect of anaerobic digestion on various microorganisms has been studied by many and it has been shown that the survival of pathogenic bacteria during anaerobic digestion is mainly dependant on the temperature (Dumontet et al., 1999). Inactivation of bacteria due to temperature is also related to time (Olsen and Larsen, 1987). T_{90}, which is the time required for a decrease by one logarithmic unit ($\log_{10}$) or 90% reduction of viable counts of a population of microorganisms, can be counted in hours in thermophilic digestion and in days in mesophilic digestion, compared to weeks and months in conventional treatment (storage) (Gibbs et al., 1995; Larsen et al., 1989). For instance, Kumar et al. (1999) studied the removal of different microorganisms during anaerobic digestion of cattle dung in batch digesters at room temperature and mesophilic conditions (35 °C). They found a complete removal of *E. coli* and *Salmonella typhi* after 25 days at room temperature and 15 days at 35 °C. Complete removal of *Streptococcus faecalis*

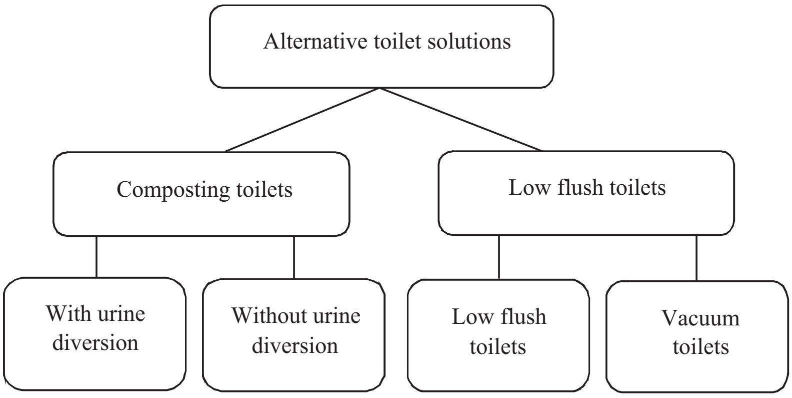

Fig. 3. Alternative toilet solutions for Arctic areas.

took longer time; 20 and 40 days at 35 °C and room temperature, respectively. In a mesophilic biogas plants, continuously fed with fresh biomass, the fecal enterococci reduction is rarely more that 1–2 log units (Bendixen, 1994). Others have observed similar reduction, as for instance Bonjoch and Blanch (2009) who found a 1 log unit reduction for enterococci populations in sludges and biosolids used in mesophilic anaerobic digestion for a period of 20 days. Berg and Berman (1980) analyzed the destruction of viruses compared to fecal coliforms, total coliforms and fecal streptococci under mesophilic conditions (about 35 °C) where the average residence time of the digested sludge was 20 days. They found that the numbers of viruses recovered from the raw sludges were reduced by about 90% and fecal streptococci more the 90%. Fecal coliforms were reduced by about 98% and numbers of total coliforms by a little more than 99%. Sanders et al. (1979) found that poliovirus type 1 is inactivated after 4.17 days at 35 °C. The ability of anaerobic digestion to reduce the quantity of antibiotic resistant bacteria in wastewater solids has been studied. Statistically significant reductions in the quantities of antibiotic resistant genes were found to occur at 37, 46 and 55 °C with the removal rates increasing as a function of temperature (Diehl and Lapara, 2010). In this study it was found that the quantities of tetracycline resistance determinants (*tet*(A), *tet*(O), *tet*(W) and *tet*(X)) and integrase genes from class 1 integrons were substantially affected by temperature. Those results were generally consistent with reductions observed in full-scale treatment facilities during previous work by the same authors. Abdul and Lloyd (1985) found that during anaerobic digestion at 37 °C counts of defined strains of *E. coli* were rapidly reduced. They tested both antibiotic resistant and sensitive strains and found that antibiotic resistant strains were more persistent. In experiments in which feeding was daily for periods of 10 days, the percentage reduction of the counts of resistant *E. coli* W3110T (R300B), J53 (R136), J53 (R144) during 10 days retention time from influent to effluent were 95.5, 94.5 and 93.3%, respectively while the reductions for sensitive *E. coli* (strains J53, MP1, C600) were 99.9, 100 and 99.4%, respectively. In both resistant and sensitive strains there were immediate decreases in numbers over a 10 h period. They also found that some of the strains isolated from the digesters had the ability to grow anaerobically, so that anaerobiosis was found not to be the only cause of rapid die-off.

