Landfill Leachate Management in Indonesia: A Review

N Emalya¹, E Munawar², W Rinaldi² and Y Yunardi²,³*
¹ Postgraduate Program in Chemical Engineering, Syiah Kuala University, Banda Aceh, Indonesia
² Department of Chemical Engineering, Syiah Kuala University, Banda Aceh 23111, Indonesia

E-mail: yunardi@unsyiah.ac.id

Abstract. Municipal solid waste has become a major environmental issue in Indonesia, due to the increase of population and quantity of waste, leachate production, lack of management and lack of public awareness. Landfill leachate generation and its treatment have been one of the main focus in the landfill management. Normally, leachate is formed through the seepage of water by external sources such as drainage, rain water and so on through the garbage in the landfill. Leachate contains suspended and dissolved solid pollutants, chemicals both organic and inorganic with high concentrations such as ammonia, nitrates, nitrites, sulfides, heavy metals, nitrogen and others. With such high concentration of pollutants, leachate is highly potential to pollute the groundwater and the environment. This paper presents an overview of landfill leachate management in Indonesia, discussing the characteristics of the leachate from different landfills throughout the country on the basis of the reported literatures, current practice of landfill leachate treatment in the country, and technological development of leachate treatment for possible implementation in the future.

1. Introduction
With the increase of population, the changes in consumption patterns and the amount of waste, domestic solid waste in urban area has become one of the main environmental problems in Indonesia. Most of domestic solid wastes will end up at landfills, either managed or unmanaged ones. Wastes in landfills consists of not only solid but also liquid. Liquid waste so-called leachate contains organic and inorganic compounds and some pathogenic bacteria. Leachate is produced when external moisture or water enters the landfill and in contact with the solid waste producing concentrated liquid waste. The quality and quantity of leachate varies greatly, affected by the amount of rainfall, composition, characteristics of waste, landfill age and the operation of the landfill [1]. One important issues of landfilling operation is the treatment of leachate continuously produced with different volumes and compositions depending on the season [2].

Leachate may contains suspended and dissolved solid pollutants, chemicals both organic and inorganic with high concentrations such as ammonia, nitrates, nitrites, sulfides, heavy metals, nitrogen, and others. If it is not managed properly, it could potentially pollute the environment and water bodies [3]. The contamination level at the water bodies caused by leachate discharge depends on the type and

* To whom any correspondence should be addressed.
characteristics of the leachate as well as its impacts in the short and long term [4]. Therefore, leachate management in every landfill becomes crucial to ensure that there will be no contamination to the environment coming from the discharge of untreated leachate.

Leachate management, including its treatment, is not an easy task, since it greatly varies not only in terms of quantity (volume) but also in composition, characteristics and quality [5, 6]. The Government of Indonesia, particularly the regional governments at the provincial and district levels that are responsible for the solid waste management, has not yet put priority on the leachate management. It has been well known that leachate infiltration into the soil could pollute not only the soil, but also contaminate ground water and surface water. Most of landfills in Indonesia currently do not have sufficient landfill leachate treatment facilities, due to many reasons. In case there is landfill leachate treatment facility, the operation of the facility is not run properly, because in many cases the treatment facility is not more than temporary storage tanks. Consequently, in majority the quality of leachate discharged to the water body still exceeds allowable limit set up by the national regulation.

This paper presents an overview of landfill leachate management and also discusses the characteristics of leachate from various landfills in Indonesia based on the reported literature. In addition, current practice of landfill leachate treatment in Indonesia is also presented, followed by issue of possible and available landfill leachate treatment technology that might be implemented in the future.

2. Landfill Leachate Regulations and Characteristics

The Government of Indonesia (GOI) has set up a regulation regarding the solid waste management, including landfill leachate management, through Act No. 18/2008. The Act stated that every city or district must have an appropriate landfill that meet the technical and environmental requirements at the latest by 2013 [7]. However, until 2019 there are still many landfills in Indonesia that are operated as an open dumping and do not meet environmental principles. With the open dumping system, it would be impossible to expect that the landfill will have a leachate management system. Consequently, leachate will infiltrate to the soil and ground water without any prior treatment.

