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A Review on Coagulation/Flocculation for the Treatment of Landfill Leachate

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Abstract
Landfill leachate (LL) is a complex, toxic liquid generated due to the decomposition of solid waste in the landfill sites. If untreated, it poses a significant environmental threat and its management and treatment has become a challenge worldwide due to its diverse composition and potential to easily contaminate soil and water resources. Before being released into the environment, the LL needs to undergo proper treatment to prevent any such adverse effects on the surroundings. Typically, the selection of a suitable treatment technique depends on various LL parameters such as COD, BOD_5/COD ratio, or landfill age. Coagulation/flocculation is a chemical treatment process that is simple yet effective for the treatment of LL. This technique depends mostly on the pH, temperature, quality of leachate, and the choice of coagulant, in yielding desirable results. This review summarizes different studies on the use and efficiency of coagulation/flocculation for the treatment of landfill leachate.

Keywords
Landfill leachate, Coagulation-flocculation, Alum, Ferric Chloride

1. Introuction

Landfill leachate (LL) is a mixture of percolated rainfall, waste-produced water, and waste-inherent water, which contains significant concentrations of dissolved organic matter (DOM), salts, and other minerals [1]. LL generation is a major issue as they can easily contaminate soil, surface water, and groundwater [2]. They are high-strength effluent with complex elements commonly characterized by foul odor, dark color, organic substances like humic acids (HAs), high chemical oxygen demand (COD), ammonia-nitrogen, biological oxygen demand BOD_5, etc., which mostly depends on the age of the landfill, the content of landfill and the biodegradation stages of the landfill [3].

The increase in municipal solid waste (MSW) generation is rising and will continue to rise resulting in major environmental and economic issues for society [3]. Each year urban areas produce about 1.3 billion tonnes of MSW per year and by the end of 2025 that amount will have doubled [4]. The disposal of MSW in landfills is still the method that is most frequently used throughout the world. Landfilling is a comparatively quick, low-cost, and popular approach for managing MSW when compared to alternative technologies such as incineration and composting [5]. Up to 95% of the MSW that is collected globally is reportedly disposed into landfills which will continuously contribute to the generation of LL [6].

Therefore, the treatment of LL prior to its discharge should be done to meet the effluent standards. A variety of biological, and physicochemical treatment techniques have been investigated to meet thes discharge criteria in various nations. Amongst these techniques, physicochemical treatments have been studied as primary treatment techniques prior to other biological treatment techniques [7]. There are several physicochemical technologies, including coagulation/flocculation, air stripping, adsorption, and advanced chemical oxidation processes, amongst which coagulation/flocculation has been commonly used because of their effectiveness, simplicity, ease of use and low cost [8]. Therefore, this review aims to present a compilation of the different studies done on the use of chemical coagulation/flocculation for LL treatment.

2. Characteristics of Landfill Leachate

The composition of LL produced by the breakdown of solid wastes varies greatly due to the age of the landfill, the degree of compaction of the wastes in the landfill and the rate at which water percolates through them [9, 10]. In addition, the anaerobic decomposition in the landfill sites causes a significant amount of ammonia-nitrogen formation[11]. LL may also contain persistent organic contaminant along with a variety of low and medium-polarity organic compounds which includes amines, alcohols, carboxylic acids, aldehydes, ketones, phenols, hydrocarbons, etc. [12]. Also traces of heavy metals such as chromium (Cr), manganese (Mn), cadmium (Cd), lead (Pb), iron (Fe), Nickel (Ni), and zinc (Zn) are commonly found in LL [13]. Typically, LL are divided into three groups with their specific characteristics as shown in Table 1 [13].

Table 1: Variation in LL characteristics with time

Parameters	Young	Intermediate	Old
Age (Years)	<5	5-10	>10
pH	<6.5	6.5-7.5	>7.5
COD (mg/L)	>10,000	5,000-10,000	<5,000
BOD_5 (mg/L)	>2,000	150-2,000	<150
BOD_5/COD	0.5-1.0	0.1-0.5	>0.1

LL characteristics such as pH, BOD, COD, and BOD/COD ratio, alter dramatically with the increase in the age of landfill [19]. For instance, due to the breakdown of organic waste the BOD and COD decrease with the increase in landfill age as a result, the BOD/COD ratio lowers with time [20]. As opposed to this, the pH value of the LL increases with landfill age and heavy metal concentrations decrease over time [21].

