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# Improving Greywater Quality by Aeration and Membrane Filtration

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**Abstract:** Water conservation is an important issue in most arid and semi-arid regions and the reuse of treated wastewater is becoming popular in many countries. Greywater is the wastewater from household showers, baths, sinks and washing machines which can potentially be recycled for domestic irrigation and therefore reduce household demand for potable water. In this paper, the improvement of greywater quality was investigated using aeration and membrane filtration process. The raw greywater was collected in two batches from a home washing machine and kept untreated for 12, 24, 36 and 48hrs before aeration. The aeration experiment was run continuously for 7 days and different water quality parameters such as dissolved oxygen (DO), dissolved organic carbon (DOC), pH and nitrogen species ($NH_3$-N, $NO_2$-N and NOx-N) were measured. The results of aeration revealed that DO levels could be increased to 9 mg/L which is good for aquatic water quality. The DOC level was decreased up to 62% in 80hrs of aeration whereas $NH_3$-N was reduced by 85% in 30hrs of aeration. However, pH level was maintained between 8-8.5. The aerated greywater was further treated using membrane filtration (MF) and the results showed that DOC level was further reduced by 44% and the total coliform (TC) was reduced to 9 cfu/100mL. The significant reduction of DOC and TC indicates that the MF can be used effectively to reduce the overall pathogen concentration in greywater. Comparing the results of treated and untreated greywater revealed that the aeration followed by MF can be considered as an effective method to improve overall greywater quality for irrigation.

**Key words:** Greywater · Aeration · Membrane · Filtration · Water quality

## INTRODUCTION

Water conservation is a primary concern in many parts of the world for meeting the huge demand of water due to development of industry, urbanization and the diversification of people's lifestyles which may cause depletion in natural water resources. One way in which water can be conserved is through recycling domestic greywater and reusing it for irrigation. Now-a-days, researchers focus on recycling greywater, which has also been accepted by general public. Greywater is the wastewater produced from areas such as the shower, bath, washing machine, kitchen sinks and hand basins and cumulatively accounts for 32% of household water consumption. Irrigation accounts for 39% of total domestic household water demand and therefore recycling greywater for this purpose can potentially reduce demand for potable water by 32% [1]. Moreover, greywater could be used for toilet flushing and outdoor uses such as car washing and garden watering as it contains low organic content. Greywater needs to be treated properly before reusing because of its different fractions and nutrients content, otherwise it may cause health risk and environmental impacts [2]. Greywater can exhibit varying levels of quality and pollutants depending on the initial use of the water in each individual household [3]; therefore reuse of this water can potentially cause negative environmental effects and health risks. Friedler and Hadari [4] reported that the cost of the greywater treatment system can be reduced by widespread use of greywater reuse at site which may attract the individual customers. Under certain condition, on-site greywater treatment could be a feasible solution as an alternative option for meeting overall water demand environmentally and economically. The building industry can bring benefits to the society if they influenced to install greywater treatment systems in new houses, new apartment complexes and public buildings, such as universities, schools, etc., where it is easy to modify the existing plumbing systems to separate greywater from blackwater [5].

