IJE TRANSACTIONS A: Basics Vol. 37 No. 07, (July 2024) 1252-1262

International Journal of Engineering

Journal Homepage: www.ije.ir

Leaching Potential and Effectiveness of Pervious Mortar Filters in Bacteria and Turbidity Removal from Surface Water

E. Yogafanny[a,b], R. Triatmadja*[a,c], F. Nurrochmad[a], I. Supraba[a]

[a] *Department of Civil and Environmental Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia*

[b] *Department of Environmental Engineering, Universitas Pembangunan Nasional Veteran Yogyakarta, Indonesi*

[c] *Center for Environmental Studies, Universitas Gadjah Mada, Yogyakarta, Indonesia*

PAPER INFO

Paper history:
Received 24 August 2023
Received in revised form 22 December 2023
Accepted 27 December 2023

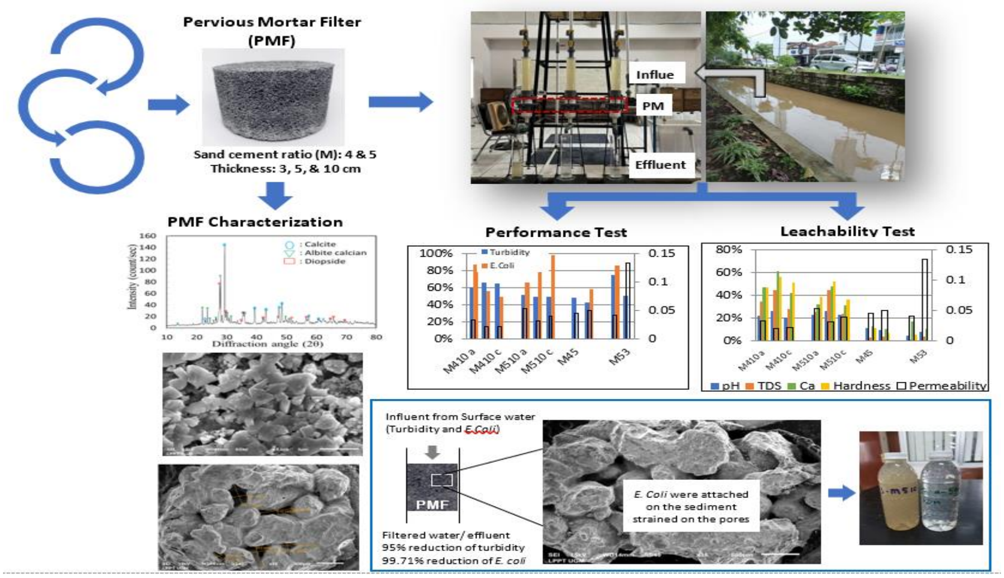
Keywords:
Pervious Mortar
Water Filter
Turbidity Removal
Bacteria Removal
Leaching

ABSTRACT

A pervious mortar filter (PMF) is a modification of pervious mortar and pervious concrete designed as a water filter that, based on its physical characteristics, can reduce turbidity and bacteria. However, chemically, it contains minerals that can dissolve upon contact with water and be found in effluent. This study aimed to determine the performance of PMF in treating surface water by reducing turbidity and *Escherichia coli* and to assess its leaching potential. PMF specimens were created by mixing sand (0.6–0.85 mm), cement, and water with sand-to-cement ratios (M) of 4 and 5 and a water-to-cement ratio (w/c) of 0.4. Each mixture was then molded into pipes with a diameter of 8.2 cm and different thicknesses: 3, 5, and 10 cm. Raw surface water was used for the performance and leaching tests. Results showed that PMF effectively removed 95% turbidity and 99.71% *E. coli*, which increased with the filtration duration. PMF reduced *E. coli* more effectively when designed with a thickness of 10 cm than 5 or 3 cm because it would provide more surface areas for suspended solids and bacteria to attach and be retained. More substantial increases (mean %) of pH, hardness, calcium ions, and TDS were observed in PMF M4 with a thickness of 10 cm than in thinner ones because it contained more cement that would dissolve when in contact with water.

doi: *10.5829/ije.2024.37.07a.05*

Graphical Abstract



---

*Corresponding Author Email: radianta@ugm.ac.id (R. Triatmadja)

Please cite this article as: Yogafanny E, Triatmadja R, Nurrochmad F, Supraba I. Leaching Potential and Effectiveness of Pervious Mortar Filters in Bacteria and Turbidity Removal from Surface Water. International Journal of Engineering, Transactions A: Basics. 2024;37(07):1252-62.

1. INTRODUCTION

Pervious concrete is a composite of cement, coarse aggregates, few to no fine aggregates, water (1), and other admixtures, additives, or organic or recycled materials as substitutes for aggregates (2, 3). Its first use in water purification can be traced back to last decades, when Park and Tia (4) stated about the application of eco-concrete as a water purifier. Then, they observed substantial reductions in total nitrogen and phosphorus concentrations in water when testing a pervious concrete filter that was made of small sand particles and thus had many pores or voids (4). The application of pervious concrete as a water filter was further solidified after being patented by Majersky in 2008 (5). Numerous studies have since confirmed its ability to reduce water pollutants, including BOD, COD, and heavy metals (5). Each pore in pervious concrete is a medium that physically captures dissolved nitrogen and phosphorus in water by filtration and chemically removes dissolved phosphorus by adsorption (6). Pervious concrete has shown promising results as a water purifier and had a potentially significant role in addressing water pollution challenges.

Pervious mortar filter (PMF) is an innovative technology that is currently under development. Unlike previous concrete, PMF does not use gravels, additives, and admixtures to ensure good-quality water treatment. Furthermore, PMF differs from conventional mortar in that it does not solely add cement, fine aggregates, and water to the mixture (7) but applies specific sand-to-cement and water-to-cement ratios. PMF mixes fine sand, cement, and water with a sand-to-cement ratio (M) of 4 or 5, resulting in a smaller pore size and permeability lower than pervious concrete but higher than conventional mortar. Due to the small pores and their hydraulic characteristics, this porous composite can transmit water while effectively entrapping the pollutants carried, such as suspended solids, bacteria, and heavy metals. One method commonly used in surface water treatment especially for turbidity removal is coagulation using alum and ferric chloride along with calcium hydroxide as a coagulant to reduce turbidity (8). PMF can be an alternative method to reduce turbidity without using these chemicals.

