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Landfill Leachate treatment by sono-evaporation

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ABSTRACT

Sanitary landfill releases two pollutants into the environment, leachate and gases. Leachate may be treated by evaporation to attain acceptable discharge limits for various types of contaminants. One of the most important operational problems with evaporation is scaling. As ultrasound can affect many leachate compounds, this study was done to test its influence on scale treatment using evaporation. In order to determine the effect of sonication on leachate evaporation, some leachate samples were sonicated at a frequency of 25 kHz and 500 W. Sonication periods were tested in the range of 10–40 min on leachate samples. Evaporation and distillation were performed on leachate samples. The tests demonstrated that 90% of the leachate was distilled. When evaporation–distillation processes were carried out, chemical oxygen demand (COD) reduction was 83.56%. However, when sonication was used, COD reduction was 86.56–88.36% for 10–40 mi sonication, respectively. During evaporation, a part of total Kjeldahl nitrogen (TKN) remained in the concentrate and the rest entered into the distillate. In case where sonication was applied, TKN reduction was 83.70% and 89.71% for 10 and 40 min, respectively. Sonication had no considerable effect on EC and heavy metals reduction. When using sono-evaporation, efficiency of scale removal (ESR) reached 95.97%.

Keywords: Leachate treatment; Evaporation; Sonication; Sono-evaporation; Distillate; Concentrate

1. Introduction

Generation of municipal solid waste (MSW) continues to grow both per capita and overall. The ultimate disposal of solid waste in to sanitary landfill sites continues. As well as being a viable method of waste disposal, landfilling minimizes environmental impact and other inconveniences by allowing waste to decompose under controlled conditions until its eventual transformation into relatively inert and stable matter [1]. Landfilling causes two types of pollution, which correspond to infiltration into the natural environment: (1) leachates, defined as water that percolate through the waste matter (rainwater or groundwater seepage), and (2) gases produced by fermentation of organic matter [2].

Leachate is produced as a result of rainfall precipitation and infiltration, phenomena which cause the infiltration of liquid into landfill waste sites and, after saturation, wastewater is generated. Liquid fractions in the waste will also add to the leachate as well as moisture in the cover material. Flow rates and composition of leachates vary from site to site, with seasonal variation at each site that depends on the age of the landfill [3]. Contaminants in leachate include organic compounds that exert a biochemical oxygen demand (BOD); high-molecular-weight non-biodegradable organic compounds that contribute

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to chemical oxygen demand (COD); suspended solids (SS), soluble metals and salts; and volatile inorganic and organic compounds such as ammonia and acetic acid [2]. Chemical and biological reactions would produce large amounts of landfill leachate that would contaminate the soil and groundwater [4].

In practice, the generation of landfill leachate cannot be entirely avoided, particularly during the actual operation, except possibly in some arid climates [5].

Environmental regulations require that the leachate levels be controlled, which means that excess leachate must be removed and disposed of [6].

Landfill leachate needs to be treated to meet standards before its direct disposal into surface water. Globally, the problem of treating leachate has existed for some time, but as yet a universal solution has not been found [2].

Conventional treatment of landfill leachate may require several unit operations to remove the various contaminants to acceptable levels. A typical treatment train may include: (1) aerobic or anaerobic biological processes to stabilize biodegradable organic components and ammonia; (2) adsorption, air stripping, or chemical oxidation to remove non-biodegradable organic compounds; and (3) chemical precipitation to remove heavy metals. With effluent discharge, quality standards become more stringent. It is apparent that landfill leachate treatment systems and the management of residue are becoming increasingly more complex operations. Treatment of leachate by evaporation may offer the advantage of attaining acceptable discharge limits for various types of contaminants by employing fewer unit operations than a treatment train composed of several sequential unit operations. Evaporative leachate treatment may also produce fewer and more concentrated residual streams than conventional operations [7]. The resulting condensate from evaporation may be high quality and easier to dispose of than effluent produced by conventional leachate-treatment processes. After evaporation, the volume of concentrated residue will be a small fraction of the volume of the original leachate [8]. One of the operational problems at the full-scale facility is that of scaling [9,10].

Scale build-up in evaporators, boilers, or heaters is one of the most difficult problems to solve in many industries where large amounts of liquid are evaporated. It has caused many economic losses because of its low heat transfer capacity [11].

