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Source separation technologies, opportunities for sustainable wastewater management

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Abstract: Recent challenges regarding urban sanitation system require innovative ideas to ensure high quality wastewater management in future. The drive towards sustainable wastewater management is challenging the conventional wastewater treatment method. Source separation sanitation method could be a new approach to minimize the pressure of population and help to improve the sustainability indicators. It is required the information about new ideas; systems and technologies become more readily accessible for addressing wastewater problems in order to reach solutions for environmental, economic and social balance. This comprehensive review focuses on the statues of current source separation sanitation techniques and summarize the efficiency of each type of technology. The method would be in modular descriptions of component and description of alternative wastewater systems, and facilitates evaluating how well each design satisfies the given context. The review shows clearly that a wide range of technique options is available to treat each type of wastewater, but none of these options can meet all the requirements of treatment in one specific technique and a combination of technique is required to treat separated water to reach optimized nutrient recovery and treated water.

Key words: Source separation sanitation system, greywater, blackwater, yellow water, conventional sanitation system, removal efficiency

1. INTRODUCTION

Even though conventional wastewater treatment resolve acute hygiene and aquatic environment related problems, it doesn't have control on generated wastewater at the source and does not consider resource recycling (Otterpohl, 2002). The conventional sanitation system usually involves enormous amounts of potable water for collection, complex treatment processes due to mixing of several types of wastewater flow of residential area and have a limited potential regarding recycling of wastewater components.

As alternatives to conventional wastewater treatment systems, many approaches based on source separation sanitation system has been introduced. Most of source separation sanitation system can be found in small scale and proposed projects in many various configuration of separating wastewater from source (Otterpohl, 2002; Peter-Fröhlich et al., 2007; Zeeman et al., 2008; Augustin et al., 2014). Based on the proposed goal of each study, source separation of wastewater is including greywater (bathroom, kitchen and laundry water), blackwater (urine, faeces and flush water) and yellow water (only urine). In many system configurations, the greywater is collected by a gravity system and treated in natural ponds or in a technical process. The blackwater is collected by a vacuum system and then treated in an anaerobic digester together with organic waste from house (Thibodeau et al., 2014).

A Comparison of different aspects of source sanitation systems has been done by many different assessment frameworks. One of the usual method is Life Cycle assessment which it can assess the potential environmental impacts of the entire value of a chain (a product system from cradle to grave) (Remy, 2009; Hellweg and Mila i Canals, 2014). Other quantitative tools such as Material Intensity Per Service unit (MIPS), exergy analysis have been used to draw material and energy balances of different source separation sanitation system and conventional treatment system (Benetton et al., 2009). These studies present data on energy consumption, production, material intensity, and emission of source separated faeces, urine, and greywater treatment and conventional wastewater treatment. However, these methods need a lot of information that is time-consuming and complicated.

Hence, from a system developer's point of view, there is still lack, which source separation sanitation system would be the most promising one to develop further in order to minimize both environmental impact and cost. With regards to the source separation sanitation systems, key processes have been identified, but the level of efficiency they must achieve in terms of source sanitation systems performance equals that of conventional for environmental and economic indicators have not been clearly determined. The previous studies presented the environmental or the economic performance of source separation sanitation system which they are specified in each study to some limited methods and mostly in the lab scale where is not still enough comparable with well-structured of conventional treatment system. Present study aims to compare the efficiency of possible source separation treatment technology that it has been used in at least pilot scale and to review their performance.

This study aims to compare various source separation sanitations systems based on the pollutant removal efficiency to determine which one has better functionality compare to conventional system.

This review report is primarily concerned with systems and technologies directly related to separated wastewater and only those sanitation technologies which have been applied in the scale of lager than lab experiments.

