The addition of lamella in anaerobic baffled reactor used for decentralized municipal wastewater treatment

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Abstract. An anaerobic baffled reactor (ABR) represents a low-cost system for decentralized wastewater treatment in a developing country. Despite the advantages of ABR units such as low operating and maintenance costs, this system requires sufficient land to construct it. In particular of an urban area, land availability is limited and therefore acquire modification in ABR design. This study aimed to test the addition of lamella for further reduction of solids particle in domestic wastewater, and therefore it could reduce the size of ABR settler. A lab-scale of an ABR lamella with a dimension of 75 cm length, 20 cm width, and 40 cm height used in the experiment. A 20 L/d of raw municipal wastewater taken from the existing ABR in Kampong Bareng, Malang (Indonesia) used to feed the lab-scale of the ABR lamella. The experiment was conducted in two months and the sample of raw and treated wastewater collected from the ABR lamella for ten times from September to October 2018. The samples were taken from the inlet, lamella compartment, and the outlet. The results showed that the addition of lamella reduced the concentration of TSS and BOD for 95% and 90% respectively. While these results could help further reduction of organic and solids particle of wastewater that meet the treated wastewater regulation. The concentration of TSS and BOD as treated wastewater were 19 mg/L and 18 mg/L respectively. Although the ABR could reduce the nutrient concentration, the level still higher than the global standard for N and P.

1. Introduction
The smart environment is waste processing management in the city by providing of sanitation system, namely septic tank, toilet, and decentralized wastewater treatment plant (DWWTP). Most of the DWWTP in Indonesia use ABR. This indicator is realized through a program, carried out by the government, called KOTAKU which primary aim is to achieve No Slums Cities [1], in which public DWWTP procurement becoming one of the attempts.

However, several technical issues found during the application of ABR in Indonesia; for instance, the effluent of domestic wastewater does not meet the wastewater quality standard. Hence, achieving the stable processing of wastewater to fulfil the standard requires further process [2]. Some countries have implemented wastewater management technology with simple maintenance, i.e., lamella. Lamella consists of two types: a plastic tube and a stainless-steel plate. The benefits of using plate lamella encompass high efficiency, low maintenance, easy application, and higher durability compared with PVC lamella, which is prone to damage when applied in construction [3]. Therefore, plate lamella uses in the development of further processing or design modification in ABR.
The flow concept of plate lamella uses gravitation to pull the solids down so that they can be settled. The angle of the lamella is designed to prevent solids from being washed together with water. Additionally, lamella sedimentation tube can reduce the average water turbidity 5–12 times better than the conventional sedimentation unit [4]. Mathematical modeling and numerical simulation were used to observe if using lamella can boost efficiency. As a result, lamella indeed rises efficiency and makes effluent quality parameters meet the water quality standard [5]. Based on that descriptions, the author aims to develop ABR for DWWTP to improve wastewater treatment process by the addition of lamella. We also applied U-shape flow pattern to ease the maintenance. The pattern, however, is rarely applied in ABR; instead, in general, DWWTPs apply zig-zag or S-shape pattern, which is quite hard in both construction and maintenance process.

2. Materials and Methods

2.1. Anaerobic Baffled Reactor with lamella

Design calculation of ABR-lamella referred to BOD concentration, retention time, and flow rates. Raw wastewater was taken from DWWTP of KPP Purwuropo in Malang that containing BOD concentration of 558.4 mg/L. The retention time of three days and up-flow velocity of 2 m/h were applied in the design calculation [6], and 0.231 ml/s of wastewater flowrate. The ABR design was calculated based on the analytical calculation of wastewater processing technology [7], literature review related to SSWM [6], and basic theory of decentralized wastewater treatment in developing countries (DEWATS) [8]. The U-turn flow pattern used to ease maintenance [9]. The choice of lamella material refers to several studies which focused on the stainless-steel plate shape as it is more efficient than PVC tube [3], the distance between lamella was 2–4 cm [10], and the angle of 60˚ was applied to enhance higher sedimentation rate [11].

The ABR made from plastic fiber. The dimension of the first compartment was 30 cm x 10 cm x 40 cm. While 15 layers of the lamella, having area of 20 x 10 cm, arranged in the compartment with a dimension of 45 x cm x 10 cm x40 cm, 60˚ of angle, and 2 cm of distance between the layers. The other three compartments have dimension of 20 cm x 10 cm x 40 cm, and the last one (outlet) was 15 cm x 10 cm x 40 cm. The overall reactor size was 75 cm x 20 cm x 40 cm. The pipe diameter of 0.5 used to connect each compartment in ABR.

