Characterization of Waste Activated Sludge for Sustainable Disposal in Jamaica

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Abstract*– *The sustainable management of waste activated sludge (WAS) involves the recovery and reuse of valuable products whilst minimizing any possible adverse impact on the environment. This study explored the possible disposal options for the sludge, generated by different activated sludge systems in Jamaica, based on the parameters of pH, EC, heavy metal concentration, and proximate analysis. The correlation between the easy to measure properties such pH. EC and volatile matter and the time-intensive parameter of heavy metal concentrations and lipid yield were also assessed.

Based on the measured parameters it was found that the sludge was not a suitable bioenergy source due to the high volatile matter and low fixed carbon content. On the other hand, the sludge samples were found to be basic in nature with a pH of 7.46 - 7.94, had a low salinity with EC values ranging from 727.7 µS/ cm - µS/ cm, sufficient organic matter content of 33.49 to 52.40% d.m and low heavy metal concentrations. These results suggest that sludge application to soil may positively affect the physicochemical properties of soil.

Keywords*-- *bioenergy, heavy metal, waste activated sludge, and wastewater.

I. INTRODUCTION

In Jamaica the most easily recorded method for the treatment of domestic wastewater is the activated sludge process. There are many different variations of activated sludge reactors and multistep systems and those utilized in this country include the extended aeration, contact stabilization and oxidation ditch [1]. These processes are the highest ranking wastewater treatment processes for small to medium sized utilities. They not only have the advantage of producing a high quality effluent but also does it at a reasonable operating and maintenance cost [2]. This is achieved by seeding the accumulated, bacteria-rich deposits (activated sludge) of settling tanks and basins into incoming wastewater in order to digest the organic content and pollutants in the raw sewage [3]. It also involves the waste of activated sludge and the disposal on drying beds for the reduction of water content. This wasted sludge is what is referred to as the waste activated sludge, a residual mixture of organic and inorganic solids [4].

While this system does a remarkable job of cleaning and recycling the water back to the environment, the resulting sludge presents a major ongoing disposal challenge for water management authorities worldwide. This is due to the drastic increase in sewage sludge production as well as the adverse effects that this organic waste has caused as a source of secondary environmental pollution. Therefore, its proper disposal and treatment are of the utmost significance.

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Sustainable Waste Activated Sludge management involves the recovery and reuse of valuable products and the minimization of the possible adverse impact of sewage sludge on both environmental and human health. A diverse range of options is available for the safe disposal and resource recovery from WAS. Current methods for energy and resource recovery include agriculture through land application and biomass energy generation through incineration [5]. The selected method of disposal is strongly dependent on the sludge's properties, degree of pathogen treatment and pollutant concentrations [6].

Land application of the sludge is a traditional disposal option because it offers the possibility of recycling plant nutrients, providing organic material, improving soil fertility along with physical properties and enhancing crop yield [6, 7]. The organic fraction in organic amendments can enhance significantly soil, water infiltration, microbial activity, structure, and water holding capacity and it can reduce soil compaction and erosion [8]. Chemical properties such as electrical conductivity (EC), organic carbon, and soil pH may also be improved by organic amendments application [9]. However, the use of WAS can also lead to environmental pollution because it contains various pollutants, especially heavy metals [10].To avoid this risk associated with the use of sludge, Jamaica has established criteria for the concentration of heavy metals in sewage sludge used for land applications [11].

Fuel produced from sludge biomass bears the potential of being considered a renewable energy source [12]. Furthermore, it is a fuel that does not have an adverse impact on biodiversity or on the available arable land resources and a product which also solves the issue of sewage sludge landfilling. Proximate analysis is used to give a crude assessment of the energy recovery potential of the biomass. It provides the percentage of the material that burns in a gaseous state (volatile matter), in the solid state (fixed carbon), and the percentage of inorganic waste material (ash), and has therefore been found to be of fundamental importance for biomass energy use [13]. Additionally, research has shown that sewage sludge has a high lipid content, making it a possible cost-effective source of biodiesel [14]. The equivalent quantity of lipid extracted from traditional feedstock would require large areas for cultivation, therefore resulting in a higher final cost [15].

There is consequently a need to garner information on the characteristic of the WAS produced in Jamaica in order to create a sustainable plan for its disposal and reuse. Therefore the present research provides information on the physicochemical characteristics of WAS collected from the parishes of St. Thomas, Portland, Kingston and St. Andrew, and St. Catherine in eastern Jamaica. This study aims to contribute to the body of knowledge of waste activated sludge characterization by assessing some of the parameters pertinent to the disposal and reuse of WAS.

