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Wastewater Characterization and pH Neutralizing Effect of Adsorbents: A Case Study of Concrete Wash Wastewater from a Ready-Mix Plant

Adhin Harum Wulaningtyas*, Ni Nyoman Nepi Marleni
Department of Civil and Environmental Engineering, Universitas Gadjah Mada, Yogyakarta, INDONESIA
Jalan Grafika No 2 Yogyakarta
*Corresponding author: adhin.harum@ugm.ac.id

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ABSTRACT This study aims to characterize concrete wash wastewater and examine the effectiveness of three different adsorbents in reducing its high pH. It is important to note that proper treatment is essential before discharging wastewater into water bodies to prevent any negative impact on the environment. Therefore, in this study, an adsorption scenario was conducted to obtain optimum treatment for concrete wash wastewater. The objectives of this study are as follows (1) to determine the typical characteristics of concrete wash wastewater based on the parameters outlined in the Ministry of Environment of The Republic of Indonesia (2014) and (2) to assess the performance of different adsorbents. Three wastewater samples were obtained from a ready-mix plant and then tested in the laboratory. The initial test was conducted to identify influent characteristics, and from this test, it was found that only the pH level exceeded the specified standard. Following this, the study then assessed the ability of three adsorbents to reduce the pH level in concrete wash wastewater using the batch test in Duplo. The pH level was measured at 0.25, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, and 24 hours. The three adsorbents tested were activated carbon, clay brick, and dried domestic sewage sludge. The result shows that dried domestic sewage sludge was the most effective at reducing alkaline wastewater due to its acidic pH. Therefore, it has the potential to replace other commercial adsorbents and reduce the problem of sludge disposal. Further research on this material is recommended, such as evaluating its performance in a more solid form, such as brick, and assessing its contamination potential.

KEYWORDS Activated Carbon, Sewage Sludge, Clay Brick, Alkaline Wastewater, Adsorbent

1 INTRODUCTION

According to Kesai et al. (2018), Indonesia is projected to have the largest construction market compared to its neighboring countries by 2025. This development will result in an increased demand for many ready-mix concrete plants in the country. These plants use water to produce concrete and the mixer drum is usually being washed during operation. However, the wastewater produced from washing ready-mix concrete poses a threat to the environment, as it pollutes the water and soil with high pH levels and dissolved solids (Asadollahfardi et al., 2015; Sandrolini and Franzoni, 2001). Ghrair et al. (2020*a*) also noted the presence of heavy metals and highly dissolved solids in the wastewater.

It is necessary to treat the concrete wash wastewater before discharge in order to meet the regulations and protect the environment. The treatment of concrete wash wastewater has three main objectives which are to neutralize pH, decrease turbidity, and eliminate pathogens (De Paula et al., 2014). Several treatment methods have been developed and implemented to carry out this treatment process, including the use of sedimentation tanks and the addition of HCl to reduce pH level (Tsimas and Zervaki, 2011), coagulation and aluminium sulphate addition for pH level reduction (De Paula et al., 2014, 2018), slow sand filter (Ciawi et al., 2022; Ghrair et al., 2020*a*), as well as barium chloride and disodium hydrogen phosphate treatment (Mohamed et al., 2015a). These treatment methods can be classified into three groups namely sedimentation, chemical addition, and filtration. Despite the various treatment methods available, there has been little discussion about the implementation of the adsorption method. Hence, the possibility of heavy metals contain-

