

BENCH SCALE MODEL STUDIES ON SANITARY LANDFILL LEACHATE TREATMENT WITH *M. OLEIFERA* SEED EXTRACT AND HOLLOW FIBRE MICRO-FILTRATION MEMBRANE

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Abstract

A laboratory-based study using a Bench Scale model of four unit operations made up of coagulation (using *Moringa oleifera* seed extract as a coagulant), flocculation, sedimentation and micro-filtration, have been adopted to treat the leachate from Air Hitam Sanitary Landfill at Puchong in Malaysia. *M. oleifera* dosages of 150 and 175 mg/L had achieved 43.8% Cadmium removal, 21.2% Total Chromium removal, 66.8% Lead removal and 16% Iron removal. It also removed 55.4% of Total Suspended Solids, 10 % of Total Dissolved Solids and 24.2% of Volatile Suspended Solids. Micro-filtration hollow fibre membrane decreased the turbidity, total suspended solids, total dissolved solids, volatile suspended solids, and organic matter in the leachate by 98.3%, 96.7%, 20.8%, 36.6%, and 21.9% respectively. Overall heavy metals removal after micro-filtration using hollow fibre membrane was 94% for Cadmium, 29.8% for Total Chromium, 73.2% for Lead, and 18.3% for Iron. The results have shown that *M. oleifera* is a promising natural polymer for removing heavy metals from leachates and may be used as a pre-treatment to eliminate a portion of the toxic heavy metals, which limits the activity of micro organisms in the leachates.

1. Introduction

With growing population, affluence, and fast development in industrial sector, a huge volume of municipal, commercial, and industrial solid wastes are being produced. The disposal of these large quantities of material in a sanitary landfill conveys with it an inherent potential for pollution of indigenous water resources. A major environmental impact resulting from the disposal of solid waste into a sanitary landfill occurs when water, either from rainfall or groundwater, passing through the refuse accumulates various contaminants by dissolved organic and inorganic components and decomposition products. This percolated liquid, otherwise called leachate, is considered very harmful and toxic. Leachate is one of the major pollution sources having serious impact on the environment. The disposal of wastes is recognized as one of the most difficult tasks associated with the operation of landfills. The containment and treatment of leachate is necessary to avoid or minimize contamination of adjacent ground or surface water resources.

Various measures have been taken in designing sanitary landfill to contain the leachate to avoid contamination of adjacent ground or surface water. Such control measures include (i) daily cover and upland diversion ditches to prevent surface water from entering the landfill, (ii) impervious liners and dikes to prevent leachate from entering adjacent surface and ground water, and (iii) on-site leachate collection and treatment systems.

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Biological treatment is the most widely used method to handle the leachate before discharge to water sources. Several studies have been conducted on leachate treatment. Experiments were carried out to treat a medium-strength leachate of COD 5000 mg/l using aerobic biological processes in continuous-flow laboratory-scale reactors at low temperatures (Robinson and Maris, 1983). The ability to treat hazardous landfill leachate by biological and physical means was studied through an extensive pilot study on the BKK landfill leachate by comparing biophysical (Powdered Activated Carbon Treatment) and conventional activated sludge treatment processes (Lebel *et al.*, 1989). Treatments of three types of landfill leachate by reverse osmosis have been studied (Linde *et al.*, 1995a). The possibility of treating a landfill leachate from special waste had also been investigated using Nano Filtration (NF) (Linde *et al.*, 1995b). Organic matter removal of 92-95% had been achieved by biological treatment, 70% of heavy metals (cadmium, zinc, lead and chromium) were removed from the leachate using NF membrane. Up to 98% of organic matter, 93% cadmium, 83% chromium and 99% iron were removed from the leachate using reverse osmosis membrane.

The existence of toxic heavy metals such as cadmium, chromium and lead in the leachate, limits the activity of micro-organisms and decreases the efficiency of the biological treatment. Consequently, the characteristics of the leachate effluent will not be of high quality that can meet the Environmental Water Quality Regulations and Standards in Malaysia.

In the present study, a laboratory Bench Scale model using a physico-chemical process (coagulation-flocculation-sedimentation) and micro-filtration was developed to investigate the performance of *Moringa oleifera* seed extract as a natural organic polymer for removing heavy metals.

