

DURABILITY CONSIDERATIONS FOR CONCRETE CONTAINMENT LINERS USE IN ENGINEERED LANDFILLS

John Omeiza Okovido

Department of Civil Engineering, University of Benin, Benin City – Nigeria

Abstract

The leachates from municipal solid waste landfill infrastructures are usually contained by sufficiently impermeable membranes in order to preserve underlying subsoil conditions and protect groundwater resources from contamination. Before concrete can become a material of choice for containment the nature of leachate chemical constituents must be ascertained to ensure that they do not become deleterious to the concrete liner thereby impacting on its durability. The chemical components critical to concrete durability are sulphate, acidity, aggressive carbon dioxide, ammonia and magnesium; although chloride possess no direct threat to concrete but to reinforcing steel, it was nevertheless investigated. Solid waste leachate compositional characteristics were investigated in experimental procedures and by examining studies on leachates from Nigerian waste dumps/landfills, leachates characteristics of landfills in some developed and developing countries were also surveyed. The results showed a wide variation of component concentrations but maximum concentration levels indicated that the exposure environment created by the leachate would be harsher than the existing most critical exposure condition of being highly aggressive and the leachate environments maybe described as extreme aggressiveness. Except the it is to be combined with protective coatings concrete lining membranes must be made of the highest quality standards and may thereafter be suited for secondary lining applications or as confinement for leak detection layers.

Keywords: landfill, leachate, chemical environments, exposure classes, concrete, containment and concentrations.

Introduction

The most commonly reported danger to human health from uncontrolled and unlined landfills is from the use of polluted groundwater contaminated by leachate

from these landfills (Kumar and Alappat, 2003). The Jamalpur landfill site of Ludhiana City, Punjab in India had neither any baseliner nor leachate collection and treatment system, therefore, all the

leachate generated finds its path into the surrounding environment, it was found that the leachate pollutant variables exceeded the permissible leachate limits (Bhalla *et al* 2014). Also in other developing countries contained landfills are rare instead unlined open waste dumps are prevalent.

This incidence is usually prevented by providing relatively impermeable liner membrane materials to underlie the waste and contain the passage of leaching fluids to subsoil layers and the groundwater. Liner materials are not completely impervious to fluid movement, but provided they are constructed using appropriate materials and engineering, leakage of small quantities of contaminated fluid is unlikely to cause significant water quality impacts. Compacted clay soil are the cheapest liner materials that can be provided, but with high risk contaminants, a containment system using a synthetic membrane liner or matrix of liners and seepage recovery systems could be utilized. The permeabilities of geomembranes and bentonitic geosynthetic clay liners are in the order of 1.0×10^{-14} cm/sec (with proven performance for a period greater than 30 years) and 1.0×10^{-10} cm/sec respectively, whereas the permeability of compacted clay liners is about 1.0×10^{-7} cm/sec (GSE Environmental 2013). Although there have been increased emphasis on prescribing composite liners consisting of geomembranes and compacted soil for hazardous and solid waste landfill designs, however, a resurgence in mid-1980s into the use of asphalt concrete for waste isolation was initiated by the US

Department of Energy in their quest for very-long-term (1000+ years) hydraulic barriers for radioactive and mixed waste sites (Bowders *et al*, 2000).

Concrete permeability is sufficiently low to make it attractive for containment purposes. Although maximum acceptable concrete core coefficient of permeability is 1.0×10^{-7} cm/sec when subjected to a 1.0m (constant) pressure head of water (Department of Water, 2013) the actual hydraulic permeability of concrete is much less. Good quality concrete containment area has permeability of 1.0×10^{-10} cm/sec (DER-17:2008). but the hydraulic permeability of concrete measured at maturity periods between 90 and 100 days showed that water/cement ratio, strength (invariably) and curing duration would influence the hydraulic permeability of concrete (Aberdeen Group, 1989). For water/cement ratio less than 0.40 the permeability is about 1.0×10^{-10} cm/sec, but rises to 2.5×10^{-10} and 7.0×10^{-10} cm/sec at water/cement ratio of 0.60 for curing durations of 7 days and 1 day respectively. But permeability rises sharply to 8.0×10^{-10} and 40×10^{-10} cm/sec at water/cement ratio of 0.75 for curing durations of 7 days and 1 day respectively. These compare favourably with the permeability performance of geosynthetic clay liners. The hydraulic permeability of concrete could further be reduced by application of supplementary cementing materials like slag (Ozyildirim 1998 and Slag Cement Association 2002). Therefore, considerations may be given to the application of concrete as primary or secondary liners in municipal and

hazardous waste landfill respectively.

However, notwithstanding the acceptable low permeability status of Portland cement, concrete materials or associated derivatives whether in the reinforced or plain forms they have not been popular for landfill lining and leachate containment. The reason for this may not be farfetched from durability concerns that could arise from contacts between the concrete surfaces with wastes and leachate on top and prepared soil base at the bottom. The concrete is therefore likely to be exposed to moist conditions and possibly to different levels of chemical constituents some of which may be harmful or deleterious to the concrete liner. Also leaks could occur from cracks, joints and penetrations, therefore adequate attention must be given to the ultimate and service conditions in addition to the durability considerations. While the soil base conditions when known are likely to remain stable but the *leachate characteristic and composition will depend on a number of factors which apart from the nature of the waste the other major factors are the amount of rainfall and the landfill age of the solid waste.*

