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Stripping/flocculation/membrane bioreactor/reverse osmosis treatment of municipal landfill leachate

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ABSTRACT

This study presents a configuration for the complete treatment of landfill leachate with high organic and ammonium concentrations. Ammonia stripping is performed to overcome the ammonia toxicity to aerobic microorganisms. By coagulation–flocculation process, COD and suspended solids (SS) were removed 36 and 46%, respectively. After pretreatment, an aerobic/anoxic membrane bioreactor (Aer/An MBR) accomplished the COD and total inorganic nitrogen (total-N_i) removals above 90 and 92%, respectively, at SRT of 30 days. Concentrations of COD and total-N_i (not considering organic nitrogen) in the Aer/An MBR effluent decreased to 450 and 40 mg/l, respectively, by significant organic oxidation and nitrification/denitrification processes. As an advanced treatment for the leachate, the reverse osmosis (RO) was applied to the collected Aer/An MBR effluents. Reverse osmosis provided high quality effluent by reducing the effluent COD from MBR to less than 4.0 mg/l at SRT of 30 days.

1. Introduction

Leachate is a high-strength wastewater formed as a result of percolation of rain-water and moisture through waste in landfills. During the formation of leachate, organic and inorganic compounds are transferred from waste to the liquid medium and pose a hazard to the receiving water bodies. Production of landfill leachate begins with introducing moistured waste into disposal area and continues for several decades following the landfill closure. Leachate contains high organic matter and ammonium nitrogen and its composition depends upon the landfill age, the quality and quantity of waste, biological and chemical processes that took place during disposal, rainfall density, and water percolation rate through the waste in the landfill. Depending upon what was placed in the landfill, leachate may contain many types of contaminants, and if not removed by treatment, these contaminants may be toxic to life or simply alter the ecology of receiving streams. Leachate should be treated before reaching surface water or ground water bodies, because it can accelerate algae growth due to its high nutrient content, deplete dissolved oxygen in the streams, and cause toxic effects in the surrounding water life. Since the composition of a leachate consists of a wide range of contaminants, it cannot be easily treated by conventional methods. Therefore, a number of scientists around the world have intensively focused on the combination of biological and physico-chemical treatment systems for effective leachate treatment.

The physical and chemical treatment processes include chemical oxidation, coagulation–flocculation, chemical precipitation, activated carbon absorption, ozonation, and pressure-driven membrane processes. Ozonation and reverse osmosis could be considered following an effective biological treatment to reach a better effluent quality. In general, physico-chemical units are not enough to remove organics from leachate. The disadvantage of treating leachate with coagulation and precipitation process is that excess sludge is produced after the treatment application, which is difficult to manage. On the other hand, biological treatment alone does not achieve high removal efficiency due to inhibition effect of some contaminants such as ammonium and heavy metals. For example, as physico-chemical treatment ensures the removal of metals and partially ammonium, biological treatment is necessary for the stabilization and degradation of organic matter, and also for the nutrient removal.

Among advanced biological treatment processes, membrane bioreactor (MBR) is the most important process, which consists of a

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membrane module and a bioreactor containing generally activated sludge with high mixed liquor suspended solids (MLSS) of greater than 10,000 mg/l. The application of membrane bioreactor as a main treatment after physico-chemical application seems to be promising due to the expected high effluent quality. However, ozonation and reverse osmosis could be used as a post-treatment following biological treatment to remove the residual organic matters.

This study presents an effective treatment configuration for landfill leachate. The objectives of this study are to investigate: (1) the performance of coagulation as a pretreatment for leachate, (2) the potential of ammonium stripping for ammonium removal under different conditions, (3) the performance of membrane bioreactor placed after the coagulation and ammonium stripping, (4) the effect of solid retention time on the aerobic/anoxic MBR (Aer/An MBR) performance, (5) the relationship between viability and inert COD in Aer/An MBR, and (6) the final effluent quality if reverse osmosis is used as an optional post-treatment for the removal of residual organic matter after aerobic/anoxic MBR.

2. Mini review on treatment trials

Unfortunately, most of the landfills in the world do not have an appropriate leachate treatment system. Although some treatment options are available, treatment alternatives for leachate are very limited because they are not usually designed by considering the leachate characteristics [1–2]. Hence, it is necessary to develop leachate treatment systems with reduced footprint and effective efficiency. High ammonium and phosphorus deficiency in young leachate constrain the biological treatment applications such as nitrification–denitrification processes following phosphorus addition [3–6].