2. Mechanisms of *M. oleifera* and micro-filtration in contaminant removal

M. oleifera is an organic natural polymer with an active ingredient, polypeptide, acting as cationic polymer. The active ingredients in an aqueous *M. oleifera* extract are dimeric proteins, with a molecular weight of about 13000 Daltons, and iso-electric point of between 10 and 11 (Ndabigengesere *et al.*, 1995). The mechanism of coagulation with *M. oleifera* appears to consist of adsorption and neutralisation of the colloidal charges. The purified proteins are more effective coagulants than alum. Sludge produced by *M. oleifera* coagulation is not only innocuous, but also four to five times less in volume than the chemical sludge produced by alum coagulation (Ndabigengesere *et al.*, 1995). As *M. oleifera* is a cationic polyelectrolyte, the optimum dosage is found to be proportional to the size of the suspended particles. The smaller size particles always produce larger masses of flocs (Muyibi and Evison, 1996). Since *M. oleifera* is a short chain low molecular weight with high charge density, the flocculation activity may be explained by the electrostatic patch charge mechanisms. Positively charged proteins bind parts of the surface of the negatively charged particles. This leads to the formation of negatively and positively charged parts of particle surfaces. Due to particle collision enhanced by agitation, inter-particle saturation of the differently charged sectors occurs and formation of flocs takes place (Gassenschmidt *et al.*, 1995).

Filtration is the process of separating dispersed particles from a dispersing fluid by means of porous media. Micro-filtration (MF) membrane is a porous membrane; its size cut-off range is from 0.05 to 1.5 μm . MF processes are used to remove turbidity and chlorine-resistant pathogens such as *cryptosporidium* and *giardia*. Depending on their cut-off limit, MF

membranes may also remove bacteria but do not offer complete removal of viruses. They are typically operated at a differential pressure of less than 1 bar and at flux rates up to 150 l/m²h (Casey, 1997). A major problem associated with operation of MF is the fouling of the membrane. Fouling is the term used to describe the loss of throughput of a membrane as it becomes chemically or physically changed by the process fluid (Eykamp, 1995). Membrane fouling is considered a major limitation of the membrane filtration process. It is caused by the gradual build-up of a fouling layer (cake formation) on the membrane surface. This layer may consist of colloidal particles, iron and/or manganese oxides, and a bio film. The cake formation may also be due to inorganic scale-formation (Casey, 1997). In order to control cake formation, two actions can be undertaken: (a) prevent the particles reaching the membrane by using abrasives (air diffusers under the membrane), filtration aids, coagulants, and electro filtration. (b) Flushing them out by periodic backwashing, ultrasound fields and pulsated flow to remove the particles already located in the membrane or at its surface (Al-Malack and Anderson, 1996).

3. Materials and Methods

3.1 Materials

Leachate samples, Collection and Preservation

Leachate samples have been obtained from Air Hitam Sanitary Landfill in Puchong, Selangor State of Malaysia, which handles solid waste of about 4000 tonnes per day from seven councils within the Selangor State in Malaysia. The average daily amount of leachate produced is 100 m³. This leachate is discharged to three sumps through gravity pipes collection system. The leachate is then pumped to three aeration ponds for biological treatment. The treatment system used in this site is a batch process, with a retention time of 24 hours. The leachate is discharged to sedimentation ponds after aeration stage, then to a filtration system consisting of three sand filter columns before the effluent is discharged into a stream. The leachate samples used in the experiment were taken from the sump in tightly closed plastic containers, in order to avoid exchange of gases with the surroundings. The sample was transferred to the laboratory and refrigerated at 4°C up to the time of the experimental run to minimize microbiological decomposition of solids (APHA *et al.*, 1998).

Preparation of M. oleifera seed suspension (stock solution)

The *M. oleifera* seeds used as a coagulant in this study were obtained from Seremban in Malaysia. Good qualities of dry *M. oleifera* seeds were selected. The seed wings and coat were removed and the kernel was ground to a fine powder using the coffee mill attachment of a Moulinex domestic food blender. In order to explore a higher efficiency of using *M. oleifera* as coagulant, oil was extracted first from the powder (Muyibi *et al.*, 2001) using hexane solvent (Ndabigengesere and Narasia, 1998).

Five grams of the *M. oleifera* cake after extraction of oil was put in a beaker and 400-ml distilled water added. The mixture was poured into a high-speed mixer of a Moulinex domestic blender and mixed at high speed for 2 minutes to extract the active ingredients. The resulting suspension was filtered through a muslin cloth and the filtrate made up to 500 ml to give a stock solution of approximately 10,000 mg/l.