3. Factors Affecting Coagulation/flocculation

The most significant operating components influencing the efficiency of the coagulation process are temperature, turbidity, pH, coagulant dosage, mixing duration and speed. For the coagulant dosage, an optimal dose effectively removes colloidal particles from the LL however, an overdosage contaminates by increasing the organic load, turbidity, and slurry volume which further increases the treatment cost [22] whereas, an underdosage prevents complete aggregation. Similarly, the pH of the LL influences chemical reactions during the treatment process which is a crucial component affecting the process. Furthermore, alkalinity, which is the capacity to neutralize acidity, is absorbed by the majority of chemical coagulants, particularly ferric salts. Thus, poor flocs are produced if the alkalinity is too low. [23]. The initial turbidity of LL is another essential component that influences coagulation as the presence of colloidal particles in the effluent resulting in turbidity affects the clarity of the effluent [24]. Since high turbidity refers to high colloidal particles, it ensures the collision between the coagulant and the colloidal particle resulting in better floc formation [24]. Larger, stronger flocs are produced by more impact and they settle more quickly, whereas, low initial turbidity lowers the likelihood of coagulants and contaminants colliding. Also, a low initial turbidity forms flake-like structures that take longer to settle. The mixing speed and time for the coagulation process is also a governing factor. When adding coagulant rapid mixing is used to promote uniform distribution of the coagulant to destabilize the suspended particle which is followed by gentle mixing to induce the particle collision forming macro flocs [23]. Since the speed and time of mixing determine the efficiency of the coagulation process, these two speed regulate the entire process.

3.1 Commonly Used Coagulants

Various types of coagulants can be employed for the tratment of LL. Aluminum sulfate (alum), aluminum chloride ($AlCl_3$), and sodium aluminate are some of the commonly used aluminum salts. These contribute to the creation of highly effective pre-polymerized inorganic coagulants, including polyaluminum chloride (PAC), polyaluminum sulfate (PAS), and polyaluminum chlorosulfate (PACS), with PAC being the most widely used [25]. Additionally, other metal coagulants such as ferric chloride ($FeCl_3$), ferric sulfate, ferrous sulfate, and ferric chloride sulfate are commonly utilized [25]. Many studies have investigated the application of coagulation/flocculation for treating LL, and Table 2 presents key findings from these investigations. Many studies have looked into using coagulation/flocculation to treat LL. Table 2 shows what some of these studies found.

Table 2: Findings from literature on optimum dose and pH for coagulation/flocculation for LL treatment

	Coagulant	Optimum dose (g/L)	Optimum pH	Parameters Removed	Reference
Landfill Leachate (Hamadan, Iran)	Polyaluminium Chloride	2.5	12	60% COD 39.14% TSS	[14]
Stabilized Landfill Leachate (Ranchi, India)	Aluminium Sulphate	9.5	6	63% COD 71% TSS 59% Turbidity	[15]
	Ferric Chloride	2.5	4	80% COD 53% TSS 65% Turbidity	
Young Landfill Leachate (Sfax, Tunisia)	Ferric Chloride	0.8	4	46% COD 50% TSS 63% Turbidity	[16]
Landfill Leachate (Perlis, Malaysia)	Aluminium Sulphate	8	5	69.4% COD 84.3% SS 94.5% Turbidity	[17]
Stabilized Landfill Leachate (Sisdole, Nepal)	Aluminium Sulphate	25	5.29	43.46% COD 84.84% Turbidity	[18]
	Ferric Chloride	13.61	5	11.85% COD 96.03% Turbidity	
	Polyaluminium Chloride	30.46	5.17	30.28% COD 96.69% Turbidity	

4. Conclusion

LL poses a serious threat to the surroundings as the presence of harmful chemicals like heavy metals, organic pollutants, and ammonia-nitrogen can easily contaminatesoil, surface and groundwater. To prevent the direct discharge of untreated LL, certain criteria have been set. In order to meet these criterias, amongst various techniques, coagulation/ flocculation is a promising one. But the optimal dosage and removal efficiency can vary for LL from different regions affecting the overall efficiency of the process. While chemical coagulants can address specific parameters, they may not treat all constituents, making coagulation-flocculation insufficient in most treatment cases. Due to which the application of coagulation/ flocculation as a pre-treatment or post-treatment method, in combination with other physico-chemical or biological techniqueswould address the complexities of LL, ensuring a more successful and efficient treatment process.

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