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LITERATURE REVIEW

The Pervious Concrete and Pervious Mortar as Water Filter in Decentralized Water Treatment– a Review

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Abstract

Decentralized water treatment system is water treatment carried out by the community on a household-scale. One of the technologies that have been developed to gain freshwater is the pervious concrete filter (PCF). This study aims to provide the researchers with an understanding of the pervious concrete filter as a potential filter technology in water treatment. The method used is a literature review from several papers and reports related to pervious concrete from past to present. PCF is a filter made from a mixture of aggregate, cement, and water with a specific ratio. PCF has enough water and air permeability due to interconnected macro pores. Some properties such as porosity, permeability, and pores size determine the ability of PCF to remove the contaminants in the water. These properties were controlled mostly by the aggregate size, aggregate-cement ratio, water-cement ratio, etc. According to its characteristic, the PCF shows a prospect to be used as water filter mainly in a decentralized water treatment system. Besides, the understanding of PCF is a basis to develop a pervious mortar filter that slightly different in the aggregate sizes used in this composite.

Keywords: Pervious Concrete, Pervious Mortar, Water Filter, Decentralized Water Treatment

1. Introduction

Water is an important resource needed by all humans, not only for basic consumption but also for environmental hygiene and health (UN-Water, 2019). Sustainable Development Goals (SDGs) sets access to safe clean water and adequate sanitation as one of the goal that must be achieved by 2030 (WHO/UNICEF, 2019). People in developed countries have access to clean water, which generally gets water from a centralized water treatment system plant. However, some families in developing countries, especially low-income or poor families and families who live in remote areas do not have access to safe clean water (Pooi dan Ng, 2018). This is partly due to the limited distribution access in hilly areas far from centralized water treatment locations.

Centralized water treatment systems are usually located in urban areas. Indonesia implements a centralized water treatment system to supply water to the community by treating water from rivers, groundwater, springs, and lakes. With complete service area coverage, the infrastructure for water treatment buildings and distribution pipes required for this system is large. Besides, this system requires considerable energy for construction and operation. To keep this system working properly in supplying clean water that meets standards, maintenance of processing buildings and pipes must be carried out appropriately and regularly (Lu et al., 2019). Some of the existing water distribution pipes are old and corroded, which may reduce the quality of treated water that is distributed to consumers. Therefore, to increase community resilience to the availability of clean water, a decentralized water treatment system needs to be well developed by the community. This system can also be used by people who still rely on natural water resources such as shallow wells groundwater, deep wells groundwater, springs, and others to get access to clean water.

Several technologies used in decentralized water treatment systems, both point-of-entry (POE) and point-of-use (POU), include sand filtration (Peter-Varbanets et al., 2012; SU et al., 2009; Yakub et al., 2013; Yogafanny et al., 2014), ceramic filter (Chaukura et al., 2020), and pervious concrete filter (Maadji, 2018a; Maadji et al., 2016a). The sand filter is an old method and has been recognized for its superiority, especially in reducing turbidity and bacteria in raw water (Fuchs et al., 2015; Kohne et al., 2002; Silva dan Fuchs, 2015; Yogafanny et al., 2014). This filter can reduce turbidity by up to 70% reaching a water turbidity value <1 NTU at the outlet (Fuchs et al., 2015; Logsdon et al., 2002). Besides, slow sand filters are also able to reduce the concentration of Total Coliform and E. Coli bacteria by up to 4.7 log-units and 5 log-units (Yogafanny et al., 2014). Another technology commonly used in decentralized water treatment systems, especially point-of-use (POU) systems in rural areas, is a ceramic filter. This technology can remove E. Coli by 99.998% or 4.69 log-units; besides, the ceramic filter is also able to remove 99.70% and 99.45% of fluoride and MS2 (Nigay et al., 2019). The ability of ceramic filters to remove bacteria and viruses is caused not only by small pores but also by the presence of biofilms that grow on the surface (Abebe et al., 2016; Nigay et al., 2019; Soliman et al., 2020; Zhang dan Oyanedel-Craver, 2013). In its production process, ceramic filters require a high temperature and a specific material composition so that it is difficult for the community to produce it by themselves. Another technological alternative that does not require a heating process, easy to produce, and has the potential to be developed is the pervious concrete filter (PCF) or concrete filter (Hu et al., 2020; Maadji, 2018b).

