From: support@drillbitplagiarism.com
Show Details

Reply Reply All Forward

Greetings, Prof. Adrian O Eberemu! Welcome to DrillBit Anti-Plagiarism software!
Thu, 02 May, 2024 16:46

Hi "Prof. Adrian O Eberemu",

You have been added to "Ahmadu Bello University" account on DrillBit Plagiarism Detection software License.

Below are your login details.

Login ID: aoeberemu@abu.edu.ng
Password: ZPDSFFMG

To sign-in to your account, please visit www.drillbitplagiarism.com

If you have any questions regarding your account, please contact your admin or support@drillbitplagiarism.com

Best Regards,
Team DrillBit

Document Viewer

Turnitin Originality Report

Processed on: 04-Jul-2019 19:52 WAT
ID: 1058253065
Word Count: 9686
Submitted: 62

project By Sabur Alim

Similarity Index	Similarity by Source	
21%	Internet Sources:	16%
	Publications:	3%
	Student Papers:	16%

include quoted include bibliography exclude small matches download
print mode: quickview (classic) report Change mode

3% match (Internet from 30-Apr-2019)
https://www.open.edu/openlearn/ocw/mod/oucontent/view.php?id=2492&printable=1

2% match (student papers from 03-Jul-2012)
Submitted to Higher Education Commission Pakistan on 2012-07-03

2% match (student papers from 31-Jan-2018)
Submitted to Kodaikanal International School on 2018-01-31

2% match (Internet from 29-Aug-2016)
https://www.scribd.com/doc/316413132/Ezennaya-Njideka-Prisca

1% match (Internet from 27-Oct-2017)
http://www.krishisanskriti.org

1% match (Internet from 16-Jul-2017)
https://en.wikipedia.org/wiki/Catalytic_converter

1% match (student papers from 23-Aug-2013)
Submitted to Universiti Tenaga Nasional on 2013-08-23

1% match (Internet from 13-Apr-2011)
http://www.drjimmirabella.com

1% match (Internet from 01-Jul-2019)
http://www.journal4research.org

<1% match (student papers from 28-Feb-2016)
Submitted to Laureate Higher Education Group on 2016-02-28

<1% match (Internet from 04-Nov-2018)
https://baadalsg.inflibnet.ac.in/bitstream/10603/43334/13/13_chapter5.pdf

<1% match (student papers from 11-May-2017)
Submitted to International Islamic University Malaysia on 2017-05-11

<1% match (Internet from 09-Apr-2018)
https://www.irjet.net/archives/V4/i11/IRJET-V4I11140.pdf

<1% match (student papers from 11-May-2018)
Submitted to CVC Nigeria Consortium on 2018-05-11

<1% match (student papers from 28-Sep-2017)
Submitted to iGroup on 2017-09-28

<1% match (Internet from 09-Apr-2019)
https://journal.nileuniversity.edu.ng/index.php/NileJBE/article/viewFile/119/159

<1% match (student papers from 18-Nov-2017)
Submitted to Our Lady of Fatima University on 2017-11-18

<1% match (student papers from 11-Sep-2018)
Submitted to University of Huddersfield on 2018-09-11

<1% match (student papers from 20-Jan-2013)
Submitted to University of Central Lancashire on 2013-01-20

<1% match (student papers from 06-Jun-2004)
Submitted to Callaghan Campus on 2004-6-6

<1% match (Internet from 23-Feb-2019)
https://baadalsg.inflibnet.ac.in/bitstream/10603/110171/15/15_chapter%206.pdf

<1% match (Internet from 06-Sep-2018)
https://www.scribd.com/document/30695814/Stakeholders-and-Sustainable-Corporate-Governance-in-Nigeria

<1% match (student papers from 06-Apr-2016)
Submitted to UNITEC Institute of Technology on 2016-04-06

<1% match (student papers from 13-Sep-2013)
Submitted to University of Central England in Birmingham on 2013-09-13

<1% match (Internet from 05-Sep-2018)
http://repository.out.ac.tz

<1% match (Internet from 08-May-2019)
http://ir.jkuat.ac.ke

<1% match (Internet from 28-May-2018)
http://erepo.usiu.ac.ke

<1% match (student papers from 20-Jun-2019)
Submitted to Ahmadu Bello University on 2019-06-20

<1% match (student papers from 27-Oct-2014)
Submitted to 65046 on 2014-10-27

<1% match (student papers from 09-Mar-2014)
Submitted to Kingston University on 2014-03-09

<1% match (student papers from 31-Jul-2017)
Submitted to RDI Distance Learning on 2017-07-31

<1% match (student papers from 15-Mar-2018)

Submitted to Cranfield University on 2018-03-15

<1% match (student papers from 12-Feb-2013)
Submitted to EDMC on 2013-02-12

<1% match (student papers from 24-Jan-2013)
Submitted to University of Newcastle upon Tyne on 2013-01-24

<1% match (Internet from 11-Nov-2018)
http://www.arpnjournals.org

<1% match (student papers from 04-Sep-2018)
Submitted to Harare Institute of TEchnology on 2018-09-04

<1% match (publications)
Nwanolue , B. O. G. | Iwuoha , Victor Chidubem. "The Conundrum and Contradictions of Human Resource Administration in Contemporary Nigerian Civil Service : A Focus on Enugu State Civil Service Commission \\ Kuwait Chapter of Arabian Journal of Business and Management Review .- 2012 , Vol. 1 , No. 10 , pp. 56 - 68.", Kuwait Chapter of Arabian Journal of Business and Management Review, 2012

<1% match (student papers from 02-Dec-2017)
Submitted to CVC Nigeria Consortium on 2017-12-02

<1% match (student papers from 24-Jul-2003)
Submitted to University of Western Ontario on 2003-07-24

<1% match (Internet from 21-Oct-2015)
http://www.meca.org

<1% match (Internet from 07-Oct-2018)
http://erepository.uonbi.ac.ke

<1% match (Internet from 15-Apr-2019)
https://repository.tudelft.nl/islandora/object/uuid:d826e500-4551-4a8e-bd80-fefea35a8c10/datastream/OBJ/download

<1% match (student papers from 18-Aug-2014)
Submitted to 87988 on 2014-08-18

<1% match (Internet from 31-Oct-2017)
http://nuicone.org

<1% match (Internet from 20-Aug-2018)
http://www.garj.org

<1% match (Internet from 08-Jun-2019)
http://unn.edu.ng

<1% match (student papers from 22-Apr-2013)
Submitted to Swansea Metropolitan University on 2013-04-22

<1% match (student papers from 13-Apr-2018)
Submitted to University of KwaZulu-Natal on 2018-04-13

<1% match (Internet from 10-Jan-2018)
http://www.ijmetmr.com

<1% match (Internet from 18-Jun-2017)

http://www.ijsrp.org

<1% match (Internet from 09-Oct-2011)
http://aqmd.gov

<1% match (Internet from 08-Feb-2019)
http://www.niosh.com.my

<1% match (publications)
Hong-ming Long, Jia-xin Li, Ping Wang. "Influence of dioxin reduction on chemical composition of sintering exhaust gas with adding urea", Journal of Central South University, 2012

<1% match (student papers from 20-May-2012)
Submitted to Asian Institute of Technology on 2012-05-20

<1% match (student papers from 06-Jan-2014)
Submitted to Universiti Teknikal Malaysia Melaka on 2014-01-06

<1% match (student papers from 26-Apr-2016)
Submitted to Institute of Technology, Nirma University on 2016-04-26

<1% match (student papers from 06-Nov-2018)
Submitted to University of Limerick on 2018-11-06

<1% match (student papers from 11-Nov-2016)
Submitted to Rivers State University of Science & Technology on 2016-11-11

<1% match (student papers from 09-Aug-2015)
Submitted to Open University of Mauritius on 2015-08-09

<1% match (student papers from 15-Dec-2016)
Submitted to Mountbatten Internship Program on 2016-12-15

<1% match (student papers from 26-Jan-2012)
Submitted to University of Bath on 2012-01-26

<1% match (publications)
S.P. Venkatesan, Desai Shubham Uday, Borana Karan Hemant, Kagita Rajarshi Kushwanth Goud, G. Lakshmana Kumar, K. Pavan Kumar. "I.C. Engine emission reduction by copper oxide catalytic converter", IOP Conference Series: Materials Science and Engineering, 2017

<1% match (student papers from 12-Jun-2017)
Submitted to Amity University on 2017-06-12

<1% match (student papers from 26-Apr-2016)
Submitted to Institute of Technology, Nirma University on 2016-04-26

<1% match (student papers from 27-Oct-2018)
Submitted to Midlands State University on 2018-10-27

<1% match (student papers from 01-Dec-2014)
Submitted to North West University on 2014-12-01

A STUDY ON THE LEVEL OF AWARENESS AND USAGE OF CATALYTIC CONVERTER IN A FLEET MANAGEMENT (A CASE STUDY OF PEUGEOT AUTOMOBILE NIGERIA KADUNA) BY TAJUDEEN MUIDEEN BIDEMI (P16EGME8030) SUBMITTED TO DEPARTMENT OF MECHANICAL

ENGINEERING, AHMADU BELLO UNIVERSITY, ZARIA. IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTERS DEGREE IN ENGINEERING MANAGEMENT SUPERVISOR: DR. D.O. OBADA MAY, 2019 CHAPTER ONE INTRODUCTION 1.1 Background to the study Emission manage catalysts constitute a crucial part of today's automobiles powered via inner combustion engines, mitigating the harmful consequences of pollution inside the exhaust which includes carbon monoxide, hydrocarbons, nitrogen oxides, and particulate be counted (Heck et al, 2009). The increasing awareness of the impact that car exhaust emissions have on the environment has led many countries to the adoption of emissions rules. Most of these policies, that are becoming ever stricter, dictate that at present exhaust catalytic converters are the best practical solutions to the emissions problem (Clarksonet al., 2014). The pollution have undesirable effect on air great, environment and human health that hints in stringent norms of pollutant emissions. A numbers of different technology like upgrading in engine design, fuel pre-treatment, use of opportunity fuels, fuel flavors, exhaust treatment or advanced tuning of the combustion procedure etc. are taken to lessen the emission degrees of the engine. Out of many technology to be had for vehicle exhaust emission control, a catalytic converter is determined to the excellent option to be manipulate HC, CO and NOx emissions from petrol pushed vehicles at the same time as diesel particulate filter out and diesel oxidation catalysts have to this point been the maximum possible choice to control particulates emissions from diesel pushed cars. The catalytic technology used nowadays is part of an integrated emission manage generation system that regularly consists of more desirable engine and gasoline management strategies (Mizanuzzaman, 2013) .A catalytic converter is located within the tailpipe through which lethal exhaust gases containing HC, CO, NOx are emitted. The feature of the catalytic converter is to convert those gases into CO2, H2O, N2 and O2 (Patel et al., 2012). Fleet control is the function that oversees, coordinates and allows various transport and transport related sports. Latest generation has been gaining attractiveness as more automobile users are getting privy to the essential position sure gadgets play in the typical performance of automobiles. Fleet management is utilized by agencies to ensure accountable vehicle use, affirm safety amongst others, hence, effective fleet control targets at reducing and minimizing basic expenses via most, cost powerful utilization of assets along with vehicles, gas, spare parts and the use of catalytic converters that's one component of fleet management in vehicle upkeep (Patel et al., 2012). Over the years, an increasing number of vehicle users and personnel of PAN have subscribed in large part to the usage of those converters in that it ensures group of workers protection, protection at the roads; automobile safety; and overall performance control. 1.2 Problem Statement There has been a false impression of using catalytic converter. Many see it as a gas reduction tool whilst many don't even are aware of it as a catalytic converter and many others. During the last years, with the awareness of dangerous exhaust gases growing because of old era cars with incorrect tuning, there was a pressing need of reducing those effects which has been of super issue to state and federal governments in Nigeria, as an instance, Kaduna state. This has necessitated the usage of catalytic converters. Despite this effort, there has been a misconception of the use of catalytic converters. Many see it as gasoline lowering tool, whereas many don't even are aware of it as a catalytic converter. The inadequate awareness of catalytic converters has hindered the use, the safety to automobiles and guarantees environmental safety. 1.3 Aims and Objectives The aim of this study is to carry out a study on the level of awareness and usage of catalytic converter among vehicle users of Peugeot Automobile Nigerian Limited Kaduna. The specific objectives are: i. To pick out the extent of awareness of catalytic converters amongst automobile customers ii. To pick out the belief of vehicle users on the usage of catalytic converters in PAN iii. To

perceive the function of fleet managers in making sure retrofits of catalytic converters 1.4 Research Hypotheses For the reason of reading the records, the subsequent hypotheses have been examined: H01: there is no full-size courting among the level of awareness of catalytic converters and automobile customers. H02: there may be no considerable relationship among the belief of vehicle users and use of catalytic converter in PAN H03: there may be no widespread dating among the position of fleet managers in ensuring retrofits and catalytic converters. 1.5 Research Questions The look at intends to answer the subsequent questions: i. what is the level of awareness of catalytic converters amongst car customers? ii. what is the belief of automobile customers on the use of catalytic converters in PAN? iv. what is the role of fleet managers in making sure retrofits of catalytic converters? 1.6 Significance of the Study The findings of this examine are predicted to assist become aware of elements that restriction the use of catalytic converters with the aid of some car customers. The have a look at is predicted to help to be greater proactive within the use of such devices. It will cope with those observed to have terrible attitudes in the direction of its use and they can encouraged to create the means to make it a part of a maintenance way of life. 1.7 Scope of the Study The examine included Peugeot car Nigeria in Kaduna state of Nigeria. The emphasis is on level of focus of the usage of catalytic converters in fleet management. CHAPTER TWO LITERATUREREVIEW 2.1 Review of Fundamental Concepts On this segment, standards fundamental to the research, such as fuel combustion, exhaust pollutants, size of pollutant, styles of catalytic converters, approach of operation, amongst others are reviewed. 2.2 Combustion of Fuel In an internal combustion engine, petrol is used as a fuel that provides power to power the vehicle. There is a layout based totally air-fuel mixture that produces the vital ignition. In a 'perfect' gadget, combustion could be whole so that the simplest exhaust merchandise could be carbon dioxide and water /steam. In practice, the complete oxidation of the fuel depends on a range of things: one of the factors is the fact that there should be sufficient oxygen present; similarly, there must be adequate blending of the petrol and air; lastly, there ought to be enough time for the aggregate to react at high temperature before the gases are cooled. Dongarrá et al., 2002 mentioned that, in internal combustion engines, the time available for combustion is restricted via the engine's cycle to only some milliseconds. There is incomplete combustion of the fuel and this results in emissions of the partial oxidation product, carbon monoxide (CO), and an extensive variety of volatile organic compounds (VOC), along with hydrocarbons (HC), aromatics and oxygenated species. Those emissions are mainly high in the course of each idling and deceleration, when inadequate air is taken in for whole combustion to arise. Oxides of Nitrogen are produced as by way of-merchandise of the combustion technique all through acceleration of the vehicle. Such oxides includes nitric oxide (nitrogen mono-oxide NO) and nitrogen dioxide (NO2). Conventionally, those oxides of nitrogen are taken into consideration collectively and represented as NOX. On the high temperatures concerned (in excess of one 500 °C) nitrogen and oxygen inside the air drawn in with the gasoline may additionally combine together to shape NO. On leaving the engine, this monoxide cools down and is oxidized through oxidants within the ecosystem to shape the dioxide. Despite the fact that the 'solving' of nitrogen from the air is the primary source of NOX, it can also stand up from the oxidation of any nitrogenous components in the gasoline (logo et al., 2000). All through combustion, a ramification of pollution launched are either primary pollutants or secondary pollutants. The primary pollution are defined as those gases emitted immediately from the exhaust of a car. None of these is a suitable addition to the atmosphere, but perhaps the most notorious outcome of exhaust emissions is their function in the formation of photochemical smog – a mixture of ozone, nitrogen dioxide, other secondary products and small particulates. those secondary pollutants can

reason extreme damage to human health. The position of an emission manipulate catalyst is to concurrently put off the number one pollution CO, VOCs and NOX by way of catalyzing their conversion to carbon dioxide (CO2), steam (H2O) and nitrogen (N2). 2.3 Exhaust pollutants 2. 3 .1 Hydrocarbons Hydrocarbon emissions result while gas molecules in the engine do now not burn or burn most effective partially. Hydrocarbons react within the presence of nitrogen oxides and daylight to form ground-stage ozone, a chief factor of smog. Ozone irritates the eyes, damages the lungs, and aggravates respiratory problems. It' s far our maximum massive and intractable urban air pollution trouble. A number of exhaust hydrocarbons also are toxic, with the capability to purpose most cancers (Brandt et al., 2000). 2.3 .2 Nitrogen Oxides (NOx) Under the high stress and temperature conditions in an engine, nitrogen and oxygen atoms within the air react to shape numerous nitrogen oxides, together referred to as NOx. Nitrogen oxides, like hydrocarbons, are precursors to the formation of ozone. In addition they make a contribution to the formation of acid rain. 2. 3 .3 Carbon Monoxide Carbon monoxide (CO) is a made from incomplete combustion and takes place whilst carbon inside the gasoline is partially oxidized instead of absolutely oxidized to carbon dioxide (CO). Carbon monoxide reduces the go with the flow of oxygen within the blood flow and is in particular dangerous to folks with heart disorder. 2. 3 .4 Carbon Dioxide In recent years, the U.S. Environmental protection employer (EPA) has began to view carbon dioxide, a made of "ideal" combustion, as a pollution situation .Carbon dioxide does not immediately impair human health, but it is a "greenhouse gasoline" that traps the earth's warmness and contributes to the capability for global warming. 2. 4 Measurement of Some Pollutants in Vehicle Exhaust The energy saved in chemical bonds is converted by using vehicle engines into mechanical strength at some point of the controlled combustion of gasoline in air (G. Balaji et al, 2014) as shown; $CxHy + O2 \rightarrow CO2 + H2O$ + warmness .....1 whilst there's the precise stability of O2 and hydrocarbons within the combustion chamber (i.e., underneath "lean" situations), complete combustion happens and CO2 and H2O are emitted in the exhaust. While the aggregate is not in balance, including the case whilst there may be too much gasoline and no longer enough oxygen (i.e., beneath "wealthy" situations), combustion is incomplete and the exhaust can comprise CO and extra hydrocarbons. Given that each nitrogen and oxygen are found in air used for combustion, the subsequent reactions might also take vicinity inside the engine, specially while the combustion temperature is high: (G. Balaji et al, 2014). $O_2+heat \rightarrow 2O$ 2

$O+N_2 \rightarrow NO+N$ 3

$N+O_2 \rightarrow NO+O$ 4

$2NO+O_2 \rightarrow 2NO_2$ 5

As a result, nitrogen oxides (NOx = NO + NO2) also are gift at excessive concentrations in vehicle exhaust. Traditional untreated automobile exhaust can also contain CO concentrations of one–2% via extent, unburned hydrocarbons levels among 500-a thousand ppm and NOx ranges between one hundred-3000 ppm. The unit of ppm, or elements-per-million, is called a mixing ratio. In reality, scientists prefer to degree the amount of hint pollution inclusive of NOx or ozone within the air in phrases of ppm or even parts in step with billion (ppb), which might be described as follows: 1 ppm = 1 molecule mentioned per a million molecules of different gases within the air 1 ppb = 1 molecule mentioned in line with 1,000,000,000 molecules of different gases in air. With approximately 1million motors in Kaduna city, human health, agricultural activities and natural places depends on human potential to lessen to a few level or cast off emissions of toxic gases like nitrogen oxide (NOx), carbon monoxide (CO) and hydrocarbons from automobile gadgets. One of

the troubles related to those pollutants is the incidence of smog in city regions. Photochemical smog is the brown, noxious haze that obscures the view of humans the primary situations required for smog to increase encompass the presence of; 1. Large amount of sunshine 2. Air with a temperature greater than 290 K or 63 °F 3. Hydrocarbons, carbon monoxide and nitrogen oxide sources 4. A steady air mass 2.5 Type of Catalytic Converters Catalytic converters are labeled based at the variety of simultaneous duties they carry out. Generally, catalytic converters are categorized into two categories (Singhet al, 2016). 2.5.1 The two-way catalytic converter A 2-way (or"oxidation", every so often called an" oxi-cat") catalytic converter has simultaneous obligations: 1. Oxidation of carbon monoxide to carbon dioxide: 2CO + O2→2CO2 2. Oxidation of hydrocarbons (unburned and partially burned gasoline) to carbon dioxide and water: CxH2x+2 + [(3x+1)/2] O2→xCO2 + (x+1) H2O (a combustion response) this sort of catalytic converter is widely used on diesel engines to lessen hydrocarbon and carbon monoxide emissions. They have been also used on fuel engines in American-and Canadian- marketplace motors till 1981.because of their inability to control oxides of nitrogen; they were outmoded with the aid of 3-way converters. Figure 2. 1: way catalytic converter (Singh et al, 2016) 2.5.2 The 3-way catalytic converter three-manner catalytic converters (TWC) have the additional advantage of controlling the emission of nitric oxide and nitrogen dioxide (both collectively abbreviated with NOx and now not to be burdened with nitrous oxide), which can be precursors to acid rain and smog. in view that 1981," 3- way" (oxidation-reduction) catalytic converters have been utilized in car emission manipulate structures within the united states of America and Canada; many other countries have also followed stringent vehicle emission policies that in effect require 3-manner converters on gas online -powered cars. 3-way catalysts may be implemented in applications wherein the engine operates in a stoichiometric circumstance (near perfect balance of available oxygen and unburned fuel). The discount and oxidation catalysts are commonly contained in a commonplace housing; but, in a few times, they will be housed separately. A three-manner catalytic converter has three simultaneous duties: 1) Reduction of nitrogen oxides to nitrogen and oxygen: 2NOx →XO2 + N2 2) Oxidation of carbon monoxide to carbon dioxide: 2CO + O2→ 2C 3) Oxidation of unburnt hydrocarbons (HC) to carbon dioxide and water: CxH2x+2 + [(3x+1)/2] O2→xCO2 + (x+1) H2O. These three reactions occur most efficiently when the catalytic converter receives exhaust from an engine running slightly above the stoichiometric point. For gasoline combustion, this ratio is between 14.6 and 14.8 parts air to one part fuel, by weight (Singh et al, 2016) Figure 2.2: Three- way catalytic converter (Singh et al, 2016) 2. 5.3 Catalysts used in Catalytic Converters There are mainly three catalysts that are used in a catalytic converter - i. Palladium (pd) - it's far utilized in oxidation reactions ii. Rhodium(Rh) –it's miles used in reduction reactions iii. Platinum (pt) –it's far used is both oxidation and reduction reactions as nicely. 2.6 Mode of Operation of a Catalytic Converter Catalytic converters are located beneath the car between the engine and the muffler. When the automobile is cold commenced (i.e. "first begin"), the converter is bloodless and the catalyst does no longer effectively dispose of the nitrogen oxide (NOx) and carbon monoxide (CO) from the exhaust. When the engine warms up, the catalytic converter warms as much as a high temperature to provoke the catalytic reactions that eliminates the pollutants. The catalytic reactions occur heterogeneously and convert deadly gases into less dangerous substances. a number of the energetic components of catalytic converters are treasured metals which include Rh, Pd and Pt, deposited on to the excessive surface vicinity ceramic monolith that's honeycomb shape like. The honeycomb support will have a diameter of 10 inches, length of 7 inches and containing about 10 to500 cells per rectangular inch, and is housed interior a steel casing. The honeycomb structure manner that