Many scholars have explored the application of fine aggregates in mortar/ concrete as water filter. Taghizadeh et al. (9) designed a water filter using only fine sand, later termed porous concrete. In Indonesia, the development of PMF technology is initiated as a water filter by using sand with a grain size of 1–2 mm as the aggregate. Subsequently, comprehensive research by Kamulyan et al. (10) investigated the use of fine aggregates with a particle size of < 2 mm.

The ability of PMF to reduce various impurities has been well-established in the literature. Pervious mortar proved highly effective in reducing turbidity, with a reported 90–95% reduction (10). PMF with 10 cm diameter and 20 cm thickness created using sand aggregate sized 0.15–0.30 mm and a sand-to-cement ratio of 4 significantly reduced turbidity to <5 NTU and impressively removed *Escherichia coli* by (*E. coli*) 98.71% or 2-log removal value (LRV). Therefore, to contribute to PMF development, the current research assessed the filtration performance of PMF made of small (0.6–0.85 mm) and uniformly sized aggregates with a sand-to-cement ratio of 4 (Figure 1).

The pollutant removal performance of PMF stems from its unique physical and hydraulic characteristics, such as pore structure and geometry. PMF composed of aggregates smaller than 1 mm with the appropriate mix design (sand-to-cement ratio of 4 or 5) has low permeability, prolonging contact with water and the substances it carries. This creates opportunities for effective entrapment and retention of impurities within the filter's pores. However, the extended contact duration also allows for dissolution and subsequent transportation of the dissolved elements, such as Ca^{2+}, into the water. This means pervious mortar or concrete can dissolve or leach if exposed to specific water qualities for an extended period (11). Leaching is a significant degradation observed in cement-based composites, representing one of the primary factors responsible for their mechanical alteration (12-16). This process starts when cement paste comes into contact with pure or acidic water (low pH), causing hydrolysis (17). Conversely, dissolution involves transporting the concrete's compounds or ions due to the reaction between water and portlandite ($Ca(OH)_2$). Portlandite is a mineral formed during the curing of cement by hydration (6, 17). Leaching evolves through the dissolution and precipitation of minerals in cement-based composites, such as PMF. The chemical reactions are expressed in Equations 1 to 4.

Formation of carbonic acid:

$$H_2O + CO_2 \leftrightarrow H_2CO_3 \quad (1)$$

Figure 1. Pervious mortar filter with the dimension of 8.2 cm (d, diameter) x 5 cm (h, or thickness), made of sand with a grain size of 0.6–0.85 mm and a sand-to-cement ratio (M) of 4

Dissolution of calcium hydroxide:

$$2H_2CO_3 + Ca(OH)_2 \leftrightarrow Ca(HCO_3)_2 + 2H_2O \quad (2)$$

Formation of calcium carbonate:

$$Ca(HCO_3)_2 + Ca(OH)_2 \leftrightarrow 2CaCO_3 + 2H_2O \quad (3)$$

Dissolution of calcium carbonate:

$$CaCO_3 + H_2CO_3 \leftrightarrow Ca(HCO_3)_2 \quad (4)$$

Numerous studies have investigated the interplay between the leaching of calcium ions (Ca^{2+}) and its impact on concrete's porosity and tensile strength, and vice versa. Exploring the effect of porosity in Portland cement on the leaching process, Haga et al. (18) found that increased pore volume led to faster dissolution of portlandite present in the cement-based composite. They concluded that diffusion regulates the transport of dissolved substances or constituents and that the primary components dissolved in hardened ordinary Portland cement (OPC) are portlandite and C-S-H gel. Solpuker et al. (19) estimated the leaching potential and the ability of pervious concrete to retain trace metals. Using the column method, they passed water with a pH of 4.3 through the pervious concrete, but the generated wastewater was basic (approximately pH of ~10). The conductivity decreased rapidly within the first 50 hours and then slowly afterward. In the early stages, there was substantial leaching of trace metals, which diminished significantly after 50 hours and then gradually declined over time.

Various researchers have extensively studied leaching in concrete or pervious concrete, primarily with immersion tests (14, 18, 19). The column method has received less attention by comparison. In this research, the column method was first adjusted to align with the function and utilization of pervious mortar as a water filter and then employed to assess the leaching potential of composites with smaller aggregate sizes, specifically pervious mortar. In this method, water flowed dynamically into the pervious mortar until saturation. Based on the above description, this study aimed to investigate the effectiveness of pervious mortar filters in treating surface water by removing impurities, i.e., suspended solids and bacteria, and their leaching potential.

2. MATERIALS AND METHODS

2. 1. Preparation of Specimens

A pervious mortar filter (PMF) comprises sand, cement, and water without admixtures. The sand used was collected from the Progo River (Indonesia), with a particle size ranging from 0.6 to 0.85 mm, while the cement used was Portland composite cement (PCC) "Semen Gresik" (Indonesia). No admixtures or additives were incorporated into the PMF mixture to prevent the risk of heavy metal dissolution (19). The physical and chemical characteristics of the sand and cement are presented in Table 1. Specimens were made with two sand-to-cement ratios (M) of 4 and 5 and a water-to-cement ratio of 0.4, as shown in Table 2.

The mixing and stirring stages were modified from the previous concrete production process in Park and Tia (4), which included the use of a Hobart mortar mixer and the 2-minute mixing time of the dry matter (instead of 1 minute). These modifications were necessary because the current research used sand with a much smaller grain size, thus creating a larger surface area. First, half of the sand and half of the cement were added into the mixer and stirred for 2 minutes. Subsequently, the remaining halves of both materials were added to the mix and stirred again for 2 minutes until homogenous. Then, water was gradually added while stirring for 2 minutes to create the final PMF mixture.

The next stage was molding on a vibrating table. This method was modified and informed by preliminary experiments conducted before commencing this study. Approximately 200 g of the final mixture was carefully poured into sand-layered PVC molds, made by cutting 3-inch PVC pipes into varying heights or thicknesses: 3, 5, and 10 cm. A stainless-steel ballast weighing 225 g was positioned on top of the mixture on the vibrating table and then vibrated at 50 Hz for 1 minute. This step was repeated until the mixture slightly exceeded the mold's rim (approximately three fillings to create a specimen with 5 cm thickness), which was later leveled off using a ruler. Afterward, the filled mold was inverted, weighed, and vibrated again for 1 minute. Finally, it was returned to its initial position and vibrated for 30 seconds. The specimens were left to dry for 24 hours at room temperature (approximately 26°C), followed by curing with a moist cloth cover for 90 days. Afterward, the PMF was ready for use as a filter.

