Hospital Wastewater Treatment Using Aerated Fixed Film Biofilter - Ozonation (Af2b/O3)

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ABSTRACT
In Indonesia, most hospital wastewater treatment use biological processes followed by chlorination. Biological processes are efficient in reducing organic matter but less for pollutant toxic (phenol, Pb) while chlorination is not environmentally friendly. Differently, ozonation process offers more advantages such as heavy metals oxidation (Pb), killing pathogenic microorganisms, colour and phenols removal, and being safe for the environment. The purpose of this experiment was to investigate the capability of Aerated Fixed Film Biofilter – Ozonation (Af2b/O3) reactor in reducing BOD5, fecal colt, phenol and Pb pollutants discharged from hospital wastewater. This study used AF2b/O3 reactor consisting of Aerated Fixed Film Biofilter Reactor (AF2b reactor) and Ozone Reactor (O3 Reactor). The hospital wastewater used in this experiment was taken from hospitals in Malang City, Indonesia which have characteristics of containing BOD5 as much as 240.25 mg/L, phenol 0.04 mg/L, fecal colt 2,400 MPN/100 ml, and Pb 0.025 mg/L. The microorganisms used were Mixed Bacterial Culture (MBC) obtained from the isolated bacteria in hospital wastewater. The wastewater flowed into the AF2b reactor with circulation flow and countercurrent flow in the O3 reactor. Experiment data were obtained through measuring the concentration of BOD5, fecal colt, phenol, and Pb from the isolated bacteria in hospital wastewater. The wastewater flowed into the AF2b reactor with circulation flow and countercurrent flow in the O3 reactor. Experiment data were obtained through measuring the concentration of BOD5, fecal colt, phenol, and Pb from the isolated bacteria in hospital wastewater. The wastewater flowed into the AF2b reactor with circulation flow and countercurrent flow in the O3 reactor. Experiment data were obtained through measuring the concentration of BOD5, fecal colt, phenol, and Pb from the isolated bacteria in hospital wastewater. The wastewater flowed into the AF2b reactor with circulation flow and countercurrent flow in the O3 reactor. Experiment data were obtained through measuring the concentration of BOD5, fecal colt, phenol, and Pb from the isolated bacteria in hospital wastewater. The wastewater flowed into the AF2b reactor with circulation flow and countercurrent flow in the O3 reactor. Experiment data were obtained through measuring the concentration of BOD5, fecal colt, phenol, and Pb from the isolated bacteria in hospital wastewater. The wastewater flowed into the AF2b reactor with circulation flow and countercurrent flow in the O3 reactor. Experiment data were obtained through measuring the concentration of BOD5, fecal colt, phenol, and Pb from the isolated bacteria in hospital wastewater.

INTRODUCTION
Hospital wastewater is wastewater discharged from all hospital activities, both medical and non-medical activities, including activities at surgery rooms, examination rooms, laboratories, nursery rooms, radiology rooms, kitchens, and laundry rooms [2,24,32]. Hospital wastewater contains hazardous pollutants such as pathogenic micro-organisms (bacteria, viruses), the remaining of medicine and laboratory chemicals (antibiotics, antitumor, phenol, and chlorofrom), chemicals toxic (Pb), and biodegradable organic materials such as protein, fat, and carbohydrate [2,5]. The materials pollutant that exceeds the quality standards and was mixed into an aquatic environment can cause pollution and health problems for humans being [12,24].

In Indonesia, the processing and management of hospital wastewater are very worrying, where only 36 % of hospitals have a Wastewater Treatment Plant (WWTP) and 64 % of wastewater is discharged directly into receiving water bodies or using infiltration wells [2]. Mostly, Hospital Wastewater Treatment Plant (HWWTP) uses a combination of biological - chlorination processes with the discharge often exceeding the quality standard, such as Pb, phenol, ammonia free, ortho phosphate, and chloride free [34]. Low quality of discharges on HWWTP especially toxic pollutants (Pb, phenol) can be caused by not-yet-optimal biological - chlorination
process. Besides that, the chlorination process is not environmental friendly [43]. Several biological processes have been used in HWWTP, namely the Activated Sludge Biological Contactor (ASBC) [15]. Anaerobic Aerobic Fixed Film Bioreactor (A2F2B) [36], Anaerobic - Aerobic Biofilter (A2B) (Said, 2000), and Submerged Membrane Bioreactor (SMB) [46].