exhaust gases travel via the converter at the quickest possible price at the same time as on the identical time hitting loads of catalyst blanketed floor on their manner out. This design aims at preserving gas efficiency and preventing a lack of power that would occur if the exhaust gases build up stress going thru the converter. In a 3-manner catalyst (TWC), oxidation of hydrocarbons and CO yields carbon dioxide (CO2) and water (H2O) as shown: $CwHw$ + (1 + w4) $O2 \rightarrow XCO2 + Y2\ H2O$…….. ……6 CO + 12O2 → $XCO2 + Y2$ $H2O$…….. 7 And nitrogen oxide (NOx) is reduced to harmless nitrogen gas (N2); NO (or NO2) + CO → N2 + CO2 ……..……8 NO2or (NO) + $CwHw \rightarrow$ N2 + CO2 + $H2O$……..……..9 those reactions are unbalanced intentionally due to the fact the system of catalysis is a complex one). The metals and steel oxides that gift inside the ceramic monolith functions to adsorb each O2 and NOx, after which breaks the nitrogen-oxygen or oxygen-oxygen bonds. The ensuing oxygen atoms at the surface react with CO or hydrocarbons, whilst the Nitrogen atoms recombine to form nitrogen gas (N2).The whole system is catalytic; that means that the steel species do not themselves completely alternate their identity during a single catalytic cycle, however serve to lessen the strength barrier (Activation energy, Ea.) to the reaction and pace the reaction up to shape more benign gases via their interplay with the reactants,. The two conditions that have to be satisfied for the converter to work properly include 1. The temperature of the catalyst must be large enough. This stems from Arrhenius equation: Ea K = A(−RT) Which shows the relationship between the temperature and the rate of a chemical reaction, Where k is the rate constant of the reaction, A is the pre-exponential factor, and Ea. is the activation energy for the reaction. 2. The engine's combustion chamber should be operated near the stoichiometric air to-fuel ratio. This is feasible due to the fact there's a slim range of air-to-gas ratios wherein each NOx discount and CO or hydrocarbon oxidation occur quite simply at the floor of the catalytic converter simultaneously. If there is an excessive amount of oxygen (O2) gift, the nitrogen oxide reduction does now not arise. At the opposite, if there is insufficient O2 gift, the CO and hydrocarbon oxidation will now not arise. This quality stability to keep the gasoline combinations inside the best range is constantly adjusted by an oxygen sensor and engine comments device placed earlier than the catalytic converter in the exhaust manifold. 2.7 Ageing control of a Catalytic Converter Ageing control is a program that monitors and continues safety-related features and additives, that are difficulty to put on and other age-related changes. The purpose is to govern age-associated degradation and prevent system from disasters due to growing older, via keeping this gadget in "as new" circumstance so it continually operates at height overall performance (Anton Erhard et al, 2010). Screw ups of catalytic converters because of ageing of its components might also have a right away poor impact on cars reliability and availability and also have an effect on lengthy-time period car performance and safety. getting older management technologies based at the prediction of disasters and getting old mechanisms ought to permit the optimization of preventative renovation activities and scheduling by assisting outline cost-powerful condition-based totally preservation programs. 2.8 Review of works on Catalytic Converter A whole lot of milestones had been achieved on the use of catalytic converters for petrol pushed motors. Wojciech et al, (2002) supplied a theoretical solution together with experimental paintings of an analyzed exhaust system with catalytic converter in a two-stroke engine. The goal of the idea of application of catalytic converter in exhaust systems is to apply the possibility of lower the engine emission inside the entire range of engine pace without decreasing of engine performances. The following observations were made within the studies; i. Application of large size catalytic converter decreases considerably emission of carbon monoxide

and hydrocarbons in steady work circumstance. ii. Growing old technique lasted very quick approximately 100 s attaining discount performance approximately 80%. iii. Leaner mixture assures less attention of CO and HC and permits to apply of enterprise catalytic converters. iv. Longer time of the usage of catalytic converter in -stroke engine without modifying of lubrication machine can reason clogging of the cells. v. Simulation manner can help to research chemical tactics taking place within the catalyst and assessment of designed exhaust machine. Results received from simulation do not deviate from experimental outcomes. Bharat et al, (2012) review paper on catalytic converters for vehicle applications. of their work, they said that through the year 2030, vehicular population increases to 1300 million. because the pollution norms are becoming an increasing number of stringent, quantity of change technology like development of engine layout, fuel pretreatment or higher tuning for green and complete combustion are being considered to reduce emission levels further. They located that amongst all technology, catalytic converter using platinum group of metals as catalytic materials were determined to be greater powerful. Mohinuddin and Ataur Rehman, (2012) have discussed approximately simulations for development of low value catalytic converter. They mentioned use of non-precious metals in catalytic converters to carry down expenses. Copper and nickel energy were chosen as opportunity catalysts that have proven that they're powerful in reduction of NOx in wealthy air/ gasoline mixture and discount of CO and HC in lean aggregate situations. They used business software program like COMSOL and FLUENT and confirmed improvement in catalyst conversion efficiency and reduction in back pressure on the engine. Gary, (2013) mentioned regarding materials used in car catalytic converters. He said that the middle is normally ceramic monolith with a honeycomb shape. Steel foil monoliths are made of iron-chromium- aluminium combos, which can be much less luxurious. Each these are designed to provide a high floor place to support the catalyst wash- coats. The catalyst wash coat is a carrier of catalytic substances, that's used to disperse them over a large surface region. Titanium dioxide, aluminium oxide, silicon dioxide or an aggregate of silica and alumina may be used. In some programs, cerium, iron and manganese are also used. Prashant, (2013) provided a review paper on catalytic converter for car exhaust emission. His evaluate paper deals with the car exhaust emission and its results, automotive exhaust emission manage by way of use of catalytic converters, catalysts utilized in catalytic converter, production of catalytic converters, kinds of catalytic converters, running of conventional catalytic converters. Additionally they diagnosed that pollution have terrible outcomes on air great, surroundings, and human health as nicely. He identified numbers of strategies like improvement in engine layout, gas pre -remedy, fuel components, and better tuning of combustion technique etc. as a way of minimizing the emission of pollution to be able to reduce harmful emission. Juhi, (2013) exact the function of engine design, car operating variables, gasoline high-quality, and emission control gadgets in minimizing pollution identification petrol and diesel pushed vehicles. In his paintings one-of-a-kind measurement strategies used to degree pollution like, Non Dispersive Infrared Analyzed (NDIR), Differential Absorption LIDAR (DIAL), Chemiluminescence NOx detection, Orsat fuel analyzer and gasoline Chromatography have been mentioned. He concluded that an intensive analysis of electricity utilization and pollutants suggests that alternative power structures are still an extended manner at the back of the conventional ones. Similarly developments in petrol and diesel engines, mixed with upgrades in the automobiles, will make fuel consumption discount of 40% or extra within the destiny cars. This, in turn, will reduce the CO2 emissions, a gasoline that's liable for greenhouse effect. Srinivasa et al, (2014) reviewed how the present day catalytic converter used in vehicles has evolved in the remaining four a long time. In their paintings, about one hundred fifty technical papers published in diverse journals have

been studied. A few 52 papers had been defined in brief which indicated the furtherance inside the stated studies. Essential conclusions drawn from a few papers are mentioned ultimately. Anupam et al, (2016) recognized the use of noble organization metallic just like the platinum group metal as a way for decreasing the exhausts as an powerful way for powerful combustion. With the assist of secondary measures efficiency of the engine is advanced as nicely. They concluded that the strategies are nevertheless underneath improvement due to the fact there are a few boundaries of the catalytic converters which are had to be treated however the application of this method has higher success factors as well. Singh et al, (2016) illustrates the layout of pollutant manage system this is catalytic converter having twin bed with air injection for application in fuel engine. In their work, they evolved a catalytic combustion version for a mixture of CO, NO and air, the usage of the stagnation-factor go with the flow geometry .They concluded that the proposed chemical reaction mechanism is able for lowering NO and oxidation of CO. Obada et al, (2016) characterized industrial grade zeolites are expecting which has extra suitable houses for use as environmental materials. There work was inspired via the development of extremely-solid kind zeolites with lots stepped forward thermal and hydrothermal stability, and such zeolites display suitable ability for his or her use as wash coat substances. They concluded that the thermal stability of these zeolite samples as characterized by thermo gravimetric is because of the purity of the industrial grade zeolites which is devoid of organic impurities and to massive quantity bodily absorbed water. 2.9 Research Gap All the literatures reviewed are normally concerned with popular aspects like gasoline first-rate, widespread automobile layout and engine tuning, design and production of catalytic converters, enhancing catalytic converters among other popular issues. One crucial difficulty this is additionally vital is the extent of recognition amongst automobile customers which may be very crucial in identifying the function vehicle person have performed in reducing the impact of environmental pollutants. This study will inspect the humans' degree of awareness on using catalytic converters in cars in PAN. It will additionally identify approach via which vehicle customers may be knowledgeable on the danger related to neglecting the usage of catalytic converters and reluctance to replacing broken ones. Judgmental sampling method might be adopted through using information accrued from vehicle users in PAN. A complete of 80correspondences will be sampled from distinctive vehicle users the use of sampling strategies and questionnaires as information collection tool. Facts amassed can be analyzed through descriptive facts and the hypotheses formulated might be examined the usage of chi-rectangular check of independence. The study will identify whether or not the adoption of the usage of catalytic converters has undoubtedly and significantly stepped forward the overall performance of automobiles as well as reduced problems associated with environmental pollutants. CHAPTER THREE MATERIALS AND METHOD 3.1 Introduction This chapter presents the step by step procedures which were adopted for and the study is as follows i) Data collection through primary sources using questionnaires ii) Descriptive statistics was to show relationship between data sets iii) The chi-square technique was used to test the hypotheses in line with the objectives of the study. The decision criterion for these hypotheses to be tested will be set at 0.05 percent level of significance. 3.2 Research Design The research design adopted for this paintings is survey studies design based totally on particular evaluation standards for figuring out the notion on using catalytic converters. Sample of the population of the PAN vehicle turned into drawn. The pattern of respondents was taken from the population of the management and non-control workforce in the business enterprise. These samples were drawn the use of suitable sampling strategies and methods. The observe made use of questionnaire to gather records on automobile customers. The questionnaire items have been

finished via customers and had been supposed to evaluate elements that have an effect on great use of the catalytic converters. The structure for the studies layout is provided. The selection of design changed into knowledgeable with the aid of the want to evaluate factors figuring out the extent of awareness profiles. The observe was mainly quantitative, exploring numerous questions and hypotheses. 3.3 Population of the study and sampling technique The population of this study was members of body of workers of PAN automobile in Kaduna State. The population distribution of the respondents consequently includes essential staff of the corporation. The issue considered for the sample population is automobile ownership to allow the collection of dependable information. The population of the observe became 80 personnel which consist of 30 management team of workers and 50 non-management personnel and their percentages as provided in table 3.1. The selection of sampling was based totally on nature of appointment and period of provider. i. Management = 30 × 100 = 37.5 80 ii. Non-management= 50 × 100 = 62.5 80 Table 3.1: Population Distribution PAN AUTOMOBILE POPULATION PERCENTAGE % Management staff 30 37.5 Non-management staff 50 62.5 Total 80 100 3.4 Sample size determination The selection of sample from the population was through cluster sampling before a further random selection of each tribe. Asika, (1991) identifies steps to be taken in cluster sampling as follows: Step 1: identification of the population to be sampled; Step 2: identification of salient characteristics such as gender, tribe and school location that would enhance representation; Step 3: location of areas where subjects with the characteristics are and to know their respective sizes (population subsets); and Step 4: use of random sampling procedure in selection of sample units or subjects from each cluster. In determining the sample size of the study, Taro, (1964) formula was used. The formula is given thus: n = 1 $+N($ E $)2$..... 10 N Where N= population size n= Sample size E= error limit or margin of error of level of significant (accepted level of 5% i.e. 0.05) Therefore, n = 1+808(00.05)2= 80 = 66 approximately 1+80(0.0025) Therefore the sample size is 66. The determination of each of the category's sample size is presented as; iii. Management = 37.5 × 66 = 25 100 iv. Non-management= 62.5 × 66 = 41 100 The sample size distribution of the listed category is presented in Table 3.2 Table 3.2: Sample Size Distribution PAN POPULATION PERCENTAGE % Management Staff 25 37 .5 Non-Management Staff 41 62.5 Total 66 100 3.4 Method of Data Collection The data collection changed into predominantly done through primary assets. The method of accumulating number one records and techniques adopted consists of; 1. A have a look at on the notice and usage of catalytic converters in fleet control system 2. Adults of both ladies and men of the look at regions 3. In phrases of educational qualification, human beings with national diploma and above have been involved 3.6 Instrument for Data Collection The studies instruments used turned into a researcher-designed questionnaire. Records have been accumulated from staff thru questionnaire. The questionnaire changed into evolved to comprise the relevant questions that would elicit important responses from the respondents and to help in efficient series of statistics. It consisted of 25 objects to test vehicle users perceptions of the use of catalytic converters of their automobiles and the dangers related to non-utilization if any. The effect and level of recognition within the use of catalytic converters has covered numerous regions with corresponding quantity of variables (see Questionnaire in Appendix A). 3.7 The Chi-Square Model The version examines the level of consciousness and use of catalytic converters in fleet control gadget in Nigeria thru the usage of statistical tool to test the hypotheses developed. First, evaluation was performed to apprehend the connection amongst variables, and to provide reliability analysis of the gadgets. To check the developed hypotheses, the chi-rectangular take a look at turned into used. 3.8 Variables Measurement

The study adopts the chi-rectangular layout analysis in which the secondary source of statistics became employed via the usage of questionnaires. The populace of the have a look at includes the 2 (2) categories of group of workers of PAN car in Kaduna as at 2018. Systematic sampling technique become used to reach on the sample size of sixty six (66) participants. Chi-square approach is used for the analysis after administering the questionnaire. 3.9 Reliability/Validity of test To enhance reliability/validity of the statistics generated, the have a look at best take into account the respondents who fall within the recognized organization (i.e., PAN group of workers). This institution had been given the questionnaire on the grounds that they are certain would provide the relevant responses. Similarly to that, the sample size and plan as empirically decided were saved. these kinds of, no longer -withstanding, the studies has a tolerable blunders margin of 5%. Validity refers to whether a take a look at or an instrument measures exactly what it purports to measure (Hughes, 2003) but, validity can in no way be "validated" however evidence of its attention must be provided. It turned into intended to envision the content validity for the adequacy of content material insurance of variables within the studies topic. CHAPTER FOUR RESULTS AND DISCUSION 4.1 Introduction This chapter deals with the systematic presentation of statistics, its analysis and discussions springing up from the responses from the questionnaires, to access the level of attention and usage of catalytic converters in PAN car in Kaduna 4.2 Data Presentation and Interpretation The subsequent segment will gift the statistics containing the facts of the respondent as well as their responses to the variables within the questionnaires. 4.2.1 Demographic Data This phase is describing the form of pattern, which took component within the look at. The goal organization become body of workers of PAN automobile in Kaduna nation. The variables that were addressed in the questionnaire beneath the demographic records were: class, intercourse, Qualification and the duration of carrier of employee. 80 questionnaires had been administered and all of them had been retrieved from the respondents. The questionnaires had been analyzed using frequency counts and tables 4.2.2 Background of the Respondents Table 4.1-4. 4 suggests the distribution of respondents through class, qualification, period of service and gender with their corresponding bar charts respectively. Fig. 4.1: Bar chart for Category Number of Staff Staff by Qualification Fig.4.2: Bar chart for Qualification Fig. 4.3: Bar chart for Duration 4.2.3 Data Presentation The table in 4.5 presents the research questions to address the level of awareness and usage of catalytic converters in fleet management. The various responses in the form of Likert scale are presented for analysis. 30 25 Number of Staff 20 15 10 SA A 5 IN D 0 The use Aof A majorBpart of I regularlyCcheck The usDe of EmphasisEon the SD catalytic the air pollution my catalytic catalytic use of Catalytic converters is caused is due to converters to converters converters does significant in vehicular avoid reduce the not play a improving the emissions RmEaSlfEuAncRtiConH QUhEoSrTseIOpoNwSer of significant role quality of fuel vehicles in emission combustion control in PAN and so should not be a serious issue Fig.4.4: Bar chart for frequency of responses Where A. The use of catalytic converters is significant in improving the quality of fuel combustion B. A major part of the air pollution caused is due to vehicular emissions C. I regularly check my catalytic converters to avoid malfunction D. The use of catalytic converter s reduce the horse power of vehicles E. Emphasis on the use of catalytic converters does not play a significant role in emission control in PAN and so should not be a serious issue 35 30 25 Number of Staff 20 15 10 5 0 F G H I J SA A IN D SD RESEARCH QUESTIONS Fig. 4.5: Bar chart for frequency of response Where F. Vehicle users are yet to fully buy into the use of catalytic converters in Peugeot Automobile. G. Catalytic converters have experienced low patronage due to inadequate awareness and education of the vehicle users. H. There is a ban on cars without catalytic converters by the government as an emission control

standard. I. Most users of catalytic converters in PAN are not literate enough to understand the importance of catalytic converters. J. The use of catalytic converters has not been enforced in other companies in fleet management to the best of my knowledge 25 20 15 Number of Staff 10 5 0 Only moKdern The usLe of Use of cMatalytic The remoNval of The useOof cars need catalytic converters has catalytic catalytic catalytic converters increased the converters is converters help converters to should be maintenance more beneficial in reducing fuel function well encouraged only cost for vehicle to the vehicle consumption in modern owner in PAN users than the rate vehicles RESEARCH QUpErSoTbIlOemNSarising from it SA A IN D SD Fig. 4.6: Bar chart for frequency of response Where K. Only modern cars need catalytic converters to function well L. The use of catalytic converters should be encouraged only in modern vehicles M. Use of catalytic converters has increased the maintenance cost for vehicle owner in PAN N. The removal of catalytic converters is more beneficial to the vehicle users than the problem arising from it O. The use of catalytic converters help in reducing fuel consumption rate 25 20 Number of Staff 15 SA 10 A IN 5 D SD 0 The UsPe of The reQmoval of Cars doRn't need TestinSg and TherTe is a catalytic catalytic the catalytic inspection of the reason for not converters converters converter, so presence of having a improves vehicle possibly will give should work just converters is catalytic performance better fuel fine without it part of the converter mileage vehicle RESEARCH QUESTreIOgisNtrSation renewal process in Kaduna state Fig. 4.7: Bar chart for Frequency of response Where P. The use of catalytic converters improves vehicle performance Q. The removal of catalytic converters possibly will give better fuel mileage R. Cars don't need the catalytic converters, so should work just fine without it S. Testing and inspection of the presence of converters is part of the vehicle registration renewal process in Kaduna state. T. There is a reason for not having a catalytic converter 25 20 Number of Staff 15 10 SA A 5 IN D 0 SD Cost as anUissue There wVill be a FailurWeof a There arXe better StrYict may jeopardize huge cost catalytic alternative for government the use of implication for converter could reducing policies is a sure catalytic incorporating prevent other emission in way to enforce converters catalytic systems and petrol driven the use of converters in structures from vehicles than catalytic your company RsaEfSetEyAfuRnCcHtioQnUESTtIhOeNusSe of converters in vehicles performance catalytic vehicles converters Fig. 4.8: Bar chart for Frequency of response Where U. Only modern cars need catalytic converters to function well V. The use of catalytic converters should be encouraged only in modern vehicles W. Use of catalytic converters has increased the maintenance cost for vehicle owner in PAN X. The removal of catalytic converters is more beneficial to the vehicle users than the problem arising from it Y. The use of catalytic converters help in reducing fuel consumption rate TABLE 4.2: Mean score table of responses S/ NO SA (5) A(4) Inff. (3) D (2) SD(1) ∑(FX) N X DECISION 1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16 17 18 19 20 21 22 23 24 25 TOTA L 14 26 9 7 8 10 15 23 5 8 17 26 5 10 15 26 4 8 10 18 28 18 8 8 22 18 6 12 2 5 10 24 5 4 5 20 18 12 10 10 5 10 12 24 15 20 8 10 15 18 12 13 5 10 18 22 10 15 18 14 9 20 13 14 10 15 18 14 11 14 13 13 2 5 12 25 5 13 16 20 18 22 6 12 21 19 11 8 8 12 10 22 12 12 10 18 12 13 14 18 264 337 296 421 Sectional mean = $\mathbf{71.74} = \mathbf{1.\ 77\ 14}$ 10 225 10 181 10 170 10 172 26 144 4 256 8 232 25 133 32 128 16 204 15 164 13 216 8 217 11 171 9 201 10 197 8 200 15 191 22 138 12 177 8 228 7 207 14 176 14 188 9 199 326 66 66 66 66 66 66 66 66 66 66 66 66 66 66 66 66 66 66 66 66 66 66 66 66 66 66 66 66 3.41 2.74 2.58 2.61 2.18 3.88 3.52 2.02 1.94 3.09 2.49 3.27 3.29 2.59 3.61 2.99 3.03 2.89 2.09 2.68 3.46 3.14 2.67 2.85 3.02 Indifferent Indifferent Indifferent Indifferent Disagree Agree Agree Disagree Disagree Indifferent Indifferent Indifferent Indifferent Indifferent Agree Indifferent Indifferent Indifferent Disagree Indifferent Agree Indifferent Indifferent Indifferent Indifferent From the table 4.2, we can see that the sectional mean is 2.87, which are approximately 3.00. This