![Figure 1. Scheme of ABR with lamella in laboratory-scale](image-url)
Figure 2. Top view of ABR-lamella

The inlet or sedimentation compartment has a function as a divider between solid and liquid by gravitation, and this can eliminate solids in the water [12]. The water then flew down and passed through the lamella compartment in which they can control the up-flow water to the next compartment, hence reduce more solids in the water [13].

The concept of flowing against the stream works when the up-flowing water goes through the angle of 60; when the water flows up, solids carried by water will collide with the lamellas hence fall and create more sedimentations [14]. The distance between lamella plates should be between 2–4 cm [10] however, to obtain the most optimum TSS removal efficiency, it was decided that the best distance was 2 cm, and we made the height of lamella to be half of the reactor’s height (20 cm).

After passing through the lamella, the water cascades towards baffled compartment. The baffled able to reduce the water velocity and lead longer retention time which triggers in organic matter reduction [15] as the baffled also create up-flow water movement.

2.2. Data Analysis

Biological and physicochemical parameters like BOD, TSS, TKN, TP, and TC were analyzed after sample collection in Jasa Tirta laboratory following the standard method for the examination of wastewater samples. T, pH, and DO were measured directly on the site using portable equipment. The removal values of BOD, TSS, TKN, TP, and TC represented the reduction efficiency of the influent (raw wastewater) and expressed it in percentage.

3. Results and discussion

3.1. pH and temperature

The observation revealed that the pH in the influent was around 6 to 7 while in the compartment after lamella and effluent the pH was about 7.8 to 8.2. These number indicated that the treatment of wastewater using ABR inserted with lamella showed very good performance. Under laboratory condition, pH parameter met the Indonesian wastewater quality standard of 6–9. The increase of pH occurred because oxygen used in degraded the organic matter; thus, CO₂ concentration fell. Increasing pH value to neutral is directly proportional to the decreasing concentration of BOD [16]. This statement is in line with research by Budiwati [17] reported that while the concentration of CO₂ declines, the pH will incline. Supporting this, Muson [18] also stated, when pH value decreases, CO₂ concentration
increases, as a further consequence, concentration of BOD increases as well. High pH value of 7.5–10 in wastewater revealed the pollution level decreases; the higher the value of pH in wastewater, the lower concentration of BOD contains in wastewater [19].

Temperature and pH are essential parameters which influence the growth and performance of microorganisms inside the reactor [20]. The temperatures at three sampling points (inlet, after lamella, outlet) were stable, averaging at 24°C; meanwhile, the temperature of water in the outlet from 22°C to 26°C. Water analysis results obtained from the experiment are presented in the following graphs.

**Figure 3.** Water analysis results of domestic wastewater treated with ABR which inserted by lamella

### 3.2. DO

DO is an important compound which supports aquatic organisms to survive, such as for breathing, metabolism process, and substance exchanges which then generates energy to grow and breed [21]. The oxygen concentration of the raw wastewater ranging from 0.1 mg/l to 2.1 mg/l and then increased in the effluent from 2 mg/l to 5.4 mg/l (Fig. 3a). The concentration of DO has already met the minimum
standard for fish breeding. The DO concentration after lamella, and outlet point was higher compared with the inlet in which it was followed by the decreased of BOD concentration. Similar results of decreasing BOD proved by Aldo [23].

3.3. BOD

BOD concentration shows the amount of dissolved oxygen concentration required by microorganisms during the degradation. Hence, the BOD concentration is equivalent to organic pollutant concentration in wastewater [23]. Regarding the lamella performance, this study showed that BOD concentration removal efficiency from the inlet to lamella (A) was 89%, it was higher compared to point B (inlet to outlet) at 82%. On average BOD of the influent was 275 mg/l, and it decreased to 23 mg/l after passed through the lamella. The addition of lamella helped the system to reduce at 84% of the organic matter as the lamella reduced the velocity of water and increased the settling of the solids particle, and therefore reduce BOD concentration (Fig. 3b).

High removal of BOD level at point A illustrated the ability of lamella inside ABR on enhancing sedimentation, which optimally reduced the BOD concentration in the domestic wastewater. It was in line with lamella’s purpose to reduce dissolved solids within the water, where 80% of BOD consists of dissolved and suspended solids [24]. This lead to the final treatment, which BOD concentration removed about 90% and met the standard quality of effluent.

