Jurnal Teknologi Lingkungan

Treatment of Mixer Truck Wash Water of a Ready-mix Concrete Batching Plant Using a Low Cost Modified Sand Filter

Pengolahan Air Cucian Truk Mixer Pabrik Beton Siap Pakai Menggunakan Modifikasi Filter Pasir Berbiaya Rendah

YENNI CIAWI[1]*, I PUTU GUSTAVE SURYANTARA PARIARTHA[2], AYUB BENNY KRISTIANTO[2]

[1]Department of Environmental Engineering Udayana University, Bali 80361, Indonesia
[2]Department of Civil Engineering, Udayana University, Bali 80361, Indonesia
* Email: yenniciawi@unud.ac.id

ABSTRAK

Pembangunan infrastruktur dan perumahan membutuhkan beton dalam jumlah besar, yang sebagian dipasok oleh pabrik beton siap pakai. Tingginya kebutuhan air dan produksi air limbah oleh industri ini menyebabkan masalah lingkungan yang signifikan. Sebuah pabrik beton di Bali mengolah air limbahnya dengan lima kolam sedimentasi sederhana yang dilengkapi dengan saringan ijuk antar kolam dan kemudian air hasil olahan dibuang ke hutan bakau di sekitarnya. Meskipun nilai Chemical Oxygen Demand (COD) telah diturunkan dari 316,149 mg/L menjadi 146 mg/L, air limbah ini masih berpotensi merusak biota hutan bakau. Padahal, air bisa didaur ulang untuk membersihkan peralatan atau bahkan menjadi air proses. Penelitian ini bertujuan merancang proses pengolahan yang sederhana dan murah beserta peralatannya. Air limbah yang berasal dari bak pengendapan di pabrik beton siap pakai diolah di laboratorium menggunakan tawas tetapi hasilnya tidak memuaskan sehingga dipilih metode fisika dengan menggunakan kolam sedimentasi dan saringan pasir lambat yang dimodifikasi, dan berhasil menurunkan nilai COD sebesar 82,83% pada pH 12,27 dan mendaur ulang 84% air limbah atau 26,7% kebutuhan air total industri ini.

ABSTRACT

Infrastructure and housing developments require vast quantities of concrete, which are supplied by the ready-mix concrete (RMC) batching plant. This industry's high water demand and wastewater generation have caused significant environmental problems. An RMC batching plant in the southern part of Bali produces liquid waste, which is disposed of into the surrounding mangrove forests after being treated using five sequential unlined wash water ponds and palm fibre. Although the COD value has been decreased from 316.149 mg/L of untreated wastewater to 146 mg/L after treatment, this still has the potential to harm the mangrove biota. On the other hand, the water can still be reclaimed for cleaning purposes or even incorporated into process water. The work aims to design a low cost and simple wastewater recycling process and equipment. Wastewater was collected from the existing settling basin at the RMC batching plant and treated in the laboratory. It was found that the chemical treatment of wastewater using alum did not produce satisfactory results; therefore, a physical method was chosen by employing a sedimentation pond and a modified slow sand filter. It removed 82.83% of the COD at pH 12.270 and reclaimed 84% wash water or 26.7% of total water needed for this industry.*

1. INTRODUCTION

1.1 Background

Infrastructure development requires large amounts of concrete, which are partly supplied by the ready-mix concrete industry. Sustainable waste management in this industry requires low carbon footprint products by reuse of all kinds of processing waste, which then can lower the environmental impacts (Xuan et al., 2020). The concrete factory needs water for production, for cleaning trucks, washing the yard, dust control, and domestic use in building (Mack-Vergara & John, 2017), which in turn will also produce wastewater containing toxic metals and harmful suspended solid and has very high pH (Holley et al., 2019). This wastewater is categorized as hazardous waste (Tsimas & Zervaki, 2011, Sharkawi et al., 2017). Generally, batching plant slurry contains water, non-hydrated cement particles, and residual mineral admixtures/additives, which pH could reach more than 12 (Tsimas & Zervaki, 2011, He et al, 2020, Mohamed et al., 2015).