In biological process, pollutants removal is affected by the temperature, pH, kinds of microorganism, time contact, the type of reactor, and the presence of inhibitors [10,29]. Tchobanoglous et al., 2003). Furthermore, several kinds of microorganisms are proven effective to reduce heavy metal compounds (toxic pollutant) contained in wastewaters [16,9,45,11,41]. The biological processes combined with ozonation process are very capable in reducing the concentration of pollutants [25]. Elimination of micro-pollutants in hospital wastewater using Membrane Bioreactor (MBR) or a combination of PAC. Ozone and UV indicates that the combination of Ozone and UV is more efficient while only MBR is less efficient to eliminate micro-pollutants [21,22]. The combination of activated sludge - ozonation process at pH 10 can reduce the concentration of COD (54.4 - 80 %), TOC (80 %), colour (80 %) and phenol (74 %) [6].

Ozone as a disinfectant in wastewater treatment is widely used by some developed countries as it provides many benefits, including: heavy metals oxidation, killing pathogenic microorganisms, colour and phenols removes, and safe for the environment [1,33]. By means of direct or indirect oxidation process, ozone is capable of oxidizing a variety of organic and inorganic materials, and kills many pathogenic microorganisms such as E. coli, Salmonella enteritis, Hepatitis A Virus [14,35]. Ozone is used after the biological stage as end treatment (coupled treatment) for extensive removal of recalcitrant compounds or within the biological stage in order to make the refractory pollutants biodegradable (integrated treatment) [7]. Some research on the ozone oxidation of phenol and its derivatives has been done. Some organic compounds such as phenol, catechol and hydro quinone can be completely oxidized using ozone and turned into CO2 and H2O [44]. (Ozonation process using rotating packed bed is especially effective for concentrated guaiacol degradation and pre-treatment of phenol wastewater [22,49].

Thus, process of toxic pollutant removal in hospital wastewater can be done through using selected microorganisms, increasing contact time in biological process and combined biological - ozonation processes. The purpose of this research was to investigate the capability of Aerated Fixed Film Biofilter - Ozonation (AF2B/O3) process in reducing BOD5, fecal coli, phenol and Pb pollutants discharged from hospital wastewater.

**MATERIALS AND METHODS**

**Materials:**

The pilot system which consists of Aerated Fixed Film Biofilter Reactor (AF2B reactor) and Ozone Reactor (O3 Reactor) was designed as given in Fig.1. The characteristic of both reactors are presented in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>AF2B Reactor:</td>
<td></td>
</tr>
<tr>
<td>- Material</td>
<td>Acrylic</td>
</tr>
<tr>
<td>- Wall thickness (mm)</td>
<td>5</td>
</tr>
<tr>
<td>- Total Volume (L)</td>
<td>20</td>
</tr>
<tr>
<td>- Effective volume (L)</td>
<td>18</td>
</tr>
<tr>
<td>O3 Reactor:</td>
<td></td>
</tr>
<tr>
<td>- Material</td>
<td>Acrylic</td>
</tr>
<tr>
<td>- Diameter (cm)</td>
<td>5</td>
</tr>
<tr>
<td>- Total Height (cm)</td>
<td>30</td>
</tr>
<tr>
<td>- Packing height (cm)</td>
<td>20</td>
</tr>
<tr>
<td>- Total surface area (m²/m³)</td>
<td>3.31</td>
</tr>
</tbody>
</table>

