Grey Water Reclamation Using Multisystem of GAC Biofilm Reactor and Sand Filter: Case Studies of Mosques in Yemen

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Abstract. A system involving a granular activated carbon (GAC) biofilm up-flow expanded bed (UEB) reactor and a slow down-flow packed sand filter was established for treating mosque grey water (ablution water). The faecal coliforms (FC), chemical oxygen demand (COD), total suspended solids (TSS), nitrate (NO₃), and ammonia as nitrogen (NH₄-N) were investigated under continuous flow operation using a hydraulic retention time (HRT) ranging from 1-6 hr over the period from 5/9/2010 to 6/2/2011. The system was arranged so that the GAC reactor is the first stage of treatment, and the sand filter is the second stage. Influent and effluent samples from the system were analysed weekly. The system demonstrated satisfactory removal of faecal coliforms with removal efficiencies of 63–80 %, and the efficiencies of COD and TSS removal were 70 % and 72 %, respectively. The system showed low removal efficiencies of nitrate which was 0–13 %. No ammonia removal was recorded in that range of retention time, while the system showed approximately 50 % removal efficiency on average for 12 hr of HRT.

Keywords: Grey water, GAC biofilm, sand filter.

1. Introduction

Because water is a limited resource, especially in countries with arid environments, water conservation has become of increased importance [1]. Even in countries with substantial water resources, the excessive use of water has affected the availability of the resource [2] and has thus spawned interest in conserving this resource. Instead of using fresh water for irrigation, recycled grey water can be used for that purpose, which will reduce water distribution and energy costs [3]. One of the concerns of using recycled grey water for irrigation purposes or toilet flushing is related to the possible presence of pathogens [1, 3].

In recent years, the recycling and reuse of ablution water has been adopted in some Middle Eastern countries. Some Arab countries, particularly the Arabic Gulf Cooperation Council States (AGCCS), have begun to treat and reuse grey water as a step in facing the water scarcity. In Yemen, this process began in 2006 in Aden city when the government, with the United Nations Development Programme (UNDP), implemented a project involving the treatment of grey water from six mosques for reuse in middle kerb irrigation and afforestation purposes.

Yemen is regarded as one of the semiarid regions as a result of rainfall shortages. Thus, within recent decades, it has been faced with an extreme shortage in the potable water supply. Therefore, the government began to search for alternative sources of water, such as grey water.

Fixed-film processes for wastewater treatment appeared in 1865, when Mueller showed that microorganisms in a filtration column could purify sewage [4]. Biofilm may be defined as a group of microorganisms and extracellular products that adhere to a solid support, forming a voluminous and thick layer, with an external structure that is not completely regular and uniform. Its chemical composition, both inorganic and organic, is a function of the substrate composition [5].

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Adsorption is an important treatment method that can be used to remove pollutants from water and wastewater. Activated carbon adsorption has been proven to be an excellent method for removing the organic pollutants from water and wastewater [6, 7].

In fixed-film wastewater treatment processes, the major components of biofilm are bacteria and fungi, with bacteria usually predominating [8]. The attachment of microorganisms to the solid surface is a result of adsorption followed by active attachment [9]. The accumulation of microorganisms on a collecting surface can be divided into three stages [10]:

- Adsorption, or the immobilisation of an organism on a collector surface,
- Attachment, or the consolidation of the interface between an organism and a collector, often involving the formation of polymer bridges between the organisms and collector, and
- Colonisation, or the growth and division of organisms on the collector surface.

2. Problem Statement

- The problem of water in the Republic of Yemen is one of the important problems facing the population in both rural and urban. Yemen suffers from water scarcity because the water drawn from wells greater than the level of nutrition.
- According to international reports the Capital Sana’a is the first town in the world will be without potable water.
- Greywater is considered a significant source of water for reuse but it is underexploited so far.
- Drinking water in Yemen is used for irrigation purpose.

3. Literatures Review

3.1. Grey Water Quality

The characteristics of household grey water can vary depending on the number of household occupants, their age, health status, lifestyle, tap water sources, water usage patterns and household products used (such as soaps, shampoos, detergents, mouthwash, toothpaste, hair dyes, shaving cream, and body oils). The typical composition of grey water is shown in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Grey water Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspended Solids</td>
<td>mg/l</td>
<td>45 - 330</td>
</tr>
<tr>
<td>Turbidity</td>
<td>NTU</td>
<td>22 - 200</td>
</tr>
<tr>
<td>BOD5</td>
<td>mg/l</td>
<td>90 - 290</td>
</tr>
<tr>
<td>Nitrite</td>
<td>mg/l</td>
<td>&lt;0.1 – 0.8</td>
</tr>
<tr>
<td>Ammonia</td>
<td>mg/l</td>
<td>&lt;0.1 – 25.4</td>
</tr>
<tr>
<td>Total Kjeldahl</td>
<td>mg/l</td>
<td>2.1 – 31.5</td>
</tr>
<tr>
<td>Nitrogen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total phosphorous</td>
<td>mg/l</td>
<td>0.6 – 27.3</td>
</tr>
<tr>
<td>Sulphate</td>
<td>mg/l</td>
<td>7.9 – 110</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>6.6 – 8.7</td>
</tr>
<tr>
<td>Conductivity</td>
<td>mS/cm</td>
<td>325 – 1140</td>
</tr>
<tr>
<td>Sodium</td>
<td>mg/l</td>
<td>29 - 230</td>
</tr>
</tbody>
</table>

Source: [11]

The characteristics of fresh and stored grey water have been studied by several authors [11, 12, and 13]. The quality of the water supply, storage time and materials used for distribution may affect the grey water quality [13].

