Attenuative Capacity of Compacted Bagasse Ash Treated Foundry Sand

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ABSTRACT

Physical and chemical as well as batch adsorption and column tests were carried out on foundry sand treated with up to 8% bagasse ash and compacted with British Standard heavy (BSH) energy. Specimens were permeated with solid waste (MSW) leachate sourced from a waste landfill. Batch equilibrium studies carried out on five foundry sand - bagasse ash mixtures prepared at stepped bagasse ash treatments of 0, 2, 4, 6 and 8% by dry weight of soil in a 1:4 foundry sand-solution ratio were used to assess the adsorption of ions present in the municipal solid waste leachate. Tests results show trends of chemical sorption by the foundry sand-bagasse ash mixtures in the order sodium, potassium, calcium and magnesium ($Na^+ > K^+ > Ca^{2+} > Mg^{2+}$). Higher bagasse ash treatment of foundry sand recorded higher retardation factors and lower diffusion coefficients with an increased sorption of the contaminant species. In general, higher bagasse ash treatment of foundry sand has significant advantages over the untreated foundry sand and will better serve as landfill liner material.

KEYWORDS: Bagasse ash, Foundry sand, Absorption, Retardation.

INTRODUCTION

Industrialization has resulted in environmental and geo-environmental problems posed by the migration of contaminants through groundwater system from waste disposal sites. The movement of contaminant contained in leachate from landfill into the groundwater system can be minimized by placing the waste in an engineered containment facility. Soil liners are not impermeable; therefore, contaminant transport through them depends mainly on their hydraulic conductivity and related advection–diffusion phenomena (Rajasekaran et al., 2005). In addition, the compatibility of a clay liner to a specific contaminant depends on two factors; the ability of the clay in the liner to resist increases in hydraulic conductivity caused by the contaminant and its capacity to retard the migration of contaminants through sorption (Li and Li, 2001).

According to Daniel and Shackelford (1988), even compacted clay barriers with a permeability of zero will not stop the release of contaminants because flow will still occur from molecular diffusion of contaminants across the barrier. The effectiveness and capacity of natural geological materials (soil) to attenuate the movement of chemical constituents that may be present in leachate can be quantified in the laboratory.

The contaminant transport in soils may be retarded through processes of sorption, precipitation, biodegradation and filtration. The attenuation processes include: cation removal, anion removal and

biodegradation. The important process for sorption of cations is by ion exchange at exchange sites and in the inter layers of clays. The rate of leakage will depend on the diffusion coefficients of ions and the permeability of the clay liners to the given leachate. While dilute solutions of inorganic chemical change the clay permeability, dilute solutions of organic chemicals have virtually no effect. Hence, the contaminant migration through the soil depends greatly on the diffusion coefficients of migrating ions. Also, it was observed that the leachates generated in normal municipal landfill have no significant influence on the permeability of the clay liners. Diffusion of species of interest in pore water between the clay particles is a complicated process. Effective diffusion coefficient (D_e) takes into consideration other attenuation processes. However, the difference between porous media diffusion coefficient and effective diffusion coefficient is very little for conservative ions like chloride. Determination of diffusion coefficients of some common ions is important in estimating the total breakthrough times. Column tests are usually employed (Shackelford, 1991a) to determine the diffusion coefficient. Diffusion coefficients are determined from the break-through curves plotted using column test data. It has been brought out that the cation exchange capacity of soil plays an important role in the attenuation of cations. Sodium ion is considered as a conservative ion, because normally sodium cannot replace other exchangeable ions of soil and is adsorbed onto the clay surface. Barone et al. (1988) have shown that the adsorption of sodium and potassium is affected by other exchangeable ions in the leachate. It is not known how the effective diffusion coefficient (D_e) of sodium is altered in the presence of these ions. Knowing the effective diffusion coefficient D_e, it is possible to calculate the rate of migration of a species.