Some researchers received nitrification efficiency higher than 95% for leachates containing high ammonium by using some expensive biological methods [7–10]. It has been realized that biodegredation mechanism depends upon the age and origin of the landfill, and the type and operation of the treatment system [7,9,11–15]. In general, almost all treatment schemes used for landfill leachate consist of a combination of physico-chemical and biological treatment units [5]. In order to asses the performance of biological treatment; COD efficiencies have generally been evaluated according to the intensity of leachate, number of treatment steps, hydraulic retention time (HRT), and organic loading rate. Alvarez-Vazquez et al. [16] estimated that the percentages of treatment systems used for leachate treatment were 72% biological processes, 11% flocculation/coagulation, 5% filtration, 4% air stripping, 4% chemical oxidation, 2% activated carbon, and 2% ion exchange.

2.1. Biological treatment for landfill leachate

Biological processes are very effective when applied to young leachates, but their efficiency decreases with an increased leachate age [17–18]. In particular, conventional biological systems cannot significantly treat old leachates, which contain contaminants resistant to biodegradation. Furthermore, old leachates have inhibition effect on activated sludge due to their high ammonium concentrations [19]. However, the phosphorus deficiency hampers the production of microorganisms and consequently the treatment performance [20]. It is found that the most studied aerobic processes for leachate treatment are aerobic lagoons which account for 21% of biological treatment systems available around the world. Other biological systems are; 18% UASB, 17% activated sludge, and 8% MBR. Recently, many researchers have been intensively focusing on the treatment of leachate by using membrane bioreactor (MBR) due to the recent advances in membrane technology. MBR seems to be a good alternative for all wastewaters with high organic and nutrient loadings, as well as high suspended solid content. In addition, MBR has also a significant effect on nitrification because high SRT promotes the growth of nitrifying bacteria. Some researchers demonstrated that both nitrification and denitrification processes could occur in a single bioreactor when an intermittent aeration is adapted to the system [21–22]. A study by Visvanathan et al. [23] showed 60–80% COD removal, 97–99% BOD removal, and 60–80% ammonium removal in a thermophilic MBR.

2.2. Physico-chemical treatment for landfill leachate

Various methods of physico-chemical treatment are used to treat wastewaters containing toxic contaminants such as heavy metals, non-biodegradable organics and ammonium. These physico-chemical treatment methods are selected based on wastewater characterization, investment and operating cost, and some local regulations. Up to now, many researchers have used a number of physico-chemical methods to treat leachate. These processes include chemical oxidation [19,24–26], coagulation and precipitation [17,27–31], electro-coagulation [32–33], adsorption [34], photooxidation [35–38], ammonium stripping [39], ozonation [40–43], and membrane processes [44–45].

Nanofiltration (NF) and reverse osmosis (RO) are used alone to purify the water microfiltration (MF) and ultrafiltration (UF) and are generally coupled with a biological process. Bodzek et al. [46] applied RO unit directly to leachate treated in activated sludge system and faced the recovery reduction significantly due to the excess fouling of membranes. Chan et al. [47] used the vibrating share mechanism to reduce the fouling potential in the RO and consequently increased the running time of membrane. The system accomplished 97% removal of non-biodegradable matter and 99% removal of ammonium.

2.3. Combination of biological and physico-chemical processes for landfill leachate

Physico-chemical treatment units are placed either as pretreatment to reduce the loading rate for biological processes or as post-treatment to reach a high quality discharge standard. For example, Bae et al. [48] studied the COD and ammonia removal by using Fenton process following the conventional activated sludge system. Haapea et al. [49] applied the processes of ozonation and ozonation/hydrogen peroxide before the biological process for the treatment of landfill leachate. Activated carbon [50] and ammonia stripping/coagulation [51] have been commonly used as pretreatment of sequencing batch reactor (SBR). On the other hand, some researchers combined the aerobic and anaerobic processes [3,52–56]. Bohdziewicz and Kwarciak [57] showed an effective removal of leachate contaminants by using reverse osmosis following upflow anaerobic sludge blanket (UASB).

3. Materials and methods

3.1. Experimental plan

Experimental study was conducted at various steps (Fig. 1), including leachate characterization, pretreatment (coagulation and ammonia stripping), main treatment (aerobic/anoxic MBR), and post-treatment (reverse osmosis). Soil and sludge samples taken from a landfill area and a municipal activated sludge treatment plant were placed into a 5-l batch reactor and the reactor was operated by continuous feeding of diluted leachate at a SRT of 5 days for 45 days. Then, the Aer/An MBR was inoculated by activated sludge obtained from the batch reactor.