All the 60 specimens were tested for porosity. Results show that porosity remained consistent across the different thicknesses and M variations. For the performance and leachability tests, several specimens were chosen according to its porosity. By this consideration, three specimens of 10 cm thickness were selected from M410 (namely M410a, M410b, and M410c) or M510 (namely M510a, M510b, and M510c). One specimen that represent the mean porosity on PMF with 5 and 3 cm thickness for both M ratio were chosen to be tested for performance and leachability test. According to the preliminary study, the thicker PMFs (10 cm) perform better than the thinner ones. Hence, for this performance and leachability test, the PMF with 10 cm thickness is evaluated in more detail by using three samples on each M. While for the 5 and 3 cm PMF, only one sample is used to be observed. In this experiment, ten specimens of PMF were chosen i.e. M410a, M410b, M410c, M510a, M510b, M510c, M45, M55, M43, and M53.

TABLE 1. Physical and chemical characteristics of the sand and cement inputted into the pervious mortar filter (PMF) mix design

Sand (Progo River)		Cement (PCC)	
Element	**Value**	**Element**	**Value**
SiO_2 (mass%)	39.10	SiO_2 (mass%)	18.52
P_2O_5 (mass%)	3.768	P_2O_5 (mass%)	6.65
SO_3 (mass%)	0.509	SO_3 (mass%)	2.051
CaO (mass%)	9.958	CaO (mass%)	67.53
TiO_2 (mass%)	4.351	TiO_2 (mass%)	0.633
MnO (mass%)	0.532	MnO (mass%)	0.121
Fe_2O_3 (mass%)	31.70	Fe_2O_3 (mass%)	4.23
CuO (mg/kg)	654.8	CuO (mg/kg)	513
ZnO (mg/kg)	660	ZnO (mg/kg)	359
Rb_2O (mg/kg)	187.6	Rb_2O (mg/kg)	73.7
SrO (mass%)	0.199	SrO (mg/kg)	519
BaO (mass%)	0.102	BaO (mg/kg)	382
Al_2O_3 (mass%)	7.65	As_2O_3 (mg/kg)	75.9
K_2O (mass%)	1.981	NiO (mg/kg)	684
Density (kg/m^3)	2,840	Density (kg/m^3)	2,960
Fineness modulus	2.7		
Uniformity coef.	1.6		

TABLE 2. The mixture design of the PMF specimens

Criteria	Value and unit
Size of sand	0.6–0.85 mm
Type of cement	Portland Composite Cement (PCC), Semen Gresik (Indonesia)
Sand-to-cement ratio (M)	4 and 5
Water-to-cement ratio	0.4
Specimen's diameter	8.2 cm (3-inch PVC pipe)
Specimen's thickness	3, 5, and 10 cm
Curing type	Moist cloth cover
Curing duration	90 days

2. 2. Performance and Leaching Tests Figure 2 presents the laboratory equipment used in the performance and leaching tests. The performance or effectiveness test of the PMF specimens was assessed based on changes in the turbidity and *E. coli* concentration after filtration. The influent was water samples collected every morning during the experiment (January 8 to March 8, 2023) from the drainage channel "Selokan Mataram" (north of the Faculty of Forestry, Gadjah Mada University (UGM), Indonesia). Samples were tested for turbidity at the Laboratory of Sanitary and Environmental Engineering (UGM) and *E. coli* presence at the Faculty of Geography (UGM). Meanwhile, the leaching test was specifically modified to the function of PMF as a water filter. The modifications made to the several steps of the leaching test performed by Vadas et al. (12) were as follows:

Figure 2. Equipment for the performance and leaching tests of PMF specimens

a. Column filtration

Mineral dissolution occurs when water flows into and directly interacts with PMF. The leaching potential of pervious mortar, acting as a filter, was analyzed by comparing the water quality before (influent) and after (effluent) passing through 100-day-old PMF specimens designed in this study. The tested water quality parameters were pH, TDS, Ca^{2+}, and total hardness ($CaCO_3$), which are indicators of mineral leaching from the filters during water treatment.

b. X-ray diffraction (XRD) and scanning electron microscope-energy dispersive X-ray (SEM-EDX)

XRD was employed to determine the minerals formed during the curing of pervious mortar. The minerals present in PMF were used as a basis for analyzing the chemical elements or compounds found in the effluent. XRD was conducted on one of the test specimens (M4 and M5) and cement that had been allowed to set for 90 days. This test was performed at the UGM-Integrated Research and Testing Institute (LPPT). In addition, SEM-EDX was employed to determine the morphology of the PMF composites to help visually identify their constituent minerals and pore sizes.

2. 3. Water Quality Test Equipment

a. Turbidity

The equipment used to measure turbidity is HACH 2100Q Turbidimeter. Turbidity is read by the unit of Nephelometric Turbidity Unit (NTU). A turbidimeter is a tool for turbidity testing with optical properties due to light dispersion and can be expressed as a ratio of reflected light to incident light. The intensity of light reflected by a solid suspension is a function of concentration if other conditions are constant.

b. Total Dissolved Solid (TDS) and pH

The equipment used to measure these two parameters are a portable multiparameter - HACH sensION 65 with the pH electrode – HACH, and conductivity/TDS electrode – HACH

c. Ca^{2+} and total hardness ($CaCO_3$)

Water hardness is analyzed using the complexometric method, the principle of which is based on the formation of soluble complex compounds between metal ions and complex-forming substances, namely the formation of Ca with EDTA.

The Sodium salt ethylene diamine tetra acetate (EDTA) will react with certain metal cations to form soluble chelate complex compounds. At pH 10.0 + 0.1, the calcium and magnesium ions in the test sample will react with the Eriochrome Black T (EBT) indicator and form a purplish red solution. If Na_2EDTA is added as a titrant, the calcium and magnesium ions will form a complex compound, the indicator molecules are released again, and at the end point of the titration the solution will change color from purplish red to blue. From this method, total hardness (Ca and Mg) can be obtained.