In addition to the treatment effect on the wastewater the mass reduction of the organic waste fractions during anaerobic digestion is significant (Borowski and Szopa, 2006; Nges and Liu, 2010; Novak et al., 2011). Salsabil et al. (2010) reported that anaerobic digestion was globally more effective in sludge reduction compared to aerobic digestion. However, one of the biggest advantages is the bioenergy that is produced during the process. Anaerobic digestion is an endogenous process and where possible, it might be a good solution to locate a biogas digester next to a solid waste incineration plant for heating of the digester in the winter. It might also be possible to use the generated gas for heating in the winter and possibly solar heating during summer. Many Arctic communities are dependent on fossil fuels that in most cases are imported. Utilizing the organic matter in the blackwater together with other organic waste fractions to produce biogas could therefore turn out to be economically as well as environmentally beneficial for Arctic communities.

4.3. Toilet solutions

There are several alternative toilet types available today that could be a good solution for many Arctic communities. For Arctic communities and households, simple technologies with high technological efficacy are the preferred strategy for new sanitary structure. Low flush or composting toilets might be good alternatives to bucket toilets and conventional flush toilets in Arctic areas. The two types and sub-types are shown in Fig. 3. These toilet solutions do not mix the human excreta with large amounts of water are suitable if composting or anaerobic digestion of blackwater is to be applied. Low flush toilets give the opportunity to have both collection and treatment at the household level, or collection at the household level and centralized processing. For centralized processing, pressure sewer and vacuum sewer systems are alternatives to gravity sewers. They need the same insulation as traditional sewers, but are less vulnerable to gradient changes that may occur in permafrost areas. Vacuum sewer systems also allow for usage of smaller pipelines and thus low flush toilets (U.S. Congress, 1994). By decentralized collection of human excrements and onsite/in-house treatment of the greywater, for instance by using biofilters, the need for expensive secondary sewer collection systems can be reduced or even eliminated (Heistad, 2008; Karabelnik et al., 2010).

Vacuum toilets or low flush toilets are considered a good choice where water supply is scarce (U.S. Congress, 1994). Vacuum toilets typically use about 1 L pr. flush (Zifu et al., 2002) while low flush toilets use approx. 0.5–1.5 L pr. flush (Jenssen et al., 2004) compared to conventional flush toilets which require approx. 9 L pr. flush (Zifu et al., 2002). However, if these types of toilets are to be installed in communities which are already served by conventional sewerage pipelines, care has to be taken when connecting this kind of toilets to the sewer since the reduced volume of flushing water will also reduce the velocity of the wastewater in the pipelines, possibly causing depositing of organic and inorganic matter in the pipelines which can lead to clogging or freezing.

For composting toilets, collection and treatment is always on household level. Composting toilets are a good alternative to the bucket toilets in non-sewered residences. Modern composting toilets can be urine diverting or not. The urine diversion has the benefit that urine is separated from the small amount of fecal matter where most of the pathogens are contained (WHO, 2006), reducing the volume to be hygienized substantially. The fecal matter can be treated by composting and the urine can be stored until it is safe to dispose or use as fertilizer. The general recommended storage time for urine is 6 months under most conditions (WHO, 2006). Another benefit of urine diversion is that more pharmaceuticals and their metabolites are excreted via urine than via faeces (Winker et al., 2008). Urine separation and separate handling of the urine is therefore a promising approach to lower the pharmaceutical load of raw domestic wastewater and to protect the aquatic environment safely from pharmaceuticals. Composting toilets without urine diversion may still be a better solution at remote locations, for instance Arctic tourist huts or other locations where the urine cannot be properly infiltrated or used.

5. Development needs

Wastewater treatment systems are mainly developed for temperate regions and little is done to specifically address the needs of the Arctic. This paper advocates decentralized treatment and shows that the excreta can be safely treated or collected onsite, but the greywater also needs treatment. Compact onsite methods for greywater treatment exist (Heistad, 2008; Karabelnik et al., 2010), but need further development to be better suited for Arctic conditions.