Since Indonesia is a tropical country having a rainy season for about six months, between October until March, leachate will be produced from a landfill at higher quantity during this period [8, 9]. Even though the dry season is expected to occur during the mentioned period, in different parts of Indonesia rainy season may occur in different months outside of the mentioned period. In addition, average humidity in Indonesia is quite high even in the dry season. Consequently, leachate from a landfill will be produced throughout the year. In relation to its regulation in the country, the Government of Indonesia issued Ministry of Environment and Forestry Regulation No. P59 2016. According to this regulation, each landfill site has to implement leachate management, stating among others: ensuring the leachate is processed in such a way that it meet the standard quality for discharging to the water body, applying the liners to ensure the leachate will not infiltrate to the environment, and periodically evaluating the quality of the leachate discharged to the water body, at least once a month [10]. Unfortunately, still many landfills are unable to fulfill all requirements set up by the regulation. The main reason is that the solid waste management in a region is under the responsibility of the regency or municipality. Regency or municipality intention to sort out this problem depends on the budget priority, as this issue is not included in high priority. Therefore, leachate produced from the landfill might directly flow to the environment without any prior treatment.

| Parameter | Highest Level |
|-----------|--------------|
|           | Value | Unit |
| pH        | 6-9 | -    |
| BOD       | 150 | mg/L |
| COD       | 300 | mg/L |
| TSS       | 100 | mg/L |
| N total   | 60  | mg/L |
| Mercury   | 0.005| mg/L |
Cadmium 0.1 mg/L

Table 1 presented the quality standard of leachate that allowable to be discharged to the water body in accordance to the regulation of the Government of Indonesia. Through a survey from a number of literatures, the characteristics of leachates produced from various parts of Indonesia, as depicted in Table 2, are generally high in BOD and COD. Although the pH of the leachates is in the range of allowable standard, the BOD and COD are mostly above the highest recommended levels. It is clear that those leachates have to be treated prior to discharging to the water body.

**Table 2.** Leachate quality data from several landfill Indonesia

| Landfill, District/City/Region | pH  | BOD (mg/L) | COD (mg/L) | References |
|--------------------------------|-----|------------|------------|------------|
| Pekanbaru city landfill       | 7.6 | 532.85     | 3750       | [11]       |
| Air dingin landfill, Padang   | 7.7 | 152.2      | 304.3      | [12]       |
| Jatibarang landfill, Semarang | 8.5 | 1600       | 4000       | [6]        |
| Supit urang landfill, Malang   | ** | 88.18      | 298.67     | [8]        |
| Tidal landfill, Banjarmasin    | 7.98| 432        | 6518       | [13]       |
| Blondo landfill, Semarang      | 8.4 | **         | 1781.4     | [14]       |
| Benowo landfill, Surabaya      | 7.9 | **         | 5044       | [15]       |
| Cipayung landfill, Depok      | 7.83| 3959.6     | 6860       | [16]       |
| Sukawinatan landfill, Palembang| 7.45| 145.7      | 291.1      | [17]       |
| Kali ori landfill, Purwokerto  | ** | 300        | 670        | [18]       |
| Talang gulo landfill, Jambi    | ** | 734        | 2800       | [19]       |
| Antang tamangapa landfill, Makassar | ** | 729     | 1277       | [20]       |
| Klotok landfill, Kediri       | 7.89| 258.8      | 143.5      | [21]       |
| Regional Bangli landfill, Bali| ** | 94.55      | 317.44     | [22]       |

**References**

| Quality standard | 6-9 | 150 | 300 |

**Table 3.** Characteristics of landfill leachate [8]

| Type of leachate | Young | Intermediate | Stabilised |
|------------------|-------|--------------|------------|
| Age of landfill (year) | <2 | 2-10 | >10 |
| pH               | <6.5 | 6.5 – 7.5 | >7.5 |
| BOD/COD          | 0.5-1.0 | 0.1-0.5 | <0.1 |
| COD (mg/L)       | >15000 | 3000-15000 | <3000 |
| NH3-N (mg/L)     | <400 | NA | >400 |
| TOC/COD          | <0.3 | 0.3-0.5 | >0.5 |
| Kjeldahl nitrogen (mg/L) | 100-2000 | NA | NA |
| Heavy metal (mg/L) | >2 | <2 | <2 |