3.4. TSS

The result of TSS removal efficiency was similar to the previous result of BOD, in which the average removal at point A was 93% and in the effluent was 95%. TSS concentration decreased at 343 mg/l, 20 mg/l and 14 mg/l respectively for inlet, after lamella and outlet (Fig. 3c). The concentration of TSS in the effluent has met the standard of discharge consent with a maximum value of 30 mg/l. The decrease of TSS proved that lamella triggers the solids particle to be settled in the first part of the ABR. Lamella (tilted plate) supported in increasing organic solids secondary sedimentation performance and worked effectively in removing suspended solids and BOD content [25].

3.5. TKN

The concept of ABR lamella performance is sedimentation oriented, which leads to removing BOD and TSS concentration. On the other hand, ineffective in reducing nutrient compound, e.g., nitrogen [6]. Figure 3d shows that the concentration of TKN fluctuated over 30 days. TKN concentration in raw wastewater ranging from 14 mg/l to 58 mg/l, and the average was 35.4 mg/l. After passed the lamella TKN level decreased with the average value of 32 g/l and slightly increased in the effluent at 34 mg/l.

It was assumed that the decline of TKN was because of organic nitrogen sedimentation along with solids particle. Besides, the decrease of nitrogen in the effluent was also be triggered by nitrification and denitrification process in ABR (Yulistyorini et al., 2019). Also, lamella can help the removal of nitrogen in ABR for 9.7%. Generally, nitrogen is essential for organisms as nutrition and mineral trace, but in large amount, it pollutes the environment, e.g., anaerobic nitrogen and ammonium nitrate (NH4NO3) which consumes oxygen hence interferes ecosystem balance and inhibits aquatic animals from living and metabolizing [26]. A high concentration of ammonium inhibits further processing, and therefore pretreatment is required [27].

Although the reactor was only sedimentation-based, the additional lamella in ABR reduced better TKN than research by McKeon [28] which total removal efficiency of nitrogen using lamellaclarifier method in domestic wastewater was only 1%.

3.6. TP

Phosphor concentration reduction showed a similar pattern in which the ABR was ineffective in reducing nutrient (phosphor). However, in comparison to TKN concentration (Fig 3d), the value of TP from the inlet to the outlet was gradually declined over time (see Fig 3e). TP concentration in raw
wastewater was very high with a minimum and maximum value at 4.1 mg/l and 26 mg/l respectively, with the average TP concentration of raw wastewater was 12 mg/l. The addition of lamella did not seem to reduce phosphor concentration in wastewater as the average TP concentration after passed lamella compartment was 11.4 mg/l. There was only 11% removal of total phosphorus from the lamella compartment to the outlet which reaches 10 mg/l.

Although the performance of ABR lamella was not good in reducing phosphorus, the 11% reduction was still higher than another study conducted by McKean [28] which obtained 6% reduction of total phosphor removal using lamella clarifier in domestic wastewater. This reduction was possible due to the phosphorus bond with organic matter and settled in the sedimentation process. High phosphorus concentration in raw and treated wastewater was probably due to excessive household laundry waste. Phosphorus comes from sodium tripolyphosphate (STPP), which is one of the detergent ingredients. Excessive phosphorus leads to eutrophication (nutrient enrichment) and to prevent it requires further wastewater polishing [29] by adding further processes such as phytoremediation or constructed wetlands.

3.7. Total Coliform
TC concentration of raw wastewater in this study was below the discharge standard of domestic wastewater where the concentration still lower than 3000 /100 ml. The maximum TC concentration in raw wastewater was 571/100 ml. Moreover, on average TC concentration reduced from 255/100 ml in influent to 168/100 ml in effluent with total removal of 34%. Since the lamella assists the ABR to enhance the settling of the solids particle, it helped to reduce TC about 27% from the raw wastewater. During sedimentation, bacteria bind with solids particle and trigger the sedimentation process [30,31].

4. Conclusion
Domestic wastewater treated in ABR-lamella to meet the discharge consent. On average, the removal efficiency of BOD and TSS were 90% and 95% respectively. While nutrient removal (N and P) were 9.7% and 11% respectively. Overall, temperature, pH, BOD, TSS, and TC met the quality standard; however, the TKN and TP concentration above the standard limit. Additional lamella in ABR reactor proved that it was lead to enhance sedimentation that removed TSS of raw wastewater at 94%.

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