Pervious concrete filter (PCF) is a filter made from a mixture of aggregate, cement, and water with a specific ratio. Pervious concrete has enough water and air permeability due to interconnected macropores allowed water to pass through (Chandrappa dan Biligiri, 2016). The energy required to produce this filter is relatively low. With its capabilities, pervious concrete can be applied for several purposes, such as permeable pavement, stormwater control, sound-absorbing materials, adiabatic materials, and water purification (Chandrappa dan Biligiri, 2016; Kim et al., 2017; Lee et al., 2014). As a water purifier, PCF can reduce turbidity in water by up to 95% (Triatmadja, 2008). PCF with a finer sand composition has a high ability to reduce turbidity (Maadji et al., 2017b). The turbidity, suspended nitrogen and phosphorus, and dissolved phosphorus can also be removed with pervious concrete (Kim et al., 2017). The content of lead (Pb) in raw water can decrease up to 97.2% using pervious concrete (Muthu et al., 2018). Not only used to treat raw water, but pervious concrete can also be used for acid mine drainage as a permeable reactive barrier with good results in increasing the pH to 12, reducing the concentrations of Al, Fe, Mn, Co, and Ni (Shabalala et al., 2017).

The studies of pervious concrete as a pavement material in many countries found a positive result as a sustainable material for construction. However, the study of the previous concrete filter for water purification purposes needs to be elaborated especially to be used and applied in a decentralized water treatment system. Hence, it is important to organize the literature of pervious concrete as a water purifier from past and current research. This literature compilation will help researchers to understand the eminence of pervious concrete filter as a promising technology in water treatment strategy. Therefore, the main purpose of this review paper was to provide the researchers with the characteristics, findings, and future prospects of pervious concrete filter as a water purifier.

2. Methods

The method used in this article is a literature review. The review was conducted by reviewing 53 articles consist of journals, reports, and standard related to pervious concrete. Fig. 1 presents the scope of the literature review.

3. Result and Discussion

Pervious concrete depicts concrete with open-graded material consists of aggregate, cement, admixture, and water with certain proportions. This type of concrete is deemed as a sustainable concrete to be used as pavement. Having the porosity in the range of 15% to 35% made this concrete allow water to infiltrate easily. The pervious concrete produced by combining a certain proportion of aggregate, cement, admixture, and water so that the effective void exists in the hardened material (American Concrete Institute, 2010; Chandrappa dan Biligiri, 2016; Sumanasooriya dan Neithalath, 2011).

3.1. Materials

According to the potentially high porosity and permeability of pervious concrete, the development of this material to be used as a water purifier showed a positive insight. The void as the prominent feature in this porous material has to be made up by a certain size of aggregate, as well as its shape and its chemical properties.

