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Treatment of Taman Beringin landfill leachate using the column technique

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ABSTRACT

Landfill leachate is currently a major environmental concern because it contains high concentrations of organic and inorganic contaminants. Leachate treatment using natural materials, such as aquifer sand, peat, and the commercial material BIRM (Burgess Iron Removal Media), was performed through column experiments. Aquifer sand was taken from Kg Teluk, Kelantan, peat was taken from Peatland Paradise, and BIRM was bought from a supplier. The heavy metals (Fe^{3+}, Cr, Ni, and Cu) from natural leachate were selected for this experiment. The concentrations of Fe, Cr, Ni, and Cu before the experiment were 11, 1.27, 4.535, and 3.293 mg L^{-1}, respectively. The physical and chemical parameters of leachate and surface water at the Taman Beringin Landfill have been studied to understand the impact of pollution in the area. The results show that leachate samples at the bottom of the landfills have the highest pollution. Both the physical and chemical parameters of leachate exceed the limits of Interim National Water Quality Standards for Malaysia. Experimental test results were also analyzed in terms of breakthrough curves and percentage of heavy metal removal. The results show that the BIRM sample has a higher adsorption capacity for heavy metals, including Fe, compared with aquifer sand and peat.

Keywords: Open tipping; Landfill leachate; Contaminant treatment; Natural materials; Efficiency

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1. Introduction

Landfills have been identified as one of the major threats to groundwater resources worldwide [1]. The solid wastes placed in landfills or open dumps are subjected to groundwater underflow, infiltration from precipitation, and any other possible infiltration of water. During rainfall, the dumped solid wastes receive water, and the by-products of their decomposition move into the water through waste deposition. The liquid, containing innumerable organic and inorganic compounds, is called "leachate." This leachate accumulates at the bottom of the landfill, percolates through the soil, and reaches the groundwater [2].

Currently, Malaysia is facing solid waste management problems, as industrialization is actively being pursued so that it can become a high-income nation by the year 2020.

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There is a total of 230 landfills in Malaysia. Open dumping is being practiced at approximately 50% of these landfills. Last year, approximately 7.34 million tons of solid wastes were generated, and each person generates approximately 1 kg of solid waste per day. This solid waste volume is still increasing at the rate of 1.5% annually due to increasing urbanization and changes in living standards and consumption patterns [3].

The majority of the landfills in Malaysia are crude dumping grounds, which cause natural resource pollution and various environmental problems, such as health hazards, surface water and groundwater contamination, and odors. There are other treatment and/or disposal methods, such as incineration and composting, that could moderate the solid waste problems, but they are not economically and socially viable at this moment. Thus, waste reduction, recovery, and recycling play important roles in addressing the pressing solid waste problems. In conjunction with the increasing number of sanitary landfills, leachate treatment has become a major environmental issue, particularly among regulatory agencies and environmentalists [4]. The treatment of landfill leachate is of concern because it has the potential to degrade the environment. Leachate is a potential hazardous waste from landfill sites. Malaysian solid wastes contain a high proportion of organic waste and thus have a high moisture content and a bulk density above 200 kg m^{-3}. A recent study conducted in Kuala Lumpur has revealed that the proportion of organic wastes for residential areas ranges from 62% to 72% [5]. Therefore, leachate production may arise because most solid wastes have a high moisture content and a high proportion of organic matter.

Most organic matter contained in solid waste is biodegradable and can be broken down into simpler compounds by anaerobic and aerobic microorganisms, leading to the formation of gas and leachate. Leachate is defined as liquid that has percolated through solid waste and has extracted dissolved or suspended materials from it. It arises from the biochemical and physical breakdown of waste [6]. Landfill leachate characteristics vary depending on the operation type and age of the landfill. Leachate is initially a high-strength wastewater, containing high concentrations of organic matter, inorganic matter, and heavy metals [7]. Risks arise from waste leachate due to its high heavy metal concentration. Major sources of heavy metals in landfills include co-disposed industrial waste, incinerator ash, mine waste, and household hazardous substances. The heavy metal contents in landfill layers are considerably higher than the background level in surface soil samples [8–15]. The pollution potential of heavy metals from landfill leachate is extremely high. The Department of Local Government stated that the majority of the landfills in Malaysia were built and being operated without proper monitoring facilities and pollution controls, such as liner materials, groundwater monitoring wells, leachate collection and treatment ponds, and methane gas ventilation pipes [9–20]. The landfills were not subject to the Environmental Impact Assessment (EIA) requirement because they were built prior to 1989, when the EIA requirement was enacted. The data on the composition of leachate are important in determining its potential impact on the quality of nearby surface water and groundwater [10]. Leachate often contains high concentrations of both organic matter and inorganic ions, including heavy metals. National Hydraulic Research Institute of Malaysia states that the landfills in Malaysia can be classified into 4 categories [11]:

- Landfills operating at the critical stage without any control to prevent environmental pollution. These landfills will be closed once a new landfill begins to operate.
- Landfill sites (open dumpsites) that have the capacity to receive waste and will be allowed to continue accepting waste but must be upgraded to manage leachate and methane gas.
- Landfills that have already closed (ceased operation) but do not have any safety closure plan prepared.
- Landfills with up-to-date technologies.

The main environmental aspects of leachate are the impacts on surface water quality and groundwater quality, as leachate may migrate from the refuse and contaminate the surface waters and groundwater. If not handled properly, leachate migration can affect aquatic ecosystems, cause human health problems, and affect the environment. Leachates must be treated and contained to prevent this occurrence [12–25]. Therefore, this study has been performed to examine the effectiveness of natural materials (peat and sand) and commercial material (Burgess Iron Removal Media, BIRM) for heavy metal removal from leachate. The main objective of this research is to study the physical and chemical characteristics of the leachate and surface water at the Taman Beringin Landfill and to study the effectiveness and performance of natural materials (peat and sand) and commercial materials (BIRM) in removing heavy metals from leachate.

2. Study area

The study area is located at latitude 03°13.78′ N and longitude 101°39.72′ E in North Jinjang district, Kuala Lumpur Federal Territory, Malaysia. It is approximately 10 km northwest of the Kuala Lumpur city center. This site has been used by Kuala Lumpur City Hall for the disposal of domestic and commercial wastes collected in the city. A waste transfer station was built next to its northern boundary, and residential flats were built south of this site [26–29]. The landfill covers an area of approximately 16 ha. Its disposal activities began in 1991, and it was closed in early 2005. The landfill has caused leachate outbreak into the nearby water body. The nearby water body in this area is Sungai Jinjang. The leachate has interfered with the water quality when it was allowed to flow into this river (Fig. 1).

The landfill was established in ex-mining land. The rapid population growth and development experienced by this urban center have created major environmental problems and issues. One of the major problems is the increase in the amount of solid wastes generated [30]. The solid wastes are mainly derived from various locations or areas including residential, commercial, institutional, industrial, and construction areas. Geologically, the landfill area lies entirely within the Kuala Lumpur Limestone, which is situated in the same area as the Batu Caves and is believed to have been deposited during the Upper Silurian.

Fig. 1. Location of the study area (from Google Maps).

2.1. General geology

The Jinjang area is located above the Kuala Lumpur Limestone Formation, which was metamorphosed from a sedimentary rock to a low-grade metamorphic rock into marble, Hawthornden Schist, granite, and alluvium. The Kuala Lumpur Limestone is also known as the Kuala Lumpur Marble because most of the limestone has undergone low-grade metamorphism [10,13]. According to Gobbett & Hutchison, the Kuala Lumpur Limestone is "Upper Silurian marble, finely crystalline gray to cream, thickly bedded, variably dolomitic rock. Banded marble, saccharoidal dolomite, and pure calcitic limestone also occur" [31]. The limestone outcrop lies to the west of the Hawthornden Schist and occupies the lower half of the area (Fig. 2). In the Batu Caves, the limestone outcrop appears on not only the surface but also beneath the thick alluvial cover, more than 10 m deep. The contact between the limestone and schist is covered by the thick alluvium. The Kuala Lumpur Limestone is predominantly calcitic limestone or calcitic marble [14]. A small quantity of powdery (saccharoidal) dolomite is also found in certain parts of the hill [13]. The age of the limestone formation is believed to be approximately Middle to Upper Silurian. The limestone varies from gray to cream in color and is fine to medium crystalline, with thick bedded, banded marble, saccharoidal dolomite, and pure calcitic limestone with minor interbeds of schist and phyllite [15]. The highly irregular karst topography is believed to have been first discovered in the opencast tin mines nearly 150 y ago. The widespread occurrence of erratic karst is confirmed by deep borehole records from construction sites in the city [16]. This karst feature is believed to have developed during

