

## Reuse of greywater and rainwater using fiber filter media and metal membrane

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### Abstract

As water resources become more limited and waste discharge becomes increasingly problematic, the concept of water reuse is becoming important. Recently, use of greywater and rainwater as alternative water resources has drawn attention. However, lack of useful information on the combined use of greywater and rainwater hinders wide application of these systems.

In this study, novel treatment options including lignocellulose filter media and metal membranes were examined to reuse greywater and rainwater in office buildings. Laboratory scale experiments were performed to evaluate the potential of these technologies. The fiber filter media was useful to control first flush rainwater but was not enough to produce water for non-potable use in buildings. Thus, the metal membrane filtration was attempted to reject particulate pollutants. The removal efficiency of various pollutants and the membrane permeability were examined using metal membranes with different pore sizes.

*Keywords:* Fiber filter; Water reuse; Phosphate removal; Building; Rainwater; Wastewater

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## 1. Introduction

Water conservation, efficiency and reuse are becoming increasingly important as we now face serious problems including reduced groundwater and surface water levels, drought and changing climate patterns. Sustainable water management systems are based on the principle that water sources should be matched with end uses in terms of the required water quality. The principles of sustainable water management help identify alternative sources of water that can be supplied to meet the water demand in ways that do not require potable water quality [1,2].

Use of greywater or rainwater to substitute non-potable water in buildings is not a novel concept but a powerful tool for sustainable water management [2–5]. Greywater is collected from indoor sources other than toilets such as showers and hand basins. This usually requires treatment such as screening, oil & grease removal, filtration, and disinfection. Rainwater can be collected from the impervious surfaces (such as rooftops and other paved surfaces) of the building premises. Rainwater requires treatment such as sedimentation, filtration, and disinfection.

Usually, rainwater collected from rooftops would require less treatment compared with the greywater because it contains fewer amounts of

pollutants. However, the quantity of rainwater collected from rooftop highly depends on the weather conditions, climate and has seasonal variations. Thus, it is desirable to use greywater and rainwater in buildings to lower the cost of treatment and to secure enough amount of alternative water resource.

Unfortunately, there is little information available on the treatment of greywater and rainwater because few attempts have been done for combined use of greywater and rainwater in buildings. Accordingly, new treatment options using lignocellulose filter media [6,7] and metal membrane filter [8] was investigated in this study to reuse gray water and rainwater in cost-effective ways.

## 2. Methods

### 2.1. Influent: greywater and rainwater

Greywater from cleaning of building floors and rainwater from rooftop were collected and used for the experiments. Moreover, to simulate the combined use of greywater and rainwater, the greywater and rainwater were mixed at 1:1 ratio and also used for the tests. Table 1 summarizes the water quality of the greywater, greywater + rainwater, and rainwater. Fig. 1 illustrates their particle size distributions and the number of particles in each size range.

Table 1  
Comparison of water quality for greywater, greywater + rainwater, and rainwater

	Greywater	Greywater + rainwater	Rainwater
pH	7.27	7.36	7.41
EC ( $\mu\text{S}/\text{cm}^2$ )	194	181	187.1
Turbidity (NTU)	12.6	5.9	4.76
Color	49	25	24
COD (mg/L)	22.9	12.5	12.6
Particle count (2–15 $\mu\text{m}$ )	22,495	17,708	2570
Total count ( $\text{mL}^{-1}$ )	60	33	49
Total coliform (MPN/100 mL)	0	0	>2419

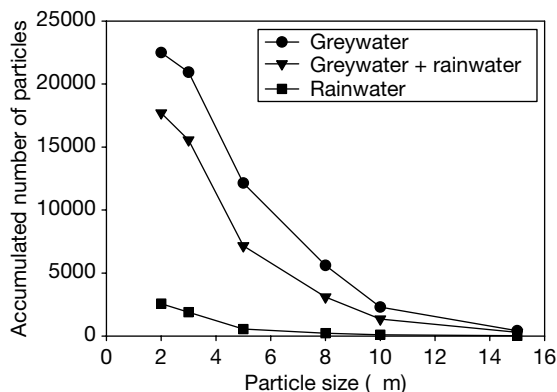


Fig. 1. Comparison of particle size distributions for greywater, greywater + rainwater, and rainwater.