Sugar cane is a major raw material for sugar production. It is grown on 25,000 – 30,000 hectares in Nigeria with a production rate of about 80 tons/hectare (Misari et al., 1998). Bagasse is the fibrous residue obtained from sugar cane after the extraction of sugar

juice at sugar cane mills (Medjo and Riskowski, 2004), while bagasse ash is the residue obtained from the incineration of bagasse in sugar producing factories. Bagasse ash has shown to possess pozzolanic properties (Sujjavanidi and Duangehan, 2004; www.ifgworld org. Osinubi and Stephen, 2005; Osinubi and Eberemu, 2006a; Osinubi et al., 2007a,b). Research works have been carried out on the improvement of geotechnical characteristics of soils using bagasse ash (Osinubi and Stephen, 2006a,b, 2007; Stephen, 2006; Osinubi et al., 2007a,b, 2008a,b, 2009). However, no work has been conducted on the effect of bagasse ash on treated foundry sand for use in liners and covers in waste curtailment applications.

There are two basic types of foundry sand available, green sand (often referred to as molding sand) that uses clay as the binder material, and chemically bonded sand that uses polymers to bind the sand grains together. Green sand consists of 85-95% silica, 0-12% clay (bentonite, kaolin,… etc.), 2-10% carbonaceous additives, such as sea coal, and 2-5% water; other minor ingredients (flour, rice hulls, starches, cereals,… etc.) may be added to absorb moisture, improve the fluidity of the sand or stiffen the sand based on the production needs of the individual foundry. Green sand is the most commonly used moulding media in foundries. The silica sand is the bulk medium that resists high temperatures, while the coating of clay binds the sand together. The water adds plasticity; however, spent foundry sand has no plasticity (Johnson, 1981).

This study is aimed at evaluating the attenuative capacity of compacted bagasse ash treated foundry sand as a hydraulic barrier material in waste containment systems.

THEORETICAL BACKGROUND

The Adsorption Isotherms

Chemical transport through earth materials is important in connection with groundwater, waste disposal and storage, corrosion, leaching phenomena,

osmotic effects in clay layers and soil stabilization (Mitchell, 1976). In particular, the design and evaluation of clay barriers for waste disposal necessitate chemical transport or solute migration through the barrier soil layers. Batch equilibrium or adsorption testing is performed to determine the relationship between the amounts of a given solute adsorbed to the surfaces of clay particles and the amount of the same solute remaining in the pore water of the soil under equilibrium conditions (Shackelford, 1994a). The relationship between the adsorbed solute concentration and the pore water concentration is referred to as an adsorption isotherm; the slope of which is called the partitioning coefficient.

The results of the chemical analysis were plotted in the form of adsorption isotherms, or sorbed concentration, C_s versus dissolved equilibrium concentration, C, of solute for each ion. The sorbed concentration was determined by mass balance using Eq. (1).

The solute per mass of solid soil is determined from the following equation:

$$C_s = \frac{(C_o - C)V}{M_s} \qquad (1)$$

where C_s = adsorbed concentration in microgram per gram; C_o = initial concentration of solute; C = equilibrium concentration in pore water; M_s = mass of soil solids; and V = volume of solution. A plot of sorbed concentration versus equilibrium concentration is called the adsorption isotherm. The slope of the adsorption isotherm is called the partition or partitioning coefficient, K_p which is represented by the following equation:

$$K_p = \frac{dc_s}{dc} \qquad (2)$$

The partitioning coefficient is used to determine the retardation factor, R_d, by the following equation (Shackelford, 1994b; Shackelford and Daniel, 1991b):

$$R_d = 1 + \frac{\rho d}{n_c} K_p \qquad (3)$$

or

$$R_d = 1 + \frac{P_d}{\theta} K_p \qquad (4)$$

where ρ_d and n_c are the dry, or bulk density and effective porosity, respectively, of the *in situ* soil and θ is the volumetric water content.

Molecular Diffusion

Diffusion is a transport process in which a chemical or chemical species in solution migrates in response to a gradient in its concentration, although the actual driving force for diffusive transport is the gradient in chemical potential of the solute (Robinson and Stokes, 1959; Shackelford, 1991a, 1993). Diffusion tends to be the dominant transport process in relatively low flow rate situation, such as clay barriers used for waste containment (Rowe, 1987; Shackelford, 1994b; Shackelford and Rowe, 1998). Based on considerations of the relatively short transport distances ($\leq$1m) and the slow flow rates associated with transport through clay liners, the dispersion process is essentially governed by diffusive transport and the dispersion coefficient, D, essentially represents diffusion coefficient. Diffusion coefficient is a parameter expressing the transfer rate of a substance by random molecular motion. Mathematically, it is defined as the specific transfer rate under a unit driving concentration gradient (Shackelford, 1994b).