The objectives of this work were:

1. To determine some of the physicochemical properties of sludge such as pH, EC, organic matter content (VM), fixed carbon, ash content and heavy metal concentration.
2. To assess the potential of the use of sludge as a soil amendment in agriculture and a renewable source of bioenergy based on the measured parameters,
3. To examine the effects of the type of AS system on the properties of the sludge.
4. To assess the relationship between the easy to measure parameters such as pH, EC, and organic matter and the time-consuming parameters such as the heavy meal concentration and lipid yield.

II. Method

A. Sample Collection

Waste activated sludge (WAS) was collected from the drying beds of six activated sludge wastewater treatment plants. The activated sludge systems included extended aeration, oxidation ditch and contact stabilization, two plants were sampled from each of these systems. Sampling was done between the months of December 2018 and June 2019. The plants sampled are presented in Table 1. Four samples were collected from dying beds that contained 2-month-old sludge, this is sludge that was ready to be removed from the drying bed for disposal. A composite sample was created from the four grab samples. The samples were then transported to the Waste Management Centre at the University of Technology, Jamaica for analytical testing.

TABLE 1
TYPE OF ACTIVATED SLUDGE PLANTS INCLUDED IN THE STUDY

AS Technology	WWT Plant	Location
Contact Stabilization (CS)	WP1	St. Catherine
Contact Stabilization (CS)	WP2	Kingston & St. Andrew
Oxidation Ditch (OD)	WP3	St. Catherine
Oxidation Ditch (OD)	WP4	Portland
Extended Aeration (EA)	WP5	St. Thomas
Extended Aeration (EA)	WP6	Kingston & St. Andrew

B. pH and Electrical Conductivity (EC)

The pH values of the sludge samples were determined using a calibrated pH/EC meter after mixing the sludge samples in a 1:2.5 (w/v) solution of distilled water after stirring the solution for 30 minutes using a glass rod. The electrical conductivity of the sludge sample was measured using the sample solution prepared for pH and meter [16].

C. Heavy Metal Concentration

The collected samples were dried at room temperature, grounded, and homogenized in a mortar; then, they were sieved through a sieve (mesh pore size: 0.14 mm), and stored at room temperature. Dry sludge samples were weighed and digested with nitric acid, using a microwave digestion system as per the procedure of the United States Environmental Protection Agency Method 3051B [17]. Pb, Cu, Cd, and Zn were analyzed using a graphite furnace atomic absorption spectrophotometer. The concentration of each heavy metal was recorded.

D. Proximate Analysis

The volatile matter content and ash content were determined using the gravimetric method according to method 1684 of the US EPA [18]. The fixed carbon (FC) content was calculated with the use of equation (1).

$$[FC]=100 - ([A]+[M]+[VM]) \quad (1)$$

where: [FC] – fixed carbon content, wt. %, [A] – ash content, wt. %, [M] – moisture content, wt. %, [VM] – volatile matter content, wt. %.

E. Lipid Extraction

The main equipment used was the soxhlet apparatus (see Fig 1). 25 g of dried specimens were placed in a thimble and paved in the extractor section of the soxhlet apparatus [19]. 50 ml of ethanol was poured into a round bottom flask to complete the set-up. Each extraction was carried out at a sludge to solvent ratio of 1:2 at the boiling point of each solvent for 4 hours. Thereafter the solvent was removed from the extracted lipid using a rotary evaporator at 80°C.

Fig1. Experimental setup for Soxhlet Extraction

The amount of lipid recovered and its percentage in the original sample were calculated using the equations below:

Mass of lipid = (weight of the flask + extracted oil) − (weight of the flask (2)

Lipid content (%) = (mass of lipid ÷ mass of dry sludge)*100 (3)

Then, the remnant lipid fraction was stored in a desiccator overnight and weighed the next day to determine the extraction yield.

F. Statistical Analysis of WAS Properties

The data obtained from the characterization of WAS experimental runs for the response variables were analyzed using the Minitab 17 Statistical Software. The software was used to carry out a basic descriptive statistics analysis on the characteristics of the WAS and an ANOVA test was carried out on both data sets. Graphs were also used to display the findings of the analysis. Lastly, Pearson's correlation was used to assess the strength and direction of association between the measured parameters. P-values lower than .05 indicates a significant difference.

