The Loo-Loop Process for Highly Efficient Stand-Alone Water Systems

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Abstract
The environmentally open disposal of faecal contaminated waste water flows has caused and is causing a broad variety of threats and problems. Hence, the cutting-off of toilet waste water from the natural water bodies can abrogate all these threats and problems. This can be achieved mainly with the following three systems: With dry toilets, with the vacuum-biogas system (Otterpohl et al., 1999) or by closing the loop of toilet flushing water as described in this paper. In a co-operation with Intaqua AG the toilet flushing water loop process ("LooLoop-Process") has been researched at the Institute of Wastewater Management and Water Protection of Hamburg University of Technology. The concept consists mainly of a solids separation, a membrane bioreactor including nitrification and post treatment for reuse of toilet wastewater (blackwater)for flushing. From this nutrient solution that operates with concentrations as in urine only a flow equal to the urine has to be abstracted and is meant to be reused as clean liquid fertiliser or in dried form. By elimination of the blackwater flow by a closed loop, the remaining waste water flow from domestic settlements (grey water) is can be to purified for a high quality reuse.

Keywords
Black water, compost, decentralised wastewater systems, ecological sanitation, source control, zero emission.

OBJECTIVES

The common state-of-the-art technology can be characterised by the term "centralised flow-through concept" comprising the following positions: *freshwater withdrawal* → *drinking water processing* → *usage* → *wastewater* → *sewerage (*→ *treatment plant)* → *disposal (most common in surface waters)* → *sea water*, whereby only a small fraction of the waste water is treated worldwide in sewage plants. Still most common is the discharge of raw sewage into our natural water bodies.
This disposal of faecal polluted waste water (black water) into our aquatic environments is still an unsolved ***quality problem*** causing Millions of deaths and infections per year. Whether treated in sewage plants, or not – pathogens, hormones, resistance plasmids and pharmaceuticals are thereby released into our water resources, causing serious threats to our environments and public health. Thus, epidemics like the dreadful cholera epidemic of Hamburg, Germany, in 1892 (Evans, 1991) can be the consequences. In many countries and regions of the world (where the drinking water is extracted from surface water bodies), this shortcut between toilets and drinking water faucets still exists.
Where groundwater is the source of drinking water extraction, the centralised flow-through concept causes also a ***quantity problem***. Here, long-term renewable water resources (renewal rates of up to several Million years) are discharged via short-term renewable water resources (surface waters, e.g.

rivers: renewal rates of days only, up to several months) into the seas. This shortcut is additionally intensifying the worldwide water crisis.
Additional treatment steps for end-of-pipe-systems, like ultra-filtration and/or ozone treatment, are applied to avoid the disadvantages. Increasingly common in the world's arid and wealthy regions (e.g. Gulf Region) is the reuse of the treated and ultra-filtrated waste water for irrigation in agriculture, or for groundwater recharge. The problem arises here, that hormones, antibiotics-resistance plasmids and pharmaceuticals can pass the ultra-filtration membranes, arrive in the food chain and finally into humans. To degrade these contaminants, the entire ultra-filtrated sewage stream needs to be additionally treated with ozone, which would be very costly considering the quantity of these flows.
Another major drawback of the centralised flow-through concept is the high investment into sewerage systems, which are typically between 70 and 90% of the overall investment into wastewater systems. Moreover, the nutrients incorporated by humans and excreted with urine and faeces are highly diluted and can hardly be recovered.
Within the last years, several concept innovations have been introduced. Within the "Gesellschaft für technische Zusammenarbeit (GTZ)" a specialised sector project, called "EcoSan" (Ecological Sanitation), for this flow-oriented concept was established (GTZ, 2002). Many proposals and common technologies for a source control wastewater management including different flow treatment already exist (Winblad, 1998, Otterpohl et al, 1999). Some of these concepts are more suitable for rural areas; whereas some are more applicable for cities. In (Otterpohl et al., 1999) ten basic scenarios are classifying the variety of combinations of modules in dependence of the different geographic and socio-economic conditions around the world. Paris and Wilderer (Paris, 2001) elaborated an extensive overview of realised concepts based on source control. Some of this concepts are based on urine separation (Braun, 2001), while this concept is based on normal flushing toilets, which don't consume any water anymore (Braun, 1998). Well known is the so called vacuum biogas concept, which has been realised in Lübeck, Flintenbreite (Otterpohl et al., 1999, OtterWasser, 2002). In Freiburg-Vauban a similar project has been realised with 40 inhabitants (Lange, Otterpohl, 2000). In Berlin, Germany, a maintenance building has been equipped with a sewage plant using urine separating toilets (BWB, 2002). In Norway, black water is treated aerobically under thermophilic conditions (Skjelhaugen, 1998).