Concrete wash water is usually disposed of at the job site, at a landfill, or into a concrete wash water pit in the ready-mix plant (Choi et al., 2021, Gowda et al., 2008, Chini & Mbwambo,1996). In Turkey, 97% of its ready-mix factory use settling ponds to treat their wastewater (Cosgun & Esin, 2006). There are also several ways of treating concrete factory wastewater that has been applied elsewhere, such as using a combination of aluminium sulfate ($Al_2(SO_4)_3$) or ferric chloride ($FeCl_3$) and the natural coagulant Moringa oleifera (MO) (Paula et al., 2016). The coagulants used are in both water-insoluble and water-soluble forms. The turbidity of wastewater can be reduced to 97.5% by adding 10% v/v from a mixture of 80:20 aluminium sulphate (5% w/v) and MO (5% w/v) solution.

Chemical stabilizing admixture is one alternative to reuse the wash water for mixing more concrete. The dosage is adjusted to the time span of reuse and amount of wastewater to temporarily stop the hydration process and to avoid the hardening of the concrete mixture content in the wash water and adherence to the inside wall of the truck drums (Xuan et al., 2020, Chini & Mbwambo, 1996).

Reused waste slurry improves the permeability and carbonation resistance of concrete and increases the compactness of concrete (Chen et al., 2020), decreasing setting time (Aldossary et al., 2020). Moreover, higher Total Dissolved Solid/TDS (in the range of 500; 1,000; 5,000 ppm) increase compressive strength by up to 20%. When using water with TDS 15,000 ppm produce compressive strength lower than control but still meet the requirement by ASTM C191-18a. This may be due to pore filling properties of TDS (Aldossary et al., 2020, Zervaki et al., 2013, Vaičiukynienė et al., 2021), which produced higher compressive strength at 3 and 7 days, but about 92% of control (de Matos et al., 2020), higher than control before three months old and similar to control thereafter (Gupta et al., 2020, Klus et al., 2019). Other properties such as workability, initial setting time were reduced but still within the acceptable limit, which may be due to the presence of Cl ion in TDS (Aldossary et al., 2020, Zervaki et al., 2013, Bouaich et al., 2021). However, untreated wash water is not recommended to be used as process water for concrete production due to the low workability and low compressive strength of the concrete produced (Ghrair et al., 2020). Filtered wastewater and stabilized ones can be used as process water for ready-mix concrete. There is no difference in workability, setting time and compressive strength of concrete using tap water, wash water or underground water (Chatveera & Lertwattanaruk, 2009, Su et al., 2002). The use of recycled wastewater only alters the concrete properties when using together with recycled aggregates (Ahmed et al., 2021; Asadollahfardi et al., 2015).

A ready-mix concrete batching plant in the southern part of Bali employed five unlined sedimentation ponds interconnected by a simple palm fibre filter between the ponds to treat its wastewater and discharge the filtrate into the mangrove swamp. The existing final filtrate still has high turbidity and high COD, polluting the surrounding mangrove areas. In fact, this water still can be processed further to be reused for washing vehicles transporting liquid concrete, for domestic use in bathrooms and toilets, even as processing water (Chen et al., 2020, Babu & Ramana, 2018, Babu et al., 2018; Klus et al., 2017; Ekolu & Dawneerangen, 2010)

1.2 Objectives

This research aims to design a low cost and simple wastewater recycling treatments and design the equipment.

2. METHODS

The wastewater was collected at a batching plant sedimentation pond in Taman Mumbul, Bali (Figure 1) and treated at Material Laboratory, Civil Engineering Department, Udayana University using jar test equipment to measure the requirement of alum powder to clarify the water. The cement concentration, COD and BOD of wastewater before and after treatment were determined.

Figure 1.   Wastewater sampling location in southern part of Bali (Google Map, 2022)

2.1 Measurement of Liquid Waste Production

The wastewater production is determined by calculating the discharge volume of several mixer trucks in litres/second. The wastewater sedimentation pond is designed based on the largest discharge.