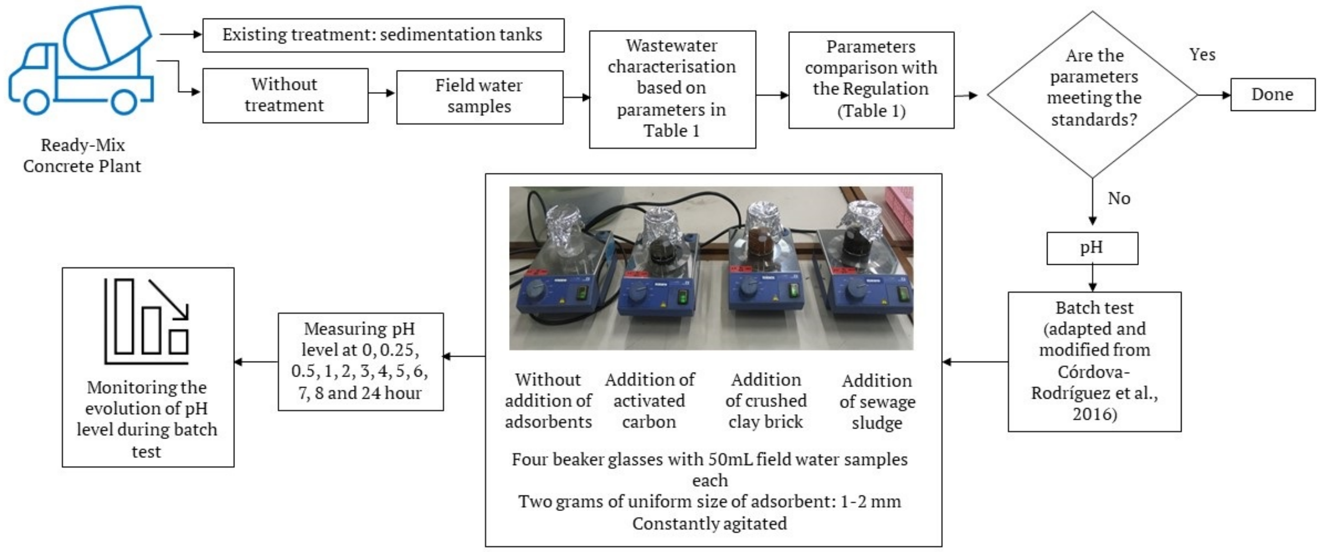

Figure 1 Flow chart representing method to measure pH at different times during batch test

ment in the washed wastewater through the absorption method should be explored.

Adsorption is one of the most attractive technologies with which numerous substances can be utilized as sorbents. Some examples of commonly used adsorbents include activated carbon, metal oxide, and zeolites (Hong et al., 2019; Metcalf and Eddy, 2014). These sorbents generally have a high adsorption capacity, which is accompanied by high costs, and in the majority of instances, the regeneration techniques are either inefficient or economically uncompetitive. It is pertinent to note that adopting inexpensive materials is a viable alternative. Two energy-efficient procedures that have gained popularity due to their environmental friendliness and cost-saving benefits are the recycling and reusing of waste. The use of waste by-products from various human activities is one example of such procedure (Erto et al., 2013). Therefore, this study aims to fill this gap in knowledge by exploring new adsorption treatment methods through the comparison of commercial sorbents with low-cost sorbents. Several absorbents used include activated carbon, clay brick, and dried sewage sludge.

Activated carbon is often used as an adsorbent because of its huge surface area, customizable pore structure, thermostability, and inexpensive cost when manufactured from by-products (Largitte and Pasquier, 2016). Accordingly, due to the increased population, the amount of sewage sludge generated from wastewater treatment plants must be treated wisely. This led to an increased concern about the most sustainable recycling or disposal methods, and the potential of using sewage sludge as an adsorbent seems promising due to the cost of commercial carbon (De Filippis et al., 2013). Following this, the construction industry not only plays an important role in the economic condition of a country, but it also produces a large volume of construction and demolition waste (CDW) (Ranaweera et al., 2021), and it is imperative to manage this waste appropriately. Besides recycling, CDW can also be used as an adsorbent. However, its use as an adsorbent has not been fully studied, regardless of the fact that few studies have indicated that this material possesses similar potential as geosorbent and biosorbent (Kumara et al., 2018).