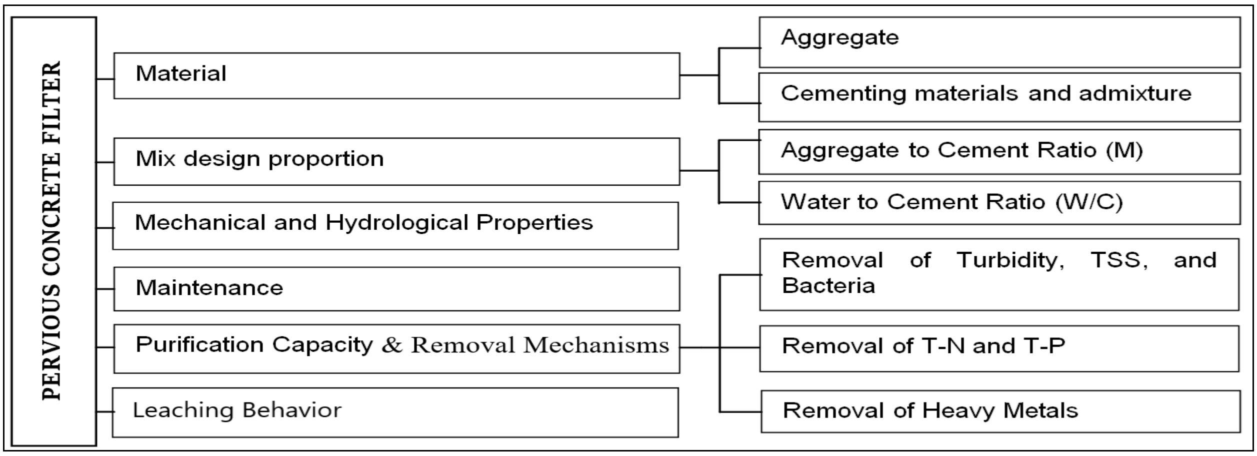

Fig. 1. Scope of literature review

The aggregate size usually used in pervious concrete pavement is in the range of 9.5 – 19 mm (American Concrete Institute, 2010), 9.5 – 25.4 mm (Tennis et al., 2004), or even smaller ranging from 2.36 – 9.5 mm (Chandrappa dan Biligiri, 2016), and 1 – 4 mm of aggregate size (Triatmadja, 2008). The void ratio made by the large aggregate size decreases the compressive strength (Neamitha dan Supraja, 2017). On the other hand, the smaller aggregate size increases the compressive strength but will decrease the void ratio as well as permeability. The smaller size of aggregate provides the larger surface area that allows the tight bonding between coarse material and cement/binder (Deo dan Neithalath, 2011; Kim et al., 2017; Neamitha dan Supraja, 2017; Nguyen et al., 2014). Not only the aggregate size but also the good proportion of aggregate, cement, admixture, and water play an important role in creating the typical void ratio in pervious concrete. Regarding its function as a water purifier, a good proportion will result in the performance of pervious concrete that is hydraulically and mechanically balanced, so that it can be used to remove the pollutant in the raw water. The effective void is the interconnected voids or open voids in a pervious concrete filter that need to be accounted for, rather than only measuring the total voids (Kim et al., 2017).

Cementing material has an essential role to keep the aggregate and increase the mechanical strength of pervious concrete. The cementing material coats around the aggregates in pervious concrete. The commonly used cement to produce pervious concrete is Portland cement (Type 1) (Haselbach et al., 2006), but some researches investigate the partial use of silica fume and fly ash as supplementary material (Fu et al., 2014; Park dan Tia, 2004). The results have shown that the use of silica fume and fly ash in pervious concrete decreases its strength properties (Fu et al., 2014). While (Park dan Tia, 2004) found that the addition of silica fume and fly ash is essential to increase the compressive strength of pervious concrete. The thickness of cement coating the aggregate is influenced by the size of the aggregate (Fu et al., 2014). The thicker the cement coats the aggregate, the greater the strength properties that the pervious concrete will have so that it can reduce the porosity and permeability of the pervious concrete (Haselbach et al., 2006; Kim et al., 2017; Park dan Tia, 2004).

3.2. Mix Design Proportion

The mixed design of materials in producing pervious concrete has important roles, especially to be used in water purification purposes. The aggregate to cement ratio (m) is one of the parameters considered in many researches. The experimental study on water purification to remove total Nitrogen and total phosphate considered the use of M 2 – M 3 (Park dan Tia, 2004), while (Triatmadja, 2008) used the M ranging from M 6 – M 12 and (Maadji et al., 2016b) used the M 4 and M 10. The aggregate to cement ratio will affect the void ratio as well as permeability and strength properties in pervious concrete. The bigger the aggregate to cement ratio leads to the bigger the void ratio and the higher the permeability rate, thus decreases the strength properties of pervious concrete filter. The bigger the void ratio, the larger space presents in pervious concrete to provide a place for the contaminant to be attached.