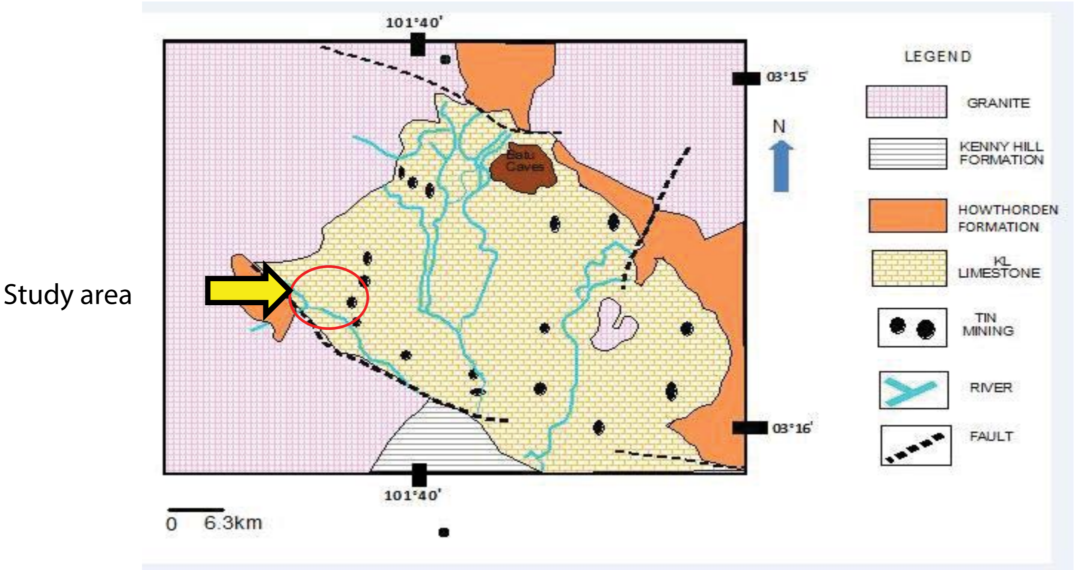

Fig. 2. Digitized geological map of the study area.

the Quaternary period, although considerable dissolution occurred during the deposition of the Permo-Carboniferous Kenny Hill Formation; this paleo-landscape is buried by alluvium to form the current landscape of Kuala Lumpur [17,32–40]. High-rise building construction above the alluvial plain with irregular limestone bedrock has been a longstanding challenge for engineers in Kuala Lumpur [17].

2.2. Hawthornden Schist

This quartz mica schist outcrop is found near the northeastern part of the Kuala Lumpur Limestone. According to a study, the schist outcrop is faulted against the limestone outcrop by the Gombak Fault [10,41]. The quartz mica schist found is typically a fine-grained black schist composed of alternating quartz and dark minerals. The dark minerals are likely iron sulfides or graphite. The formation is the oldest found in the study area and is aged from Ordovician to Lower Silurian.

2.3. Granite

The granites are a part of the Main Range batholith, which continues on the northeastern part of the study area. The young granitoid intrudes in the older metasedimentary rock of quartz mica schist and graphitic schist along with the limestone outcrop. The contrasts (boundaries) between the granite, Hawthornden Schist, and Kuala Lumpur Limestone are not visible because they are overlain by a thick alluvial plain. The granite is divided into three types, porphyritic biotite granite, micaceous microgranite, and sheared granite [10,42–44]. The medium- to coarse-grained megacrystic biotite granite comprises nearly 90% of the three types of granite. It is later cut by fine microgranite dykes and veins, which form approximately 5% of the granite, along with some quartz veins. The sheared granite commonly occurs in the vicinity of the fault zones. These granites are Triassic in age.

2.4. Alluvium

The granite, metasedimentary, and sedimentary rocks are overlain by a Quaternary deposit of stanniferous alluvium along the dredge tailing. The alluvium started to deposit in the past and continues to deposit via the Batu River, the Gombak River, and their tributaries. Subsurface drilling shows the presence of three layers: thin humid soil, alluvium with slight brownish to white clay and silty sand, and light gray limestone bedrock ranging from 15 to 26 m in thickness [45]. Past mining activities have removed a large part of the alluvium, leaving behind tailing and old mining pools.

2.5. Quartz vein

A quartz vein over 200 m thick and a few kilometers in length intrudes into the granite in the northern and eastern part of Gombak. It is currently the longest quartz vein ridge in the world (Figs. 3(a) and (b)).

2.6. Hydrology and climate

Kuala Lumpur and Selangor receive approximately 2,266 mm of rain annually; this large amount of rainfall is likely due to the convection that occurs intermittently and rainstorms accompanying the rainfall pattern [46]. The average rainfall in Jinjang was approximately 200 mm. The average rainfall day was approximately 20 d. Rainfall intensity can reflect the erratic features of limestone.

There are two rivers in the study area, Sungai Jinjang and Anak Sungai Jinjang. Both of these rivers are connected to Sungai Batu. Sungai Jinjang is located beside Taman Beringin, and Anak Sungai Jinjang is separated from Sungai Jinjang by the residential area. Both of these rivers flow from North to South [47,48]. The Jinjang Flood Detention Pond is located in the southern portion of the study area. Both Sungai Jinjang and Anak Sungai Jinjang flow toward the pond before flowing to Sungai Batu. The Jinjang Flood Detention Pond was constructed to protect Kuala Lumpur from flash floods during heavy rainfall. This pond is currently being enlarged to ensure that it can support more water during heavy rainfall.

3. Methods

3.1. Sampling

Sampling was conducted in the area at seven different locations. At the first location (S1), a leachate sample

Fig. 3. (a) Outcrop in the study area (limestone), (b) Thin section of the outcrop.

was collected from the drain at the bottom of the landfill. At the next two locations (S2 and S3), samples were taken at Sungai Jinjang. The next two stations (S4 and S5) were located at Anak Sungai Jinjang. The last two stations (S6 and S7) were located downstream and at the outlet of the river channel, respectively (Fig. 4). All the samples were collected in plastic bottles using a peristaltic pump. The water samples were preserved in an acidified condition, with a pH range of 2–4, to reduce the precipitation and avoid any alteration of cations in the sample. Preserved samples were sent back to the laboratory for further analysis using inductively coupled plasma–optical emission spectrometry (ICP-OES).

Physiochemical parameters for water quality were studied in the field using a multiparameter Hydrolab MS5 and total suspended solid (TSS) meter. Hydrolab can measure temperature, pH, dissolved oxygen (DO), salinity, turbidity, total dissolved solids (TDS), oxidation-reduction potential (ORP), depth, and specific conductivity. Furthermore, the TSS meter was used to determine the suspended solid concentration in wastewater samples [18].

3.2. Leachate used for the column experiment

The leachate samples underwent ICP-OES to determine the heavy metal contents in the sample. Based on these results, the leachate sample at the bottom of the landfill has the highest concentration of heavy metals. The leachate samples used to conduct the column experiment were collected in 6 L plastic bottles using a peristaltic pump (Fig. 5). All the leachate samples were preserved against heavy metal precipitation with 5 M nitric acid until the pH reading reached 2.8.

3.3. Materials used as filtration media

Three materials were used as filter media for the column experiment: sand, peat, and BIRM. All of the materials were tested for their physical and chemical properties.

3.3.1. Sand

The aquifer sand media sample was taken from Kg Teluk by drilling a well. The Kg Teluk aquifers are of shallow quaternary alluvium type and have high hydraulic conductivities. The area has intensive agriculture, and the groundwater is rich in organic carbon and nitrogen. Thus, the reduced water condition favors a high dissolved iron level. The media sample of aquifer sand in Kg Teluk inflow brings high levels of nitrogen, organics, and coliform bacteria to the pumping zone. The first part of the analyses was conducted at the basement laboratory of the Geology Department of University Malay and included sieve analyses and the determination of pH. These analyses were performed for each sample to obtain detailed information about their depth distribution (Fig. 6).

Dry samples from the aquifer were sieved through a sieve mesh. The weight of the sieve was known. Then, different sieves with specific meshes (3.35 mm, 1.18 mm, and 300 μm) were used for separation into fine-, medium-, and coarse-grained sand, respectively. Grain size distributions were analyzed after the sieving experiment.

3.3.2. BIRM

BIRM is produced by impregnating a core made of aluminum silicate with manganous salts. This granular filter media is black in color and moderately dense. BIRM is an

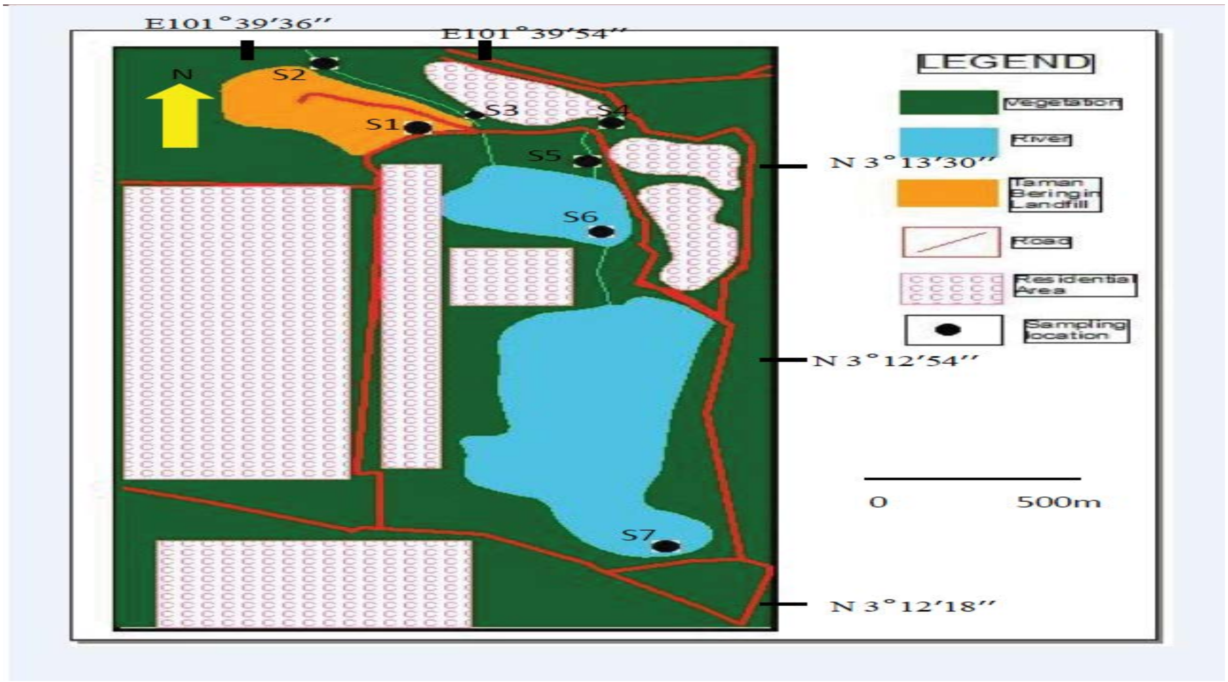

Fig. 4. Digitized map of the sampling location.