2. METHODOLOGY DESCRIPTION

The goal of this study is to compare different developments of source separation systems more feasible than conventional treatment of wastewater considering sustainability criteria. This study focuses on innovative systems and leading edge technologies that are commercially available and have the potential to be implemented in a real housing project in the short or mid-term. As the results are meant to guide the development of source separation sanitation system entailing better environmental performance, the study is intended for use by sanitation system designers, sanitation system providers, urban planners and decision makers dealing towards sustainable sanitation system in urban areas. The scope of the study entails the treatment of sanitation systems under analysis. The model of source separation sanitation systems was developed by the authors based on a literature review, brainstorming and expert advice. The data for analysing is gained from the facilities of different source separated projects in mostly Germany (WWTP Stahnsdorf in Berlin which was owned and operated by the Berliner Wasserbetriebe, SCST, 2006 and Lübeck-Flinterbreute housing development) and the Netherlands (Sneek and Groningen) and Sweden.

Based on the proposed goals of the study, different technologies for separated wastewater treatment is investigated. Technologies are defined as the specific infrastructure or method to treat wastewater. A wide variety of sanitation technologies are either currently under development or are not yet fully mature and available. 57 technologies have been introduced in the compendium of sanitation systems and technologies (Tilley et al., 2014). However, the quantitative data of this technologies are not available. A comparison model in Excel was developed based on literature data to investigate existing various treatment technologies of source separation system based on the type of separated wastewater. The concentration of this study is just only on liquid fraction of wastewater and the domestic bio-waste is not considered.

For better comparison between various technologies, the pollutant loading in the wastewater influent was considered to originate only from the domestic wastewater streams of urine, faeces and greywater including COD (Chemical Oxygen Demand), TN (Total Nitrogen), TP (Total Phosphorus) and the effluent of each sanitation technology is considered based on the percentage of pollutant removal efficiency. Description of the technologies is done based on dividing to the type of separated wastewater since these are used as the basis for comparison.

3. RESULTS

3.1 Greywater treatment processes

Commonly treatment systems are used to remove organic material and nutrients from greywater including sequencing batch reactor (SBR) (Hernandez et al., 2010) and constructed wetlands (CW) (Avery et al., 2007). Greywater flows through a gravity sewer network and collected in a lager pipe systems or stored for a long period that need for pre-treatment and then to a constructed wetland. In pre-treatment, suspended solids are removed mechanically by gravity, screens, filters or other possible method. The need for this removal depends on how the water will be treated and used.

Due to the considerably high land area requirement, the use of CW is not suitable for densely populated urban areas (Brix and Arias, 2005). One alternative could be implement CW as a green roof (Avery et al., 2007). To utilize the organic material present in greywater, excess sludge from the greywater treatment system can be potentially co-digested in the UASB reactor instead of using energy-intensive sludge transport and disposal (Hernandez et al., 2010). To avoid extensive mineralization of greywater sludge, a bio-flocculation unit, such as a high loaded membrane bioreactor (MBR) or A-trap from the AB-process (Böhnke, 1981) can be used to concentrate greywater at short hydraulic and sludge retention times (HRT and SRT). A post-treatment system (such as TF) can be applied to remove the remaining organic material from greywater effluent prior to reuse. (Tervahauta et al., 2013)

Other technical components such as, soil filtration systems (Wissing and Hofmann, 2002; Geller and Hoener, 2003) septic tank, sand filters (Ridderstolpe, 2004) are used to remove particles and purified the greywater in different steps of the treatment process.

The selected treatment process of greywater is presented in Table 1 shows the basic removal efficiency of the different treatment processes of greywater.

Table 1. Pollutant removal efficiency of various technologies for greywater treatment (%)

Parameter\system	SBR (1)	Atrap (2)	MBR (3)	Septic tank (4)	Constructed wetland (4)
COD	90	45	75	33	94
BOD5	90	42	75	70	90
TSS	76	42	95	19	-
TN	35	36	81	54	63
TP	28	40	65	9	88