means that the overall response of the section is Indifferent 4.3 Validity of Variables To test the validity of each argument, question 1 to 25 is used and the expression to determine the chi square test is presented as; $X2 = \sum (El-Ec)2$.....11 Ec Where X2 is chi-square Fo = observed frequency Fe= expected Frequency $Fe = cllrll\ rlral \times Rlw\ rlral$.....12 $Eralc\ rlral$ $Fe = Eralc\ rlral$ Also .....13 $Nl\ lc\ Irclr$ Decision Rule Reject Null Hypothesis (Ho) if the computed chi-square is greater than the tabulated or critical value. Otherwise accept Ho. The degrees of Freedom in all case = (R -1) = (5 -1) = 4 and the level of significance at 5% (0.05). 4.4 Testing of Research Hypothesis H01: There is no significant relationship between the level of awareness of catalytic converters and vehicle users. Table 4. 3Chi -square test on the level of awareness of catalytic converter and vehicle users Value df Asymp. Sig. (2- sided) Pearson Chi-Square Likelihood Ratio Linear-by-Linear Association N of Valid Cases 146.405a 135.464 57.746 66 16 16 1 .000 .000 .000 a. 21 cells (84.0%) have expected count less than 5. The minimum expected count is .36. The test revealed that 66 respondents were sampled. The observed chi square calculated is 146.405 which is greater than the chi square critical of 26.296 and the degree of freedom is 16. The probability level of significance observed in the test is 0.000 (P <0.05). This indicates that there was significant relationship between the level of awareness of catalytic converters and vehicle users. Therefore, the null hypothesis that there is no significant relationship between the level of awareness of catalytic converters and vehicle user was therefore rejected. H02: There is no significant relationship between the perception of vehicle users and use of catalytic converter in PAN Table 4.4Chi-square test on perception vehicle users and catalytic converter Value df Asymp. Sig. (2- sided) Pearson Chi-Square Likelihood Ratio Linear-by-Linear Association N of Valid Cases 132.000a 143.554 46.106 66 16 16 1 .000 .000 .000 a. 22 cells (88.0%) have expected count less than 5. The minimum expected count is .36. The test revealed that 66 respondents were sampled. The observed chi square calculated is 132.000 which is greater than the chi square critical of 26.296 and the degree of freedom is 16. The probability level of significance observed in the test is 0.000 (P <0.05). This indicates that there is significant relationship between the perception vehicle users and the use of catalytic converter. Therefore, the null hypothesis that there is no significant relationship between the perception of vehicle users and use of catalytic converter in PAN was therefore rejected. H03: There is no significant relationship between the roles of fleet managers in ensuring retrofits of catalytic converters. Table 4. 5Chi -square test on the role of fleet managers in ensuring retrofits of catalytic converter Value df Asymp. Sig. (2- sided) Pearson Chi-Square Likelihood Ratio Linear-by-Linear Association N of Valid Cases 118.528a 118.932 54.981 66 16 16 1 .000 .000 .000 a. 22 cells (88.0%) have expected count less than 5. The minimum expected count is .48. The test revealed that 66 respondents were sampled. The observed chi square calculated is 118.528 which is greater than the chi square critical of 26.296 and the degree of freedom is 16. The probability level of significance observed in the test is 0.000 (P <0.05). This indicates that there is significant relationship between the role of fleet managers in ensuring retrofits and catalytic converters. Therefore, the null hypothesis that there is no significant between the role of fleet managers in ensuring retrofits and catalytic converters was therefore rejected. 4.5 Discussion of Research Hypotheses From the result shown in the chi-square tables , the calculated chi-square is seen to be greater than the tabulated value for the first and second hypothesis and less for the third hypothesisat level of 0.05(5%). So, the Hoi hypothesis is rejected in cases 1 and 2 while H1 is accepted and Ho is accepted in case 3. The decision arising from this statistical relationship is presented thus; Table 4.6: Decision table Hypotheses N χ2 calculated χ2 table value Df Decision H(O1) 66 37.18

36.42 24 H0 is being Rejected H(O2) 66 87.22 36.42 24 H0 is being Rejected H(O3) 66 17.66 21.03 12 H0 is being Accepted Decision 1 Since the computed chi-square of 37.18 is greater than the tabulated or critical value of 36.42, we reject the null hypothesis (that there is no difference between the observed and expected) in favour of the alternative hypothesis (that there is a difference between the observed and expected) and conclude that there is a significant relationship between the use of catalytic converters and vehicle users. Decision 2 Since the computed chi-square of 87.22 is greater than the tabulated or critical value from the chi square distribution table of 36.42, we reject the null hypothesis (that there is no difference between the observed and expected) in favour of the alternative hypothesis (that there is a difference between the observed and expected) and conclude that there is a significant relationship between the level of awareness and undesirable effect of pollution on air quality, environment and human health. Decision 3 Since the computed chi-square of 17.66 is less than the tabulated or critical value from the chi square distribution table of 21.03, we accept the null hypothesis (that there is no difference between the observed and expected) and conclude that there is no significant relationship between the type of vehicle and the quality of combustion 4.6 Summary This chapter presented the data and its interpretation to help the researcher draw a meaningful conclusion on the subject matter. Result from the data analysis shown in the chi-square tables confirmed that the calculated chi-square is seen to be greater than the tabulated value in cases 1 and 2and so, the Ho hypothesis is rejected in both cases while in case 3, Ho is accepted since the p-value is less than 0.05. CHAPTER FIVE SUMMARY, CONCLUSION AND RECOMMENDATIONS 5.1 Summary The topic of this study is the level of awareness and usage of catalytic converters in fleet management in PAN Automobile, Kaduna. The purpose emanates from the researcher's desire to investigate, uncover and describe usage habits of vehicle users with a view to improve the information level on the contribution to limiting environmental pollution. The belief is that if vehicle users have positive habits towards the use of catalytic converters, it will be transferred to other individual who have every prospect of owning one in the future. The investigation was carried out through formulation of three research questions with their corresponding null hypotheses. The research questions were designed to find out the vehicle performance, level of awareness and type of vehicle with respect to the use of catalytic converters. The research questions also sought to find out whether there significant relationship between the use of catalytic converters and performance of vehicle or not and the extent to which level of awareness affect air quality, environment and human health is also investigated. Three corresponding hypotheses were formulated for the study. Data collection was carried out through administration of questionnaire and observation. Eighty staff was randomly selected from each of the two categories. The findings authenticates that there is no significant relationship between the type of vehicle and the quality of combustion. It also indicates that the use of catalytic converters improves the performance of a vehicle, reduce fuel consumptions and the level of awareness has a way of reducing environmental pollution contributed by automobiles. Result also shows that there will be a huge cost in incorporating the catalytic converters in vehicles that lack them. In an organization like PAN, it will translate to a huge cost of production. Use of catalytic converters has increased the maintenance cost for vehicle owner in PAN and such additional cost users say is an issue which may jeopardize the use of catalytic converters 5.2 Conclusion This final chapter summarizes the study and its main findings. It discusses the implications of the study for vehicle users, companies that are into fleet management business, industries manufacturing catalytic converters and the general public. The conclusion is based on the three findings which is in line with the objectives and these are: i) From the findings there is high level of

awareness of catalytic converters among vehicle users as shown in table 4.3. This means that vehicle users know the importance of catalytic converter in the vehicles. ii) There is the perception of vehicle users and the use of catalytic converter on vehicle fuel consumptions. iii) The roles of fleet manager in ensuring retrofits of catalytic converters and the chapter proposes solutions in the form of recommendation 5.3 Recommendations The following recommendations are made to enable all the players make decision that will be used to emphasize the need to either adopt the use of catalytic converter or not. The recommendations are as follow; 1. Testing and inspection of the presence of catalytic converters should be part of the vehicle registration and registration renewal process. 2. Strict government policies should be adopted as a way to enforce the use of catalytic converters in vehicles 3. There should be a ban on cars without catalytic converters by the government as an emission control standard 4. Several studies should be conducted with emphasis on ageing management system of catalytic converters. Table 4.1: Frequency Table on a study of the level of awareness and usage of catalytic converters in fleet management S/No Items SA A IN D 1. The use of catalytic converters is significant in improving the quality of fuel 14 26 9 7 combustion 2. 3. 4. A major part of the air pollution caused is due to vehicular emissions I regularly check my catalytic converters to avoid malfunction The use of catalytic converters reduce the horse power of vehicles 8 5 5 10 8 10 15 17 15 23 26 26 5. Emphasis on the use of Catalytic converters does not play a significant role 4 8 10 18 in emission control in PAN and so should not be a serious issue 6. Vehicle users are yet to fully buy into the use of catalytic converters in 28 18 8 8 Peugeot Automobile 7. Catalytic converters have experienced low patronage due to inadequate 22 18 6 12 awareness and education of the vehicle users 8. There is a ban on cars without catalytic converters by the government as an 2 5 10 24 emission control standard 9. Most users of catalytic converters in PAN are not literate enough to 5 4 5 20 understand the importance of catalytic converters 10. The use of catalytic converters has not been enforced in other companies in 18 12 10 10 fleet management to the best of my knowledge 11. Only modern cars need catalytic converters to function well 5 10 12 24 12. The use of catalytic converters should be encouraged only in modern vehicles 15 20 8 10 13. Use of catalytic converters has increased the maintenance cost for vehicle 15 18 12 13 owner in PAN 14. The removal of catalytic converters is more beneficial to the vehicle users than 5 10 18 22 the problem arising from it 15. The use of catalytic converters help in reducing fuel consumption rate 10 15 18 14 16. The Use of catalytic converters improves vehicle performance 9 20 13 14 17. The removal of catalytic converters possibly will give better fuel mileage 10 15 18 14 18. Cars don't need the catalytic converter, so should work just fine without it 11 14 13 13 19. Testing and inspection of the presence of converters is part of the vehicle 2 5 12 25 registration renewal process in Kaduna state 20. There is a reason for not having a catalytic converter 5 13 16 20 21. Cost as an issue may jeopardize the use of catalytic converters 18 22 6 12 22. There will be a huge cost implication for incorporating catalytic converters 21 19 11 8 in your company vehicles 23. Failure of a catalytic converter could prevent other systems and structures 8 12 10 22 from safety function performance 24. There are better alternative for reducing emission in petrol driven vehicles 12 12 10 18 than the use of catalytic converters 25 Strict government policies is a sure way to enforce the use of catalytic 12 13 14 18 converters in vehicles SD 10 10 10 10 26 4 8 25 32 16 15 13 8 11 9 10 9 15 22 12 8 7 14 14 9

REFERENCES Abhinesh, A. OK., & Dinesh okay. (2014)."Minimization of Engine emission through the use of Non – Noblemetal based totally catalytic converter" Vol. 4, difficulty, eleven, pp. 2663- 2468. Anupam M., & Kunal R. (2016).Catalytic Converter in automobile Exhaust Emission. Magazine for research| volume 02 | trouble 10, ISSN: 2395-7549. Retrieved at https://www.researchgate.net/booklet/311962764 Asika, N.

(1991). Studies methodology within the Behavioural Sciences. Longman Nigeria % Bruce Clarkson, F. A. (2014). A global evaluation of the impacts of urbanization on chicken and plant variety. Lawsuits of the Royal Society B: biological science, 281(1780), 20133330 Bharat. S. Patel et al- (2012) A evaluate paper on catalytic converter for car exhaust emissions. International magazine of carried out Engineering studies Vol 7No.11 2012 Brandt, Erich; Wang, Yanying; Grizzle, Jessy (September 2000), "Dynamic Modeling of a 3 manner Catalyst for SI Engine Exhaust Emission manipulate", IEEE Transactions on control systems generation 8 (five): 767-776, ISSN 1063-6536, ftp://www.eecs.umich.edu/human beings/grizzle/papers/TWC98.pdf. David O. O., Muhammad D., Fatai O., Anafi & Samaila U. (2016). Characterization of zeolites as environmental wash coat materials on cordierite ceramics. Complaints of the Twenty-6th (2016) global Ocean and Polar Engineering convention Rhodes, Greece Dongarra J. & G Knothe, (2010) Biodiesel and renewable diesel: A comparison, development in strength and Combustion science. 36, 364-373. Fritz, J. D. (1997). Sensitization and stabilization of type 409 ferritic chrome steel. Substances overall performance, 36(eight), fifty seven. G rainbowbalaji, M Cheralathan (2014) Experimental reduction of NOx and HC emissions in a CI engine fuelled with methyl ester of Neem oil using p-phenylenediamine antioxidant. Journal of clinical & commercial research. 73,177-one hundred eighty. Heck, R.M.; Farrauto, R.J.; & Gulati, S.T. (2009).Catalytic Air pollution manage: commercial generation, third ed.; John Wiley & Sons, Inc.: Hoboken, NJ, usa.Air pollutants: dimension, modelling, and mitigation. (Second ed., pp.127-137). ny, big apple: Spon Press. Hughes-Hassel, S. and Lutz, C. (2006). A survey of the conduct and attitudes of urban center school college students closer to enjoyment reading. Young person Literacy services, 39- 405. Jobson E., Laurell M., Hogberg E., Bernler H., Lungren S., Wirmak G.,& Smedler G.,(1993),SAE Paper 930937, Pg. 639- 652 Jay M. ., Keyur D. T. (2014). Overall performance of Limestone lined Wiremesh Catalytic Converter for Emission control of C.I Engine; worldwide magazine for scientific research &improvement (IJSRD); ISSN (on line): 2321-0613, Vol. 1, issue 11 JuhiSharaf. (2013). Exhaust Emissions and Its manipulate era for an internal Combustion Engine. JuhiSharaf / worldwide journal of Engineering research and programs (IJERA) ISSN: 2248-9622 www.ijera.com, Vol. 3, difficulty 4, pp.947-960 Mohinuddin, K.M., Ataur R. (2012).Investigations the usage of simulations for the improvement of low value catalytic converter from non-precious metals—A—superior material studies Vol 445, pp899-904. M. Shelef, &R.W. McCabe. (2000). “Twenty-five years after advent of automobile catalysts: What next?” Catalysis today, vol. 62, pp. 35-50, Md. Mizanuzzaman, Amitava Ghosh Dastidar, Mohammad Rajib Uddin Rony, Reasat Azam, Md. Almostasim Mahmud. (2013). Exhaust fuel evaluation of SI Engine and performance of Catalytic Converter; worldwide Journal of Engineering studies and packages (IJERA) ISSN: 2248-9622; Vol. three, issue four, pp: 313-320. Mitianiec, W. (2000). Thermo-chemical model of catalyst in -stroke exhaust device (in polish), convention materials KONES’2000, Nałęczów, September 2000 Patel B. S., Patel ok. D. (2012).A evaluate paper on Catalytic Converter on car Exhaust Emission, worldwide journal of implemented technological know-how studies, ISSN 0973-4562, Vol. 7 No. eleven Prashant k. (2013). Evaluate Paper on Catalytic Converter for automobile Exhaust Emission. International magazine of technology and studies (IJSR) ISSN (on-line): 2319-7064Index Copernicus cost Pukalskas Saugirdas., Zautra Rytis., Nagurnas Saulius., Matijosius Jonas., Svelnia Virginijus., Vegneris Recardas., Zuraulis Vidas., Juknelevicius Romualdas, (2013). Research of efficiency of Catalytic Converters in automobiles with an Otto Engine, shipping Engineering college of VGTU 8thNational conference, ISSN: 2029-2384 vilnius, Lithuania. Singh M.P, Suman Raj, (2016)A review on Catalytic Converter for car Exhaust Emission. global magazine of scientific & Engineering research (IJSER) extent 7, issue 2, ISSN 2229- 5518

Srinivasa Chalapathi, okay., Bhavanarayana Murthy, Sudheer Prem Kumar, (2014).improvement of vehicle Catalytic Converter during last 4 decades – A assessment. quantity 2 trouble XI, November 2014ISSN: 2321-9653 Wojciech Marek & Władys regulation Mitianiec (2002) Modeling and research evaluation of catalytic converter in a small Si -Stroke engine journal of KONES internal Combustion Engines 2002 No. three-four ISSN 1231 - 4005 APPENDIX A:(STUDY QUESTIONNAIRE) (A case study of some selected vehicle users in Peugeot Automobile Nigeria, Kaduna State) CONFIDENTIAL Dear sir/ma, This questionnaire is to seek your opinion about the usage of catalytic converters in your car. Any information will be treated confidentially and will be used for the purpose of recommendation to relevant authorities after the completion of the study Thank you. …… Tajudeen Muideen Bidemi APPENDIX A: (SAMPLE QUESTIONAIRE) SECTION B :(PAN) Please tick accordingly Strongly Agreed (5) Agreed (4) Indifferent (3) Disagree (2) Strongly Disagree (1) 1. The use of catalytic converters is significant in improving the quality of fuel combustion 2. A major part of the air pollution caused is due to vehicular emissions 3. I regularly check my catalytic converters to avoid malfunction 4. The use of catalytic converters reduce the horse power of vehicles 5. Emphasis on the use of Catalytic converters does not play a significant role in emission control in PAN and so should not be a serious issue 6. Vehicle users are yet to fully buy into the use of catalytic converters in Peugeot Automobile 7. Catalytic converters have experienced low patronage due to inadequate awareness and education of the vehicle users. 8. There is a ban on cars without catalytic converters in PAN as an emission control standard 9. Most users of catalytic converters in PAN are not literate enough to understand the importance of catalytic converters 10. The use of catalytic converters has not been enforced in other companies to the best of my knowledge 11. Only modern cars need catalytic converters to function well 12. The use of catalytic converters should be encouraged only in modern vehicles 13. Use of catalytic converters has increased the maintenance cost for vehicle owner in PAN 14. The removal of catalytic converters is more beneficial to the vehicle users than the problem arising from it. 15. The use of catalytic converters help in reducing fuel consumption rate 16. Use of catalytic converters improves vehicle performance 17. The Removal of catalytic converters possibly will give better fuel mileage without sacrificing performance of the vehicle 18. Cars don’t need the catalytic converter, so should work just fine without it 19. Testing and inspection of the presence of converters is part of the vehicle registration renewal process in Kaduna state 20. There is a reason for not having a catalytic converter 21. Cost as an issue may jeopardize the use of catalytic converters 22. There will be a huge cost implication for incorporating catalytic converters in your company vehicles 23. Failure of a catalytic converter could prevent other systems and structures from safety function performance. 24. There are better alternative for reducing emission in petrol driven vehicles than the use of catalytic converters 25. Strict government policies is a sure way to enforce the use of catalytic converters in vehicles Thank you. APPENDIX B Chi-square Distribution Table

ETIM PROGRESS 3 SEMINAR

by Mech Engrg

Submission date: 08-May-2023 02:10AM (UTC+0800)
Submission ID: 1968600569
File name: ETIM_PROGRESS_3_SEMINAR.docx (2.15M)
Word count: 12873
Character count: 73866

COMPATIBILITY INTERACTION, SORPTION PROPERTIES AND OPTIMIZATION TECHNIQUE OF BIOTREATED-COMPACTED LATERITIC SOIL

Progress Seminar III on Thesis Title
SUITABILITY OF COMPACTED TROPICAL RESIDUAL SOIL BIO-TREATED WITH *BACILLUS MEGATERIUM* FOR USE IN WASTE CONTAINMENT FACILITIES

By

ROLAND KUFRE ETIM (B.Eng., M.Sc.)

P16ENGCV9011

Presented in

Civil Engineering Department
Faculty of Engineering
Ahmadu Bello University, Zaria

Supervisors
Prof. K. J. Osinubi
Prof. A.O. Eberemu
Prof. T. S. Ijimdiya

March 2023

Introduction

One of the main causes of failure of compacted clay barrier has been due to interaction of leachate with the barrier materials. Most barrier materials are permeable to some degree because some soil particles used as compacted clay barrier are extremely vulnerable to changes due to physico-chemical interactions with the liquid to be contained (Shackelford et al., 2000; Egloffstein, 2001; Frempong and Yanful, 2008; Osinubi and Moses 2015; Osinubi et al., 2017a). Several researches (Daniel and Benson, 1990; Edil *et al*., 1992) suggested that the selection of a suitable material for waste containment facility should be based on the compatibility of such material with Municipal solid waste leachate (MSW). Compatibility of a waste containment system is attained when impedance to leachate transport or waste water is retained/maintained less than or equal to 10^{-9} m/s average permeability criterion (the specified boundary limit) throughout the design span or useful life of the barrier system and its structural integrity intact as well (Shackelford et al., 2000; Osinubi et al., 2020; Adeyemi et al., 2022). Accordingly, barrier failure ensues as soon as overall permeability is compromised due to increase beyond the design value or specified upper limit (Peterson and Gee 1985; Osinubi et al., 2020).

The advection and diffusion mechanisms are mostly the primary movement phenomenon of contaminant transport through saturated clayey barriers or the matrix of an intact rock (e.g., shale). The movement of leachate generated from a municipal solid waste landfill (contaminants) to soil and groundwater transference is more often than not reduced and or mitigated by multilayered bottom liners and top covers to the landfill scheme constructed from different material of very low permeability. The bottom liners and top covers multilayer layout mostly made up of natural or compacted clay or mixtures of clayey soils, granular filters and geosyntetics (Francisca and Glatstein, 2010; Ozcoban *et al*., 2006; Petrov and Rowe 1997; Touze- Foltz *et al*., 2006) are designed primarily to regulate advection and diffusion potentials with purpose of controlling the contaminant fate transport by diffusion through adsorption desorption (sorption) capacity for cations and anions, hydraulic conductivity and chemical compatibility, throughout its service and post-closure life of the system.

Statement of Problem

Several soil stabilizers/techniques of soil improvement have emerged to enhance engineering properties of deficient soils as well as regulate the advection and diffusion potentials with purpose of controlling, mitigating and limiting the contaminant transport through adsorption desorption mechanism. The use of industrially manufactured chemical additives like lime and cement has not only increased the cost of improving deficient soils but has implicit negative impact on the environment due to its carcinogenic effect and emission of greenhouse gas during their production. Also, the use of agro-based or bio pozollan have been applied as admixture in compacted clay for waste containment schemes. However, the open and or closed burning of bio-industrial and agricultural wastes (e.g., rice husk, sugarcane bagasse, locust bean pods, etc.) to obtain natural ashes with pozalanic properties for use in soil improvement, equally emit carbon (II) oxide (CO) to the environment that could pose a negative impact on humans health and environment.