Water to cement ratio is another important factor to control the permeability as well as the strength of the pervious concrete. The ratio number is determined according on the application of the pervious concrete. There is various W/C ratio used in pervious concrete filter for some application such as pervious concrete pavement and pervious concrete filter (water treatment). Ibrahim (Ibrahim et al., 2014) used the W/C ratio in the range of 0.3 – 0.4. The study showed that the higher compressive strength resulted from the W/C ratio of 0.4 than that on the W/C ratio of 0.3. On the other hand, the porosity was found higher in the pervious concrete with W/C ratio of 0.3 than that on W/C ratio of 0.4. The W/C ratio of 0.4 combined with various M ratio was used in the research conducted by Triatmadja (Triatmadja, 2008) and Maadji (Maadji, 2018a; Maadji et al., 2017a) in pervious concrete that is functioned as a water purifier. Another study conducted by Neamitha (Neamitha dan Supraja, 2017) uses the aggregate size of 10 to 12.5 mm and the W/C of 0.28, 0.3, 0.32, 0.33, and 0.34. The results showed that the W/C ratio of 0.33 produced the optimum compressive strength in both aggregate sizes. The water will coat the aggregate surface lead to the increasing of compressive strength. The low W/C ratio tends to increase the porosity as well as permeability due to the dry mixture of pervious concrete. The high W/C ratio results in the drawdown effect in the mixture causes the void filled by the cement paste, thus close the void and decrease the permeability as well as the porosity (Neamitha dan Supraja, 2017).

3.3. Hydrological Properties

The hydraulic properties, including porosity and hydraulic conductivity (k) play the main role in the pervious concrete filter mainly to be used as a water purifier. The hydraulic conductivity in pervious concrete is controlled by some factors i.e., water to cement ratio (W/C), aggregate size, cement properties, aggregate to cement ratio (M), compaction method, etc. Total porosity consists of an open void (interconnected pores/ effective porosity) and a close void. The effective porosity influences the k value (Ziccarelli dan Valore, 2019), that the higher open void tends to the higher k value (Ibrahim et al., 2014; Kim et al., 2017; Park dan Tia, 2004). The typical porosity of pervious concrete filter is 15 – 35% (Ibrahim et al., 2014). Functioned as a water purifer, the pervious concrete filter will trap the suspended material from the raw water in the void space then block the interconnection path among the voids, called clogging. Clogging is the common condition caused by the filtration process in porous media such as a pervious concrete filter that will reduce the removal capacity as well as its hydraulic conductivity. Thus, the maintenance of a pervious concrete filter is a must-have-done to assure its efficiency as a water purifier.

3.4. Maintenance

As the pervious concrete filter clog, some maintenance should be done to clean it from the impurities trapped in the voids. The study conducted by Maadji (Maadji, 2018a) proposed the backwash as the maintenance mechanism of the pervious concrete filter after some hours of operation. The other maintenance methodologies proposed by Sandoval (Sandoval et al., 2020b) are surface cleaning, air cleaning, and water cleaning for pervious concrete pavement. Due to the clogging caused by sand sediment, the air cleaning method was the most efficient way to pull out the sediment grains from the voids. This study also found that the sediment is mostly trapped in the surface of pervious concrete. After the maintenance of pervious concrete, the hydraulic conductivity will not fully recover. The maintenance method depends on the type of sediment clogged in pervious concrete (Sandoval et al., 2020a). Other maintenance mechanisms of pervious concrete pavement were evaluated by Hu (Hu et al., 2020) i.e., pressure wash (various pressure), vacuum (various pressure), and sweep. The efficiency of pressure wash was much higher than that of vacuum and sweep. The periodic maintenance was important to enhance the lifetime of pervious concrete, although there will be a decrease in hydraulic conductivity after some treatment cycles (Hu et al., 2020).