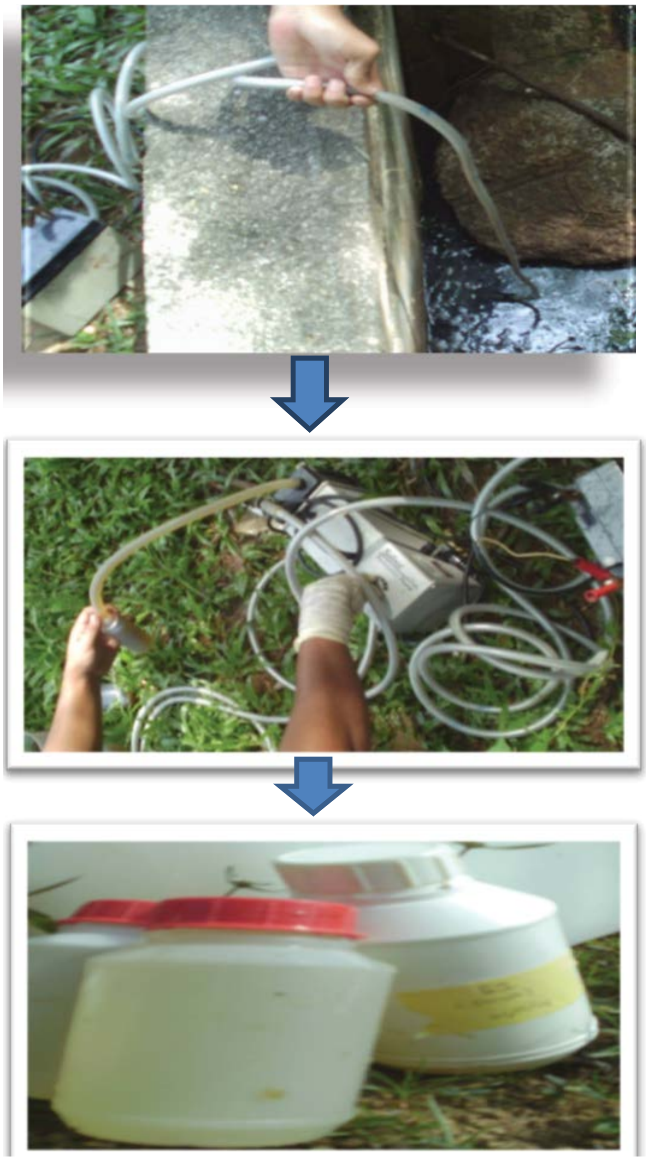

Fig. 5. Leachate and water sampling steps.

Fig. 6. Aquifer sand sample from Kg Teluk.

efficient and economical medium for the reduction of dissolved iron compounds in raw water supplies. It may be used in either gravity fed or pressurized water treatment systems. BIRM acts as an insoluble catalyst to enhance the reaction between DO and iron compounds.

In groundwater, dissolved iron is typically in the ferrous bicarbonate state due to the excess free carbon dioxide and is not filterable. BIRM, acting as a catalyst between oxygen and the soluble iron compounds, enhances the oxidation reaction of Fe^{2+} to Fe^{3+} and produces ferric hydroxide, which precipitates and may be easily filtered. The physical characteristics of BIRM provide an excellent filter medium that is easily cleaned by backwashing to remove the precipitant. BIRM is not consumed in the iron removal operation and thus offers a tremendous economic advantage over many other iron removal methods (Fig. 7).

When using BIRM for iron removal, it is necessary that the water meets the following criteria: no oil or hydrogen sulfide, organic matter content not exceeding 4–5 ppm, DO content equal to at least 15% of the iron content, and pH of 6.8 or more. If the influent water has a pH of less than 6.8, neutralizing additives such as SWT Neutralizing Media (P/N PH10001 or P/N PH10003) or soda ash may be used prior to the BIRM filtering to raise the pH. Water with a low DO level may be pretreated by aeration.

3.3.3. Peat

Peat samples were collected at the Peatland Paradise at Sepang by digging with a hoe. The samples were then placed in plastic bags and taken back to the laboratory. Ten plastic bags were used to sample this media. The samples were then oven-dried for 24 h at 60°C. The roots and other materials in the dried samples were then separated before placing in the column to ensure that the leachate could not flow through the roots (Fig. 8).

3.3.4. X-ray diffraction spectra

The BIRM, peat, and sand samples were ground to powder and subjected to X-ray diffraction (XRD) analysis using a Panalytical Empyrean diffractometer with Highscore Plus software.

3.4. Column experiment

The column experiment was performed to investigate the effectiveness of natural materials (peat and sand) and a commercial material (BIRM) in filtering heavy metals from leachate. The column experiment was setup with an inside diameter of 0.05 m and a length of 0.3 m. Column tests were used in the laboratory analysis to analyze the long-term stability of the iron treatment (Fig. 9).

Column experiments can also be used to determine the dissolution or desorption rates of contaminants from various materials, estimate the reduction rates of chlorinated hydrocarbon, predict the long-term performance of reactive barriers, and determine an appreciable flow-through thickness for an iron reactive wall [49]. The long-term performance of an *in situ* heavy metal remediation system depends on the continued effectiveness of the heavy metals (Fe, Cr, Cu, and Ni) as electron donors, and certain reactions

Fig. 7. BIRM materials.

Fig. 8. Dried peat from Peatland Paradise.

may increase or decrease its lifetime. Therefore, the column experiment is easy to perform and acts upon the reactive barrier installation in a contaminated aquifer.

3.4.1. First stage of the experiment: determination of the effective flow rate

The first stage of the experiment was conducted at the Hydrogeology Laboratory. A column experiment with sand was conducted to determine a suitable flow rate for the remaining experiments. Deionized water was used before the leachate, and the flow mode was downflow mode to ensure that there was no pore space and that the materials used in the column were fully saturated. In downflow mode, the water will move faster because of gravity and can cause the sample in the column to not be fully saturated. The objective of this experiment was to obtain a suitable flow rate for use in the next experiment. The total flow rates used were 18, 25, and 30 mL min^{-1}, which are considered low, medium, and high flow rates of the peristaltic pump, respectively. It was necessary to calculate the volume in the column that was filled with sand. The pore volume (PV) of the sand media in the column is approximately 250–300 mL. The passage of a sample of water from the bore well to the column was taken for interval times of 15, 30, 45, and 60 min. In these experiments, these 4 samples were collected for each flow rate. These samples underwent ICP testing to obtain the concentration of heavy metals and determine the suitable flow rate (Fig. 10).

3.4.2. Second stage of the experiment: performance measurement of each filter medium

For this second stage, a column experiment was conducted with the different media to measure the performance of each medium in the column in the removal of heavy metals, such as iron and chromium. Five columns were tested, each filled with different media, to test the performance as heavy metal filters.
Media:

- BIRM
- Fine sand
- Medium sand
- Coarse sand
- Peat

The flow rate used in all tests was based on the electron beam computerised tomography experiment. The suitable flow rate used in the second-stage column experiment was

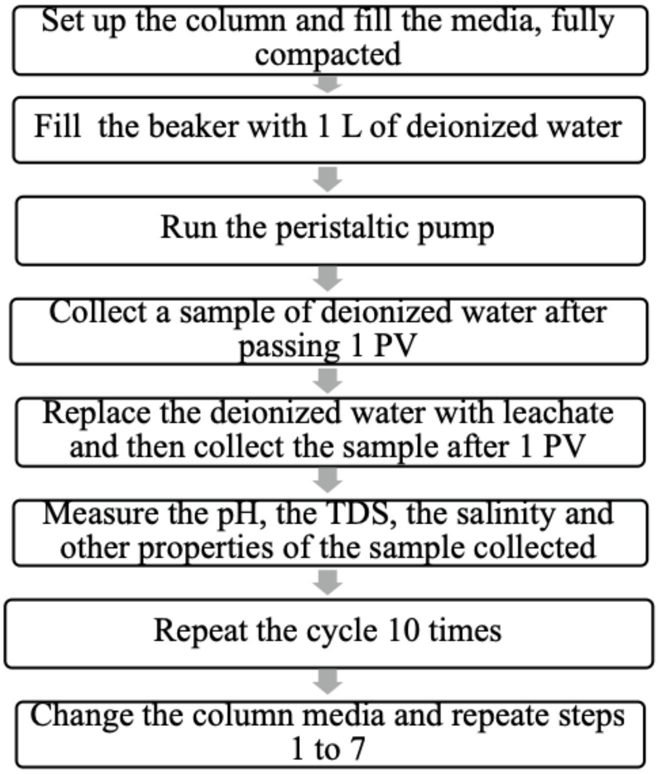

Fig. 9. Steps of the column experiment.