The use of pressure or vacuum sewers in Arctic conditions should be explored. Such alternative transport systems are interesting from an economical point of view and can transport wastewater to areas suited for local treatment systems without the need for a large collection network.

This paper points to possible environmental and health risks caused by inadequate wastewater treatment in the Arctic. However, additional analyses are needed of to better assess the risk of pharmaceutical residues and microbial agents, in the aquatic environment of the Arctic.

Studies of possibilities to take advantage of the cold climate when designing treatment methods for Arctic regions should also be done. This could for instance be to include freezing in treatment of wastewater, which has not been addressed in this article. Development and testing of small and simple treatment units, for instance composting toilets and anaerobic digestion plants, under cold conditions would also be valuable for small and often remotely located Arctic communities.

6. Conclusions

Treatment of wastewater is often inadequate or completely lacking in Arctic regions. Bucket toilets are still widely used in Arctic regions, even in villages and towns, and the risk of exposure to human waste and spreading of diseases is unacceptably high. Out-phasing the use of this toilet type will improve public health, but also indoor comfort. Conventional collection and treatment systems are expensive to build and operate under Arctic circumstances. Onsite or decentralized treatment will reduce the need for expensive collection systems. Possible alternative wastewater treatment methods for Arctic communities are dry composting or anaerobic digestion of excreta collected at household level using dry or water saving toilets. This opens up for co-treatment of wastewater and other organic waste fractions. Non-ordinary toilet solutions such as vacuum toilets and urine separation toilets may be particularly well suited under Arctic circumstances. The blackwater contains pharmaceuticals and their metabolites and separate treatment of the excreta fraction facilitates their removal. Since a higher portion of many pharmaceuticals and their metabolites are excreted via urine than via faeces, urine separation techniques are a promising approach to lower the pharmaceutical load of raw domestic wastewater and to protect the Arctic aquatic environment from pharmaceuticals. Composting and anaerobic digestion have been shown to be effective sanitation methods, where the temperature appears to be the most important factor. Composting also seems to be a promising method to degrade PPCPs but there is a lack of information about breakdown of these substances during anaerobic digestion.

Further development of simple and robust treatment units for the small and often remotely located Arctic communities is needed. Such units should include composting processes and take advantage of the freezing as to enhance treatment.

References

Abdul, P., Lloyd, D., 1985. The Survival of antibiotic resistant and sensitive *Escherichia coli* strains during anaerobic digestion. Appl. Microbiol. Biotechnol. 22, 373–377.

Arctic Monitoring and Assessment Programme (AMAP), 2009. Arctic Pollution 2009. Arctic Monitoring and Assessment Programme (AMAP), Oslo.

Arctic Monitoring and Assessment Programme (AMAP), 2011. Snow, Water, Ice and Permafrost in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo.

Andersen, H., Siegrist, H., Halling-Sørensen, B., Ternes, T., 2003. Fate of estrogens in a municipal sewage treatment plant. Environ. Sci. Technol. 37 (18), 4021–4026.

Arikan, O.A., Sikora, L.J., Mulbry, W., Khan, S.U., Foster, G.D., 2007. Composting rapidly reduces levels of extractable oxytetracycline in manure from therapeutically treated beef calves. Bioresour. Technol. 98, 169–176.

Bach, L., Fischer, A., Strand, J., 2010. Local anthropogenic contamination affects the fecundity and reproductive success of an Arctic amphipod. Mar. Ecol. Prog. Ser. 419, 121–128.

Bach, L., Forbes, V.E., Dahllöf, I., 2009. The amphipod *Orchomenella pinguis*—a potential bioindicator for contamination in the Arctic. Mar. Pollut. Bull. 58, 1664–1670.

Batt, A.L., Aga, D.S., 2005. Simultaneous analysis of multiple classes of antibiotics by ion trap LC/MS/MS for assessing surface water and groundwater contamination. Anal. Chem. 77, 2940–2947.

Bendixen, H.J., 1994. Safeguards against pathogens in Danish biogas plants. Water Sci. Technol. 30 (12), 171–180.

Bensah, E.C., 2009. Technical Evaluation and Standardization of Biogas Plants in Ghana. A Thesis submitted to the School of Graduate Studies, Kwame Nkrumah University of Science and Technology, in partial fulfilment of the requirements for the degree of Master of Science in Mechanical Engineering, Faculty of Mechanical and Agricultural Engineering College of Engineering.