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There are various ways to recycle the greywater. Some of them are physical treatment systems – coarse filtration or membrane often coupled with disinfection; biological based systems – rotating biological contactor, Membrane bioreactor, reed beds; chemical treatment systems – photo-catalysis, electro-coagulation, coagulation and magnetic ion exchange resin and conventional coagulation [6 to 10]. Pidou *et al*. [11] reported that coarse filtration has limited performance in removing fractions from the greywater. Itayama *et al*. [12] also reported that soil filter could remove biochemical oxygen demand (BOD) and suspended solids below their standard values while working with high strength kitchen sink water. Biological systems alone usually seldom use; mostly it is preceded by a physical pre-treatment. Recent researches show that Membrane Bioreactors (MBR) are becoming increasingly popular in the treatment of industrial wastewater due to the high level of effluent output quality which can be achieved and their relatively small footprint [11]. Friedler *et al*. [13] reported that RBC (rotating biological contactor) and MBR treatment units can produce very high quality effluent and observed minimum health risk associated with the reuse of greywater effluents by monitoring faecal coliforms regrowth. Greywater treatment with ultra-filtration membranes provides 100% removal of turbidity and suspended solids [14] and 92-97% removal of turbidity [9]. It is also reported that greywater treatment with nanofiltration produced high quality of permeate than ultrafiltration [9]. However, membrane has limited achievement in removing organics [11] and micro-organisms [15] associated with a common drawback of membrane fouling which increased linearly with increasing organic matter concentration. Therefore, it is a vital importance to find out a solution which can reduce the organic matter concentration while coupled with membranes. Friedlier and Alfiya [16] worked with ferric chloride as a coagulant followed by sedimentation and filtration in a semi-batch mode reactor and found that most of the pollutants are removed in the coagulation-sedimentation process and filtration was used as a polishing unit. Mondal *et al*. [17] reported that treatment using filtration followed by aeration and disinfection for domestic greywater is itself adequate to irrigate a small garden. Conducting greywater treatment using alum coagulation followed by disinfection in a pilot-scale study of Kariuki *et al*. [18] noticed that it could restrict the pathogen level within the standard but economic evaluation was not reported.

There was not sufficient report concerning the combined effects of aeration followed by membrane filtration process for greywater purification. Previous research [19] showed that Membrane bioreactors incorporate aeration and membrane filtration treatments into a single process.

Kim *et al*. [20] observed that MF system could be effective to remove COD, turbidity, colour and suspended solids, while the oxidation process was effective to remove E. coli, total coliform, Salmonella and Staphylococcus. They suggested that disinfection system is mandatory for complete removal of E. coli, total coliform, Salmonella and Staphylococcus in addition of MF unit. In our laboratory, the aeration unit and handmade membrane filter were constructed to investigate the individual and combined effects of aeration and the membrane filtration process on greywater quality and assess the viability of this treatment system for recycling domestic greywater to be used for irrigation. The purpose of this study was firstly; to find out what improvement of greywater quality can be achieved by aeration process and to determine the optimum aeration time; secondly, to determine the effect of membrane filtration on the greywater quality by filtering the aerated greywater through a homemade MF. Finally, the study aimed to analyse the results from both of these steps to determine the total improvement in greywater quality by MF coupled with aeration process.

## MATERIALS AND METHODS

**Collection and Storage of Greywater:** In this study, laundry greywater was collected from a home washing machine. Laundry greywater is usually produced in large scale among all domestic water uses. Two independent batches of greywater were collected from a 'Hoover Commodore heavy duty, top loader washing machine' run on a normal 15 minute wash cycle. 'OMO Ultimate' washing powder, which contains no added phosphorous and readily biodegradable surfactants (AS4351) was used in the wash. The amount of washing powder added was not accurately measured however two level scoops were added to both independent batches as per the instructions on the washing powder packaging for large wash loads. Similarly the cleanliness and type of the textiles used in the washing machine was not strictly controlled however a conscious effort was made to ensure both loads were of similar size and consistency. However, different types of clothing ensure the randomness of loads representing 'real life' situations.

The two batches of greywater (named as ‘Batch A’ and ‘Batch B”) were collected 12 hours apart. The Batch A was collected at 9am on Monday and Batch B was collected at 9pm on Monday. The collection of two batches of greywater produced from ‘similarly run’ washing procedures but provided a range of varying greywater quality. The collection interval of 12 hrs between these two batches helped for conducting experiments after preserving greywater for different time periods. The discharged water from different stages of the wash cycle can result in different strengths of greywater with later stages of the wash cycle being ‘cleaner’ than the discharge from initial stages of the wash [3]. However, a mixture of all wash stage discharges was collected in a 20L plastic sealed container for both batches.

