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Greywater Treatment & Reuse: A Technological Review

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ABSTRACT

Freshwater scarcity is a serious issue that affects at least one-fifth of the world's population and more will be affected due to population growth, mismanagement, increased urbanization and climate change. Innovative concepts and technologies are straight away needed to close the loop for water. Greywater reuse is one of the main alternatives for reducing potable water consumption in households, industries and commercial buildings. This article aims to review some of the principle greywater treatment technologies and their applications.

KEYWORDS : Greywater, Population growth Scarcity, Urbanization

1. Introduction

Urban agglomerations import large volumes of clean water to cater the water needs of their increasing populations and produce large volumes of wastewater and storm water that together, are quickly evacuated, decontaminated and disposed of, usually into rivers or lakes. Within this context, new approaches are emerging to achieve a more sensible and sustainable management of existing water resources (Domened and Sauri, 2010). Rainwater, greywater and desalinated sea water are considered to be good alternative resources. Rain water harvesting is one of the most useful options of water conservation but it has some limitations such as it is only useful for areas receiving good amount of rainfall throughout the year. On the other hand, seawater desalination results in increased emission of CO_2 and other pollutants to the atmosphere and causes disturbance to the adjacent marine environment. Hence, greywater reuse is a viable option that can be very useful in water arid and semi-arid areas. There are variety of system designs from simple to sophisticated systems designed according to quality and type of reuse. This paper presents a review of some of the systems.

2. Greywater Conceptual Aspects

Greywater is generally defined as "Low polluted wastewater originating from bathtubs, showers, hand washing basins and washing machines excluding wastewater from toilet flushing system" (Kraume et al., 2010). Greywater constitutes about 70% of household water consumption and has lower concentration of organic compounds and fewer pathogens compared to domestic wastewater. As a result, greywater may be treated and reused much easily than composite domestic wastewater for the point of treatment technologies applied and relevant costs (Sachin, 2015).

2.1 Characteristics of greywater

Common Contaminants found in greywater are salts, food particles, oil, surfactants and microorganisms. Indeed, the greywater characteristics are highly variable as influenced by factors such as lifestyle, social and cultural behavior of residents, and water availability (Couto et al., 2015). Table 1 shows the average characteristics of greywater generated from a typical middle-class Indian household.

Table 1: Average characteristics of greywater generated from a typical Middle-class Indian Household (Vakil et al., 2014)

Parameters	Bath/ Shower	Washbasin	Kitchen	Laundry	Average
pH	7.5	7.5	6.2	9.4	7.6
TDS (mg/L)	277	237	245	1060	455
COD (mg/L)	461	225	602	824	528
BOD (mg/L)	81	43	293	269	172
TSS (mg/L)	148	48	308	1852	589
Ammonia-Nitrogen	2.1	1.6	4.7	10.7	4.8
Nitrate-Nitrogen	2.6	2.5	11.4	79	24
Orthophosphorous (mg/L)	0.0	0.0	5.3	18.0	11.7
Fecal Coliforms (MPN/100ml)	930	39	230	430	407

2.2 Advantages and Disadvantages of Greywater Reuse

Even though greywater reuse is very advantageous in arid and semi-arid places like Bengaluru, it is accompanied with some of the disadvantages. Some of the advantages and disadvantages of greywater reuse are listed in the following section.

2.2.1 Advantages

- Reduction of overall water demand
- Reduction of Organic and hydraulic loadings on the municipal wastewater system
- Reduction in water bills
- Replenishment of ground water which contributes to a healthy water cycle
- Protection of aquatic ecosystems due to decreased diversions of freshwater

2.2.2 Disadvantages

- Cannot be stored for more than 24 hrs (since nutrients break down and cause bad odor)
- Biodegradable soaps and detergents can also present a problem over a period of time when greywater is used for irrigation
- Health standards of the water and quality concerns
- Contains fats, oils, grease, hair, lint, soaps, cleansers, fabric softeners, and other chemicals that are harmful to plants

2.2.3 Norms and Regulations for Greywater Reuse

Selection of a technology also depends on the local norms and regulations for greywater reuse. There are no particular norms and regulations for greywater reuse in India since the concept of greywater reuse is still in infant stage. For this reason, the norms and regulations of some other countries where greywater reuse is widely practiced has been collected and presented below.

