**Cactus opuntia as coagulant in treating landfill leachate via coagulation process**

N A Zainol¹,³, F N Syarmimi³, S N Zailani², N A Yusoff², A A Ghani¹,³ and K S Ahmad Sohaimi²

¹Water Research Group (WAREG), Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia.
²Faculty of Chemical Engineering Technology, Universiti Malaysia Perlis (UniMAP), Kampus UniCITI Alam, Sungai Chuchuh, 02100 Padang Besar, Perlis, Malaysia.
³Faculty of Civil Engineering Technology, Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia.

Email: aineezainol@unimap.edu.my

**Abstract.** Coagulation-flocculation treatment is often used for the treatment of stabilized landfill leachate. However, uses a non-environmentally friendly chemical coagulant which is a threat to environment quality, therefore *Cactus opuntia* is proposed to replace the use of current chemical coagulants such as aluminium sulphate in order to achieve sustainable growth. In this regard, the comparative suitability of *Cactus opuntia* and alum as coagulants for the treatment of the stabilised leachate of the Padang Siding Landfill Site was evaluated via a series of Jar Test experimental works with a rapid mixing speed of 100 rpm for 3 minutes, a slow mixing speed of 30 rpm for 10 minutes and a set-up period of 30 minutes. In addition, the sludge volume index (SVI) of the treated leachate sample was calculated under optimised conditions. *Cactus opuntia* was able to remove 66.8 per cent turbidity and 42 per cent COD at optimal pH 2 with a favourable dose of 8000 mg / L, while the optimal pH 5 with a coagulant dose of 8000 mg / L induced 94.5 per cent turbidity and 69 per cent COD reduction from the same leachate sample. In addition, the SVI of alum coagulant was 42.2 while the *Cactus opuntia* was 4.45 with a relative ratio of alum to *opuntia* of 9:1. *Cactus opuntia* may also be proposed as a plentiful coagulant of metal cationic ions such as aluminium, iron and silica elements for the treatment of leachate.

1. **Introduction**

Leachate is a liquid from landfill sites that includes dissolved and suspended matter. If not collected, the leachate will contaminate the groundwater supply. It can also be graded as high-strength and toxic wastewater because it is rich in organic and inorganic pollutants. In addition, leachate is one of the major pollution problems caused by municipal solid waste (MSW) landfill [1].

In order to reduce wastewater pollution, coagulation-flocculation techniques have been used to remove pollutants such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), colour, heavy metals, turbidity and ammonia-nitrogen[2]. For effective coagulation-flocculation techniques, chemical coagulants are used to remove particulates and heavy metals from landfill leachate. Natural plant-based coagulant (*Cactus opuntia*) has been used as a coagulant to compare its efficiency with chemical-based coagulants (alum) in the treatment of landfill leachate through coagulation-flocculation. The results indicate that *Cactus opuntia* shows more productivity in the reduction of turbidity for sewage and wastewater treatment. *Cactus opuntia* contains...
"mucilage" consisting of polygalacturonic acid (biopolymer) with a 50 per cent potential turbidity removal with aid from some other active coagulant agent [3].

The purpose of this study was to investigate the optimal pH and coagulant dose for the coagulation-flocculation process using Cactus opuntia as a natural coagulant. Secondly, to compare the efficiency of Cactus opuntia and alum in the removal of turbidity and COD under optimum conditions. Thirdly, to determine the sludge generation through the sludge volume index (SVI) for Cactus opuntia and alum under optimum conditions.

2. Materials and Method

2.1. Collection of leachate sample

The initial experimental work began with the collection of leachate samples at the Padang Siding landfill leachate collection pond. Leachate samples were immediately moved to the laboratory and stored in the refrigerator at 4°C prior to the experiment to minimise potential volatilization or biodegradation of the samples. Characterisation of the samples was carried out in accordance with the Standard Methods for the Examination of Water and Wastewater [4].