Jar test trials proved that the stock solution of 10,000 mg/l was found more effective for removal of turbidity, organic matter and heavy metals. Therefore, it was used for all jar test

trials to determine the optimum speed and time for rapid mixing, and the effective dosage of *M. oleifera*.

Experimental Bench Scale Model

A schematic diagram of the experimental set-up is shown in Figure 1. Raw leachate sample was discharged into a 30-litre rapid mixing tank for the coagulation process. The effective dosage of *M. oleifera* at the optimum speed and time of mixing was predetermined previously from jar tests. The mixture was then passed into a 32-litre slow mixing tank for the flocculation process at optimum speed and time. A settling time of one hour was allowed in the slow mixing tank before the supernatant was discharged into filtration tank, which has a volume of 30 litres. Filtration was carried out using submerged micro-filtration hollow fibre membrane of 0.1 μm surface pore hole diameter (D_p), (Model UMF022421-TOYOTA TSUSHO Corporation). Suction pressure from a Master Flex pump was used to collect the filtered water.

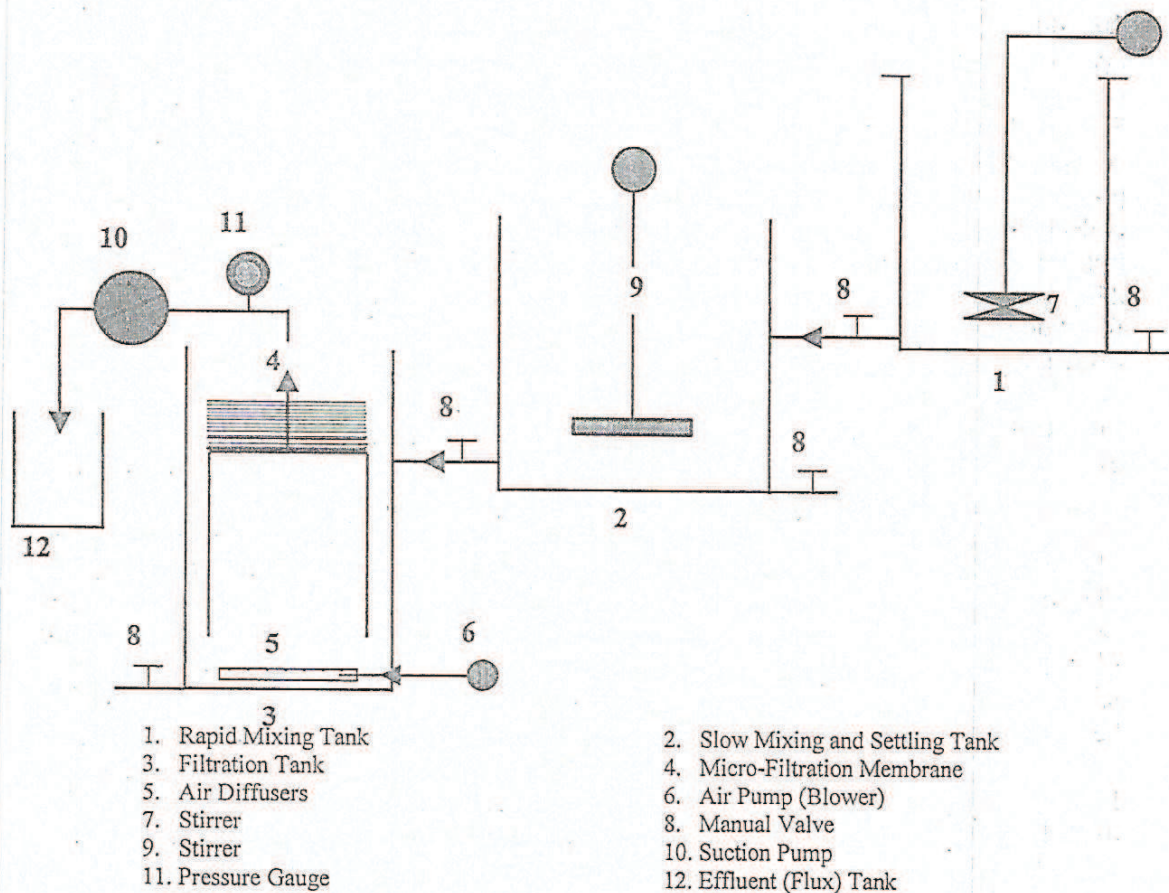


Figure 1: Schematic diagram of the Bench Scale Model for leachate treatment with *M. oleifera* seeds and MF hollow fibre membrane

The filtration tank was provided with 3 diffusers installed under the membrane to generate a cross-flow stream of air bubbling to remove the cake layer formation. The air bubbles flow upward with a fluid along the membrane surfaces and induce a moderate shear stress that generates the back-transport of filtered colloidal particles from the membrane surfaces.