3.5. Purification Capacity

Pervious concrete (PC) can be used for many kinds of purposes. One of them is for water treatment. The development of pervious concrete or concrete filters in water treatment/water purification was started by M. Tamai, A. Kawai, and H. Tikada (1992) using environmentally friendly concrete as water purifiers. Next, Park and Tia tested the ability of a concrete filter as a water purifier. They stated that a filter composed of small sand and a large number of pores/voids was able to remove Total Nitrogen and Total Phosphorus in the water (Park dan Tia, 2004). Taghizadeh (2007) modified the material (uniform and small sand size) used in pervious concrete to be a water filter which than called porous concrete (Taghizadeh et al., 2007). This kind of composite which began to be developed in Indonesia and was subsequently called the concrete filter by Triatmadja in 2008, showed satisfactory performance in reducing turbidity and the backwashing as the maintenance mechanism, especially concrete filters with an aggregate (sand) diameter between 1 – 2 mm (Triatmadja, 2008). Concrete filters were then developed by Kamulyan (2014) and Maadji from 2016 to 2018 (Maadji et al., 2016a, 2016b). The latest term of pervious concrete using only fine aggregate with nearly uniform in size is than called pervious mortar as can be seen in Fig. 2. As this composite is proposed for water treatment, this is called pervious mortar filter (PMF).

a. Removal of Turbidity, TSS, and Bacteria

The study conducted by Maadji found that PMF with a composition of M = 4, 10 cm of diameter and 20 cm of height was able to reduce turbidity to <5 NTU and E. Coli bacteria reached 98.71% or Log Removal Value (LRV) = 2 (Maadji et al., 2016a, 2016b).

The effect of zeolite and pumice powder as a partial cementitious material in pervious concrete was investigated by Azad. This study found that the pumice leads to a better physical property of pervious concrete. In contrast zeolite leads to improve the ability of pervious concrete in removing contaminants from wastewater i.e., chemical oxygen demand (COD), zinc (Zn), Copper (Cu), Cadmium (Cd), and Lead (Pb) (Azad et al., 2020). That study found no significant effect of zeolite and pumice as cementitious material on turbidity and TSS removal. The particle size on suspended solid is usually larger so that the effective removal mechanism is straining by the small pores or voids present in the pervious concrete that more controlled by the aggregate size, the aggregate to cement ratio, and the water to cement ratio, rather than the cement properties (Azad et al., 2020).

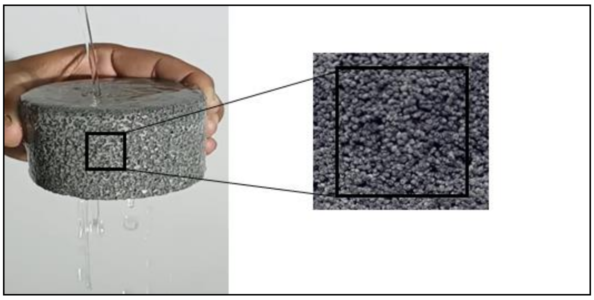

Fig. 2. The pervious mortar filter

b. Removal of T-N and T-P

The ability of pervious concrete to remove the total nitrogen (T-N) and total phosphate (T-P) was 2.8 and 1.7 times higher respectively in the pervious concrete containing 5 – 10 mm aggregate compared to that of 10 – 20 mm (Park dan Tia, 2004). The smaller aggregate size provides the larger specific surface area; this leads to a higher void content so that the ability of pervious concrete increases in removing T-N and T-P (Park dan Tia, 2004). The study by Kim reported that PCF was able to reduce the concentration of suspended phosphorus and nitrogen in water through a physical filtration process in the pores, while dissolved phosphorus could be lost through the adsorption process on PCF (Kim et al., 2017).