Two 5L of samples were taken from greywater ‘Batch A’ at 24hrs and 48hrs of preservation and labelled ‘A2’ and ‘A3’ respectively. The remaining ‘Batch A’ greywater in the 20L container (named as ‘A1’) was used as untreated greywater. Similarly, two 5L of samples from Batch B was taken at 12hrs and 36hrs of preservation and named as B2 and B3 respectively. The storage of untreated greywater results in the formation of micro-organism due to micro-biological activity and reduces the dissolved oxygen (DO). As a result, DOC decreases due to oxidation processes. The storage of greywater samples before aeration for different time periods (B2=12hrs, A2=24hrs, B3=36hrs and A3=48hrs) enhances natural changes in water due to micro-biological activity and differs in initial greywater qualities.

**Method of Aeration:** After collecting the samples on Monday, first aeration experiment was started on Tuesday 9am with batches A2 (after preserving for 24hrs) and B2 (after preserving for 12hrs) respectively. The second aeration experiment was started on Wednesday 9am with batches A3 (after preserving for 48hrs) and B3 (after preserving for 36hrs). Aeration experiment was conducted using a twin outlet electric aquarium air pump operated at its maximum flow rate of 84L/hr. A delivery hose was connected to the pump to deliver air into the water sample container and an ‘aquarium stone’ was then attached to the hose and placed at the bottom of each 5L sample containers (A2/A3/B2/B3). The hose length and aquarium stone ensured uniform airflow and even distribution of airflow throughout the greywater batches. All aeration experiments were run for seven days. During the aeration, greywater samples from each container (A2/A3/B2/B3) was collected each day and measured for water quality parameters such as DOC, $NH_3$-N, $NO_2$-N, $NO_X$, pH, Temperature and DO. Measurements were taken twice a day at 10:00 am and 4:00 pm for the first five days and once daily in the afternoon thereafter. Measurements were also taken at these intervals for the untreated ‘Batch A1’ as a control. Each time, duplicate samples were collected for replication.

**Membrane Preparation and Greywater Filtration:** The membrane was prepared in the lab using a bundle of micro-filtration fibres. The micro-filtration fibres were sealed at the base and open at the top as shown in Fig 1. The top of the bundle is inserted into a plastic syringe by removing the plunger from the top to create an opening. The gaps between the fibres and syringe are filled with liquid silicone to make it water tight. The membrane fibre and the syringe wall were also made airtight using liquid silicone. The sealed bottom end of the membrane fibre bundle is ‘dipped’ in liquid silicone and covered by a plastic cap to block water from entering up through the bottom of the fibres.

The design of this handmade membrane micro-filter requires an airtight barrier at the top of the syringe which the open end fibres protrude through into the tube of the syringe and a sealed bottom end. The concept is that the only way in which water can enter the syringe is through the walls of the MF fibres therefore being filtered. The tip of the syringe was attached to peristaltic pump to create a vacuum and filtered samples were collected. Ten set of handmade micro-filtration system were made for duplicate samplings for all batches (A1/A2/A3/B2/B3). All aerated (A2/A3/B2/B3) and non-aerated (A1) samples were used for micro-filtration.

Fig. 1: Handmade micro-filter for greywater filtration

Five samples of 300mL from each set of A1/A2/A3/B2/B3 of filtered and non-filtered greywater were collected. Half of these samples (150mL) were then kept in sterilised plastic bottles with a sealable screw on lids supplied by "Silliker Australia" and were sent to Silliker Australia for coliform analysis. The second half of 150mL samples were used for DOC analysis. Extra five set of micro-filtration system were made at the same time and the process was repeated for data replication.

**Analytical Methods:** The DOC measurement was done by measuring the TOC using Sievers 5310C Laboratory TOC analyser. First the samples were filtered with 0.45 µm filter paper and diluted for measuring TOC using Sievers 5310C Laboratory TOC analyser which was taken as the corresponding DOC of greywater. The DO, pH and Temperature were measured by an electronic meter (HACH HQ 300d) using corresponding probes (±0.1). For nutrients measurements, the samples were also filtered with 0.45 µm filter paper and analysis were made following standard methods given in APHA [21] using AQUAKEM 200 water analyzer (Labmedics Analytical Solutions) (±0.015-0.02). All in-house parameters were obtained for duplicate samples and the mean values were used.