**NA = Not Available**

The characteristics of leachate generated from a landfill influenced by many factors, including type of solid wastes dumped in the landfill, degree of compaction in the landfill, climatic and hydrogeological condition of the landfill site, pH, age of the landfill, and chemical and biological processes occur during the degradation. Table 3 presented the characteristics of the leachate on the basis of the landfill age. Variations of leachate quality are clearly seen at different stages of landfill operation. At young age, say less than five years, leachate contain high contains high biodegradable organic matter, as indicated by high ratio of BOD/COD. The ratio of BOD/COD can be used as an indicator to determine the age of the solid waste landfill. It has been well known that the BOD levels decrease with age faster than COD because of fast breakdown of the biodegradable refuse. As a consequence, the ratio of BOD/COD of the leachate will decrease with age and can be used to indicate the age of the waste in the landfill. A typical value of BOD/COD ratio of leachate generated from young landfill is between 0.5 to 1.0 as shown in
Table 3. Any leachate or wastewater having a ratio of BOD/COD of greater than 0.5 would be easily treated using biological processes. Therefore, biological means would be appropriate to treat the leachate generated from young landfill. As the ratio of BOD/COD decreases with the age of the landfill, the leachate may contain organic matters that are more difficult to break by biological means. As in the case of medium age landfill, in which the BOD/COD ratio is between 0.1 to 0.5, the treatment of leachate by biological process is still possible utilizing the acclimated microorganisms. In most cases, leachate having the ratio of BOD/COD of more than 0.1 and less than 0.5 still exists in the landfill operated up to 15 years. However, in the case of stabilized landfill having leachate with a ratio of BOD/COD of less than 0.1, biological process is no longer effective to treat such leachate, since it already contains toxic substances which inhibit the microbial activity. Consequently, such leachate would require physical-chemical for its stabilization. Changes in treatment options of leachate on the basis of the landfill age has unfortunately been considered in the design and operation of solid waste landfill in Indonesia.

3. Current Practice of Landfill Leachate Treatment in Indonesia

In general, leachate treatment processing facilities in Indonesia have not yet operated in accordance with existing required technical criteria. Lack of funding allocated to operate and maintain the facility is the main issue. Actually, the fund allocated for the solid waste management in a city or regency is very limited, causing the fund for the operation and maintenance of the leachate treatment facility is even smaller. As the responsibility solid waste management, including leachate treatment, is under the local government, up to now such management is not listed in the priority. This is the reason for limited allocation of funding. The next issue is limited competent personnel to operate the facility. In most landfill leachate treatment facilities in the country, the operators do have not background on biological process knowledge while the facility involves with controlling microorganisms to grow optimally at specific conditions. Another problem is that no appropriate control and monitor in the operation of the facility. As a consequence, it would be impossible to get microbes to grow optimally in the system. The most important issue is that there is almost no inspection from the local environmental authority to monitor and evaluate if the operation of the landfill leachate has fulfilled the criteria and the treated leachate has met the quality allowable by the regulation.