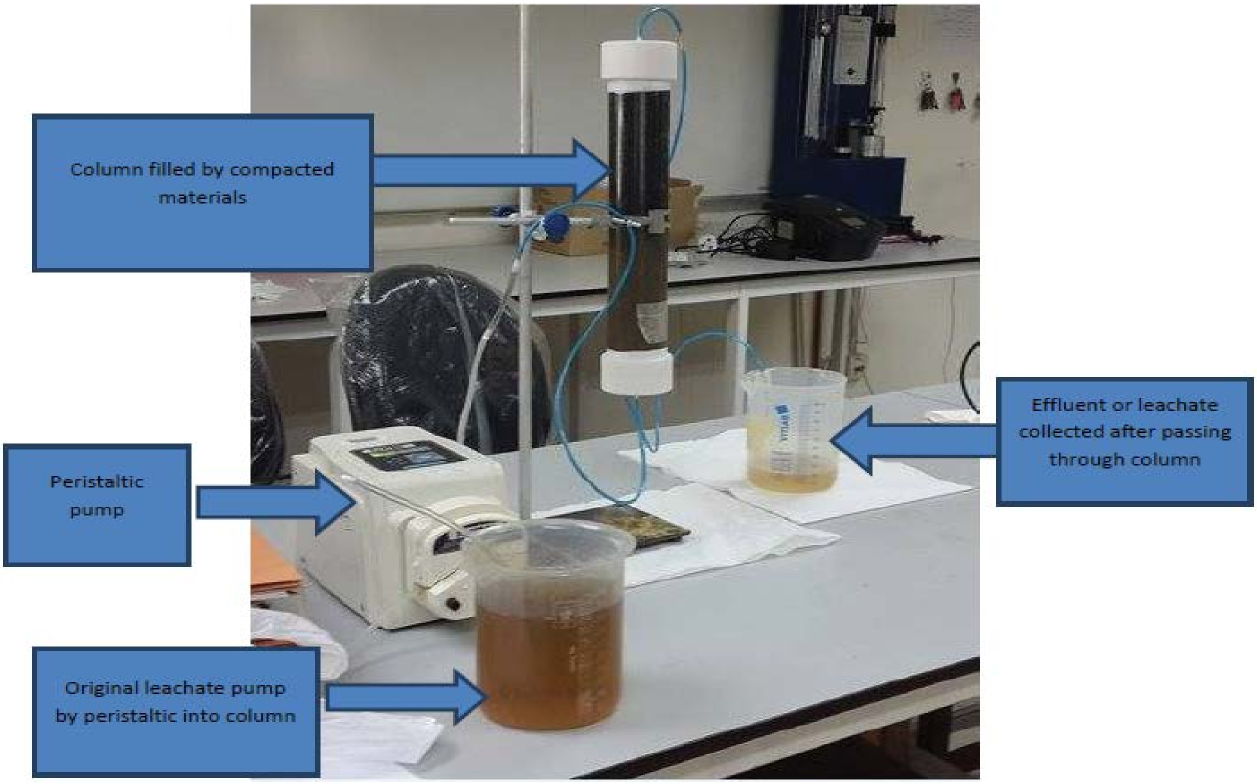

Fig. 10. Column experiment setup.

the medium flow rate of 25 mL min^{-1}. Five experiments were conducted in the second stage. For each column test, 10 samples were collected for every 1 PV until 10 PV passed in total. The parameters of pH, salinity, TDS, conductivity, and temperature before and after the leachate passed through column were measured.

4. Results and discussion

4.1. Characterization of filtration media

4.1.1. Sand characteristics

A composite soil sample was collected from the first-layer aquifer in Kg Teluk, Kelantan, Malaysia. The soil was dried in an oven overnight at 105°C, following the protocol presented, and then crushed and passed through a 2 mm sieve to be analyzed by XRD.

XRD analysis was performed using a Panalytical Empyrean diffractometer with Highscore Plus software. The soil pH was measured by USEPA SW-846 Method 9045D, and Eh was measured by an ORP electrode following ASTM Method D 1498-93 after preparing the sample by USEPA Method 9045 (SW-846 series) for soil samples.

The samples were digested to measure metal contents by ICP-OES (Perkin-Elmer Optima 7000DV, USA) using Perkin-Elmer standard solutions. All the samples were analyzed in triplicate, and the results were reproducible within ±3.5%.

The XRD analysis of both spiked and unspiked soils revealed that the soil samples contained silicon dioxide (82.75%) as quartz (SiO_2, XRD displacement 0.158), magnesium aluminum silicate hydroxide as mica ($((Mg, Al)_6 (Si, Al)_4O_{10} (OH)_8$, XRD displacement 0.119), sylvine, sodium ($Cl_1K_{0.9}Na_{0.1}$, XRD displacement –0.171), magnetite Q (isometric $Fe_{21.333} O_{32}$, XRD displacement 0.001), and feldspar albite ($Al\ Na\ O_8\ Si_3$, XRD displacement –0.053), as shown in Table 1.

4.1.2. BIRM characteristics

Fig. 11 shows the micro-X-ray diffraction (XRF) analysis: the 3 highest element content peaks in BIRM media are Si, Ca, and Mn. Manganese oxide (MnO) represents 42.64% of the oxide compound. BIRM medium is originally an alkaline material due to the high content of Mn.

4.1.3. Peat characteristics

Peat is an accumulation of partially decayed vegetation or organic matter that is unique to natural areas called peatlands or mires. The peatland ecosystem is the most efficient carbon sink on the planet because peatland plants capture the CO_2 that is naturally released from the peat, maintaining an equilibrium. Table 2 shows the mineral content composition in the peat sample collected from Peatland Paradise. O is the highest proportion of the peat (50%), followed by Si (36%). The peat sample from this area also has a high Fe content (4.34%). Based on the results, including the high proportion of Si, the peat in this area is composed of organic materials buried by sand and other sediments.

4.2. Leachate and water characteristics

4.2.1. Physical parameters

4.2.1.1. Temperature

Temperature is a measure of how much heat is present in the water and was measured in degree Celsius. For all sampling locations, the water temperature from river ranges was generally between 27.96°C and 29.87°C. The average river temperature was 28.86°C, and the leachate collected at the bottom of landfill was warmer, 31.51°C. Table 3 shows the water quality parameters at all sampling locations.

Table 1
Sand characteristics

<table>
<tr><th colspan="3">Characterization of the natural soil sample</th></tr>
<tr><th>Soil properties</th><th>Value</th><th>Method</th></tr>
<tr><td>pH</td><td>4.5</td><td>USEPA SW-846 Method 9045D</td></tr>
<tr><td>Specific gravity</td><td>2.64</td><td>ASTM D 854 – Water Pycnometer method</td></tr>
<tr><td>Organic matter content</td><td>0.14%</td><td>Loss of weight on ignition (Storer, 1984)</td></tr>
<tr><td>Total silicon (mg kg^{–1})</td><td>~390,000</td><td>USEPA 3050B</td></tr>
<tr><td>Aluminum (mg kg^{–1})</td><td>2,400</td><td></td></tr>
<tr><td>Total manganese (mg kg^{–1})</td><td>185</td><td></td></tr>
<tr><td>Magnesium (mg kg^{–1})</td><td>635</td><td></td></tr>
<tr><td>Lead (mg kg^{–1})</td><td>11</td><td></td></tr>
<tr><td>Zinc (mg kg^{–1})</td><td>18</td><td></td></tr>
<tr><th colspan="3">Soil particle size distribution</th></tr>
<tr><td>Sand (<50 μm)</td><td>90.66%</td><td>Sandy soil according to USDA Soil Classification</td></tr>
<tr><td>Silt (50–2 μm)</td><td>7.2%</td><td></td></tr>
<tr><td>Clay (>2 μm)</td><td>2%</td><td></td></tr>
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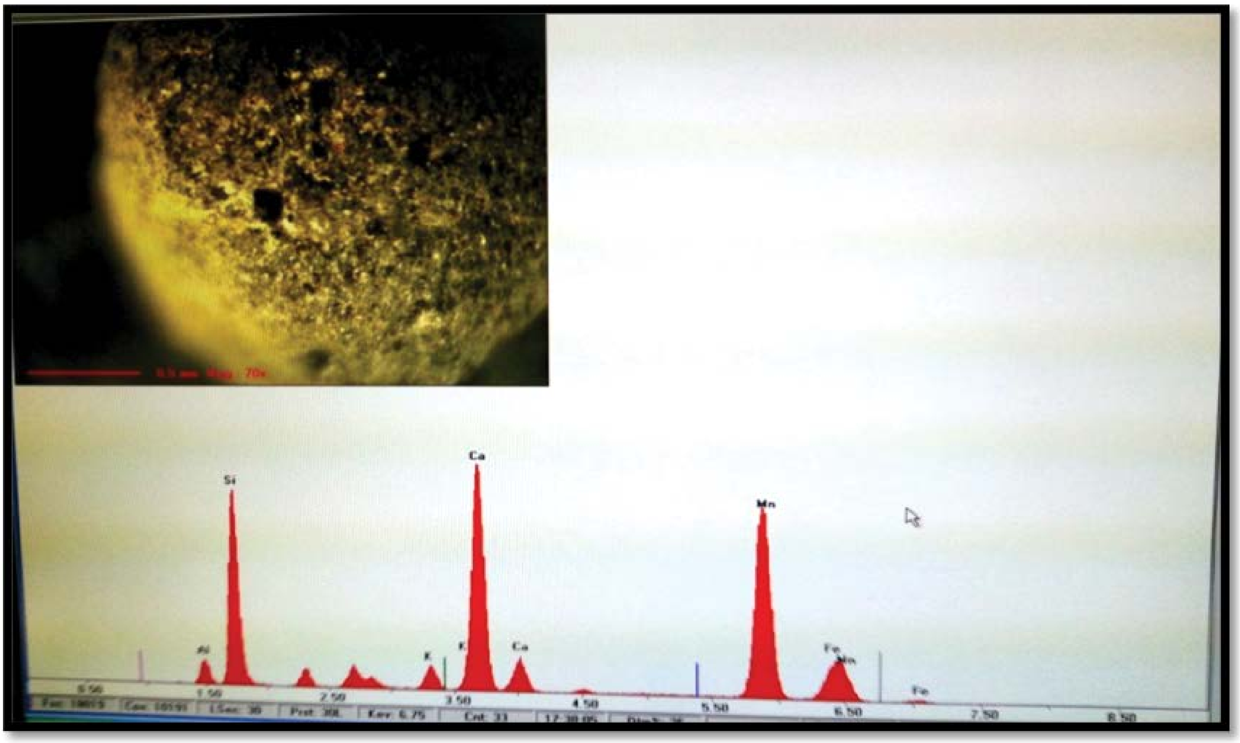