At present, there are various commonly used methods (chemical, mechanical and physical) for cleaning. However, because scale sticks strongly on to walls of tubes or vessels, its removal often requires a synergistic method. At the same time, whatever method is used, the evaporation process must be stopped, and evaporators tend to become worn and corroded. In order to solve this problem, many methods of scale prevention have been proposed, such as deploying antiscalants, ion exchange, electric, ultrasound, or magnetic fields [12].

The use of ultrasound has been reported to have many effects on compounds in solution; therefore its influence on the build up of scale in evaporators was studied [13].

The objectives of this study were to investigate the effect of ultrasound and evaporation on COD, total N-Kjeldahl, electrical conductivity (EC), and heavy metals (Ni and Zn). In order to observe the prevention of scale build up and scale removal in an evaporation process, various operating sonication times were also investigated.

2. Materials and methods

The experiments were performed in Mashhad solid waste landfill site for solid waste during 2008–2011.

2.1. Experimental set-up

Laboratory-scale evaporation and distillation experiments were conducted on leachate samples. One-stage evaporation and distillation was performed under 100 °C. In addition, COD, total N-Kjeldahl (TKN), concentration of heavy metals (Zn and Ni), and electrical conductivity (EC) were determined to assess the quality of evaporate that could be achieved. The volume of each sample was 400 ml, and 90% was distilled in each analysis.

In the second stage, samples were sonicated in an ultrasonic bath (HF-Leistung), operating at a frequency 25 kHz and 500 W in order to determine the effect of sonication on leachate evaporation (Fig. 1). Each sample was sonicated for four time durations of 10, 20, 30, and 40 min.

Mass balances on constituents were performed to quantify any errors in analyses. Measurements for COD, TKN, heavy metals, and EC were analyzed in both concentrate and distillate.

2.2. Analyses

Each sample was analyzed before and after sonication and evaporation–distillation to determine COD, N-Kjeldahl, heavy metals and EC. All experiments were conducted according to those methods introduced as standard methods for the examination of water and wastewater [14].

Characteristics of raw leachate were as follow:

- COD= 33,670 ± 3384.27 mg L^{-1},
- TKN= 783.33 ± 63.66 mg L^{-1},

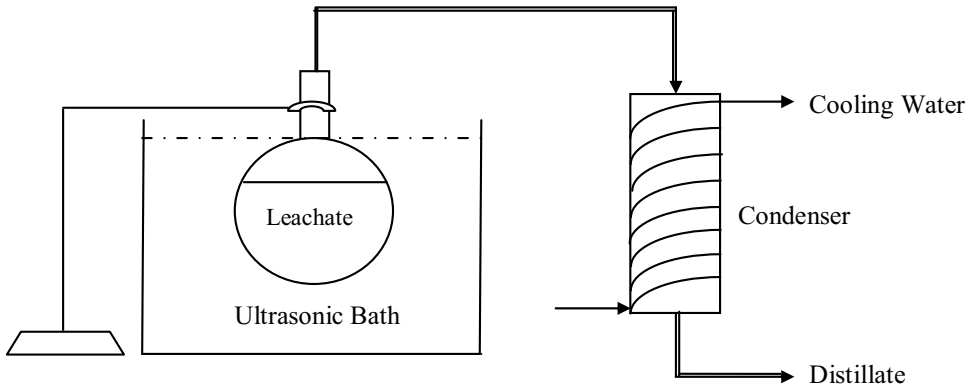

Fig. 1. Laboratory leachate sonication and evaporation apparatus.

- EC= 1030 ± 161.75 μs cm^{-1},
- Ni = 1.43 ± 0.35 mg L^{-1},
- Zn = 3.61 ± 0.2 mg L^{-1}.

Determination of the efficiency of scale removal (ESR) was as follows. Before and after evaporation and evaporation–sonication, beakers were dried and weighed. ESR was expressed as the percentage of scale removed, which equals the difference of beaker weights without and with ultrasound divided by the beaker weight without ultrasound.

3. Results and discussion

Sonication and evaporation–distillation were performed on leachate samples where 90% of the leachate was distilled. Distillates were colorless.