Ablution basins in mosques can be considered a source of grey water. Mosque grey water is has different characteristics compared to household grey water because it does not contain food or chemical products. Ablution water is the water that has been used by worshippers for washing (wudhu) parts of their bodies before prayer. This grey water may contain suspended solids, biological oxygen demand (BOD), pH, dirt, turbidity, and some
faecal coliform contaminants. Sometimes, this water contains chemical pollutants, such as nutrients and sodium, which are produced because some worshippers use chemical products, such as soap, for washing.

Prathapar et al. [14] analysed ablution water samples from two mosques in Oman in terms of the pH, electrical conductivity, turbidity, dissolved oxygen, BOD$_5$, COD, coliforms, E. coli, TSS, total dissolved solids (TDS) and total carbon. The results indicated that the pH, E.C. and TDS of the grey water produced at both mosques were within the limits of water suitable for irrigation, but the BOD$_5$, COD, coliform and E. coli levels exceeded the permissible concentrations, requiring treatment before reuse.

3.2. Guidelines for Reclamation

Each country has (or needs to create) its own regulations or guidelines for reclaimed water and allowable applications. The guidelines or standards for reclaimed water depend on the type of application the water will be reused in and the opinion of each country on safety. For example, the Jordanian standards for the irrigation of cooked vegetables are 50, 100 and 45 mg/l and 100 N/100 ml for TSS, COD, T-N, and faecal coliform, respectively, while they are 150, 500 and 70 mg/l and 1000 N/100 ml, respectively, for the irrigation of trees and green areas. In Oman, the reclaimed water standards range from 15-30, 150-200, 5-10 mg/l and 200-1000 N/100 ml for TSS, COD, ammonia as N, and faecal coliform, respectively, and depend on the field of water reuse. Yemen has adopted most of the Jordanian standards for treated wastewater reuse.

3.3. GAC Biofilm Reactor and Sand Filter System

Granular activated carbon is a particularly good adsorbent medium due to its high surface area to volume ratio [15]. Granular activated carbon (GAC) biofilm reactors can combine these two features; the adsorptive capacity and irregular shape of GAC particles provide niches for bacterial colonisation protected from high fluid forces [16], while the variety of functional groups on the surface can enhance the attachment of microorganisms [17].

A granular activated carbon (GAC) biofilm reactor was established [18], and the degradation of 4-CP was investigated under continuous flow operation with a hydraulic residence time of 17 min over a 6-month period. The reactor had 4-CP removal efficiencies of 69–100%.

Slow sand filter treatment has been employed around the world as an economic and simple system to provide a safe water supply [19]. Technically, a sand filter is a vessel filled with sand, through which the water usually travels by gravity from the top to the bottom, with a flow velocity between 0.1 and 0.3 m/h [19, 20, and 21].

A multisystem consisting of a granular activated carbon (GAC)-biofilm configured up-flow fluidised expanded bed (UFEB) reactor and a slow down-flow packed sand bed reactor was used by Rasid and Rahman [22] for rainwater treatment. The removal efficiencies were more than 92.6 % and 45.16 % for COD and ammonia, respectively.

4. Materials and Methods

This experiment was performed in the capital city, Sana'a. The location was in a closed place to prevent people, especially children, from entering. The inspection chamber, which receives the ablution water, was prepared to include the collection tank. The plumbing of the other sewers was rerouted to outside of the collection tank.

Before the experiment the daily grey water quantity of mosque was determined over three weeks to estimate the volumes of the collection tank, storage tanks and reactor and to determine the quantity of reclaimed water that will be obtained. The daily mosque grey water quantity determination was dependent on the number of worshippers performing the ablution and the average water quantity consumed by one worshipper during the ablution. The numbers of worshippers were determined by counting the worshippers that performed the ablution in each of five prayer times for one week, and the average was calculated as person/day. The average water quantity consumed by one worshipper during the ablution was determined for three people selected randomly in each prayer five times a day for a week, and the average was calculated as L/person. The mosque grey water quantity finally was calculated as m$^3$/day.

The collection and treatment system for the mosque conditions has been outlined in Fig. 1. The grey water from the ablution points first flowed into the underground collection tank through a mesh screen. The mesh
screen was replaced with new one once a week. Next, the grey water was pumped to the elevated storage tank. The pump was operated automatically depending on the water surface level in the collection tank.