## 2.2. Fiber filter media

Filtration with lignocellulosic fiber mats has potential to clarify water contaminated by various pollutants. Thus, the possibility for using the fiber filter media was examined here. The fiber filter media made of recycled wood fibers was manufactured in USDA Forest Products Lab. Experiments were performed using both a laboratory-scale device. The devices consist of an initial settling tank and a separation tank containing the filter media (see Fig. 3). Chemical modification of the fiber filter using aluminum oxide was performed to enhance the removal of phosphate and heavy metals. Only rainwater was used for the test of fiber filter media because the primary role of fiber filter media is to treat first flush of rainwater.

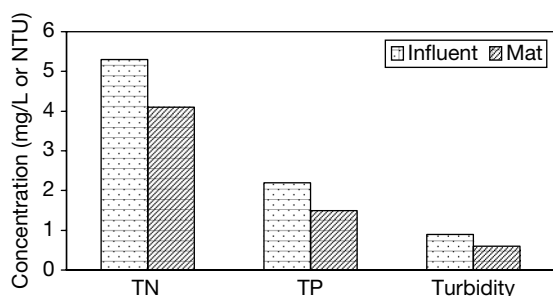


Fig. 2. Removal of total nitrogen (TN), total phosphate (TP), and turbidity by fiber filter media.

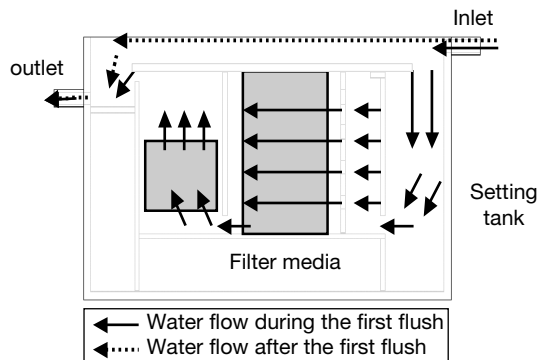


Fig. 3. Schematics of the filtration system using fiber mats.

## 2.3. Metal membrane

Commercially available MMFs (metal membrane filters), supplied by a manufacturing company (FiberTech, Korea), were used for filtration tests. The dimensions and basic characteristics of MMFs are provided in Table 2.

## 2.4. Analytical methods

Spectrophotometric methods of Hach [9] using DR-4000 spectrophotometer were adapted to measure the ion concentrations and turbidity. Conductivity and pH were also measured using a conductivity/pH meter and the results were automatically corrected for temperature influence. Total viable bacteria were counted using the Compact Dry Kits provided by Nissui, Japan. The size distribution and number of particles in rainwater samples were analyzed using a particle size analyzer (Malvern Mastersizer/E) and a particle counter (Met One). All tests were duplicated to ensure reproducibility of the results.

## 3. Results and discussion

### 3.1. Pollutant removal by fiber filter media

The rainwater sample was treated using the fiber filter media at a flow velocity of 11.0 mm/min. Then, the treatment efficiency of the fiber filter media was examined by analyzing

Table 2  
Summary of metal membrane filters

Parameter	5 $\mu\text{m}$ metal membrane filter	1 $\mu\text{m}$ metal membrane filter	0.5 $\mu\text{m}$ metal membrane filter
Nominal pore radius ( $r_p$ )	5 $\mu\text{m}$	1 $\mu\text{m}$	0.5 $\mu\text{m}$
Filter area length ( $L$ )	0.222 m	0.222 m	0.222 m
Membrane area ( $A_m$ )	$9.76 \times 10^{-3} \text{ m}^2$	$9.76 \times 10^{-3} \text{ m}^2$	$9.76 \times 10^{-3} \text{ m}^2$
Membrane resistance ( $R_m$ )	$1.01 \times 10^{10} \text{ m}^{-1}$	$1.04 \times 10^{10} \text{ m}^{-1}$	$1.04 \times 10^{10} \text{ m}^{-1}$