AF2B reactor is divided into 3 equal parts where each part contains bio-filter which is made of plastic and shaped like a Bee Nest. A diffuser is placed at the bottom of the bio-filter which is connected to a compressor that supplies air for the growth of microorganisms and for the perfection of the mixing process. pH controller is fitted on the inlet of AF2B reactor and O3 reactor while the pump is fitted on the sedimentation tank to recycle some of the sludge into each biofilter. O3 reactor is a reactor bed that is made of acrylic containing packed of reschig rings shaped ceramic while the upper part has a spray to distribute water into the reactor. Feed water and ozone flow rate are set by using the valve fitted on the feed water and ozone generator inlet. The characteristic of biofilter is material (plastic), density (0.125 g/cm³), volume (2,160 cm³), specific surface area (150 - 240 m²/m³), and number (3).

Wastewater was taken from hospitals in Malang City which had characteristics as follow: Temperature: 30 C, pH: 8, BOD5: 240.25 mg/L, phenol: 0.04 mg/L, fecal coli: 2,400 MPN/100 ml, Pb: 0.025 mg/L. The microorganisms used were Mixed Bacterial Culture (MBC) obtained from the isolated bacteria in hospital.
wastewater. MBC consists of several types of bacteria, such as: *Pseudomonas capica, Pseudomonas diminuta, Bacillus sp1, Bacillus sp2*. Isolate of MBC was grown through the acclimatization process by dissolving it in distilled water and added nutrients and hospital wastewater gradually so that MBC could reach its maximum growth.

**Methods:**

Wastewater was flowed into the AF2B reactor using a pump (Type: Voss SN 3500). Influent flow rate of wastewater was set by using a flow meter of 0.1 L/min and Hydraulic Residence Time (HRT) of AF2B reactor was maintained constant for 3 hours. Wastewater flowed from the top of the bio-filter towards the bottom, then, moved circulation in every part of bio-filter and flowed to the sedimentation tank where the deposits were formed and partly recycled while the overflow flowed into tank, moving from the pump into the O3 reactor. Each bio-filter contained MBC derived from the results of the acclimatization process that had been adapted to the hospital wastewater. Wastewater was flowed out of the AF2B reactor to the top of the O3 reactor using pump, where flow rate was set by a valve of 0.2 L/min so that HRT of O3 reactor was maintained at 1 minute. Furthermore, the wastewater was sprayed from the top of the O3 reactor and contacted with ozone by countercurrent flow. Ozone was produced from ozone generator (Type: Resun 25) where ozone flow rate was set at 0.25 g/h. Sampling was done at every 2 hours for 120 hours at the outlet AF2B reactor and every 5 minutes for 60 minutes on the outlet O3 reactor.

**Analysis Method:**

BOD5, phenols, fecal coli and Pb were measured periodically while pH and temperature were controlled every time. Pb was measured using Atomic Absorption Spectrophotometry (AAS) (Type: Perkin-Elmer AA900), fecal coli was measured using the Most Probable Number (MPN) method, phenol was measured using a UV-Vis (Type: Hitachi-U900), BOD5 was measured using the modified Winkler method, and Mixed Liquor Suspended Solid (MLSS) was measured using a Gravimetric method (APHA, 1998).

**RESULTS AND DISCUSSION**

**AF2B Reactor:**

This research used real hospital wastewater as feed. Hospital wastewater contained pollutants in different concentrations, and AF2B/O3 reactor’s performance was measured based on the initial concentration of pollutants in the feed.

The results of acclimatization and adaptation MBC in hospital wastewater media showed that MLSS concentration increased continuously until 1,500 m/L. These conditions indicated that the MBC had grown and adapted to fit well with its surroundings and was ready for use in the biodegradation of pollutants. The pollutants concentration (BOD5, fecal coli, phenol, Pb) in the effluent AF2B reactor was measured at each period (Fig.2).
The concentration of BOD5 and fecal coli decreased at the first 4 hours and reached a maximum decrease at 96 hours with the percentage of pollutant removal of 91% (Fig. 2). The largest decrease of the concentration of pollutants occurred in the period of 2 - 96 hours when BOD5, fecal coli, phenol, Pb were 74.01%, 67.6%, 62%, 60%, respectively.