Description of the experimental Jar Test trials

Jar tests have been adopted in the preliminary trials and in all other trials for determination of the effective concentrations of *M. oleifera* seed extracts, optimum speed and time for rapid and slow mixing and for the determination of the effective *M. oleifera* dosage.

Preliminary Jar Test Trials

Five preliminary trials were carried out with 50,000 mg/l and 10,000 mg/l *M. oleifera* stock solutions to determine the effective concentrations of *M. oleifera*. The speed and time for rapid and slow mixing were fixed to be 100 rpm for 4 minutes and 30 rpm for 20 minutes, respectively. Leachate samples were taken out from the refrigerator and left to adjust to room temperature. Six beakers of 500 ml capacity were washed with distilled water and dried and 400 ml of leachate sample was poured in to each of the six beakers. Dosages varying from 150 to 650 mg/l, 25 to 175 mg/l and 50 to 175 mg/l, were added to each of the six beakers simultaneously. The leachate was agitated by the stirrer at 100 rpm for 4 minutes, and then at 30 rpm for 20 minutes. The leachate was allowed to settle for 30 minutes. Raw leachate and the supernatant from each of the six beakers were analysed directly or after filtration with glass micro-fibre filters GF/C (47mm diameter circles-1.2 µm pores size, Whatman, England) for chemical oxygen demand (COD) using closed reflux, titration method (APHA et al., 1998). Heavy metals (cadmium, chromium and lead) were analysed using atomic absorption spectrophotometer (Perkin Elmer, model 5100 Pc). The pH, temperature, and turbidity of the leachate were also measured. The effective dosage concentrations of *M. oleifera* were found to be 50, 75, 100, 125, 150, and 175 mg/l.

Optimisation of speed and time for rapid and slow mixing

The matrix of different *M. oleifera* dosages and the variable speeds and times of mixing as shown in Table 1, have been used to determine the optimum speed and time of rapid and slow mixing that will give the best removal of cadmium in order to apply it for the operation of the Bench Scale model. The values of rapid and slow mixing shown in the table have been chosen from past experiments (Yeh and Huan, 1993; Amirtharajah et al., 1993; Booker et al., 1991). Nine trials were done to determine the optimum speed and time of rapid mixing. For each trial, a 400 ml of the leachate sample was put in each of 6 half-litre beakers and placed under the jar test apparatus. The paddles were inserted with the varying speed and time stated in the table to agitate its content while the different dosages of *M. oleifera* stock solution were added to the beakers simultaneously. After settling for 30 minutes, the supernatant of each beaker was filtered before analysis for cadmium as the control parameter. The values obtained have been compared to determine the optimum speed and time for rapid mixing according to the best amount of cadmium removal. The optimum speed and time for rapid and slow mixing that were applied to the Bench Scale model runs after the optimisation studies were found to be 100 rpm for 8 minutes, and 30 rpm for 20 minutes respectively.

Cadmium was chosen as a control parameter for the determination of optimum speed and time for rapid and slow mixing and for the determination of the effective dosage of *M. oleifera*.

**Table 3: Raw leachate characteristics of the four leachate samples
(October to November, 2000)**

Parameter	Unit	Concentration of raw leachate
Temperature	°C	25.5-28.7
pH	----	6.47-9.03
Turbidity	NTU	105-2980
Total alkalinity	mg/l as CaCO ₃	248.4-345.6
Total suspended solids (TSS)	mg/l	0.038-2.64
Total dissolved solids (TDS)	mg/l	11.582-27.77
Volatile suspended solids (VSS)	mg/l	2.402-14.07
Chemical oxygen demand (COD)	mg/l	3200-54400
Cadmium	mg/l	0.0026-0.0768
Total chromium	mg/l	0.4947-0.85
Lead	mg/l	0.0538-0.5570
Iron	mg/l	5.716-35.04

Tables 4, 5, 6 and 7 show the results of the experimental runs.