2.2 Preparation of Cactus Opuntia

Cactus opuntia used in this study was collected from a nursery in Kangar, Perlis. The opuntia was washed with tap water and then sliced into strips of about 1 cm to facilitate drying. The sliced Cactus opuntia was then dried in oven at 65°C for 24 hours. The dried Cactus opuntia was grinded into fine powders and sieved to size range of 53-106 µm. This fine powder was then added to distilled water to produce 1g/L of stock solution. The solution was then stirred for an hour to liberate active coagulant agents.

2.3 Jar test experiments

Coagulation-flocculation experiments were conducted using Cactus opuntia as a natural-plant based coagulant and alum as a chemical-based coagulant. The optimal pH and optimal coagulant dose for both coagulants were then calculated using several experimental jar experiments with acceptable operating parameters. The optimal pH dose and optimum coagulants can be calculated from the highest percentage removal of metals and the elimination of turbidity from the landfill leachate samples.

The JLT6 VELP Scientifica with six paddle rotors fitted with rectangular blades was used. 6 experimental work beakers are filled with 500 ml of the leachate sample. First, pH was changed to the optimal pH using 1.0 M H₂SO₄ and 1.0 M NaOH. The rapid mixing speed was set at 130 rpm for 3 minutes, while the slow mixing speed was set at 30 rpm for 10 minutes, followed by the settling process of 30 minutes. Finally, the presence of two separate layers was aqueous and solid. After that, about 50 mL of supernatant was removed using a plastic syringe from a point 2 cm below the surface of the water. Analysis were made from a triplicate to derive the mean values of the results. In order to obtain optimum pH for the coagulation-flocculation process, the pH initially varied and coagulant dosage was maintained constant at 1000 mg/ L. The selected pH values were 1.0, 2.0, 3.0, 5.0, 7.0 and 9.0. In addition, the favourable dose range was between 1000 mg / L and 10,000 mg / L for both coagulants.

2.4 Analytical analysis

2.4.1 Turbidity (Method 2130B). The turbidity of the leachate sample was measured using HACH 2100N Laboratory Turbidity Meter. It has a wide range of 0 to 10000 NTU with an advanced optical ratio system to ensure accurate readings. The unit for the calculation of turbidity is the Nephelometric Turbidity Unit (NTU).

2.4.2 Chemical Oxygen Demand, COD (Method: APHA 5220 D). COD was analysed using the HACH DR 2800 Portable Spectrophotometer. COD digestion reagents have been prepared using concentrated sulphuric acid (H₂SO₄) and potassium dichromate (K₂Cr₂O₇). However, the concentration of sulphuric
acid was prepared by adding 5.5 g of Ag$_2$SO$_4$ dissolved in 543.5 mL of H$_2$SO$_4$. After one or two days, Ag$_2$SO$_4$ dissolved fully and was ready to be used. 10.216 g of K$_2$Cr$_2$O$_7$ was dried in an oven at 103°C for 2 hours for the preparation of potassium dichromate, 167 mL of H$_2$SO$_4$ and 33.3 g of HgSO were added to 500 mL of distilled water. The solution was mixed and cooled at room temperature. Next, the COD reactor was pre-heated to 150°C. A clean volumetric pipette was used to apply 1.5 mL of K$_2$Cr$_2$O$_7$ solutions, 2.5 mL of leachate sample with dilution factor of 10 and 3.5 mL of H$_2$SO$_4$ in 6 vials, and 2.5 mL of deionized water was applied to the other vial for blank preparation. After that, the cap vials were firmly and gently inverted to blend the contents. Next, the vials were inserted and heated for 2 hours at 150°C. Then, the sample were cooled about 20 minutes to 120°C and needed to reach ambient temperature prior to analysis.

2.4.3 Sludge Volume Index (SVI). SVI is the amount of sludge in millimetres occupied by 1g of suspensions after 30 minutes of settling time in a 1L graduated cylinder. After the optimal pH and optimum coagulant dose have been calculated, the sludge formed under optimum conditions was used for sludge volume index (SVI) measurements.