This happened because at the first 4 hours, microorganisms (MCB) were still adapting to the environment so the growth of MCB was not maximized, and it was indicated on the little slime formed on the surface of the bio-filter.

At time of 4 - 12 hours, the MCB began to adapt so the growth of MCB and the biodegradation process began to take place, and it was shown by the increased thickness of the slime on the surface of the biofilter. Biofilm formation in a submerged biofilter takes place in five stages: initial attachment, irreversible attachment, maturation 1, maturation 2 and dispersion [18].

AF2B reactor is composed of several biofilter shaped like a Bee Nest that has a large specific surface area (150 - 240 m2/m3) where microorganisms grow and are in contact with wastewater [38]. At the time of 12 - 96 hours, MCB growth is increasing, in line with the increasing consumption of substrate (pollutant) by MCB which causes all surface of biofilter covered by the MCB to increase the speed of biodegradation process. On the other hand, by making the flow circulation in the reactor, supplies of air uniformly and continuously will increase the contact time in the Biofilter, causing biodegradation processes of pollutants going on rapidly [10,47,38].

![Graph](image_url)
At time 96 - 120 hours, stationary phase was reached where the rate of growth was proportional with rate of death of MCB in the biofilter so that the biodegradation of pollutants in stayed in steady state. These conditions reduced BOD5 and fecal coli up to 91.59 % and 85.42 %, respectively.

In the aerobic biological process, biodegradation rate of organic material and phenol by microorganisms were affected by the temperature, initial concentration, pH, type of microorganism, HRT, the type of reactor and the presence of inhibitors [10,29,30,42].

The ASBC process was able to decrease the concentration of COD and coliform up to 87.8 % and 99.98 %, respectively [15]. A2F2B process can reduce the concentration of pollutants in the hospital wastewater, namely BOD5, COD and coliform up to 89 %, 82 %, and 90 %, respectively [36]. Submerged Membrane Bioreactor (SMB) can reduce the BOD5 (47.7 - 70 %) and coliform (50 - 75 %) [46]. The combination of the Up flow Anaerobic Fixed Bed (UAF-B), Suspended Aerobic Reactor (SAR) with the Membrane (Micro Filtration, MF) can reduce the concentration of COD (94 - 98%) [20].

Phenol and Pb concentrations began to reduce at 12 hours and reached a maximum decrease at 96 hours with the removal percentage up to 62 % (Fig. 2). The biggest decrease of phenol and Pb occurred in a period of 24 - 84 hours which were 55 % and 52 %, respectively. Then they reached steady state at 96 hours with the percentage of pollutants phenol and Pb were 62.5 % and 60 %, respectively. Phenols are aromatic organic compounds and Pb are the toxic substance (inhibitor) for microorganisms, making the biodegradation of phenol and Pb by microorganisms slower than that of BOD5 and fecal coli in the AF2B reactor.

Phenol biodegradation by microorganisms is influenced by the shape of phenol compound, HRT, initial concentration and form of the enzyme [30]. The Biodegradation of phenol by mixed cultures is more efficient than that by pure cultures with biodegradation of phenol produce simple compounds such as carboxylic acids, CO2 [37]. This experiment used mixed cultures (MCB) so that biodegradation of phenol was faster than the other, and biodegradation period of HTR was 3 hours. This made biodegradation time of 120 hours could reduce phenol by 62.5 %. MCB consists of Pseudomonas capica and Bacillus sp1 that has the ability to degrade organic compound such as phenols and lead in aerobic / anaerobic [45]. Sridevi et al., 2012). UASB reactor with HRT of 40 days was able to reduce phenol by 80 % while SBR reactor with HRT of 30 days was able to reduce phenol by 95 % [13].