c. Removal of Heavy Metals

The ability of the pervious concrete filter in removing contaminants is excellent not only from the natural water but also from wastewater, such as acid main drainage (gold and coalfield). The study conducted by Shabalala, et al. (2017) found that the pervious concrete successfully removed the heavy metals that exist in the acid mine drainage i.e., Al, Fe, Mn, Co, and Ni. Besides, the pervious concrete could increase the pH higher up to 12 compared to the pervious concrete contained fly ash (Shabalala et al., 2017). The lead (Pb) removal by PC was investigated by Muthu, et al (2018). found that the PC could remove about 97.2% to 99.1% Pb concentration in a Pb containing solution. The study investigated the effects of accelerated carbonation and hydraulic retention time (HRT) on removing Pb by PC (Muthu et al., 2018). Another study focussing on Pb removal by PC was conducted by Chen, et al (2020). This study found that the highest removal efficiency (98.05%) was achieved by PC with the porosity of 14.36%, containing alkali-activated slag (AAS-PC) as a cementitious material. This study also confirmed that there was a negative correlation between Pb removal efficiency and water permeability. The higher the permeability value, the faster the water infiltration through the AAS-PC, the less time for Pb containing solution to permeate on AAS-PC specimen, thus the Pb removal efficiency decreased (Chen et al., 2020).

3.6. Removal Mechanism

Theoretically, pervious concrete can function as a permeable reactive barrier or filtration media to remove pollutants in water. The removal mechanisms found in pervious concrete filters are chemical precipitation, sorption (absorption and adsorption), diffusion, and filtration (Holmes et al., 2017; Shabalala, 2021; Xu et al., 2022).

Pervious concrete made from cement, gravel, and sand produces high alkalinity (high pH). When water flow through pervious concrete, the water tends to have a high pH which can reduce the solubility level of most heavy metals, thereby causing heavy metals precipitation significantly. The chemical precipitation mechanism is very effective in removing heavy metals in an alkaline solution with pH 9 – 12 (Shabalala, 2021). Pervious concrete filters or pervious mortar, with Portland cement hydration products in it, can release hydroxide (OH^-) and carbonate (CO_3^{2-}) thereby causing the increase of pH increment in the water. Heavy metals dissolved in water react with hydroxide (OH^-) and carbonate (CO_3^{2-}) which come from calcium in concrete to form insoluble solids that can settle and be removed later through a filtration process (Shabalala, 2021).

The filtration process in pervious concrete occurs due to the existence of the open or interconnected pores in pervious concrete. These pores can pass water and retain pollutants carried along with the water. This mechanism predominantly occurs in the polluted water with large particles, larger than the pore size of pervious mortar. Apart from that, physical trapping occurs in insoluble particles or solids resulting from chemical precipitation. This mechanism predominantly occurs in the removal of total suspended solids and turbidity.

The adsorption capacity of pervious concrete comes from additives such as bentonite and fly ash (Junling et al., 2018) or from coarse aggregates such as zeolite, activated carbon, and iron slag, as well as the cement material used. Apart from that, one of the adsorbents in pervious concrete is the ettringite mineral, which is a hydration product of Portland cement used in pervious concrete. The ettringite mineral in pervious concrete has a layer that can bind heavy metals through electrostatic interactions between heavy metal ions and ettringite (Harada dan Yanbe, 2018).

The metal removal mechanism with pervious concrete usually occurs through an adsorption process. At low metal concentrations, adsorption is the main mechanism for metal removal. Meanwhile, at high metal concentrations, precipitation is the main mechanism for metal removal (Holmes et al., 2017; Shabalala et al., 2017). The hydration product from Portland cement, which is used as an adhesive for pervious concrete, produces water conditions with high alkalinity up to pH 12. This alkaline condition causes metals in the water to precipitate or be absorbed into cement hydration products such as ettringite or calcium-silica-hydrate (C-S-H) gel. Cement and aggregate that have been mixed into pervious concrete contain reactive calcium, such as calcium carbonate, calcium hydroxide (Portlandite), or calcium-silica-hydrate (CSH) gel. The adsorption process of heavy metals on cement or pervious concrete is caused by the exchange of calcium ions on the surface of the material (Shabalala et al., 2017).