1. Zeeman et al., 2008, 2. Kujawa, 2005, 3. Vlaeminck et al., 2009, 4. Peter-Frohlich et al., 2007

The greywater treatment in a soil filter system needs less energy than a technical process. The natural process of appropriate for the purification of the nutrient-depleted greywater. The treatment of faeces filtrate together with the greywater can increase the nutrient loads considerably. In general, the natural process can reach sufficient results in greywater treatment if the required area for soil filter is available (Remy et al., 2006). Otherwise, the greywater is proposed to be treated in a compact system, a subsequent UASB/SBR or AS (activated sludge), instead of a constructed wetland preceded by a septic tank. By applying a UASB instead of a septic tank for greywater treatment, a substantial lower reactor volume can be installed and moreover produced biogas (Elmitwalli and Otterpohl, 2007; Zeeman et al., 2008)

According to different studies, the efficiency of pollutant removal and effluent quality is affected by SRT (Sludge Retention Time) Wilsenach and van Loosdrecht (2006) showed higher effluent quality of A-trap by SRT 0.8 day compare to A-trap with SRT 0.6 day (DeSaH, 2010). However, due to limited experimental data and the different composition of greywater, more research is required to confirm the relation between the SRT of the A-trap and the pollutant removal efficiencies. Consequently, if the SRT of the A-trap for greywater treatment is increased to 0.8 day, the pollutant removal efficiency could be increased, resulting in higher effluent quality (Tervahauta et al., 2013).

3.2 Yellow water source separation

Urine contains most of the soluble nutrients in very high concentrations. Separation and direct use of urine as a fertilizer can be used to increase nutrient recovery, improve wastewater effluent quality and to decrease operational energy consumption, due to lower nutrient concentration in wastewater (Maurer et al., 2003). Urine separation and use as a secondary fertilizer are as an essential part of the source separation approach in terms of efficiency use of valuable nutrients. Most important target in urine treatment are volume reduction, improved handling, and inactivation of micro pollutants.

The collection and direct application of urine as a fertilizer has been surveyed in pilot projects in Sweden (Johansson et al., 2001) and in smaller scale in Germany (Otterpohl et al., 2002) and in addition, Maurer et al. (2003, 2006) reviewed possible urine treatment and related process to volume reduction and the elimination of micro-pollutants in a lab scale. Pilot scale experiments of urine treatment process has been done in Sweden (Ganrot, 2005) and Germany (Peter-Fröhlich et al., 2007). Most of urine treatment option found in the literature are: hygienisation (storage), volume reduction (freeze-thaw, reverse osmosis), stabilisation (acidification), P-recovery (struvite formation), N-recovery (ion-exchange, ammonia stripping), nutrient removal (annamox) and handling of micropollutant (electrodialysis) (Maurer et al., 2006). Since a single unit process cannot provide all the treatment process, a combination of technique is required. In the present study, different process combination for yellow water treatment are compared based on the efficiency of nutrient recovery and result has been shown in Table 2. In the accessible of the yellow water studies, the result has been shown based on the recovery of material.

Table 2. Efficiency of nutrient recovery of various technologies for yellow water treatment (%)

Parameter\system	Storage (1)	Struvite precipitation+ Ion exchange (2)	Steam stripping+ Ozone+ Evaporation (3,4)	Struvite precipitation+ Steam stripping (2,3,4)
N recovery %	99	90	96	95
P recovery %	100	99	100	90
K recovery %	-	30	100	30

1. Johansson et al., 2001, 2. Ganrot,2005, 3. Maurer et al., 2006, 4. SCST, TUHH, 2007

Source separation of urine not only increase the effluent quality in terms of nutrient concentration and the overall pollutant loading, but also improves the energy balance and nutrient recovery (Tervahauta et al., 2013). Social acceptance of stored urine may be difficult due to strong smell and some may find it offensive to work with or to have it nearby (Tilley et al., 2014). The transport of a large volume of yellow water over long distance can consume considerable amount of truck fuel and cause respective emission of CO_2. A further consideration of yellow water to reduce transport volume and inactivate potentially harmful micro-pollutant is possible; however, energy intensive process like steam stripping and evaporation should be ecologically optimized (Remy et al., 2006)