In Indonesia, almost all leachate treatment facilities employ purely biological process without considering the characteristics of leachate, very few apply a combination of biological and chemical process. The chemical process is usually an additional unit installed after the operation of the leachate treatment facility and it is not included either in the initial design or construction. Since the chemical unit requires high operational cost, eventually its operation is terminated due to lack of fund. Basically the facility consists of three stages of biological process, namely anaerobic stabilization, facultative and maturation. In addition to these three units, in some facilities another treatment in the forms of biofilter or wetland is added [4,6]. The fundamental reason to install biological process for the treatment of leachate is mainly because it is relatively simple and cheap to operate, which is not always true. This might be right if the quantity and the quality of the incoming leachate are relatively stable throughout the years. Unfortunately, as a tropical country having rainy and dry seasons, it would be very difficult to have a stable leachate composition over time, even though there is possibility to keep the incoming quantity at a constant rate. The anaerobic pond in the facility acts as a pretreatment to reduce the high BOD level and suspended solid of the incoming leachate. The rate of anaerobic biodegradation is faster in the hot region, like Indonesia. The facultative pond represents to further degrade the organic substances in the leachate from the anaerobic pond. The treatment of leachate in this pond involves both anaerobic and aerobic processes. In the upper part of the pond, the aerobic process dominates as the zone is rich in oxygen, while the lower part is regarded as anaerobic zone. The last stage is the maturation pond which functions to treat the incoming leachate from the facultative pond and is usually called as the stabilization pond. In addition to further reduce the suspended solids and BOD, this stage is also expected to remove the pathogenic microbes through rapid changes in the condition and high pH. The degradation is achieved through activities of aerobic microbes and algae [4].
Although the biological processes for the treatment of landfill leachate are relatively simple and inexpensive to operate, they pose a number of drawbacks. The main shortcoming of using such systems is long residence time, besides slow degradation rate and generation of bad smell. An aerobic pond, for example, requires a residence time of 20-50 days with a BOD removal efficiency of 50-85%, while facultative pond needs 5-30 days with 70-80% of BOD removal efficiency and maturation pond takes 7-20 days to remove 60-89% of BOD [23]. As a consequence, the construction of all ponds demands a vast of land area. In most cases, the quality of leachate treated through these processes still can not meet the standard allowable to be discharged to the water body. Therefore, in some cases in the leachate treatment facilities in Indonesia, an additional chemical treatment unit is installed but failed to sustain due to the operational cost constraint.

4. Technological Development on Leachate Treatment

Leachate management can be performed in combination of three following ways, namely isolating the landfill to minimize water or liquid from external sources to enter the landfill, recycling the leachate to the landfill, and treating the leachate produced by the landfill [24]. With regard to the landfill leachate treatment, it is also not possible to operate with only single of physical, chemical or biological process to meet the standard for discharge to the water body [25]. Since leachate characteristics vary due to season and age of landfill, among others, such variation in quantity and quality has to be considered in the design and operation of a landfill leachate treatment. Although biological treatment processes (aerobic, anaerobic and anoxic) are widely used in Indonesia to remove biodegradable compounds [26], it has been reported that the effluent quality has not yet met the standard set up by the regulation [27,28,29]. There have been numerous reports describing good practices of landfill leachate treatment that could be implemented in Indonesia.

Recycling leachate back to the landfill has been regarded as a part of a good treatment practice in the landfill management, because it is easy to install and control with reasonable operation cost. Leachate recirculation will preserve the moisture of solid waste in the landfill, promoting the degradation of organic compounds [30] and reducing the level of COD in leachate [31]. In a pilot test trial, COD removal using this method could reach 63-70% [32]. Recirculation leachate back to the landfill not only improves leachate quality, but also shortens the time needed to stabilize landfills [33]. However, if the recirculation rate is too high it will affect the anaerobic degradation of solid waste [31] and will cause problems in the saturation process [34].

Another possible inexpensive treatment is to combine leachate with domestic wastewater [35]. Leachate and domestic wastewater are channeled to the conventional waste treatment units. However, this method becomes ineffective in the case of too high organic compounds in the leachate which can inhibit the activated sludge process and increase the effluent concentration [32]. As an alternative, pre-treatment needs to be done to remove the nitrogen from the leachate and phosphorus from domestic wastewater. The decrease of COD and NH$_3$-N are in line with the increasing volumetric ratio of landfill leachate / domestic wastewater. Using a Sequencing Batch Reactor (SBR) system, with volumetric ratio of leachate and domestic wastewater of 9:1 would be able to eliminate BOD levels up to 95% and nitrogen up to 50% on a daily basis [32].

Leachate treatment using biological process is the most employed method [36]. Biological process of leachate can be performed with three approaches, namely aerobic, anaerobic and anoxic. The biological process treatment of leachate treatment is very effectively used to remove biodegradable compounds. The process is able to remove up to 50% COD from leachate of a new landfill. However, the process is no longer effective for old landfills with a BOD / COD ratio of <0.1 [2].

