



## Characterization of Alum Sludge for Reuse and Disposal

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### ABSTRACT

The properties of spent drinking water treatment sludge (WTS) were investigated to determine its physical and chemical properties. WTS was obtained from the Semanggar Water Treatment Plant, Kota Tinggi, Johore, Malaysia. Bulk density, particle density, porosity, surface area, particle size, moisture content, ash content, chemical composition, leachability of heavy metals, pH and the total organic carbon (TOC) were determined. Surface and other physicochemical properties were also studied using the scanning electron microscope (SEM), field emission scanning electron microscope (FESEM), X-ray diffractometer (XRD), TGA, FTIR, BET single point surface area analyzer, and TOC analyzer. Results showed that the particle size, bulk density and particle density of WTS were 2-5  $\mu\text{m}$ ,  $0.831 \pm 0.061 \text{ g/cm}^3$  and  $2.66 \pm 0.029 \text{ g/cm}^3$ , respectively. The porosity was 68-69% with surface of 38.92  $\text{m}^2/\text{g}$  and ash content of 67%, reflecting the high TOC of  $1440.37 \pm 14.71$ . The sludge contained 29% moisture and showed a pH value of 4.28 in solution. Analysis of acid digest indicated a high content of Al and Fe. The WTS were shown to leach very low levels of selected heavy metals.

| Drinking water treatment sludge | Aluminium | Iron | Hazardous material disposal |

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## 1. INTRODUCTION

Drinking water treatment sludge (WTS) is produced together with processed drinking water in a typical water treatment facility. A large amount of Alum derived WTS is generated in Malaysia, such that disposal of the sludge and its beneficial reuse is of concern. The management and disposal of WTS is important due to stringent regulations on waste management by the Department of Environment [1]. The Semanggar Water Treatment Plant in Kota Tinggi, Johore has a 40-acre landfill area designed to support 30 years of operation for disposal of sludge. The plant accommodates as much as 120 tonnes of raw sludge and generates an estimated 80 tonnes of dried sludge per year. Studies had shown that heavy metal in the WTS generated by some water treatment plants in Malaysia were within safe limits [2], although accumulation of heavy metals in landfills is still a concern. Options for reusing WTS such as adsorbents for wastewater treatment and construction material had been documented [3-10]. The aim of this study is to investigate the properties of the WTS in terms of structural identity, leachability of heavy metals, chemical composition and other properties that are important for its potential reuse and safe disposal into the environment.

## 2. EXPERIMENTAL

### 2.1 Materials, method and instruments

Raw WTS, obtained from the Semanggar Water Treatment Plant was drained of liquid, dried in an oven and grinded. The moisture content, particle density, bulk density, porosity, ash, particle size and pH were determined. The chemical composition was determined by performing wet digestion on the WTS sample followed by analysis using FAAS. Other parameters were performed based on general analytical methods. Leachability of the WTS was tested using the extraction technique of the UK leach test and measuring the metal concentration using FAAS. Elemental, physical and chemical analyses of the WTS were carried out using, BET single point surface area analyzer, FTIR and TOC analyzer. Thermal stability analysis on WTS using TGA was also performed. The morphological structure of the WTS was examined by scanning electron microscope (SEM), field emission scanning electron microscope (FESEM) and X-ray diffractometer (XRD).

## 3. RESULTS & DISCUSSION

### 3.1 Physiochemical characteristics of WTS

Results of the chemical composition analysis, bulk density, particle density, porosity, pH, TOC, ash and moisture content of the WTS are shown in Table 1.1.