The amount of rainfall has a major influence on the leachate chemistry. The rainwater infiltration could effect a reduction in the concentration of all leachate chemical components. From a hydrogeological consideration of the chemical composition and the rainfall distribution, three types of leachates have been distinguished (Vadillo *et al*, 1999): leachates produced during severe droughts, leachates of high rainfall periods

and leachates of normal rainfall periods. The first type, show the highest mineralization. The second type, are samples with low mineralization and low concentration of chemical components, these are the most diluted samples. The third type belongs to the mean composition of the leachate and occurs in normal rainfall conditions. Also leachate characterizations maybe *categorized in phases* (Environment Agency, 2009) and in the *initial phase of aerobic microbial decomposition the putrescible wastes* undergo aerobic biodegradation until the available oxygen is used up. During this time, generally less than one month, carbon dioxide is the main gas produced and heat is generated, the leachate contains low molecular weight carbon compounds and ammonia and its pH is approximately neutral. The second *phase is acidogenesis and aerobic bacteria* are superseded by anaerobes as oxygen levels drop, also complex organic material is hydrolysed and volatile fatty acids are produced and the leachate pH drops as volatile fatty acids accumulate; carbon dioxide and hydrogen are produced. In the third phase known as the *acetogenic acid phase* long chain fatty acids are broken down by acetogenic bacteria to acetate, carbon dioxide and hydrogen. The pH of the leachate may drop to less than 5.0. The (fourth) *methanogenic* phase anaerobic methanogenic bacteria convert the products of acetogenesis into carbon dioxide and methane. The pH rises (pH7.5-9.0) and the degradability of the residual leachate dissolved organic carbon is reduced. *The fifth and final stage is the aerobic phase* when aerobic conditions are

re-established and aerobic microorganisms replace the anaerobes. Generally, the pH for young municipal solid waste landfills are within 5.6-7.0, for the acid and methanogenic phases the pH ranges are 4.5-7.5 and 7.5-9.0 respectively, phase overall pH range is about 4.5-9.0.

Therefore waste characterization, rainfall patterns and landfilled waste age would engage in a complex interface to determine the nature and concentrations of leachates to be produced in the landfills so that leachate characteristics would consequently be expected to vary considerably. It is important to ascertain the range of variation of the lethal leachate chemical constituents in order to determine the impacts of landfill leachate on concrete durability. The ensuing information is needed to ascertain the suitability or otherwise and possible application procedures or incorporation of concrete materials to landfill lining systems which may nevertheless be a relatively more economical convenient option of safeguarding public healthcare by preserving subsoil geology and protecting groundwater resources in developing countries where most waste landfilling infrastructures (or open dumps) are unlined.

Deterioration Of Concrete In Chemically Reactive Environments

Most known substances have degrading influence on concrete to varying degrees and extents in duration and concentration of the substance. Even pure (soft) water has low concentrations of dissolved ions which make the water aggressive when it flows in quantity over a concrete surface. The

Portland Cement Association (2001) lists more than 100 potentially destructive inorganic and organic substances which have been reported as attacking concrete. Although the possibility of encountering most of them either in the ground or as effluent is rare, it may nevertheless require one or two or more of the deleterious substances to significantly affect the durability of the concrete. The Aberdeen Goup (1975) compiled a list of substances that could cause concrete to disintegrate, some of the substances and their effects are described in Table-1. Garbage, sewerage, slaughterhouse wastes, vegetable fats and oils, lactic/butter/sour milk, animal fats and oil, vinegar (acetic acid), etc. which have varying concrete degrading influences are all expected to constitute landfill wastes serving municipalities. Secondary substances like carbonic and sulphuric acids may be produced within the landfill by dissolution of carbon dioxide in water and the hydrogenation of the free sulphide and sulphate ions respectively, both acids would inadvertently attack concrete and embedded reinforcing steel. Therefore, the use of concrete liners for leachate containment must be critically assessed and design recommendations strictly complied with since the environment and exposure conditions are very likely to impact harshly on the durability of the concrete which may lead to damage and rupture and subsequent pollution of the underlying soil strata and groundwater by the released leachates.

Critical Chemical Concentrations Of Deleterious Substances In Contact With

Concrete

Preceding specifications standards (CP110-1973 and BS8110-1985) to the subsisting Eurocodes on structural concrete emphasized that sulphates, acids and chlorides in structural applications of concrete were to be investigated and specifications procedures were to ensure that they were either below critical limits or adequate adjustments should be made to concrete mixes in order to provide concrete that would be durable in chemically aggressive environments. A

moisture condition in the environment was taken to be near neutral when the pH is between 6 and 9, and acidic condition becomes prevalent when the pH is less than 5.5. Sulphate levels less than 300mg/l were considered safe, but at higher concentrations in near neutral acidic conditions ordinary Portland cement would not be adequate, instead sulphate resisting Portland cement or super sulphated cement should be utilised.

Table-1: Some substances that may affect and cause damage to concrete (Aberdeen Group, 1975)	
Chemical substance	Effect on concrete
Animal fats and oil, vegetable oil, mineral oil, linseed oil, etc	Attack concrete to varying degrees, depending on concentration of fatty acids and viscosity of the oil
Vegetable fats and oil	Attack concrete to varying degrees, depending on viscosity of oil and concentration of fatty acids
Carbon dioxide	Harmless to mature concrete, but may dissolve in water to produce carbonic acid. When freshly placed concrete is exposed to sufficient concentration of CO ₂ it will harden with chalky, dusting surface.
Carbonic acid	Highly corrosive to lean permeable concrete and causes slow disintegration of better concretes.
Water, natural pure	Can contain harmful carbonic pure acid produced when carbon dioxide dissolves.
garbage	Disintegrates concrete slowly.
gasoline	Not harmful to concrete.
Hydrobromic, hydrochloric, hydrofluoric, nitric, sulphuric acids, etc.	Continued contact with strong solution destroys concrete, weak solutions attack slowly.
Hydrogen sulphide	Not harmful, except in moist, oxidizing environments where it produces sulphuric acid, causing slow disintegration.
Iron sulphide (pyrites)	Disintegrates concrete of inadequate quality if it contains ferric sulphate
Lactic acid, sour milk, buttermilk,	Causes slow disintegration
Magnesium sulphate	Solutions of 0.50 percent or more strongly attack concretes of inadequate sulphate resistance, producing disruptive expansion
Seawater	Disintegrates concrete of in-adequate sulfate resistance and attacks reinforcement in porous or cracked concrete

Sewage	Usually not harmful to good concrete. If hydrogen sulfide gas is present and exposed to air, sulfuric acid may form and attack the concrete
Slaughterhouse wastes	Cause severe deterioration of concrete
Sodium carbonate (in solution)	Not harmful to well-cured concrete but may cause fresh concrete to deteriorate
Sodium chloride	Not chemically aggressive to concrete but causes reinforcement corrosion in porous or cracked concrete
Sodium hydroxide (lye)	Not harmful at ordinary concentrations except where concrete is made with alkali -reactive aggregates. Above about 20% attacks concrete
Sodium sulfate	Solutions of 0.5% or more strongly attack concrete of inadequate sulfate resistance, causing disruptive expansion
Sugar and sugar products, marmalade, molasses	Dry: no effect on hardened concrete, but even trace amounts of sugar in freshly mixed concrete retard set, and may make concrete totally unusable. In solution: attacks concrete.
Sulphur dioxide	Dry gas has no effect on dry concrete. Combined with moisture, it forms acids which cause etching and long term deterioration
Vinegar (5% acetic acid)	Slow disintegration of concrete.