MATERIALS AND METHODS

More efficient technologies are based on source separation of toilet wastewater. In a close cooperation with the Hamburg University of Technology (TUHH), Intaqua AG has developed the internationally patented "LooLoop-Process" – the loop processing of toilet waste water generating concentrated and thoroughly treated liquid and solid fertilisers plus soil conditioners. The LooLoop-Process has been researched at the TUHH, where a semi-technical (20 PE) plant has been designed, built and operated for almost 2,5 years. The treatment steps of the process comprise of

1. separation of solids, which are further worm-composted (Vermicomposting) in smaller units or digested (larger units),
2. Ureolysis / equalisation tank
3. biological oxidation comprising nitrification of the liquids,
4. Ultra-filtration
5. UVC radiation, respective ozone treatment.

The following compounds have been used:

1. Liquid/solids separation with a riddle-screen, SWECO Separators, model LS18S33, SWECO Inc., USA
2. Ureolysis in a not aerated storage tank

3. VA-steel-reactor with aeration membranes (in-house construction)
4. VUM (Vacuum Upstream Mambrane) Ultra-filtration membrane of Hans Huber AG, Germany
5. UVC Radiation: sterilAqua UVC Radiator, model AQD2136-3 by sterilAir AG, Switzerland
6. Ozone treatment: Sander Labor-Ozonisator, 20 / 80 g/m^3, Erwin Sander Elektroapparatebau GmbH, Germany
7. Sensor measurement: WTW IQ Sensor Net, System 2020.

Analytics have been proceeded with

1. COD: Lange Küvettentest LCK314 TC, TOC, TIC - autoanalyzer
2. BOD: Respirometer Selutec BSBdigi
3. $NH_4/NO_2/NO_3$: Dr. Lange Küvettentests, RQflex. MERCK
4. Temperature, pH, O_2, conductivity, redox, TS: WTW IQ Sensor Net

First, the process of ureolysis has been investigated. Three reactors and one reference reactor à 7.7 litres have been constructed and operated:

1. reference reactor
2. aerated pumped fixed bed reactor
3. pumped fixed bed reactor
4. anaerobic stirred reactor

Besides the reference reactor, all reactors have been inoculated with sewage sludge. All reactors have been fed then with an increasing amount of artificial black water, composed of 12 g faeces diluted in 1 litre urine. During increase, the activity of ureolysis was measured. Furthermore experiments regarding biological oxidation of urine, storage of oxidised urine, and decolourisation of urine have been carried out.

Fig. 1: Toilets installed in the lab

Fig. 2: LooLoop research installation

After researching the LooLoop plant was installed. A normal flush toilet and a waterless urinal have been installed on the upper level of the TUHH test hall. Figure 1 is showing the toilet area in the upper level, figure 2 shows the LooLoop plant beneath. The plant was designed for approx. 20 PE. The plant has been started-up with normal, untreated tap water. Students and scientific researchers of the institute have used the toilet facility and reported the kind of usage (urinating only, defecating only, or both) and the plant was operated for almost 2.5 years.

RESULTS AND DISCUSSION

Ureolysis

It could be shown, that the not aerated fixed bed reactor had the most effective results. During the experiments a close correlation between conductivity and NH4 concentrations could be proven. In the aerated reactor, NO_2 could be measured, but disappeared from a retention time less that 60 minutes. Variations of recirculating had no influence on ureolysis efficiency. Simulating the entrance of nitrate (LooLoop Process) into the reactors by addition of $Ca(NO_3)_2$, no nitrate losses could be detected in the aerated reactor, but a dissimilatory nitrate reduction ($NO_3 \rightarrow NO_2$) could be measured in not aerated reactors.

Riddle screen

The riddle screen protected the membrane very well. The mesh size could be variated to investigate the effect on the dry matter content of the faeces

Biological oxidation

Problems occurred during the start-up operation due to the low growth rates of the nitrifying bacteria. An accumulation of NO_2 could rarely be observed and NO_2 accumulation disappeared without external regulations. It was necessary to buffer the pH of the reactor. The reactor did not emit any smells – regarding this aspect it also could be operated without a cover. The reactor was not fed with substrate for several weeks, and then started again under full load within one day. The biocenoesis immediately started again without efficiency losses. The oxidised black water in the reactor was of a brown colour. During operation, the nutrients were increasingly concentrating in their oxidised forms (NO_3, SO_4, PO_4). The theoretical final molar nutrient concentrations (approximately equalling urine) could not be achieved so far.

Ultra-filtration

The membrane was under-dimensioned, because no smaller membrane unit was available. Within the 2.5 years of operation, no chemical cleansing of the membrane was necessary. By membrane filtration, the brown colour changed into yellow.

UVC radiation and ozone treatment

It could be shown, that after this step a clear, colour and odourless flushing water can be produced, which is sensually indistinguishable from normal tap water. Drawbacks are the high energy consumptions. It could be shown, that the energy consumption of ozone treatment is significantly lower compared to decolourising by UVC radiation.

During the period of operation, no major process disturbances (membrane blockage, etc.) of the LooLoop-Process could have been observed. It could also been shown, that a black, humus-like compost can be hygienically safely produced from faecal matter and toilet paper. The optimal conditions for the composting process have been shown.