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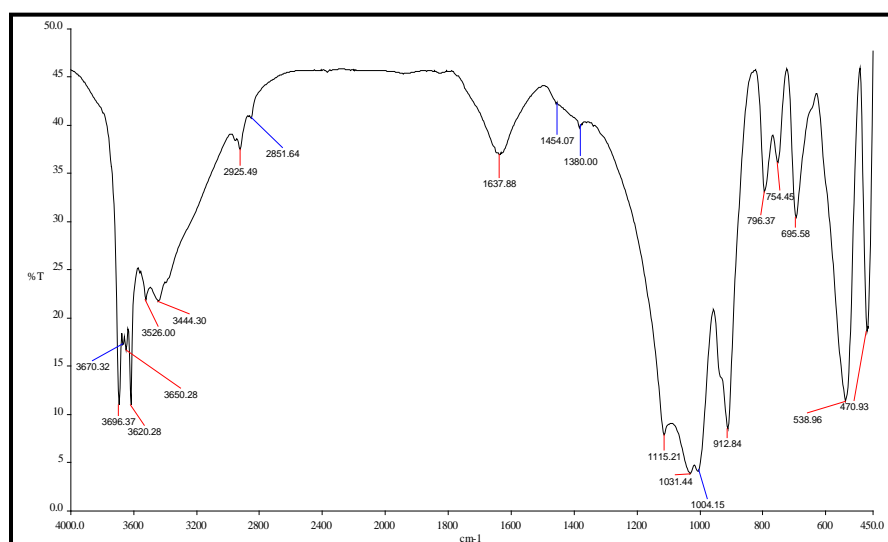
**Table 1.1** Properties and chemical composition of WTS

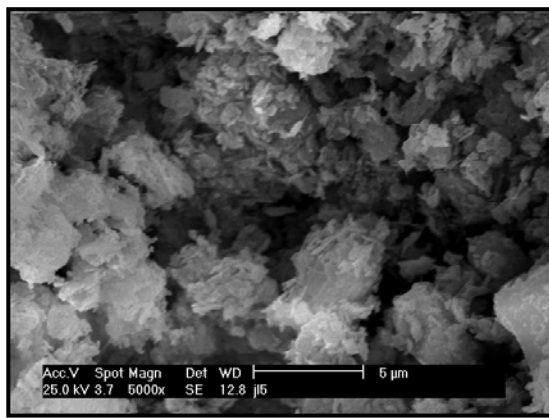
Physical Property	Mean $\pm$ SD	Chemical Composition	
		Metal	Concentration (mg/g)
Bulk Density ( $\text{g}/\text{cm}^3$ )	0.831 $\pm$ 0.061	Al	12.8033 $\pm$ 0.2052
Particle Density ( $\text{g}/\text{cm}^3$ )	2.66 $\pm$ 0.029	Cd	0.0024 $\pm$ 0.0002
Porosity (%)	68-69	Cr	0.0155 $\pm$ 0.0006
Ash (%)	66.67 $\pm$ 1.155	Cu	0.0171 $\pm$ 0.0005
Moisture (%)	28.67 $\pm$ 0.577	Fe	7.3517 $\pm$ 0.0155
Total organic carbon (TOC):		Mn	0.0395 $\pm$ 0.0013
- Organic carbon	1570.33 $\pm$ 12.055	Ni	0.0066 $\pm$ 0.0001
- Inorganic carbon	129.97 $\pm$ 2.650	Pb	0.0371 $\pm$ 0.0002
- TOC	1440.37 $\pm$ 14.706	Zn	0.0339 $\pm$ 0.0007
pH of solution	4.28 $\pm$ 0.012		
Surface area ( $\text{m}^2/\text{g}$ )	38.92 $\pm$ 2.68		

The WTS was acidic in nature ( $\text{pH} \approx 4$ ) while the particle density and bulk density were  $2.66 \pm 0.029$  and  $0.831 \pm 0.061 \text{ g}/\text{cm}^3$ , respectively. A low bulk density generally enhances adsorption. A bulk density value of less than 1.2 indicates fine particles, while particle density value of 2.2-4.0 means that the particles are medium. The WTS showed a moderate single point surface area value ( $\approx 40 \text{ m}^2/\text{g}$ ) and the percent porosity was about 68%. In this study the adsorbent particles can be categorized as a mixture of fine and medium sized particles. Based on the properties discussed, the WTS is expected to provide a relatively high adsorption capacity because smaller particulate materials provide more available surface area for inter-particulate bonding.