The paradigm shift in soil improvement which considers the use of urease producing micro-organisms in soil improvement have been adopted in quite a number of studies (Whiffin et al., 2007; DeJong et al., 2006; DeJong et al., 2010; Wen et al., 2020; Xiao et al., 2020; Osinubi et al., 2020a,b; Osinubi et al., 2021), to mitigate some of the problems associated with the use of cement and other related additives for soil enhancement. However, not much studies reported or relate the benefit or potential of MICP in sustaining the hydraulic compatibility over an extended duration or long term as well as sorption and diffusion properties as applied to waste containment facilities. Also the application of optimization principles in MICP based studies is up to date still limited. The focus of this research is to assess the compatibility and sorption properties of lateritic soil treated with *B. megaterium in* stepped suspension densities of 0, 1.5×10^{8}, 6×10^{8}, 1.2×10^{9}, 1.8×10^{9} and 2.4×10^{9}/ ml respectively, with municipal solid waste leachate for possible application in land fill barrier system.

Aim and Objectives

The objectives of this study is to evaluate the long term hydraulic performance and sorption characteristics of lateritic soil - *B. megaterium* mixture

The objectives include:

1. To determine the long-term hydraulic conductivity of bio-treated lateritic soil
2. To determine the sorption performance of lateritic soil – *B. megaterium* mixtures
3. To carry out optimization techniques on the laboratory results.

Materials and method

Soil: The test soil was obtained from Abagana (6°10′60.00″ N and 6°58′59.99″ E), Anambra state, Nigeria. Samples were well preserved and sealed in water-proof bags. The soil samples in their moist forms were dried, and then passed through sieve with 4.75 mm opening and preserved for use.

Bacteria: The microorganism employed in this study is *B. megaterium* in varying cell concentration. The bacteria is aerobic, urease and gram-positive and can form endospores. Series of biochemical tests standards was used for isolating the bacteria from the lateritic soil (Sura and Hiremath, 2019; Osinubi *et al*., 2019a). The isolated bacteria were cultured in nutrient agar petri dishes. The function of the microorganism (*Bacillus megaterium)* was to supply enzyme urease during its biochemical activity under appropriate condition. The characteristic mechanism of MICP is represented by Equation (1) and (2), in which pH is increased and thus act to make the environment best favourable for precipitation of calcite.

$$CO(NH_2)_2 + 3H_2O \xrightarrow{Urease\ enzyme} 2NH_4^+ + HCO_3^- + OH^- \quad (1)$$

$$Ca^{2+} + HCO_3^- + OH^- \rightarrow CaCO_3 + H_2O \quad (2)$$

Cementation reagent: The cementation reagent is a cementation source that provides appropriate Ca^{2+} and ample urea for microorganisms to produce calcite. Composition of; 30.03 g $CO(NH_2)_2$, 12.12 g $NaHCO_3$, 10 g NH_4Cl, 55.4 g $CaCl_2$ and 3 g nutrient broth by mass per 1000 ml de-ionised water constitute 0.5 M concentration of cementation solution used in this study.

Batch Equilibrium Adsorption Test (BEAT)

Sample preparation

The preparation of samples for Batch Equilibrium Adsorption Test (BEAT) was considered based the outcome of Atterberg limit test which was made possible from two different methods with varying proportioning ratio of bacteria suspension density and cementation solution (Osinubi et al., 2019). With reference to the improvement method, the most excellent method and optimal proportioning ratio of bacteria suspension density and cementation concentration was used. The Atterberg limit test of 75 % of liquid limit as *B. megaterium* suspension and 25 % of liquid limit as cementation solution, making a total of 100 % LL (75 % of LL *B. megaterium* + 25 % of LL Cementation reagent) bacteria suspension and cementation solution mixture yielded the excellent result and was continued for BEAT.

BEAT procedure

The BEAT was implemented in compliance with methods designated by Shackelford and Daniel (1991a). The discharge, leaking, percolating and filtering processes that summarizes the leachability potential of the various cations and anions (Na^+, K^+, Ca^{2+}, SO_4^{2-} and Cl^-) from MSW leachate into the environment was studied/estimated/performed using the batch equilibrium tests for the lateritic soil – *B. megaterium* suspension densities mixture. Five leachate samples of different/varying concentrations of ions were used to assess the leaching potential of higher candidate ions of Na^+, K^+, Ca^{2+}, SO_4^{2-} and Cl^- from MSW into the environment. The experiment consist of a single batch extraction test sample carried out by formulating/constituting in successions a series of 120 ml of leachate L1, L2, L3, L4 and L5 respectively, comprising bio-treated soils (30g dry weight) at varying *B. megaterium* suspension densities of; 0, 1.5, 6,

12, 18 and 24 [x 10^8]/ml, respectively, in 1:4 mixing ratio. The resultant constituted mixture were mouth-sealed and or closed tight and were transferred to a mechanical shaker where samples were agitated for a time duration of 48-hours until a complete slurry paste was formed. The slurry was transferred into a cone-shaped filter paper placed inside a funnel and the bio-treated soil-leachate contaminant solutions (i.e., solute) collected in clean bottles as filtrates/residues were gradually decanted and filtered using filter paper (Plate 4.9). The solute were taken for laboratory analysis and the equilibrium concentrations of the cations were carried out using UNICAM 969 Atomic Adsorption Spectrometer (AAS). The pH of the samples were also measured. The mass of solute adsorbed/desorbed per mass of soil solid was calculated using the expression of Eq. (3):

$$C_s = \frac{(C_i - C_f) \times V}{M_s} \qquad (3)$$

where: C_s = Mass of solute adsorbed/desorbed per mass of soil solid (mg/l), C_i = Initial concentration of municipal solid waste leachate (mg/l) determined from the AAS analysis of leachate 1-5, C_f = Equilibrium concentration of solute (mg/l), V = Volume of municipal solid waste leachate used (cm^3), M_s = Mass of dry soil (g)

Plate 1: Photograph representation of sample filtration for Atomic Adsorption Spectrometer

Diffusion

The single - reservoir, decreasing source tests in compliance with the implemented procedure and method specified by Shackelford and Daniel (1989); Shackelford and Daniel (1991b); Oluremi, 2015; Osim, 2017; Sani 2019; Yohanna (2021) was utilized for the diffusion analysis. The systematic set-up of diffusion test protocol is made up of soil compacted to a height of about 12 cm inside a polyvinyl chloride (PVC) pipe of 0.25 m height and 0.1 m diameter.

Sample preparation

Soil samples were first bio-treated at one-third pore volume *B. megaterium* suspension densities of 0, 1.5, 6, 12, 18 and 24 [x 10^8]/ml (as recommended by Rowshanbakhta *et al.*, 2016) before compaction using OMC relative to BSH compactive effort to take up the same volume and density of the samples used for permeability test. 0.5 M cementation solution was introduced in three cycles into the soil after compaction and allow to suffuse freely by gravity for gradual activation of MICP protocol. After 24-hours of the third

cycle, the prepared sample was saturated from the top column with distilled water for the duration of the 21 days so as to minimize mass solute mass transport of candidate contaminants. The water was thereafter transferred out and the diffusion set-up were sealed at the top with Perspex material such that a tiny hole (5mm) fitted with a hose connected to a funnel is provided. Leachate sample 1 was then gradually poured into the sample through the pipes to simulate saturated field condition of waste containment barrier material under sorption of leachate. The set-up were allowed on the laboratory table undisturbed for the period of 90-days so as to allow the chemical species (candidate ions) in the leachate to diffuse through the saturated compacted bio-treated soils profile under free hydraulic concentration gradient at laboratory temperatures of around 25 to 27 °C. The diffusion process were terminated at the end of 90 days, and the compacted soil in each cells were extruded, placed horizontally and divided across equally into slice portions of approximately 1.1cm thickness (height). The sectioning was carried out to provide data for understanding the profile pattern of water distribution before drying and the chemical ions concentration profile needed to evaluate the effective diffusion coefficients. Each of the slices were then divided into two parts for which one set of the part was used for water content determination and the second for ion concentration. The moisture content along the vertical profile of the diffusion column setup was determined by oven drying while the level of concentrations of the various selected candidates ions is in the pore fluid of the specimen were air dried under laboratory condition (i.e., room temperature) prior to extraction and determination and measurement of targeted ions candidates using UNICAM 969 Atomic Absorption Spectrophotometer.

The effective diffusion coefficient was then evaluated using equations 4, 5 and 6 respectively.

$$\frac{c(x \geq 0, t)}{C_0} = \frac{\alpha}{1+\alpha} + \sum_{m-1}^{\infty} \frac{2\alpha}{1+\alpha+q_m^2\alpha^2} exp\left(\frac{Dq_m^2 t}{R_d L^2}\right) \frac{cos\left[q_m\left(1-\frac{x}{L}\right)\right]}{\cos(q_m)} \quad (4)$$

where all qm values were assumed non zero positive roots for the following functions:

$$\tan(q_m) = -\alpha q_m \quad (5)$$

were α in the above equation is expressed as:

$$\alpha = \frac{H_L}{nR_d L} \quad (6)$$

where H_L and L = height of the liquid and the source reservoir and length of the soil specimen, respectively and n = total porosity of the soil specimen.

The Retardation factor (R_d) obtained from the batch studies result which is as reported by Shackelford, 1994; Shackelford and Daniel, 1991b and Yohana (2021) was calculated using equation 7.

$$R_d = 1 + \frac{\rho_d}{n_e} K_d \quad (7)$$

where; K_d = distribution/partition coefficient; n_e = Effective porosity; ρ_d -dry density of soil.

The tortuosity factor, τ_a defined as the ratio of effective diffusion coefficient to the free solution (aqueous) diffusion coefficient of the solute was computed using equation 8.

$$\tau_a = \frac{\text{Effective diffusion coefficient}}{\text{Free solution (aqueous) diffusion coefficient}} \quad (8)$$

Bacteria Foraging Optimization Procedure

Results for all experiments were measured during laboratory work. Measured soil factors include; coefficient of permeability (hydraulic conductivity) as dependent factor and *B. megaterium suspension density* (d_0), void ratio (d_1), bulk density (d_2), water content relative to optimum (d_3), compactive effort (d_4),

pH (d_5), degree of saturation (d_6), plasticity index (d_7), liquid limit (d_8) and viscosity (d_9) as self-determining(independent) factors. GeneXproTools 5.0 was used to develop the fitness (objective) function use for Bacteria Foraging Optimization to predict hydraulic conductivity of treated lateritic soil with *B. coagulans* suspension density. The fitness function was integrated with codes in Matlab 2016 version to predict the minimum hydraulic conductivity for a given set of self-determining factors. The fitness function is shown in equation 9. The Fitness function was obtained with the aid of gene expression trees made of four generations as shown in Figure 1. The flow chart for Bacterial Foraging optimization used is shown in Figure 1

Fitness/Objective function

$$y = \tan^{-1}\left[\left(\frac{(x_{10}+10.83)}{x_9\cos x_1}+{x_4}^4\right)^6\right]+\tan(-196.06)-\frac{x_5}{\log x_{10}}+x_3x_6 + \tan^{-1}\left[\frac{(e^{x_4})^2}{x_8}-(e^{x_2}+2x_4)\right]+\tan\left[\cos\left(\frac{2x_4-x_7}{-0.61x_8\cos -6.06}\right)\right] \quad (9)$$

Where:

x_1 =*B. megaterium suspension density* (B.meg), x_2=d_1= void ratio (e), x_3= dry density (ρ_d), x_4= water content relative to optimum (WCRO), x_5= compactive effort (CE), x_6= pH, x_7= degree of saturation (Sr), x_8= plasticity index (PI), x_9= liquid limit (LL), x_{10}= viscosity (Vs), Y = ln(HC)=hydraulic conductivity.

Constraints

$1.33E-10 \le y \le 4.05E-06$	Hydraulic conductivity
$0 \le x_1 \le 2.4E-09$	B.megaterium suspension density
$-1 \le x_5 \le 2$	Compactive effort
$7.8 \le x_4 \le 17.6$	moulding water content

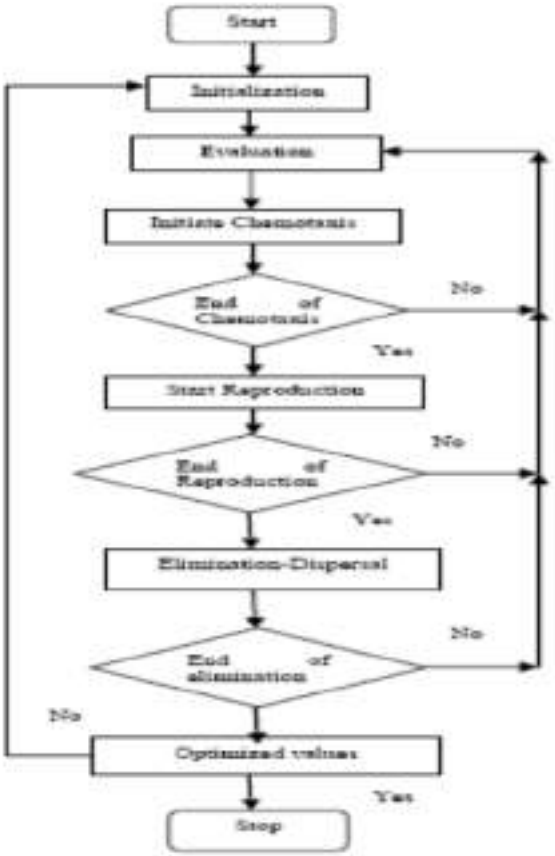


Figure 1: Flowchart of the bacterial foraging algorithm.

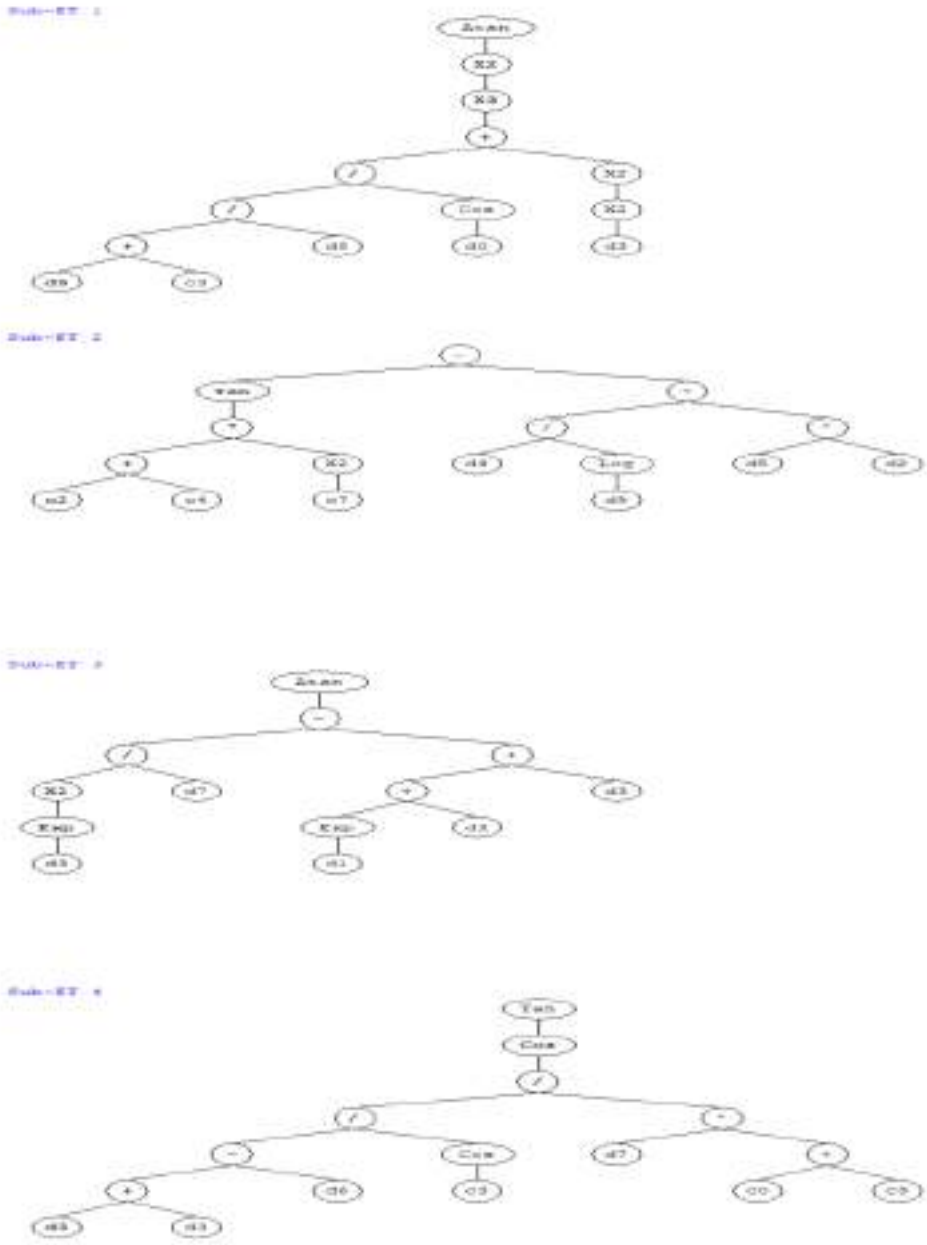


Figure 2: GenXproTool expression tree for four generations

RESULTSAND DISCUSSION

Chemical constituents of leachates samples

The chemical constituents of the five leachates samples used are as shown in Table 1. Leachate samples use for both chemical compatibility and long term tests were simulated in the laboratory.

Table 1: Chemical composition of leachate generated and used in this study

	Concentration in ppm (mg/L)				
Measured content	L1	L2	L3	L4	L5
Sodium, Na	890	720	593	440	350
Potassium, K	210	180	135	108	87
Magnesium, Mg	9.204	4.734	2..641	1.552	1.244
Calcium, Ca	68.567	55.624	39.803	21.317	8.416
Iron, Fe	3.860	0.0604	0.0473	0.0217	0.0136
Cadmium, Cd	0.358	0.0031	0.0028	0.0015	0.0026
Chromium, Cr	0.205	*	0.0018	0.0073	0.0046
Zinc, Zn	0.147	0.0047	0.0063	0.0017	0.0032
Lead, Pb	0.216	0.0052	0.0025	0.0019	0.0031
Sulphate SO_4^{2-}	23.500	18.000	14.832	8.063	5.725
Nitrate NO_3^-	0.073	0.058	0.051	0.046	0.041
Chloride Cl	135.30	105.3	84.2	57.4	31.4
Dissolved oxygen, DO	257	255	280	260	270
Total dissolved solid, TDS	1650	1500	1380	1205	1100
Total hardness, TH	224	203	184	156	139
Turbidity (NTU)	35	28	25	19	21
Chemical oxygen demand, COD	1385	1380	1579	1613	1497
Biological oxygen demand, BOD	120	209	354	320	275
pH	7.2	7.1	7	6.8	6.9
Electrical conductivity, E (µs/cm)	3.2	2	2.3	1.6	2.8

* - Trace quantity, L1, L2, L3, L4, L5- Leachate samples 1, 2, 3, 4 and 5 respectively.

Compatibility

Effect of municipal solid waste leachate on long-term hydraulic conductivity

The cementation concentration which offered effective stiffening and strength of biocemented specimen formed a base line for the long term permeability. Therefore, MICP specimens for long-term hydraulic conductivity were prepared for the various bacterial suspension densities [i.e., 0, 1.5, 6, 1.2, 18 and 24] × 10^8 cells/ml and 0.5M cementation concentration. The long-term hydraulic conductivity of bio-treated specimens serially permeated with only water, water and leachate and only leachate is presented in Figure 3-5. In the case of permeation with only water, the baseline hydraulic conductivity values of specimen permeated are 1.44×10^{-9}, 1.01×10^{-9}, 1.50×10^{-9}, 1.77×10^{-9}, 1.17×10^{-9}, 2.81×10^{-10};, which varied up to the 90th day at 1.60×10^{-9}, 7.04×10^{-10}, 4.55×10^{-10}, 1.48×10^{-9}, 2.40×10^{-10}, 1.40×10^{-10} m/s; for stepped suspension densities of [0, 1.5 , 6 , 1.2, 18 and 24] × 10^8 cells/ml, respectively. The variation in hydraulic conductivity showed a decrease that correspond to absolute values of 1.08, 6.96, 1.64, 7.95 and 5.00 for 0, 1.5×10^8, 6×10^8, 1.2×10^9, 1.8×10^8, and 2.4×10^9 cells/ml bacterial cell suspension density, respectively. The reduction in hydraulic conductivity could be due to plugging of the soil pores due to either increased calcite formation from the bio-treated specimen or microbial growth as a result of bioactivity in the soil-water-bacteria interaction (Frempong and Yanful 2008; Francisca and Glatstein 2010; Rowe 2005; Osinubi et al., 2020). The alkaline pH emphasis and resultant microbial calcium metabolism are fundamental facts in the precipitation mechanism (Hammes and Verstraete 2002). The sudden spike in hydraulic conductivity can be due to the recharge of the permeability tube with the permeant percolating freely by gravity, while the

erratic hydraulic conductivity suggests swift and random pore plugging up of micro, mini and macro pore sizes within the soil fabric (Rebata-Landa and Santamarina 2006; Nikolova-kuscu et al., 2013).

