Organic, nitrogen, and phosphorus removal in hospital wastewater treatment using activated sludge and constructed wetlands

V Hanny¹, A M Rizal¹, and Nasuka¹

¹Balai Besar Teknologi Pencegahan Pencemaran Industri, Jl. Kimangunsarkoro no. 6, Semarang

hannyvistantybbtppi@gmail.com

Abstract. Due to COVID-19 pandemic, hospital becomes the main and critical facility in any countries. This has also negatively affected the environment, as the wastewater discharged was also increased. Wastewater treatment plant in the hospital will also be affected as there will be fluctuations in volume and quality of wastewater. Hence there is an urgency to choose the appropriate technology as main solution and to improve existing wastewater treatment plant. We will report the performance of integrated system of activated sludge and constructed wetlands applied in a hospital wastewater treatment plant. Both technologies were chosen because they are simple, cheap, and highly effective technologies for wastewater treatment. Activated sludge was able to reduce organic, ammonia, and phosphat content significantly. However, the quality of effluent was still not able to meet the regulation. Application of constructed wetlands as finishing treatment was able to improve the quality of effluent to meet the standard and resulted in BOD, COD, ammonia, and phosphate of 25 mg/L, 24.18 mg/L, <0.01 mg/L, and 0.46 mg/L, respectively. Hence it can be concluded that the integration of activated sludge and constructed wetlands can be an appropriate and effortless treatment system for low-strength wastewater to meet a strict quality standard.

1. Introduction
Hospital as a vital facility providing health care service is one of primary institution existing in society, especially in this pandemic COVID-19 period. While it is needed to ensure public’s health, its activity also may have a potential negative impact to the environment and human health. Hospital requires a high amount of water and, consequently, results in generation of large volumes of wastewater, which is specifically originated from laundry activity [1]. The wastewater is generally specific in characteristics, such as, low COD and BOD, high concentration of detergent, particulate, and microbial load.

Characteristics of hospital wastewater: similar to domestic wastewater (low pathogen and pharmaceutical content and high detergent, due to the higher volumes of laundry wastewater). Surfactant content originated from laundry department will contribute to higher concentration of ammonia and phosphate, due to the presence of natrium tripoly-phosphate and quaternary ammonium compounds in detergent and soap. The phosphorus and nitrogen compounds, even in low concentration, will be concentrated in water body and river. These two compounds will increase growth of aquatic plants (algae) and invade the aquatic area. This phenomenon will disturb the existing balance of aquatic
environment because it will specifically reduce oxygen concentration in water. Thus, this two parameters are also important to be considered in monitoring the effluent quality.

Conventional wastewater treatment such as, anaerobic and activated sludge are widely employed as low-strength wastewater treatment, such as hospital wastewater. Activated sludge system commonly has two main functions, i.e., 1) oxidation of biodegradable organic matter and converted to new cell mass and 2) flocculation, which is, separation of newly formed biomass from treated effluents. It also commonly used as various wastewater treatment at varied scale [2,3]. Activated sludge, specifically, is assumed as an appropriate technology for hospital wastewater treatment, due to its high ability in integrated removal of carbon, nitrogen, and phosphorus [4]. It is also suitable for low-strength wastewater, such as domestic and hospital wastewater, which may satisfy the C, N, and P requirements of various microorganisms (C:N:P ratio of 100:5:1). However, this single technology cannot remove ammonia and phosphate into a low value and meet a strict environmental standard set by the government. Thus, it is important to develop and combine another appropriate technique to remove ammonia and phosphate more efficiently in order to meet the national discharge standard and achieve an excellent effluent quality.

Constructed wetlands recently has received greater attention and developed as wastewater treatment in many area [5,6] and even applied full-scale [7–9]. Constructed wetlands (CW) has also been studied as a tool of nitrogen removal contained in wastewater treatment [10,11]. Though studies show CW as a high performance system to remove organic contaminant, it still requires pretreatment as it has a limitation in high-strength wastewater. CW often combined with biological processes, such as activated sludge and anaerobic process, in various wastewater treatment [12–14] and showed a high performance in organic removal. Another study also showed a high phosphorus removal in seven CW unit. Considering the strength and weakness of each technology, we combine those two technologies as one system for a full-scale hospital wastewater treatment plant. The purpose of this research is to study the performance of integrated system of activated sludge and constructed wetlands as applied in hospital wastewater treatment. Furthermore, we will also evaluate the quality of effluent as compared to the standard regulation set by the government.

2. Methodology

2.1. Wastewater treatment plant and operational setting

Figure 1 depicts the schematic diagram of wastewater treatment plant setup in this research. Wastewater treatment plant studied in this paper was built in a hospital in Semarang Regency, Central Java. The system is composed of equalization tank, activated sludge unit, aeration tank, wetland unit, and disinfection tank. Activated sludge (AS) seed was taken from another activated sludge unit and loaded into AS unit and acclimatized with wastewater gradually. DO concentration was kept higher than 4 mg O₂/L and the hydraulic retention time was 18 h.