Calcium can be determined directly with EDTA, if the pH of the test sample is made high enough (12-13), so that magnesium will precipitate as magnesium hydroxide and at the end point of the titration the Eriochrome Black T (EBT) indicator will only react with calcium to form a blue solution. From this method the calcium (Ca) concentration in the water can be obtained.

d. *E.coli*

This research uses the Most Probable Number (MPN) method which consists of an presumptive test, confirmation test, and refinement test, using solution concentrations of 0.1 ml, 1 ml and 10 ml.

The initial step of the experiment, namely a presumptive test, was to sterilize the equipment using an autoclave at a temperature of 121°C for 30 minutes. After that, the media was prepared, the made media were Lactose Broth (LB), Brilliant Green Lactose Bilebroth (BGLB), and Eosin Methylene Blue (EMB).

Next is the confirmation test. At this stage, 9 culture tubes containing sterile LB media equipped with Durham tubes were then poured into the water samples with a dropper in different volumes, namely 10 ml, 1 ml and 0.1 ml in each of the 3 test tubes, then incubated for 24 hours at 37 °C. In the confirmation test, each culture tube containing 10 ml of Brilliant Green Lactose Bilebroth (BGLB) equipped with a Durham tube is prepared, positive samples are added. Pour water into the 1 ml lactose culture that has been incubated and is considered positive, the tube is incubated for 24 hours at 45°C.

The final stage is the refinement test, samples that are positive in the confirmation test are inoculated using a loop needle onto the surface of Eosin Methylene Blue (EMB) media in a zig-zag manner and then incubated at a temperature of 37°C for 24 hours. Colony growth was observed on Eosin 63 Methylene Blue (EMB) media. Colonies that show a metallic sheen are colonies of *Escherichia coli* bacteria. After all tests are completed, the *Escherichia coli* MPN value is determined by matching the analysis results with the MPN table (20).

3. RESULTS AND DISCUSSION

3. 1. Characteristics of PMF Specimens

The same M value represents an identical composition of cement and sand. PMFs with M4 (PMF-M4) and PMF-M5 were characterized and analyzed morphologically and chemically using XRD and SEM-EDX tests. Figure 3 shows that PMF-M4 consisted of three major minerals: calcite, albite calcian, and diopside. Further details on their morphology and visual appearance were obtained from the SEM-EDX test, as presented in Figures 5 and 6.

Figure 6 also shows the presence of capillary and gel pores. All data obtained from the XRD and SEM-EDX tests provided the basis for analyzing the leaching potential of PMF when used as a filter.

The X-ray diffractograms in Figure 7 identified calcite, albite calcian, and diopside as the mineral constituent of PMF-M5. Figures 8 and 9 provide further information on their mineral morphology and the distribution of capillary and gel pores.

3. 2. Performance of PMF Specimens

Pervious concretes act as an effective water filter by retaining suspended solids and adsorbing metals and other chemicals present in water (5). Similarly, porous mortars possess comparable physical and hydraulic

Figure 3. Examples of PMF specimens during the production process

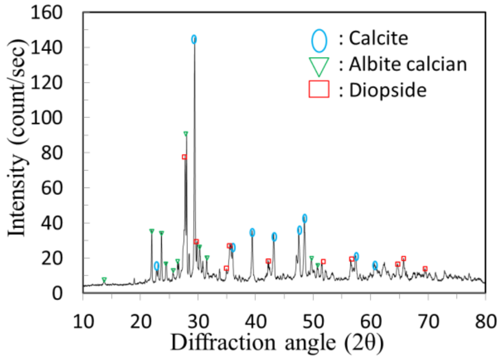


Figure 4. X-ray diffractograms showing the mineral composition of PMFs with M4 (PMF-M4)

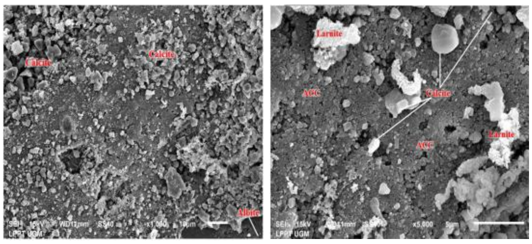


Figure 5. SEM of PMF-M4 at 1000x (left) and 5000x magnifications (right)

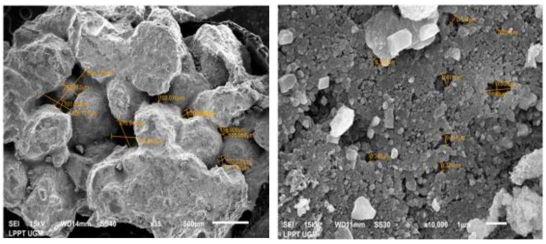


Figure 6. Identification of capillary pores (left) and gel pores (right) in PMF-M4

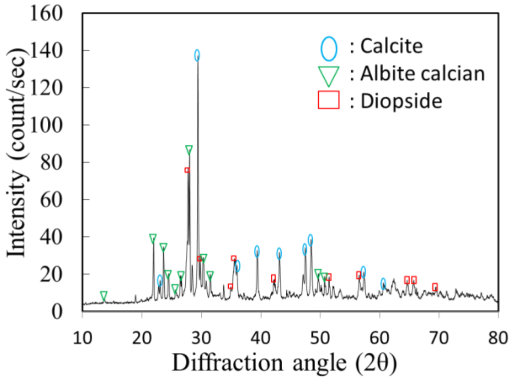


Figure 7. X-ray diffractograms showing the mineral composition of PMF-M5

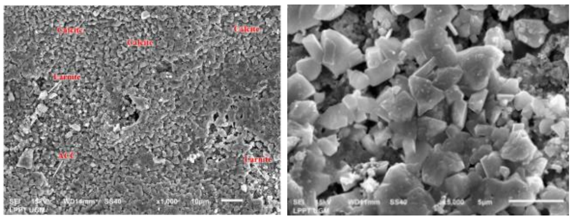


Figure 8. SEM of PMF-M5 at 1000x (left) and 5000x magnifications (right)

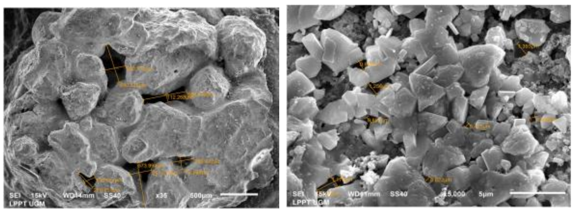


Figure 9. Identification of capillary pores (left) and gel pores (right) in PMF-M5

characteristics, enabling them to filter water effectively. Previous studies have demonstrated the ability of pervious mortars to entrap and remove suspended particles (5, 9), heavy metals, such as Cu, Pb, Cd, and Zn (12), and bacteria from raw water, resulting in better-quality effluents. In the mortar's composition, sand and cement form pores that facilitate the storage and retention of water impurities. This study analyzed the performance of PMFs using two water quality parameters: turbidity and *E. coli* bacteria. Further, to complement previous research findings, it observed the time taken to perform filtration until saturation. The performance test equipment, process, and output of filtration of water samples collected from the drainage channel "Selokan Mataram" with the PMF specimens are shown in Figure 10.