Furthermore, Bioremoval of Pb by microorganisms in the AF2B reactor had the same pattern with phenol biodegradation, where biodegradation was running slow and low. Increasing initial concentration of Pb may cause a decrease in the removal of BOD5. However, BOD5 removal re-increased by microorganisms acclimation to changes [31].

At time 36 - 96 hours, the largest removal of Pb was 40%, and it was followed with the achievement of steady state. Bioremoval of Pb is affected by initial concentration of Pb and the number of microorganisms at pH 7 – 8 while aeration time at 48 hour and the initial concentration of Pb (30 mg/L) can reduce Pb concentration by 93.3 % [8]. This experiment was with HRT 3 hours, pH 8, biodegradation time at 120 hours and initial concentration of Pb (0.01 mg/L) had decreased the removal of Pb (60%). Thus, AF2B was not really able to reduce toxic pollutants (Pb). The AF2B reactor was able to reduce of BOD5, fecal coli, phenol and Pb, with the biggest pollutant removal capability at 96 hours when it could reduce BOD5, fecal coli, phenol, and Pb up to 91.59 %, 85.42 %, 62.5 %, and 60 %, respectively (Fig.2). This means that AF2B reactor began operating optimally at 96 hours.

**O3 Reactor:**

Furthermore, AF2B reactor effluent flowed into the O3 reactor at the flow rate of 0.2 L/min and flowing in the countercurrent flow with the flow of ozone and then in the influent - effluent of O3 reactor was measured pollutant concentration order to obtain data as Fig. 3.

At pH 8 and ozone dose of 0.25 g/min, all pollutant concentrations decreased in the first 10 minutes and reached a maximum reduction after 40 minutes for BOD5, fecal coli, phenol and Pb which were reduced up to 77.58 %, 94.82 %, 100 %, and 100 %, respectively (Fig. 3).

Ozone reacts with aqueous compounds in two ways: direct reactions of the molecular ozone with the compounds and indirect reactions of the radicals resulted from the decomposition of ozone with the compounds [27].

Ozonation process in water and wastewater treatment systems has been shown to be a process that is limited by mass transfer which is influenced by hydrodynamic and physicochemical effects.
Hydrodynamic effects are concerned with the movement of the molecules. If intense mixing is applied to a liquid containing gas bubbles, the bubbles are sheared and mixed thoroughly, increasing both the interfacial area and contact time, and reaching therefore higher mass transfer rates. Some types of reactors used to improve mass transfer, among others are fixed packed bed, rotating packed bed, bubble column and bubble diffuser reactor. The percentage removal of organic matters was higher in the bubble column as compared to the bubble diffuser because dissolved ozone concentration of bubble column reactor was higher compared to the bubble diffuser [28].

Physicochemical effects include decomposition reactions of ozone, temperature, pressure and chemical composition of the liquid [27]. While in this experiment more emphasis was given to the influence of hydrodynamics in making smaller movement of the molecules in fluid (wastewater) and creating an effective contact with the gas (ozone) by using a packing shaped reschig rings so that the flowing fluid formed a thin layer which could increase the mass transfer of ozone into the fluid. The most effective way to increase contact time is to increase the interfacial area available for mass transfer by decreasing the size of the ozone gas bubbles that are dispersed in solution [23,26].

Fig. 3 shows that in the first 10 minutes, wastewater with ozone did not create a perfect contact, that was when wastewater did not fill all packing surface in the reactor so that the pollutants oxidation process by ozone was low. With the increasing volume of waste water that filled the packing surface during 15 - 40 minutes, the mass transfer between the gas (ozone) to fluid (wastewater) on the packing surface became larger so that the ozonation reaction went on rapidly and reached a steady state at 40 minutes. Ozone oxidation is influenced by several factors, such as pH and contact time which increase in pH and contact time will be able to increase the pollutants removal [23]. Longer contact time will enhance the oxidation reaction, making a larger pollutant removal occurs [3]. [28]. The increasing Ozonation time will enhance the colour and COD removal with the
ozone dose of 125 mg and ozonation time for 25 minutes can reduce the colour concentration up to 51.3 % and COD by 67 % [48].