This study was conducted to explore the suitability of waste materials as adsorbents that use concrete wash wastewater. In this situation, two primary objectives were outlined. The first involves the identification of the characteristics of the wastewater, and the second is to test the pH-neutralizing effect and the heavy metal removal capacity of each absorbent. Several questions were addressed in this research, they include (1) what are the critical parameters of concrete wash wastewater according to the wastewater effluent quality standards? (2) can the adsorbent materials lower the pH level and the heavy metals concentration in the water to the required levels to meet the standard water discharge limits? Accordingly, the Regulation of the Ministry of Environment of Indonesia No 5 of 2014 was used to determine this study's required discharge water quality values. Both laboratory and batch tests were conducted using concrete wash wastewater, which was obtained from one of the ready-mix concrete plants in Yogyakarta, Indonesia. The measurements were conducted within 24-hours after the batch tests. The results obtained from this test were then discussed and compared with that of previous related studies or literature. This study was expected to contribute to the existing knowledge of adsorbent usage for wastewater treatment.

2 METHODS

Three concrete wash wastewater samples were obtained from a ready-mix concrete plant on three different days. These samples were then sent to laboratories for the examination and identification of the parameters that exceeded the Ministry of Environment of The Republic of Indonesia (2014) about wastewater effluent quality standards. Furthermore, the sewage sludge used in this study was collected from the sludge drying treatment in a wastewater treatment plant (WWTP) in Yogyakarta. The obtained dried sludge and clay brick were then crushed and sieved into a uniform size between 1-2 mm. The activated carbon was also sieved to have the same grain size.

The batch experiments were conducted using field samples from the ready-mix concrete plant. The method employed for these experiments was adapted from Córdova-Rodríguez et al. (2016) and modified. The process involves filling four 100 mL beaker glasses with 50 mL of field sample in the batch test and each glass served different purposes. The first glass was used as a control without adsorbent, the second was mixed with activated carbon, and the third and fourth were combined with clay brick and dried sewage sludge, respectively. The pH level of each sample was measured both before and after adding 2 g of adsorbent material. The mixtures were agitated constantly at 200 rpm and their pH level were measured at room temperature in a covered beaker glass at different times such as 0.25 hours, 0.5 hours, 1 hour, 2 hours, 3 hours, 4 hours, 5 hours, 6 hours, 7 hours, 8 hours, and 24 hours. These measurements were conducted in Duplo, and the values were reported. Figure 1 summarizes the method used to measure the pH level at different times during the batch test.

Furthermore, the pH level of each adsorbent was measured based on ISO 10390 (2021). A total of 10 mL of adsorbent were diluted with 50 mL of distilled water and stirred for 60 minutes. The pH level was then determined using a Portable Multiparameter HACH sensION, which served as the pH meter. The device was calibrated daily using a buffer solution with pH 4 and 7. The alkalinity of the wastewater was measured as carbonate concentration before adding adsorbent and after adding dried sewage sludge using titration.

3 RESULTS

From the chemical analysis of the water samples, the obtained concentration level of the parameters can be compared to the effluent standard to determine which parameter exceeded the threshold set by the regulation. The overall characteristics of the treatment influent are summarized in Table 1. From the table, it can be seen that all the measured values fall within the standard, except for pH and temperature. Sulfide concentrations were observed to be high but still within threshold limits, and as a result, this research focuses on pH reduction by using three different materials with the aim of determining the most effective.

Figure 2 shows the experimental findings for the time-dependent treatment of high-pH wastewater with activated carbon, clay bricks, and sewage sludge. The data shown were collected from the Duplo experiments. The dried domestic sewage sludge showed the highest reduction rate of all three materials. In contrast, a significant reduction effect was not observed from activated carbon. The pH reduction rate from the activated carbon and the control sample were similar. It is also important to note that further experiments were conducted to capture the pH evolution at the last 8-hour of the reaction. These results, as shown in Figure 3, are similar as before, in which samples with wastewater sludge experienced the most reduction, followed by those with brick addition and activated carbon respectively. However, in Figure 4, the effect of stirring was omitted from the data. It presents the reduction of pH because of the addition of materials only, and this varied for each

Table 1. Characteristics of wastewater samples, pH value, and temperature exceed threshold set by the regulation.