CONCLUSIONS

An integrating process is being introduced maximally conserving our renewable water resources. Potential recyclables are almost fully recovered: by-products of the LooLoop Process are compost, a fertiliser raw material and optionally and biogas. In combination with the "groundwater-loop process" (loop processing of grey water via a groundwater passage), even safe water self-sufficient settling becomes possible if 10 to 25 litres of water per person and day can be renewed from local resources (rain, groundwater, river, lake, sea). Domestic wastewater can be physically eliminated – and with that all the known and unknown potential threats of public health and the environment caused by faecal contamination.

The LooLoop Process can be seen as a core technology for high-efficient water management technologies, whereas for treatment and reuse a broad variety of possibilities exist. Two basically different reuses of grey water can be discriminated: Figure 3 illustrates the LooLoop Process in combination with an ***external*** grey water reuse (irrigation, landscaping, industrial process water, etc.). Figure 4 illustrates the indirect ***internal*** (after a passage through an artifical or natural groundwater body) reuse of grey water to drinking water – leading nearly to a water autarky with a remaining supply demand of 10 to 20 litres per person and day, which can be produced from rain water in most regions of the earth.

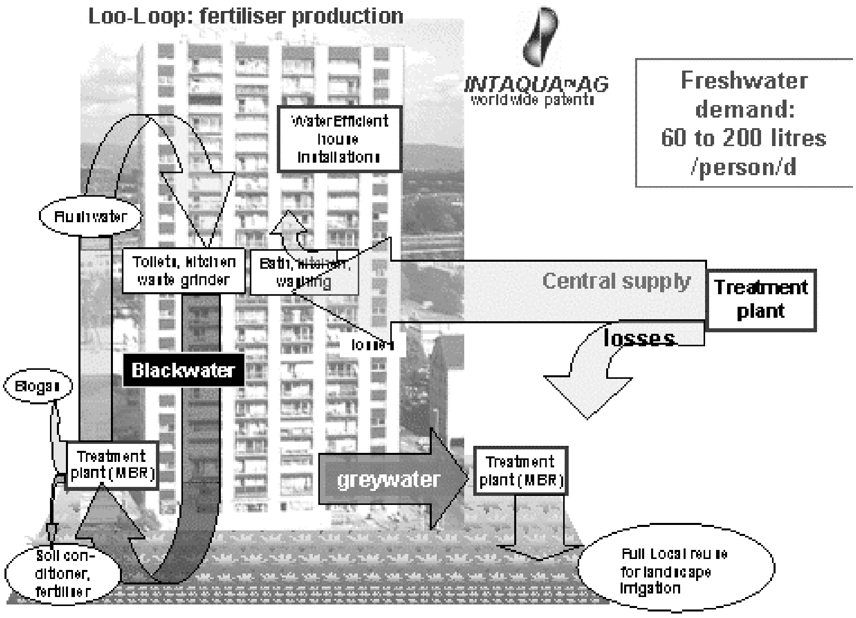

Fig. 3: LooLoop Process combined with greay water reuse as irrigation water

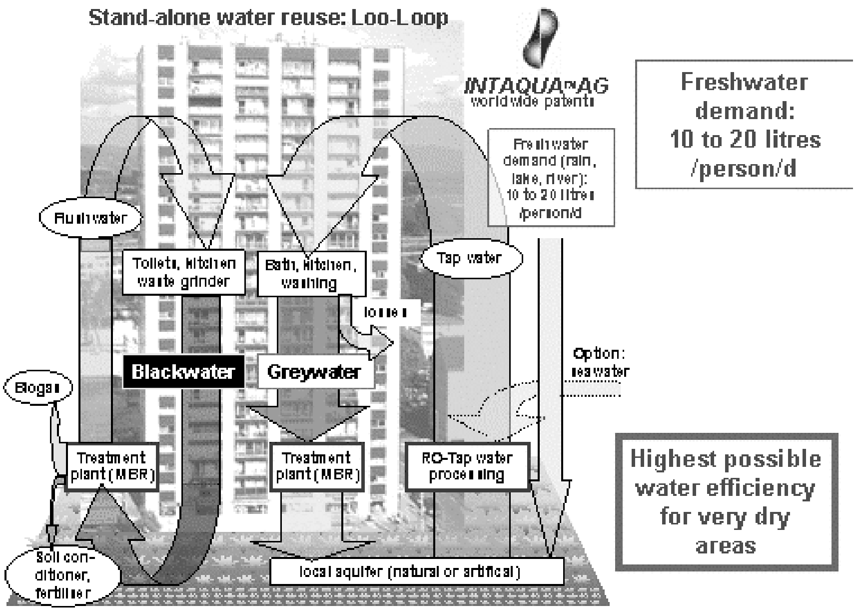

Fig. 4: LooLoop Process combined with water autarky

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