The ozone oxidation of phenol and Pb was faster than fecal coli and BOD (Fig. 3). This was caused by the adequate supply of electrons from the hydroxyl group of phenol [17]. Ozone as a disinfectant is highly effective in killing bacteria (fecal coli) and heavy metals oxidize [14,33,35]. Ozone is highly soluble in water and reacts to form hydroxyl (OH) that functions as a strong oxidizer, with the oxidation takes place rapidly in the first 10 minutes [33,35].

The process of ozonation for 60 minutes could reduce phenol concentration up to 48.5 % (pH 8.3) and 74 % (pH 10). This was because the increase in pH that made deprotonating phenol (pKa = 10) occur and the rate constant of ozone increase by 6 times [39]. This experiment was with pH 8 and time contact for 40 minutes, and it could reduce BOD5, fecal coli, phenol and Pb up to 77.58 %, 94.82 %, 100 %, and 100 %, respectively. Thus, O3 reactor that contains reschig rings shaped packing and flow countercurrent revealed to have a good performance to remove organic pollutant (BOD5), fecal coli, phenol and Pb in hospital wastewater.

**AF2B/O3 Reactor:**

AF2B/O3 reactor as a combination of AF2B reactor and O3 reactor so AF2B/O3 reactor capability can be seen from the combined capabilities of both.

Table 3 shows that the total removal of AF2B/O3 reactor at pH 8, HRT of AF2B reactor: 3 hour, HRT of O3 reactor: 1 minute of BOD5, fecal coli, phenol, Pb were 97.92 %, 99.23 %, 100 %, 100 %, respectively. AF2B reactor was very capable in removal of organic matter (BOD5) of 91.59 % while the O3 reactor very capable to remove fecal coli, phenol, and Pb up to 94.8 %, 100 %, and 100 %, respectively. However, it does not mean that reducing the concentration of fecal coli, phenol, and Pb did not require biological processes or reducing the concentration of BOD5 did not require ozonation process. It was revealed in these experiments that the AF2B reactor and the O3 reactor both were of one integral system whose characteristics were affected by initial concentration of pollutant and wastewater characteristics.

**Table 3: Total removal of pollutants in AF2B/O3 reactor.**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Quality Standard</th>
<th>AF2B Reactor</th>
<th>O3 Reactor</th>
<th>% Total Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD5 (mg/L)</td>
<td>30</td>
<td>240.25</td>
<td>20.2</td>
<td>91.59</td>
</tr>
<tr>
<td>Fecal coli (MPN/100 ml)</td>
<td>4000</td>
<td>2,400</td>
<td>350</td>
<td>85.42</td>
</tr>
<tr>
<td>Phenol (mg/L)</td>
<td>0.01</td>
<td>0.04</td>
<td>0.015</td>
<td>62.5</td>
</tr>
<tr>
<td>Pb (mg/L)</td>
<td>0.01</td>
<td>0.025</td>
<td>0.01</td>
<td>60</td>
</tr>
</tbody>
</table>

Table 3 shows that the AF2B reactor was able to reduce pollutants concentration to quality standard. However, anticipation and tolerance for fluctuations in pollutant load necessitated the need of ozonation process (O3 reactor) to remove phenol and Pb that often exceeded the quality standard. In this way, the AF2B process could remove most of the pollutants. While the ozonation process supported the AF2B as an additional method to improve the pollutant removal for hospital wastewater, penetration condition was charged.

**Conclusions:**

It can be concluded that The Aerated Fixed Film Biofilter - Ozonation (AF2B/O3) process has a large capability of pollutants removal in hospital wastewater such as BOD5, fecal coli, phenol, and Pb up to 97.92 %, 99.23 %, 100 %, and 100 %, respectively.

**REFERENCES**