Grey water was continuously fed from the storage tank to the GAC reactor by up-flow mode and into the sand filter by down-flow mode. The GAC reactor with a diameter of 40 cm and a height of 80 cm was filled with approximately 50 cm of granular activated carbon as the adsorbent and pieces of plastic media as filter media. The GAC reactor was placed inside the sand filter with a 10 cm circular space between them. A protection tank with a diameter of 60 cm and height of 80 cm was placed between the GAC reactor and sand filter. The purpose of this tank is to protect the GAC reactor from the pressure of sand and to be free to move inside or outside the compound. Fig. 2 shows the treatment system with the storage tank, and Fig. 3 shows the GAC reactor, protection tank, and sand filter.

The sand filter was established as circular tank with a diameter of 100 cm, a height of 130 cm and a 0.1 slope of the base towards the centre. The tank was filled with 5 cm in height of gravel, and 30 cm of fine sand with sizes of 0.15-0.6 mm was placed on the gravel layer. The protection tank was placed in the centre of the sand filter tank and on the layer of sand. Another layer of fine sand approximately 75 cm thick was applied to surround the protection tank. Water was drained from the centre of the base of the filter through a 2.5 cm pipe.

![Fig. 1: Schematic diagram of the collection and treatment system](image1)

![Fig. 2: Elevated storage tank and treatment system](image2)

![Fig. 3: GAC reactor, protection tank, and sand filter](image3)
4.1. Experimental Operation
The multi system of the GAC reactor and sand filter was continuously operated during a 22 week period, with different HRTs of 1, 2, 4, and 6 hr. Four weeks was adopted for the 1 hr retention time and six weeks for each of others. The HRT was controlled by controlling the flow rate via the flow meter as follows:

Volume of reactor = 0.8 \( \times (\pi \times (0.4)^2 / 4) \) = 0.1 m³
Flow rate = volume / HRT

The flow rates were 2400, 1200, 600, and 400 L/day for HRTs of 1, 2, 4, and 6 hr, respectively.

5. Results and Discussion
The system of composed of a GAC reactor and a sand filter has been operating with 1, 2, 4, and 6 hr of HRT for 158 days. Sample investigations were carried out weekly on the influent and effluent of the system. The total suspended solids removal efficiency reached to 72%. The TSS levels were reduced from 43 mg/l to 18 mg/l on average using the system (Fig. 4).

The chemical oxygen demand (COD) was removed with a 65 % removal percentage average and the percent reduction range was between 54% and 70%. The average COD concentration was reduced to 50 mg/l (Fig. 5). The ability of the system to remove nitrate (NO₃) was weak. The removal efficiency ranged between zero and 13% (Fig. 6). NO₃ removal occurred by a denitrification process in which nitrate is converted to nitrite by facultative heterotrophic bacteria. The system showed the reverse results for ammonia removal in the range of HRT from 1 to 6 hr (Fig. 7). These results because the system was anaerobic, while ammonia needs oxygen to be converted into nitrate as presented in the following formulas:

\[ \text{NH}_4^+ + 3/2 \text{O}_2 \rightleftharpoons \text{NO}_2^- + \text{H}_2\text{O} + 2\text{H}^+ \]
\[ \text{NO}_2^- + 1/2 \text{O}_2 \rightleftharpoons \text{NO}_3^- \]

The two steps of the conversion process, called nitrification, require sufficient time to occur. Therefore, the low HRT may have contributed to obtaining these results, and when the system was operated at 12 hr of HRT, the removal efficiency of ammonia was 46% on average (Fig. 8).

The low ammonia removal efficiency in this study is related to the low oxygen in the anaerobic system because the nitrification process requires oxygen to oxidise the ammonia to nitrate. The average percentage of faecal coliform (FC) removal was 80% with an average concentration reduction of 253 to 72 mg/l (Fig. 9).

![Fig. 4: TSS concentration in grey water and after reclamation](image)

![Fig. 5: COD concentration in grey water and after reclamation](image)
6. Conclusion
The results of this study indicate that the system consisting of a granular activated carbon (GAC) biofilm upflow reactor and slow down-flow packed sand filter is effective in treatment of the mosque grey water (ablution water), particularly in faecal coliform removal. According to the guidelines and standards of some of the countries mentioned above the reclamation level of this system is acceptable. It has demonstrated a satisfactory level of efficiency in the treatment of the physical pollutant TSS, the organic chemical pollutant COD, and the microbial pollutant FC. The pollutant concentrations in the effluent of the reclaimed water were acceptable for irrigation in Yemen compared to the standards adopted for this purpose. When the reuse purpose of water is irrigation, nutrient removal is not critical because these nutrients are important for plant growth. Thus, it is recommended to use an HRT of 2 to 8 hr to remove physical, organic chemical and microbial pollutants. This system is suitable for countries that face a water shortage problem. The advantages of this system include the low cost of operation and maintenance.

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8. References