Also sulphate resisting cement and super sulphated cements are considered to have acidity resisting potentials and maybe provided in environments with pH less than 5.5, but when the sulphate concentration exceed 5000mg/l protective liner membranes or covering such as polyethylene, polychloroprene or surface coating based on asphalt, chlorinated rubber, epoxy or polyurethane to prevent contact with the sulphate solution must be provided in addition to the combined use of sulphate resisting Portland cement or super sulphated cement. The adverse effects of chloride become significant when the substance fully penetrates the concrete cover and corrodes reinforcing steel reducing their effective sizes and strength capacity. This was to be mitigated with a concrete cover of 50mm, with minimum cement content of 400kg/m³ and maximum water/cement ratio of 0.45 to provide minimum grade strength of 50N/mm². The

ensuing concrete would be impermeable enough to ensure that full cover penetration does not occur within the design life of the structure. The Eurocode specifications standards (BS EN 206-1:2000 and EN 1992-1-1:2008) considered three more substances deleterious to concrete material stability in addition to acids and sulphates described in earlier specifications models. The three new substances are aggressive carbon dioxide, ammonia and magnesium. Therefore, five chemical substances form the basis of design considerations which are possibly assumed to be critical to concrete material stability. The chemical actions of the five substances and chloride are discussed as follows.

Sulfate attack

When in contact or ingresses into concrete sulfate anions (SO₄²⁻) would stage chemical attacks on the unhydrated aluminate

component of cement to produce sulphoaluminate hydrates, also the sulphate would react with the calcium hydroxide in concrete to produce gypsum, both reactions and products are accompanied by relatively large volume increases which would often rupture the concrete. The reaction with calcium hydroxide would reduce the passivity and durability of embedded steel reinforcements.

Acid attack

Acids dissolve the cement paste matrix resulting in the weakening of the affected concrete. The rate of attack depends more on the rate of water movement over the surface and on the quality of the concrete, than on the type of cement or aggregate, therefore high quality concrete is needed. Mildly acidic (pH above 5.5) mobile water will attack concrete significantly, but the rate of attack will be generally slow, particularly if the acids are primarily organic in origin.

Attack from aggressive carbon dioxide

carbonic acid (H_2CO_3) which is formed when carbon dioxide dissolves in water reacts with any carbonated cement (or limestone aggregate) to form calcium bicarbonate ($\text{Ca}(\text{HCO}_3)_2$) which is soluble, thereby depleting the concrete material. Consequently the bicarbonate ions (HCO_3^-) in solution would require a certain amount of the dissolved carbon dioxide to stabilise it resulting in reduced levels of carbon dioxide in solution that will be available for further attack on carbonated concrete. The 'aggressive' carbon dioxide is the remaining available dissolved portion.

Ammonium ions

Ammonium salts act as cation-exchange compounds [Environment Agency 2000] to transform the insoluble calcium in the hardened cement paste into soluble and leachable calcium salts with the release of ammonia as gas. The removal of both reaction products results in mass loss and consequent increase in porosity of the concrete with vulnerability to further attack. Ammonium salts also act as weak acids which neutralise the alkaline in the hardened cement paste destroying the passivity thereby reducing the durability; the removal of the hydroxide ions results in softening and gradual decrease in strength of the concrete in addition to the corrosive action of the ammonium ion.

Magnesium ions

Magnesium is hazardous to concrete when the magnesium cation (Mg^{2+}) is in high concentrations and in association with certain other chemical substances mainly the sulfate anions (SO_4^{2-}), magnesium chloride (MgCl_2) is also aggressive to concrete. A major mechanism of the action of magnesium ions in concrete is the replacement of calcium in calcium silicate hydrates to form magnesium silicate hydrates resulting in loss of the binding properties and strength. Brucite ($\text{Mg}(\text{OH})_2$) also results from magnesium attack.

Chloride ions

The presence of chloride may be beneficial in concrete since it generally reduces sulphate attack. While not usually causing

chemical attack on concrete, chlorides can lead to degradation of concrete by crystallisation of chloride salts near to the surface of the concrete. High chloride concentrations will increase the risk of corrosion since chloride ions may migrate into the concrete and lead to a reduction in passivity at the metal surface. The presence of chloride ions, together with a pH below 5.5, could indicate the existence of hydrochloric acid that may cause acid attack.

The Eurocode EN206-1:2000 identified three categories of concrete exposures to these deleterious chemical substances which are slightly, moderately and highly aggressive conditions depending on the concentration of the substance.

The ranges of concentration are provided in Table-2. The lower limits of sulphates for slightly, moderately and highly aggressive conditions are 200, 600 and 3000mg/l respectively. Acidity conditions with pH range of 5.5-6.5 is described as slightly aggressive but pH levels of 4.5-5.5 and 4.0-4.5 are the higher levels of acidity for moderately and highly acidic aggressive conditions respectively. Ammonia, magnesium and dissolved carbon dioxide concentrations above 15, 300, and 15mg/l respectively would already have made the chemical environment to become respectively aggressive.

Chemical characteristic	Slightly aggressive	Moderately aggressive	Highly aggressive
SO ₄ ²⁻ mg/l	≥ 200 and ≤ 600	>600 and ≤ 3000	>3 000 and ≤ 6000
pH	≤ 6.5 and ≥ 5.5	<5.5 and ≤ 4.5	<4.5 and ≤ 4.0
CO ₂ mg/l (aggressive)	≥ 15 and ≤ 40	>40 and ≤ 100	>100 up to saturation
NH ₄ ⁺ mg/l	≥ 15 and ≤ 30	>30 and ≤ 60	>60 and ≤ 100
Mg ²⁺ mg/l	≥ 300 and ≤ 1000	>1 000 and ≤ 3000	>300 0 to saturation
water/cement ratio (max)	0.55	0.50	0.45
Cement content kg/m ³ (min)	300	320	360
minimum strength class	C30/37		C35/45

The liquid or aqueous substance is usually subjected to a full range of chemical assessments with particular interest on the components considered critical to durability. When more than one aggressive substances are detected the one with the highest level of assigned aggressiveness will determine the class (**BS EN206-1:2000**) but when two or more substances have the same level of assigned aggressiveness then the environment shall be considered into the next higher class.