Based on the performance test shown in Table 3, the highest to the lowest maximum effectiveness of PMF in reducing turbidity was 95% (10 cm/M5), 93% (10 cm/M4), 78% (3 cm/M4), 77% (5 cm/M4), 74% (3 cm/M5), and 66% (5 cm/M5). PMF also proved effective in removing *E. coli* by up to 99% (10 cm/M4 and M5), 58% (5 cm/M5), and 86% (3 cm/M4). Table 4 shows the influent and effluent turbidity and *E. coli* concentrations for all PMF specimens.

Figure 11 demonstrates the relationship between the permeability and the performance of PMF specimens in lowering turbidity and *E. coli*. Permeability was measured using the constant head method with the pressure level set at 30 cm. The graph generally indicates that for PMFs with the same thickness, lower permeability coincided with greater turbidity reduction and, thus, higher effectiveness. However, this trend did not apply to performance in reducing *E. coli*.

Among the specimens, M510a produced the highest effectiveness with the most significant turbidity reduction of up to 95%, although a fairly wide range of

Figure 10. Process (A) and equipment setup of the PMF performance test (B), water in the drainage channel "Selokan Mataram" as influent (C), and water samples before and after filtration with PMF (D)

TABLE 3. Permeability and effectiveness of PMF specimens in reducing turbidity and *E. coli*

PMF	Turbidity (%)		*E. coli* (%)		Permea-bility (cm/s)	Vol. of treated water (L)
	min	max	min	max		
M410a	33	93	0	93.75	0.033	83.9
M410b	42	79	0	86.36	0.021	44.83
M410c	53	84	0	99.36	0.022	98.27
M510a	8	95	0	99.71	0.053	86.6
M510b	20	80	91.25	97.08	0.032	46.56
M510c	6	92	98.83	98.75	0.040	70.13
M45	34	77	0	0	0.045	133.36
M55	28	66	0	58.18	0.050	229.17
M43	73	78	0	86.36	0.041	31.05
M53	28	74	0	0	0.134	75.89

TABLE 4. Turbidity and *E. coli* concentration in the influent (before) and effluent (after filtration)

PMF	Filtration time (hour)	Turbidity (NTU)		*E. coli* (MPN/100ml)	
		Inf	Eff	Inf	Eff
M410a	7.5	184	8.26	2400	210
M410b	5.5	184	23.9	2400	150
M410c	8.5	173	29.7	28	7
M510a	9	156	13.8	2400	7
M510b	4.4	156	49.2	2400	7
M510c	6.9	156	19.1	2400	3
M45	17.5	121	20.8	1100	1100
M55	21	121	18.4	1100	1100
M43	5.25	182	72.1	460	150
M53	5.75	323	73	1100	1100

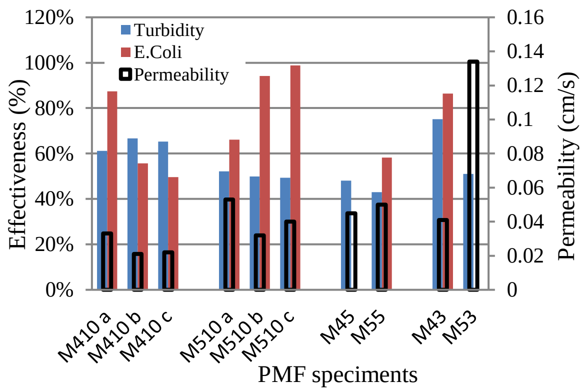


Figure 11. Permeability and effectiveness of PMF specimens in removing turbidity and *E. coli*

effectiveness was observed (minimum effectiveness of 8%). For comparison, M43 exhibited moderate effectiveness by lowering turbidity levels by 73–78%, similar to Hosseini & Toghroli (21), who reported that pervious concrete successfully reduced total suspended solids by 75 to 85%. Performance variations in M510a indicate that PMFs with 10 cm thickness reduced turbidity to a varying degree. This occurred because the filter required time to accumulate suspended particles on its pore walls, contributing to increasing turbidity reduction over time. The longer the PMF operates, the higher its effectiveness in lowering turbidity before reaching saturation.

PMF-M4 showed a higher average of turbidity reduction than PMF-M5 of the same thickness (5 or 3 cm). This could be attributed to the larger proportion of cement in the M4 mix that created a less porous filter with a better ability to retain suspended particles. The maximum turbidity reduction of PMF-M4 and PMF-M5 with 10 cm thickness varied from 79% to 95%, with no noticeable difference between both sand-to-cement ratios.

PMFs with thicknesses of 5 and 3 cm showed a maximum turbidity reduction of 66% to 78%, although the latter performed better than the former. This might stem from its smaller pore area, which enabled suspended solids to fill the pores almost immediately and hold onto other suspended particles, increasing effectiveness. However, due to the limited pore area, this PMF became clogged or saturated more quickly, thus transmitting and treating less water than the one with a thickness of 5 cm (see Table 3).

The biological parameter observed to estimate the amount of bacteria in the water was *E. coli*, a species found in the environment, food, and the intestines of humans and animals. While most *E. coli* are not harmful, a small percentage of certain kinds of this microorganism can result in pneumonia, urinary tract infections, and diarrhea. Therefore, detecting their presence in a clean water supply is essential. Based on the analysis results presented in Table 3, the PMF specimens could remove *E. coli* from the influent up to 99.71%. The zero percentage indicates no removal of *E. coli*, possibly because the filters were relatively new. In filters that have been operated for a long time, many bacteria are attached and growing on the walls of their pores and can later bind *E. coli*. In other words, with more frequent use, the PMF improves its effectiveness in removing *E. coli* from water.