Berg, G., Berman, D., 1980. Destruction by anaerobic mesophilic and thermophilic digestion of viruses and indicator bacteria indigenous to domestic sludges. Appl. Environ. Microbiol. 39 (2), 360–368.

Bergheim, M., Helland, T., Kallenborn, R., Kümmerer, K., 2010. Benzyl-penicillin (Penicillin G) transformation in aqueous solution at low temperature under controlled laboratory conditions. Chemosphere 81 (11), 1477–1485.

Bitton, G., 2005. Wastewater Microbiology, 3rd ed. John Wiley & Sons, Inc., Hoboken, New Jersey.

Bogomolni, A.L., Gast, R.J., Ellis, J.C., Dennett, M., Pugliares, K.R., Lentell, B.J., Moore, M.J., 2008. Victims or vectors: a survey of marine vertebrate zoonoses from coastal waters of the Northwest Atlantic. Dis. Aquat. Org. 81, 13–38.

Bonjoch, X., Blanch, A.R., 2009. Resistance of faecal coliforms and enterococci populations in sludge and biosolids to different hygienisation treatments. Microb. Ecol. 57, 478–483.

Borowski, S., Szopa, J.S., 2006. Experiences with the dual digestion of municipal sewage sludge. Bioresour. Technol. 98, 1199–1207.

Büyüksönmez, F., Şekeroğlu, S., 2005. Presence of pharmaceuticals and personal care products (PPCPs) in biosolids and their degradation during composting. J. Residuals Sci. Technol. 2 (1), 31–40.

Colt, S., Goldsmith, S., Wiita, A., 2003. Sustainable Utilities in Rural Alaska: Effective Management, Maintenance and Operation of Electric, Water, Sewer, Bulk Fuel, Solid Waste. Final Report, Part B: Supporting Chapters. Institute of Social and Economic Research, University of Alaska Anchorage, Retrieved from <http://www.iser.uaa.alaska.edu/Publications/sustainB.pdf> (30.11.11).

Danish Environmental Protection Agency, 2005. Udrednings- og pilotprojekt vedr. håndtering af miljøproblemer som følge af spildevand i de grønlandske byer. Fase 2 Katalog over tekniske løsningsmuligheder (Danish report, written by the engineering firm COWI for the Danish Environmental Agency).

Diehl, D.L., Lapara, T.M., 2010. Effect of temperature on the fate of genes encoding tetracycline resistance and the integrase of class 1 integrons within anaerobic