No	Parameter	Unit	Sample number			Ministry of Environment of The Republic of Indonesia (2014)
			1	2	3	
1	Temperature	°C	28	24.6	25.4	38
2	pH	-	10.51	10.5	10.59	6-9
3	TDS	mg L^{-1}	736	450	612	2000
4	Fe	mg L^{-1}	0.02	0.02	0.00	5
5	NO_2-N	mg L^{-1}	0.053	0.076	0.054	1
6	NO_3-N	mg L^{-1}	0.6	0.6	0.6	20
7	Manganese (Mn)	mg L^{-1}	0.2	0.2	0.2	2
8	COD	mg L^{-1}	58.252	7.767	116.505	100
9	TSS	mg L^{-1}	31	110	55.67	200
10	Free Chlorine (Cl_2)	mg L^{-1}	< 0.1	< 0.1	< 0.1	1
11	Ammonia (NH_3-N)	mg L^{-1}	0.014	0.022	0.018	1
12	Fluoride (F^-)	mg L^{-1}	0.098	0.169	0.145	2
13	Arsenic (As)	-	< 0.001	< 0.001	0.003	0.1
14	Cadmium (Cd)	mg kg^{-1}	0.0097	0.0104	0.0089	0.05
15	Chromium Val 6 (Cr^{6+})	mg L^{-1}	0.04	0.029	0.032	0.1
16	Chromium Total (Cr)	mg L^{-1}	0.0136	0.0145	0.0105	0.5
17	Mercury (Hg)	mg L^{-1}	< 0.0001	< 0.0001	< 0.0001	0,002
18	Lead (Pb)	mg L^{-1}	0.0207	0.0218	0.021	0.1
19	Copper (Cu)	mg L^{-1}	0.0513	0.0376	0.0655	2
20	Cyane (CN^-)	mg L^{-1}	< 0.006	< 0.006	< 0.006	0.05
21	Zinc (Zn)	mg L^{-1}	0.0288	0.0582	0.0305	5
22	Sulfide (H_2S)	mg L^{-1}	0.03	0.024	0.026	0.05
23	Phenol	mg L^{-1}	< 0.002	< 0.002	< 0.002	0.5
24	Detergent/MBAS	mg L^{-1}	0.081	0.196	0.006	5

material in 24 hours.

Figure 4 also shows that the pH level decrease was faster in the first 8 hours for both brick and sewage sludge samples. This reduction was increased continually for the first 8 hours, after which it stayed steady before decreasing at the last measurement. Following this, the wastewater sample with sewage sludge addition had a more significant reduction than the one with clay brick. The sample with activated carbon showed a slight decrease over time, and unlike samples with clay brick and sewage sludge, its pH level reduction in the first 8 hours of reaction was less significant than in the last 8 hours.

The sample had an initial carbonate concentration (CO_3^{2-}) of 67.81 mg L^{-1} but after the addition of dried sewage sludge, its concentration increased to 135.39 mg L^{-1}. Meanwhile, the pH level of each material showed that clay brick and dried sewage sludge had a similar acidic pH level of 5.79 and 5.88, respectively, while activated carbon had neutral pH of 6.92.

4 DISCUSSION

The measurement result in Table 1 shows that only the temperature and pH values of the samples were out of range. In this experiment, the measured temperature may be affected by laboratory temperature because the measurement was conducted in the laboratory and not in the field. The pH level of the observed concrete wastewater was affected by the cement content in the con-

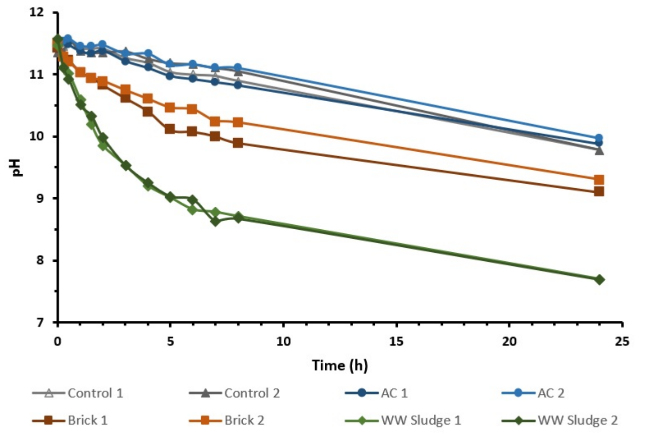

Figure 2 Evolution of pH level during first 8-hour and 24 hour contact time in samples treated with activated carbon (AC), crushed brick, and dried sewage sludge (WW Sludge)