## RESULTS

### Effect of Aeration

**Dissolved Oxygen (DO):** The dissolved oxygen was measured for greywater age for all samples taken from unaerated (A1) and aerated (A2/A3/B2/B3) greywater and shown in Fig. 2. The DO levels of greywater significantly dropped in 24hrs of collection as seen in the unaerated greywater and those were preserved for more than 24 hrs for aeration. The DO level of A1 was reduced from 9.01 to 1.97mg/L in 24 hrs (78% reduction) and further 10% was reduced in next six days of experimental duration. The small fluctuation of DO after 24 hours was mainly due to the ambient temperature variation over the experimental period. Dixon *et al*. [22] found a fluctuation range of 0.2-0.3mg/L after initial drop of DO. The results found in this study revealed that the aeration has significant effect on the regaining of dissolved oxygen. However, the sample A1 did not have sufficient DO reduction in 12 hours of preservation. When the aeration started, the DO levels of samples collected from A2, B3 and A3 (the preservation of 24, 36 and 48 hrs) rose quickly. Similar results were also seen in Dixon *et al*. [22].

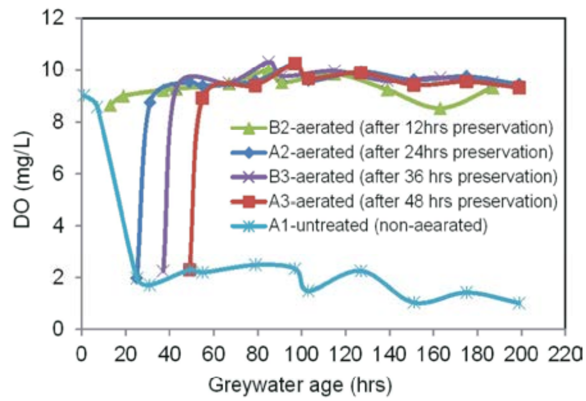


Fig. 2: Dissolved Oxygen Levels with greywater age

The results showed that aeration can increase the level of DO in greywater dramatically after 12 hours of continuous aeration. A previous study of Tal [23] showed that the greywater DO level can be maintained within 7 – 8 mg/L when aerated over 14 days. In this study, greywater was stored maximum of 48 hours before aeration. The results suggests that aeration has a significant effect of increasing and maintaining DO in greywater, preventing decreasing of DO due to oxidation by micro-organisms as well as maintaining aerobic conditions within the water. Furthermore a distinct difference was noted in the smell of water, with the non-aerated sample producing unpleasant odours after an extended 15 days of storage whereas all aerated samples had no noticeable aroma.

**Dissolved Organic Carbon (DOC):** Dissolved organic carbon (DOC) was measured for aerated and non-aerated samples throughout the aeration phase of the laboratory investigation. The results of these measurements showed the decrease of DOC with increasing the age of greywater (Fig. 3). Although the general trend of DOC measurements was same for both aerated and non-aerated samples, the results indicated that the aerated samples had faster DOC reduction than non-aerated samples. All the tested aerated samples reached a level of DOC of approximately 80 mg/L at about 120 hours of age. At the same age the non-aerated sample has slightly higher level of DOC (95 mg/L). This was also found in the previous study of Tal [23]. The greater reduction in DOC in aerated samples indicates the improvement of greywater quality. This is because the aeration process increasing the level of DO and thus enhancing the micro-biological degradation of the dissolved organic matter in aerobic oxidation process.