and aerobic digesters treating municipal wastewater solids. Environmen. Sci. Technol. 44, 9128–9133.
Dolliver, H., Gupta, S., Noll, S., 2008. Antibiotic degradation during manure composting. J. Environ. Qual. 37 (3), 1245–1253.
Dumontet, S., Dinel, H., Baloda, S.B., 1999. Pathogen reduction in sewage sludge by composting and other biological treatments: a review. Biol. Agric. Hortic. 16, 409–430.
Edlich, R.F., Hill, L.G., Mahler, C.A., Cox, M.J., Becker, D.G., Horowitz, J.H., Nichter, L.S., Martin, M.L., Lineweaver, W.C.J., 2003. Management and prevention of tetanus. J. Long Term Eff. Med. Implants 13 (3), 139–154.
Ekama, G.A., Wentzel, M.C., 2008. Organic material removal. In: Henze, M., Van Loosdrecht, M.C.M., Ekama, G.A., Brdjanovic, D. (Eds.), Biological Wastewater Treatment. IWA Publishing, London.
Engemann, C.A., Adams, L., Knapp, C.W., Graham, D.W., 2006. Disappearance of oxytetracycline resistance genes in aquatic systems. FEMS Microbiol. Lett. 263, 176–182.
Environmental Signals Canada's National Environmental Indicator Series, 2003. ISBN 0-662-33138-9, Cat. no. En40-775/2002E. Retrieved from http://dsp-psd.pwgsc.gc.ca/Collection/En40-775-2002E.pdf (30.11.11).
Eriksson, E., Auffarth, K., Henze, M., Ledin, A., 2002. Characteristics of grey wastewater. Urban Water 4, 85–104.
Finstein, M.S., Cirello, J., Suler, D.J., Morris, M.L., Strom, P.F., 1980. Microbial ecosystems responsible for anaerobic and composting. J. Water Pollut. Control Fed. 52 (11), 2675–2685.
Gallagher, N.T., Sharvelle, S.E., 2010. Decentralized anaerobic blackwater management: a sustainable development technology concept for urban water management. World environmental and water resources congress 2010: Challenges of change. In: Proceedings of the World Environmental and Water Resources Congress 2010.
Gessner, B.D., 2008. Lack of piped water and sewage services is associated with pediatric lower respiratory tract infection in Alaska. J. Pediatr., 666–670.
Ghendon, Y., Robertson, S.E., 1994. Interrupting the transmission of wild polioviruses with vaccines: immunological considerations. Bull. World Health Org. 72 (6), 973–983.
Gibbs, R.A., Hu, C.J., Ho, G.E., Phillips, P.A., Unkovich, I., 1995. Pathogen die-off in stored waste-water sludge. Water Sci. Technol. 31 (5-6), 91–95.
Hanssen, J.F., Paruch, A., Jenssen, P.D., 2005. Composting human waste from waterless toilets. In: Presentation at the 3rd. Int. Conf. on Ecological Sanitation, Durban, May 24, p. 2005.
Heinke, G.W., Prasad, D., 1979. Anaerobic treatment of human waste in northern communities. Can. J. Civil Eng. 7, 156–164.
Heistad, A., 2008. Small scale wastewater treatment: design optimization, reduction efficiency and risk prediction. PhD Thesis. Dept. of Mathematical Sciences and Technology, Norwegian University of Life Sciences (UMB), Ås, Norway.
Hedström, A., Hanæus, J., 1999. Natural freezing, drying, and composting for treatment of septic sludge. J Cold Reg. Eng. 13 (4), 167–179.
Hennessy, T.W., Ritter, T., Holman, R.C., Brüden, D.L., Yorita, K.L., Bulkow, L., Cheek, J.E., Singleton, R.J., Smith, J., 2008. The relationship between in-home water service and the risk of respiratory tract, skin, and gastrointestinal tract infections among rural Alaska natives. Am. J. Public Health 98 (11), 2072–2078.
Holbrook, R.D., Novak, J.T., Grizzard, T.J., Love, N.G., 2002. Estrogen receptor agonist fate during wastewater and biosolids treatment processes: a mass balance analysis. Environ. Sci. Technol. 36, 4533–4539.
Hübinette, M., 2009. Tillsyn på minireningsverk inklusive mätning av funktion. Länsstyrelsen i Västra Götalands län, vattenvårdsenheten. Rapport: 2009:07. ISSN: 1403-168X. 95s (report in Swedish). www.lansstyrelsen.se/vastragotaland.