3.1. COD removal efficiency

The effect of evaporation and sonication–evaporation on COD are presented in Fig. 2. Results show that high reduction efficiency for COD occurred when sonication was used. When evaporation–distillation processes were carried out, COD reduction was 83.56%. Nevertheless, when sonication irradiation was used, COD reduced in distillates. COD reduction was 86.56% for 10 min sonication. Young leachate has volatile and non-volatile organic compounds. During the evaporation–distillation, volatile organic compounds were carried over into the distillate during the evaporation. After sonication, destruction of volatile organic compounds most likely occurs inside cavitation bubbles and volatile organics in the distillate are decreased [15]. The time of sonication had no considerable effect on COD reduction ($p > 0.05$). When sonication time increased, COD reduction was 86.56 and 88.36 for 10 and 40 min sonication, respectively.

3.2. TKN removal efficiency

The effect of sonication and evaporation on TKN is shown in Fig. 3. During evaporation–distillation, a part of TKN remains in the concentrate and a partly enters

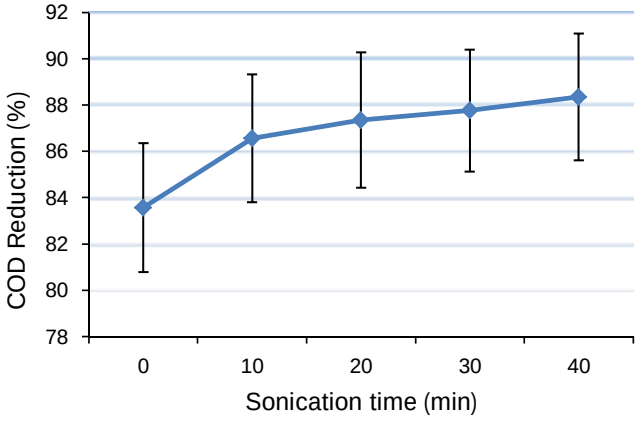

Fig. 2. Effect of sonication–evaporation on COD removal.

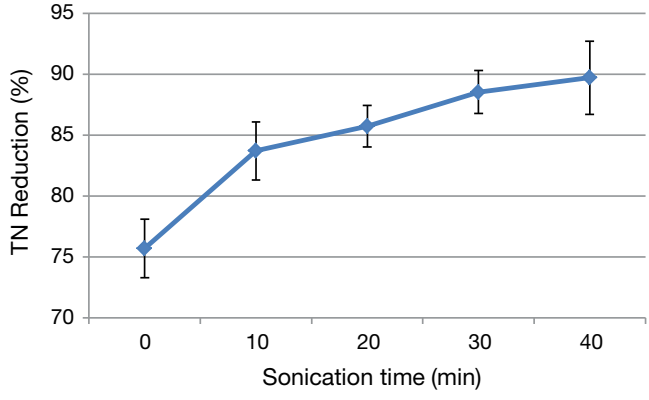

Fig. 3. Effect of sonication–evaporation on TKN removal.

the distillate. Results show that high reduction efficiency for TKN occurred when sonication was used. When evaporation–distillation processes were carried out, TKN reduction was 75.69%. When sonication irradiation was used, TKN reduction was 83.70% and 89.71% for 10 and 40 min sonication, respectively. In general, the sonochemical degradation of chemical compounds can occur through two distinct pathways, that of oxidation by hydroxyl radicals and by pyrolytic decomposition. Volatile compounds tend to migrate into the bubble and usually degrade via pyrolytic reactions occurring inside the bubbles, while non-volatile compounds tend to accumulate in the liquid phase, where they degrade via hydroxyl radical reactions [16]. As ammonia is volatile, it is reasonable to assume that ammonia nitrogen degrades through thermal reactions occurring inside the bubbles and aquasonolytic degradation of organic nitrogen takes place in the surrounding water by OH radicals.

3.3. EC and heavy metals removal efficiency

EC reduction of distillates was 92.25% for evaporation–distillation alone. As shown in Fig. 4, sonication had no considerable effect on EC reduction ($p > 0.05$). Maximum and minimum reduction of EC was 92.36% and 92.29% for 30 and 40 min, respectively. A single-step, acidic distillation of strong leachate samples removed more than 95% of ionic impurities, except for volatile organic acids, which were removed at 85% [8].