Table 4: Analysis of treated leachate after coagulation process and after MF process with *M. oleifera* dosage of 175 mg/l (1st sample-2nd run)

Parameters	Concentration of raw leachate	Effluent concentration after	
		Coagulation	Micro-filtration
Temperature [°C]	25.5	29	30.8
pH	8.85	8.86	8.94
Turbidity [NTU]	108	120	4.78
Total alkalinity [mg/l as CaCO ₃]	248.4	249.6	266
Total suspended solids (TSS) [mg/l]	0.038	0.030	0.004
Total dissolved solids (TDS) [mg/l]	15.406	14.398	13.606
Volatile suspended solids (VSS) [mg/l]	5.140	3.898	2.470
Chemical oxygen demand (COD) [mg/l]	6240	6448	5120
Cadmium [mg/l]	0.048	0.027	0.026
Total chromium [mg/l]	0.85	0.74	0.66
Lead [mg/l]	0.23	0.16	0.10
Iron [mg/l]	6.71	6.17	5.85

Table 5: Analysis of treated leachate after coagulation and MF processes with *M. oleifera* dosage of 150 mg/l (2nd sample-2nd run)

Parameters	Concentration of raw Leachate	Effluent concentration After	
		Coagulation	Micro-Filtration
Temperature [°C]	28.7	29.3	31.3
pH	9.03	8.88	9.29
Turbidity [NTU]	186	183	4.38
Total alkalinity [mg/l as CaCO ₃]	345.6	211.2	242.4
Acidity [mg/l as CaCO ₃]	-----	-----	-----
Total suspended solids (TSS) [mg/l]	0.166	0.074	0.040
Total dissolved solids (TDS) [mg/l]	11.582	11.840	11.152
Volatile suspended solids (VSS) [mg/l]	2.280	2.912	2.292
Chemical oxygen demand (COD) [mg/l]	3200	4480	3200
Cadmium [mg/l]	0.0072	0.0048	0.0039
Total chromium [mg/l]	0.4947	0.4614	0.4136
Lead [mg/l]	0.0644	0.0214	0.0564

Table 6: Analysis of treated leachate after coagulation process and after MF process with *M. oleifera* dosage of 150 mg/l (3rd sample-3rd run)

Parameters	Concentration of raw leachate	Effluent concentration after	
		Coagulation	Micro-Filtration
Temperature [°C]	28.1	30.3	31
pH	8.97	8.91	9.02
Turbidity [NTU]	105	116	6.67
Total alkalinity [mg/l as CaCO ₃]	286.4	264	266.4
Acidity [mg/l as CaCO ₃]	-----	-----	-----
Total suspended solids (TSS) [mg/l]	0.086	0.098	0.048
Total dissolved solids (TDS) [mg/l]	13.064	12.668	11.898
Volatile suspended solids (VSS) [mg/l]	2.402	3.492	2.896
Chemical oxygen demand (COD) [mg/l]	5280	5440	5440
Cadmium [mg/l]	0.0026	0.0015	Not Detected
Total chromium [mg/l]	0.5600	0.5670	0.4370
Lead [mg/l]	0.0538	0.0311	0.0367
Iron [mg/l]	5.7160	4.796	4.028

Table 7: Analysis of treated leachate after coagulation process and after MF process with *M. oleifera* dosage of 125 mg/l (4th sample-1st run)

Parameters	Concentration of raw leachate	Effluent concentration after	
		Coagulation	Micro- Filtration
Temperature [°C]	27	27	27.3
pH	6.47	6.41	6.43
Turbidity [NTU]	2980	2870	47.9
Total alkalinity [mg/l as CaCO ₃]	250	247.4	237.2
Acidity [mg/l as CaCO ₃]	-----	-----	-----
Total suspended solids (TSS) [mg/l]	2.64	2.12	0.071
Total dissolved solids (TDS) [mg/l]	27.77	34.2	29.175
Volatile suspended solids (VSS) [mg/l]	14.07	22.25	15.14
Chemical oxygen demand (COD) [mg/l]	54400	54400	52800
Cadmium [mg/l]	0.0768	0.0432	0.0058
Total chromium [mg/l]	0.5070	0.5010	0.3820
Lead [mg/l]	0.5570	0.4270	0.1920
Iron [mg/l]	35.04	35.49	29.70

pH and Total Alkalinity

pH after application of *M. oleifera* and MF did not significantly change. It decreased slightly after coagulation process, while it increased slightly after MF process. The decrease in pH may be due to hydrogen ions of the weak acidity of *M. oleifera* stock solution (pH = 6.44), which balanced the hydroxide ions of the weak alkalinity of the leachate (pH = 8.85-9.03).