Concrete surfaces exposed to wet and rarely dry conditions or in long contact with water are likely to suffer carbonation

and subsequent corrosion of reinforcing steel. Industrial waters containing chlorides are particularly harmful when porous concrete permits ingress and corrosion of reinforcing steel when contact is established. Eurocode EN206-1:2000 recognised these exposure classes and environmental conditions to be requiring special considerations. Chloride is generally assumed to be harmless to concrete, but its reaction with some components of the hydration products and crystallization of salts on the concrete surfaces and porous interstices can initiate secondary reactions that may degrade the concrete.

Table-3: Concrete quality in environment susceptible to carbonation and chloride attack (EN 197-1:2000)

Corrosion cause		Carbonation-induced	Chloride-induced
minimum strength class		C25/30	C30/37
Concrete cover	50 years design life	25	40
	100 years design life	35	50
water/cement ratio (max)		0.60	0.55
Cement content kg/m ³ (min)		280	300
Cement type		Ordinary Portland Cement	

Chemical aggressiveness is mitigated primarily by deploying good quality, well compacted and sufficiently impermeable concrete. Concrete minimum cylinder/cube strength classes are shown in Table-2 and Table-3. Concrete covers are for 50 and 100 years design life, also provided are the minimum cement content and maximum water/cement ratio. The minimum strength classes were derived from the relationship between water/cement ratio and the strength class of concrete made with cement of strength Class 32.5. Cement type

considered for the specifications is the Portland cement CEM I conforming to EN 197-1 and aggregate with maximum nominal upper size in the range of 20mm to 32mm. although small amounts of sulphate resisting cement maybe used in moderate exposure classes of sulphate concentrations but sulphate resisting cements must be used in highly aggressive sulphate exposure conditions. Care must be exercised when deploying sulphate resisting cements in exposure environments with appreciable chloride concen-

trations since such cements are known to reduce concrete resistance to chloride migration.

Experimental Procedures On Leachate Quality And Data Acquisition

Municipal wastes were obtained from the students hostels of the University Of Benin and were segregated and characterised into various constituents. A leachate extraction

apparatus was prepared as shown in Figure-1. A screening layer of fine aggregates is placed between the sampled waste and the drainage layer of coarse aggregates. Geotextile separation material was placed on top of the waste and at the boundary between the waste and the sand screening layer and also the boundary between the screening and the drainage layer.

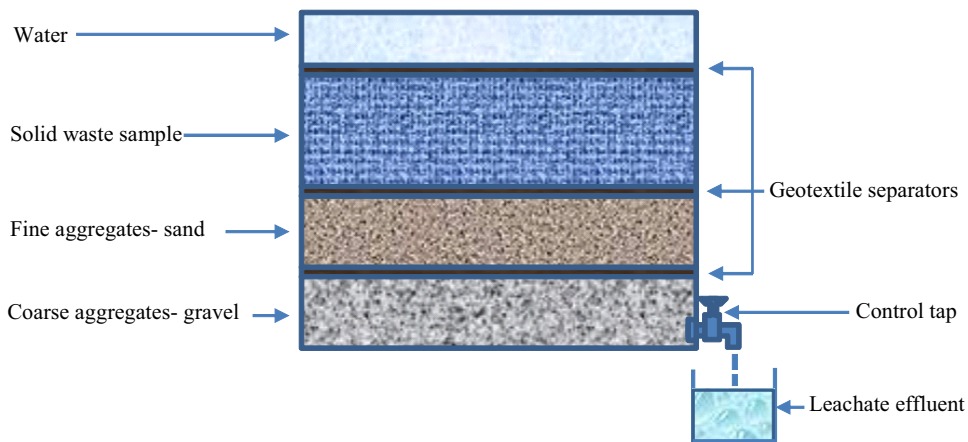


Figure-1: leachate extraction instrumentation apparatus

Water was poured from the top of the container with reservoir layer above the waste with a depth of 150mm. The drainage layer with thickness of 200mm is tapped to collect the leachate. The waste and the screening layers are 450 and 300mm respectively. The leachate was collected at 24hours from charging the waste with water and also collected five days after. The leachate samples were examined for chemical constituents. Leachate samples were also obtained from the landfill facility at Ughelli in Delta State. A review of leachate assessments from previous research studies was conducted on thirty (30nos) landfills and waste dumps.

Results And Discussions

The investigated subjects were the wastes character and distribution, leachate quality from landfill across Nigeria. The results are presented and discussed as follows.

Results

Waste Characterization

The waste from which laboratory leachates were extracted was characterized into ten (10) groupings as shown in Table-3. The organic waste component made up of food and garden waste had the highest percentage composition of 23.205percent and would account for being the main biodegradable components of the waste.

Table-3: waste characterization model from derived samples

S/N	Category	Indicative compositions	Weight (kg)	Percentage
1	Paper waste	papers, books, cardboards, packaging, etc.	25.50	9.846
2	Metal wastes	Ferrous and nonferrous metals	38.25	14.768
3	Glass wastes	Refillable glass, beverage containers, etc.	33.15	12.799
4	Yard wastes	Leaves, Grasses, pruning, etc.	12.75	4.923
5	organic wastes	Food, garden, etc.	60.10	23.205
6	textile waste	Clothing, packaging, etc.	25.50	9.846
7	Plastic wastes	Polyethylene, HDPE, containers, etc.	15.30	5.907
8	wood wastes	Plywood, timbers, etc	17.85	6.892
9	Foam waste	Rubber, latex, etc.	5.10	1.969
10	other wastes	Leather, hair, nylon, concrete, ceramics, etc.	25.50	9.846
Total			259.00	100.000

Leachate Characteristics From Sampled Effluents

The results of chemical analyses on the sampled leachates from the existing landfill and from laboratory assessments are shown in Table-4. Over a five days

period the sulphate content in the leachate reduced from 2.46 to 2.16mg/l and the pH increased marginally from 6.42 to 6.50, the magnesium content remained less than 0.005mg/l over the five day period for the laboratory sampled leachate.