Heavy metals reduction was 95.6% and 94.68% (Ni and Zn, respectively) in distillates for evaporation–distillation alone. Maximum effect of sonication on heavy metals was 96.81% and 95.75% for Ni and Zn, respectively (Fig. 5). Over 94% removal efficiency was reported on Cu and Zn in leachate evaporation in landfill leachate treatment in north Italy [17].

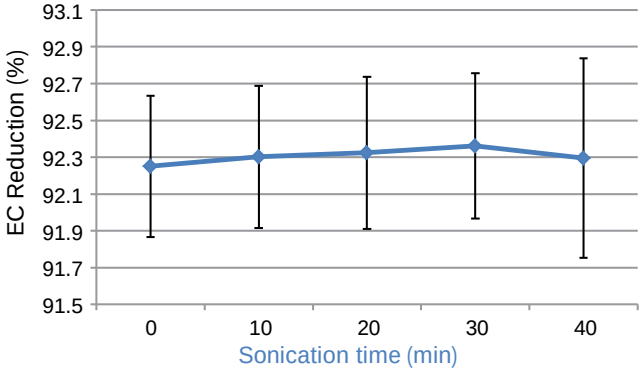

Fig. 4. Effect of sonication–evaporation on EC.

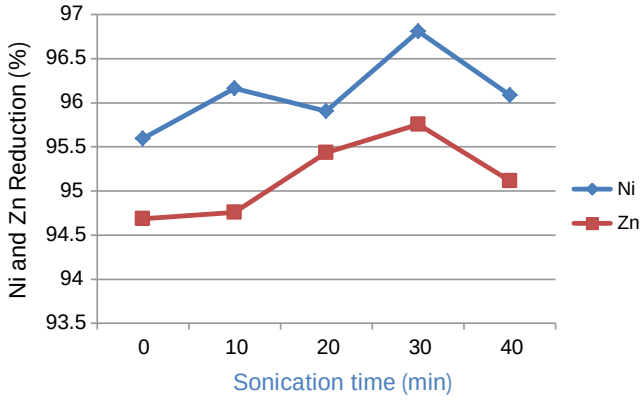

Fig. 5. Effect of sonication–evaporation on heavy metals removal.

3.4 Effect of sonication on scale

Results indicated that ultrasound could not only inhibit the formation of scale, but could also be used for efficient removal of scale. Results showed, weight of beaker increased by 308.60 (±23.67) mg after evaporation, while it increased by 12.42 (±3.77) mg when 10 min sonication was used ($p = 0.013$). In summary, ESR reached 95.97% when sono-evaporation was used. With an increasing duration of ultrasound, there were no significant changes ($p > 0.05$). Scale formation on the heating area of the heat transfer equipment conforms to the mechanism of mass crystallization. Under the effect of ultrasonic cavitation, the induction period of nucleation of several materials that form scale is shortened, thus crystal scale nuclei are produced in a short time. A large proportion of inorganic or organic impurities can be deposited onto the nuclei, instead of on the surface of the beaker. These deposits remain suspended in the concentrate, and flow out. They can then be separated from the beaker. Thus the amount of precipitate deposited onto the surface of evaporator tubes can be greatly reduced [13].

Scaling problems at large the full-scale facility in Bavaria were managed by flushing with sulfamic acid and a high-pressure rinse with water [8]. This method is used with many chemicals and water and is economically viable. In sono-evaporation, energy consumption for 10 min is 0.3 kWh/l leachate and due to the lack of chemical use and environmental compatibility of this method, it can be recommended for use in landfill leachate treatment.

4. Conclusion

The aim of this research was to investigate the effect of ultrasound irradiation on landfill leachate evaporation (sono-evaporation). Based on results of this study, the following conclusions can be drawn:

- Distillation resulted in removal of more than 96% of COD by sono-evaporation in the leachate samples and essentially no color.
- The technique of ultrasonic irradiation is an effective method for the decomposition of TKN in distillate of landfill leachate evaporation. Increasing sonication time had no significant effect on TKN removal.
- There was no significant influence of ultrasound on EC and heavy metals reduction.
- Scale removal efficiency was more than 95% under ultrasonic treatment.
- Ultrasound can be used to inhibit the formation of scale and to remove scale; and the most appropriate time is 10 min.

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