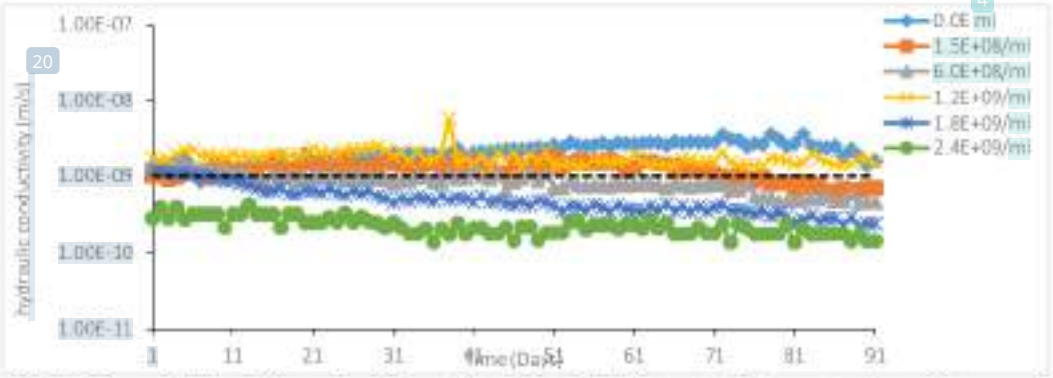


Figure 3: Variation of hydraulic conductivity of lateritic soil - bio-treated *B. megaterium* mixtures with time (permeated with water only)

The permeability values of bio-treated specimen serially permeated with water up to the first 21st day and then with leachate up to the next 69th day is presented in Figure 4. The trend of initial increase in hydraulic conductivity up to the initial 21 days and thereafter decreased continuously for the following 69 days was recorded. This initial increase may be due to rapid flow through soil clods which offers least resistance to liquids passage. The coefficient of permeability plotted with variation of time in days of compacted bio-treated specimen with stepped *B. megaterium* suspension density of [0, 1.5 ,6 , 1.2, 18 and 24] $\times 10^8$ cells/ml, decreased from baseline values of 3.75×10^{-9}, 5.02×10^{-9}, 9.13×10^{-10}, 1.65×10^{-9}, 3.80×10^{-9}, 4.59×10^{-10} m/s to 4.31×10^{-10}, 7.64×10^{-10}, 1.01×10^{-10}, 2.39×10^{-10}, 2.46×10^{-10}, 6.63×10^{-11} m/s, respectively; and in terms of absolute order of magnitude they also gave values of 8.85, 8.48, 8.89, 8.55, 9.35, and 8.56, respectively. It is noted that the hydraulic conductivity decreased significantly with time when compared with when it was permeated with water only. This could be as result of high alkalinity of the medium (higher pH) that favoured bioactivities i.e., build-up of biofilms such as extracellular polymeric substances (EPS) in the leachate and soil. Wen et al., (2020) reported that the availability of nutrients was responsible for the formation and stimulation of yeast and bacteria colonies that partly clogged the soil pores rendering the soil fabric non-passible to fluid. Osinubi et al., (2017) also reported similar mechanism of pore blockade by bioactivities of bacteria colony. Also, the bioactivities breakdown of unclassified organic substance in the leachate enabled the generation of CO_2 (aq) that ionized into CO_3^{2-} and reacted with the Ca^{2+} at high pH concentration in the leachate to form insoluble carbonate precipitate (Xie et al., 2020). The precipitate is deposited on the surface and into soil pores that mitigate drainage of fluid thereby contribute to decreasing porosity and permeability of the specimen which causes clogging in the long term.

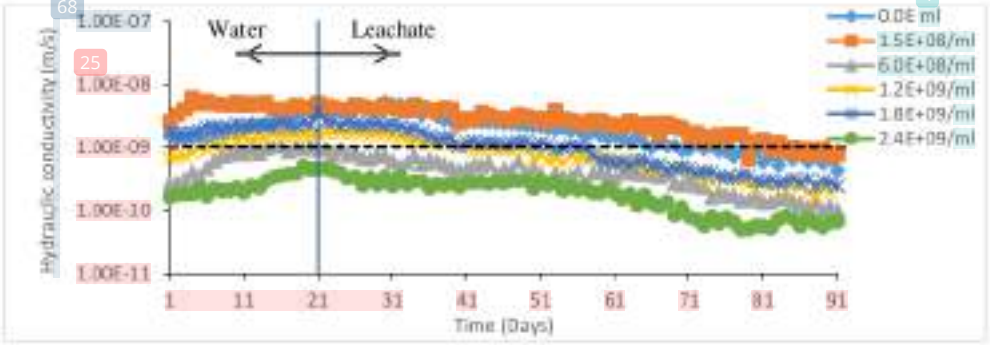


Figure 4: Variation of hydraulic conductivity of lateritic soil - bio-treated *B. megaterium* mixtures with time (sequentially permeated with water and leachate).

In the case of bio-treated sample permeated with leachate only(see Figure 5), the coefficient of permeability plotted with variation of time in days of compacted bio-treated specimen with stepped suspension density of [0, 1.5 , 6 , 1.2, 18 and 24] $\times 10^8$ cells/ml *B. megaterium*, decreased from baseline values 1.103×10^{-9}, 8.34×10^{-10}, 4.58×10^{-10}, 2.30×10^{-10}, 8.94×10^{-10} and 5.57×10^{-10} m/s to 7.71×10^{-10}, 4.89×10^{-10}, 2.16×10^{-10}, 1.76×10^{-10}, 4.30×10^{-10}, and 3.22×10^{-10} m/s in absolute order of 3.53, 4.41, 5.28, 2.33, 5.19 and 4.21, respectively. The results of hydraulic conductivity of specimen permeated with only leachate are generally lower in contrast to other results previously obtained for specimen successively permeated with water and leachate and specimen permeated with only water. This can be explained by the biological, chemical and physical effects which induced biofilm, inorganic precipitate $CaCO_3$ and trapped suspended solids (SS), respectively (Nikolova-kuscu et al., 2013; Liu et al, 2018; Stibinger 2016; Yu and Rowe 2013). These effects are noted to result in clogging micro pores of the soil structure thereby offering higher resistance to flow and causing reduction in hydraulic conductivity. It is also known to significantly reduce hydraulic conductivity owing to microorganisms' growth inside the soil pores under prolonged time frame. The decrease in k due to bioactivity can be related to the presence of biofilms accumulation and associated bioclogging mechanisms controlled by the relative size of micro-organisms with respect to pore and throat sizes (Osinubi et al., 2020a; Rebata-Landa and Santamarina, 2006). Bio-clogging is viable process to build low-cost and low-hydraulic conductivity barriers in soils (Tang et al., 2016). Francisca and Glatstein (2010) used regression model to confirm that microorganism is responsible for the controlled displacement of liquid in soils permeated with leachate. Nikolova-kuscu et al (2013) reported the presence of COD and Ca^{2+} in higher amount mg/L in leachate is responsible for biological clogging (biofilm) and chemical clogging ($CaCO_3$).

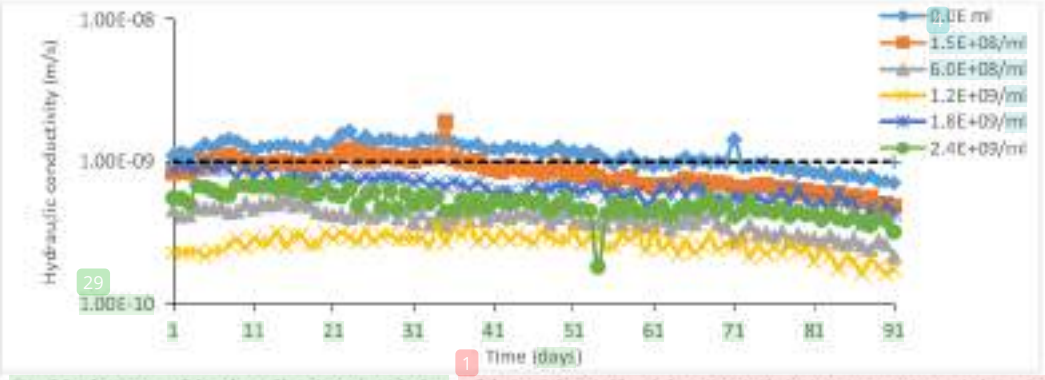


Figure 5: Variation of hydraulic conductivity of lateritic soil - bio-treated *B. megaterium* mixtures with time (permeated with leachate only).

Calcite content

Calcite content (CC) was studied using the washing method. The various specimen from demoulded long term permeability sample of the various treatment were sliced into three equal sections representing top, centre and bottom. The samples were air-dried under laboratory condition 25±2°C. The result of $CaCO_3$ content (CC) obtained by washing method for specimen permeated with water only is shown in Figure 6. The CC increased with increase in bacteria suspension density. The calcite content for top specimen increased from 3.7 % for 0 cell/ml to 5.0% for 2.4×10^8 cells/ml *B. megaterium* suspension density. Similar trends were observed for centre and bottom specimens, although each having calcite content of lower values in contrast to top specimen. This could be associated with the plugging of the soil surface fabric of the compacted specimen which offered higher resistance to non-uniform percolation of cementation reagent.

Pan et al (2020) reported that the distribution of calcite in using biogrout through MICP technique decreased from top to base due to aggregation of calcite crystal during percolation through soil particles.

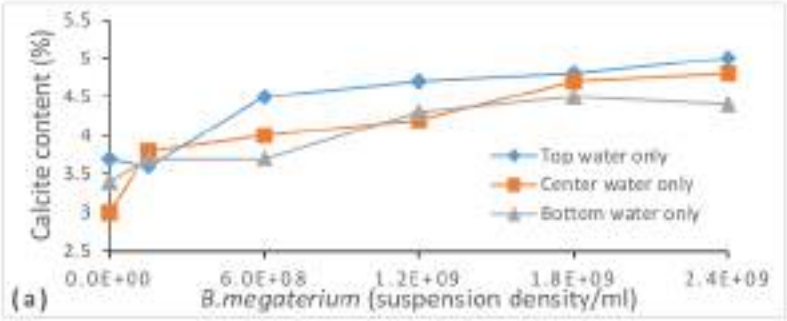


Figure 6: Variation of calcite content with *B. megaterium* suspension density for sample permeated with water only.

In the case of sample sequentially permeated with water and leachate, the variation calcite distribution with bacterial suspension for is presented in Figure 7. The CC for top sample increased from 4.0 to 5.1% for 0 to 6.0×10^9 cells/ml *B. megaterium* suspension density, respectively, and thereafter decreased to 4.2 % at 2.4×10^9 cells/ml *B. megaterium* suspension density. Similar trends were obtained for centre and bottom samples.

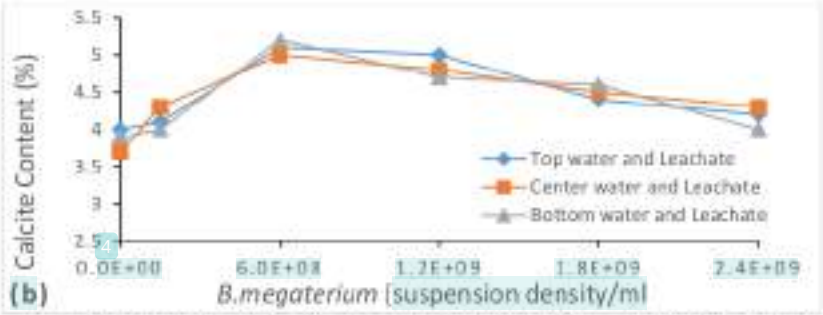


Figure 7: Variation of calcite content with *B. megaterium* suspension density for sample permeated sequentially with water and leachate

The CC for top, centre and bottom in the case of sample permeated with leachate only (Figure 8), generally decreased with increased *B. megaterium* suspension density. The leachate concentration from the onset of permeation may have speedily activated the growth of biofilms and EPS which predominated calcite formation thereby leading to the reduction in CC. The CC ranged from 4 to 5.8 %, 3 to 5.4 % and 3.6 to 5.3 % for top, centre and bottom samples, respectively. The slight variation for each of the section considered could be related to the non-uniform precipitation of calcite at bacterial cell surface within the inter-granular pore spaces of the soil fabric. The non-uniform distribution of calcite with depth for the specimen could be due to: (1) the increased bioactivities (biofilm) activated by the leachate which eliminated the possible uniformity in calcite distribution and (2) the alteration of initial bio-cemented soil structure following the permeation sequence. This indicated that the relative pore size distribution of specimen decreased with increasing clogging with biofilm formed (Rowe et al 2005).

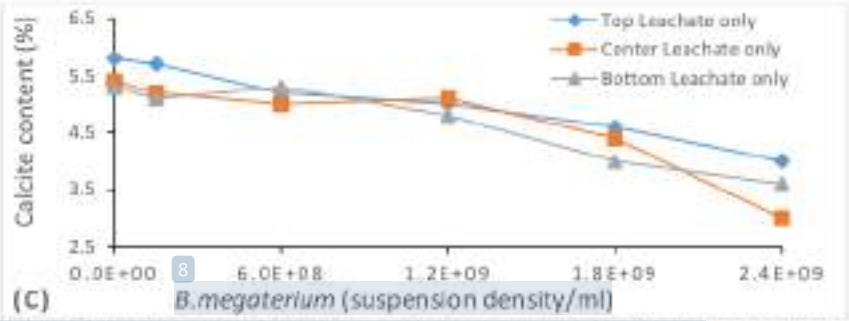
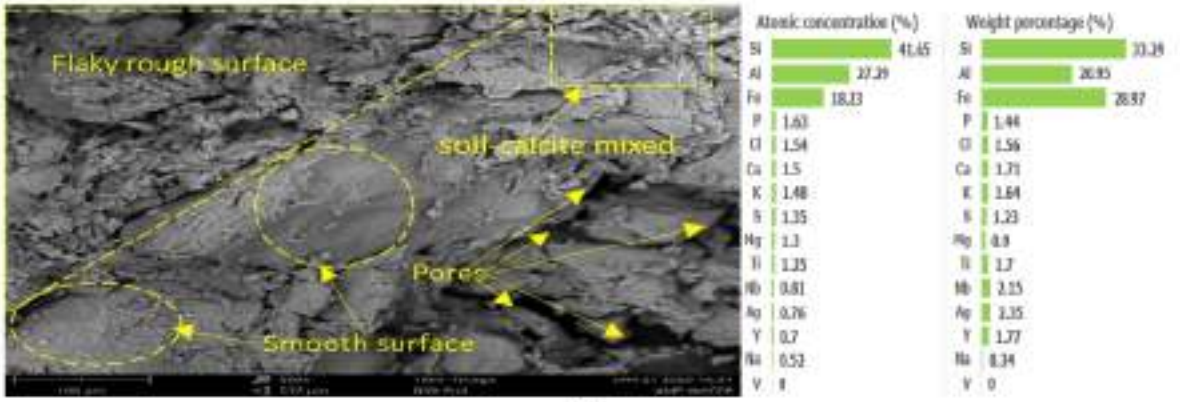


Figure 8: Variation of calcite content with *B. megaterium* suspension density for sample permeated with leachate only

Scan electron microscopy

The SEM image of MICP-treated samples permeated with water only, had mixed structural morphology at different surface sections on the mapped output micrograph as shown in (Figure 9). The morphology possessed flaky, rough and smooth structure at different surface segments and also had pores and mixed print of soil-calcite. The flaky and rough morphology of the MICP treated sample permeated with water could be due to the hardening behaviour of the soil due to deposition of calcite (Whiffin 2004; Whiffin et al., 2007; Dejong 2010; Van Paassen et al., 2010).

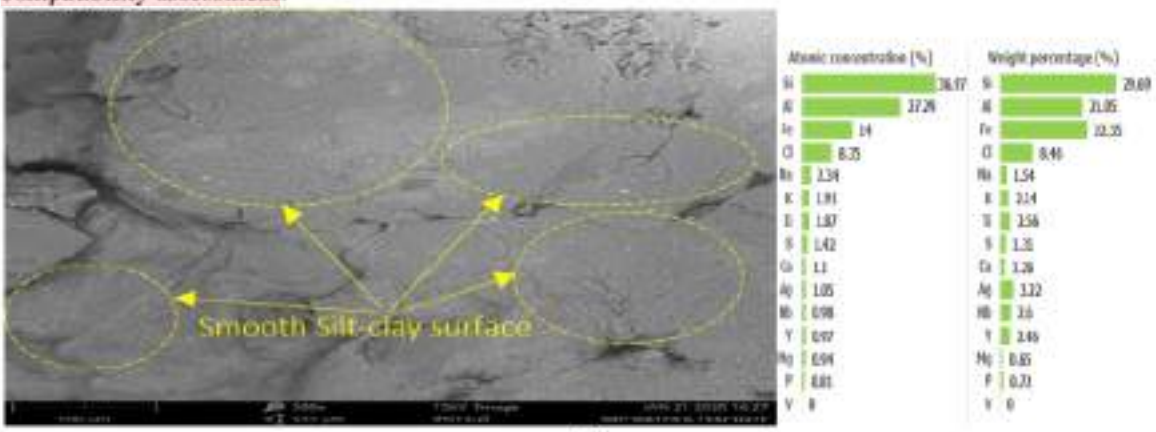


(a)

Figure 9. SEM/EDS with corresponding atomic concentration and weight percentage of elemental composition of bio treated sample permeated with (a) water only at 100 μm optimum resolution, 500× magnification, 15kV image mode and BSD full detector

The micrograph of MICP-treated specimen sequentially permeated with water and leachate (Figure 10) had predominately smooth morphology probably due to calcite formation and biofilm coverage. It is mostly expected that the prolonged permeation period could have led to the formation of biofilm due to the leachate interaction with soil (Francisca and Glatstein 2010; Francisca and Glatstein 2010; Thullner et al., 2002a,b). It has been reported for this specimen that the content of calcite increased initially and then decreased with increase in concentration of *B. megaterium* suspension density as biofilm formation in the long run predominated calcite formation. This possibly suggest that the reduction in hydraulic conductivity may not necessarily be due to calcite formation as would be ordinarily thought of based on previous report on permeability reduction from MICP treated sample (Whiffin et al., 2007; Dejong et al., 2010; Chu et al., 2012), but rather by biofilm formation.This therefore suggests that the critical assessment of hydraulic

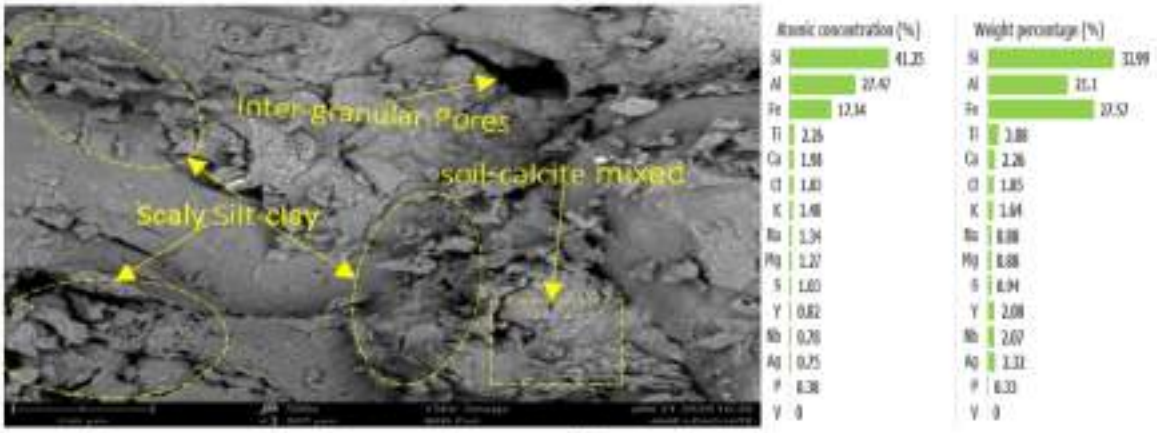
conductivity of MICP treated sample subjected to prolong permeation period, provide a better criterion for compatibility assessment.



(b)

Figure 10. SEM/EDS with corresponding atomic concentration and weight percentage of elemental composition of bio treated sample permeated with (b) water and leachate at 100 μm optimum resolution, 500× magnification, 15kV image mode and BSD full detector

The SEM micrograph of MICP-treated specimen permeated with only leachate (Figure 11) had microspores; clay silt-clay structure, intergranular pores, calcite print; smooth silt-clay surface. The scaly surface could be the result of dissolution and precipitation of clay minerals within the soil fabrics. A self-modification from an aggregated structure to a matrix-dominated structure upon permeation with only leachate. The morphology could be related to: i) leachate interaction with soil clay minerals, ii) activation of mineral clogs, iii) formation of, gelatinous biofilms secreted by extracellular polymeric substance (EPS) i.e., microorganisms. This suggest that the decreased hydraulic conductivity in MICP treated specimen permeated with only leachate may not be solely due to calcite formation but on the viability of nutrient solution which aided bioactivities that ultimately induced biofilm formation.



(c)

Figure 11. SEM/EDS with corresponding atomic concentration and weight percentage of elemental composition of bio treated sample permeated with (c) leachate only at 100 μm optimum resolution, 500× magnification, 15kV image mode and BSD full detector

Batch Equilibrium Adsorption Test

Effect of pH on batch equilibrium adsorption

The pH of lateritic soil characteristically determined on leachate soaked/saturated extracts/filtrate of clay soils is an inclusive compositional dynamics essentials/ elements which can show/offer a far-reaching or significant role that helps regulate adsorption potential of cations in leachate-soil interactions during/in a batch equilibrium adsorption test (Mitchel 1993). This is possible because inter-particle associations and repulsions mainly occurs in reasonable high pH medium/condition, while also maintaining positive charged edges at low pH, thus increase in ions concentration in leachate, leads to increase in sorption of leachate by the soil fraction. The variation of pH of soil-leachate interaction filtrate with *B. megaterium* suspension density in batch equilibrium adsorption tests mixtures is shown in Figure 12. The pH of the mixture (lateritic soil – *B. megaterium*) decreased with increased bacteria suspension density except for few case where a deviation for increase was observed. The pH of the mixture varies in the range from 10.01 – 9.88; 10.19 – 9.68; 10.11 – 9.47; 9.82 – 9.32 and from 9.83 – 9.35 for MSW leachate 1, 2, 3, 4, and 5, respectively. The observed/recorded decreased in pH might be as a results of a sorption (adsorption) of heavy metals while the sorption (desorption) of non-heavy metals was probably due to increase pH (Abollino et al., 2003; Angelica et al., 2015). Furthermore, the changes in the pH of treated soil/specimen could be due to the interactions between the respective leachate, *B. megaterium* and cementation solution used (Yohanna, 2021; Sani, 2019). Also, calcite content, micro-sized organic content in either leachate or soil, dissolved and soluble salts, CEC and exchangeable cations, and specific surface area are compositional factors that could affect the adsorption protocol in a BEAT experiment (Mitchel, 1993; Page et al., 1982).

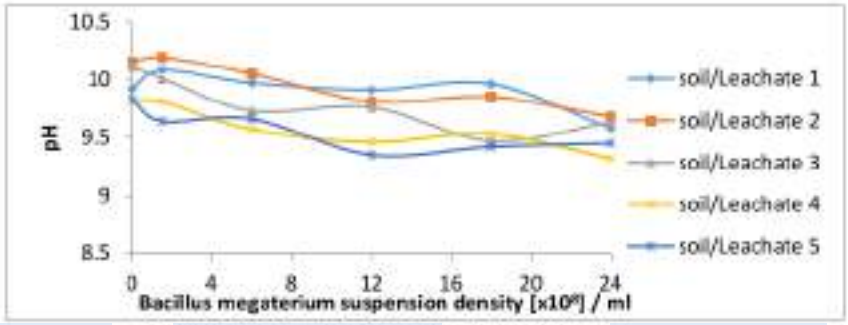


Figure 12: Variation of pH of lateritic soil-with *B. megaterium* suspension density filtrate with *B. megaterium* suspension density exposed to individual leachates during batch equilibrium adsorption test.