total nitrogen (TN), total phosphate (TP), and turbidity. As shown in Fig. 2, the removal of TN, TP, and turbidity were 22, 32 and 33%, respectively. It appears that the fiber filter media not only rejects particulate pollutants but also remove soluble ions. The fiber filter media is known to remove contaminants in rainwater through ion exchange mechanisms: Cation exchange reaction occurs for metal removal and anionic exchange occurs for nitrogen and phosphate removal. Two-stage filtration, which consists of precipitation and collection on the fiber, also helps to reduce the contaminants from water.

### 3.2. Incorporation of fiber filter mat into first flush separator

Treating the first flush of rainwater is critical for ensuring high quality of water in the storage tank. Thus, the system was designed to selectively filter the first flush of rainwater. Fig. 4 shows how the system behaves under various lengths of inlet gap width and the input flow rate. As shown in Fig. 3, all of the input water will enter into the settling tank and pass through the fiber mat filter when the gap width is large and/or the input flow rate is small. On the other hand, all the input water will bypass the filtration unit at high flow rate of input water. Fig. 4 illustrates the operating modes under different conditions, suggesting that the system can be controlled by

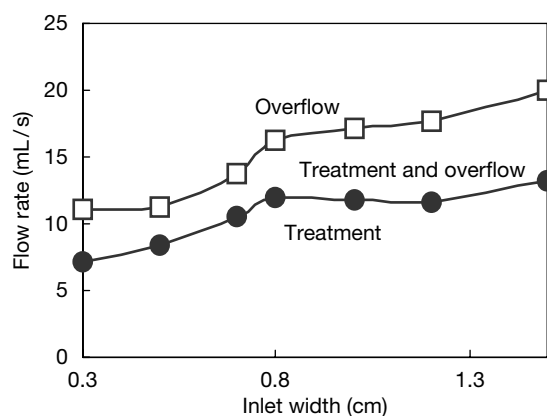


Fig. 4. Dependence of operating modes on inlet width and input flow rate.

adjusting the size of the inlet width. For instance, the input water overflows the filtration unit over 11 mL/s at 0.3 cm of the gap width. The flow rate required for total overflow may increase up to 20 mL/s with increasing the gap width to 1.5 cm. This will allow operating the system in an easy and convenient way.

### 3.3. Metal membrane

Although the fiber filter media is useful to remove some of the pollutants from rainwater, the quality of produced water was not enough for use in spraying, cleaning, and toilet flushing. Moreover, the greywater contains substantial amounts

of particles that cannot be sufficiently rejected by the fiber filter media. It may be possible to apply conventional or advanced filtration techniques such as microfiltration and ultrafiltration but the cost of polymeric membrane systems is substantial and not economically feasible. On the other hand, metal membranes made of stainless steel have potential for this application because of high flux ( $>1000 \text{ L/m}^2\text{-h}$ ), low cost, long lifetime, and easy operation. Thus, filtration using metal membranes with different pore sizes was attempted to produce high quality of water for non-potable use.

Table 3 compares the water quality of influent water and filtrates from metal membranes. Removal efficiency of turbidity ranges from 50 to 75% for greywater and 18 to 54% for rainwater. In case of greywater treatment, metal membranes were also effective to remove pollutants that cause color and COD. Removal efficiency of color

was between 50 and 73% and that of COD was between 45 and 70%. On the other hand, negligible amount of color was removed by metal membranes in rainwater tests. Generally, the removal efficiency increases with decreasing nominal pore size of metal membranes.