3.7. Leaching Behavior

Ca leaching is one of the degradation phenomena that occurs in concrete. Leaching or dissolution is one of the main factors that changes the mechanical properties of cement-based composites (Lin et al., 2011). In this study, the dissolution referred to is the process of carrying away calcium compounds/ions contained in concrete as a result of the dissolution process that occurs in the concrete due to the reaction between water and portlandite ($Ca(OH)_2$).

Portlandite is a hydroxide-bearing mineral formed from a mixture of cement and water (Haga et al., 2005; Kim et al., 2017). Hydrolysis produces a significant increase in the porosity of concrete or cement paste, resulting in the dissolution of hydrates such as calcium hydroxide (portlandite ($Ca(OH)_2$) and decalcification of Calcium Silicate Hydrate (C-S-H) (Marinoni et al., 2008).

Several studies have researched about the effect of calcium dissolution (Ca leaching) on the porosity and compressive strength of concrete or vice versa. Haga et al. (2005) examined the influence of the porosity of hardened ordinary Portland cement on the dissolution process. The larger the pore volume, the faster the portlandite contained in the sample will dissolve. This study concludes that the transport of dissolved materials/constituents is controlled by the diffusion process. The main dissolved ingredients of hardened ordinary Portland cement (OPC) are portlandite and C-S-H gel (Haga et al., 2005).

Marion et al. (2005) conducted a study on the dissolution process in concrete composed of porphyry aggregate, river sand, and Portland cement. This dissolution test was carried out using demineralized water. The research found that the amount of dissolved heavy metals is very small, much lower than the drinking water quality standards regulated by the European Directive, and can be ignored after a long soaking process. At the end of the test, the dissolved heavy metal fraction was <1% of the total heavy metal content of the cement (Marinoni et al., 2008)

A study on the effect of leaching on the mechanical properties of cement-based composites was carried out by Lin et al. (2011). This study used two water to cement ratio (w/c) values and two types of mineral mixtures (silica ash and slag). The study showed that Ca leaching reduced the compressive strength of concrete specimens and this was seen in concrete specimens without mineral mixture. By using mineral admixtures in concrete, especially silica ash, Ca leaching is decreased. The microstructural density of composites containing silica ash causes the limited movement of calcium ions. Thus, the use of mineral additives can increase concrete's resistance to dissolution (leaching resistance) and increase its compressive strength and reduce concrete permeability (Lin et al., 2011).

Research conducted by Solpuker et al. (2014) not only studied the leaching potential but also the ability to retain trace metals in porous concrete. In the column experiment, water is passed through porous concrete. The effluent water results showed a high pH value (pH ~10), conductivity decreases rapidly in the first 50 hours and then decreases slowly. In the initial stage, the dissolution of trace metals is very high, but becomes low after 50 hours and gradually decreases over time (Solpuker et al., 2014).

Study on Ca leaching behavior of pervious mortar filter (PMF) was conducted by Yogafanny et. al (2023) using the surface water (irrigation water) as influent. The study found that the Ca leaching of PMF from the pure water as influent was less than that of the irrigation water. The low increment of Ca leaching from PMF in the irrigation water was due to the impurities of the water that blocking the chemical reaction between the water and hydration cement product. Regarding to the filtration rates, the lower filtration rates, the longer contact time between water and PMF pores, thus causing the dissolution process of cement hydration products such as calcium hydroxide ($Ca(OH)_2$) occurs more intensively. This dissolution process then produces hydroxide (OH^-) or carbonate (CO_3^{2-}) ions which cause the water contacted/flowed into the pervious mortar or pervious concrete to have a high pH. The cement-based composites or cement-based materials will produce concrete or mortar with a very alkaline pH water ranging from 12 - 13.8. Other research also reveals that pervious concrete used as a filter for surface runoff water (stormwater) can increase the pH of the effluent (Pilon et al., 2019). Wijeyawardana et al. (2022) tested the pH of effluent from various water sources with various pH values. The pH of the effluent in this study ranged from 7.5 – 11.5. An effluent pH of 11.5 is produced by an influent with an alkaline pH (10 and 10.5) and an effluent pH of 11 is produced by a normal pH influent. In the case of an acidic influent pH (3.5), the resulting effluent pH is alkaline (10.5) (Wijeyawardana et al., 2022). Water entering the pervious mortar or pervious concrete dissolves cement hydration products such as calcium hydroxide ($Ca(OH)_2$), producing hydroxide ions or carbonate ions. These two ions can react with dissolved ions in water if contact occurs between these two cations and anions. This reaction is also called precipitation or deposition where in the case of removing dissolved heavy metal such as iron in the water, Fe^{2+} ions react with hydroxide (OH^-) or carbonate (CO_3^{2-}) ions or compounds (Shabalala, 2021; Xu et al., 2022).