Table-4: Leachate chemical characteristics of laboratory and landfill sampled effluents

Chemical parameter	Municipal landfill effluent	Model solid waste effluent	
		Day-1	Day-5
SO ₄ ²⁻ mg/l	10	2.463	2.16
pH	4.5 to 10.5	6.42	6.50
CO ₂ mg/l aggressive	NA	NA	NA
NH ₄ ⁺ mg/l	500	NA	NA
Mg ²⁺ mg/l	230	<0.005	<0.005
Cl ⁻ mg/l	1000 - 5000	220	102

The concentrations of the sampled landfill leachate components are higher and more critical than for the laboratory leachate. The sulphate content was measured to be 10mg/l and the pH varied over a wide range of 4.5 to 10.5. The ammonia and magnesium content were as high as 500 and 230mg/l respectively. Chloride content from the model leachate reduced from 220 to 102mg/l but the sampled landfill leachate chloride concentrations varied over the wide range of 1000-5000mg/l.

Selected Nigerian Landfill Leachate Component Concentrations from Reported Investigations

The quality of effluents or leachate from waste dumps and landfills across Nigeria has been a subject of interest to the research community. The objectives have been to determine the generic strength or concentrations of leachate constituents and to ascertain the extent of contaminant migration. The chemical components critical to the durability of concrete are provided in Table-5. The spread is sufficiently representative of the various parts of the country.

Study / Location	landfills	Acidity (pH units)	Chemical concentrations (mg/l)			
			SO ₄ ²⁻	NH ₄ ²⁺	Mg ²⁺	Cl ⁻
Olorunfemi et al, 2011 [Benin]	3	4.70	138.00		1.47	789.1
	5	7.876	63.14			183.6
Osazuwa & Abdullahi 2008 [Kaduna]	1	6.63	251.08			
Aderemi et al 2011 [Lagos]	1	8.10	1.21	1.21	1.21	
Egharevba et al, 2013 [Benin]	10	6.82	1.09	3.88		43.3
Kola-Olusanya A., 2012 [Lagos]	3	5.50	175.00			1992.0
Aiyesanmi & Imoisi , 2011 [Benin]	3	7.06	0.03	0.94	38.23	1267.2
Aderemi et al 2012 [Lagos]	1		1.21	4.50		
Olaniyan et al, 2009 [Kaduna]	1	8.80	268.10		13.00	2241.0
Eni and Digha , 2014 [Calabar]	1	6.60				4.7
Alimba et al 2009 [lagos]	2	7.11	70	80		770
minimum	1	4.70	0.03	0.94	1.21	4.7
median	1	6.63	63.14	3.88	13.00	1267.2
mean	3	6.23	96.88	18.11	93.38	429.72
maximum	10	9.00	268.10	80.00	413.0	2241.0

Reported Leachate Component Concentrations from Landfills in Developed Countries

The concentrations of leachate compo-

nents in studies conducted on properly developed landfills with adequate containment systems are provided in Table-6

Table-6: Leachate components concentrations obtained from studies involving developed landfills

study/investigation	Acidity (pH units)	Chemical substance concentrations (mg/l)				
		SO ₄ ²⁻	NH ₄ ²⁺	Mg ²⁺	Cl ⁻	
Reinhart & Grosh 1998, [USA]	4.5-9.0		2-3000		30-5000	
Ngo, guo and xing w [Australia]	5.3-8.9	1.4-295		0.7-740	40-19800	
Saltworks Technologies Inc. 2014 [USA]	7.4	1172.0	45.8	240	5844	
Yusmartini et al, 2013, [Indonesia]	6.9-7.5	0-199	11.3-65.0		160-175	
Bhalla et al, 2012, [India]	6.5-9.5	48.7-65.1			1448-1836	
Baig S. et al [France]	8.2-8.3		300-690			
UNEP 2005 [Developing countries]	4.5-9.0	20-1750	30-3000	40-1150	100-5000	
Kjeldsen et al 2002 [Europe and USA]	4.5-9.0	8-7750	50-2200	30-15000	150-4500	
El Fadel <i>et al.</i> , 2001	0-5years	3.0-6.0	500-2000	500-1500	500-1500	1000-3000
	5-10years	6.0-7.0	200-1000	300-500	500-1000	500-2000
	10-20years	7.0-7.5	50-200	50-200	100-500	100-500
	>20years	7.5-9.0	0-50	<30	<100	<100
Pillai et al, 2014, [India]	6.8	20.6		393.2	960.0	
Lee & Jones-Lee, 1994 [[USA]	5.0-7.5	10-1000	100-400	30-500	100-2000	
overall range	3.0-9.0	0-7750	1.1-3000	0.70-15000	30-19800	

Discussion

The chemical substances critical to the durability of concrete have been investigated for leachates obtained from municipal solid wastes. The substances are sulphate (SO₄²⁻), acidity (pH), aggressive carbon dioxide (CO₂), ammonia (NH₄²⁺), magnesium (Mg²⁺) and chloride (Cl). While the study obtained leachates from laboratory prepared extraction systems and from an existing landfill, the results of studies on waste dumps and landfills in selected locations in some cities in Nigeria and developed countries were also examined. The concentrations for the various substances varied over wide ranges (Table-5 and Table-6) from trace levels to relatively high concentrations even between source data models. The concentrations vary over relatively large ranges even within the same region.

Studies on Nigerian waste dumps indicate minimum and maximum pH of 4.7

and 9.00 respectively with a mean of approximately neutral acidity of 6.82. Depending on the respective site the other substances may be practically non-existent or present in trace concentrations. But the concentrations nevertheless vary over wide ranges with average and maximum concentrations of 99.87 and 268.10mg/l respectively for sulphate. The ammonia contents were generally low with maximum concentration of 4.50mg/l. magnesium and chloride varied from trace levels to maximum concentrations of 413.0 and 2241.0mh/l respectively with mean concentrations of 93.38 and 440.94mg/l respectively. The median concentrations of ammonia and chloride were above the mean values whereas for sulphate and magnesium the median concentrations were higher than the mean concentrations.