No removal of *E. coli* concentration was primarily observed in PMFs with a thickness of 5 cm. As seen in Table 3, they processed or filtered the highest amount of treated water compared to PMFs with thicknesses of 10 and 3 cm. These results suggest that pore condition or effective porosity significantly affects how much water PMFs can filter. Nonetheless, more information than the total porosity presented in the table is required to analyze the effect of porosity on the filter's ability to treat water. Also, further studies are needed to identify the size and number of open and closed pores to support water filtration analysis with PMF.

Based on its minimum and maximum values, M510 consistently demonstrated good effectiveness in removing about 97.08 to 99.71% of *E. coli*. These results did not substantially differ from the maximum effectiveness of M410, which varied from 86.36 to 99.36%. In conclusion, the sand-to-cement ratio (M) does not directly affect the filter's ability to retain bacteria. Instead, thickness is believed to have a more significant influence. Generally, 10-cm thick PMFs exhibited better *E. coli* reduction than those designed with thicknesses of 5 and 3 cm. Thicker PMFs provide more space to entrap and retain suspended particles and bacteria. These results found that thicker PMFs had higher effectiveness in removing *E. coli*, specifically those with a thickness of 15 cm and a sand-to-cement ratio of 4

3. 3. Leaching Potential of PMF Specimens

Water can be filtered effectively by pervious concrete and pervious mortar. However, because of the chemical composition of their basic materials, there is a chance of disintegration when exposed to water. Disintegration occurs when the calcium ions in the cement detach and flow together with water into the filter's surroundings, hence called calcium leaching (22, 23). Calcium leaching potentially affects the strength and durability of all cement-based composites (24). Calcium contents, total hardness ($CaCO_3$), total dissolved solids (TDS), and pH levels of the effluent may increase due to water contact with the chemical composition of pervious concrete or pervious mortar filters during filtration (5).

This research investigated how sand-to-cement ratio (M) and thickness affected the effluent's pH, hardness, TDS, and calcium levels. In doing so, it adds more evidence of the leaching potential to earlier studies on PMF, as demonstrated by changes in these parameter values. The leaching test aimed to determine the leaching patterns of PMF when exposed to the inflow of natural water sources. Therefore, it used the same influent as the performance test.

Table 5 shows the mean percentage of increase in total hardness, Ca^{2+}, TDS, and pH. It indicates a correlation between smaller sand-to-cement ratios and higher increases in Ca^{2+} and hardness levels. The percentage of increase for each parameter was generally higher in thicker (10 cm) than in thinner PMF specimens (3 cm), indicating a higher water alkalinity level. Lee et al. (25) found that pH increased more substantially in thicker (20 cm) than thinner pervious concrete (10 cm) because pervious concrete contains hydrated cement products that easily dissolve in water, releasing substances like OH^- that can increase the water pH. Thicker pervious concrete has more cement, resulting in the dissolution of more products of cement hydration reactions that leads to effluent with increased pH. The current study shares some similarities with Lee et al. (25), as it found pH, hardness, Ca^{2+}, and TDS generally increased more significantly in PMFs with a thickness of 10 cm than 3 or 5 cm.

Each PMF has its unique capacity to drain water, thus creating different durations of filtration, times to saturation, and filtered water amounts. For all the specimens, the pH levels of the influent ranged from 6.7 to 7.5. Meanwhile, the pH levels of the effluent were as follows: 8.5–10.5 for M410, 8.5–10.6 for M510, 7.5–8.5 for M45, 7.1–9 for M55, 7.3–7.4 for M43, and 7.2–8.5 for M53. The TDS levels of the influent ranged from 87 to 119.5 mg/l and the TDS levels of the effluent were as follows: 100.9–565 mg/l for M410, 96.3–582 mg/l for M510, 109.3–119.5 mg/l for M45, 109.4–133.6 mg/l for M55, 103.2–106.1 mg/l for M43, and 94.4–114.1 mg/l for M53. The Ca^{2+} levels of the influent ranged from 15.84 to 25.6 mg/l and the Ca^{2+} levels of the effluent were as follows: 22.97–89.09 mg/l for M410, 28.67–106.5 mg/l for M510, 25.6–32.77 mg/l for M45, 24.58–40.96 mg/l for M55, 22.53–27.14 mg/l for M43, and 17.41–29.7 mg/l for M53. The total hardness ($CaCO_3$) levels of the influent ranged from 27.72 to 69.3 mg/l and the total hardness levels of the effluent were as follows: 43.56–387.52 mg/l for M410, 51.2–230.4 mg/l for M510, 46.08–61.44 mg/l for M45, 43.52–66.56 mg/l for M55, 61.44–76.8 mg/l for M43, and 55.04–70.4 mg/l for M53.

Increased pH levels in the effluent are consistent with the outcome of water treatment using pervious concrete (12, 25, 26). Vadas et al. (12) stated that pervious concrete could entrap suspended particulates, which later enhanced the retention of heavy metals, such as Cu, Zn, Cd, and Pb, effectively reducing their concentrations by up to 95%. This process was followed by an increase in

TABLE 5. Mean percentages of increase in pH, TDS, Ca^{2+}, and total hardness ($CaCO_3$), after filtration using all the PMF specimens with their varying porosity characteristics

PMF	Average of increment percentage (%)			
	pH	TDS	Ca^{2+}	Hardness
M410a	22%	35%	47%	47%
M410b	26%	45%	61%	56%
M410c	20%	28%	42%	51%
M510a	23%	25%	32%	39%
M510b	26%	44%	48%	52%
M510c	23%	24%	32%	36%
M45	12%	3%	13%	11%
M55	10%	4%	10%	7%
M43	5%	2%	17%	5%
M53	8%	4%	10%	0%

pH levels from 7 (influent) to a maximum of 7.8 (effluent) (12). Lee et al. (25) also observed an increase in pH from 2 in the influent to 7 in the effluent after filtration with pervious concrete.

3. 4. Analysis of Variance (ANOVA) ANOVA was used in this research to compare variances across the means (or average) of different groups (ratio M and thickness). Tables 6 and 7 show the results of analysis of variance (ANOVA) with SPSS for performance of PMF and leachability of PMF.