2.2 Measurement of COD and BOD5

COD was determined by using the titration method, in which excess $K_2Cr_2O_7$ reduced by ferrous ammonium sulphate (FAS), whereas BOD_5 was determined by the difference of dissolved oxygen of water sample at day 0 and day 5 (Rice et al., 2017)

2.3 Jar test

Ready-mix concrete factory liquid waste was put into jar test equipment (Minimix Laboratory mixer, EC Engineering, Novatech, USA), which consist of 500 ml vessels. Into the vessels, 10 grams, 20 grams, 40 grams, 50 grams, 100 grams, and 150 grams of alum are added, respectively (Figure 2). Samples that were not given alum were used as controls. Stirring is carried out for 30 minutes. Then the observations were made visually to determine the clearest solution. The turbidity of the solution was measured at a visible wavelength.

Figure 2. Jar test

2.4 Cement Concentration Measurement

The concentration of cement in the wastewater was measured using a Spectronic 20 Spectrophotometer (Genesys 20 model 4001/4) at an optimum wavelength. This was determined by using 4 grams/liter cement in water and measured the transmittance value on a spectrophotometer between wavelengths 590–620 nm with 5 nm intervals and the highest absorbance will be considered as the optimum wavelength according to Lambert-Beer law. Whereas the calibration curve was prepared by suspending the stock solution of cement (20,000 ppm) in water in several dilutions. Samples that did not contain cement were used as controls. The absorbance data at the optimum wavelength of each cement concentration was plotted to produce the calibration curve, and the regression line equation was calculated. It was used to determine the concentration of solids in the wastewater.

2.5 Simulation of Waste Treatment Plant

The simulation of the waste treatment plant was carried out using several buckets as a sedimentation pond, a retention pond, and a sand filter pond.

2.6 Regulations Used in Design

The design of wastewater treatment units used the regulation in Indonesia as follows:
a. Design of Slow Sand Filter (Indonesian National Standard, 2008)
b. Design Procedure for Water Treatment Installation Package Unit (Indonesian National Standard, 2007)
c. Environmental Quality Standards and Environmental Damage Quality Standards (Governor of Bali Province Regulation, 2007)
d. Management of Water Quality and Water Pollution Control (Indonesian Government Regulation, 2021)

3. RESULT AND DISCUSSION

3.1 Existing Wastewater Treatment and Disposal

The ready-mix concrete factory conducted wastewater treatment by passing wastewater through 5 ponds sequentially and between the ponds, a palm fibres filter is placed (Figure 3). It is similar to the wastewater treatment described by Chini & Mbwambo (1996). The wastewater is collected in a settlement pond to recover aggregate. Then, the supernatant can be reused for washing truck or hold in an unlined retention pond also into which also stormwater runoff and wastewater from dust spraying are discharged. The wastewater is then allowed to evaporate or percolate to the ground.
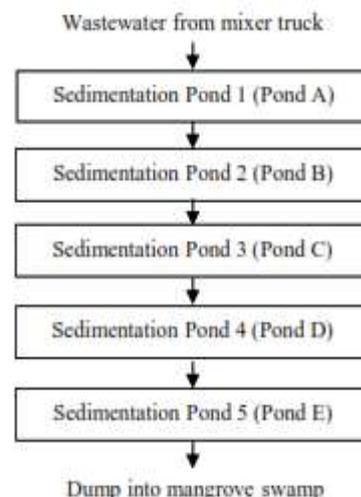

Figure 3.   Schematic of the existing wastewater treatment process (↓ palm fibre filter)

3.2 Liquid Waste Generation from Mixer Truck Washing

The volume of liquid waste is given in Table 1. The maximum generation of liquid waste is 0.812 liters/second.