Leachate concentration ranges from landfills in developed countries are

significantly large with overall maximum concentrations for sulphate, ammonia, magnesium and chloride measured as 7750, 3000, 15000 and 19800mg/l respectively. Also acidity of the leachate could be expected to be quite high with a minimum pH value of 3.0. For developing countries in particular (UNEP 2005) the range of leachate components concentrations are shorter with much lower maximum concentrations, such that the expected maximum concentrations for sulphate, ammonia, magnesium and chloride are 7750, 3000, 1150 and 5000mg/l respectively, and pH range is 4.5-9.0. Leachate chemical substances would also have lower ranges and magnitudes of concentrations as the age of the landfill facility increases, the highest concentrations of 1750, 3000, 1150 and 5000mg/l for sulphate, ammonia, magnesium and chloride are expected to be obtained in the first five years, which subsequently reduces by about half over the next ten years. The acidity of the leachates is expected to drop with increasing age of the landfill; in fact the leachates from landfills may no longer be expected to be acidic after ten years of operation.

Sulphate concentrations in sampled leachates although were within the range of assessment studies, they were either relatively low or varied within a narrow range compared with assessment studies. The sampled landfill had a sulphate concentration of 10.0mg/l. Maximum sulphate concentration from the assessments was as high as 268mg/l which has a slightly aggressive categorization level. The pH levels increased from 6.42 to

6.50 in the laboratory leachates but the sampled landfill leachate and the measurements from assessment studies show the pH to be as low as 4.5-4.7, the leachates could be substantially acidic and within moderate aggressiveness classification, but pH levels could rise to levels as much as 11.0 approximately. Ammonia in the assessment studies were all less than 5.0mg/l, but the sampled landfill leachate had concentration as high as 500mg/l, which is beyond the most lethal categorization level of highly aggressive. Magnesium ion concentration levels in the laboratory sampled leachate was insignificant at less than 0.005mg/l but was 230mg/l in the sampled landfill. Assessment studies showed mean magnesium concentration of 93.4mg/l but with maximum concentration of 413mg/l the concrete would be exposed to slightly aggressive conditions of exposure.

Chloride limits are to be more than 4.0percent by mass of the cement content. Assuming a cement content of 320kg/m³ and water/cement ratio of 0.50, the equivalent limiting chloride concentration would be 80.0mg/l. but chloride concentrations were all higher with sampled landfill leachate chloride concentration in the range of 1000 to 5000mg/l, assessment studies showed mean and median concentrations of approximately 440 and 1300mg/l but maximum concentration was 2241mg/l. therefore the chloride environment of the leachate would be very corrosive to embedded steel.

The wide range of measurements may be due to a number of factors, but two of them can be described. The first is that

the samplings were conducted at different times of climatic seasons, therefore the leachates from exposed waste dumps or landfills would have higher concentrations of chemical constituents during the dry season since the leached substances are primarily products of organic decomposition or material degradation, but the concentrations are diluted by rainwater in the wet season and the leachates are washed away at higher rates during the wet season. Secondly, most of the waste dumps are not contained, therefore the substance accumulation and build up may be non-existent so that freshly produced leachates would always most certainly be sampled which would have lower substance con-

centrations than if the leachate accumulated. The laboratory sampled leachates is indicative of freshly sampled wastes, but the landfill sampled leachates had most adverse acidity condition of pH of 4.5 and maximum concentrations of ammonia and chloride of 500 and 5000mg/l respectively probably because the landfill was contained which allowed for leachate accumulation. The leachate conditions in the assessment studies would be intermediate between freshly sampled leachates and substances from accumulated leachates and the results are indicative.

Table-7: Adverse chemical conditions and exposure environments

Chemical parameter	Chemical condition/concentration		Classification of aggressiveness	
	Maximum measured	Range for developing countries (UNEP 2005)	Local	Global
Sulphate (SO ₄ ²⁻)mg/l	268	20-1750	Slight	Moderate
Acidity (pH)	4.5	4.5-9.0	Moderate	Moderate
CO ₂ mg/l aggressive	NA	NA	NA	NA
Ammonia (NH ₄ ⁺) mg/l	500	30-3000	Extreme	Extreme
Magnesium (Mg ²⁺) mg/l	413	40-1150	Slight	Moderate
Chloride (Cl ⁻) mg/l	5000	100-5000	Extreme	Extreme

A summary of the maximum or adverse chemical conditions with the associated classifications of exposure environments is provided in Table-7. From the ascertained leachate conditions from Nigerian waste dumps/landfills the levels of

aggressiveness ranged from slightly aggressive with respect to sulphates and magnesium but moderately aggressive with respect to acidity. But the exposure conditions with respect to ammonia may become more extreme than the highly aggressive classification and the chloride

condition of the leachate may be very adverse and caustic to embedded steel. But the results of studies in developing countries are seen to have leachate component concentration ranges much wider than anticipated from the studies done in Nigeria. The reason for this gap could be the absence of adequately developed landfills in Nigeria; in fact most landfills are open dumps without provisions for leachate containment. Therefore most of the leachates samples were fresh without the possibility of accumulation. A contained landfill that is adequately managed would have its leachate drained regularly and treated before discharging effluents to the environment; the leachate management system could therefore be designed such that it precludes relatively long term leachate accumulation or timed dilutions with water or treated effluents can be incorporated to reduce substance concentrations. The reality of the results from the broader studies show that the leachate chemical substances could reach much higher concentrations and aggravating exposed environmental conditions and grading thereby posing great danger to the immediate and long term durability of any proposed concrete containment liner. With acidity levels, sulphate and magnesium concentrations all at moderate ranks of aggressiveness the leachate would have been moved a step further to highly aggressive substance, but the classification of the leachate would be complicated since the expected ammonia concentrations of 3000mg/l is significantly higher than the worst anticipated concentration of just

100mg/l. the situation is further worsened by the seemingly high chloride concentration.