III. Results and Discussion

A. pH and Electrical Conductivity (EC)

The pH and electrical conductivity results of the WAS collected is presented in Table 2. The sludge was found to be slightly basic with pH values ranging from 7.46 ± 0.24 - 7.94 ± 0.23. Since the pH is not acidic, this would reduce the heavy metal absorption ability of the sludge and hence reduce the possible toxicity [16]. According to Rajkumar [20], activated sludge can only be suitably applied to the biological treatment if the pH value is near neutral at approximately 6.5-7.5. The EC of the sludge samples ranged from 758.7 ± 8.08 µS/ cm to 1735.7 ± 109.7 µS/ cm. Generally, the sludge produced by these plants, classified based on pH and EC values are deemed acceptable for land application or agricultural purposes in accordance with the literature [21].

TABLE 2
Descriptive statistics of pH and EC of the Waste Activated Sludge

AS Technology	WWT Plant	Parameter	
		pH ± SD	EC (µS/ cm) ± SD
Contact Stabilization (CS)	WP1	7.90 ± 0.30	924.7 ±22.9
Contact Stabilization (CS)	WP2	7.66 ± 0.03	1315.7 ± 81.8
Oxidation Ditch (OD)	WP3	7.54 ± 0.24	758.7 ± 8.08
Oxidation Ditch (OD)	WP4	7.74 ± 0.28	1735.7 ± 109.7
Extended Aeration (EA)	WP5	7.94 ± 0.23	1227.3 ± 127.7
Extended Aeration (EA)	WP6	7.46 ± 0.24	1024.0 ± 19.5
NEPA			

The ANOVA analysis revealed that the difference in the pH value from one AS technology to the next was not statistically significant. This factor had a p-value of 0.689 which is greater than 0.05 and therefore the null hypothesis could not be rejected. All the mean pH values were statistically the same. Additionally, the interaction between the sludge type and the plant did not yield a significant effect on EC values obtained. This is realistic as sludge with a slightly basic pH value is a characteristic of the biological treatment process and therefore all the sludge samples are expected to have similar pH values as they were all collected from activated sludge treatment plants.

The results of the ANOVA indicated that the effect of the technology on the EC value was significant. The technology had a p-value of 0.776 which is greater than 0.05 at a confidence level of 95%. Therefore the difference in the EC that was found in the descriptive analysis was not significant.

B. Volatile Matter and Ash Content for Agricultural Use

The organic matter in sludge has been found to improve the soil structure and nutrient quality of soil when used in agriculture. However, in terms of landfilling the high volatile matter content may lead to the development of malodours and biogas production [22]. The ash content represents, the inorganic aspect of the sludge, which mainly consists of silica, aluminium, iron and calcium. The ash in sludge has been found to increase the shear strength of soil [23].

The volatile matter of the sewage sludge samples collected ranges from 33.49±3.91% to 52.40±12.02% (see Fig 2). Previously reported studies also demonstrated volatile matter content for sludge within this range [24, 25].

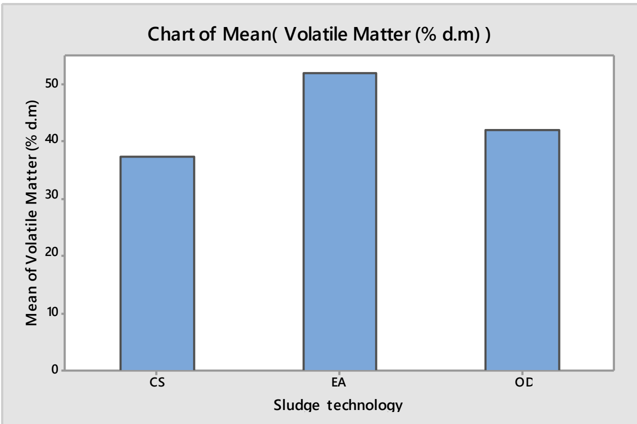

Fig. 2 Mean VM (%d.m) versus the AS Technology

Overall the ash content ranged from 32 % to 50% (see Fig 3). This was found to be higher than the ash content based on literature which was found to be between 25% - 39% [26].