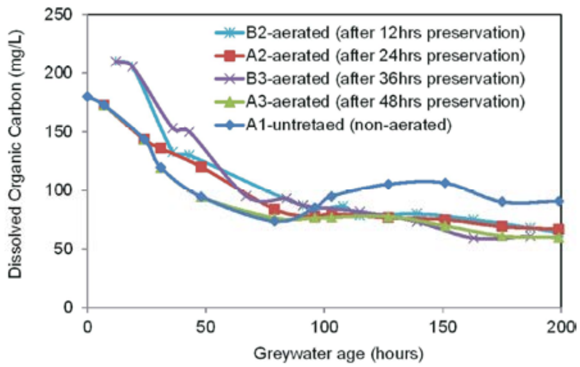


Fig. 3: DOC levels with the age of aerated and non-aerated greywater

The initial level of DOC in different aerated samples varied due to different initial storage periods. Both samples generated from Batch A greywater had lower initial DOC levels than those from Batch B, indicating that the level of initial greywater quality varies even though the greywater production process was similar using the same washing machine. Sample A3 generated from batch A was stored for 48 hours prior to aeration and DOC was measured 95 mg/L at the commencement of aeration, whereas the sample A2, generated from the same batch and stored for 24 hours prior to aeration had a higher initial level of DOC of 143 mg/L. Similarly samples B2 and B3 from the second batch had initial levels prior to aeration of 200 mg/L and 153 mg/L respectively. These results revealed that the storage of greywater for longer periods will result in lower DOC levels due to micro-biological oxidation. However, the initial DOC levels of two batches A and B (180 mg/L, 200 mg/L respectively) are similar with the DOC levels (158 mg/L) usually found in domestic greywater [3].

**Nitrogen Species:** The concentration of nitrogen species ($NH_2$-N, $NH_3$-N and NOx-N) in different greywater samples for non-aerated (A1) and aerated (A2/A3/B2/B3) samples were measured and the results are presented in Fig. 4. The results show that the aeration process has significant effect on the removal of nitrogen species from greywater. More than 85% removal of $NH_3$-N occurs in first 30 hrs of aeration with a 95% removal at the end of the experiment. Whereas, the $NH_3$-N concentration in non-aerated sample (A1) increased by 268% after 7 days. Inorganic nitrogen oxide (NOx-N) measurements indicate the level of nitrite ($NO_2$-N) and nitrate ($NO_3$-N) production. The increase in the aerated samples of NOx-N with the reduction in ammonia suggest that nitrification processes are