A number of test procedures available for applications have been reviewed by Shackelford (1991). The easiest among the various diffusion testing procedures is the single-reservoir, decreasing source concentration method. Crank (1975) stated that for one-dimensional contaminant transport, the fundamental equation for diffusion is governed by Fick's first law, which is given as:

$$J = -D_0 \frac{d_c}{d_X} \qquad (5)$$

where J = the diffusive mass flux (mass flowing through a unit cross-sectional area in a unit of time), x= the direction of transport, D_o= the 'free-solution'

diffusion coefficient, and c = the concentration of the solute in the liquid phase.

Fick's first law describes steady-state flux of solute (Shackleford, 1988; Shackleford et al., 1989). The free diffusion coefficient (D_o) depends on the type of diffusion. Generally, there are four different types of diffusion: self diffusion; tracer diffusion; salt diffusion; and counter diffusion or inter diffusion. These have been extensively discussed by Robinson and Stokes (1959), Lerman (1979), Shakelford (1989) as well as by Shakelford and Daniel (1991b).

It is essential to note that solutes diffuse at slower rates in soil than in free solution, because of the following: (1) there is a reduced cross-sectional area of flow, (2) there is a more tortuous diffusion pathway because of the particulate nature of the porous medium; and (3) there may be reduced mobility of the diffusing chemical species in the soil pores because of interactions with the pore walls (Shackelford and Daniel, 1991a; Shackelford, 1988, 1993). In recognition of these, and for diffusion in saturated porous materials, Fick's first law has been modified to take the following form (Shackelford and Daniel, 1991a; Shackelford, 1988, 1993):

$$J = -D_0 \frac{d_c}{d_X} \qquad (6)$$

$$J = -\tau D_0 n \frac{d_c}{d_X} \qquad (7a)$$

$$J = -D^* n \frac{d_c}{d_X} \qquad (7b)$$

where τ = a dimensionless tortuousity factor and D^*= the "effective" diffusion coefficient. The porosity term accounts for the total cross-sectional area of the porous medium, while the tortuousity factor accounts for the increased distance of transport and the more tortuous pathways experienced by solutes diffusing through porous media. Shackelford (1993) expressed tortuousity as:

$$\tau = \left(\frac{L}{L_c}\right)^n \qquad (8)$$

where L = the macroscopic, straight-line distance between two points defining the flow path, and L_c = the actual, microscopic or effective distance of transport between the same points.

The retardation factor represents the relative rate of fluid flow to the transport rate of a reactive solute (Freeze and Cherry, 1979).

$$\frac{d_c}{d_t} = \frac{D^*}{R_d} \cdot \frac{d^2c}{dx^2} \qquad (9)$$

$$R_d = 1 + \frac{P_d}{\theta} K_p \qquad (10)$$

where R_d = retardation factor and is dimensionless. Shackelford et al. (1997) stated that one analytical solution to Fick's second law for one-dimensional diffusion through saturated soil for the case of a decreasing source concentration and for finite cell length is:

$$\frac{c(x\geq 0.\,t.\,)}{c_0} = \frac{\alpha}{1+\alpha} + \sum_{m=0}^{\infty} \frac{2\alpha}{1+\alpha+\alpha^2 q^2 m^2}$$

$$\exp(\frac{-D^* q^2 m t.}{L^2 R_d}) \frac{Cos[q_m(1-(\frac{x}{L}))]}{Cos(q_m)} \qquad (11a)$$

where C_o = the initial concentration of the solute in the source reservoir, D^* = the diffusion coefficient ($=\tau D_o$), which expresses in quantitative terms the rate at which a diffusion process occurs (Crank, 1975). R_d = the retardation factor for linear, instantaneous and reversible sorption, L = the length of the soil specimen and x is the direction of the diffusive transport.

$$tan(q_m) = -\alpha(q_m) \qquad (11b)$$

where α is a constant defined as follows:

$$\alpha = \frac{H_L}{nLR_d} \qquad (11c)$$

and n = the total porosity of the soil specimen.

MATERIALS AND METHODS
Materials

Foundry Sand: The foundry sand used in this study was obtained from Defense Industries

Corporation of Nigeria (DICON) industries, in Kaduna State of Nigeria. The location lies within latitude 10° 30'N and longitude 7°27'E. Specimens were varied with 0, 2, 4, 6 and 8% of bagasse ash by dry weight of foundry sand.