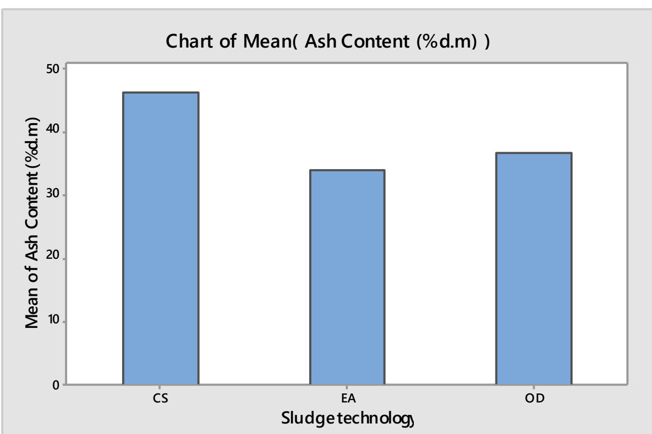

Fig. 3 Mean Ash Content (% d.m) versus the AS Technology

C. *Heavy Metal Concentration for Agricultural Use*

The concentration of heavy metals determined is presented in Figure 4. The heavy metals, Cd, Pb, Cu and Zn, were found to be present in the sewage sludge. The mean values of concentration, the heavy metals were ranked in decreasing order as follows: Zn >Cu > Pb > Cd. Previous studies have reported the concentration of heavy metals in this descending order [28, 29]. The mean value of each heavy metal was 618.14 mg/kg, 143.81mg/kg, 18.96 mg/kg, and 1.48 mg/kg, respectively.

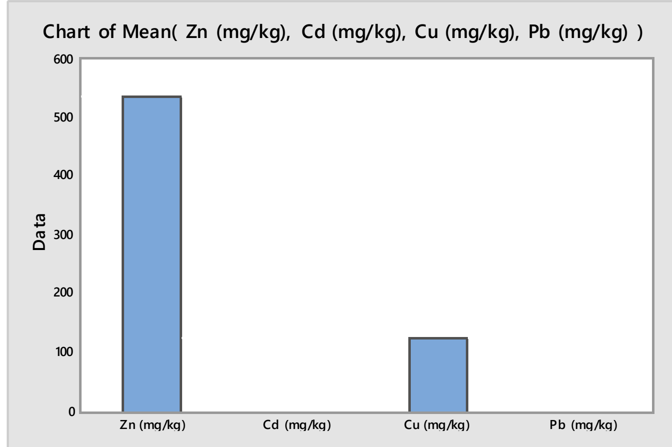

Fig. 4 Mean Heavy metal concentration of the Sludge samples

The content of Zn was the highest, while that of Cd was the lowest in all samples (see Fig 4). The Zn concentrations were in the range 411 to 1000 mg/kg which greater than the maximum permissible concentration of 400 mg/kg [27]. The origin of Zn is a constituent of galvanized steel including water distribution pipes and the possibility is that its presence might be due to corrosion and the metal may be carried to treatment plants and hence in the sludge [11]. The concentrations of Zn found were significantly greater than the findings of Tytla in which it was found that Zn values ranged from 14.3–600.5 mg/kg [4].

Based on the ANOVA analysis, the concentration of the heavy metals did not significantly change with the variation in the type of activated sludge technology (see Fig 5).

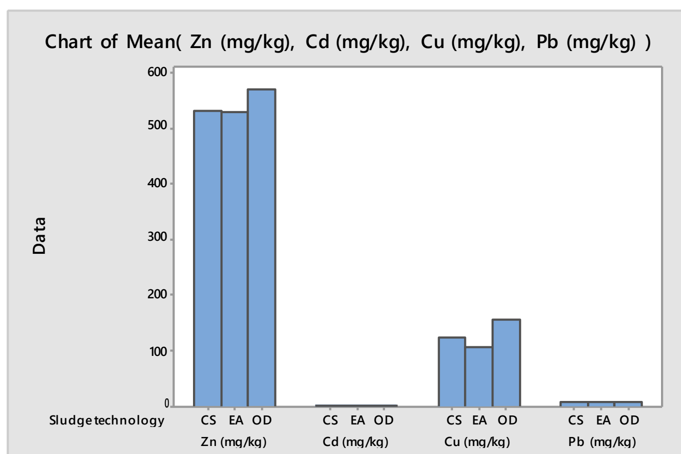

Fig. 5 Mean Heavy metal concentration versus Activated Sludge Technology

D. *Proximate Analysis for WAS as a Source of Bioenergy*

Proximate analysis of the sludge samples ranged from 33.49±3.91% to 52.40±12.02% for volatile matter, 6.81±2.47% to 15.31±4.04% for fixed content and 32.85±4.67% to 50.01±3.24% for the inorganic ash content (Table 3). There is a positive relationship between fixed carbon from biomass and charcoal yield while the volatile content and ash relate negatively with charcoal yield [12]. The higher VM content is more characteristic of low-rank coals, while the decreased value is more typical of higher-rank coals [12]. Thus, the greater the sludge volatile content the greater the gas production instead of the solid phase needed for bioenergy. Whilst the high volatile matter of the tested sludge does not lend itself to a good source of bioenergy, it has been found to high VM does improve structure and nutrient quality of soil when used in agriculture [23].

