A novel concept: use of saline water in the water cycle of coastal cities

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ABSTRACT

Direct saline water, seawater or brackisch water, usage for toilet flushing could alleviate the freshwater shortage, but its worldwide application was hindered due to several issues and challenges. Over the last decade a group of researchers from Hong Kong, The Netherlands and South-Africa developed, tested and applied a novel approach to water management in coastal cities, where saline water is used as secondary quality water. This approach addresses traditional issues such as the need for a dual water system, requirement for use of non-corrosive materials, issues with H_2S formation, impact of increased salinity on biological wastewater treatment, reduced reuse options due to saline effluent, and lack of proper cost-benefit analysis of different options, in a holistic fashion and introduces novel technological interventions and developments at various parts of the urban water infrastructure system. Direct use of saline water replaces a substantial part of freshwater usage, exploits sewerage as a bioreactor and introduces new Sulphate reduction, Autotrophic denitrification and Nitrification Integrated (SANI) process technology for treatment of sulphate-rich wastewaters. This paper outlines the concept that has been evolved over the last 50 years in Hong Kong and has recently matured to the degree that can be applied at full scale in coastal cities.

KEY WORDS: *Innovative, Sanitation, SANI-process Seawater, Sustainability, Water-saving*

INTRODUCTION

Due to often combined effects of population growth, rapid urbanization, densification of urban area and climate variability, people are increasingly experiencing freshwater shortages worldwide. Nowadays, one fifth of the world population lives under water scarcity (World Business Council for Sustainable Development, 2005) and the situation is expected to be only worsened in the near future.

Traditional mitigation measures, like introduction of water saving devices or rainwater harvesting, are often insufficient e.g. solve the problem only partially. Therefore, novel alternative urban water management strategies need to be further explored and developed as an answer to ever increasing water stress. These strategies should preferably be focused on the reduction of the demand for freshwater and introduction of new approaches to urban water management that often includes a paradigm shift.

For production of potable water from saline water (seawater or brackish water), desalination techniques, such as multi-stage flash distillation, multiple-effect-distillation and membrane processes (e.g. reverse osmosis) are applied, as they are often the only way to make drinking water (Khawaji et al. 2008). Nevertheless, despite the recent technological advances, desalination is still a relatively expensive and unsustainable technology (Roest et al. 2010). Desalination techniques have a considerable negative environmental impact, because of the reject water production and high need for energy (Tsiourtis, 2001).

USE OF SALINE WATER IN URBAN ENVIRONMENT

An alternative to alleviate fresh water scarcity in coastal areas is to reduce the required amount of freshwater by replacing a part of non-potable demand by direct use of saline water. For example, in many countries approximately 30% of domestic water consumption is used for toilet flushing, (Foekema et al. 2008). It is not necessary to use potable water for such waste transport. Seawater and brackish water are excellent suggestions for second quality water as it is an almost infinite water resource (Ekama et al. 2010) and require minimal treatment of screening and chlorination for safe usage (Lu *et al*. 2011). This approach is already for 50 years successfully applied in Hong Kong, but was not adopted worldwide yet due to several disadvantages that hindered the wider application, like the need for a dual water supply system, requirement for use of non-corrosive materials, issues with H_2S formation, impact of increased salinity on biological wastewater treatment, reduced reuse options due to saline effluent, and lack of proper cost-benefit analysis of the traditional systems and novel alternative approaches. However, over the last decade a team of researchers from Honk Kong, The Netherlands and South-Africa, developed, tested and applied a novel approach to urban water (cycle) management that addresses most of the above challenges in a holistic manner providing a sustainable and cheaper set of solutions in comparison to business as usual practice.

ADVANTAGES

In Hong Kong about 80% of the city is equipped with a dual water supply system; one for potable fresh water and one for saline water. After some simple pre-treatment of screening en electro-chlorination, seawater is directly used for toilet flushing resulting in a considerable reduction in potable water demand. Public health concerns due to eventual cross connections are minimized as seawater is easily detectable by the user. Thus, no expensive sensors are needed. Furthermore, a novel approach introduces urine diversion toilets (UDT) which allows for selective on-site urine collection, partial treatment (nitrification), and controlled discharge of nitrate-rich (instead of ammonia) urine to the sewer system (Mackey *et al*. 2011). It is a known fact that nitrate presence in the sewer system will hinder H_2S formation and therefore will address the issue of odor, safety and corrosion in the sewer system. Furthermore, it will allow for (partial) denitrification to take place in the sewer and reduce aeration requirements at the centralized wastewater treatment plant (WWTP).

