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Household Treatment Unit for Greywater by Using Ceramic Tablet Membranes

[1,2]*Abdelkader T. Ahmed*

[1]Civil Engineering Department, Faculty of Engineering, Aswan University, Egypt
[2]Civil Engineering Department, Faculty of Engineering, Islamic University, Saudi Arabia

Abstract: This study aims to investigate and design a simple and cheap unit to treat the greywater in household via using ceramic membranes and reuse it in supplying water for toilet flushing. The study include an experimental program for manufacturing several tablet ceramic membranes from clay and sawdust with three different mixtures. The productivity and efficiency of these ceramic membranes were investigated by chemical and physical tests for greywater before and after filtration through these membranes. Then a treatment unit from this ceramic membrane was designed based on the experimental results of lab tests to be used in household applications. Results showed that increase sawdust percent with the mixture increase the flow rate and productivity of treated water but decrease in the same time the water quality. The efficiency of the new ceramic membrane reached 95%. The treatment unit save about 350 L/day water for toilet flushing without need to consume this amount from the fresh water supply network.

Key words: Greywater · Treatment · Filtration · Ceramic membranes

INTRODUCTION

Water becomes a rare resource and the ideal solution to overcome this issue is to discover alternative water resources for non- potable water applications in order to save the freshwater. Many studies agreed the necessary of finding another option of water to fulfill the needs of human demand other than the potable water. The onsite reuse and recycling of greywater is practiced in many countries as a sustainable solution to reduce the overall urban water demand [1, 2]. Greywater is defined as the urban wastewater that includes water from baths, showers, hand wash basins, washing machines, dishwashers and kitchen sinks, but excludes input from toilets. Greywater constitutes 50-80% of the total household wastewater [2, 3, 4]. In terms of organic contents, greywater shows similar characteristics to that of the entire municipal wastewater. However, as urine is not included in greywater, it has a limited amount of nitrogen [5, 6].

There are set of conditions boost up the re-use of treated greywater. Drought weather condition is the most popular reason let to the high rate of tap water usage for gardening and other outdoor households' applications. Santos *et al*. [7] pointed out to the significant role of reuse the greywater in terms of protecting the highly demand of freshwater consumptions as well as sewage productions. This is if the greywater undergo adequate and safe treatment systems in order to ensure the quality for only non-potable applications purposes. Further Briks *et al*. [8] implied that the countries with water sources limitations in different parts of the world have a prospective option of re-use the greywater for all water uses rather than drinking. If sufficient treatment is introduced to the greywater in order to obtain a proper treated water, which is safe and ready for the second applications. Moreover, the re-use of greywater systems should be safe, easy and accurate to be implemented with sufficient treatment in a manner that creates no risk to the public health.

A number of technologies have been applied for greywater treatment worldwide, varying in both complexity and performance. However, most of the greywater treatment pants include a biological step. However, the performance of biological treatment can be affected, especially at small scale, by the variability in strength and flow of the greywater. The high COD/BOD ratio of the greywater and the deficiency of both nitrogen and trace nutrients in the greywater can further limit the treat efficiency of the biological processes [9].

Corresponding Author: Abdelkader T. Ahmed, Civil Engineering Department, Faculty of Engineering, Aswan University, Egypt.
E-mail: dratahmed@yahoo.com.

Furthermore, a disadvantage of the biological treatments is that nutrients, which are beneficial for plant growth, are partially lost due to biochemical transformation. Organic materials, which can be applied for biogas production, are also eliminated by biochemical transformation. Therefore, the membrane filtration processes appear to be an attractive solution for greywater reuse and recycling. Among the available membrane modules, the ceramics filter is the least expensive one and has relative higher packing density [10].

The different greywater systems say to be effective and efficient if only satisfied the following conditions of effluent quality, easy to operate, simple in maintenance and at affordable price due to low energy. The study done by Nolde *et al*. [11] showed that the treatment system shall fulfill the four criteria, hygienic safety, aesthetics, environmental tolerance and technical as well as economic feasibility. To obtain a sustainable re-use of treated greywater, certain parameters must take in consideration. The parameters as it proposed by [3, 8, 12] are pH, SS, DS, BOD , COD, total nitrogen and total phosphorus, electrical conductivity, heavy metal and coliform. Hence the chemical and biological parameters tests are required for long term uses of treated greywater. Riper *et al*. [13] carried out an experimental greywater treatment system onsite and came out with set of benefits such as: reduce the total cost of transporting and uniquely investment reduction in the matter of system's installations and durability maintainer.