Fig. 11. Chemical compound of BIRM in the Micro XRF 3D analyzer.

Table 2
XRF results for peat

Element	Concentration (%)
O	50.11
Si	36.06
Fe	4.34
Ca	2.5
S	1.94
Al	1.82
Ti	1.33
Cl	0.39
K	0.37
Mg	0.28
Na	0.24
P	0.24
Mn	0.11
Zr	0.1
Zn	0.06
Br	0.05
Sr	0.03
Pb	0.02

4.2.1.2. Salinity

Salinity is defined as the concentration of dissolved salt in the water. The unit used for this parameter is the Practical Salinity Unit (PSU). Based on Table 3, the salinity of the leachate sample is the highest with 4.81 compared with other locations. The salinity of the water in this area is not particularly high because the location is far from the sea. Thus, salt water from the sea does not affect the water body in this area. The leachate sample has higher salinity due to the many materials contained in it. The salinity at the river ranged from 0.13 to 0.33 PSU.

4.2.1.3. Total dissolved solids

TDS are the total amount of mobile charged ions, including minerals, salts, or metals, dissolved in a given volume of water. The TDS of the river ranged between 176.8 and 421.5 mg L^{-1} (Table 3), and the TDS of the leachate was extremely high (5,483 mg L^{-1}). The high TDS in the leachate can be attributed to dissolved organic materials in the water. Dissolved solids also come from inorganic materials, such as rocks, which may contain calcium, bicarbonate, nitrogen, sulfur, iron, phosphorous, and other minerals. Many of these materials form salts. Salts typically dissolve in water and form ions, which have a positive or negative charge [19]. Therefore, TDS is related to specific conductivity. As TDS increases, the specific conductivity also increases due to the availability of more dissolved ions in water. Therefore, the leachate can conduct electricity.

4.2.2. pH

The ranges of pH values in different sampling locations were recorded. The pH value varied at different locations (Table 3) from 6.98 to 7.87. The majority of the stations exhibited alkaline pH values. The lowest pH was recorded in the flood detention pond, and the highest pH was recorded upstream

Table 3
Physical parameters of the leachate and water samples

Sample	Temperature (°C)	Salinity (mg L^{-1})	Total dissolved solids (mg L^{-1})	pH	Specific conductivity (μS cm^{-1})	ORP (mv)
S1 (Leachate)	31.51	4.81	5,483	7.86	8,555	43
S2 (Sungai Jinjang)	29.49	0.17	214.9	7.87	336	49
S3 (Sungai Jinjang)	29.87	0.19	243.1	7.46	379.7	28
S4 (Anak Sungai Jinjang)	27.96	0.33	416	7.3	650.7	46
S5 (Anak Sungai Jinjang)	28.45	0.34	421.5	7.05	659	10
S6 (Flood Detention Pond)	28.92	0.13	176.8	6.98	275.7	115
S7 (Outlet)	28.49	0.16	203.1	7.05	317.3	13

of Sungai Jinjang, with values of 6.98 and 7.87, respectively. The pH reading for leachate exhibited a high value of 7.87. The pH values of the samples are slightly alkaline because of the geology of the area. This area is underlain by sedimentary rocks, namely, limestone. Limestone is an alkaline agent with the ability to neutralize or partially neutralize strong acids. The neutralization process occurs when strong acids, in close contact with limestone chips, react with calcium carbonate ($CaCO_3$, the primary constituent of limestone) to form water, carbon dioxide, and calcium salts [20]. The following reaction depicts the neutralization of hydrochloric acid by limestone:

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 + H_2O$$

Due to the presence of other calcium products in the limestone chips typically used, it is possible for limestone to exert alkaline influences on the wastewater stream up to and beyond a pH of 11.0, meaning that an upper pH limit of 9.0 can be easily surpassed.

4.2.3. Specific conductivity

Specific conductivity is a measure of the ability of a substance to conduct electric current. It offers a rapid and nondestructive way to measure ion content in the sample. Specific conductivity values varied with location. Table 3 shows that the leachate sample has the highest specific conductivity (855.5 μS cm^{-1}), and S6, the sample from the flood detention pond, has the lowest specific conductivity value (275.7 μS cm^{-1}). As the specific conductivity increases, the ion content also increases, which means that in most cases the specific conductivity provides a good approximation of the TDS. Specific conductance is an important water quality measurement because it provides an accurate estimate of the amount of dissolved material in the water. Fig. 18 indicates that the specific conductivity value at S1 and the value of TDS at S1 are both the highest values. Therefore, high specific conductance indicates the high dissolved solid concentration. Dissolved solids can affect the suitability of water for domestic, industrial, and agricultural uses [21].

4.2.4. Oxidation-reduction potential

One of the methods to quantify whether a substance is a strong oxidizing agent or reducing agent is by using the ORP. ORP is the activity or strength of oxidizers and reducers in relation to their concentration. Oxidizers accept electrons, whereas reducers lose electrons. ORP is measured in millivolts (mV). A high positive value indicates an environment that favors the oxidation reaction, such as free oxygen, whereas a low negative value indicates a strong reducing environment, such as free metals. Table 3 shows that S6 has a high ORP value of 113 mV and S5 has the lowest value of 10 mV. Strong reducing agents have a high electron transfer potential, whereas strong oxidizing agents have a low electron transfer potential. Reducing and oxidizing agents occur as a couple, with a strong reducing agent coupled with a weak oxidizing agent and vice versa. Because these processes involve the transfer of electrons, the resulting charge separation can be quantified by the voltage measurement between the couple. Therefore, the majority of the water in Taman Beringin is controlled by oxidation processes [22].

4.3. Chemical parameters

In this section, we focus on certain heavy metals that can damage human health and discuss whether they exceed the limits of the Interim National Water Quality Standards for Malaysia (INWQS).

4.4. Lead

The values for the concentration of lead are mainly higher than 0.01 mg L^{-1}, which is the INWQS limit (Table 4). Lead seldom occurs naturally in water supplies but enters the water primarily as a result of the corrosion or wearing away of materials containing lead in the water distribution system and household or building plumbing. These materials include lead-based solder used to join copper pipe, brass, and chrome plated brass faucets and, in some cases, pipes made of lead that connect houses and buildings to water mains. Excess lead inhibits hemoglobin, interferes with enzymatic processes, and causes disorders in the trachea-bronchial and alveolar region, chronic anemia, abdominal pain, muscle weakness, and other related urological disorders.

4.5. Cadmium

The cadmium concentration level in the study area is very low. The maximum permissible level by INWQS is 0.01 mg L^{-1}. Based on Table 4, the concentrations of Cd

Table 4
Concentration of heavy metals in leachate and water at the Taman Beringin Landfill

Station (mg $L^{-1)}$	Pb	Cd	Al	Mn	Cu	Zn	Fe	As	Ni	Cr
INWQS	0.010	0.01	–	0.1	0.02	5.000	1.00	0.010	0.050	0.050
S1	0.0123	0.0072	1.1623	1.3571	0.4964	BDL	16.7064	0.0395	0.8842	1.4283
S2	0.0120	0.0005	1.0532	0.1328	0.0358	0.0522	0.4528	0.0352	0.0446	0.0636
S3	0.0221	BDL	0.5872	BDL	0.0150	0.0054	0.2848	0.0184	0.0194	0.0509
S4	0.0342	0.0023	0.4689	0.1119	0.0264	0.1070	0.4032	0.0708	0.0223	0.0317
S5	0.0368	0.0021	0.8639	0.0964	0.0605	BDL	2.8921	0.0641	0.0845	0.6325
S6	0.0330	BDL	0.5483	0.0749	0.0208	0.0701	0.9655	0.0202	0.0188	0.1688
S7	0.0231	0.0001	0.3829	0.0916	0.0164	0.0735	0.1984	0.0379	0.0114	0.0206

*BDL = Below the detection limit.

at Taman Beringin Landfill are below the INWQS value. Cadmium in water tends to sink. Furthermore, cadmium is a potentially toxic element. It is notorious for its high renal toxicity due to its irreversible accumulation in the kidney.