Bagasse Ash: The bagasse ash utilized in this work was obtained from Anchau Local Government Area of Kaduna State, Nigeria. Bagasse was openly incinerated within a temperature range of 500-700^{0}C to obtain the bagasse ash. The oxide composition of bagasse ash is given in Table 1.

Table 1. Oxide composition of bagasse ash

Oxide	Bagasse ash (%)
CaO	3.23
SiO$_2$	57.12
Al$_2$O$_3$	29.73
Fe$_2$O$_3$	2.75
Mn$_2$O$_3$	0.11
Na$_2$O + K$_2$O	-
SO$_3$	0.02
TiO$_2$	1.10
Loss on Ignition	5.89

(Osinubi et al., 2008a)

Leachate: The leachate used in this study was obtained from a non-engineered active open landfill located outside the premises of Ahmadu Bello University, Zaria, Nigeria. Generally, the waste generated is from students, staff and others. Furthermore, the quality of the waste dumped in terms of its ability to generate high concentration leachate cannot be compared to that from a city landfill with higher population and volume of waste generated. The leachate, which can be classified as stabilized based on the foregoing, was collected by scooping from a low lying open point in the landfill. A summary of the chemical properties of the MSW landfill leachate specimen L$_1$ and L$_2$ is given in Table 2.

Table 2. Chemical characteristics of leachates

Parameters (mg/l)	Concentration (%)	
	Leacheate (L$_1$)	Leacheate (L$_2$)
Na	440.0	173.2
K	240.0	46.44
Mg	0.8	0.3
Ca	30.1	21.5
Pb	0.8	0.7
Cr	1.2	0.7
Cl	2041	765
COD	2000	1500
BOD	1000	750
TDS	4000	4000
pH	10	10.1

BOD = Biological Oxygen Demand.

COD = Chemical Oxygen Demand.

TDS = Total Dissolved Solids.

Methods
Batch Equilibrium Adsorption Tests

Batch equilibrium adsorption tests (BEATs) were performed with the soil samples and the leachate to quantify the potential adsorption of some specified cations and anion; namely Ca^{2+}, Na$^+$, K$^+$ and Cl$^-$. The procedures used for BEATs generally followed those used by Shackelford et al. (1989), Shackelford and Daniel (1991b) and Cotton et al. (1998). The batch equilibrium test was carried out on bagasse ash treated foundry sand. Tests were carried out on foundry sand treated with up to 8% by dry weight of soil. The foundry-bagasse ash was mixed at 1:4 ratio. An amount of 50g of the soil was taken and 200 cm^3 of the leachate of known initial concentration was placed into a plastic container. The mixtures were placed in a table shaker (HS 500 Janke and Kunker, Ika-Werk) at a speed of 30 hub/min and allowed to mix for a period of 48 hours before obtaining the supernatant by filtering into plastic bottles using filter papers. Cation concentrations were measured using UNICAM 969 Atomic Absorption Spectrophotometer (AAS). The

results of the chemical analysis were plotted in the form of adsorption isotherms, or sorbed concentration, C_s *versus* dissolved equilibrium concentration, C, of solute for each ion.

Sample Preparation for Diffusion

The procedure of the diffusion test was in accordance with Shackelford and Daniel (1991); i.e., the single-reservoir, decreasing source test. The diffusion set-up consists of PVC pipes with a height of 25 cm and 10 cm diameter containing compacted soil samples with a height of 12 cm. Each of the soil samples was compacted at 2% water content wet of optimum water content based on the optimum water contents using British Standard heavy compactive effort to assume the same volume and density of the specimens used for foundry sand-leachate compatibility test. The diffusion cells were sealed at the top using perpex with a narrow hole through which the leachate was introduced. Prior to sealing of the top of the cells, distilled water was allowed to pond over the top of each compacted soil sample for at least 30 days. This was done in order to achieve soil saturation and to minimize mass transport of contaminants due to suction in the soil.

Diffusion, Sectioning and Extraction

After 30 days, the distilled water was removed and the MSW leachate was introduced through the holes made in the perspex ensuring that there were no air bubbles on top of the solution. Diffusion test was continued for a period of 90 days to allow for the movement of the contaminants under a hydraulic gradient. The chemical species in the leachate were allowed to diffuse into the saturated, compacted soils for three (3) months. At the end of the diffusion stage, each cell (10 cm diameter by a height of 25 cm, foundry sand thickness maintained at 12 cm) thick soil was extruded and sectioned into slices of equal dimensions (1.1cm thick).