CW unit in this WWTP was designed as horizontal subsurface flow constructed wetlands (HSSFCW) and comprised of two stages of CW tank. Two small ditches was designed between CW 1 and 2 and after CW 2, which was used as control and recirculation tank in the same time. Effluent of CW 1 and 2 was recirculated back to influent of CW 1. CW unit was first loaded with gravel as media and subsequently planted with *echinodorus palifolius*, *equisetum hyemale*, *canna indica*, *heliconia* and *typha latifolia*. Plants were acclimatized for 2 weeks by recirculating fresh water continuously before introduced to wastewater gradually.

Hospital wastewater treated in this research was generated from toilet, laundry, laboratory, hospital ward, pharmacy unit which then collected in several control tanks. Hospital wastewater of 50 m³ per day was fed continuously to equalization tank before pumped into activated sludge unit.
2.2. Analytical methods
COD, ammonia, and phosphate were analyzed using spectrofotometer UV-VIS (Shimadzu) as proposed in Standard Methods. BOD was analyzed as proposed in Standard Methods. Samples were taken in equalization tank as influent and in the outlet pipe of activated sludge and constructed wetlands as effluent of each unit. All reagents used in analysis were pro analysis grade and used without any treatment.

3. Result and discussion

3.1. Performance of activated sludge unit
In this research, activated sludge was used as pretreatment before constructed wetlands, aimed to reduce organic and toxic pollutant present in hospital wastewater. Wastewater characteristics used in this research are shown in Table 1.

![Diagram of hospital wastewater treatment plant](image)

**Figure 1.** Schematic diagram of hospital wastewater treatment plant.

**Table 1.** Characteristics of wastewater.

| No | Parameter             | Unit | Content |
|----|------------------------|------|---------|
| 1  | BOD                    | mg/L | 48      |
| 2  | COD                    | mg/L | 1079    |
| 3  | TSS                    | mg/L | 30      |
| 4  | Ammonia (NH₃-N)        | mg/L | 47.71   |
| 5  | Phosphate              | mg/L | 6.7     |

Activated sludge unit was able to form stable flocs after 2 weeks’ acclimation with 100% of wastewater. After acclimation, aerobic flocs were dark brown in color with robust and compact form, indicating healthy and stable flocs. Performance of activated sludge was evaluated in terms of COD, ammonia, and phosphate removal, as main indicator parameters. As described in Figure 2, activated sludge unit showed a high performance in pollutant removal, as indicated by high COD, ammonia, and phosphate removal. This result is in accordance with another studies which reported up to 98% and 96% nitrogen and phosphorus removal [4]. High organics removal in activated sludge is highly expected as wastewater treated in this experiment was categorized as low-strength with adequate nutrients ratio.
Figure 2. (a) COD, (b) ammonia and (c) phosphate removal of activated sludge unit.
3.2. Nitrogen and phosphorus removal in constructed wetlands
Due to the strict standard of hospital wastewater discharge, the effluent of activated sludge was still not able to meet the requirement and needs to further processed. Ammonia and phosphorus content in AS effluent has to be less than 0.1 mg/L and 2 mg/L, respectively. Constructed wetlands was chosen as secondary treatment because it is simple, cheap, and highly effective in removing organics, nitrogen, and phosphorus contaminant.

After acclimation, CW was continuously fed with activated sludge effluent and able to show a high performance in contaminant removal, as described in table 2 and Fig. 3.

![Figure 3. Constructed wetland unit in hospital wastewater treatment.](image)

**Table 2. Quality of constructed wetlands effluent.**

| Parameter  | Unit | CW effluent | Limit |
|------------|------|-------------|-------|
| BOD        | mg/L | 28          | 32    | 85    |
| COD        | mg/L | 30.67       | 24.18 | 28.12 | 175   |
| NH₃-N      | mg/L | < 0.01      | < 0.01| < 0.01| 0.1   |
| PO₄-P      | mg/L | 0.5         | 0.57  | 0.46  | 2     |

Constructed wetlands unit was able to remove nitrogen and phosphorus and meet the required standard. As table 2 shows, the ammonia content was decreased to less than 0.01 mg/L, which indicates a removal efficiency of up to 98%. It possibly explained by the predominance of anaerobic conditions in the HSSFCW and resulted in higher denitrification, as also indicated by another study [10]. Nitrogen and phosphorus removal was possible by plant uptake as the main mechanism, in which N and P are main nutrients required for plant growth and can be taken in wastewater. Aside from that, recirculation applied in CW unit is also possibly another determining factor in the high performance. This result is supported by another study which reported that internal circulation showed a positive effect on pollutant removal, especially nitrogen [9]. They also mentioned that internal circulation was also helpful in improving phosphorus removal efficiency which is also in accordance with the result of this study.

4. Conclusion
Activated sludge process showed high performance in organic, nitrogen, and phosphorus removal (COD, ammonia, and phosphate up to 8.2, 0.5 and 1.467 mg/L, respectively). However, the effluent was not able to meet the discharge limit. Thus the effluent was further processed in constructed wetlands as secondary treatment. CW was also able to show a high performance in nitrogen and phosphorus removal,
in which both parameters in concern were still above the limits. Ammonia and phosphate concentration of CW effluent was less than 0.01 mg/L and 0.46 mg/L, respectively. Activated sludge was suitable as pretreatment while CW hold a role as secondary and finishing treatment. The combination of both processes shows a high performance in organic, nitrogen, and phosphorus removal with a potential to be applied in other wastewater treatment.

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