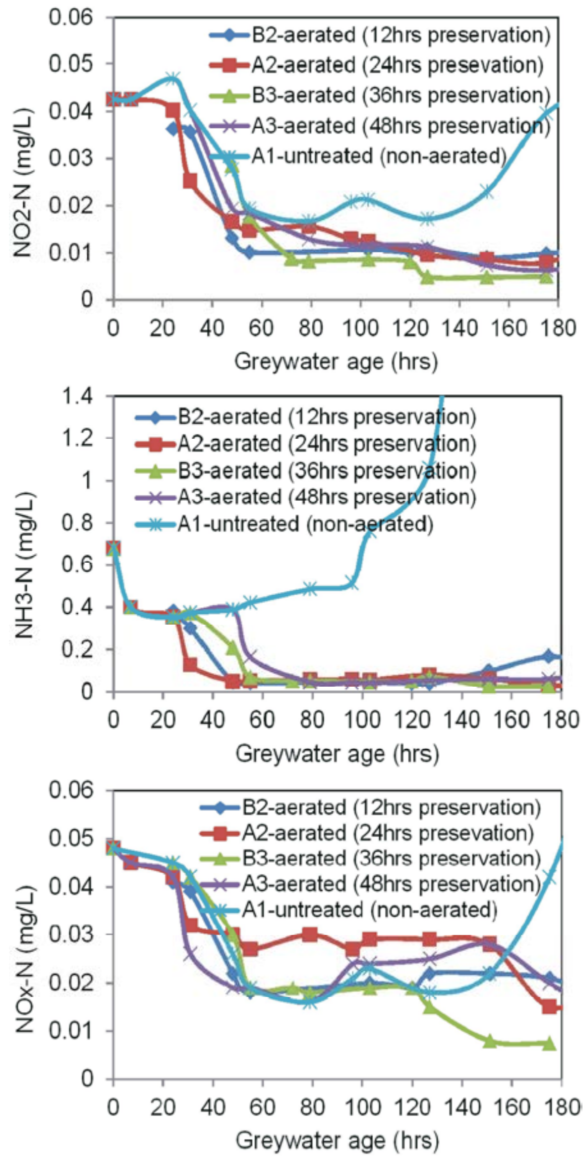


Fig. 4: Removal of nitrogen species with aeration time

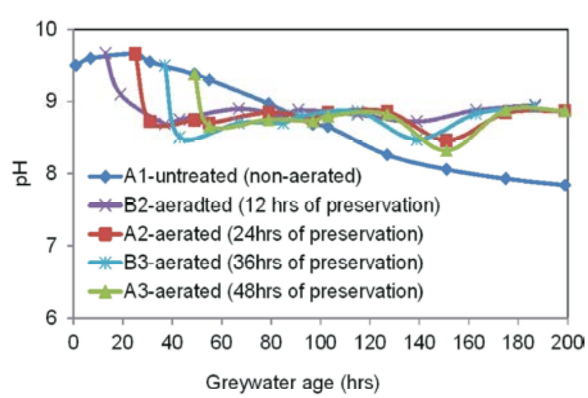


Fig. 5: The pH level of different greywater samples

Table 1: The effect of micro-filtration on Total Coliform and DOC

| Greywater samples | Total Coliform (cfu/100mL) | | DOC (mg/L) | | |
|---|---|---|---|---|---|
| | Before MF | After MF | Before MF | After MF | %removal |
| B2-aerated (12hrs preservation) | >80 | 9 | 63.87 | 40.25 | 37 |
| A2 - aerated (24hrs preservation) | >80 | 24 | 66.68 | 33.5 | 50 |
| B3- aerated (36hrs preservation) | >80 | 9 | 60.87 | 38.25 | 40 |
| A3-aerated (48hrs preservation) | >80 | 9 | 59.87 | 30.25 | 49 |
| A1-non aerated (untreated) | >8000 | 44 | 90.68 | 32.75 | 64 |

occurring; which involves the conversion of ammonia to nitrite and then nitrate by micro-biological processes under aerobic conditions.

The slight increase of $NH_3$-N, $NO_2$-N and NOx-N levels after 100 hours providing slight reduction of DOC indicates the ammonification may be occurring after this period. The decrease in DO levels and DOC consumption indicate the reduction in aerobic oxidation process and therefore aerobic bacterial population. Decaying micro-organisms will release inorganic nitrogen back into the water which can then be reduced by the nitrification process by different types of bacteria suited to the low levels of dissolved oxygen.

**The Effect on pH:** The pH levels of all greywater samples were measured and shown in Fig 5. Initial pH of greywater was 9.5 (±0.3) which started to decrease with time. This decrease was continuing for unaerated sample whereas the aeration samples the pH level was within 8.5 (±0.1). Initially for the non-aerated sample A1 the pH value was alkaline (pH=9.5) and after 200 hours it reduces to 7.84. This indicates, alkaline greywater may convert to acidic greywater if it is kept for longer time without aeration.

**Effect of Membrane Filtration:** Each aerated samples and non-aerated samples were filtered using handmade micro-filter (membrane). The DOC and total coliform were measured before and after micro-filtration process. The results are shown in Table 1. The results revealed that the DOC of aerated greywater was reduced further by approximately 44%. However, the removal of DOC for non-aerated samples using micro-filtration process was found 64%. The results of total coliform for all aerated and non-aerated samples were more than 80 cfu/100mL and 8000 cfu/100mL respectively. The micro-filtration process could reduce the total coliform to as low as 9 cfu/100mL. This is a significant reduction of total coliform which indicates that the membrane filtration may be used for improving the greywater quality where there is a significant generation of total coliform.