Direct usage of saline water results in salty and sulphate-rich wastewater, and the latter was recognized not as a barrier but as an opportunity which lead to development and pilot application of a novel process for sulphate-rich wastewater treatment called Sulphate reduction, Autotrophic denitrification and Nitrification Integrated (SANI) process (Lu *et al*. 2009; Tsang *et al*. 2009; Wang *et al*. 2009).

The SANI process consists of two reactors; an up-flow anaerobic sludge bed (UASB) reactor, and a reactor with anoxic and aerobic filters (Wang *et al*. 2009). The UASB reactor is designed to remove organic matter by sulphate reducing bacteria (SRB). Consequently, sulphate reduction leads to production of sulphide. Typical factors affecting sulphate reduction are salt, temperature, pH, sulphate concentration (COD/SO_4^{2-}), influent COD composition and types of microorganisms present (Visser et al. 1993; Bhattacharya et al. 1996; Vallero et al. 2003). The anaerobic reactor is followed by a second reactor with (1) an anoxic zone for autotrophic denitrification of nitrate with dissolved sulphide generated from sulphate reduction in the previous step and, (2) an aerobic zone to nitrify ammonia and reticulate nitrate to the anoxic zone for the denitrification (Wang *et al*. 2009). The SANI process combines three important advantages (heavy metals removal and recovery potential due to production of sulphide, comparatively better pathogen removal, and substantially lower excess sludge production) over conventional wastewater treatment system processes, while retaining excellent and stable COD and N-removal efficiency (>95%, (Tsang et al. 2009; Lu et al. 2011). This results in lower costs and energy requirement. Analysis shows that direct usage of seawater for toilet flushing is approximately 6, 20 and 15 times cheaper regarding the capital investment, life cycle unit costs and electricity consumption, respectively, in comparison to seawater reclamation by reverse osmosis (Chen *et al*. 2010).

Even though the fresh water consumption is significantly decreased when direct seawater use is applied, this practice is considered disadvantageous when the produced wastewater is intended for reused, because of its elevated salinity content compared to fresh wastewater. The issue of hindered sewage treatment plant effluent reuse due to increased salinity may be partially mitigated by separate treatment of saline black water (toilet water) and grey water

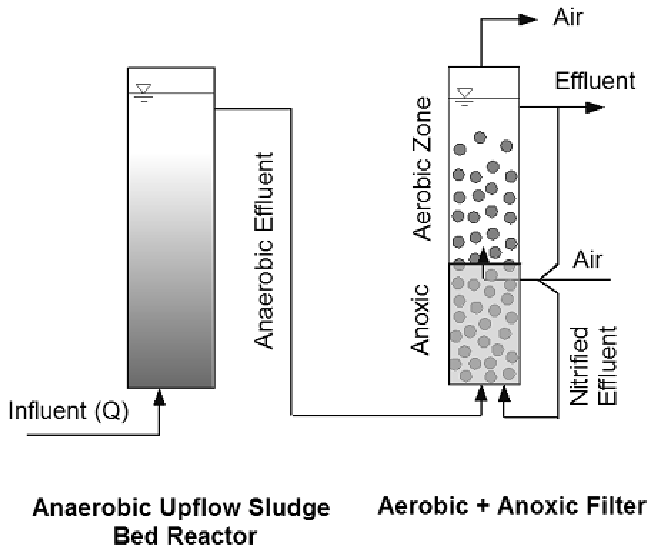

Figure 1. *A schematic diagram of the experimental setup of the Sulphate reduction, Autotrophic denitrification and Nitrification Integrated (SANI) system (Lau et al. 2006)*.

('other' wastewater) which will lead to approximately a five fold higher salinity content in the influent of the SANI treatment plant. Preliminary results indicate that the treatment of wastewater with higher salinity content is promosing.

CONCLUSIONS

The novel sanitation concept for direct use of saline water for e.g. toilet flushing is a very effective method to reduce stress on often scarce freshwater resources. The introduction of saline water to the urban water system is relatively simple, safe, sustainable and economically affordable in urban coastal areas. The novel approach successfully addresses major concerns and challenges that hindered its wider use in the past and opens window of opportunities for its worldwide application. The saline wastewater treatment concept SANI can not only be applied in coastal cities, but also at locations where wastewater contains excessive amounts of sulphate as a result of (*i*) sea and brackish water intrusion into the sewage, (*ii*) discharge of industrial sulphate-rich effluents into the sewer, and (*iii*) elevated sulphate content of the drinking water). The SANI-process is an excellent technology to treat saline wastewater, due to its advantages over conventional systems, like minimal sludge production, pathogens removal and adequate COD and N removals with reduced energy requirement and lower costs.

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