Effect of electrical conductivity on batch equilibrium adsorption

The variation of electrical conductivity (EC) of biotreated lateritic soil-leachate mixtures with *B. megaterium* suspension density for five individual leachate concentrations in BEATs is shown in Figure 13. The EC of the mixture increased non-linearly with increased bacteria suspension density. The EC varies in the range from 15 – 18.6; 14 – 17.8; 13 – 17; 12 – 16.5; and from 12 – 16 for MSW leachate 1, 2, 3, 4, and 5, respectively. Peak EC value of 18.6 was recorded at 24×10^{-8} cells/ml for soil/leachate 1 while lowest EC value of 12 was recorded at 0 cell/ml. The increased in EC is a response to increase salinity which is a function of increased dissolved ions (Ghosh et al., 2013; Oluremi, 2015; Yohanna 2021) in the soil-*B.megaterium*-leachate solutions.

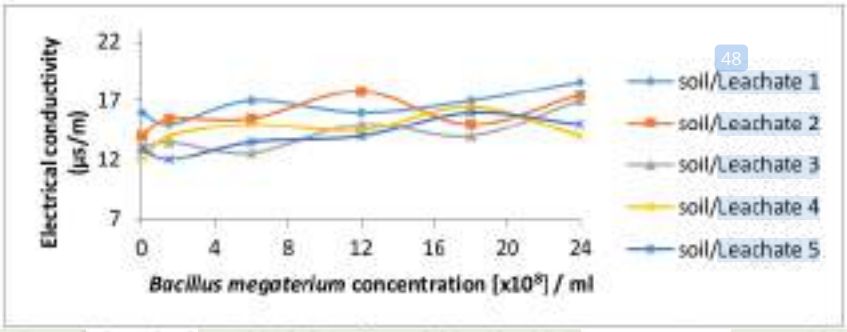


Figure 13: Variation of electrical conductivity of lateritic soil with *B. megaterium* suspension density during batch equilibrium adsorption test

Sorption performance assessment lateritic soil – *B. megaterium* mixtures

Sorption (adsorption or absorption) assessment performs a fundamental part in contaminants attenuation in a soil-leachate system and is a major factor amongst several factors that regulate and or controls the level or extent of contamination or pollution of underground water. Characterization of the adsorption ability of soils (in respect to candidate ions) is typically performed using batch equilibrium testing procedures. Batch equilibrium adsorption tests (BEATs) were performed on the bio-treated soil –leachate specimens to evaluate sorption potentials of some identified cations and anion; namely Sodium (Na^+), Potassium (K^+), Calcium (Ca^{2+}), Chloride (Cl^-) and Sulphate (SO_4^{2-}), dominant in the leachate. Adsorption reactions are processes by which contaminant solutes in solution become attached to the surfaces of the various soil fractions. These reactions are basically governed by the surface properties of the soil fractions (lateritic soil-*B. megaterium* suspension medium), the chemistry of the pollutants and the porewater, as well as the pH of the environment of interaction. The capacity of flow of candidate cations and anions in the soil is represented or designated by the retardation factor (R_d), while the partitioning/distribution coefficient k_d is used to describe contaminant or pollutant partitioning between liquid (leachate) and solids. K_d is the slope of an adsorption isotherm for a linear adsorption isotherm, or a section along its curve in a nonlinear adsorption isotherm. The results of the BEATs which shows the pattern of chemical sorption by soil-*B. megaterium* suspension blends are presented as adsorption isotherms for each selected/considered cations and anions. An adsorption isotherm shows the amount of chemical sorbed as a function of its equilibrium solution concentration. Depending on the affinity of the various composition of the leachate on the biotreated soil surface and the entire surface interaction properties, a number of varying adsorption isotherm shape is possible (Strawn et al., 2020). The adsorption isotherm may vary in shape and could be either linear or non-linear. The non-linear which is sigmoidal S- or L –shape, or sometimes convex or concave shape (Strawn et al., 2020). Positive isotherms defines the occurrence of adsorption, while negative isotherm proposes the incidence or occurrence of desorption of the ions under considerations (Shackelford and Daniel, 1991b; Shackelford, 1994; Boateng et al., 2019). The adsorption isotherm considered in this study for cations (Sodium (Na^+), Potassium (K^+), Calcium (Ca^{2+})) and anions (Chloride (Cl^-) and Sulphate (SO_4^{2-}).

Adsorption of sodium

The plot of equilibrium concentration against the sorbed concentration for sodium ion (Na^+) is shown in Figure 14. The adsorption isotherm is non-linear (concave shape) which is a common trend in cations as recommended/suggested by (Shackelford and Daniel 1991b; Hong and Shackelford, 2017 and Strawn et al., 2020). The values of adsorbed Na^+ ion concentration varies in the ranges from 23.9 -27.6; 16.9 – 19.8; 12.72 – 15.02; 8.4 – 11.36 and 6 – 9.3 mg/l for leachates 1, 2, 3, 4 and 5, respectively, when lateritic soil was bio-treated with *B. megaterium* suspension densities up to 2.4×10^9 cells/ml. Generally, adsorption of sodium ion increases with increase bacteria suspension densities. The level of Na+ adsorbed can be considered or regarded inconsequential because the recorded values were below the maximum allowable regulatory limits values of 200mg/g and 250 mg/g certified by World Health Organization (WHO) and

Nigerian Standard for Drinking Water Quality (NSDWQ) (McGinley and Kmet, 1984; Lee and Jones, 1991a, b; Amadi, 2008; Eberemu, 2008; Ijimdiya, 2010; Ijimdiya and Osinubi, 2011; Moses, 2012; Oluremi, 2015; Osim, 2017). Therefore the quantity of sodium ion assessed/found may not amount to any environmental threat to ground water on exposure when used in a liner system. Also, the presence of sodium in the soil-bacterial interaction could encourage an increased diffuse double layer in the soil and thereby give rise to dispersion of the soil fabric (e.g., McGregor, 1999; Lee and Jones, 1991a, b; WHO, 2006; Osinubi et al., 2014; Scalia et al., 2018). The recorded retardation factors (Rd); 45.61, 42.21, 49.65, 53.46, 50.72 and 54.16, of sodium ion increased with increased bio-treatment (population of microbes) of lateritic soil, when biotreated with (0, 1.5, 6, 12, 18 and 24) $x10^8$ cells/ml suspension densities, respectively. The general increase of retardation factor suggest the reduction or decrease rate or percentage of sodium ion adsorbed. This occurrence might be associated with the decrease in pH of the mixture thereby result in weakening of the ion concentration as well as reduction in the binding electrostatic attraction between oppositely charged adsorbate.

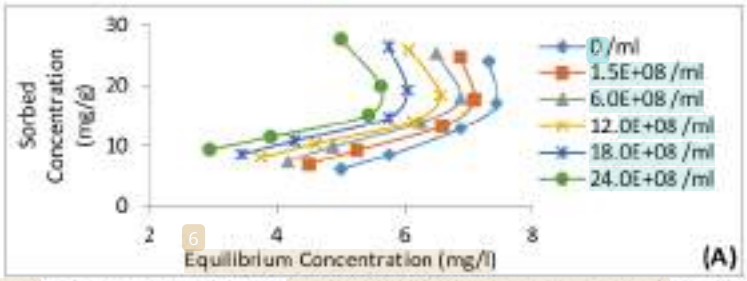


Figure 14: Variation of sorbed concentration with equilibrium concentration for sodium ion

Adsorption of potassium

The variation of equilibrium concentration with sorbed concentration for potassium ion (K^+) is shown in Figure 15. The adsorption isotherm is non-linear (sigmoidal S-shape) which is a common trend in cations as recommended/suggested by (Shackelford and Daniel 1991a,b; Hong and Shackelford, 2017 and Strawn et al., 2020). On one hand, the sorbed concentrations increase with equilibrium concentration of the leachate regardless of the bacteria cell densities while on the another hand, it marginally decrease with increase bacteria suspension densities. The values of adsorbed Na^+ ion concentration varies in the ranges from 2.88 – 3.53; 2.7 – 3.27; 1.3 – 1.84; 0.82 – 1.45 and 0.78 – 1.42 mg/l for leachates 1, 2, 3, 4 and 5, respectively, when lateritic bio-treated with *B. megaterium* suspension densities of up to 2.4×10^9 cells/ml. Also, the retardation factors (R_d) values of; 7.87, 8.21, 8.07, 8.08, 8.53 and 8.20 were recorded for specimen biotreated with; 0, 1.5, 6, 12, 18 and 24 [$\times 10^8$] cells/ml suspension densities, respectively. This indicates an increase in the amount of Na^+ absorbed out of the solution as the bacteria population increased. The results is consistent with that of Yohanna (2021). The equilibrium isotherm for K^+ had a strong Freundlich model shape as described by Hong et al., (2016).

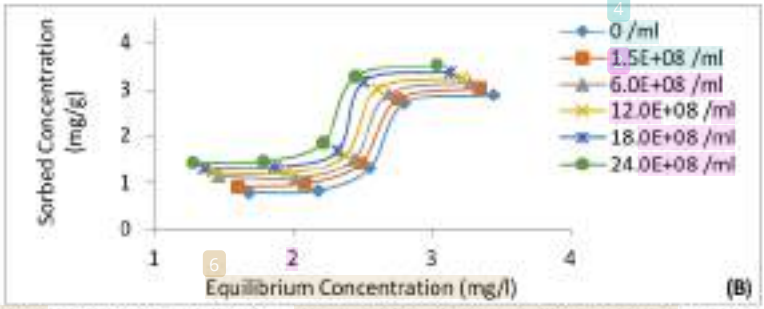


Figure 15: Variation of sorbed concentration with equilibrium concentration for potassium ion

Adsorption of Calcium

The adsorption isotherm for (Ca^{2+}) shown in Figure 16 revealed non-linear L-shape for all (0, 1.5, 6, 12, 18 and 24 [$\times 10^8$]) cells/ml suspension densities treated soil. The adsorbed Ca^{2+} ion ranged from 0.035 mg/g to 1.32 to 1.56 mg/g for leachate sample 1, 1.22 to 1.44 mg/g for leachate sample 2, 1.11 to 1.26 for leachate sample 3, 0.63 to 0.73 for leachate sample 4 and 0.31 to 0.33 mg/g for leachate sample 5 for lateritic soil bio-treated with up 2.4×10^9 cells/ml. Retardation factors values recorded are 7.97, 8.61, 9.71, 11.03, 11.42 and 11.09 for lateritic soil when treated with *B. megaterium* suspension density of (0, 1.5, 6, 12, 18 and 24) $\times 10^9$ cells/ml, respectively. This confirms total adsorption of Ca^{2+} from filtrate solution. The Ca^{2+} absorption is due to the role of *B.megaterium* in biogeochemical MICP interaction leading to precipitation of calcium ions by enzymatic metabolic action of urease. This results is consistent with the report of Gadzama (2021).

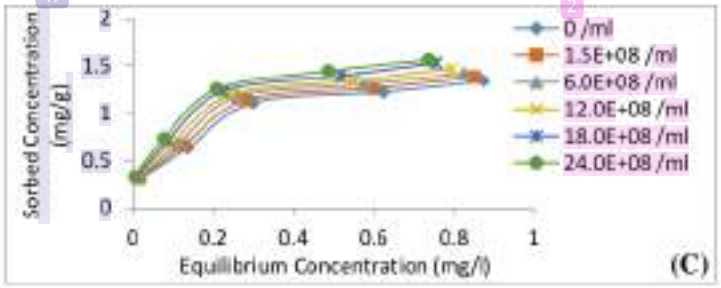


Figure 16: Variation of sorbed concentration with equilibrium concentration for calcium ion

Adsorption of sulphate

The adsorption isotherm of sulphate ions shown in Figure 17, exhibit non-linear shape which is a common trend in cations as proposed by (Shackelford and Daniel 1991b; Hong and Shackelford, 2017 and Strawn et al., 2020). The values of adsorbed suphate ion concentration varies in the ranges from 0.214 to 0.246 mg/l for leachate 1, 0.136 to 0.193 mg/l for leachate 2, 0.109 to 0.145 mg/l for leachate 3, -0.107 to -0.005 mg/l for leachate 4 and -0.146 to -0.087 mg/l for leachate 5 when lateritic bio-treated with up to 2.4×10^9 cells/ml (*B. megaterium* suspension densities). Also, the retardation factors (Ra) values of: 11.47, 11.36, 10.12, 10.57, 10.55 and 10.48 were recorded for specimen biotreated with; 0, 1.5, 6, 12, 18 and 24 [$\times 10^8$] cells/ml suspension densities, respectively. The retardation factor which decrease with increase bacteria suspension density signifies reduction in the rate of flow of sulphate ions and of course depend on the pH of the medium (Sani 2019; Strawn et al., 2020; Yohanna 2021).

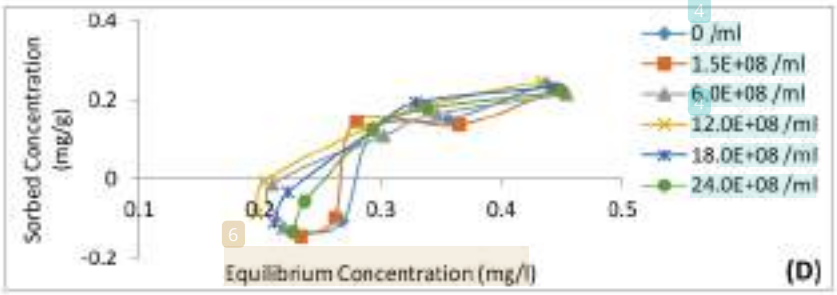


Figure 17: Variation of sorbed concentration with equilibrium concentration for sulphate ion

Adsorption of Chorine

The adsorption isotherm of chlorine ions shown in Figure 18 exhibit non-linear shape which is a common trend in cations as proposed by (Shackelford and Daniel 1991b; Hong and Shackelford, 2017 and Strawn et al., 2020). The adsorbed chlorine decreased with increased equilibrium concentration, which signifies a

negative distribution coefficient and low affinity adsorption site of chlorine ions to form stronger complex ions. The values of adsorbed chlorine ion varies in the ranges from 5.051 to 5.142 mg/l for leachate 1, 3.536 to 3.775 mg/l for leachate 2, 1.109 to 1.346 mg/l for leachate 3, 1.158 to 1.361 mg/l for leachate 4 and -0.604 to -0.322 mg/l for leachate 5 when lateritic bio-treated with up to 2.4×10^9 cells/ml (*B. megaterium* suspension densities). Also, the retardation factors (R_d) values ranged from -41.58 to -36.68 when specimen were treated with up to 24×10^8 cells/ml suspension densities (Sani 2019; Strawn et al., 2020; Yohanna 2021). Amongst all ions measured in the bio-treated sample mixture. It was observed that only Cl^- recorded retardation factor of less than 1.0. The Rd values greater than 1.0 implies that the ionic retardation or attaenuation had occurred in the specimen. These results are consistent with those reported in literature (e.g., Muhammed, 2004; Frempong and Yanful, 2008; Ijimdiya and Osinubi, 2011; Bello and Osinubi, 2010, 2011).

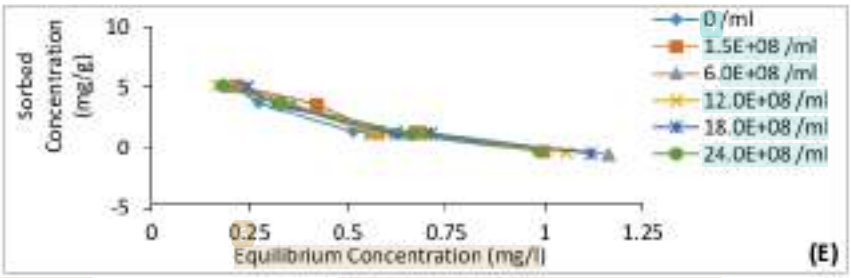


Figure 18: Variation of sorbed concentration with equilibrium concentration for chlorine ion

Retardation factor

The variation of retardation factor of lateritic soil with *B. megaterium* suspension density is shown in Figure 19. Adsorption interactions (positive retardation factor) was predominant for most candidate ions. The recorded results indicate that adsorption occurred for the three cations and one of anions while desorption took place on only chlorine ion. The retardation factor (R_d) which is a function of portioning/distribution coefficient (K_d), increased with corresponding increase bacteria suspension density for all (K^+, Na^+, Ca^{2+}, Mg^{2+}, Cl^-) individual ions except for sulphate ions which decreased with increased bacteria suspension density. For example the R_d obtained for the natural lateritic soil (i.e., 0 cell/ml) and biotreated soil (e.g. soil treated with *B. megaterium* suspension density of 2.4×10^{-9} cells/ml) were 45.61, 7.87, 7.97, 11.47, -30.71 and 54.16, 8.20, 11.09, 10.48, -39.6 respectively, for K^+, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, respectively. While desorption occurred for only chorine ions in both cases (i.e., natural and biotreated specimen), specimen bio treated with highest/maximum *B. megaterium* suspension density recorded a comparative higher retardation factors for all the studied ions except sulphate ions. The higher retardation factor might be associated with release of urease enzyme for urea hydrolysis. The enzyme released then alters the specific surface area of treated soil fabric, reduced the marginal micropores in the matrix and resulted in the increased adsorption of the ions. Microbioactivities of the microbes (e.g., bioclogging) might also be accountable for the recorded trend (Ives and Pienvichitr, 1965; Clement et al., 1996; Francisca and Glatstein, 2010; Dejong et al., 2010, 2013; Osinubi et al., 2019a). Also, the decrease retardation factor of SO_4^{2-} ions might be due to; 1) SO_4^{2-} easily displaced Cl^- anions adsorbed on a positively charged iron oxide mineral surface of the soil and 2) soluble sulphate react/interact swiftly with positive charged sites of mineral particle and other free or exchangeable cations in the soil 3) co-ion interaction and ionic transfer, surface precipitation and or formation of complexes (Strawn et al., 2020).

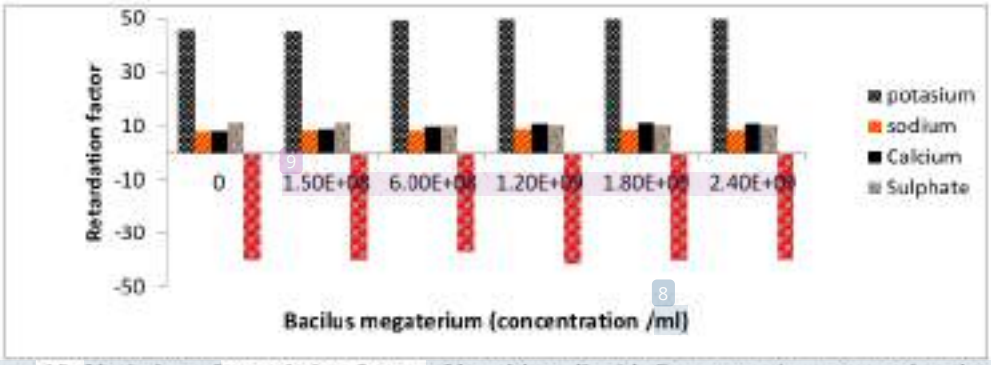


Figure 19: Variation of retardation factor of lateritic soil with *B. megaterium* suspension density

Basically, retardation factor value more than 1.0 is a sign that reactive (adsorbing) solutes are transported at a very slow rate relative to non-reactive solutes (non-adsorbing) (Bello and Osinubi, 2011; Osim, 2017; Sani 2019).Therefore, the process of ionic retardation or attenuation of K^+, Na^+, Ca^{2+} and SO_4^{2-} ions must have taken place within the lateritic soil – *B. megaterium* mixtures with retardation factor greater than 1 as reported by Bello and Osinubi (2011) as well as Moses and Osinubi (2015). The least retardation factor value obtained for stepped *B. megaterium* suspension densities for Cl- showed that there was a minimum resistance to desorbed flow.

Diffusion analysis of bio-treated lateritic soil

The possible pollution or contamination of ground water as well as the evaluation of the fate of transported effluent contaminant from a MSW containment structure is occasionally associated with advective-disoersive transport taken place along tortuous interconnected fractured micro and macro pores within the material matrix or composite (Sudicky and Frind, 1982; Rowe and Booker, 1989; Fityus *et al.*, 1999; Neretnieks, 2002; Sivakumar, 2011; Barone *et al.*, 1990; Shackelford, 1991; Liu *et al.*, 2002; Sivakumar, 2011). Diffusive contaminant transport is also possible through fractures or micropores of adjoining interconnected permeable matrix (Barone et al., 1990; Shackelford, 1991; Liu et al., 2002; Sivakumar, 2011; Eberemu, et al., 2013; Scalia et al., 2018; Boateng et al.,2019).

High concentration candidate metallic cations (K^+, Na^+, Ca^{2+}) and non-metallic anions (SO_4^{2-} and Cl) (cations and anions) in the leachates were considered in estimating the adsorption capacity of bio-treated lateritic soil (lateritic soil - *B. megaterium* mixtures) column. Their effect in hydraulic barrier system was examine in natural aqueous systems and polluted groundwater, as well as landfill leachate diffusing through soil matrix was evaluated. In estimating the adsorption capacity of metallic and non-metallic ions (cations and anions) for bio-treated lateritic soil (lateritic soil - *B. megaterium* mixtures); Potassium, Sodium, Calcium, Sulphate and Chloride (K^+ , Na^+ , Ca^{2+}, SO_4^{2-} and Cl^-) respectively were chosen to examine their effects in natural aqueous systems and polluted groundwater, as well as landfill leachate diffusing through soil matrix. *B. megaterium* treated soil specimens compacted into PVCs column sequentially saturated with tap water for 21 days and afterward substituted/replaced with MSW leachate for another 90 day to limit/mitigate contaminants solutes mass transport which could have occurred in the unsaturated state. Free downward gravity diffusion was utilized through the 90 days duration of diffusion.