3.3 Blackwater source separation

The blackwater source separation system is investigated on the sanitation facilities in Lübeck-Flinterbreute housing development in Germany (Otterpohl et al., 2002). Using a vacuum and pumping system, blackwater is collected and directed to a centralized treatment station. Processes that are specific to blackwater treatment based

Anaerobic treatment is a key technology of blackwater in an up-flow anaerobic sludge blanket (UASB) reactor (Zeeman et al., 2008; Kujawa, 2005). These technologies can be specified based on the digested mass reduction goal with reverse osmosis and acidification or digestate treatment by means of phosphorus precipitation and nitritation -anammox reactors (Thibodeau et al., 2014). Nutrient recovery and pollutant removal from the UASB reactor effluent can be established by struvite precipitation, autotrophic nitrogen removal using oxygen limited anaerobic nitrification denitrification (OLAND) reactor and a post-treatment, such as a trickling filter (TF), to remove remaining organic material (Zeeman et al., 2008).

As shown in Table 3 from different studies, nitrogen removal during struvite precipitation is negligible, introduction of an additional treatment step is needed. Nitrogen removal based on the autotrophic conversion of ammonium to nitrogen like CANON (Sliekers et al., 2003) and OLAND (Windey et al., 2005) are promising in combination with anaerobic processes. The biorotor system as presented by Windey et al. (2005) could be a simple post treatment process for removal of nitrogen from anaerobically pre-treatment blackwater.

Table 3. Pollutant removal efficiency of various technologies for blackwater treatment (%)

Parameter\system	UASB (1)	OLAND (1)	Struvite (2)	TF (3)	Septic tank (4)	Constructed wetland (4)
COD	83	53	-	85	14	93
BOD5	83	53	-	85	7	98
TSS	83	-	-	85	21	-
TN	1	73	9	-	19	41
TP	33	-	96	-	10	76

1. Kujawa, 2005, 2. Wilsenach et al., 2006, 3. Tervahauta et al., 2013, 4. Peter-Frohlich et al., 2007

3.4 Brown water source separation

In the source separation sanitation concept, brown water produced from faeces where with flush water are either drained off by gravity drainage and composted together with bio-waste or collected by a vacuum system and co-digested with bio-waste to gain biogas for energy production and then is pumped to solid-liquid separators. The filtrate from the faeces dewatering is treated together with the remaining household wastewater from kitchen, washing machine, and personal hygiene (greywater) and in this study, has been analyse in the blackwater section. The solid fraction is further thickened and transported by truck to a composting plant. Although composting of faeces to produce organic fertilizer is a well-known treatment for small scale sanitation units or dry toilet, most of the studies for brown water is in lab scale and it has not been investigated and tested within the dimension of a larger settlement. Therefore, analysing of this kind of flow was not possible.

4. CONCLUSIONS

In this paper, the number of unit processes for treating separated wastewater have been studied in respect of their removal efficiency. The review of different processes of source separated sanitation made clear that a very large number of technical options are available with different strengths and weaknesses. We are aware that much more literature is available and regret not being able to refer to all of it.

However, all the processes cannot be archived with a single unit process. Whether the aim is to concentrate on a specific purpose such a nutrient removal or to combine different process unit to achieve a more comprehensive goal depends on the circumstances and is not discussed in this paper.

The choice of technique treatment system depends on many factors such as climate, density, type of habitation, land-use patterns, existing drainage systems, degree of pollution and sensitivity of the recipient. Therefore, the best solution suit to the local conditions and consider the potential risks the different techniques bring about.

A general assessment of source separation sanitation system is not possible only based on process engineering technology. Although other aspects connected to source separation system may be more difficult to solve. However, it is important to carefully evaluate the new approaches in terms of their sustainability, including environmental, economic and social impacts.

Source separating technologies are still considered immature and risky by most wastewater professionals. This turns into a self-fulfilling prophecy. The present centralized system was developed over decades by uncountable researchers and practitioners; therefore, more research is required in source separating technologies to identify more realistic picture of new approaches.

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