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# Potential Treatment System for Ammonia in Leachate, A Case Study for Jatibarang Landfill, Central Java

**Badrus Zaman[1,]*, Purwanto[1], Sarwoko Mangkoedihardjo[2]**

[1]Doctoral Programme of Environmental Science, Diponegoro University, Jl. Imam Bardjo, Pleburan, Semarang, 50241.
[2]Department of Environmental Engineering, Sepuluh Nopember Institute of Technology (ITS), Campus ITS Sukolilo, Surabaya, 60111.
(**INDONESIA**)

## ABSTRACT

This paper reviewed potential treatment system for ammonia under the organically toxic conditions that meet leachate quality at Jatibarang landfill. Various research results were selected using criteria that covered biological process, process parameters, design and operation, affordable and sustainable. Analysis was directed on the basis of leachate toxicity, aiming to establish the ammonia treatment system configuration. It revealed that the potential treatment system would be a combination of heterotrophic denitrification and evapotranspiration process. The sequence processes of the system would be operated alternately, which depended on the quality of leachate.

**Keywords**: Ammonia, Anaerobic, Evapotranspiration, Landfill, Leachate

.

## INTRODUCTION

Jatibarang landfill is located at $7^0 01' 19.13''$–$7^0 01' 35.71''$ E and $110^0 21' 21.24''$–$110^0 21' 46.29''$ S. The landfill was built in 1992 for final processing solid waste from the city of Semarang, Central Java. The total area was rounded to 460,183 $m^2$, where divided into waste disposal and operational infrastructure, each of which was 60% and 40% [1]. The waste disposal area received solid waste with an amount of about 2,368 $m^3d^{-1}$ [2] in which the portion of non-biodegradable and biodegradable waste were about 39% and 61% respectively. The highest portion contributed leachate production, which was treated in leachate treatment plant (LTP) with the operational capacity of 250 $m^3d^{-1}$. The LTP consisted of an anaerobic lagoon, aeration pond and sedimentation pond that were built in the area of operational infrastructure. Observation showed that leachate produced all the year with the maximum flow of 327 $m^3d^{-1}$ in rainy season [3]. It was noted that leachate and solid waste ratio at maximum flow condition was 0.14, which was comparable to Benowo landfill, Surabaya under similar environmental conditions [4]. Hence, the LTP could not treat all leachate and consequently an excess of 77 $m^3d^{-1}$ disposed to surrounding open water bodies such as natural ponds and rivers [5,6].

The effluent of LTP contained BOD, COD, TSS and colour [3] as well as some heavy metals (Al, Cd, Fe, Zn, Ni, Cu, Pb, Co, Ag, Mn, Hg) in water bodies [7] that exceeded acceptable levels [8]. Thus, the existing treatment system of LTP did not work properly. Since the system was microbial process, the failure process might be due to the presence of toxic materials in untreated leachate. Preliminary observation recorded the average loads of ammonia and COD during rainy season were 79 kg-N.$d^{-1}$ and 222 kg-COD.$d^{-1}$ respectively. The results were comparable to untreated leachate at Benowo landfill, Surabaya, under the similar environmental conditions [9]. Thus, the untreated leachate at Jatibarang contained inorganic substances in particular the largest one was ammonia, and non-biodegradable organic compounds. The facts suggested that the quality of the untreated leachate was toxic towards microbial processes and the existing treatment system was not suitable.

Therefore, the preliminary research was to review potential treatment system for solving the main problem on ammonia treatment under the organically toxic conditions. This review was intended to design an empirical study of the leachate treatment at Jatibarang landfill, aiming to develop a novel treatment system that suit to local conditions.

## MATERIALS AND METHODS

Potential treatment system for ammonia under the organically toxic conditions was found out by selecting references from various research results. Selection criteria were integrated biological system, capable to treat all quality paramaters with high range loading, high process efficiency, simple design, easy to operate, affordable and sustainable. Analysis was directed on the basis of leachate toxicity, aiming to establish the ammonia treatment system configuration.

***Corresponding Author:** Badrus Zaman, Doctoral Programme of Environmental Science, Diponegoro University, Jl. Imam Bardjo, Pleburan, Semarang, 50241. Email: badrus_z@yahoo.com

The treatment system configuration preceded by the study of leachate toxicity towards biological life to ensure the process runs well and sustainable. The biological life consisted of microbes and plants that would be examined for ammonia treatment. In the formulated treatment system was anaerobic process and evapotranspiration process. When the ratio of BOD/COD was non-toxic to heterotrophic denitrifier, then the potential treatment system is an anaerobic-evapotranspiration system (AES). In contrast, under the ratio of BOD/COD was toxic to heterotrophic denitrifier, the potential treatment system is an evapotranspiration-anaerobic system (EAS). In practice there may be two possible uses of these systems in turn.