Alkalinity of the leachate samples had decreased after the coagulation process with *M. oleifera* dosages varying from 100 to 175 mg/l. The maximum decrease in alkalinity of the leachate was 38.88% (345.6-211.2 mg/l) after the coagulation process with the effective *M. oleifera* dosage of 150 mg/l (Table 5). After the MF process, alkalinity of the effluent had increased during all runs of the 1st, 2nd and 3rd trials, while it decreased with all the 4th trial runs. The maximum increase in alkalinity was 14.77% (211.2-242.4 mg/l), which might be due to the increase in the hydroxide ions, resulting from re-stabilization of colloidal flocs into dissolved solids. The decrease in alkalinity during coagulation may be due to the decrease in the hydroxide ions, resulting from the adsorption of some dissolved solids by *M. oleifera*.

Turbidity

Turbidity of raw leachate samples varied from 105 to 2980 NTU. After the coagulation process with the effective *M. oleifera* dosages, turbidity of the leachate increased in most of

the experimental runs, while it decreased a little bit with few other runs. The maximum increase in turbidity was 10.50% (105-116 NTU), while the maximum decrease was 6% (2980-2800 NTU). After MF process, the maximum turbidity removal was found to be 98.33% (2870-47.9 NTU). The increase in turbidity of the leachate after the coagulation process is due to the very minute floc particles of *M. oleifera*, which did not settle and remained as colloidal material or micro-floc in the leachate. The upper limit of the colloidal material is approximately 1 μ m and the lower limit is approximately 5 nm. Suspended solids consisted of particulate larger than approximately 0.5 μ m. Particulates smaller than 5 nm are considered to be in true solution (McBean *et al.*, 1995). Colloidal particles normally range in size from about 1 to 1000 nm, and for the most part are not visible even with the aid of the ordinary optical microscope (Sawyer *et al.*, 1994)

Acidity

The results showed that no mineral acids were available in the leachate due to the high pH, so no acidity was recorded.

Total suspended solids (TSS)

TSS of the raw leachate samples varied from 0.038 to 2.64 mg/l. After the coagulation process, TSS of the leachate had decreased by 55.42% as the maximum with the dosage of 150 mg/l and by 10.52% (0.038-0.034 mg/L) as the minimum with the dosage of 150 mg/l. TSS removal accomplished by MF hollow fibre membrane varied from 22.85% (0.070-0.054 mg/l) to 96.65% (2.12-0.071 mg/l). The best overall TSS removal was 97.46% (2.64-0.067 mg/l). The MF hollow fibre membrane could not achieve 100% TSS removal due to its pore size of 0.1 μ m that could not retain the minute particles. The upper and lower limits of the colloidal material are approximately 1 μ m and 5 nm respectively. Suspended solids consisted of particulate larger than 0.5 μ m. Particulate smaller than 5 nm are considered to be in true solution (Montgomery *et al.*, 1985).

Total dissolved solids (TDS)

TDS of the raw leachate samples varied from 11.6 to 27.8 mg/l. After the coagulation process, TDS of the leachate decreased a little bit with leachate samples of low turbidity (105-108 NTU), while it increased with samples of higher turbidity (186-2980 NTU). The maximum decrease was 9.98% (15.406-13.868 mg/l) with the dosage of 150 mg/l. While the maximum increase was 26.93% (27.77-35.25 mg/l) with the dosage of 175 mg/l. The decrease in TDS might be due to the absorption mechanisms of *M. oleifera*, while the increase might be due to *M. oleifera* seeds extract itself that contains significant concentrations of dissolved substances (Muyibi *et al.*, 2001). After MF process TDS lowered by 20.83% (35.25-27.905 mg/l) as a maximum value and by 2.97% (13.868-13.456 mg/l) as a minimum value. The best overall TDS removal was 17.79% (13.064-10.740 mg/l).