Table: Norms and Regulations for Greywater Reuse (Couto et al., 2015)

References	Type of Reuse	Reclaimed water quality
United States Environmental Protection Agency (2004)	Urban reuse: All types of landscape irrigation, toilet flushing, fire protection, commercial air conditioning Construction – soil compaction, dust control, washing aggregate, making concrete Agricultural Reuse – food crops not commercially processed – surface or spray irrigation Restricted access area irrigation – sod farms, areas where public access is prohibited	pH = 6-9, BOD = ≤10 mg/L, Turbidity = ≤2 NTU, FC = no detectable fecal coli/100 ml, Chlorine, Cl_2 = 1 mg/L residual (minimum) pH = 6-9, BOD = ≤30 mg/L, TSS = ≤30 mg/L, FC = ≤200 fecal coli/100 ml, Cl_2 = 1 mg/L residual (minimum) pH = 6-9, BOD = ≤10 mg/L, Turbidity = ≤2 NTU, FC = no detectable fecal coli/100 ml, Cl_2 = 1 mg/L residual (minimum) BOD = ≤30 mg/L, TSS = ≤30 mg/L, FC = <200 fecal coli/100 ml, Cl_2 = 1 mg/L residual (minimum)
Environmental Agency UK (2011)	Spray application: Pressure washing, garden sprinkler use and car washing Non-spray application: WC flushing Non-spray application: Garden watering Non-spray application: Washing machine use	pH = 5-9.5, Turbidity = <10 NTU, FC = 10 fecal coli/100 ml, Chlorine (Cl_2 = <2 mg/L) pH = 5-9.5, Turbidity = <10 NTU, FC = 1000 fecal coli/100ml, Chlorine (Cl_2 = <2 mg/L) pH = 5-9.5, FC = 1000 fecal coli/100 ml, Chlorine (Cl_2 = <0.5 mg/L) pH = 5-9.5, Turbidity = <10 NTU, FC = 10 fecal coli/100 ml, Chlorine (Cl_2 = <2 mg/L)
Ministry of Health Canada (2010)	Toilet flushing	Turbidity = <5 NTU, BOD = ≤20 mg/L, TSS = ≤20 mg/L, FC = <200 fecal coli/100 ml, Cl_2 = >0.5 mg/L residual
World Health Organization (2006)	Restricted irrigation Unrestricted irrigation of crops	Helminth eggs <1/L, *Escherichia coli* <1,00,000 (relaxed to 10,00,000 when exposure is limited or regrowth is likely) Helminth eggs <1/L, *Escherichia coli* <1000 (relaxed to 10,000 for high growing leaf crops of drip irrigation)

3. Greywater treatment technologies: An overview

The technologies applied for greywater treatment include physical, chemical and biological processes. Greywater reuse must increasingly become part of a set of integrated actions towards the rational use of water, since this type of effluent represents an alternative source for non-potable uses, with extensive applicability not only in residential, commercial and industrial buildings but also in buildings like airports. Couto et al., 2015 analyzed the suitability of anaerobic filtration followed by ultraviolet disinfection for treatment of greywater generated from the Brazilian airport. The operation flow was maintained at 2.82 m^3/day. The removal efficiencies for turbidity and suspended solids were 88% and 77% respectively. Due to its simple operation, the system is mostly indicated for small and mid-size airports, or for decentralized treatment in large airports.

The performance of a Drawer Compacted Sand Filter (DCSF) was evaluated by Assayed et al., 2015. The system was designed to overcome the problems commonly found in traditional sand filter designs such as clogging, emission of bad odors and need for a large area to house the filter. Nine pilot DCSF plants were operated at different locations in Jordan for a period of 2 years and the results showed 78-96% of BOD_5 and 69-98% of TSS removal. However, the system was found to be maintenance intensive having large footprint (20 sqm to treat 142 L/day and 30g BOD_5/m^2/day).

The economic feasibility of an artificial wetland (AW) and a Commercial Bio Filter (CBF) to treat greywater from households in Syria were evaluated by Mourad et al., 2011. The analyses showed that, in the current water tariff in Syria, the payback period for AW and CBF in block systems will be 7 and 52 years respectively. The system is suitable for buildings and separate houses that have the required area of 0.8 m^2/person.