Table 1. Liquid waste generation

Truck Mixer	Rate, Q (liter/second)
I	0.376
II	0.536
III	0.572
IV	0.636
V	0.801
VI	0.812

3.3 The Solid Content of Wastewater

The maximum wavelength (λ_{max}) for the determination of the solid content is 600 nm, with an absorption value of 1.185 (Figure 4). The calibration curve is presented in Figure 5. The equation for the regression line is y = 2.385.1x-311.51. The solid content of wastewater is presented in Table 2.
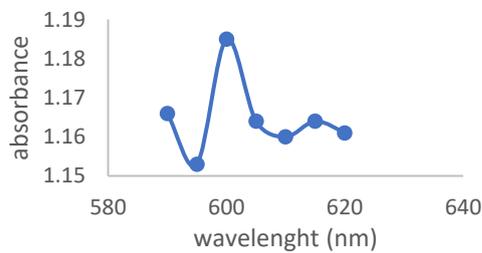
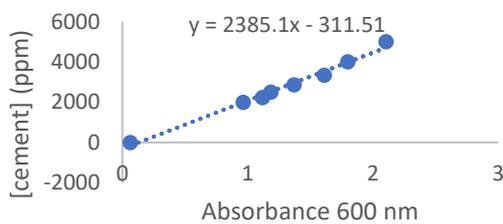Figure 4. Determination of maximum wavelength

Figure 5. Calibration curve: concentration of cement in water (ppm) vs absorbance at 600 nm

The initial BOD and COD (Table 2) show that the ready-mix concrete factory wastewater contains very high levels of inorganic material (COD = 316.15 mg/L), at the same time the organic matter content is very low, as shown by the BOD value = 2.04 mg/L. Existing palm fibre filters can only reduce the COD to 146 mg/L (Table 2), which does not meet the requirements for disposal into the environment. The high COD value may be contributed by the solid content derived from cement and other admixtures (Holley et al., 2019, Tsimas, & Zervaki, 2011 , He et al., 2020, Mohamed et al., 2015, Chen et al., 2020).

Table 2. COD and BOD$_5$ values of liquid waste of existing treatment

Sample	COD (mg/L)	BOD$_5$ (mg/L)	Solid content (ppm)
Influent	316.149	2.041	2,530
Effluent	146	0.074	155

The first trial of the wastewater treatment used alum as the coagulant. Jar test was employed to determine the optimum amount of alum needed to clarify the wastewater. The results were determined using visual judgement (Figure 6 and Table 3).
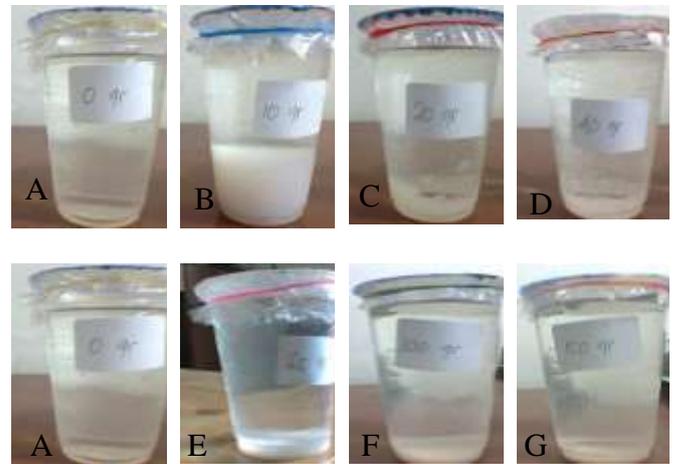

Figure 6. Jar test results (the number stated in figure is in grams of alums per 500 ml wastewater sample) A=without alum, B=20 g/l, C=40 g/l, D=80 g/l, E=100 g/l, F=200 g/l, G=300 g/l alum addition)

Table 3. Jar test result

Sample	Alum addition (g/L)	Results
A	0	Feedwater (very cloudy) (Sample from pond B)
B	20	Clearer than A with a lot of sediment
C	40	Clearer than B with less sediment than B
D	80	Clearer than C with less sediment than C
E	100	Clearer than D with almost no sediment
F	200	Cloudier than A with a lot of sediment
G	300	Cloudier than F less sediment than F

The best clarity of the water was obtained when using 100 g/l alum. The resulting water is clear and minimal sediment is produced. However, with the requirement of 100 g/L of alum, it will be impractical as the wastewater treatment will be very expensive. Therefore this option was not be selected and instead sand filtering was then investigated, which was simulated at a laboratory scale.