This study aimed to investigate and design a simple and cheap unit to treat the greywater of in household applications via using ceramic membranes and reuse it in supplying water for toilet flushing and plant irrigations. The study included an experimental program for manufacturing several tablet ceramics membranes from the local materials. The productivity and efficiency of these ceramic membranes were investigated by chemical and physical tests for greywater before and after filtration through these membranes. Then a household treatment unit from ceramics membrane was designed based on the experimental results of lab tests.

MATERIALS AND METHODS

Clay Powder: The organic and coarse materials in the clay were removed by hand. The clay was mixed with water until continuous homogeneous colloidal slurry was obtained. The slurry was sieved through a 355µm sieve. Successive decanting was done to obtain a silt of clay. The silt was then poured into a plaster of Paris mold to remove the excess water. The semi-dry cast was left to dry in air. The dried cast was ground by pestle and mortar to fine powder which was then sieved through the 30 mesh sieve.

Sawdust Powder: The sawdust from the workshop was dried in the sun and then crashed in an electric blender into fine powder. The fine powder was then sieved through the 30 mesh sieve. Wood consists of volatile oils and small quantities of mineral content. The mineral matter in wood consists mostly of salts of calcium, potassium and magnesium.

Mixing: The clay and the sawdust powders were weighed in various proportions and then thoroughly mixed manually with different types of additives. To ensure that the powders were properly dry mixed, the dry mixing process was done for a long time and at least for not less than 30 minutes. Water of about 20% by weight was added to the powder mixture. The wet mixture was wedged by folding the clay over upon itself repeatedly and applying pressure until a smooth knead was formed. An electrically powder mixing machine may be used to combine the ingredients. The wet clay mix is formed into cubes for pressing the cubes are turned and thrust against a tarpaulin to remove air bubbles in the mix prior to pressing and therefore to reduce imperfection in the clay. Drying of filter elements removes the excess water in preparation of filtering in Alkin. The initial drying of filter elements is on drying in the air. It removes much of the excess water required for molding the clay to the desired shape after this initial drying period the filters are able to hold their shape but are not strong and remain water soluble.

Firing of Filter Elements: Sintering was aimed to densify the compact and affect the microstructure of the ceramic. The firing process begins with a low heat of a round 100°C which removes the remaining excess water. Further heating then removes water chemically bonded to clay as alumina and silica molecules. The samples were fired in a furnace to 450°C for 6 hours to drive out the hydroxide ions. Finally at high temperatures (over 600°C) verification of the clay occurs where the silica and alumina molecules melt and bond into a new mineral with fibrous needle like structures. The samples were then sintered at a fixed temperature of 860°C for 5 hours. The sintering temperature was determined by trial and error ensuring that the filters are hard enough.

Filtration Experiments: The experiments have been carried out in the laboratory of sanitary engineering at Aswan faculty of engineering. These experiments has been made by using three tablets of ceramics which were manually fabricated. Those tablets had dimensions of 30 × 30 cm and a thickness of 2 cm. Those tablets, as mentioned earlier, had variable sawdust ratios by weight from the clay namely 0, 5 and 10%. Greywater sample has been collected from wash hand basin in the lab. A box made of glass has been used for allocating the sheets and greywater samples. The box was supplied with a tap at the bottom to get the filtered water out. A sample of 9000 cm^3 of greywater has been used for every ceramic tablet. The time and flow rate of filtration have been calculated until the whole sample was filtered. Four samples have been collected, one for the raw greywater before treatment and the others after filtration through the three different ceramic filters. Each filtration test was repeated three times.

RESULTS AND DISCUSSION

The productivity and efficiency of these ceramic membranes were investigated by chemical and physical tests for greywater before and after filtration through these membranes. These tests included determining the flow rate through filters, pH, EC, TDS, Zn, Pb, Fe, Cl, Mg and Ca. Then a household treatment unit from the best ceramic membrane was designed based on the experimental results of lab tests. The experimental results were discussed in the following sections.