Research on biological treatment of leachate has been carried out by a number of researchers [23] [43]. The biological process of leachate requires pre-treatment to eliminate the levels of ammonia and organic compounds that may inhibit the microbial growth in the aerobic process [37]. Leachate treatment with anaerobic process using bio-filter of 8 day residence time can eliminate organic pollutants up to 90% [23].
Constructed wetland is another biological method that can be employed for leachate treatment. Such system is designed and arranged involving vegetation, media and microorganisms. Water plants effective for leachate treatment are those having long and stringy roots. *Limnocharis flava*, *Ipomoea aquatic*, and *Scirpus validus* plants have been found to be effective to eliminate nitrogen levels up to more than 90% at concentrations of 112 - 610 mg/L. In other study it was shown that *Cyperus haspan*, *Cyperus alternifolius*, *Eriocaulon sexangulare* and *Typha domingensis* are effective in reducing BOD and COD up to 60% with the influent BOD concentrations of 514 - 686 mg/L and COD of 923.4 - 1279 mg/L [38].

For several years, flotation has been widely used to reduce the level of colloids, ions, macromolecules, microorganisms and fibers. Research on the use of the flotation method was carried out as a post-treatment of leachate to remove the remaining humic acid, a compound that is difficult to degrade. Under optimized condition, almost 60% of humic acid can be removed from leachate using this method [39].

The use of coagulation and flocculation methods will be effective for the treatment of leachate from old landfills having the BOD/COD of less 0.5 or 0.1 [40]. This method is widely used as a pre-treatment before the biological process or reserve osmosis, or as a final leachate treatment process to remove organic materials that are difficult to degrade. In general, the coagulants usually used in the leachate treatment include aluminum sulfate, ferrous sulfate, ferric chloride and ferric chloride sulphate.

Water stripping is the most common waste treatment method employed to remove high concentration NH$_4^+$-N in leachate. Leachate usually contains high levels of ammonium which can enhance wastewater toxicity [41]. This method will work effectively if the leachate has a high pH value and the used gas is first contacted with H2SO4 or HCL.

Membrane technology has been adopted in various areas of applications, including in the wastewater treatment. Membrane is a selective thin barrier allowing relatively free passage of one component while retaining another. Membrane filtration methods utilized in leachate treatment include microfiltration, ultrafiltration, nano-filtration and reserve osmosis. However, membrane filtration methods cannot be used without any pre-treatment or in combination with other membrane processes [42]. Microfiltration is commonly used to retain microorganisms, small particles, large emulsion droplets and colloids [43]. Ultrafiltration is a separation process that utilizes a pressure up to 10 bar [42]. This method can be used to remove macromolecules in the leachate that have the potential to damage the osmotic membrane. Nano filtration can be used to remove organic compounds and heavy metals in leachate [44]. Nano filtration has a looser structure, allowing higher flux and lower operating pressure in the leachate treatment. This method is able to remove particles having weight of more than 300 g/mole through electrostatic interactions between ions and membranes [31].

5. Conclusions

On the basis of the literature review on the landfill leachate management in Indonesia, the followings can be concluded:

1. Most of solid waste landfills in Indonesia produce leachates having the strength that are above the standard quality allowable to discharge to the water body, requiring the treatment prior to discharging to the environment.

2. The regulation in Indonesia requires every landfill has to completed with leachate treatment system. However, the design of the leachate treatment system is almost the same throughout the country with lack consideration on the characteristics of the leachate.

3. Although there is a treatment system in most of solid waste landfill in Indonesia, the use of single method of treatment (biological process), poor management, lack of funding, unskilled personnel, and lack of monitoring have caused the failure of the landfill leachate treatment to produce the effluent quality to meet the standard allowable to be discharged to the environment.

4. For future development and implementation, the issue of leachate has to be started from the design by considering various aspect, so the system may consist combination of different approaches, biological, physical and/or chemical processes.
Acknowledgement
The authors wish to express their deep gratitude to the Syiah Kuala University for providing financial support for this study through a scholarship given to the first author, under Syiah Kuala University Excellent Research for the Doctoral Acceleration Program.

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