4.6. Aluminum

Aluminum was present in all samples, with a maximum concentration of 1.1623 mg L^{-1} and a minimum concentration of 0.3829 mg L^{-1}. Aluminum occurs as a trace element in natural water. It is highly stable and cannot be dissolved or disintegrated easily (Table 4).

4.7. Manganese

The values of manganese ranged from 0.0749 to 1.3571 mg L^{-1}. Three locations exceeded the INWQS limit, S1, S2, and S4 (Table 4). The most common source of manganese is naturally occurring from the weathering of manganese-bearing minerals and rocks.

4.8. Copper

The values of copper ranged from 0.015 to 0.496 mg L^{-1}. Several samples showed values exceeding the INWQS limit (Table 4). Copper is a reddish metal that occurs naturally in rock, soil, water, sediment, and air. It has many practical uses in society and is commonly found in coins, electrical wiring, and pipes. It is an essential element for living organisms, including humans, and, in small amounts, is necessary in our diet to ensure good health. However, an excessive amount of copper can cause adverse health effects, including vomiting, diarrhea, stomach cramps, and nausea. It has also been associated with liver damage and kidney disease [23].

4.9. Zinc

Zinc was present in all samples except S1 and S5, with maximum and minimum values of 0.107 and 0.0054 mg L^{-1}, respectively. The value of zinc concentration was below the INWQS limit at all locations (Table 4). A high zinc content in potable water gives an undesirable taste. A water softening system should be adopted to lower the content of zinc to make the water more pleasant for drinking.

4.10. Iron

Iron was present in all samples with maximum and minimum values of 16.7 and 0.19 mg L^{-1}, respectively. The higher value of iron in the study, especially in S1, may be due to disposed materials that are high in iron. The materials that leach when in contact with water become leachate, as in S1 (Table 4).

4.11. Arsenic

The arsenic concentration level in Taman Beringin exceeded the INWQS limit of 0.01 mg L^{-1} at all locations. The minimum value of 0.0202 mg L^{-1} was recorded at location S6, and the maximum value of 0.0708 mg L^{-1} was recorded at S4. Arsenic has long been recognized as a toxin and carcinogen. The long-term ingestion of high concentrations of arsenic in drinking water can lead to various health problems, particularly skin disorders, such as pigmentation changes (dark/light skin spots) and keratosis [24]. The World Health Organization guideline value for arsenic in drinking water was reduced from 50 to 0.01 mg L^{-1} in 1993 (Table 4).

4.12. Nickel

The maximum and minimum nickel concentration levels were 0.8842 and 0.0114 mg L^{-1}, respectively. The maximum value was recorded at S1, and the minimum value was recorded at S7 (Table 4). The high value of nickel at S1 occurred because the leachate contains various materials from the landfill. Nickel is necessary in many organisms' diets but can become toxic at high doses. Women are more likely to be allergic to nickel exposure than men.

4.13. Chromium

The maximum and minimum chromium concentrations were 1.4283 and 0.0 mg L^{-1}, respectively. The maximum value was recorded at S1, and the minimum value was recorded at S7 (Table 4). The high concentration of chromium at S1 occurred because the leachate contains various materials that come from the landfill. Four locations exceeded the INWQS limit, namely, S1, S2, S3, and S5, with chromium contents above 0.05 mg L^{-1}.

4.14. Column experiment

4.14.1. Leachate characteristics used for the column experiments

Four types of heavy metals were used for this experiment, namely, iron (Fe), nickel (Ni), copper (Cu), and chromium (Cr). These four heavy metals were selected based on their concentration levels, which were higher than those of the other studied metals. Table 5 shows the properties of the leachate used for this experiment.

4.14.2. Effect of flow rate

Before conducting the column tests for performance evaluation of the sand, peat, and BIRM media, the effect of flow rate on Fe removal from leachate was studied by employing short-duration column tests at different flow rates. Tests were conducted with high (30 mL min^{-1}), medium (25 mL min^{-1}), and low (18 mL min^{-1}) flow rates with sand media. Filters were operated for 60 min, and the effluents were analyzed for total Fe content. The evaluation of Fe content was based on the concentration level compared with other metals. The results presented in Fig. 12 show that when using the high flow rate, the initial Fe content of raw leachate dropped from 11.05 to 2.77 mg L^{-1} within 15 min and to 8.67 mg L^{-1} within 60 min. Using the low flow rate, the initial Fe concentration of 11.05 mg L^{-1} dropped to 0.33 mg L^{-1} in 15 min and to 2.55 mg L^{-1} in 60 min. Interestingly, the medium flow rate showed similar performance to the low flow rate. By using a medium flow rate of approximately 25 mL min^{-1}, the initial Fe concentration of 11.05 mg L^{-1} dropped to 0.54 mg L^{-1} within 15 min and to 3.66 mg L^{-1} in 60 min. This result indicates that the high rate of the peristaltic pump achieves less Fe removal over the same time period than the low and medium flow rates. Over a long period of time, the medium and low rates showed similar performance in removing Fe. Thus, the medium flow rate of 25 mL min^{-1} was chosen because its performance in the removal of Fe was similar to the low rate, and the time consumed can also be reduced by using the medium flow rate.

Table 5
Composition of leachate for the column experiments (pH 5)

Parameter	Value (mg L^{-1})
Cr	1.279
Cu	3.293
Fe	11.015
Ni	4.535

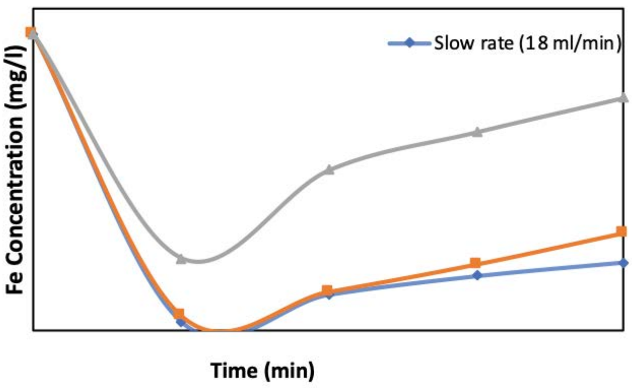

Fig. 12. Fe removal at different flow rates in the sand column.

4.15. Performance of materials for heavy metal removal

To study the performance of each material for heavy metal removal, breakthrough curves (BTCs) were plotted between relative concentrations (C_e/C_0) against the PVs. PV is defined as the volume necessary to displace the volume of interstitial liquid in the pore spaces within the soil column. C_e/C_0 is the ratio between the concentration of heavy metals in the effluents and the concentration of heavy metals in the influent (raw leachate). A C_e/C_0 value of 1.0 represents the total breakthrough of HMs through the compacted soil column. For this experiment, the discussion is based on the BTCs and percentage of heavy metals removed by different materials.

4.15.1. Fine sand

Fig. 13 shows the BTCs of Cr, Fe, Cu, and Ni for fine sand as observed in the column. Based on the BTCs, the relative concentration values increased with the number of PVs. The plots also showed that Fe was the most mobile heavy metal, with a C_e/C_0 after 10 PV of 0.6. After 1 PV, the C_e/C_0 of Fe was still below 0.1 but continuously increased until 0.6 after 10 PV. Low C_e/C_0 values (i.e., BTCs < 1.0) indicated that the sorption of heavy metals was high. The BTCs indicated that different heavy metals have different affinity (or selectivity) for sorption. Furthermore, the C_e/C_0 values for Cr and Ni were below 0.1, which indicated that both Ni and Cr are less mobile and that sorption of these heavy metals was high compared with that of Fe. The relative concentration for Cu showed an interesting trend of being higher at the first two PVs, more than 0.2, whereas from 3 PV until 10 PV, it decreased to below 0.1. The pH range was from 5.8 to 3.1. The pH profile showed that fine sand does not have good buffering and thus cannot resist any changes from acid testing to maintain its pH until 10 PV.

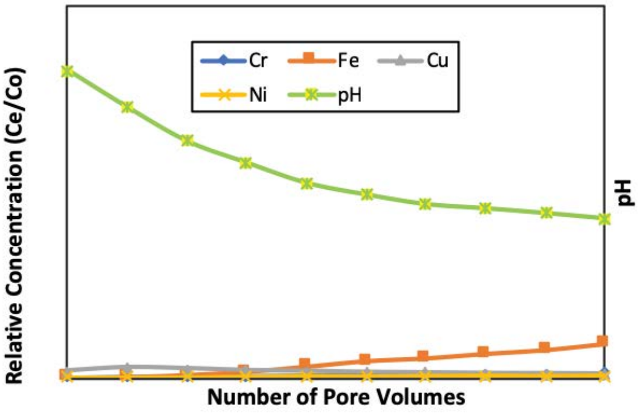

Fig. 13. Breakthrough curves for fine sand.