Chemo-Physical Properties: Fig. 1 presents flow rate through different ceramic filters, the Total Dissolved Solids (TDS), pH and Electrical Conductivity (EC) for the untreated and treated samples of greywater. Flow rates under a water pressure of one bar were 3, 10 and 20 $l/hr/m^2$ after filtration through 0, 5 and 10% sawdust ratios of ceramic tablets respectively. Results showed that with increase the sawdust percent in the mixture of ceramic filter the flow rate increased due to the increase in voids and internal pore sizes into the ceramic tablets.

The TDS values were 170, 853 and 1865 mg/l for treated samples respectively, while untreated sample was 1950 mg/l, as shown in Fig. 1. 0% ceramic tablet and also 5% showed significant reduction for TDS value which refers to the powerful capability of theses ceramic filters in purification of polluted water and holding contaminations. According to WHO [14] the general TDS values were found to be lower than the permissible value, i.e. 1000 mg/l. pH is a measure of the acidity or basicity of water. The values of this parameter for treated greywater samples were 7.1, 7.15 and 7.35 for water samples collected after filtration through 0, 5 and 10% sawdust ratios of ceramic tablets respectively. While pH of untreated greywater sample is 7.4. Tap water is generally neutral and adding soap to generate the greywater in lab didn't make significant effect on its pH. Ceramic tablets with 0 and 5% showed a high reduction in water pH while 10% ceramic tablet slightly affect pH of original greywater sample. The general pH values were found to be in the permissible range from 6.5 to 8.5 [14]. EC results showed the same behavior of pH values as the untreated sample read 3385 μS/cm while readings of treated samples were 33.5, 161.5 and 321 μS/cm for tablets 0, 5 and 10% sawdust ratio respectively.

Anions: Fig. 2 shows the concentration of major anions for the untreated and treated greywater samples. Chloride (Cl^-) content was reduced significantly after filtration by all of the studied ceramic tablets. The best one was 10% tablet which held around 98% from the original element content and passed only 2%. While the concentration of bicarbonate (HCO_3^-) is reduced slightly after filtration through different ceramic tablets. The best one was 0% tablet with maximum reduction of 33% from the original content of the untreated greywater sample. The concentration of these ions after filtration ranged between 0.05 and 0.73 g/l and 0.12 and 0.14 g/l for Chloride and bicarbonate respectively.

Cations: The concentration of Magnesium (Mg^{2+}) ion were 0.786, 0.91 and 1.1 after passing through three ceramics tablets respectively while was 1.22 g/l for untreated greywater. 0% ceramic tablet was the best as it reduced the cation by 37% from the original content of greywater. Calcium (Ca^+) content showed highlighted drop after filtration through filters especially 0% ceramic tablet which reduced the Ca content by 82% from the original content in greywater. 5 and 10% ceramic tablets also reduced the content by 46% and 45% respectively. Results of Ca and Mg are shown in Fig. 3. Sodium (Na^+) results showed also improvement in water characteristics as ceramic filters reduced Na content by 54, 26 and 10 % respectively.

Heavy Metals: Some heavy metals such as Fe, Zn and Pb showed also low levels after filtration through ceramic tablets. Fe was reduced by 0.75 to 0.98% and Zn was reduced by 64 to 86% while Pb not detected at all. Fig. 4 presents results of Fe and Zn.