## DISCUSSIONS

The results showed that aeration increases the levels of DO and can reduce 85% of $NH_3$-N within 30 hours of continuous application and it can go up to 95% removal after 7 days. Aeration can reduce the DOC of greywater up to 62% in 80hrs. The pH level could be maintained with 8-8.5 by aeration. Membrane filtration (MF) could reduce total coliform to as low as 9cfu/100mL and DOC was reduced further by 44%.

The above results indicate that aeration followed by micro-filtration process may be an effective method to improve greywater quality. This improved greywater may not be suitable for drinking purposes but can be reused for irrigation. The major concern for reusing the greywater is its environmental and health effects. This includes high levels of ammonia, low levels of DO and increased amount of total coliform. High ammonia content may enhance eutrophication and increase soil acidity if greywater is discharged into water body or irrigated onto soil surfaces.

Irrigation with high salinity water can accumulate salts within the soil structure reducing its ability to absorb water [24]. In addition, acidic water with low pH allows toxic heavy metals to be dissolved easily in water and therefore threatening the environment health. Release of water contaminated with pathogens (e.g. total coliform) can also pose a health risk and may contaminate water supplies with devastating impacts on the community.

The results showed that membrane filtration can improve the greywater quality reducing some of the potential negative impacts discussed above; however its viability in recycling domestic greywater for irrigation also relies on the guidelines for reuse, costs and market demand of this process. The report of DoH [24] states that primary treated greywater without disinfection can only be used in domestic single dwellings through subsurface irrigation. Greywater can be used for subsurface irrigation by greywater diversion devices which do not need to meet quality guidelines in the effluent produced [24]. Greywater treatment systems, such as membrane bioreactor process can be used in domestic premises but must meet 20/30 standards (<20 mg/L BOD, <30 mg/L SS) [24]. Biochemical oxygen demand (BOD) measures the amount of oxygen required for microbes to oxidise organic matter within the water body. With further testing required, the reduction of 64% DOC through MF process suggests that the limit of 20mg/L BOD could most likely be achieved. Furthermore membrane filtration was shown in the literature to remove up to 100% suspended solids (SS) and generally achieves <10mg/L SS [11].

If through further testing MF process can be shown to achieve 20/30 standard, it would provide the ability for households to retain greywater in the aeration tank for periods of time and use this water resource as required therefore greatly improving the efficiency of its reuse and its viability as a domestic greywater treatment method.

However even if meeting this standard, the only approved use of this treated greywater is subsurface irrigation and the guidelines also permit subsurface irrigation to be applied through relatively cheaper greywater diversion systems [24]. Thus without the inclusion of disinfection stages in the MF process, the relatively higher costs and limited application methods could result in limited households adopting these systems.

## CONCLUSION

In this paper, the quality of greywater was improved using aeration and membrane filtration process. Two batches of raw greywater were collected from home washing machine resulting from wide varieties of cloth washes. The raw greywater was preserved for 12, 24, 36 and 48 hrs before aeration. The different water quality parameters such as DO, DOC, nitrogen species ($NH_3$-N, $NO_2$-N, NOx-N) and pH were measured for aerated and non-aerated greywater samples for 7 days. The results revealed that aeration process have a significant positive effect on greywater quality by increasing DO, reducing DOC and nitrogen species respectively. The DO level was increased to 9mg/L which is good for aquatic water quality. The $NH_3$-N content was reduced by 85% in 30hrs and DOC level was decreased 62% in 80hrs of aeration. The pH level was maintained approximately within 8-8.5. The aerated greywater was further filtered using membrane filtration and the results showed that the total coliform was reduced to 9cfu/100mL in most of the samples and DOC was reduced further by 44%. These results confirmed that the aeration followed by membrane filtration may be an effective method for improving greywater quality for irrigation. But it is recommended to add disinfection treatment stage in filtration process that will allow the opportunity for greater applications of greywater such as surface irrigation, toilet flushing and washing machine application.

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