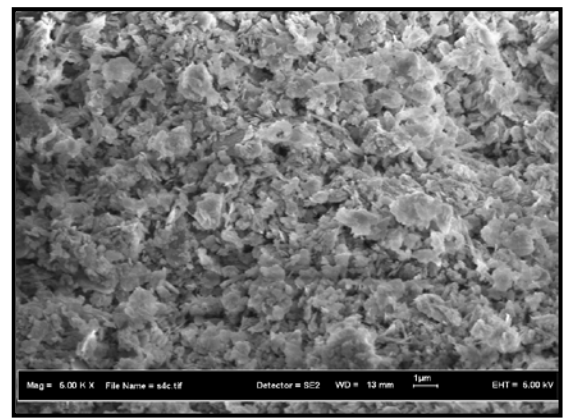
Al and Fe were the dominant components in the WTS, where Al was almost twice the amount of Fe. Al was almost 400 times more than the other metals that were present in trace quantities. The ash content which was approximately 67% represented other non soluble compounds or minerals (not including heavy metals) that can be found in the sludge. The WTS also contained a significant amount of organic matter or humic matter as shown by the TOC value of approximately 1440.

The WTS was also analyzed using FTIR, SEM and FESEM. Figure 1.1 shows the FTIR spectrum for WTS on KBr discs (WTS powder:KBr, 1:100) analyzed using the FTIR spectrometer. Figure 1.2 shows the SEM and FESEM micrographs of WTS.

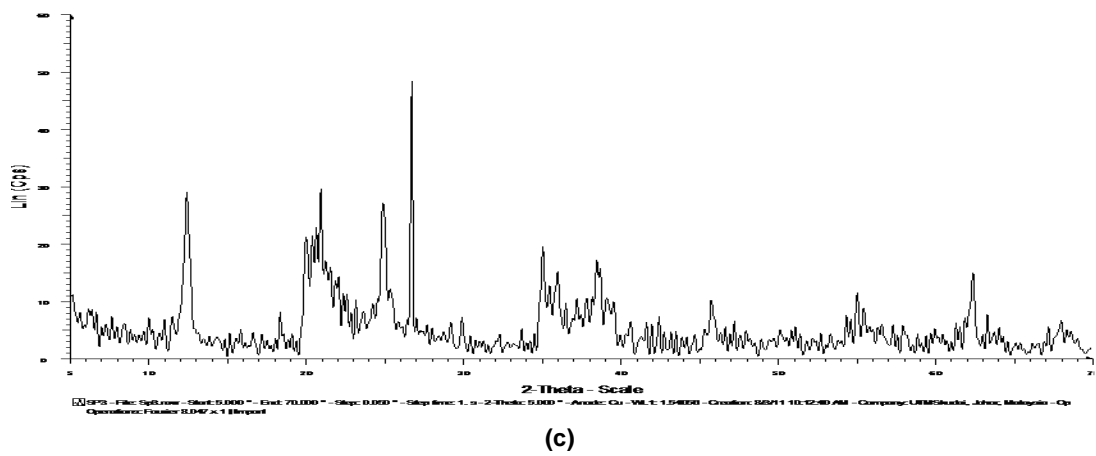
**Fig. 1.1** FTIR spectrum of dry WTS powder



(a)



(b)



(c)