Volatile suspended solids (VSS)

The VSS of the raw leachate samples varied from 2.28 to 14.07 mg/l. After the coagulation process, VSS of the leachate increased in most of the runs, while it decreased in few other runs. The maximum increase in VSS was 58.84% (14.07-22.35 mg/l), while the maximum decrease was 24.16% (5.140-3.898 mg/l). VSS of the effluent after micro-filtration process decreased in the range of 13.11% (3.524-3.062 mg/l) to 36.63% (3.898-2.470 mg/l) in the 4th leachate sample. The best overall VSS removal was 51.94% (5.140-2.470 mg/l).

Chemical oxygen demand (COD)

The COD of the raw leachate samples varied from 3200 to 54400 mg/l. After the coagulation process with *M. oleifera* dosages varying from 100 to 175 mg/l, organic matter in the leachate increased in most of the experimental runs, while it decreased in few other runs. The maximum increase was 40% (3200-4480 mg/l) with the dosage of 125 and 150 mg/l, while the maximum decrease was 6.67% (6240-5824 mg/l) with the dosage of 150 mg/l. However 28.57% (4480-3200 mg/l) of organic matter removal was achieved by MF hollow fibre membrane. The best overall organic matter removal was 24.24% (5280-4000 mg/l). The crude water extract of *M. oleifera* seeds contains significant concentrations of organic matter present (Ndabigengesere and Narasiah, 1998). After the coagulation process, some of the organic matter remained in the treated leachate, thus increasing its COD. The availability of organics in the leachate may be in soluble and colloidal forms, hence the MF membrane surface pore size of 0.1 μm can retain a small portion of organic matter in the leachate. This will tend to increase the efficiency of the membrane to retain smaller particles. Since *M. oleifera* is also an organic substance, it will therefore increase the COD of the leachate, and as a result, fail to remove dissolved COD. This increase in COD after the coagulation process may be due to the very minute particles of *M. oleifera*, which remained as dispersion colloidal particles.

Heavy metals

An increase in the concentration of some heavy metals in the leachate after the coagulation process or after MF process might be due to stirring and aeration. Most of the colloidal particles re-stabilized into dissolved solids. Colloidal-sized particles may be formed from ions that react to form insoluble compounds. Under the proper conditions, aggregates of molecules do not grow into crystals of a size large enough to settle or be filtered out (Sawyer *et al.*, 1994).

Cadmium

The concentration of cadmium in raw leachate samples varied from 0.0026 to 0.0768 mg/l. Best cadmium removals were 43.75% (0.048-0.027 mg/l) with the dosage of 175 mg/l and 43.75% (0.0768-0.0432 mg/l) with the dosage of 125 mg/l, while that achieved by MF hollow fibre membrane was 94% (0.0538-0.0032 mg/l). The overall cadmium removal attained its highest value of 95.83% (0.0768-0.032 mg/l).

Total chromium

The concentration of chromium in raw leachate samples varied from 0.4947 to 0.85 mg/l. Best chromium removals were 21.17% (0.85-0.67 mg/l) with the dosage of 150 mg/l, while that achieved by MF hollow fibre membrane was 29.81% (0.587-0.412 mg/l). The best overall chromium removal was 27% (0.4947-0.3611 mg/l).

Lead

The concentration of lead in raw leachate samples varied from 0.0538 to 0.557 mg/l. Up to 66.77% (0.0644-0.0214 mg/l) removal was achieved with 150 mg/l dosage, while with MF hollow fibre membrane, 73.2% (0.418-0.112 mg/l) was removed. The overall lead removal was 79.9% (0.557-0.112 mg/l).

Iron

The concentration of iron in raw leachate samples varied from 5.716 to 35.04 mg/l. In this case, the best iron removals were 16% (5.716-4.796 mg/l) with the dosage of 150 mg/l, while

that achieved by the MF hollow fibre membrane process was 18.28% (5.218-4.264 mg/l). The overall iron removal was 29.53% (5.716-4.028 mg/l).

5. Conclusion

M. oleifera was found to be inefficient in the removal of organic matter from leachate. It also had minimal effect in changing the pH of the effluent after treatment. Micro filtration process that followed the application of *M. oleifera* was able to achieve heavy metal removals of 98 % for cadmium, 73.2 % for lead, 29.8 % for total chromium and 28 % for iron respectively. For TSS, TDS and VSS, overall solid removals after treatment were 98.3, 96.7 and 20.8 % respectively.

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