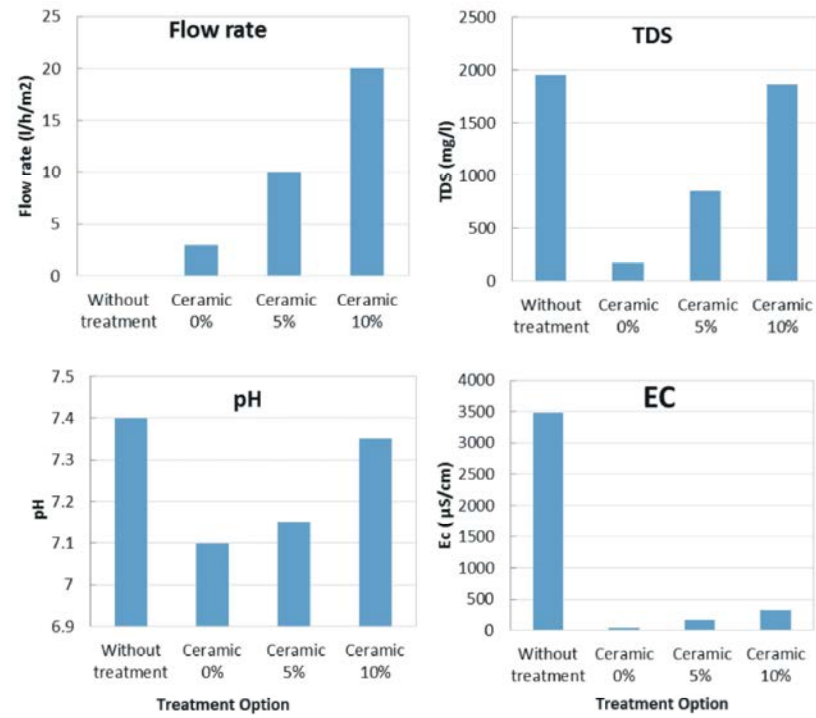

Fig. 1: Chemo-physical properties of greywater before and after filtration

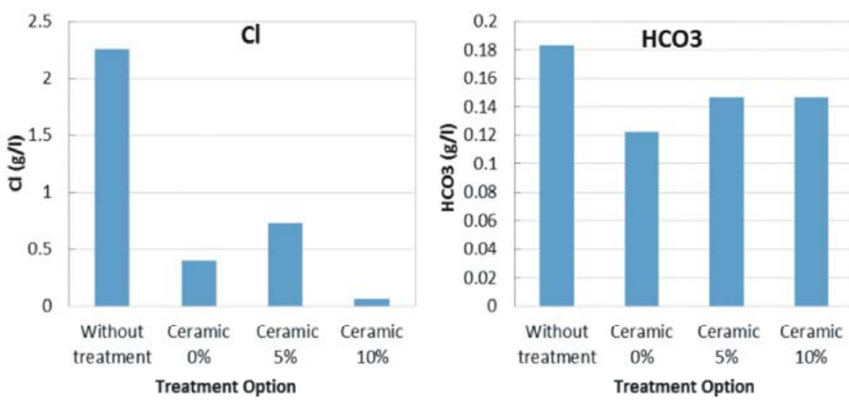

Fig. 2: Anions of greywater before and after filtration

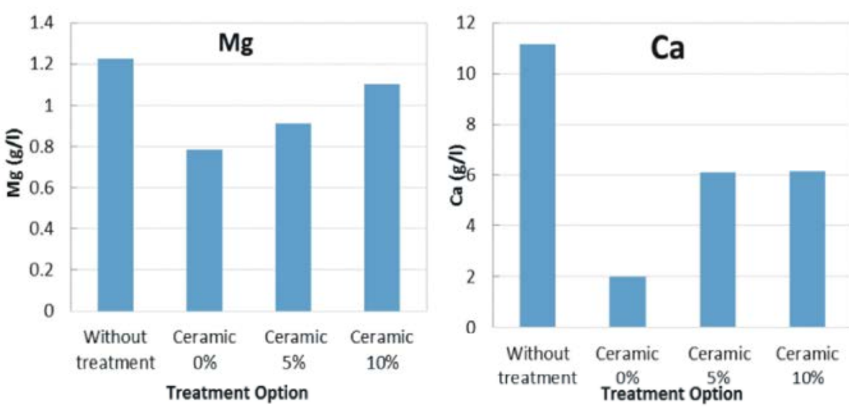

Fig. 3: Cations of greywater before and after filtration

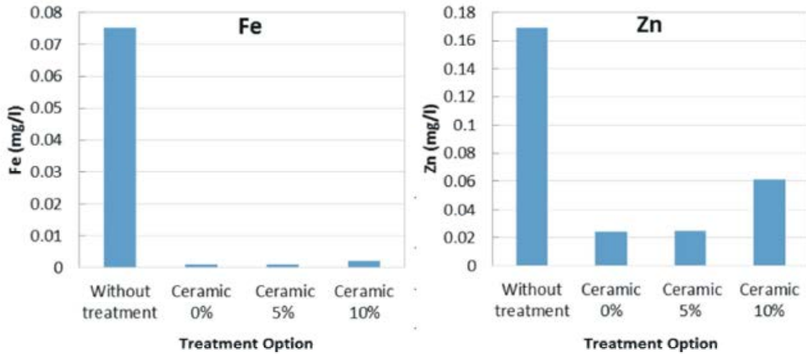

Fig. 4: Heavy metals of greywater before and after filtration

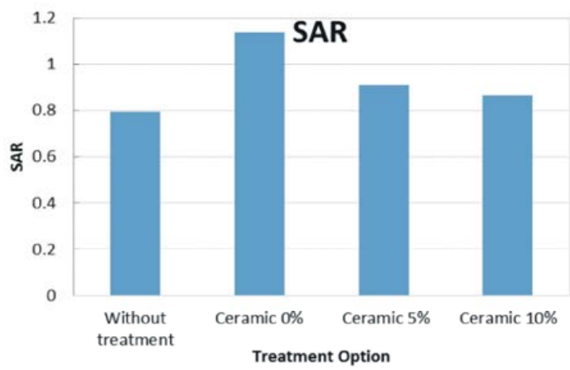

Fig. 5: SAR values for greywater before and after filtration

Fig. 6: A greywater treatment unit working by ceramic filters

Suitability of Treated Greywater for Irrigation: The quality of irrigation water can be evaluated using several parameters such as the total amount of dissolved salts in the water and the ratio of soluble sodium to calcium and magnesium ions. This ration is called the sodium adsorption ratio (SAR) and it is a calculated as follows:

$$SAR = \left(\frac{N_a}{\left(\frac{C_a + M_g}{2} \right)} \right)^{1/2} \qquad (1)$$

where the concentrations are reported in meq/L.

The SAR values are 1.14, 0.91 and 0.86 for treated greywater through the three ceramic tablets respectively as shown in Fig. 5. While the SAR value for untreated greywater is 0.79. According to SAR and EC values presented previously, greywater samples treated by 0 and 5% ceramic tablets fall in the field of C3S1 classification, indicating relatively high salinity and low sodium water, which can be used for irrigation on almost all types of soils with little danger of exchangeable sodium. The untreated sample and treated with 10% ceramic filter are found in the classification of C4-S4 which is unsuitable for irrigation uses due to the too high salinity hazard.

Application of Ceramic Filter in a Household Treatment Unit: According to the above mentioned sections, which discussed the results of the three different ceramic tablets, the 0 and 5% showed good results in greywater treatment. 