Fig. 5 shows the rejection of particles as a function of their size. Only particles ranges from 2 to 15  $\mu\text{m}$  were considered in this test. In greywater filtration, the pore size of metal membrane was found to affect the rejection significantly. The rejection of 15  $\mu\text{m}$  particles was less than 70% for 5  $\mu\text{m}$  metal membrane fiber while the rejection of same particles by 0.5  $\mu\text{m}$  metal membranes was more than 95%. The difference in treatment efficiency among metal membranes with different particle sizes became smaller for greywater + rainwater and rainwater cases, as shown in Fig. 5(b) and (c). Based on the results in Fig. 5, it is

Table 3  
Water quality of influent and filtrates from different metal membrane

	Influent	5 $\mu\text{m}$	1 $\mu\text{m}$	0.5 $\mu\text{m}$
Panel a — Greywater				
pH	7.27	7.36	7.41	6.81
EC ( $\mu\text{S/cm}^2$ )	194	181	187.1	163.8
Turbidity (NTU)	12.6	5.9	4.76	3.20
Color	49	25	24	13
COD (mg/L)	22.9	12.5	12.6	6.8
Panel b — Greywater:rainwater = 1:1				
pH	7.49	7.49	7.51	7.08
EC ( $\mu\text{S/cm}^2$ )	156.2	140.6	139.9	124.2
Turbidity (NTU)	7.04	2.78	1.96	1.36
Color	15	14	14	11
COD (mg/L)	13.3	5.6	5.4	5.6
Panel c — Rainwater				
pH	7.57	7.52	7.49	7.18
EC ( $\mu\text{S/cm}^2$ )	82.6	82.4	82.2	87.0
Turbidity (NTU)	1.19	0.98	0.948	0.55
Color	12	12	12	11
COD (mg/L)	6.1	2.5	2.7	2.0

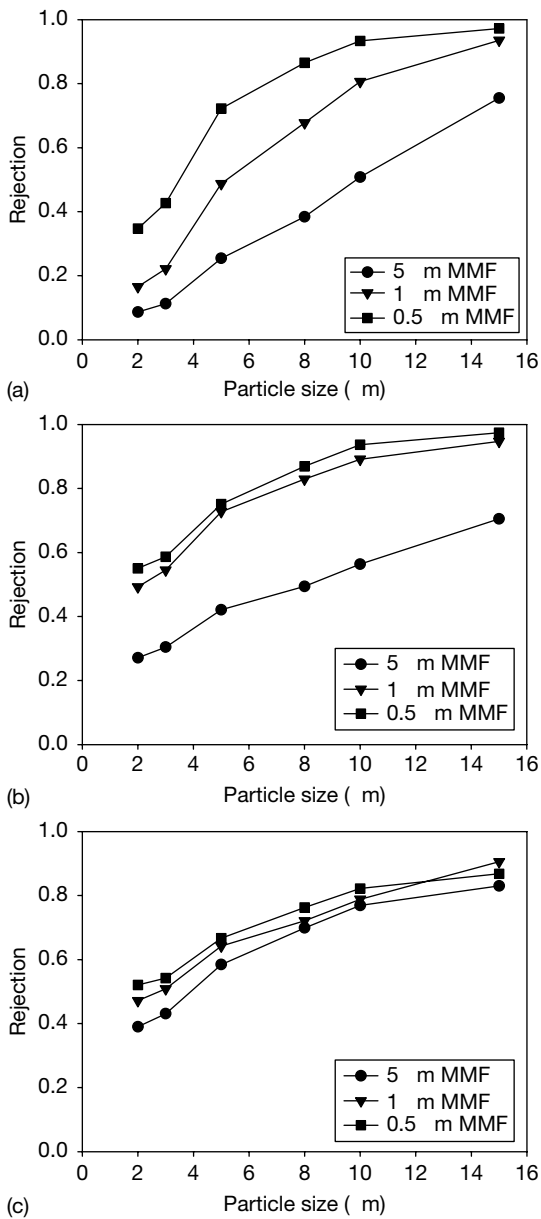


Fig. 5. Rejection of pollutants as a function of their particle size by three metal membranes: (a) greywater; (b) greywater + rainwater; (c) rainwater.

likely that the effective pore size of metal membrane seems to be much larger than the nominal pore size.