Fig. 14 shows the percentage of heavy metals removed by fine sand from 1 to 10 PV. The graph shows that fine sand can remove more than 80% of the original Ni, Cu, and Cr values, although the removal decreased from 1 to 10 PV because the capacity of fine sand to adsorb these heavy metals began to decrease relative to the number of PVs. The removal of Fe shows poor results. Although nearly 99% of the Fe was removed at 1 PV, this value decreased to 34% after 10 PV. This result shows that the capability of fine sand to trap Fe in the column began to decrease as an increasing amount of influent passed through the column. Based on the percentage graph, the removal of heavy metals by fine sand can be ranked as Fe < Cu < Cr < Ni.

4.15.2. Medium sand

Fig. 15 shows the BTCs of Cr, Fe, Cu, and Ni for medium sand. These curves illustrate the same trend as in the fine sand: the relative concentration of each heavy metal increases with the number of PVs. This plot shows that the relative concentration of Fe was the highest. The relative concentration of Fe at 1 PV was below 0.1, but it increased to 0.7 after 10 PV. This result differs from the fine sand, for which the relative concentration was 0.6 at 10 PV. The relative concentration values for Cr, Cu, and Ni also showed an increase compared with the use of fine sand. The relative concentration is higher than in fine sand because the grain spacing is looser than in fine sand. Increasing the space between the grains increases the permeability of leachate in the soil column. Therefore, the capability of medium sand to trap heavy metals is lower than that of fine sand. The pH profile is similar to the profile for fine sand. The pH values at 1 and 10 PV were 5.8 and 3.1, respectively. The pH reading corresponds with the increase in relative concentration, indicating that the sorption of heavy metals decreased with decreasing pH. Fig. 16 shows the percentage of heavy metals removed by medium sand from 1 to 10 PV. The graph shows that medium sand still has the capability to remove more than 80% of the original values of Ni, Cu, and Cr, although the removal decreased from 1 to 10 PV because the capacity of medium sand to trap these heavy metals starts to decrease relative to the number of PVs. The removal of Fe shows similar results to fine sand. For medium sand, Fe removal after 10 PV was 23%, compared with 34% for fine sand. Acidic pH hindered the precipitation of Fe as Fe (III) because heavy metals are more mobile in an acidic state. Based on the percentage graph, the removal of heavy metals by medium sand can be ranked as Fe < Cu < Cr < Ni.

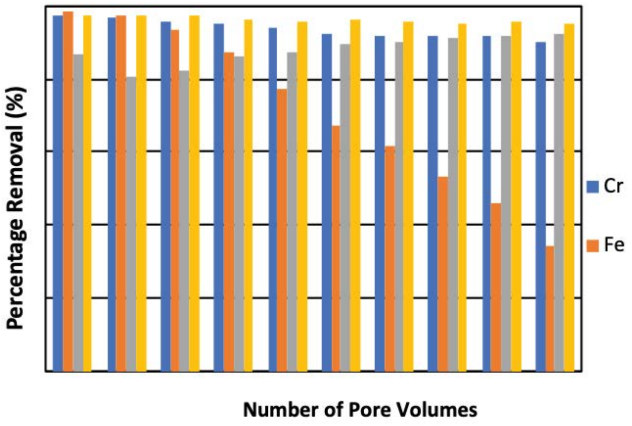

Fig. 14. Percentage of heavy metal removal by fine sand.

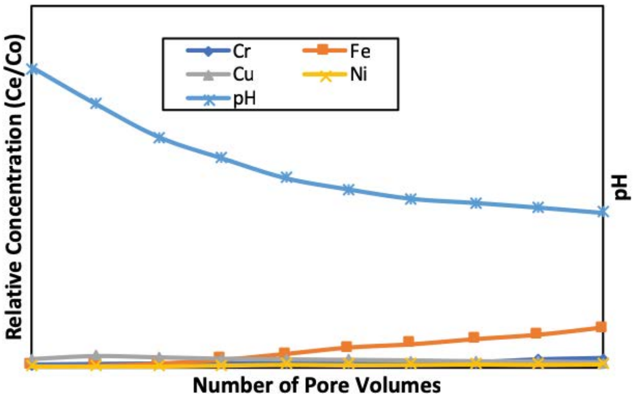

Fig. 15. Breakthrough curves for medium sand.

4.15.3. Coarse sand

Fig. 17 shows the BTCs of Cr, Fe, Cu, and Ni for coarse sand. These curves show the same trend as in the fine sand and medium sand, which is that the relative concentration of each heavy metal increases with the number of PVs. This

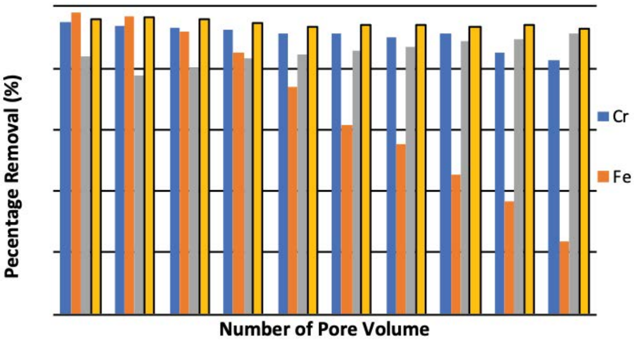

Fig. 16. Percentage of heavy metal removal by medium sand.

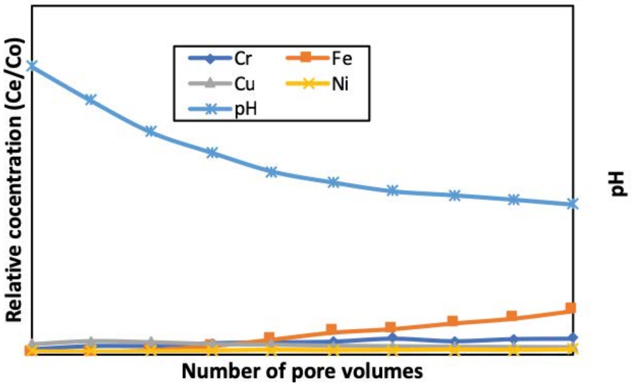

Fig. 17. Breakthrough curves for coarse sand.

plot shows the highest relative concentration for Fe. The relative concentration of Fe at 1 PV was below 0.1, but after 10 PV, it increased to 0.8. The relative concentrations for Cr, Cu, and Ni also increased compared with the use of fine and medium sands. The relative concentration is higher than in fine sand because the grain spacing is larger. Increasing the space between the grains increases the permeability of leachate in the soil column. Thus, the capability of coarse sand to trap heavy metals is lower than that of fine or medium sand. The pH profile is similar to the profile for fine sand. The pH values at 1 and 10 PV were 5.8 and 3.1, respectively. The pH reading corresponds to the increase in relative concentration, which means less sorption of heavy metals at lower pH.

Fig. 18 shows the percentage of heavy metals removed by coarse sand from 1 to 10 PV. The graph shows that the capability of coarse sand to remove Ni, Cu, and Cr is lower than that of fine and medium sands. The removal of Cu and Ni remains in the range of 80% after 10 PV but shows a decreasing pattern, and less than 80% of Cr is removed above 10 PV. This phenomenon occurs because the capacity of sand to trap these heavy metals starts to decrease relative to the number of PV. The removal of Fe shows similar results to the fine and medium sands. For coarse sand, Fe removal after 10 PV was 12%, which was lower than that for the other two types of sand. The acidic pH made the precipitation of Fe as Fe (III) difficult because heavy metals are more mobile in the acidic state. Based on the percentage graph, the removal of heavy metals by coarse sand can be ranked as Fe < Cu < Cr < Ni.

4.15.4. Peat

Fig. 19 shows the BTCs of peat after 10 PV of column leaching tests. The C_e/C_0 values were below the total breakthrough value of 1.0, although Fe showed higher mobility (less sorption) in the soil column, with values ranging from 0.8 to 0.99. Interestingly, after 3 PVs, Fe breakthrough slowly decreased from a relative concentration of 0.92–0.8 until 8 PVs of leaching. After this, it increased again from 9 PV to 10 PV. The mobility of Cr in this column was low compared with the sand column, less than 0.1 from 1 PV to 10 PV. For the sand column, the mobility of Cr was higher than that in peat, but the relative concentration remained low at 0.3. For Cu, the relative concentration range was 0.3–0.4 and for Ni 0.2–0.3. The value was also higher than that in the sand column, which means that Cu and Ni were more mobile (less sorption) in peat than in the sand column. The pH reading for the effluent showed acidic values ranging from 2.69 to 2.63. The value was lower than that for the influent because the pH of peat, which ranged from 2.3 to 2.6, affected the solution. Peat has a low buffering capacity, which made the precipitation of heavy metals, especially Fe, more difficult.

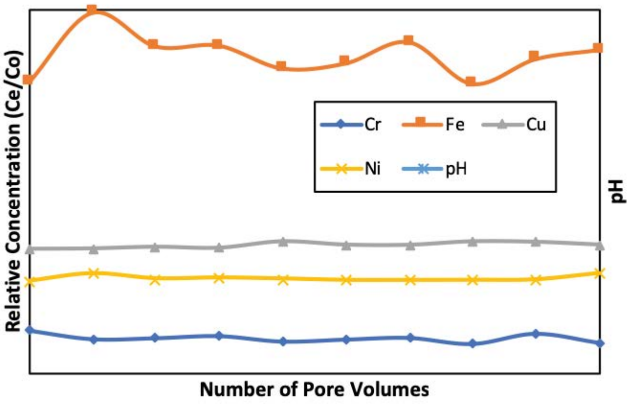

Fig. 19. Breakthrough curves for peat.