3. Results and discussion

3.1 Raw landfill leachate

The detailed characteristics of the leachate sample collected from Padang Siding Landfill Sites between November 2016 and February 2017 are shown in table 1. From the data obtained, it is shown that the Padang Siding Landfill has stabilized and matured leachate due to its pH range of 8.0 to 8.4, which exceeds pH 7. The pH of raw leachate is not appropriate for discharge unless it has undergone a series of treatments using purification technology because it reaches the maximum discharge limit set out in the Second Schedule, Environmental Quality Regulations 2009 (Control of Emissions from Solid Waste Transfer Station and Landfill). First, the COD value measured in the raw leachate samples ranged from 2765 to 4880 mg / L and the mean value was 3822.5 mg / L. According to Alvarez-Vazquez et al. (2004), the COD value for fresh / young leachate was more than 15000 mg / L while the stabilized / mature leachate was less than 3000 mg/L. The mean value of suspended solids (SS) for raw leachate is 199.2 mg / L. In addition, the turbidity level for Padang Siding Landfill Sites raw leachate was approximately 81.65 NTU (mean value). The accumulation of decomposed waste increased the concentration of ammoniacal-nitrogen, NH$_3$-N (1396 mg/L) produced by the degradation of soluble nitrogen from solid waste sites. NH$_3$-N has been identified as a primary toxicant that may increase the toxicity of aquatic species.

| Parameter                     | Reading     | Average reading | Standard Discharge |
|-------------------------------|-------------|-----------------|--------------------|
| pH                            | 8.0-8.4     | 8.2             | 6.0-9.0            |
| COD (mg/L)                    | 2765-4880   | 3822.5          | 400                |
| Suspended Solids, SS (mg/L)   | 87.7 – 310.7| 199.2           | 50                 |
| Turbidity (NTU)               | 75.4 – 87.9 | 81.65           | -                  |
| Ammoniacal nitrogen, NH$_3$-N (mg/L) | 1248 – 1544 | 1396            | -                  |

a=Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill) Regulations, 2009 (ILBS, 2014) [5]
3.2 Effect of pH on coagulation-flocculation process

pH is a parameter that plays an important role in the coagulation-flocculation process for removal of contaminated compounds. Figure 1 shows the highest percentage removal of turbidity and COD by using *Cactus opuntia* as coagulant were 69.4% and 63.1% respectively at pH 2. Additionally, the turbidity and COD removal efficiencies were decreased as the pH was increased. pH 3 was better than pH 1 for both responses where pH 3 with the removal percentage of 70.9% for turbidity removal and 65.7% for COD removal. From figure 2, the highest turbidity and COD removal efficiency values for alum as coagulant were achieved at pH 5. The percentage turbidity removal was 62.7% while the percentage of COD removal was 40% at the same pH level. This phenomenon is in agreement with [2] that the extent of pH value not only depends on the type and concentration of coagulant but also depends on the characteristics of wastewater.

![Figure 1](image1.png)

**Figure 1.** Percentage of turbidity and COD removal against pH (*Cactus opuntia*).

![Figure 2](image2.png)

**Figure 2.** Percentage of turbidity and COD removal against pH (alum).
3.3 Effect of dosage on coagulation-flocculation process

The study regarding the effect of coagulant dosage on the turbidity and COD was done via the experimental work using jar test apparatus by varying the coagulant dosage (1000 ~ 10000 mg / L) for both coagulants used while keeping other variables constant such as pH, mixing speed and duration of mixing for both rapid and slow mixing. The pH for aluminium dosage determination was maintained at pH 2 while the pH for *Cactus opuntia* dosage determination was maintained at pH 5. Moreover, the results of the effects of coagulant dosages for both alum and *Cactus opuntia* on the removal of turbidity and COD from landfill leachate were shown in figure 3 and figure 4. Figure 3 and figure 4 show that the removal of turbidity and COD increases as both *Cactus opuntia* and aluminium doses increase. Removal efficiency of turbidity by the use of *Cactus opuntia* as coagulant was observed to increase linearly to 66.8 per cent at a dose of 8000 mg/L but decreased as *Cactus opuntia* was added to 10000 mg/L with a turbidity removal efficiency value of 53.5, compared with 42 per cent at a dose of 8000 mg/L for COD removal efficiency.