0% was the best option for purification of greywater as showed significant reduction after filtration for all elements but also it showed very slow flow rate which is not preferable for practical application of using ceramic filters in treatment units with big amounts of untreated water. The 5% tablet is more convenient because it showed good results in both sides, high purification and relatively high flow rate. Thus, the tablet having 5% ratio of sawdust was chosen and adopted to design a treatment unit for purification and reuse of greywater in household applications. The new design was applied in the environmental and sanitary lab at the campus of Aswan University, Egypt. The components of the treatment unit and its setup are shown in Fig. 6. The ceramic treatment unit contains a screen to hold the solid impurities of greywater and discharge it into the sewage network. The greywater then was filtrated through the ceramic filter and pumped to the flushing toilet tank. There is a sensor control the water level in the flushing tank. The unit is expected to produce 350-500 L/day water for toilet flushing and plant irrigation, if applicable, without need to consume them from the fresh water supply network.

CONCLUSIONS

Ceramic tablets showed significant reduction for TDS value and also for different element contents which refers to the powerful capability of theses ceramic filters in purification of polluted water and holding contaminations.

Reduction in element contents adversely deepened on the void ratios of the tablets which increased with increase the sawdust percent in the mixture.

The 0 and 5% ceramic tablets showed good results in greywater treatment. 0% was the best option for purification of greywater as showed significant reduction after filtration for all elements but also it showed very slow flow rate which is not preferable for practical application of using ceramic filters.

The 5% tablet is more convenient because it showed good results in both sides, high purification and relatively high flow rate. Thus, the tablet having 5% ratio of sawdust was adopted to design a treatment unit model for purification and reuse of greywater in household applications.

The new unit saves water around 350-500 L/day from freshwater supply for toilet flushing and plant irrigation in household applications.

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