3.4 Simulation of Wastewater Treatment

The waste treatment plant consists of a sedimentation pond, a retention pond and a sand filter pond. The wastewater treatment process produced clean water as much as 8.4 litres from 10 litres (84%) of wastewater input, earlier research can reclaim only 75% of wastewater (Chini & Mbwambo, 1996). The filtering duration is 4,010 seconds. The remaining filtrate (1.6 l) is turbid as the feed water. Table 4 shows the COD and

pH values of the processed water. Truck and backyard washing need 93 kg water/m³ concrete produced compared to 200 kg of water incorporated into the product (Mack-Vergara & John, 2017) or 30% of total water consumption (Férriz-Papi, 2014), if 84% of water wasted can be reclaimed, then there will be 26,7% of saving for water needed for this industry.

Table 4. COD and pH of wastewater after filtration

Sample	COD (mg/L)	pH	Solid content (ppm)
Feed	96.333	11.73	155
Filtrate	54.164	12.27	140
Cloudy filtrate (after 4,010 seconds)	-	12.27	168

There are several methods used by the existing RMC plant that have been reported (Table 5), from settling box (Tsimas, & Zervaki, 2011, de Matos et al., 2020), slow sand filter (Ghrair et al., 2020), treatment using $BaCl_2$ (Mohamed et al., 2017), and using a combination of Moringa, alum and $FeCl_3$.

Table 5.   pH and solid content of wastewater of several ready-mix concrete batching plants

Method/equipment	pH	Solid content	References
Settling box	11.07	6,240 ppm	(de Matos et al., 2020)
Settling tank	11.96	2,420 ppm	(Tsimas, & Zervaki, 2011)
Water pit	12.11	1,991.2 ppm	(Ekolu & Dawneerangen, 2010)
Water pit	13–13.5	<40,000 ppm	(Sandrolini & Franzoni, 2001)
Slow sand filter	12.70	≥ 9,000 ppm	(Ghrair et al., 2020)
$BaCl_2$ treatment	12.60	5,890 ppm	(Mohamed et al., 2015)
Moringa+alum +$FeCl_3$	9.5	10.14 NTU	(Paula et al., 2018, Férriz-Papi, 2014)

The quality of all recycled wastewater meets the standards of ASTM C1602, which the normative solid content of concrete mixing water is <50,000 ppm. In this work, the filtrate solid content is comparable with the process that used Moringa, which successfully removed 99.88% of the turbidity with initial wastewater turbidity of 84.5 NTU (28,1 ppm) using a combination of 0.36 g/L alum, 0.47 g/L Moringa dan 0.18 g/L $FeCl_3$ (Paula et al., 2018, Férriz-Papi, 2014). Furthermore, when the alum concentration was doubled to 0.72 g/L, turbidity removal increased slightly to 99.92%. However, ferric chloride is not recommended because of its corrosive features to iron, which is used in reinforced concrete. On the other research, which used a slow sand filter that contains a compacted layer of sandstone and limestone aggregate, the filtrate has COD 48.7, BOD 13.4, and pH 12.7, and after neutralized using CO_2, the pH decreased to 7.2, TDS 1493 ppm, COD 39.5 and BOD 10.9 (Ghrair et al., 2020). This current work produced an improved quality of the wastewater. Without pH correction it

can be used as a stabilization agent for sewage sludge (Gowda et al., 2008) or even process water in the RMC factory (Su et al., 2002, Ahmed et al., 2021). The water can be classified as class IV according to Indonesian water regulation after pH correction (Hossain et al., 2017, Indonesian Government Regulation, 2021), e.g. by using CO_2 (Ghrair et al., 2020) or by using carbonate nanoparticles (Sandrolini & Franzoni, 2001).