Hyaric, R.L., Canler, J., Barillon, B., Naquin, P., Gourdon, R., 2010. Pilot-scale anaerobic digestion of screening from wastewater treatment plants. Bioresour. Technol. 101, 9006–9011.
Jennera, A.M., Rafter, J., Halliwell, B., 2005. Human fecal water content of phenolics: the extent of colonic exposure to aromatic compounds. Free Radic. Biol. Med. 38, 763–773.
Jenssen, P.D., Greatorex, J., Warner, W.S., 2004. Sustainable wastewater management in urban areas. In: Kayser, K. (Ed.), Konzeptionen Dezentralisierter Abwasserreinigung und Stoffstrommanagement (concepts of de-centralized wastewater treatment and resource management). Universitat Hannover Weiterbildendes Studium Bauingenieurwesen Wasser und Umwelt, 51 pp.
Johannessen, E., 2012. Optimizing phosphorus removal in onsite wastewater treatment facilities. PhD Thesis. 2012–13. Norwegian University of Life Sciences. ISBN 978-82-575-1050-3.
Kallenborn, R., Fick, J., Lindberg, R., Moe, M., Nielsen, K.M., Tysklind, M., Vasskog, T., 2008. Pharmaceutical residues in Northern European environments: consequences and perspectives. In: Kümmerer, K. (Ed.), Pharmaceuticals in the Environment. , 3rd ed. Springer Verlag, New York, Tokyo, Heidelberg, 522 pp.
Karabelnik, K., Kõiv, M., Kasak, K., Jenssen, P.D., Mander, Ü., 2010. Greywater treatment in a hybrid filter system with Ca-rich media—a pilot scale study. In: Masi, F. (Ed.), Proc. 12th IWA International Conference on Wetland Systems for Water Pollution Control. Venice October 4–10, 2010, pp. 509–511.
Khan, S.J., Ongerth, J.E., 2002. Estimation of pharmaceutical residues in primary and secondary sewage sludge based on quantities of use and fugacity modeling. Water Sci. Technol. 46 (3), 105–113.
Kim, M., Ahn, Y.H., Speece, R.E., 2002. Comparative process stability and efficiency of anaerobic digestion; mesophilic vs. thermophilic. Water Res. 36, 4369–4385.
van Lier, J.B., 1996. Limitation of thermophilic anaerobic wastewater treatment and the consequences for process design. Antonie van Leeuwenhoek 69, 1–14.
Kimiran-Erdem, A., Arslan, E.O., Sanli Yurudu, N.O., Zeybek, Z., Dogruoz, N., Cotuk, A., 2007. Isolation and identification of Enterococci from seawater samples: assessment of their resistance to antibiotics and heavy metals. Environ. Monit. Assess. 125 (1), 219–228.
Kreuzinger, N., Clara, M., Strenn, B., Kroiss, H., 2004. Relevance of the sludge retention time (SRT) as design criteria for wastewater treatment plants for the removal of endocrine disruptors and pharmaceuticals from wastewater. Water Sci. Technol. 50 (5), 149–156.
Kumar, R., Gupta, M.K., Kanwar, S.S., 1999. Fate of bacterial pathogens in cattle dung slurry subjected to anaerobic digestion. World J. Microbiol. Biotechnol. 15 (3), 335–338.
Kümmerer, K., 2004. Resistance in the environment. J. Antimicrob. Chemother. 54 (2), 311–320.
Kümmerer, K., 2009. Antibiotics in the aquatic environment—A review—Part II. Chemosphere 75, 435–441.
Larsen, H.E., Munch, B., Olsen, J.E., Nansen, P., 1989. Om smitsofdrab og smitterisici ved udrådning af husdyrgødning i biogasanlaeg. Dansk Vet. Tidskrift. 72 (24), 1411–1418 (in Danish).
Larsson, D.G.J., Adolfsson-Erici, M., Parkkonen, J., Pettersson, M., Berg, A.H., Olsson, P.-E., Förlin, L., 1999. Ethinyloestradiol—an undesired fish contraceptive? Aquat. Toxicol. 45 (2), 91–97.
Leclerc, H.L., Schwarzbrod, L., Dei-Cas, E., 2002. Microbial agents associated with waterborne disease. Crit. Rev. Microbiol. 28, 371–409.
Liu, Z., Kanjo, Y., Mizutani, S., 2009. Removal mechanisms for endocrine disrupting compounds (EDCs) in wastewater treatment-physical means, biodegradation, and chemical advanced oxidation: a review. Sci. Total Environ. 407 (2), 731–748.
Lopez Zavala, M.A., Funamizu, N., Takakuwa, T., 2005. Biological activity in the composting reactor of the bio-toilet system. Bioresour. Technol. 96, 805–812.