## RESULTS AND DISCUSSION

### Leachate toxicity

Leachate contained various compounds such as organic matter, ammonia-nitrogen, heavy metals, chlorinated organic compounds and other inorganic salts [10]. The contents were undergoing various chemical and biochemical reactions and transformed into toxicants that were more toxic than individual substance. Open exposure of leachate could pollute soil, groundwater and surface water, resulted in adverse effect towards biotic species. The toxicants could accumulate in the biotic species and passed to higher consumers through food chain mechanism, causing bioamagnification over long-term exposure [6,11,12,13]. In short-term, the toxicants also affected organisms in environment, including microorganism and plants. Those were confirmed with many studies on leachate toxicity such as for aquatic species, plants and bacteria [14,15,16,17,18].

Effects of untreated and treated leachate towards *Vibrio fisher* had been assessed by means of microtox assay [19]. The results showed that the toxic levels of both leachate were characterized by spesies sensitivity, organic and inorganic leachate matrix, high concentration ammonia in leachate. Unionized ammonia concentration was strongly correlated with mortality of the test organism however the degree of DNA damage was weakly related to physicochemical parameters [20]. In addition, leachate toxicity due to simple matrix organic matter was apparently less toxic to the test organisms. Researchers reported that ammonia was responsible for the leachate toxicity [21]. Leachate toxicity significantly correlated with COD and ammonia in untreated and treated leachate [17]. Ammonia concentration of more than 10 $mgNL^{-1}$ was toxic to sensitive microorganism and probably it was a reducing agent with a long-term persistence [22] that caused possible inhibition of microorganism activity [23].

Leachate toxicity towards plant was assessed by Bialowiec *et al*. [24] using young willow plant (*Salix amygdalina* L.). The results suggested an ability of willow plant to tolerate high strength of landfill leachate in limited conditions such as plant growth phase, method of cultivation, and leachate dilution. Marchand *et al*. [25] reported the adverse effect of leachate on growth of duckweed (*Lemna minor L*.). It was suggested that the determining factors of leachate toxicity to plants were age of plant, toxicant concentration in leachate, toxicant concentration in cultivated soil. Žaltauskaitė,J. and Čypaitė [26] demonstrated that higher plants can be effectively used for the toxicity assessment of landfill leachate. It was observed that each plant species has different tolerance levels to the different contaminants and young plant was more sensitive to leachate toxicant than old plant. An adverse effect of leachate towards plant was influenced by toxicant species and its concentration. However, different response in tested organisms made difficult in interpretation, since toxicity depended on leachate characteristics and could be changed by treatment level [19]. It was demonstrated that plant treatment could reduce bio-toxicity of leachate to non-mortality level and non-damage of DNA that was similar to non-exposed plant [20].

Chemical analyses and risk evaluation suggested that ammonia plays an important role in leachate toxicity [27]. The adverse effect of ammonia in leachate toxicity had been mentioned by several authors [17,28,29]. In addition, ammonia in leachate could cause various types of injury to plants including necrosis, growth reduction, growth stimulation and increased frost sensitivity [30,31,32]. However, ammonia also caused the availability of carbohydrates, where plant can detoxify ammonia as long as it can convert ammonia into amino acids [33].

### Microbial process of ammonia

Based on the determining factor of substance in leachate toxicity as mentioned above, it was no doubt that ammonia has to be removed from leachate. Ammonia can be removed by biological methods as an effective conventional treatment but inexpensive [34]. Some researcher used anaerobic system as biological denitrification process to transform ammonia into nitrate using various reactors design [35,36,37,38,39]. Subsequently, biological denitrification was performed to reduce nitrate into nitrogen gas by facultative heterotrophic organisms that require carbon as a source of food. A sufficient carbon/nitrogen (C/N) ratio at least 2:1 was necessary to complete denitrification reaction in natural systems [40].

Anaerobic system in the first stage commonly has a function to lighten aerobic system in the second stage, where ammonia was removed. Some researcher revealed that the limiting factors for an aerobic process were bacteria presence, oxygen concentration, electron acceptor, chemical concentration as carbon sources, and detention time. Anaerobic process as denitrification process was performed by various chemoorganotrophic, lithoautotrophic and phototrophic bacteria and some fungi [41].

Denitrifying bacteria were most effective in the absence of oxygen where active denitrifiers presented in the range 6.0 x $10^6$ to 92.0 x $10^6$ MPN/100 ml and an average value of 30.0 x $10^6$ MPN/100 ml. Moreover, specific amount of organic carbon was needed to perform the denitrification [36]. The extent of organic matter degradation under anaerobic conditions depends on the availability of a terminal electron acceptor, i.e. nitrate for denitrifying bacteria, $CO_2$ for methanogenic bacteria [38]. No denitrication took place without addition of external carbon source and since methanol was added, the denitrification process started and nitrate reduction increase immediately. A complete denitrification was achieved when methanol/nitrite ratio was in the level of 3/1 [42]. In anaerobic baffle reactor under nitrate-free conditions showed that ammonium would be produced from the proteolysis of the proteinaceous materials. Subsequently, bacteria would assimilate the ammonia in order to synthesise vital amino acids. Nevertheless, when nitrate was added to the reactor, ammonium might be formed via dissimilatory reduction [35]. Heterotrophic denitrification process in sand bed reactor revealed the detention time in the reactor and phosphorus concentration were the limiting factors. The maximum detention time was 1 hour and the phosphorus concentrations were 0.4-0.6 mg P $L^{-1}$ [43].