Sulphate resistant cements would have been desirable because of the moderate aggressiveness of the sulphates, and their applications would be needful since concrete made with sulphate resistant cements are known to be slightly more resistant to acid attacks which would therefore be particularly desirable because of the moderate aggressive conditions with respect to acidity. But sulphate resistant cement concrete would be a drawback in this environment since they have reduced resistance to chloride penetration, with expected leachate with chloride concentrations of as high as 5000mg/l such concretes must be prevented from contacts with the leachates. Even when plain concrete is utilised which preclude corrosion incidences, equilibrium or steady state seepage flows through the depths of the sulphate resisting cement concrete would weaken the containment functions of the concrete liner. Because of the probable multiple chemical attacks from leachate constituent substances on concrete, ranging from moderate to extreme (further than highly) aggressiveness and the possibility of ingress of high chloride concentrations the overall categorization of concrete exposure to solid waste leachate maybe considered to be extreme aggressiveness which should be considered to be more lethal than the subsisting furthest categorisation of highly aggressive.

water/cement ratio (max)		0.45
Cement content (min)		360 kg/m ³
Concrete cover		50mm
minimum strength class	cylinder	35 N/mm ²
	cube	45 N/mm ²
Additional protection		Coating, polyethylene sheets, etc,

A combination of precautions would have to be undertaken to preserve the concrete and protect embedded steel. For design purposes concrete quality requirement for highly aggressive chemical attack should be considered with concrete cover specifications satisfying 100+years design life. Additional protection in the form of coating or polyethylene sheeting should be considered.

Carbon dioxide is a major component of landfill gas resulting from the biological degradation of solid waste. The amount of carbon dioxide in landfill gas could be as much as 40percent (Lee & Jones-Lee, 1994). As the landfill becomes pressurized as a result of increasing gas production the leachate may subsequently contain dissolved gases which would include carbon dioxide. The character of dissolved gases in landfill leachate with peculiar reference to carbon dioxide is yet to be adequately determined.

Conclusion

All known chemical substances have varying levels of deleterious effects on concrete. Even pure natural water may contain carbonic acid when carbon dioxide dissolves in it which can cause disinte-

gration of the concrete. Leaching chemical substances from garbage, animal fats and oil, vegetable oil, lactic acid, buttermilk, sugar and molasses, slaughterhouse wastes, chlorides, hydroxides, acids, sulphates etc. would attack and degrade concrete to varying degrees and at different rates. These aforementioned materials would nevertheless constitute wastes that would usually be deposited in waste dumps or landfills. Containment liner systems are essentially incorporated into landfills to protect groundwater and preserve the underlying subsoil conditions. The exposure conditions to leachate substances and the implications of utilising concrete as liner systems have been considered in this study.

Chemical substances considered critical to concrete durability are sulphates, acids, ammonia, carbon dioxide, and magnesium. While chlorides may not primarily attack concretes, their involvements in intermediate reactions may result in the crystallisations of salts on the surfaces and interstices of permeable concrete with the implications of secondary damaging impacts on concretes. Experimental investigations and reviews of investigations to determine the chemical concen-

trations of the substances critical to the durability of concrete showed that the substances are in concentrations high enough to undertake moderate chemical attacks on concrete but in the case of ammonia the concentrations are in significantly more lethal amounts than the worst anticipated environmental exposure considered critical to durability. The overall municipal solid waste leachate environment classification can therefore be described as extreme exposure that will subject the concrete liner material to multiple chemical attacks and degrading influences with associated increased passage of high concentrations (5000mg/l) of corrosive chlorides, the consequence of these unmitigated attacks and subsequent damage of the containment liner and exposition of groundwater and subsoil conditions to contaminations and modifications respectively. Therefore, engineering and construction requirements for proposed landfill liners must ensure that good quality concrete capable of withstanding the multiplicity of chemical attacks from the various leachate substances must be provided. Measures expected to produce concrete with adequate quality to resist chemical deterioration and remain durable in deleterious environments are not farfetched from what is usually espoused for good concrete practice. limiting the tricalcium aluminate content in the cement to levels less than 8.0percent or even the possibility of eliminating it to produce sulphate resisting cements and to increase acid resistance must be carefully weighed against the fact that such cements result in

concrete that have low resistance to chloride migration or transport. The concrete production procedures should include making well compacted dense concrete with high cement content and low water/cement ratio (0.44max). Air entrainment with adequate concrete cover must be provided, curing for at least 7days with flushing daily with fresh water. Protective coatings in the form of thick vinyl or neoprene coatings, also tiles or vitrified brick set in acid-proof mortar maybe considered.

References

- Aberdeen Group (1975), Chemical Attack on Hardened Concrete, Concrete Construction, Publication No C750328.
- Aberdeen Group (1989), Permeability of Concrete, Publication No. 890870.
- Slag Cement Association (2002), Reducing Permeability. Slag Cement in Concrete No-6: 1-2.*
- Aderemi A. O., Adewumi G. A. and Otitolaju A. A. (2012), Municipal Landfill Leachate Characterization and its Induction of Glycogen Vacuolation in the Liver of *Clarias gariepinus*, *International Journal of Environmental Protection IJEP* Vol. 2 No. 4: 20-24.
- Aderemi A. O., Oriaku A. V., Adewumi G. A. and Otitolaju A. A. (2011), Assessment of Groundwater Contamination by Leachate Near a Municipal Solid Waste Landfill, *African Journal of Environmental Science and Technology* Vol. 5(11): 933-940.

- Aiyesanmi A. F. and Imoisi O. B., 2011. Understanding Leaching Behaviour of Landfill Leachate in Benin-City, Edo State, Nigeria Through Dumpsite Monitoring, *British Journal of Environment & Climate Change*, 1(4): 190-200.
- Alimba C. G., A. Bakare A. A. and Arinola O. A. (2009), Effects of Municipal Solid Waste Leachate on Leucocyte and Differential Counts in Rats, *Global Journal of Environmental Research* 3 (3): 135-140.
- Bhalla B., Saini M. S. and Jha M.K. (2012), Characterization of Leachate from Municipal Solid Waste (MSW) Landfilling Sites of Ludhiana, India: A Comparative Study, *International Journal of Engineering Research and Applications (IJERA)* Vol. 2, Issue 6: 732-745.
- Bhalla B., Saini M.S. and Jha M.K. (2014), Assessment Of Municipal Solid Waste Landfill Leachate Treatment Efficiency By Leachate Pollution Index, *International Journal Of Innovative Research in Science, Engineering And Technology*, Vol. 3, No-1: 8447-8454.
- Bowders J. J, Loehr J. E., Mooney D. T. and Bouazza A. (2000). Asphalt Barriers for Waste Isolation, *Geoeng 2000 Conference Proceedings*, Melbourne Australia: 19-24.
- BS8110-1:1985, Structural Use of Concrete. British Standards Institution, London.
- CP110-1:1972, Structural Use Of Concrete -Design Materials And Workmanship, British Standards Institution, London.
- Department Of Water (2013), Liners for Containing Pollutants Using Engineered Soils. Water Quality Protection Note 27, Government of Western Australia.
- DER-17:2008, Guidelines for Inspecting and Certifying Secondary Containment Systems of Above Ground Petroleum Tanks Major Oil Storage Facilities. DER Program Policy, New York State Department of Environmental Conservation.
- Egharevba A. P., Amengialue O. O., Edobor O. and Omoigberale M. N. O. (2013), Microbiological and Physico-Chemical Quality Assessment of Solid Waste Dumpsites in Benin City Nigeria, *International Journal of Agriculture and Biosciences*, 2(6): 344-348.
- El-Fadel, M., Alayli, B., Bou-Zeid, E. and Chahine, W. (2001), Temporal Variation of Leachate Quality From Pre-Sorted and Baled Municipal Solid Waste With High Organic and Moisture Content. *Waste Management*, 22 (1): 269 – 282.
- EN 197-1:2000, Cement (Part-1): Composition, Specifications and Conformity Criteria for Common Cements. European Committee for Standardization, ICS 91.100.10, Brussels.
- EN 206-1:2000, Concrete (Part-1): Specification, Performance, Production and Conformity, European Committee for Standardization,