Wastewater from 200 to 700 NTU and pH 6–8 and the resulted water can be used for cleaning truck (Férriz-Papi, 2014). For non-potable reuse, coagulation and pH correction should be done because the aluminium content is often linked to Alzheimer disease (Kawahara & Kato-Negishi, 2011) as preventive measures due to direct contact with the processed water. Wastewater with solid content below 40 g/L (40,000 ppm) can be used for mixing for producing fresh concrete with comparable compressive strength (Aldossary et al., 2020, Sandrolini & Franzoni, 2001), the number is below 1,000 ppm. The pH of wastewater is not always been maintained by the ready-mix concrete factory (Cosgun & Esin, 2006, Ghrair et al., 2018). The alkalinity of the wash water can be reduced by using barium chloride and carbon dioxide bubbling (Mohamed et al., 2015) or by using strongly acidic volcanic ash or flue gas of solid waste incineration plant (Morita, 1992). Reusable wastewater for mortar production is with maximum TDS of 5,000 ppm, maximum alkalinity of 1,800 mg/L, range of pH between 10.5 and 11.5, maximum total hardness of 1,000 mg/L, and maximum turbidity of 280 NTU (Sharkawi et al., 2017).

3.5   Planning of Waste Processing Units Prototype

3.5.1 Planning of Sedimentation Unit Prototype

The planning of the sedimentation unit in the prototype was made to deposit the sludge so that only the liquid waste passes to the sand filter tubes. Sedimentation tank planning is based on SNI DT-91-0002-2007 (Indonesian National Standard, 2007) with the use of a rectangular tube, resulting in a surface load of 0.8 m³/m²/hour (2.22.10-4 m³/m²/second), a depth of 3 m, a retention time of 3 hours (10,800 seconds), and with the slope of the bottom of the pond are 450. The assumption used for the ratio of length to width is 1:2. Determination of the dimensions of the sedimentation unit building using the Equation 1.

L x W x H = Q.td ……………………………. (1)

where: L = length, W = width, H = height, Q = discharge (m³/sec), td = retention time

The dimensions of the sedimentation unit are L = 3 m, W = 1.5 m, and H =3 m. The free height is 0.3 m.

3.5.2 Planning of Filtration Unit Prototype

The filtration unit prototype used sand, gravel, and charcoal. Sand functions as a water filter, gravel functions as a medium to hold water during the filtering process and charcoal act as an absorbent for color and odor. The sand filter pond is planned based on SNI DT-91-0002-2007 (criteria for

planning the filtration unit, rapid sand filter) (Indonesian National Standard, 2007). The calculation of the number of filter ponds uses the equation $N = 12Q^{0.5}$, with N = number of filter ponds and Q = discharge (m^3/s). It was found that 3 sand filter ponds are needed. The dimensions of the filtration unit were determined by firstly calculating the surface area of the filtration unit (A). Surface area calculation using Q = 0.812 l/s, assuming a filtering speed of 6 m/hour (SNI DT9100022007) (Indonesian National Standard, 2007). The equation used is A= Q/v, with A: the surface area of the ponds, m^2, Q: discharge, m^3/s, v: filtering speed, m/h. Thus A = 0.487 m^2, then by using the ratio of length (P) and width (L) 2:1, then P=2L and $A=2L^2$. This gives a length of 1 m and a width of 0.5 m. The height of the filtration unit is planned based on SNI 3981-2008 (Indonesian National Standard, 2008). The dimensions of the sand filter pond are presented in Table 6.

Table 6. Depth of filtration ponds (D)

No.	Depth of pond (D)	Units (m)
1.	Freeboard	0.3
2.	The water level above the media	1.0
3.	The thickness of the top holding gravel	0.15
4.	Thickness sand filter	0.6
5.	Thickness of activated charcoal (color absorbent)	0.6
6.	The thickness of the bottom holding gravel	0.15
7.	The thickness of the concrete supporting the media	0.1
8.	Underdrain	0.1
	Total	3.0

It is shown that the total height of the filtration building is 3 m and the effective height is 2.7 m. Thus, the dimensions of the filtration pond are 1 m (length), 0.5 m (width), and 3 m (height). The effective volume of the filtration unit is L x W x Effectiveness = 1 x 0.5 x 2.7 = 1350 m^3. Figure 7 shows the design drawing of sedimentation and filtration unit prototype.