Effect of pore water content

The pore water solution content distribution after diffusion test generally decreased with column depth of soil slices as shown in Figure 20. The decrease could perhaps be associated with decreased degree of saturation of the bio-treated soil depth (Yohanna 2021). The percentage pore solution recorded at the top slice (i.e., slice 1) is comparatively greater than those recorded for the succeeding slices due to its straight interaction with the inlet surface leachate. Also, the increase *B. megaterium* suspension density up to 2.4 ×

10^9/ ml. had no marginal difference or order with depth of soil slices. Apart from the top slice, the lowest or bottom slice in the column recorded marginally increased pore water content relative to the other slice depth apart from the top slice. The recorded increase could be due to the fact that the bottom slice functioned as a collector reservoir that enclosed all diffused leachate from the slices above it. Similar observation was reported by Oluremi (2015) and Yohanna (2021).

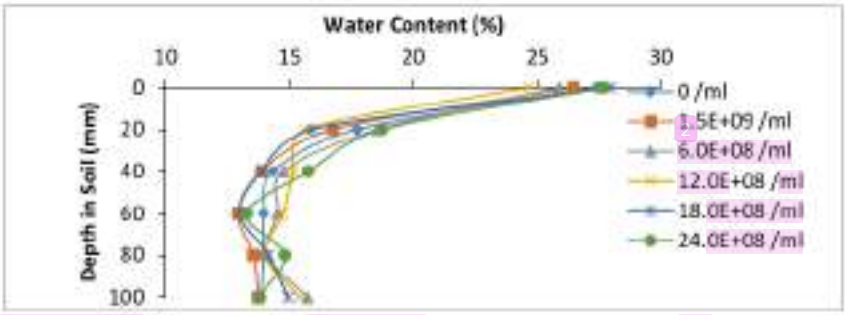


Figure 20: Variation of pore water content with depth after diffusion testing for all soils used

Effect of pH of pore solution

The pH of the untreated soil (0 cell/ml) slightly decreased with depth of soil column while the specimen bio-treated with up to 24 × 10^8 cells/ml initially increased from 0 to 20 mm depth and later increased significantly to 100 mm (Figure 21). The untreated kaolinite soil is and acidic soil. The opening increase in pH recorded from depth 0 -20 mm might due to urea hydrolysis brought about by the interactive metabolic activity initiated by the bacteria urease enzyme. In a more general scope, it was largely observed that the effect of bio-treatment using *B. megaterium* translate to a reduction in pH with depth from 20 – 100 mm. The decrease in pH values with depth was probably due to the replacement of protons (H+) on the faces of the clay minerals with the metallic cations in the MSW leachate (Yohanna 2021).

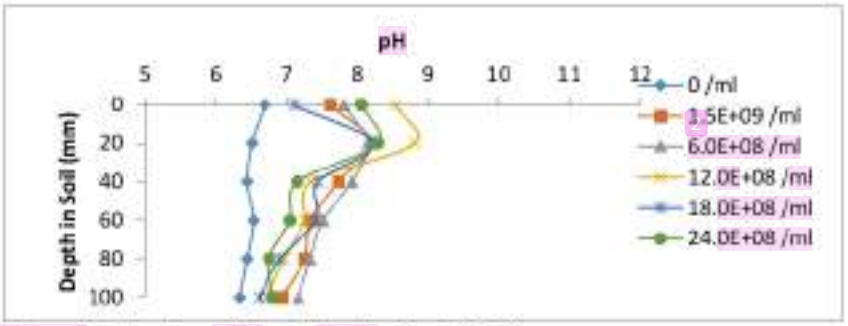


Figure 21: Variation of pH values with soil depth after diffusion

Effect of pore solution on electrical conductivity

The variation of electrical conductivity (EC) with depth/slices (0 - 100 mm) of soil pore solution recorded after diffusion for the various bio-treated soil depth is shown in Figure 22. Regardless of the treatement concentration, the EC generally decreased non-linearly with increasing depth of the various slices in contrast to the naturally untreated soil (0 cell/ml). The EC of natural soil (0 cell/ml) initially increased from 0 to 40 mm depth corresponding to increase EC from 0.1 to 0.19 and later decreased marginally to 0.1 at 100 mm depth. The EC of pore solution of bio-treated lateritic soil (i.e., lateritic soil – *B.megaterium* suspension density mixture) recorded after diffusion which generally decreased non-linearly with depth of slices as earlier stated ranged from; 0.44 to 0.64, 0.54 to 0.62, 0.37 to 0.63, 0.37 to 0.55, and 0.41 to 0.62 within depth 0-100mm for 1.5, 6, 12, 18 and 24 (×10^8 cells/ml suspension densities), respectively. The

changes in EC is associated with the interaction between ion concentration of leachate and the ion exchange at the surface structure of the soil mineral (Eberemu et al., 2013; Boateng et al., 2019), which probably influenced the degree of salinity of the resultant pore solution at various depth after an extended diffusion of leachate (Ghosh et al., 2013; Yohanna 2021).

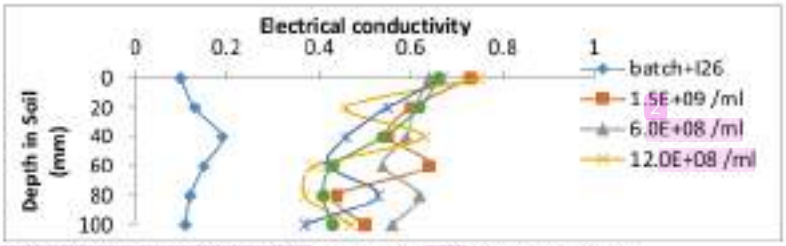
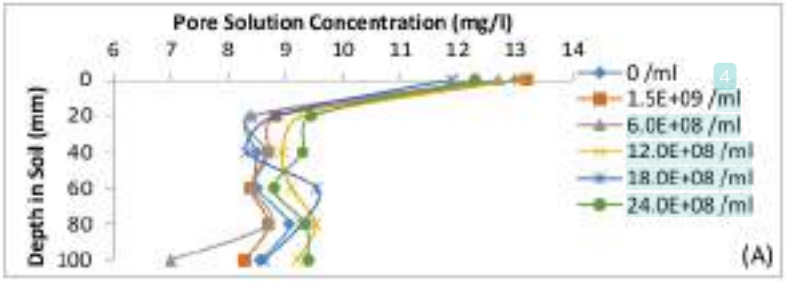
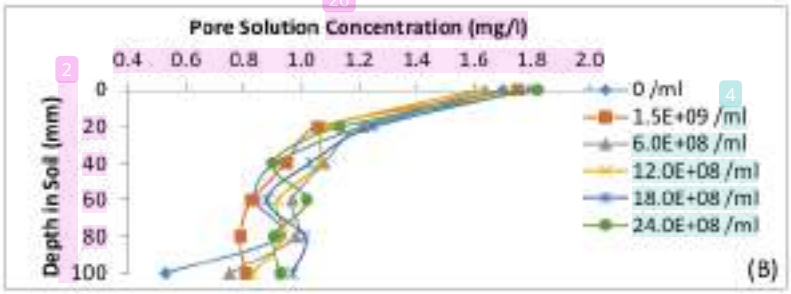


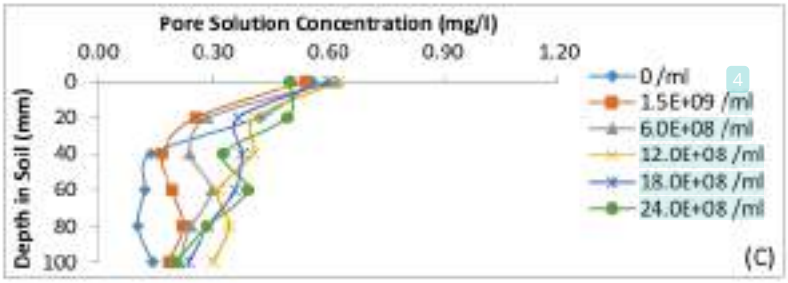
Figure 22: Variation of electrical conductivity values in soil after diffusion

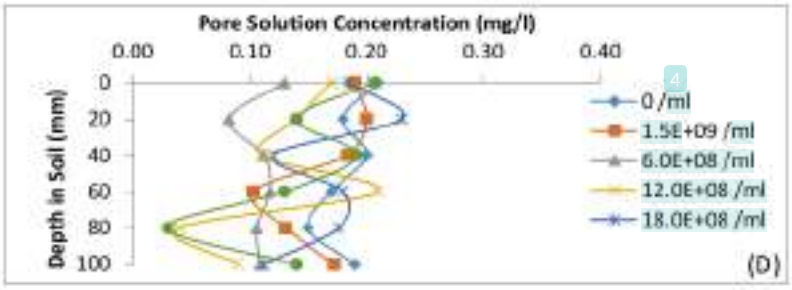
Effect of pore solution concentrations

The variation of pore solution concentration of lateritic soil – *B. megaterium* mixtures with soil column depth for Na^+, K^+, Ca^{2+}, SO_4^{2-} and Cl^- are shown in Figure 23. The plots of apparent diffusion coefficient (D*) and tortuosity factor (τa) are shown in Figures 24 and 25, respectively.









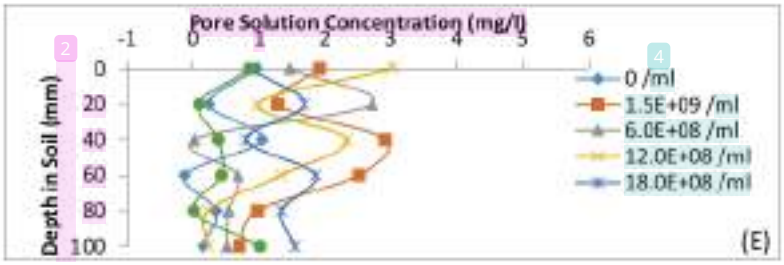


Figure 23: Variation of pore solution concentration of lateritic soil – *B. megaterium* mixture with soil column depth for different ions: (A) Sodium (Na^+) (B) Potassium K^+) (C) Calcium (Ca^{2+}) (D) Sulphate (SO_4^{2-}) (E) Chlorine (Cl^-)

The apparent diffusion coefficient (D*) for Na+ increased from 5.22×10^{-9} m^2/s at 0 cell/ml to peak value of 6.63×10^{-9} m^2/s at 1.2×10^{-9} cells/ml suspension density(see Figure 5.88). The corresponding tortuosity factor (τa) follows the same trend and increased from 3.93 at 0 cell/ml to peak value of 4.98 m^2/s at 1.2×10^{-9} cells/ml suspension density (see Figure 23a).

In the case of potassium, the apparent diffusion coefficient (D*) show an initial marginal increase from 1.10×10^{-9} m^2/s at 0 cell/ml to 1.14×10^{-9} m^2/s at 1.5×10^{8} cells/ml suspension density and then thereafter decreased linearly to its least value of 1.02×10^{-9} at 2.4×10^{9} cells/ml suspension density (see Figure 5.88). Similarly the tortuosity factor (τa) for sodium followed the same pattern and was in the same range of marginal increase from 0.56 – 0.58 for up to 1.5×10^{8} cells/ml suspension density and marginal linear decrease from 0.58 to 0.52 for up to 2.4×10^{9} cells/ml suspension density(see Figure 23b).

The apparent diffusion coefficient (D*) for calicium increased linearly in the range 1.10×10^{-9} to 1.53×10^{-9} m^2/s with increase in *B. megaterium* suspension density up to 2.4×10^{9} cells/ml (see Figure 5.88). in like manner, the the tortuosity factor (τa) increased with values of 1.38, 1.50, 1.68, 1.85, 1.93 and 1.88 recorded for *B. megaterium* suspension density of 0, 1.5, 6, 12, 18 and 24 ($\times10^{8}$ cells/ml), respectively (see Figure 23c).

The apparent diffusion coefficient (D*) for sulphate show an initial decrease from 1.53×10^{-9} m^2/s at 0 cell/ml to 1.38×10^{-9} m^2/s at 6×10^{8} cells/ml and thereafter varies slightly with values of 1.44×10^{-9}, 1.43×10^{-9} m^2/s and 1.42×10^{-9} m^2/s recorded at 12×10^{9}, 18×10^{9} and 24×10^{8} cells/ml suspension density, respectively (see Figure 5.88). Similarly, the tortuosity factor (τa) for sulphate varies slightly with treatment concentration and values recorded were 1.45, 1.44, 1.30, 1.36, 1.35 and 1.34 for *B. megaterium* suspension density of 0, 1.5, 6, 12, 18 and 24 ($\times10^{8}$ cells/ml), respectively (see Figure 23d).

In the case of chlorine, recorded apparent diffusion coefficient (D*) of -3.54×10^{-9} m^2/s was constant from 0 cell/ml to 1.5×10^{8} cells/ml suspension density of *B. megaterium* and thereafter increased slightly to a marginal values of -2.51×10^{-9} m^2/s and -2.59×10^{-9} m^2/s at 18×10^{8} cells/ml and 24×10^{8} cells/ml, respectively (see Figure 5.88). Similarly, the corresponding tortuosity factor (τa) followed the same pattern and -1.75, -1.74, -1.56, -1.29, -1.23 and -1.28 tortuosity values were recorded at *B. megaterium* suspension densities of 0, 1.5, 6, 12, 18 and 24 ($\times10^{8}$ cells/ml), respectively (see Figure 23f).

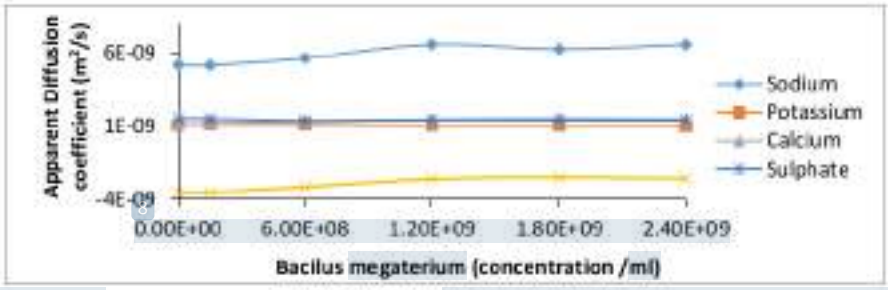


Figure 24: Variation of apparent diffusion coefficient of lateritic soil with *B. megaterium* suspension density

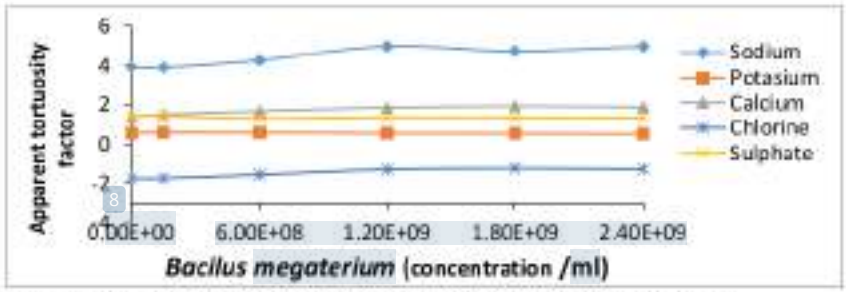


Figure 25: Variation of tortuosity factor with *B. megaterium* (concentration /ml)

Bacterial Foraging Optimization

Optimizations approach involves the selection of a best possible option or choice from a number of available options using a robust mathematical computer programs and approach. The best choice option also known as optimal value is usually a value relative to extreme minimum and maximum in an array of outcomes. A wide range of many engineering specializations has successfully used Bacterial foraging optimization (BFO) technique (Passino, 2002; Badamchizadeh *et al*., 2010; Dharminder and Vinay, 2012; Gautam and Soumya, 2013; Nitin and Dipak, 2014; Yohanna 2021, Gadzama 2021).

Bacterial foraging optimization (BFO) techniques is use in this study to determine the minimum hydraulic conductivity based on outcome of a combination self-determining laboratory measured variables (x_1 =*B. megaterium suspension density* (B.meg), x_2=d_1= void ratio (e), x_3= dry density (ρ_d), x_4= water content relative to optimum (WCRO), x_5= compactive effort (CE), x_6= pH, x_7= degree of saturation (Sr), x_8= plasticity index (PI), x_9= liquid limit (LL) and x_{10}= viscosity (Vs)) that produced the minimum lab hydraulic conductivity value. The fitness (objective) function for optimizing hydraulic conductivity given in Eq. 7 was developed using GeneXproTools 5.0. The various output for the model developed and its corresponding validation results are contained in Table 2.

$$y = \tan^{-1}\left[\left(\frac{(x_{10}+10.83)}{x_9\cos x_1}+{x_4}^4\right)^6\right] + \tan(-196.06) - \frac{x_5}{\log x_{10}} + x_3x_6 + \tan^{-1}\left[\frac{(e^{x_4})^2}{x_8} - (e^{x_2}+2x_4)\right] + \tan\left[\cos\left(\frac{2x_4-x_7}{-0.61x_8\cos -6.06}\right)\right] \quad (7)$$

Table 2: Variables measured for Fitness function generated by GeneXproTools 5.0 for training (model) and validation data

S/No	Variable	Training (model)	Validation output
1	Fitness	585.303	442.903
2	MSE	0.502	1.582
3	RMSE	0.709	1.258
4	MAE	0.543	1.030
5	RSE	0.064	0.247
6	RRSE	0.254	0.497
7	RAE	0.223	0.488
8	Correlation Coefficient	0.968	0.875
9	R-square	0.936	0.800
10	Number of gens	4	4

The relationship between predicted hydraulic conductivity (Target) against the measured laboratory values from the laboratory use for the model (model) is shown in Figure 26 and 27. The result shows a strong association between the predicted values and the measured values in the laboratory using a regressed line with coefficient of determination R=0.936. This indicate that the self determinning variables use to develop the model has strong effect on the hydraulic conductivity of lateritic soil-*B. megaterium* mixtures and should be carefully studied and considered during the design and construction phase of a waste containment system.

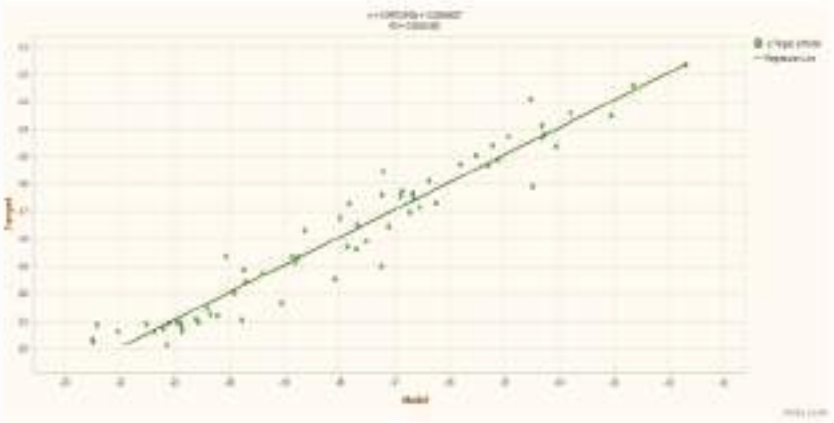


Figure 26: Scatter plot obtained from GenXprool Model

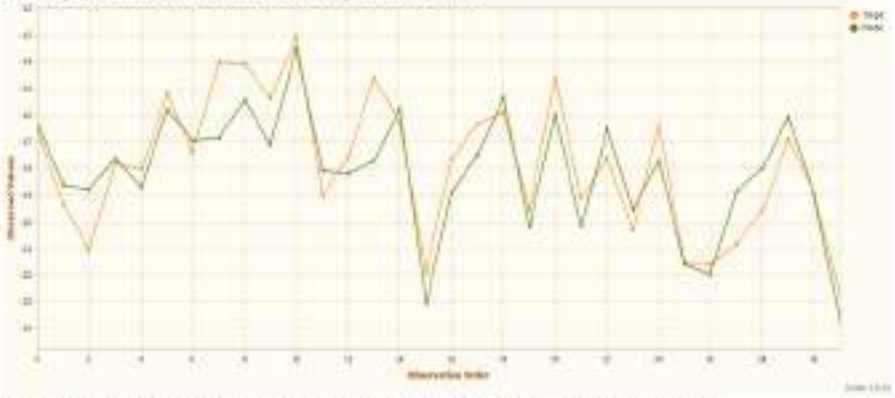
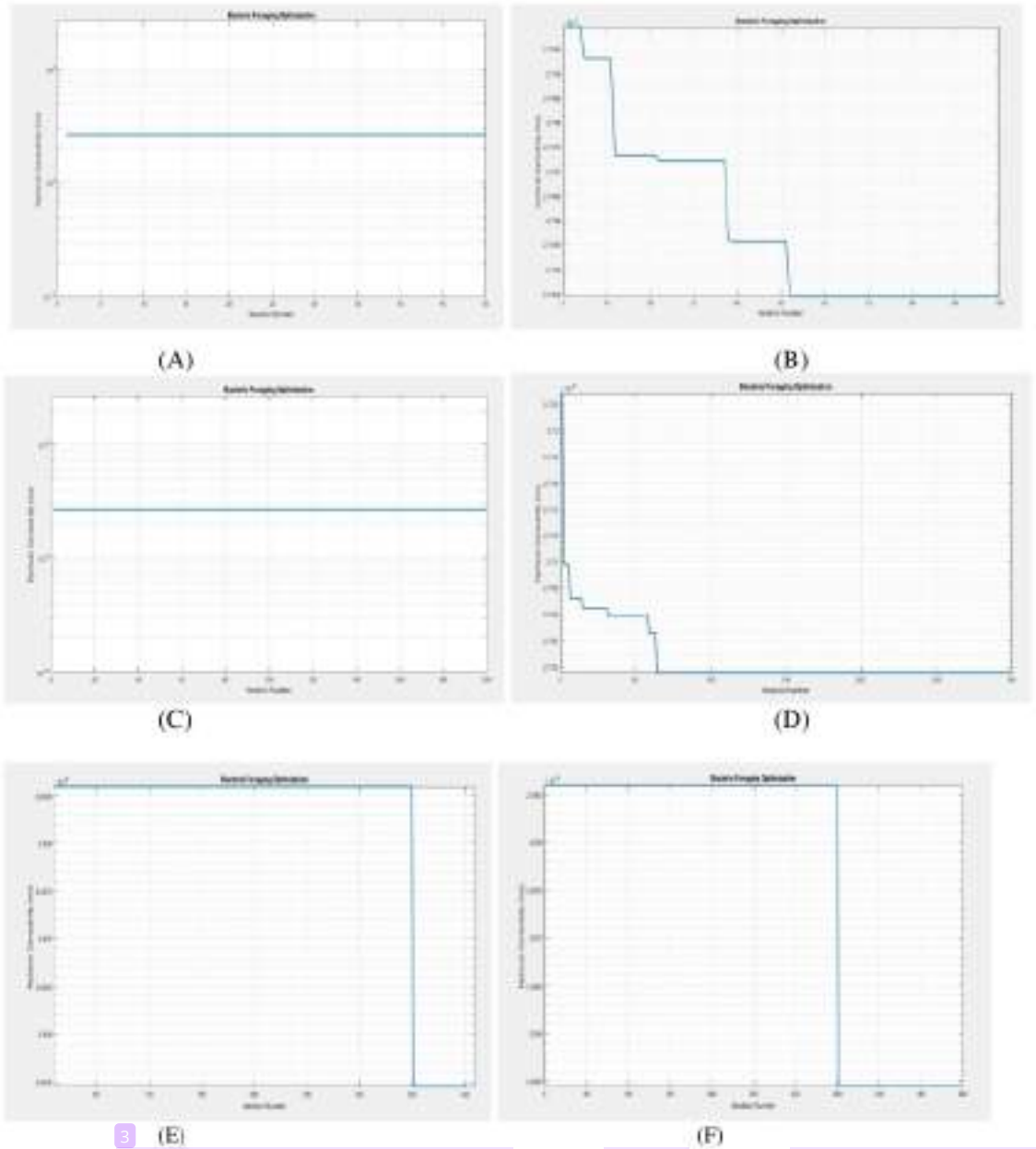


Figure 27: Plot of observed value against observation from GenXprool Model

The plots of hydraulic conductivity against iteration number using bacterial foraging optimization (BFO) algorithm, Particle swarm optimization (PSO) algorithm smell agent optimization (SAO) algorithm are shown in Figures 28, 29 and 30, respectively. The detail rundowns and summaries of the optimization results using the algorithm under selected varied iterations number of 10 -500, 10 - 700 and 10 -2000 for BFO, PSO and SAO algorithm, are presented in Table 3, 4 and 5, respectively.