Sectioning was carried out to provide:
(1) A distribution of water contents existing in the

specimens by oven-drying.
(2) A concentration profile of the specified ions for use in determining the effective diffusion coefficients.

The slices were divided into two portions; one set was used to determine water contents of the slices, while the second set of slices was allowed to air-dry prior to extraction. The water contents of the slices were determined by oven-drying.

The air-dried slices for concentration profile were digested by adding aqua regia (mixture of HCl and HNO_3 at a ratio of 1:3; that is, 5 ml of HCl to 15 ml of HNO_3) into 1g of the foundry sand-bagasse mixture in a beaker. The material in the beaker was boiled with content stirred for about 30 to 45 minutes to dryness under a fume cupboard. After cooling, some distilled water was added to the material in the beaker before being passed through filter paper. The filtrate was collected in a 250 ml volumetric flask and the content was made up to the 250 ml mark of the flask. Then, the elemental analysis was carried out using the UNICAM 969 Atomic Absorption Spectrometer (AAS).

The effective diffusion coefficient for each of the samples was calculated using Eq. (11), with retardation factors (R_d) obtained from the batch equilibrium results and reservoir concentration data taken for x = 0. The tortuosity factors were obtained by using the self-diffusion coefficients for representative ions at infinite dilution in water (see Shackelford and Daniel, 1991a).

RESULTS AND DISCUSSION

Index Properties

The index properties and compactions of the untreated and treated foundry sand are shown in Table 3. The non-plastic sand is classified as A-3 according to AASHTO classification system (AASHTO, 1986) and SC according to the Unified Soil Classification System (ASTM, 1992).

Table 3. Index properties of treated and untreated foundry sand

| Properties	Bagasse ash content (%)				
	0	2	4	6	8
LL, %	19.0	18.0	23.3	19.4	18.8
PL, %	N.P.	N.P	N.P.	N.P	N.P
PI, %	N.P.	N.P.	N.P.	N.P.	N.P.
SL, %	0.9	1.0	0.0	0.9	0.7
Void Ratio, %	0.31	0.34	0.38	0.32	0.31
% Passing No. 200 Sieve	31	26.5	27	27.5	26.5
AASHTO	A-3(0)	A-3(0)	A-3(0)	A-3(0)	A-3(0)
USCS	SC	SC	SC	SC	SC
GS	2.64	2.65	2.66	2.60	2.56
MDD (BSH) Mg/m^3	2.084	2.078	2.048	1.990	1.994
MDD (BSH) OMC%	8.3	8.6	7.7	8.6	8.3
pH	8.9	9.9	10.2	10.6	10.8
Colour	Brown				
Clay mineral	Smectite				

NP = Non-plastic.

Index Properties

The liquid limit value initially slightly decreased from 19% to 18% and later increased to a peak value of 23.3% at 4% bagasse ash treatment. This increase can be attributed to the increase in water absorption or changes in the particle packing of the mixture. Beyond 4% bagasse ash content, the liquid limit reduced in value. Foundry sand does not possess plasticity, largely due to the presence of a high percentage of fine sand and also bentonite that was subjected to high temperature (Johnson, 1981). Treatment of foundry sand with bagasse ash did not improve its plasticity, while the linear shrinkage was not significantly affected, since the soil is predominantly sand.

The Adsorption Isotherms

The adsorption isotherms at varying amounts of bagasse ash contents are shown in Figs.1 – 4.