- ICS 91.100.30, Brussels.
- EN 1992-1-1:2008, Eurocode 2: Design of Concrete Structures — Part 1-1: General Rules and Rules for Buildings, European Committee for Standardization, ICS 91.010.30; 91.080.40, Brussels.
- Eni D.I., Ubi A.E. And Digha N. (2014). Vulnerability Assessment Of Boreholes Located Close To Lemna Landfill In Calabar Metropolis, Nigeria, *International Journal Of Physical And Human Geography* Vol.2, No. 2: 6- 15.
- Environment Agency (2009), Attenuation of Organic Contaminants in Leachate by Mineral Landfill Liners, Integrated Catchment Science Programme, Science report: SC020039/SR5 Project Record. Bristol, United Kingdom.
- Environment Agency (2000), Risks of contaminated land to buildings, building materials and services: A Literature Review, R&D Technical Report P331, Environment Agency, Swindon.
- GSE Environmental (2013), Geosynthetics in Landfills, SWANA/A&WMA'S Third Annual Operations Training.
- Kjeldsen P., Barlaz M.A., Rooker A. P., Baun A., Ledin A. Christensen T. H. (2002), Present And Long-Term Composition Of MSW Landfill Leachate: A Review, *Critical Reviews In Environmental Science And Technology*, 32(4): 297-336.
- Kola-Olusanya A. (2012), Impact Of Municipal Solid Wastes On Under-ground Water Sources In Nigeria *European Scientific Journal*, May Edition Vol. 8, No.11: 1-19.
- Kumar D. and Alappat B. J. (2003), Analysis of Leachate Contamination Potential of a Municipal Landfill using Leachate Pollution Index, *Chennai, Workshop on Sustainable Landfill Management, India: 147-153.*
- Lee, G.F. and Jones-Lee A. (1994), 'Impact of Municipal and Industrial Non-Hazardous Waste Landfills on Public Health and the Environment: An Overview', prepared for California EPA Comparative Risk Project, Sacramento, CA.
- Ngo H., Guo W. And Xing W., Applied Technologies in Municipal Landfill Leachate Treatment, <http://www.eolss.net/eolssampleallchapter.aspx>
- Ojoawo S. O., Agbede O. A., and Sangedoyin A. Y. (2012), Characterization Of Dumpsite Leachate: Case Study Of Ogbomosoland, South-Western Nigeria, *Open Journal Of Civil Engineering*, 2: 33-41.
- Olaniyan I.O., Alayande A.W. and Bamgboye O. (2009), Predicting Surface Water Contamination From The Kaduna, Yola And **Maiduguri Landfill Sites**, *Researcher*, 1(6): 63-68.
- Olorunfemi D. I., Jegede G. and Nnakwe C. C. (2011), Comparative Biomonitoring Of Raw Leachates From Some Urban Waste Dumpsites Using *Allium Cepa* Assay, *Continental Journal of Environmental*

- Sciences 5 (1): 6-12.
- Osazuwa I.B And Abdullahi N.K., (2008). Electrical Resistivity And Induced Polarization Investigation At An Open Solid Waste Dumpsite, Case Study: Kaduna, Nigeria, *Journal Of Environmental Hydrology*, Volume 16 No 29: 1-11.
- Ozyildirim C. (1998), Fabricating and Testing Low-Permeability Concrete for Transportation Structures. Virginia Transportation Research Council and U.S. Department of Transportation Federal Highway Administration, Charlottesville, Virginia. VTRC 99-R6.
- Pillai S., Peter A. E. Sunil B.M., and Shrihari S. (2014), Soil Pollution near a Municipal Solid Waste Disposal Site, in India International Conference on Biological, Civil and Environmental Engineering, Dubai (UAE): 17-18.
- Portland Cement Association (2001), Effects Of Substances on Concrete and Guide to Protective Treatments. Concrete Information IS001. PCA. Skokie, Illinois. (Can be web-downloaded from www.cement.org).
- Reinhart D. R. and Grosh C. J. (1998), Analysis Of Florida MSW Landfill Leachate Quality, Florida Center For Solid And Hazardous Waste Management, Report #97-3.
- Saltworks Technologies Inc. (2014), Landfill Leachate- Case Study, project@saltworkstech.com
- Slag Cement Association (2002)*, Reducing Permeability. *Slag Cement in Concrete No-6: 1-2*.
- UNEP (2005), United Nations Environment Programme. Proceedings: Division of Technology, Industry, and Economics on Solid Waste Management. http://www.unep.or.jp/ietc/Publications/spc/solid_waste_management/index.asp
- Vadillo I., F. Carrasco F., Andreo B., García de Torres A., Bosch C. (1999), Chemical composition of landfill leachate in a karst area with a Mediterranean climate (Marbella, southern Spain) *Environmental Geology* 37 (4): 326-332.
- Yusmartini E.S., and Setiabudidaya D., Ridwan, Marsi, and Faizal, (2013), Characteristics Of Leachate at Sukawinatan Landfill, Palembang, Indonesia, *Journal of Physics: Conference Series* 423 (2013) 012048.