Lorenzen, A., Chapman, R., Hendel, J.G., Topp, E., 2005. Persistence and pathways of testosterone dissipation in agricultural soil. J. Environ. Qual. 23, 854–860.
Neela, F.A., Nonaka, L., Suzuki, S., 2007. The diversity of multi-drug resistance profiles in tetracycline-resistant *Vibrio* species isolated from coastal sediments and seawater. J. Microbiol.—Seoul 45 (1), 64.
Nges, I.A., Liu, J., 2010. Effects of solid retention time on anaerobic digestion of dewatered-sewage sludge in mesophilic and thermophilic conditions. Renew. Energy 35, 2200–2206.
Nielsen, U., Nielsen, K., Mai, P., Frederiksen, O., 2006. Organisk industriaffald i Grønland-Værktøjer til fremme af bedste tilgængelige teknik og nyttiggørelse af restprodukter. Realistiske muligheder for nyttiggørelse/udnyttelse af organisk industriaffald i Grønland. Report nr. M. 127/001-0164 (in Danish).
Novak, J.T., Banjade, S., Murthy, S.N., 2011. Combined anaerobic and aerobic digestion for increased solids reduction and nitrogen removal. Water Res. 45, 618–624.
Olsen, J.E., Larsen, H.E., 1987. Bacterial decimation times in anaerobic digestions of animal slurries. Biol. Wastes 21, 153–168.
Palmquist, H., Hanæus, J., 2005. Hazardous substances in separately collected grey- and blackwater from ordinary Swedish households. Sci. Total Environ. 248, 151–163.
Purdom, C.E., Hardiman, P.A., Bye, V.V.J., Eno, N.C., Tyler, C.R., Sumpter, J.P., 1994. Estrogenic effects of effluents from sewage treatment works. Chem. Ecol. 8 (4), 275–285.
Rodgers-Gray, T.P., Jobling, S., Morris, S., Kelly, C., Kirby, S., Janbakhsh, A., Harries, J.E., Waldock, M.J., Sumpter, J.P., Tyler, C.R., 2000. Long-term temporal changes in the estrogenic composition of treated sewage effluent and its biological effects on fish. Environ. Sci. Technol. 34, 1521–1528.
Routledge, E.J., Sheahan, D., Desbrow, C., Brighty, G.C., Waldock, M., Sumpter, J.P., 1998. Identification of estrogenic chemicals in STW effluent. 2. In vivo responses in trout and roach. Environ. Sci. Technol. 32, 1559–1565.
Ryckeboer, J., Mergaert, J., Vaes, K., Klammer, S., De Clercq, D., Coosemans, J., Insam, H., Swings, J., 2003. A survey of bacteria and fungi occurring during composting and self-heating processes. Ann. Microbiol. 53 (4), 349–410.
Sahlström, L., 2003. A review of survival of pathogenic bacteria in organic waste used in biogas plants. Bioresour. Technol. 87 (2), 161–166.
Salsabil, M.R., Laurent, J., Casellas, M., Dagot, C., 2010. Techno-economic evaluation of thermal treatment, ozonation and sonication for the reduction of wastewater biomass volume before aerobic or anaerobic digestion. J. Hazard. Mater. 174, 232–333.
Sanders, D.A., Malina, J.F., Moore, B.E., Sagik, B.P., Sorber, C.A., 1979. Fate of poliovirus during anaerobic digestion. J. Water Pollut. Control Fed. 51, 333–343.
Sanin, D.F., Vesilind, P.A., Martel, C.J., 1994. Pathogen reduction capabilities of freeze/thaw sludge conditioning. Water Res. 28 (11), 2393–2398.
Salste, L., Leskinen, P., Virta, M., Kronberg, L., 2007. Determination of estrogens and estrogenic activity in wastewater effluent by chemical analysis and the bioluminescent yeast assay. Sci. Total Environ. 378, 343–351.
Sjölund, M., Bonnedahl, J., Hernandez, J., Bengtsson, S., Cederbrant, G., Pinhassi, J., Kahlmeter, G., Olsen, B., 2008. Dissemination of multidrug-resistant bacteria into the Arctic. Emerg. Infect. Dis. 14 (1), 70.
Smith, D.W., Low, N., 1996. Cold Regions Utilities Monograph, 3rd ed. Technical Council on Cold Regions Engineering, American Society of Civil Engineers and Cold Regions Engineering Division, Canadian Society for Civil Engineering.
Statistics Greenland, 2012. Greenland in Figures. Edited by David Michelsen, Statistics Greenland. ISBN 978-87-986787-6-2, EAN 9788798678762, ISSN 1602-5709.