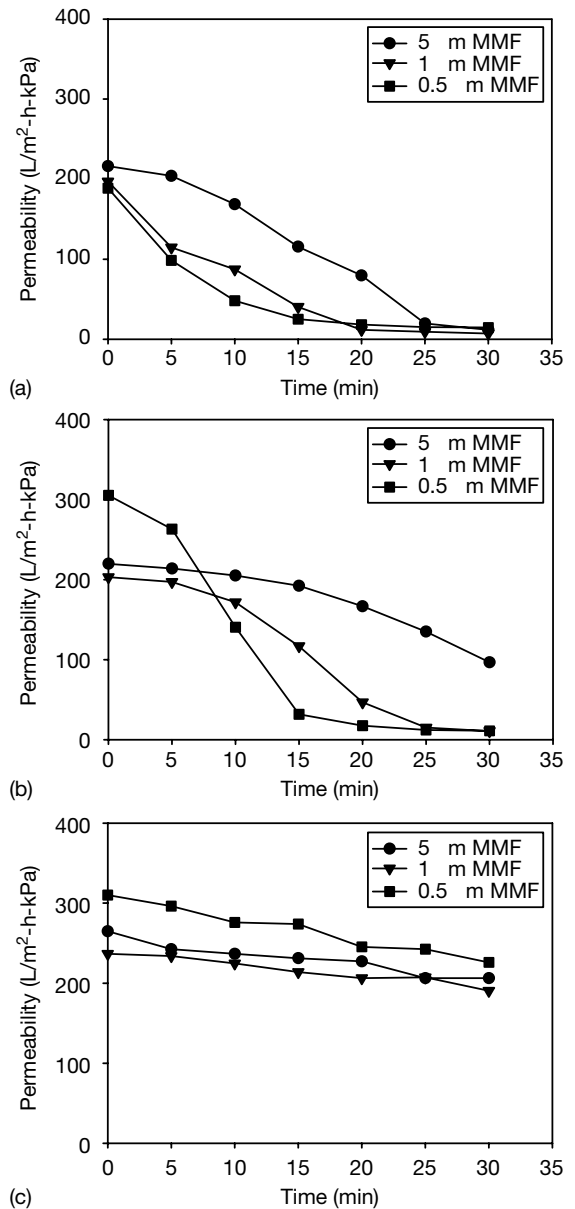


Fig. 6. Dependence of membrane permeability (defined as the permeate flux divided by transmembrane pressure) on filtration time for three metal membranes: (a) greywater; (b) greywater + rainwater; (c) rainwater.

Fig. 6 shows the permeability of metal membranes as a function of filtration time. Here, the permeate was defined as the ratio of flux to

transmembrane pressure ( $L/m^2-h-kPa$ ). For greywater filtration, 1  $\mu m$  metal membrane and 0.5  $\mu m$  metal membrane show similar decline patterns. However, 5  $\mu m$  metal membrane shows much slower permeability decline probably because that the membrane rejects fewer amounts of particles in the influent solution.

For the mixture of greywater and rainwater, the initial permeability of 0.5  $\mu m$  metal membrane was the best but it rapidly decreased with time. After 10 min, 0.5  $\mu m$  metal membrane resulted in the smallest permeability. Pore blocking may occur at the beginning of operation for 0.5 and 1  $\mu m$ , which causes smaller permeability for 0.5 and 1  $\mu m$  metal membrane. Since there was less number of particles in rainwater samples, the permeability of three metal membranes was similar for rainwater treatment.

#### 4. Conclusions

In this study, the feasibility of treatment techniques using the fiber filter media and metal membranes were examined for reuse of greywater and rainwater. The following conclusions were drawn:

- (1) The fiber filter media removed not only particles but also nutrients such as nitrogen and phosphate. The integration of the fiber filter media into first flush treatment unit allowed efficient treatment of rainwater under various conditions.
- (2) The metal membranes efficiently rejected particles in greywater and rainwater. The metal membrane having larger pore size resulted in slower fouling but lower rejection. It is evident that the treatment of rainwater costs much less than that of greywater.

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