3.8. Future Prospect

The scheme in Fig. 3 is used to assess the feasibility of pervious concrete to be modified into pervious mortar as water filter to support the decentralized water treatment system. Recently, the PC is categorized as suitable-well technology in terms of its purification capacity in removing contaminant size larger than bacteria (including heavy metal and organic compound), maintenance, and material, including the possibility of manufacturing by the local community. This capability of PC in removing some contaminants and in manufacturing process show a possibility of pervious mortar filter (PMF) to be used for the same purpose as pervious concrete in water treatment. According to the previous study, research prospects related to pervious mortar as water purifier in the future are as follows:

- The ability of PMF as a water filter with low pH water such as peat water or acid mine drainage or any other water with high heavy metals concentration.
- The maintenance methods for cleaning the clogged PMF.
- The molding and compaction methods to produce PMF with suitable hydraulic characteristics that fit its purpose as a water purifier.
- PMF modification in the water treatment system by adding some processing stages before or after.
- The retention and leaching capabilities of PMF must be analyzed to determine the best ratio of ingredients, the proper age of PMF as filter, characteristics of raw water that can be filtered, utilization strategies, etc.

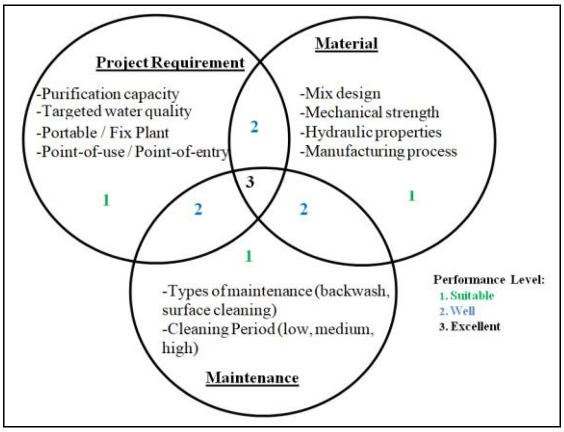

Fig. 3. Feasibility of pervious concrete filter in decentralized water treatment system (adapted from Sandoval 2020 (Sandoval et al., 2020a))

4. Conclusions

The use of a pervious concrete filter as a water purifier is one of the applications of the pervious concrete that is usually used as a pavement material. According to the typical properties of pervious concrete i.e., porosity and permeability, this composite could have potentially high capability in removing the contaminant in the water especially heavy metals. Those properties were controlled by some parameters such as aggregate size, type of cement, water to cement ratio, aggregate to cement ratio, chemical composition, etc. Typically, the characteristics of PC are as follows: (a) effective void is ranging from 15% to 35 % and (b) water to cement ratio is 0.3 – 0.4. Those characteristics may change depending on the aggregate size, the type of cement or binder material, aggregate to cement ratio, water to cement ratio, and the addition of admixture. All of those mixed designs are customized to produce the pervious concrete filter as a water purifier. A good understanding of pervious concrete is required to produce a pervious mortar as a water filter. Moreover, this filter can be subjected as a water purification technology in removing not only heavy metals but also suspended solids and bacteria, especially in a decentralized water treatment system.

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