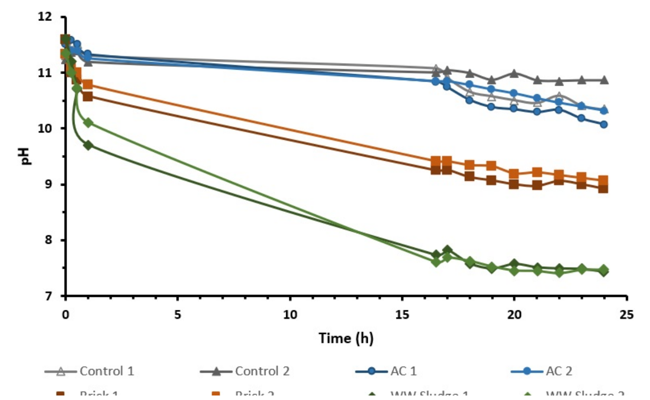

Figure 3 Evolution of pH level during first-hour and last 8-hour contact time in samples treated with activated carbon (AC), crushed brick, and dried sewage sludge (WW Sludge)

crete mixture (Chatveera et al., 2006). Accordingly, the plant used ordinary Portland cement, which mainly consists of calcium oxide (CaO), silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and ferric oxide (Fe_2O_3)(Marchment et al., 2019; Zhang, 2011). During the experiment, the pH level of the wastewater elevated, and this was attributed to the presence of dissolved alkali hydroxide, such as $Ca(OH)_2$, when cement reacts with water (De Paula et al., 2014; Ghrair et al., 2020*b*). In addition, dissolved limestone solids made the concrete wash wastewater to be caustic and had a high pH level (Mohamed et al., 2015b).

It is also important to note that the heavy metal concentrations did not exceed the standards, as outlined in the Ministry of Environment of The Republic of Indonesia (2014). The concentra-

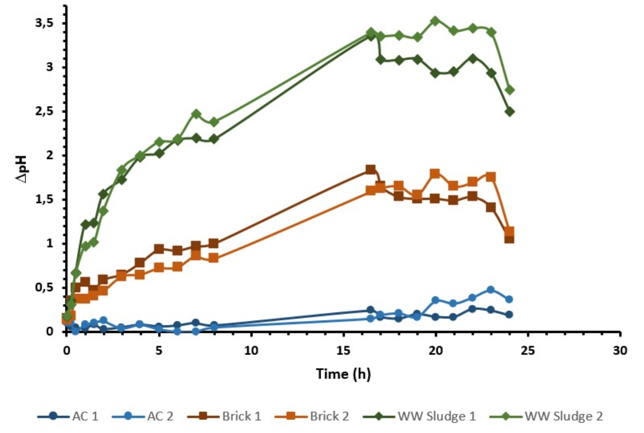

Figure 4 Reduction of pH level during contact time in samples treated with activated carbon (AC), crushed brick, and dried sewage sludge (WW Sludge)

tions were far below the standard. Accordingly, other studies related to washed concrete wastewater also measured the concentration of heavy metals such as cadmium, mercury, copper, zinc, chromium, and lead in the wastewater (Ciawi et al., 2022; Mohamed et al., 2015b; Vaičiukynienė et al., 2021). With the exception of chromium and lead, the concentration of most heavy metals from the aforementioned studies was also low, which is similar to the obtained result of this study. Heavy metals like chromium and lead in concrete wastewater could be attributed to the cement type used or the elements introduced into the cement during production, such as the addition of gypsums, pozzolan, slag, mineral component, and cement kiln dust (Bielski et al., 2020; Biglarijoo et al., 2012). This metal or trace concentration depends on both the raw material used and the factory that produced it (Ogunbileje et al., 2013). Therefore, heavy metal concentration in cement may vary between places. It can be inferred that the ordinary Portland cement used in this study exhibits a low of heavy metals.