TABLE 6. ANOVA on performance of PMF

Turbidity removal				
Variables		**Mean**	***Significant value**	
			Sig.	**No Sig.**
Ratio S/C (M)	4	61.46%		0.163
	5	47.97%		
Thickness of PMF (cm)	3	63.08%	0.390	
	5	45.24%		
	10	58.37%		
***E.coli* removal**				
Variables		**Mean**	***Significant value**	
			Sig.	**No Sig.**
Ratio S/C (M)	4	37.68%		0.648
	5	45.90%		
Thickness of PMF (cm)	3	21.59%	0.002	
	5	6.46%		
	10	68.38%		

*Significant if the significant value is < 0.05

TABLE 7. ANOVA on leachability of PMF

pH increment				
Variables		**Mean**	***Significant value**	
			Sig.	**No Sig.**
Ratio S/C (M)	4	18.04%		0.722
	5	16.66%		
Thickness of PMF (cm)	3	6.53%	0.000	
	5	10.55%		
	10	23.46%		
TDS increment				
Variables		**Mean**	***Significant value**	
			Sig.	**No Sig.**
Ratio S/C (M)	4	22.67%		0.609
	5	17.22%		
Thickness of PMF (cm)	3	2.81%	0.011	
	5	3.95%		
	10	33.39%		
Ca^{2+} increment				
Variables		**Mean**	***Significant value**	
			Sig.	**No Sig.**
Ratio S/C (M)	4	35.76%		0.179
	5	23.48%		
Thickness of PMF (cm)	3	13.83%	0.001	
	5	11.61%		
	10	44.09%		
Hardness increment				
Variables		**Mean**	***Significant value**	
			Sig.	**No Sig.**
Ratio S/C (M)	4	34.69%		0.302
	5	23.48%		
Thickness of PMF (cm)	3	2.27%	0.000	
	5	9.19%		
	10	47.33%		

*Significant if the significant value is < 0.05

Based on the results of the ANOVA significance value, there was a significant difference in the average reduction in *E. coli* as well as an increase in pH, TDS, Ca, and hardness based on PMF thickness. However, there is no significant difference in the average values of all variables based on the sand-cement ratio (M).

The significant difference in variable mean values based on PMF thickness is in accordance with findings in other studies that filter thickness greatly influences *E. coli* removal and leachability of PMF. The thicker the pervious concrete, the higher the pH of the effluent in pervious concrete filter (25, 26).

4. CONCLUSION

The effectiveness of pervious mortar filters (PMFs) in reducing turbidity and *E. coli* is caused by the physical filtration process. The filter needs to first entrap some suspended solids from water and allow them to accumulate on its pore walls. This buildup further captures suspended particles from subsequent influents, increasing effectiveness in reducing turbidity. Among PMFs with the same thickness, those with M4 have higher effectiveness than M5. This can be attributed to the higher presence of cement as an adhesive material in M4, which makes the filters less porous and enhances the retention of suspended particles as well as *E. coli*. In addition, thicker PMFs (10 cm) generally have higher effectiveness in removing *E. coli* than the thinner ones (5 and 3 cm) because they provide more surface area and, thus, more chances for suspended solids and bacteria to attach and be retained.

The leaching potential of PMFs can be seen from changes in calcium ions, pH, total dissolved solids (TDS), and hardness between the influent and the effluent. The effluent shows substantially higher parameter values after filtration with the 10-cm thick PMFs than with the thinner ones, suggesting more leaching in the former than the latter. In addition, among PMFs with the same thickness, a smaller sand-to-cement ratio (M4) produces a higher percentage of increase in pH, TDS, Ca^{2+}, and hardness than M5, especially Ca^{2+} and hardness. Calcium ions are released from reactions with water in the form of calcium carbonate. The trend of water hardness in the effluent mirrors that of Ca^{2+}.

5. ACKNOWLEDGMENT

This work received funding from the Indonesia Endowment Fund for Education awarded to the first author (Grant no: KET 248/LPDP.4/2021). The authors would gratefully acknowledge the assistance and support provided by the Hydraulics Laboratory of the Department of Civil and Environmental Engineering, Universitas Gadjah Mada.