Stenström, T.A., 2001. Reduction efficiency of Index pathogens in dry sanitation compared with traditional and alternative wastewater treatment systems. In: Proceedings of the First International Conference on Ecological Sanitation, 5–8 November 2001 Nanning, China EcoSanRes, Stockholm, 5 p. <www.ecosanres.org/Nanning_Conf_Proceedings.htm>.

Tønner-Klank, L., Moller, J., Forslund, A., Dalsgaard, A., 2007. Microbiological assessments of compost toilets: in situ measurements and laboratory studies on the survival of fecal microbial indicators using sentinel chambers. Waste Manage. 27 (9), 1144–1154.

Torrella, F., Lopez, J.P., Banks, C.J., 2003. Survival of indicators of bacterial and viral contamination in wastewater subjected to low temperatures and freezing: application to cold climate waste stabilisation ponds. Water Sci. Technol., 105–112.

U.S. Congress, 1994. U.S. Congress, Office of Technology Assessment, An Alaskan Challenge: Native Village Sanitation, OTA-ENV-591. U.S. Government Printing Office, May 1994, Washington, DC.

U.S. Department of Health and Human Services, 2006. Norton Sound Service Area, Overview. U.S. Department of Health and Human Services. Indian Health Service. The Federal Health Program for American Indians and Alaska Natives, Retrieved from: <http://www.ihs.gov/facilitiesservices/areaoffices/alaska/dpehs/documents/ns.pdf> (30.11.11).

Umhverfisstofun (UST), 2003. Staða mála hvað varðar hreinsun skólps á Íslandi, skýrsla Umhverfisstofunanar sbr. 28. gr. reglugerðar nr. 798/1999, um fráveitur og skólp (report in Icelandic. English title: Status of wastewater treatment in Iceland).

USEPA, 2000. Package plants. Wastewater Technology Fact Sheet. EPA 832-F-00-016.

Vasskog, T., Bergersen, O., Anderssen, T., Jensen, E., Eggen, T., 2009. Depletion of selective serotonin reuptake inhibitors during sewage sludge composting. Waste Manage 29, 2808–2815.

Vinnerås, B., Björrklund, A., Jönsson, H., 2003. Thermal composting of faecal matter as treatment and possible disinfection method-laboratory-scale and pilot-scale studies. Bioresour. Technol. 88 (1), 47–54.

Vogelsang, C., Grung, M., Jantsch, T.G., Tollefsen, K.E., Liltved, H., 2006. Occurrence and removal of selected organic micropollutants at mechanical, chemical and advanced wastewater treatment plants in Norway. Water Res. 40, 3559–3570.

Wang, G., 2010. Biogas Production from Energy Crops and Agricultural Residues. PhD Thesis. Biosystems Division, Risø, Technical University of Denmark.

Weigel, S., Berger, U., Jensen, E., Kallenborn, R., Thoresen, H., Hühnerfuss, H., 2004. Determination of selected pharmaceuticals and caffeine in sewage and seawater from Tromsø/Norway with emphasis on ibuprofen and its metabolites. Chemosphere 56, 583–592.

Wiley, B.B., Westerberg, S.C., 1969. Survival of human pathogens in composted sewage. Appl. Microbiol. 18 (6), 994–1001.

Winker, M., Faika, D., Gulyas, H., Otterpohl, R., 2008. A comparison of human pharmaceutical concentrations in raw municipal wastewater and yellowwater. Sci. Total Environ. 399 (1–3), 96–104.

Winther, L., Henze, M., Linde, J.J., Jensen, H.T., 1998. Spildevandsteknik, Polyteknisk Forlag, ISBN:87-502-0809-8 (a textbook in Danish).

World Health Organization (WHO), 2006. Guidelines for the Safe Use of Wastewater, Excreta and Greywater, vol. IV. Excreta and Greywater Use in Agriculture.

World Health Organization (WHO), 2008. Hepatitis A, Fact sheet No. 328, May 2008, Retrieved from: <http://www.who.int/mediacentre/factsheets/fs328/en/> (30.11.11).

Yri, A., Hensel, G.R., Aasen, R., Mæhlum, T., 2007. Examination of small wastewater treatment plants in normal operation. (Report in Norwegian: Undersøkelse av mindre avløpsanlegg i normaldrift.). Bioforsk report no.146/07, Bioforsk, Ås, Norway.

Zhang, X., Zhang, T., Fang, H.H.P., 2009. Antibiotic resistance genes in water environment. Appl. Microbiol. Biotechnol. 82, 397–414.

Zifu, L., Gajurel, D.R., Otterpohl, R., 2002. Development of source control sanitation systems in Germany. EcoSanRes, 1–4.

Zuccato, E., Castiglioni, S., Fanelli, R., Reitano, G., Bagnati, R., Chiabrando, C., Pomati, F., Rossetti, C., Calamari, D., 2006. Pharmaceuticals in the environment in Italy: causes, occurrence, effects and control. Environ. Sci. Pollut. Res. 13 (1), 15–21.