This study contributes to the environment by using a simple method for reclaiming water for reuse within the RMC factory, thus lowering the cost for conserving water (Tsimas & Zervaki, 2011, Hossain et al., 2017, Xuan et al., 2016, Treloar et al., 2003) because mismanagement of waste will affect the municipal environment, i.e., pollution of soil and groundwater (Ferronato & Torretta, 2019). This research is also in line with the principles of sustainable development goals (SDGs) to achieve sustainable and environmentally sound management of all wastes, particularly hazardous ones, by 2030.
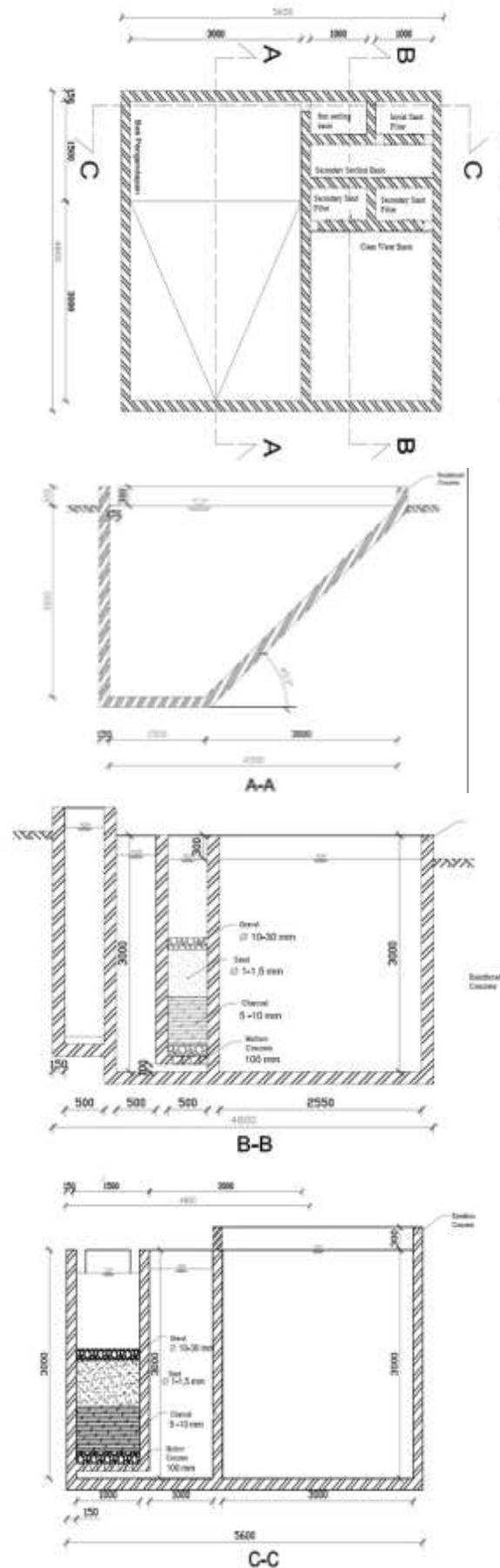

Figure 7.   The design drawing of sedimentation and filtration unit prototype

4. CONCLUSION

The simulated sand filter reclaims 84% of the wash water better than previously reported, which is 75% by settling pond and can recycle 26.7% of total water needed for this industry. Using the same method, the process removes more solid than similar method as has been reported and comparable to when used a combination of Moringa, alum, and FeCl₃, the latter should be avoided due to its corrosive feature to iron.

The planning of the actual building is based on the flow rate of Q = 0.812 liters/second. A sedimentation pond is planned to have a residence time of three hours, to separate the sludge deposits from the ready-mix concrete wastewater, which is then fed to the filter pond. Sand filter ponds are planned with Q = 0.812 liters/second, with three ponds and the filtering speed of each pond 6 m/hour.

With the addition of pH adjustment, the filtrate of the processed wastewater meets class IV Indonesian water quality standards, which is for agriculture and animal husbandry and can be used as process water in the ready-mix concrete factory.

ACKNOWLEDGMENT

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