Figure 3 shows the effect of different doses of *Cactus opuntia*. A consistent increase in turbidity removal was observed and the highest dose 8000 mg / L removal was achieved with an efficacy of 66.8 per cent. In addition, the removal of turbidity decreased steadily with an increase in dose. The optimal dose of cactus *opuntia* at 8000 mg / L reduced the COD value by as much as 42 percent. It may also be assumed that the initial pH of the leachate was not within the range of the coagulation-flocculation process.

At the initial stage, both turbidity and COD removal increased smoothly. However, the values then decreased with an increased in dosage followed by a consistent increase and reached a maximum dose of 8000 mg / L. An optimal coagulant dose of 8000 mg / L induced a 94.5 percent turbidity removal and 69 percent for COD removal. On the other hand, *Cactus opuntia* coagulant also showed the same effect as alum coagulant. In addition, the removal efficiency of the parameters could be further enhanced by increasing the dosage until the optimum value is reached. This condition may have been attributed to the restabilization of the colloids when the coagulant was used in excessive quantities.

![Figure 3. Percentage of turbidity and COD removal against dosage (Cactus opuntia).](image-url)
3.4 **Sludge Volume Index (SVI) for alum and Cactus opuntia under optimized conditions**

From figure 5, SVI for alum was higher than *Cactus opuntia*. The SVI treated by alum was 42.2 whereas *Cactus opuntia* approximately 4.45. Even though the removal of turbidity was achieved at 66.8 NTU, *Cactus opuntia* was not able to get such better removal [6]. According to [6], it stated that this was due to the development of a number of smaller flocs which were not able to grow in size or attach with larger flocs, and thereby were unable to settle within 30 minutes settling time. Both alum and *Cactus opuntia* gave ratio of 9:1. Although both coagulants were classified in the range below than 10 mg/L, *Cactus opuntia* produces relatively compact and less sludge with rapid settling rate as compared with alum. Excess volume of sludge produced by using alum may induce detrimental issues to operator who handling the sludge discharge and disposal.

4. **Conclusion**

This study has successfully explored the treatment of landfill leachate using *Cactus opuntia* as a coagulant. *Cactus opuntia* effectively removed 66.8 per cent of turbidity and 42 per cent of COD under
optimum pH 2 and a favourable dose of 8000 mg/L. In comparison, the use of chemical coagulant (alum) at pH 5 at an optimum dose of 8000 mg/L induced 94.5 per cent turbidity and 69 per cent COD in the same leachate sample. The SVI of alum coagulant was 42.2 while for cactus opuntia it was 4.45 with a relative ratio of alum to cactus opuntia of 9:1. In addition, the abundant cactus opuntia source which can easily be found in several tropical and subtropical countries has a potential value to be used as a wastewater treatment coagulant.

Acknowledgements
The author would like to acknowledge the support from University Malaysia Perlis for the instrument used, laboratory equipment and chemicals.

References
[1] Adhikari, B. &. (2015, January). Qualitative Study of Landfill Leachate from Different Ages of Landfill Sites of Various Countries Including Nepal. J Environ Sci Toxicol Food Technol, 9(1), 23-36
[2] Aziz, H.A., Alias, S., Adlan, M.N., Faridah, Asaari, A.H., Zahari, M.S., 2007. Colour removal from landfill leachate by coagulation and flocculation process. Bioresour. Technol. 98, 218–220
[3] Miller, S. E. (2008). Toward understanding the efficacy and mechanism of Opuntia spp. as a natural coagulant for potential application in water treatment. Environ. Sci. Technol 76, 4274-4279
[4] APHA (2012) Standard Methods for the Examination of Water and Wastewater. 22nd edition. American Public Health Association, Washington DC
[5] International Law Book Services (2014). Law of Malaysia- Environmental Quality Act 1974 (Act 127) Regulations, Rules, Orders. Kuala Lumpur, Malaysia
[6] Arslan, M. W. (2015, April). A Preliminary Study of Opuntia stricta as a Coagulant for Turbidity Removal in Surface Waters. Proc. Pakistan Acad. Sci 52(2) 117-124