TABLE 3
PROXIMATE ANALYSIS OF THE WASTE ACTIVATED SLUDGE COMPARED TO COAL

AS Technology	WWTP	VM (%d.m)	FC (%d.m)	Ash (%d.m)
Contact Stabilization (CS)	WP1	36.27±8.45	8.17±5.66	48.19±3.68
Contact Stabilization (CS)	WP2	38.48±3.72	9.87±4.39	44.19±6.47
Oxidation Ditch (OD)	WP3	52.40±12.02	7.22±4.21	35.05±12.88
Oxidation Ditch (OD)	WP4	51.31±4.93	6.81±2.47	32.85±4.67
Extended Aeration (EA)	WP5	39.48±4.60	15.31±4.04	39.01±7.49
Extended Aeration (EA)	WP6	33.49±3.91	7.82±3.53	50.01±3.24
Coal		2% - 50%	50% - 98%	24% - 49%

ANOVA was used to determine if the type AS treatment plant had an effect on VM, fixed carbon and ash content of the different samples tested. The p values with respect to the proximate analysis the effect of the AS technology was only significant in the outcome of VM and ash content with p values of 0.02 and 0.042 respectively.

E. WAS Lipid for Biodiesel Production

The lipid yield is an important factor in the choice of feedstock for biodiesel production. The lipid yield obtained from the sludge generated in Jamaica is close to the yields reported for sludge generated in the United States by Kargbo [30, 31]. These researchers also examined the potential of producing biodiesel from the lipids from waste sludge. However, the current result establishes the possibility of producing biodiesel from Jamaican WAS but does not speak to its feasibility. The feasibility of this production route is based on not only the lipid yield but also the amount of sludge generated by each plant over a specified period of time.

TABLE 4
LIPID CONTENT OF WAS FROM SEVEN DIFFERENT TREATMENT PLANTS

WWT Plant	Lipid Yield [w.t %]		
	Minimum	Mean ± SD	Maximum
WP1	3.52	3.61 ± 0.13	3.76
WP2	3.07	3.39 ± 0.49	4
WP3	5.95	6.32 ± 0.40	6.74
WP4	7.13	7.26 ± 0.17	7.45
WP5	3.42	3.74 ± 0.28	3.97
WP6	3.89	3.94 ± 0.06	4.01

The variation in treatment plant was found to have had a very significant effect on the lipid content; p was found to be less than 0.001 for WWTP. Therefore the difference in the lipid content is due to the fact that sludges from the different plants are statistically different. The decreasing lipid content of the WAS samples were as follows: WP4>WP3>WP6>WP5>WP1>WP2. The oxidation sludge systems resulted in the sludge samples with the highest lipid yield, followed by the extended aeration and the contact stabilization systems.

E. Relationship of Measured Parameters

The relationship between measured parameters was assessed using all samples (Table 5). The correlations between easy to measure parameters and time-intensive parameters may provide useful information related to the monitoring of sludge whilst reducing the need for time-consuming laboratory analysis [32]. However, the only significant relationship that was identified was between pH and lipid yield based on a p-value value of 0.024.

TABLE 5
RELATIONSHIP BETWEEN SLUDGE PARAMETERS USING PEARSON'S CORRELATION

	EC	Volatile Matter	pH
Zn (mg/kg)	0.299007271	0.328826161	0.034643619
	0.228	0.183	0.891
Cd (mg/kg)	0.188583325	0.186570533	0.041297446
	0.454	0.459	0.871
Cu (mg/kg)	0.185420931	-0.130414048	-0.11033028
	0.461	0.606	0.663
Pb (mg/kg)	0.219302422	-0.174974786	-0.179493366
	0.382	0.487	0.476
Lipid Yield (%)	-0.443	0.220	-0.58
	0.066	0.381	0.024

IV. CONCLUSION

The WAS samples were characterized based on the physicochemical properties of pH, EC, heavy metals (Zn, Cu, Cd and Pb), proximate analysis and lipid content. The sludge samples were found to be alkaline in nature with low salinity and with sufficient organic matter content. Additionally, the lipid yield obtained was comparable with previous literature which explored the WAS as a source of lipids. The lipid yield has established the potential of the WAS as a biodiesel feedstock but further research is needed in order to determine its feasibility. Thus the most suitable option based on the parameters assessed was an agricultural application with minimal impact on the environment based on low heavy metal concentration.

Based on the results the type of activated sludge technology had a significant effect on the parameters of volatile matter, ash content and lipid content. Additionally, predictive parameters were not able to be established due to a lack of strong correlations between the measured parameters. It is important to note that there was no previous work identified that reported on the characteristics of the sludge generated in Jamaica and therefore the findings of this work contribute to the creation of a sludge profile for the country. The sludge profile aids in the selection of a suitable and sustainable method of disposal for the sludge.

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