Fig. 1.2 Morphology of WTS as determined using (a) SEM, (b) FESEM and (c) XRD

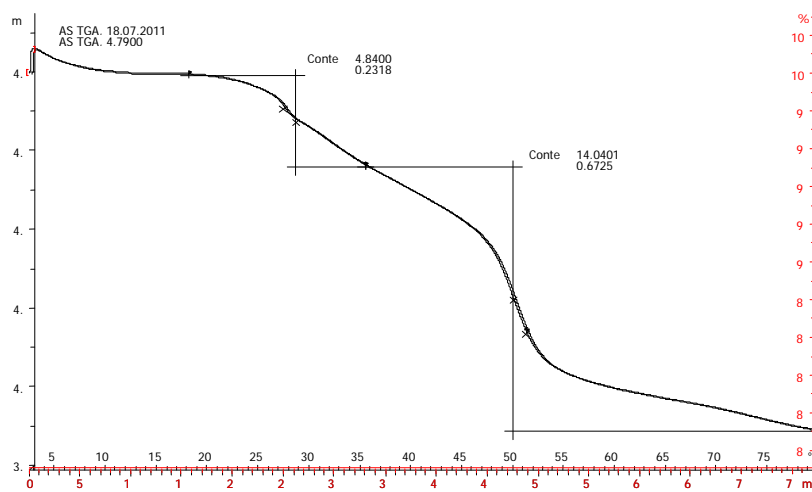


Fig. 1.3 Thermogram of WTS

**Table 1.2** Thermogravimetry data for WTS

Thermal Stability	Temperature range	Weight loss (%)
Low	180- 280°C	4.8400 %
High	280- 500°C	14.0401 %

The FTIR showed that the WTS contained some organic matter, confirmed as expressed in TOC. SEM only provided a qualitative description of the sludge structure. From the SEM micrograph, the particle size of WTS was determined to be in the range of 2-5  $\mu\text{m}$ . The SEM micrograph of the WTS did not find any well-defined crystalline structures on the sludge surface [11]. The homogeneity of the WTS also depended on its particle size. The WTS is a non-homogeneous material due to its unclear particle shape as demonstrated by FESEM. Based on the appearance of the SEM and FESEM analysis it is reasonable to conclude that the WTS is amorphous in nature. In order to determine the components or minerals in the samples, XRD analysis was performed. XRD diffractograms can also provide qualitative description on sample structure [11].

The diffractogram indicates that the particles of WTS are semicrystalline, as well as poorly ordered. The fitting of the diffractogram to data available in the XRD catalogue reflected the most presence of kaolinite which is one of the major minerals [12] in sediment.

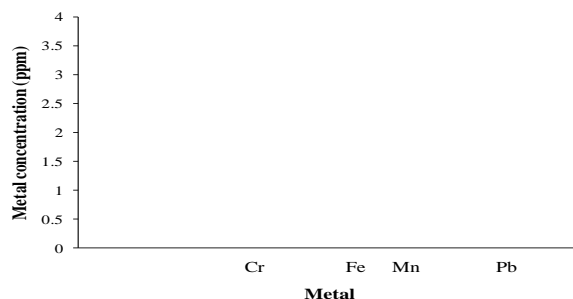
Figure 1.3 illustrates the thermal stability of WTS and the percent weight loss tabulated in Table 1.2. From the thermogram, it can be clarified that an approximately 5% weight loss of WTS was detected between the temperatures of 180-280 °C, and about 14% weight loss between 280-500 °C which indicated that a large portion of the WTS contained undefined component(s) with lower thermal stability.

### 3.2 Heavy Metal Leachability of WTS

Table 1.3 and Figure 1.4 illustrate the profile of metal ions that were leached out from the WTS by using the UK Leach Test, with distilled water as the leaching eluent. Although the presence of Al, Cd, Cu, Ni and Zn was detected in the chemical composition of the WTS, the metals were not leached out of the WTS when the UK Leach Test was performed. However, Pb, Fe and Mn were leached out in the range of 1.2 - 3.7 ppm, and less than 0.07 ppm Cr was leached out.

**Table 1.3** Metals leached out from the sample WTS

Metal	Concentration (ppm)
	(mean $\pm$ SD)
Al	ND
Cd	ND
Cr	0.06 $\pm$ 0.01
Cu	ND
Fe	2.74 $\pm$ 0.02
Mn	1.28 $\pm$ 0.02
Ni	ND
Pb	3.63 $\pm$ 0.04
Zn	ND



**Fig. 1.4** Leachability profile of metals from WTS  
[Leaching eluent: Distilled water, Temp: 25°C, Extraction time: 60 min]

#### 4. CONCLUSION

The WTS contained permitted levels of Al, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn. Leach Tests showed that very low levels of Pb, Fe, Mn and Cr were leached out by distilled water from the WTS. The WTS contained a significant amount of organic or humic matter as shown by FTIR spectra and TOC analysis. The results of the SEM and FESEM analysis concluded that the WTS is amorphous in nature. The WTS is expected to provide a relatively high adsorption capacity due to small particulate materials which provide available surface area for inter-particulate bonding.

#### ACKNOWLEDGEMENT

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