When the graphs were plotted from the origin, the adsorption isotherms are linear for Ca^{2+}, K^+, Na^+ and Mg^{2+}. This is in agreement with Shackelford and Daniel (1991b) who reported that adsorption isotherms can be linear or non-linear. The observed trends suggest that for K^+ and Na^+ chemical sorption was more effective at lower concentrations, while desorption as was the case for Ca^{2+} and Mg^{2+} occurred at higher concentrations of bagasse ash mixture. However, Rowe et al. (1995) reported that linear isotherms are reasonable representations of the adsorption of contaminants found in leachate from municipal waste disposal sites where concentrations are often low.
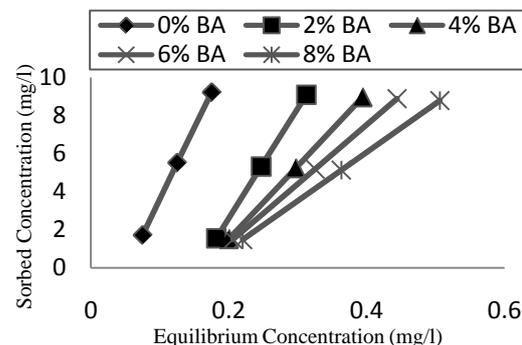
Figure (1): Variation of Potassium ion with equilibrium concentration
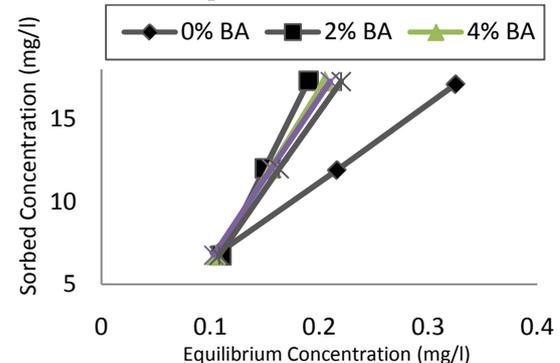
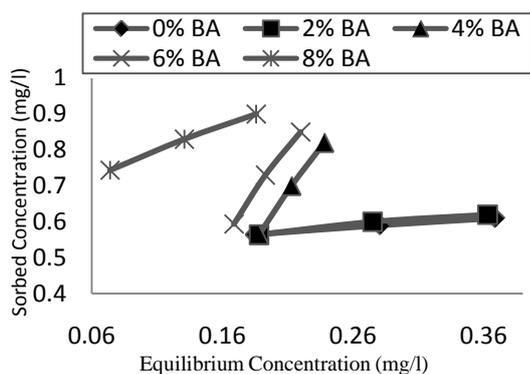**Figure (2): Variation of Sodium ion with equilibrium concentration**

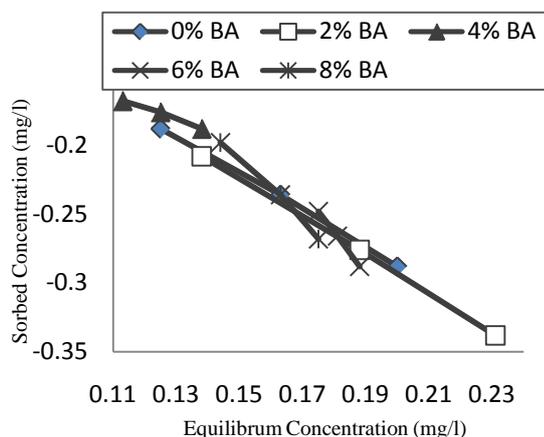**Figure (3): Variation of Calcium ion with equilibrium concentration**

Figure (4): Variation of Magnesium ion with equllibrum concentration

It was observed that there was a decrease in the adsorbed (see Figs.1-2) K^+ and Na^+ ions from 9.22-8.79 and 17.3-17.1 28 mg/l with the increase in bagasse ash content up to 8%. This trend connotes that more K^+ and Na^+ ions are absorbed from the solution as the amount of bagasse ash content increases. This could largely be attributed to the increase in the pH values with increasing bagasse ash content. An increase in pH value created a condition for establishment of electro-static forces that enhances the adsorption of cation specie (Shackelford, 1993; Osinubi and Amadi, 2003; Osinubi and Stephen, 2011). However, the adsorption isotherms for Ca^{2+} and Mg^{2+} gave increasing values of 0.62-0.90 and -0.34 to -0.19 mg/l with the increase in bagasse ash content. This trend connotes that more Ca^{2+} and Mg^{2+}

ions are desorbed (see Figs.3-4) from the solution as the amount of bagasse ash content increases; however, this amount can be considered insignificant (McGregor, 1999; Lee and Jones, 1991a, b).

The Influence of Bagasse Ash on the Coefficient of Diffusion

The influences of bagasse ash on the coefficient diffusion of treated and untreated foundry sand for the various ions are shown in Fig.5. Lower coefficient of diffusion at higher bagasse ash treatments of the various ions indicates that it has significant advantages over the untreated specimen, since increased coefficient of diffusion indicates that there was decreased distance of transport and tortous pathways (Eberemu, 2008; Stephen, 2010) experienced by solutes diffusing through bagasse ash treated foundry sand.