**Evapotranspiration process of ammonia**

Ammonia removal using natural process such as evapotranspiration bed was potential to be applied in the leachate treatment facilities. By evapotranspiration bed the net water loss would be caused by the evaporation of moisture from the soil surface and transpiration by vegetation. For continuous evaporation, three conditions must be met. First, there is a latent heat requirement of approximately 590 cal/g of water evaporated at 15 $^0$C. Second, a vapor pressure gradient is needed between the evaporative surface and the atmosphere to remove vapor by diffusion, convection, or a combination of the two. Third, there must be a continuous supply of water to the evaporative surface [44]. The presence of plants in the bed resulted in higher water loss from the bed due to transpiration. Therefore, evapotranspiration bed has an advantage to split the water movement into multiple media in addition to the capability of being waste treatment reactor.

In vegetated landfill cover showed there was additional removal of excess leachate volume and chemicals from the system [45]. Phytoremediation in engineered wetland has been successfully tested in many locations worldwide and the success were applied in wetlands, grass lands, crops, and tree plantations. The rate of biodegradation and mineralisation during phytoremediation was affected by the nature and concentrations of contaminants as well as surrounding soil/air moisture, pH, temperature, soil elemental contents and their bioavailability, and the supporting microbial media. Ammonia was suggested to be low concentration that was not acutely phytotoxic [46].

However, some researchers found that ammonia was not acutely phytotoxic at high concentration. Willow plants apllication did not react negatively, despite very high annual loads of nitrogen ($\leq$ 2160 kg N $ha^{-1}$), chloride ($\leq$ 8600 kg Cl $ha^{-1}$) and other elements. Treatment efficiency varied considerably for different elements, but was adequate when moderate loads were applied [47]. Landfill leachate positively affected growth of *Salix* and *Populus* and increased biomass production due to the fertilization properties of wastewater with up to 2144 kg N $ha^{-1}$, 144 kg P $ha^{-1}$, 709 kg K $ha^{-1}$, 1010 kg Cl $ha^{-1}$, and 1678 kg Na $ha^{-1}$ average mass load in the experiment [48]. Vetiver grass was applied in the landfill and used leachate as water source and nutrient showed excellent establishment [49]. Moreover, flow rate and recirculation ratio should be taken into account for proper design of evapotranspiration reactor [50]. Another plant species *C. haspan* was reliable to be applied in treating leachate with sub-surface flow in constructed wetland and efficient in removing of some parameters in leachate. Sand and gravel as media were suitable for plant growth [51]. There was *Populus* used in laboratory scale and field scale that resulted in good growth and genotip respond when irrigated and fertilized with landfill leachate [52,53]. Other plant species *Typha angustifolia* L. and *Cyperus minvolucratus* were used for treating high-strength of inorganic and organic compounds (*ca*.300 $mgL^{-1}$ of COD and *ca*. 300 $mgL^{-1}$ total-nitrogen) under tropical condition. The system showed the number of *Nitrosomonas* was two to three orders of magnitude higher in the planted systems compared to the unplanted systems [54] .

**Potential treatment of ammonia contained leachate**

It was identified the untreated leachate at Jatibarang landfill contained predominantly ammonia and non-biodegradable organic compounds. In addition, the existing leachate treatment plant (LTP) failed to remove ammonia as well as organic matter significantly. The facts directed to find out a novel treatment system, consisting of microbial and evapotranspiration processes in combination.

In practice, there was a fluctuation of chemical concentrations and therefore two systems alternately are considered with the following limiting conditions. First, anaerobic-evapotranspiration system (AES) will be performed when the level of organic matter is not toxic towards heterotrophic denitrifier. In anaerobic reactor, nitrate will be transformed into nitrogen gas, which is collected and/or absorbed by plants in evapotranspiration bed. Ammonia will pass through anaerobic reactor and flow into evapotranspiration bed where plants absorb the ammonia. In addition, the evapotranspiration bed provides air, which oxidized ammonia into nitrate under heterotrophic conditions. The nitrate has to be recirculated into anaerobic reactor in order to complete the whole ammonia processes.

Second, evapotranspiration-anaerobic system (EAS) will be performed when the level of organic matter is toxic towards heterotrophic denitrifier. In evapotranspiration bed, the toxic organic matter will be attenuated into non-toxic one by means of dilution by plant exudates that supports heterotrophic denitrifier. In addition, ammonia can be absorbed by plants as their major nutrient. The remaining ammonia will be oxidized into nitrate, which partly can also be absorbed by plants. The remaining nitrate in leachate has to be recirculated into anaerobic reactor where denitrification process takes place. The final nitrogen gas can be absorbed by plants or collected for safety.

## CONCLUSION

Leachate toxicity was chemically determined by ammonia content and non-biodegradable organic matter. Individual process of chemical substances could be treated successfully but combination processes, involving microbial and evapotranspiration processes would be promising. Particularly, anaerobic and evapotranspiration systems in combination would solve Jatibarang landfill leachate, which was rich in both chemical compounds.

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