Fig. 20 shows the percentage of heavy metals removed by peat from 1 to 10 PV. The percentage of Fe removal showed the poorest result after 10 PV of column leaching, i.e., 10%. The percentage of Cr removal showed a promising result, above 80% removal. For Ni and Cu, the percentages of removal were 60%–70% and 60%–70%, respectively. Based on the percentage graph, the removal of heavy metals by peat can be ranked as Fe < Cu < Ni < Cr.

4.15.5. BIRM

Fig. 21 shows the BTCs of BIRM. The C_e/C_0 values were below 0.12 for all heavy metals. These results show that mobility of all heavy metals is lower in BIRM than in peat and sand. Lower mobility means that the sorption is high. Fe showed the least mobility and Cu showed the highest mobility, less than 0.02 and 0.1, respectively. Cr and Ni showed similar mobility, indicating similar rates of sorption. The relative concentrations of Cr and Ni ranged from

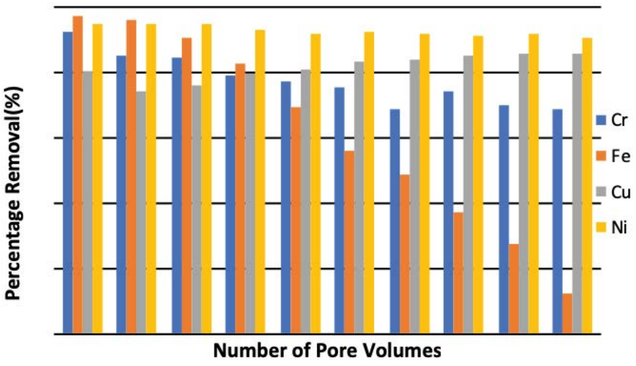

Fig. 18. Percentage of heavy metal removal by coarse sand.

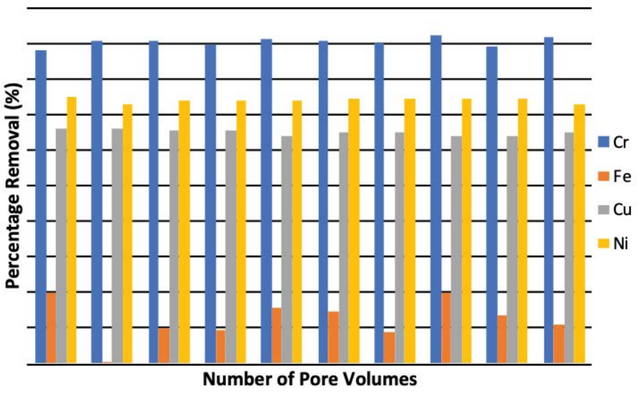

Fig. 20. Percentage of heavy metal removal by peat.

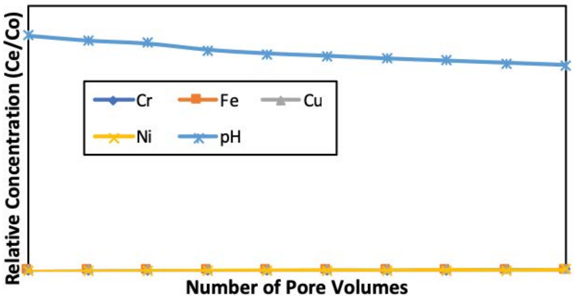

Fig. 21. Breakthrough curves for BIRM.

0.02 to 0.08. The sorption of heavy metals also corresponded well with the buffering capacity of the soil, as indicated by the pH line. The pH line was nearly constant from start to end, with values ranging from 9.3 to 10.9. The pH of the test solution was 2.8. The pH profile showed that BIRM materials have a good buffering capacity and thus a good capacity to resist any changes from an acidic test solution to maintain their pH from the start to the end of the test. Fig. 22 shows the percentage of heavy metals removed by BIRM from 1 to 10 PV. BIRM is highly effective in removing heavy metals. The percentage of heavy metals removed was above 90% for all heavy metals. The removal of Fe was more efficient within 10 PV leaching, ranging from 97% to 99%. Based on the percentage graph, the removal of heavy metals by BIRM can be ranked as Cu < Ni < Cr < Fe.

4.16. Overall performance

Fig. 23 shows the overall performance of all three materials used. The graph shows that different filtration media have different capabilities to remove heavy metals from leachate. For Cr, the BIRM material shows the highest percentage of removal at approximately 95%, followed by fine sand at 93%. The lowest Cr removal was by coarse sand, at approximately 73%. Coarse sand has the lowest capability to remove Cr because the arrangement of grains is not as good as that in fine sand. The grain arrangement of coarse sand was not tight, which might allow the leachate to move more rapidly in the column.

BIRM also shows the highest removal percentage for Fe. The average percentage of heavy metals removed by BIRM was 98%, which proves that the commercial material BIRM can be used to remove Fe from water. The three types of sand also show good performance in the removal of Fe. Fine, medium, and coarse sands remove Fe from leachate at 71%, 66%, and 62%, respectively. Peat shows the poorest performance for Fe removal. The average removal of Fe by peat is very low, 12%, because the iron content in peat is higher than that in sand and BIRM. Fe leached from the column at high concentrations because this heavy metal was undergoing complexation with the Fe content in peat, preventing the Fe in the solution from being adsorbed by the peat.

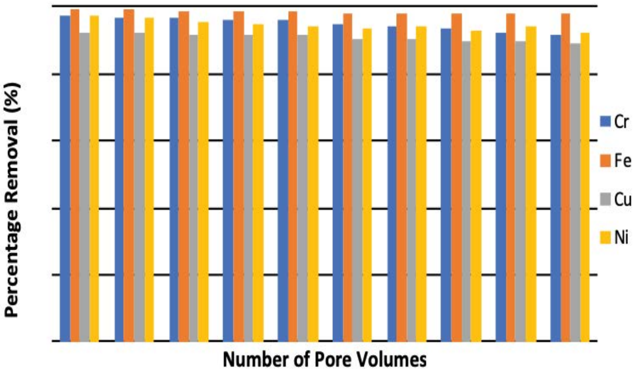

Fig. 22. Percentage of heavy metals removed by BIRM.

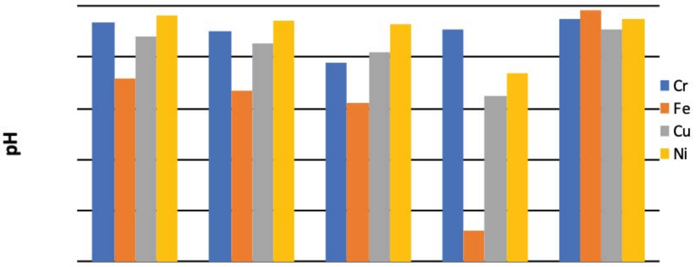

Fig. 23. Average percentage of heavy metal removal by all filtration materials.

BIRM also shows the highest removal percentage for Cu. The percentage of Cu removed by BIRM is 91%, followed by fine sand, which removes approximately 87% of the Cu. Medium and coarse sands remove 85% and 81% of Cu, respectively. Peat is ranked last, with only 64% of Cu removed. For Ni removal, the sand materials show good performance. The three types of sands exhibit an average Ni removal from leachate of more than 90%. Fine sand shows the best performance, removing approximately 96% of Ni from leachate. The medium sand and BIRM materials have the same percentage of Ni removal, 94%, and coarse sand removes approximately 92%. Peat shows the lowest performance, removing approximately 74% of Ni.

Based on the overall heavy metal removal performance, BIRM can be ranked first because it can remove more than 90% of all four heavy metals after leaching 10 PV. The material with the next best performance is fine sand, followed by medium sand and coarse sand. Peat has the lowest ability to remove heavy metals, especially Fe [25].

5. Conclusion

This study demonstrates that the quality of leachate at the bottom of the landfill has poor physical and chemical behaviors, which can pollute the nearby surface and groundwater water sources. The results of the chemical study show that the leachate has the highest concentrations of heavy metals. Fe exhibits the highest concentration in the leachate. The column experiment study revealed that BIRM is the best material for removing heavy metals from the leachate. The overall performance shows that BIRM can remove more than 90% of heavy metals, such Fe, Ni, Cr, and Cu. The removal of Fe from the leachate by BIRM shows the best performance. BIRM can remove nearly 100% of Fe from the leachate in the column. This result demonstrated that this commercial material is suitable for use in water treatment. Based on this study, BIRM can be proposed for use in leachate treatment based on their heavy metal removal performance. The study also revealed that the column test is a good experimental tool to assess the retention capability of soils for heavy metals, as shown by the use of BTCs. BIRM is the most effective material for heavy metal removal. Based on the study, the removal of heavy metals by materials can be ranked as follows: (1) BIRM, (2) fine sand, (3) medium sand, (4) coarse sand, and (5) peat.

Conflict of Interest

The author certifies that there is no conflict of interest with any financial organization regarding the material discussed in the paper.

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