An aerobic digestion unit integrated with Hydrogen Peroxide disinfection is found to be simpler for greywater treatment in comparison with other treatment processes. The system successfully removes TSS and COD (88% and 68%) with optimal operational settings of 5 hour HRT and organic loading rate of 216 g COD/L.day. Nonetheless, the system requires further optimization to achieve higher treatment efficiency and is more suitable for implementation in small communities due to minimal microbial activity after storage and relatively small area required for treatment (Teh et al., 2015).

Submerged Sequential Batch Reactor (SM-SBR) for greywater is especially interesting in cases of space limitations where the small footprint of the system can outweigh inconveniences like frequent chemical cleanings. Kraume et al., 2010 operated three pilot plants in three different countries with distinct wastewaters. The permeate quality fulfilled in most cases the high mandatory values of different European directives. Membrane permeability was found to decline significantly within a period of 3-4 months so that recovery cleanings were necessary 3-4 times year. In general, the treated greywater from an SM-SBR can be reused for irrigation or cleaning purposes. The biggest advantage of the system is its high efficiency resulting in high hygienic quality and small footprint that suits remote tourism locations. On the other hand, the disadvantage is its critical operational stages that require very skilled and trained personnel.

Main and Ingavale, 2012 conducted a study to examine the applicability of SBR technology for treatment of greywater for various reuse purposes and found that, greywater treated with SBR can be reused for various purposes such as surface irrigation (food crops that are commercially processed), urban reuse including landscape irrigation (e.g. golf course, parks), vehicle washing, toilet flushing, fire protection systems, commercial air conditioners etc., recreational impoundments, aesthetic impoundments and construction use (soil compaction, dust control etc.) since the system removed 94.57% BOD, 84.85% COD, 89.73% Suspended Solids and 63.89% Total Solids since these characteristics falls within the standards of US EPA for the above mentioned reuse purposes.

The performance of a Moving Bed Biofilm Membrane Reactor (MBBMR) was analyzed by Favero and Jabornig, 2013 for an onsite greywater treatment for a single household with four inhabitants over 10 months. Synthetic greywater with different loadings and varying ambient temperatures was part of the study. Natural hair color could be removed by almost 80% and energy consumption was less than 1.3 kWh/m^3. The process configuration proved to be feasible for the implementation of onsite Microsystems with high flow and load variation.

A submerged spiral wound Membrane Filtration module can efficiently remove TOC and nutrients and hence can produce permeate which is low in turbidity (below 1 NTU) and free of Suspended Solids and E. coli with excellent physical appearance (Sachin, 2015a). MBR systems being the advanced technologies appear to be attractive with respect to all aspects including high efficiency resulting in high hygienic quality of water, low energy consumption and small footprint (Li et al., 2009).

Another technology that is being widely used for greywater treatment is the Rotating Biological Contactors (RBCs). RBCs can efficiently treat greywater with removal efficiencies of 93-96% and 84-95% respectively for BOD and TSS respectively. However, the system has large footprint (approximately 0.5 m^2 clarifier surface area for treating 400 L) (Sachin 2015b).

Electro coagulation treatment is another advanced technology that has been implemented in various places for greywater treatment. A combination of aluminum and graphite electrodes removes 70% of total COD and more than 99.9% of pathogens from greywater generated by a typical Indian Middle-Class household with energy consumption of 0.3 kWh/m^3 of greywater treated (Vakil et al., 2014). However, according to the authors, the electrodes operate with high potential difference and hence show high potential for scale-up for real-life use in households for removal of pathogens, turbidity and COD contents of greywater.

On reviewing various research papers, it was found that physical processes alone are not sufficient to guarantee an adequate reduction of the organics, nutrients and surfactants. The chemical processes can efficiently remove the suspended solids, organic materials and surfactants in the low strength greywater. The combination of aerobic biological process with physical filtration and disinfection is considered to be the most economical and feasible solution for greywater recycling.

4. Summary and Conclusions

The major challenges in greywater treatment in order to meet all quality requirements are the fact that the quality of such effluent varies according to source, geographical location, demographics, level of occupancy and occupancy rate. The technology should be chosen based on these criteria along with the desired end use.

The greywater reuse has great potential in wide range of applications in domestic, commercial, institutional as well as industrial buildings. Full scale systems are operational in various parts of the world and substantial growth in the number and size of installations is anticipated as a viable alternative for many wastewater challenges like water quality issues.

Thus we conclude that it is possible to treat greywater produced in all types of buildings using simple technologies which are easily replicable, inexpensive and that satisfy international reuse recommendations for non-potable activities.

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