The effect of neutralization on the pH level of three materials was also tested in the laboratory. After a 24-hour batch reaction, the dried sewage sludge was found to exhibit the best effect during the 24-hour batch test, followed by clay brick and then activated carbon. The pH of the control sample was also found to decrease without the addition of any materials. This can be attributed to the presence of oxygen due to stirring. The presence of oxygen led to the formation of hydrogen peroxide, which is a weak acid. Furthermore, to explain the pH-reducing mechanism of sewage sludge and brick material, one can look at the composition of its materials. Generally, sewage sludge contains sulfur (Forsberg and Ledin, 2006), and based on the sulfur cycle (Kuenen et al., 1985), the element is oxidized into sulfate with oxygen in the water. When sulfate undergoes assimilation and mineralization, it is transformed into sulfide. With oxygen, sulfide is oxidized and this condition decreases the water's pH level. The dried sludge used has high organic matter composition, and the decomposition of organic matter produces organic acid, which acts as a weak acid, thus lowering the pH (Zhou et al., 2019). On the other hand, one of the most prominent compositions of brick is aluminum oxide (Erdogmus et al., 2021; Liew et al., 2004). As shown in Equation 1, aluminum hydrolyzes in water, producing an H^+ ion that changes the water's pH. In addition, the possible remaining organic acid from brick production could also contribute to the pH-lowering effect of the brick.

$$Al^{3+} + 3H_2O \rightarrow Al\left(OH_3\right) + 3H^+ \qquad (1)$$

Although this study showed the neutralization effect from the three observed materials, it has limitations as it did not include laboratory characterization of each material. Instead, it relied on literature data. It is, thus, recommended to analyze the composition of each material. Furthermore, changes in parameters or contaminant concentrations should be investigated, regardless of the fact that they were already found to be below the effluent standard. It is also advisable to use continuous pH measurement to avoid delay in measurement that could occur while using the manual pH meter.

Despite its limitations, the results showed that domestic sewage sludge best neutralized the alkaline solution. However, it is not practical to use the dried sludge directly since it disintegrates in water. Forming the dried sludge into another form, such as bricks, may yield better results. Although the production of bricks from sewage sludge has been studied and its use is mostly intended for construction (Ding et al., 2021; Wanare et al., 2022). However, it is recommended that bricks from domestic sewage treatment sludge be further investigated as an adsorbent. It is also important to further investigate the possibility of heavy metal leaching from the sludge to ensure the safe disposal of effluent water.

5 CONCLUSION

In conclusion, this study aimed to access the effect of adsorbents on the concrete wash wastewater from a ready-mix plant. Two questions were addressed and the first focused on the critical parameters of concrete wash wastewater in accordance with the wastewater effluent quality standards. Accordingly, laboratory tests were conducted and it was found that all concentrations were far below the specified standard, except for pH and thus, the next main concern was to lower the pH levels of the wastewater. The first obtained result affected the second research question, which was asked with the aim of evaluating the adsorbent materials that could affect the concerned parameter. Furthermore, it was observed that domestic sewage sludge gave the highest reduction among the other two adsorbents namely activated carbon and clay brick. This study is not void of disadvantages, one of which is the fact that its only focus was on the composition of each material from the literature and not on analyzing the composition of each adsorbent. Therefore, it is recommended to add composition analysis and parameter measurements both before and after adding the adsorbents to understand their various effects. In this situation, the use of bricks from household sewage treatment sludge can be examined as an alternative adsorbent. The next crucial aspect is to study the probability of heavy metals leaching from the sludge to ensure that the wastewater discharge will not include any heavy metal.

DISCLAIMER

The authors declare no conflict of interest.

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