6. REFERENCES

1. Pachideh G, Gholhaki M, Moshtagh A. Performance of porous pavement containing different types of pozzolans. International Journal of Engineering, Transactions C: Aspects,. 2019;32(9):1277-83. https://doi.org/10.5829/ije.2019.32.09c.07
2. Shafabakhsh G, Ahmadi S. Evaluation of coal waste ash and rice husk ash on properties of pervious concrete pavement. International Journal of Engineering, Transactions B: Applications. 2016;29(2):192-201. https://doi.org/10.5829/idosi.ije.2016.29.02b.08
3. Shantveerayya K, Kumar CL M, Shwetha K, Jima F, Fufa K. Performance Evaluation of Hollow Concrete Blocks Made with Sawdust Replacement of Sand: Case Study of Adama, Ethiopia. International Journal of Engineering, Transactions C: Aspects,. 2022;35(6):1119-26. https://doi.org/10.5829/ije.2022.35.06c.03
4. Park S-B, Tia M. An experimental study on the water-purification properties of porous concrete. Cement and concrete research. 2004;34(2):177-84. https://doi.org/10.1016/S0008-8846(03)00223-0
5. Majersky G. Concrete filtering systems and methods. Google Patents; 2008.
6. Kim G, Jang J, Khalid HR, Lee H-K. Water purification characteristics of pervious concrete fabricated with CSA cement and bottom ash aggregates. Construction and Building Materials. 2017;136:1-8. https://doi.org/10.1016/j.conbuildmat.2017.01.020
7. Jebadurai S, Tensing D, Hemalatha G, Siva R. Experimental investigation of toughness enhancement in cement mortar. International Journal of Engineering, Transactions B: Applications. 2018;31(11):1824-9. https://doi.org/10.5829/ije.2018.31.11b.04
8. Davarpanah L, Abdollahzadeh Sharghi E. Performance of Continuous Electrocoagulation Process for Turbidity Removal from Sand Filter Backwash Water. International Journal of Engineering, Transactions C: Aspects,. 2019;32(12):1696-703. https://doi.org/10.5829/ije.2019.32.12c.01
9. Taghizadeh M, Torabian A, Borghei M, Hassani A. Feasibility study of water purification using vertical porous concrete filter. International Journal of Environmental Science & Technology. 2007;4:505-12. https://doi.org/10.1007/BF03325987
10. Kamulyan B, Nurrochmad F, Triatmadja R, Sunjoto S, editors. Capacity of concrete sand filter to treat high turbid water. Int Conf Sustain Dev Water Wastewater Treat; 2009.
11. Hartwich P, Vollpracht A. Influence of leachate composition on the leaching behaviour of concrete. Cement and Concrete Research. 2017;100:423-34. https://doi.org/10.1016/j.cemconres.2017.07.002
12. Vadas TM, Smith M, Luan H. Leaching and retention of dissolved metals in particulate loaded pervious concrete columns. Journal of Environmental Management. 2017;190:1-8. https://doi.org/10.1016/j.jenvman.2016.12.047
13. Ueno T, Yanaka A, Okazaki S, Matsumoto N, Yoshida H. Physical Property and Heavy Metal Leaching Behavior of Concrete Mixed With Woody Ash. GEOMATE Journal. 2023;24(102):77-84. https://doi.org/10.21660/2023.102.s8530
14. Liang T, Zhou J, Wu Q. Experimental investigation on leaching behavior of ultra-high performance concrete submitted to a flow environment. Construction and Building Materials. 2023;372:130843. https://doi.org/10.1016/j.conbuildmat.2023.130843
15. Overmann S, Lin X, Vollpracht A. Investigations on the leaching behavior of fresh concrete–A review. Construction and Building Materials. 2021;272:121390. https://doi.org/10.1016/j.conbuildmat.2020.121390
16. Wang Y, Tao M, Feng D, Jiao Y, Niu Y, Wang Z. Effect of leaching behavior on the geometric and hydraulic characteristics of concrete fracture. Materials. 2022;15(13):4584. https://doi.org/10.3390/ma15134584
17. Youssari FZ, Taleb O, Benosman AS. Towards understanding the behavior of fiber-reinforced concrete in aggressive environments: Acid attacks and leaching. Construction and Building Materials. 2023;368:130444. https://doi.org/10.1016/j.conbuildmat.2023.130444
18. Haga K, Sutou S, Hironaga M, Tanaka S, Nagasaki S. Effects of porosity on leaching of Ca from hardened ordinary Portland cement paste. Cement and concrete research. 2005;35(9):1764-75. https://doi.org/10.1016/j.cemconres.2004.06.034
19. Solpuker U, Sheets J, Kim Y, Schwartz F. Leaching potential of pervious concrete and immobilization of Cu, Pb and Zn using pervious concrete. Journal of contaminant hydrology. 2014;161:35-48. https://doi.org/10.1016/j.jconhyd.2014.03.002
20. Nurjannah L, Novita DA. Uji bakteri Coliform dan Escherichia coli pada air minum isi ulang dan air sumur di kabupaten Cirebon. Jurnal Ilmu Alam Indonesia. 2018;1(1).
21. Hosseini SA, Toghroli A. Effect of mixing Nano-silica and Perlite with pervious concrete for nitrate removal from the contaminated water. Advances in concrete construction. 2021;11(6):531-44. https://doi.org/10.12989/acc.2021.11.6.531
22. Long W-J, Ye T-H, Li L-X, Feng G-L. Electrochemical characterization and inhibiting mechanism on calcium leaching of graphene oxide reinforced cement composites. Nanomaterials. 2019;9(2):288. https://doi.org/10.3390/nano9020288
23. Müllauer W, Beddoe RE, Heinz D. Leaching behaviour of major and trace elements from concrete: effect of fly ash and GGBS.

Cement and Concrete Composites. 2015;58:129-39. https://doi.org/10.1016/j.cemconcomp.2015.02.002

24. Lin W, Cheng A, Huang R, Chen C, Zhou X. Effect of calcium leaching on the properties of cement-based composites. Journal of Wuhan University of Technology-Mater Sci Ed. 2011;26:990-7. https://doi.org/10.1007/s11595-011-0350-x
25. Lee M-G, Tia M, Chuang S-H, Huang Y, Chiang C-L. Pollution and purification study of the pervious concrete pavement material. Journal of Materials in Civil Engineering. 2014;26(8):04014035. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000916
26. Alighardashi A, Mehrani MJ, Ramezanianpour AM. Pervious concrete reactive barrier containing nano-silica for nitrate removal from contaminated water. Environmental Science and Pollution Research. 2018;25:29481-92. https://doi.org/10.1007/s11356-018-3008-9

Persian Abstract

چکیده

فیلتر ملات گذر (PMF)اصلاحی از ملات گذرا و بتن گذری است که به عنوان فیلتر آب طراحی شده است که بر اساس ویژگی های فیزیکی آن می تواند کدورت و باکتری ها را کاهش دهد. با این حال، از نظر شیمیایی، حاوی مواد معدنی است که می تواند در تماس با آب حل شود و در پساب یافت شود. این مطالعه با هدف تعیین عملکرد PMF در تصفیه آب های سطحی با کاهش کدورت و اشریشیا کلی و ارزیابی پتانسیل آبشویی آن انجام شد. نمونه های PMF با اختلاط ماسه (۰.۶–۰.۸۵ میلی متر)، سیمان و آب با نسبت ماسه به سیمان 4 (M) و ۵ و نسبت آب به سیمان 0.4 (w/c) ایجاد شدند. سپس هر مخلوط به لوله هایی با قطر ۸.۲ سانتی متر و ضخامت های مختلف: ۳، ۵ و ۱۰ سانتی متر قالب گیری شد. از آب سطحی خام برای آزمایش عملکرد و شستشو استفاده شد. نتایج نشان داد که PMF به طور موثر ۹۵٪ کدورت و ۹۹.۷۱٪ *E. coli* را حذف کرد که با مدت زمان فیلتراسیون افزایش یافت. PMF زمانی که با ضخامت ۱۰ سانتی‌متر از ۵ یا ۳ سانتی‌متر طراحی می‌شد، *E. coli* را به طور مؤثرتری کاهش داد، زیرا سطح بیشتری را برای چسبیدن و نگهداری مواد معلق و باکتری‌ها فراهم می‌کرد. افزایش قابل توجهی (میانگین درصد) pH، سختی، یون‌های کلسیم و TDS در PMF M4 با ضخامت ۱۰ سانتی‌متر نسبت به نمونه‌های نازک‌تر مشاهده شد، زیرا حاوی سیمان بیشتری بود که در تماس با آب حل می‌شد.