The Influence of Bagasse Ash Content on Retardation Factor

The influences of bagasse ash on the retardation factor of treated and untreated foundry sand are shown in Fig.6. The computed retardation factors are very large at higher bagasse ash content which indicates that adsorption took place on the surfaces of the foundry sand platelets due to diffusion flow of cations (Muhammed, 2004; Osinubi and Stephen, 2011). Generally, it was observed that as bagasse ash content increased there was a corresponding increase in the retardation factor, except for K^+ which did not vary significantly in value. Least R_d value was obtained beyond certain bagasse ash treatment which indicates that there was a minimum resistance to diffusion flow which could possibly be due to the amount of ash in the foundry sand matrix which made it more porous as can be observed from void ratio values. Therefore, it can be concluded that the foundry sand-bagasse ash mixtures with higher bagasse ash content generated lower R_d because of the lower double diffuse layer thickness which eventually created more pore spaces for solute mobility (Osinubi and Stephen, 2011).
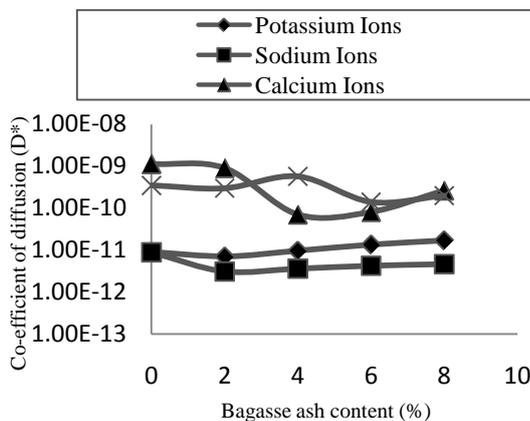
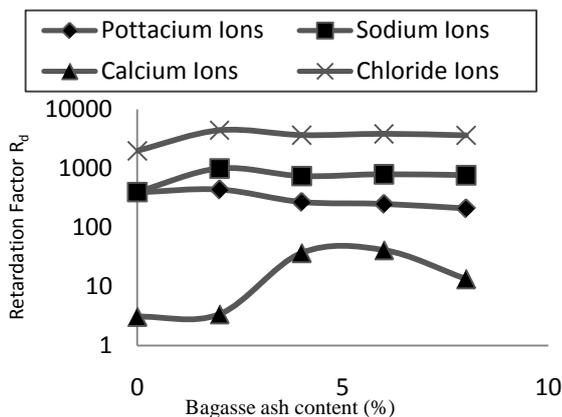**Figure (5): Variation of coefficient of diffusion with bagasse ash content**

Figure (6): Variation of retardation factor with bagasse ash content

CONCLUSIONS

The study evaluated the attenuative capacity of bagasse ash treated foundry sand as a landfill barrier

material. Foundry sand-bagasse ash mixtures prepared at stepped bagasse ash treatments of 0, 2, 4, 6 and 8% by dry weight of foundry sand were subjected to batch equilibrium and diffusion tests using two leachate samples. The results of effluent chemical analysis were used to obtain adsorption isotherms for the four selected cations, while the single source decreasing concentration diffusion test was used to determine the coefficient of diffusion and retardation factor. Test results show trends of chemical sorption by the foundry sand-bagasse ash mixtures in the order sodium, potassium, calcium and magnesium ($Na^+ > K^+ > Ca^{2+} > Mg^{2+}$). Higher bagasse ash treatment of foundry sand recorded higher retardation factors and lower diffusion coefficients with an increased sorption of the contaminant species. The presence of bagasse ash in the mixture increased the pH value which optimized the conditions that led to the immobilization of the cationic contaminants. Consequently, ionic species became fixed in the substrate by the combination of adsorption and precipitation mechanisms. The study shows that pollutants represented by calcium, magnesium, potassium and sodium can be effectively attenuated by using foundry sand-bagasse ash mixtures containing an optimum 4% bagasse ash by dry weight of foundry sand. In general, higher bagasse ash treatment of foundry sand has significant advantages over the untreated foundry sand and therefore, will better serve as landfill liner material.

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