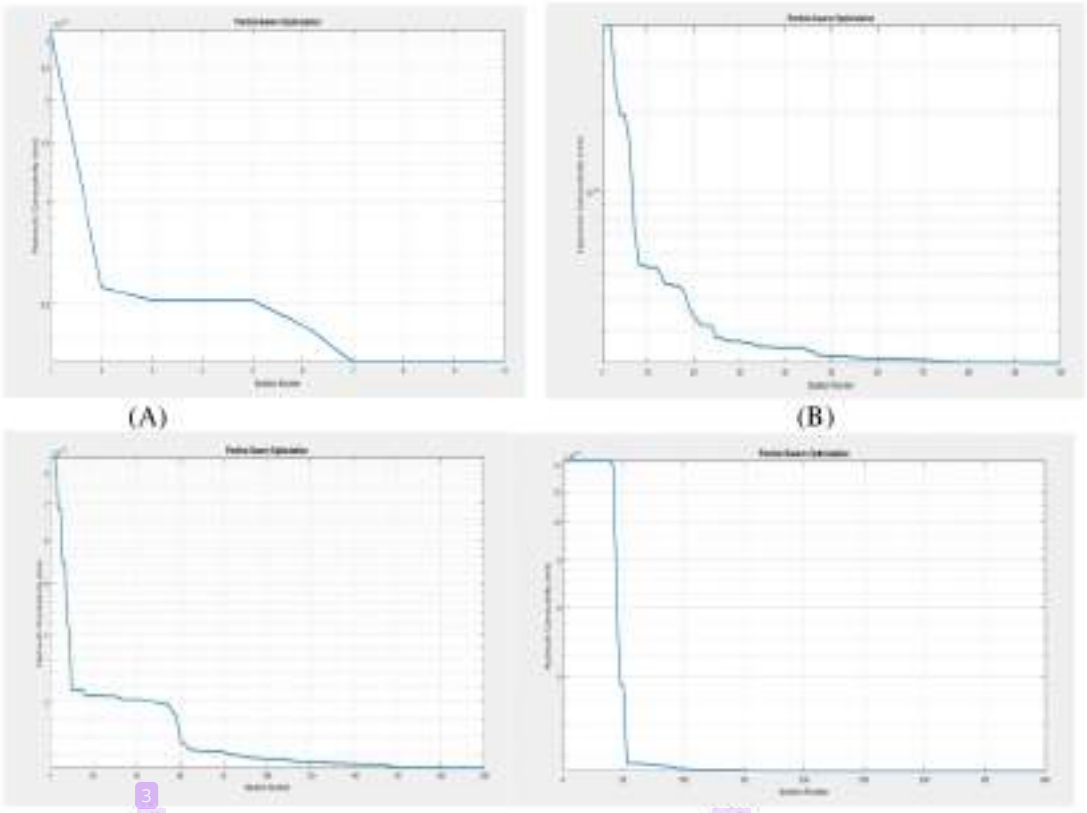


(A) (B)

(C) (D)

(E) (F)

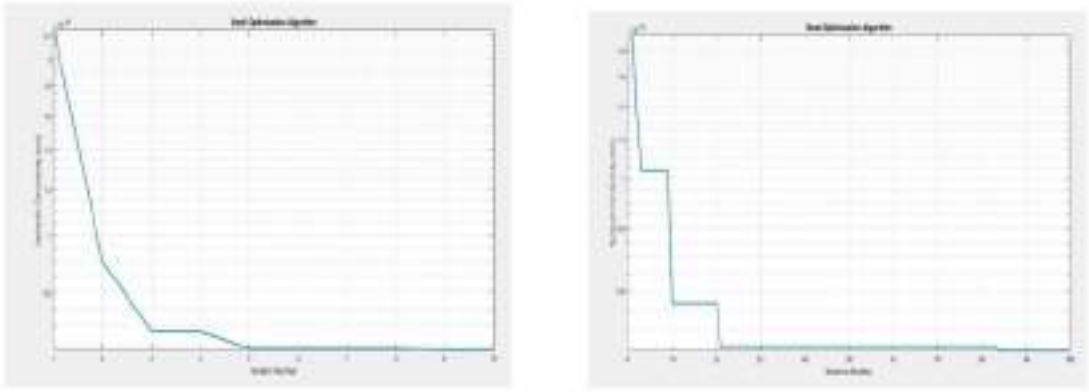
Figure 28: Plots of hydraulic conductivity against varying iteration numbers using Bacterial foraging optimization algorithm for (A) 10 (B) 100 (C) 200 (D) 300 (E) 400 and (F) 500 iterations.



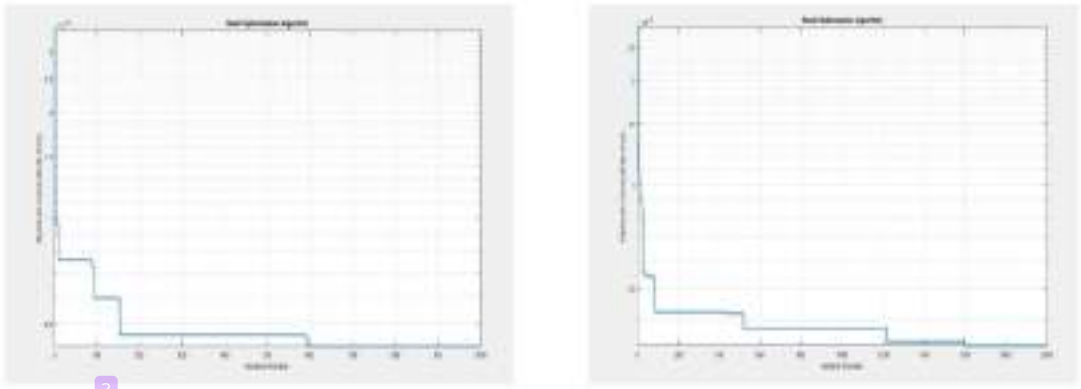
(A) (B)

(C) (D)

Figure 28: Plots of hydraulic conductivity against varying iteration numbers using Particle Swarm Optimization algorithm for (A) 10 (B) 100 (C) 200 and (D) 400 iterations.



(A) (B)



(C) (D)

Figure 28: Plots of hydraulic conductivity against varying iteration numbers using smell agent optimization algorithm for (A) 10 (B) 100 (C) 1000 and (D) 2000 iterations.

Based on all the optimization results, it is recommended that lateritic soil be prepared at 11.8 - 13.8% moisture content when treated with B. megaterium suspension density in the range $1.5x10^8$ - 24 x 10^8 cells/ml and compacted using British standard heavy (BSH) energy. The results fall within the range of optimal values from overall acceptable zone (OAZ) generated from laboratory result. Therefore, the compactive effort, moisture content and B. megaterium suspension density should be considered primarily during design and construction of the compacted clay liner in the field or in any related geotechnical engineering applications.

Table 3: Bacteria Foraging Optimization results

No of Iterations	H (m/s)	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
10	2.70E-09	8.000	0.728	1.900	3.999	1.000	8.100	99.900	25.630	44.500	19.682
50	2.66E-09	7.999	0.728	1.900	4.000	1.000	8.100	99.858	25.627	44.500	18.543
100	2.70E-09	8.000	0.728	1.900	3.996	1.000	8.100	89.472	25.375	44.500	18.218
200	2.70E-09	8.000	0.728	1.900	3.999	1.000	8.100	99.900	25.630	44.500	19.682
300	2.70E-09	7.999	0.728	1.900	4.000	1.000	8.100	89.199	24.921	44.500	18.061
400	2.70E-09	8.000	0.728	1.900	3.999	1.000	8.100	88.999	25.272	44.499	17.896
500	2.70E-09	8.000	0.728	1.900	3.999	1.000	8.100	88.999	25.272	44.499	17.896

Table 4: Particle Swarm Optimization results

No of Iterations	H (m/s)	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
10	2.39E-11	2.770	0.491	1.900	1.107	1.000	8.100	87.795	21.971	42.381	23.038
50	2.39E-11	4.301	0.591	1.900	1.089	1.000	8.100	83.489	23.426	42.668	10.000
100	2.31E-11	4.550	0.705	1.900	1.332	1.000	8.100	95.169	22.733	41.621	10.000

200	2.27E-11	4.679	0.728	1.900	1.936	1.000	8.100	99.900	16.332	44.343	10.000
300	2.27E-11	1.605	0.728	1.900	1.939	1.000	8.100	99.900	24.189	42.822	10.000
400	2.27E-11	1.604	0.728	1.900	1.939	1.000	8.100	99.900	21.295	44.060	10.000
500	2.27E-11	4.678	0.728	1.900	1.939	1.000	8.100	99.900	24.347	42.981	10.000
600	2.27E-11	4.677	0.728	1.900	1.939	1.000	8.100	99.900	17.427	41.495	10.000
700	2.27E-11	4.679	0.728	1.900	1.939	1.000	8.100	99.900	23.808	43.644	10.000

Table 5: Smell Agent Optimization Algorithm results

No of Iterations	H (m/s)	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
10	6.38E-11	5.914	0.722	1.895	0.309	0.962	7.718	96.039	21.978	43.304	11.879
50	4.84E-11	2.880	0.549	1.866	0.966	0.760	8.077	93.896	20.681	43.088	16.772
100	4.56E-11	3.473	0.544	1.887	1.035	0.700	8.025	**93.232**	18.180	41.424	12.904
200	3.55E-11	5.816	0.544	1.885	0.602	0.920	8.083	81.115	18.664	44.340	10.338
300	4.12E-11	3.451	0.610	1.878	0.430	0.959	7.974	97.347	19.087	43.062	10.050
400	3.46E-11	3.422	0.710	1.886	0.705	0.975	8.085	95.829	22.022	42.084	17.127
500	4.45E-11	7.068	0.481	1.899	0.368	0.667	8.089	81.786	23.760	42.278	10.058
600	3.15E-11	3.280	0.724	1.893	0.525	0.874	8.081	95.456	24.219	42.058	10.431
700	3.75E-11	6.916	0.719	1.894	0.032	0.870	8.065	94.067	23.589	42.063	10.002
800	3.73E-11	2.796	0.467	1.885	1.008	0.888	8.058	92.360	23.042	43.525	13.804
900	2.98E-11	3.758	0.659	1.898	0.738	0.847	8.084	93.041	18.620	43.173	10.010
1000	4.31E-11	4.039	0.501	1.899	1.185	0.791	8.050	97.143	18.953	43.521	26.493
1100	3.93E-11	3.144	0.597	1.891	0.463	0.924	8.017	97.753	18.549	43.943	13.435
1200	3.42E-11	3.886	0.487	1.891	0.993	0.913	8.088	91.862	23.257	43.504	16.208
1500	2.85E-11	3.145	0.720	1.898	0.944	0.878	8.086	80.851	17.370	42.692	10.327
2000	3.40E-11	3.412	0.556	1.888	0.631	0.920	8.094	92.861	22.181	41.493	13.325

Where y = Least Hydraulic conductivity (m/s), x_1 = *B. megaterium* suspension density (B.meg), x_2 void ratio (e), x_3 = dry density (ρ_d), x_4 = water content relative to optimum (WCRO), x_5 = compactive effort (CE), x_6 = pH, x_7 = degree of saturation (Sr), x_8 = plasticity index (PI), x_9 = liquid limit (LL) and x_{10} = viscosity (Vs)

Conclusion

1. The long-term hydraulic conductivity (k) of compacted bio-treated specimens decreased with time for most part of the test for all cases of permeation in the order; water only > for serial permeation with water and leachate > leachate permeation only. The compatibility increased with leachate interaction.
2. MICP-treated specimens were chemically compatible with the leachate, having k values design criterion of $\leq 10^{-9}$ m/s for most points except for a few cases for which the values were slightly greater than the maximum regulatory for liners.

3. The study also showed that compatibility is not only dependent on the physicochemical interactions and chemical precipitation of carbonates calcite, but on biofilm formation.
4. Regardless of the increase in *B. megaterium* suspension density, there was a general reduction in the sorption capacity of cations and anions with.
5. PSO and SAO algorithm are reasonable optimization technique that can be used to obtain minimum hydraulic conductivity values which falls or converges within the overall acceptable zone.

Recommendation

Based on the results, lateritic soil be prepared at 11.8 - 13.8% moisture content when treated with *B. megaterium* suspension density in the range $1.5 \times 10^8 - 24 \times 10^8$ cells/ml and compacted using British standard heavy (BSH) energy is recommended for construction of liner and cover in a waste containment scheme.

References

Abollino, O., Aceto, M., Malandrino, M., Sarzanini, C. and Mentasti, E. (2003) Adsorption of heavy metals on Na-montmorillonite. Effect of pH and organic substances. *Water research* 37(7), pp 1619-1627.

Adeyemo, K.A., Yunusa, G.H., Ishola, K., Bello, A.A., and Adewale, S.A. (2022). "Cassava peel ash modified black cotton soil as material for hydraulic barriers in municipal solid waste containment facility." *Cleaner materials*. 3, 100045. https://doi.org/10.1016/j.clwas.2022.100045

Amadi, A. A. (2008). *Hydraulic And Containment Transport For Performance Of Compacted Lateritic Soil-Bentonite Mixture Proposed As Waste Containment Barrier*, Unpublished PhD. Thesis Civil Engineering Department, Ahmadu Bello University, Zaria.

Angelica, N., Giancarlo, F., Takeshi, K. and Hirofumi, S. (2015) Factors influencing hydraulic conductivity and metal retention capacity of geosynthetic clay liners exposed to acid rock drainage. *The 15th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering*. Theme New Innovations and Sustainability. Fukuoka, Kyushu, 9th – 13th of November 2015, Japan. Japanese Geotechnical Society Special Publication.

Badamchizadeh, M.A., Nikdel,A., Kouzehgar, M.(2010) Comparison of Genetic algorithm and particle swarm optimization for data fusion method based on kalman filter' International Journal of Artificial Intelligence,5(10), pp 67-78.

Barone, F. S., Rowe, R. K. and Quigley, R. M. (1990). "Laboratory determination of chloride diffusion coefficient in an intact shale." *Canadian Geotechnical Journal*, 27 (2): 177-184.

Bello, A. A. and Osinubi, K. J. (2010) "Attenuative Capacity of Compacted Three Reddish Brown Tropical Soils" *Continental Journal of Engineering Sciences* 5 (2): 39 - 54.

Bello, A. A. *and* Osinubi, K. J. (2011) "Attenuative Capacity of Compacted Abandoned Dumpsite Soils" *Electronic Journal of Geotechnical Engineering*, 16, Bund. A. 71–91.

Boateng, T.K., Opoku, F. and Akoto, O. (2019) Heavy metal contamination assessment of ground water quality: A case study of Oti landfill site, Kumasi. Journal of applied water science. 9(33). https://doi.org/10.1007/s13201-019-0915-y

Cizer, O., Rodriguez-Navarro, C., Ruiz-Agudo, E., Elsen, J., Gemert, D. V., & Balen, K. V. (2012). Phase and morphology evolution of calcium carbonate precipitated by carbonation of hydrated lime. Journal of Materials Science, 47, 6151–6165.

Clement, T. P., Hooker, B. S. and Skeen, R.S. (1996). "Macroscopic models for predicting changes in saturated porous media properties caused by microbial growth." *Ground Water* 34 (5): 934 – 942.

Daniel, D. E. and Benson, C. H. (1990). "Water content density criteria for compacted soil liners", *Journal of Geotechnical Engineering, ASCE*, 116 (12): 1811 – 1830.

DeJong J.T., Fritzges, M.B. and Nüsslein, K. (2006)."Microbially Induced Cementation to Control Sand Response to Undrined Shear," Journal of Geotechnical and Geoenvironmental Engineering, 132(8):1381 – 1392.

Dejong, J. T., Mortensen, B. M., Martinez, B. C., and Nelson, D. C. (2010). "Bio-mediated soil improvement." Ecol. Eng., Vol. 36, No. 2, pp. 197-210.

Dejong, J.T., Soga, K.S., Kavazanijian, E., Burns, S., Van Paassen, L., Al Qabany, A., Aydilek, A., Bang, S.S., Burbank, M., Caslake, L., Chen, C.Y., Cheng, X., Chu, J., Ciurli, S., Fauriel, S., Filet, A.E., Hamdan, N., Hata, T., Inagaki, Y., Jefferis, S., Kuo, M., Laloui, L., Larrahondo, J., Manning, D.A.C., Martinez, B., Montoya, B.M., Nelson, D.C., Palomino, A., Renforth, P., Santamarina, J.C., Seagren, E.A., Tanyu, B., Tsesarsky, M. and Weaver, T. (2013). "Biogeochemical processes and geotechnical applications: progress, opportunities and challenges." Geotechnique 63(4):287–301 [http://dx.doi.org/10.1680/geot.SIP13.P.017]

Dharminder, K and Vinay, C (2012) Image Quantization using HSI based on Bacteria Foraging Optimization. *International Journal of Information Technology and Knowledge Management, vol 5, No. 2, pp. 335-343*

Eberemu, A. O., Amadi, A. A and Edeh, E. J. (2013) Diffusion of municipal waste contaminants in compacted lateritic soil treated with bagasse ash. Journal of Environmental Earth Sciences. 70:789-797. DOI 10.1007/s12665-012-2168-z

Eberemu, A.O. (2008) *Evaluation of compacted bagasse ash treatedlateritic soil as hydraulic barriers in waste containment systems*. Ph.D. dissertation, Dept. of Civil Engineering, Ahmadu Bello Univ.

Edil, T. B.; Sandstrom, L. K. and Berthoux, P. M. (1992) Interaction of inorganic leachate with compacted pozzolanic fly ash. Journal of Geotechnical Engineering, ASCE, 118(9): 1410 –1430

Edil, T. B.; Sandstrom, L. K. and Berthoux, P. M. (1992) Interaction of inorganic leachate with compacted pozzolanic fly ash. Journal of Geotechnical Engineering, ASCE, 118(9): 1410 –1430

Egloffstein, T.A., (2001) Natural bentonites–influence of the ion exchange capacity and partial desiccation on permeability and self–healing capacity of bentonites used in GCLs. Geotextiles and Geomembranes, 19: 427– 444

Egloffstein, T.A., (2001) Natural bentonites–influence of the ion exchange capacity and partial desiccation on permeability and self–healing capacity of bentonites used in GCLs. Geotextiles and Geomembranes, 19: 427– 444

Etim, R.K., Attah, I.C., Ekpo, D.U., Usanga, I.N., 2021. Evaluation on Stabilization Role of Lime and Cement in Expansive Black Clay - Oyster Shell Ash Composite. Transportation Infrastructure Geotechnology. https://doi.org/10.1007/s40515-021-00196-1

Etim, R.K., Attah, I.C., Yohanna, P., 2020. Experimental study on potential of oyster shell ash in structural strength improvement of lateritic soil for road construction. International Journal of Pavement Research Technology, Chinese Society of Pavement Engineering, 13 (4), 341-351. Springer Nature Singapore. https://doi.org/10.1007/s42947-020-0290-y

Fityus, S. G.; Smith, D. W.; Booker, J. R., (1999). "Contaminant transport through an unsaturated soil linear beneath a landfill." *Canadian Geotechnical Journal*, 36 (2): 330-354.

Francisca, F.M. and Glatstein, D.A. (2010) Long term hydraulic conductivity of compacted soils permeated with landfill leachate. *Journal of Applied Clay Science*. Vol 49, pp 187–193

Frempong, E. M. and Yanful, E. K. (2008) "Interactions between three tropical soils and municipal solid waste landfill leachate." *Journal of Geotechnical and Geoenvironmental Engineering, ASCE*, Vol. 134, No. 3, pp.379-396.

Frempong, E.M., Yanful, E.K., 2008. Interactions between Three Tropical Soils and Municipal Solid Waste Landfill Leachate. Journal of Geotechnical and Geoenvironmental Engineering, 134 (3), 379-396. http://dx.doi.org/10.1061/(ASCE)1090-0241(2008)134:3(379)

Frempong, E.M., Yanful, E.K., 2008. Interactions between Three Tropical Soils and Municipal Solid Waste Landfill Leachate. Journal of Geotechnical and Geoenvironmental Engineering, 134 (3), 379-396. http://dx.doi.org/10.1061/(ASCE)1090-0241(2008)134:3(379)

Osinubi, K. J., Eberemu, A. O., Ijimdiya, T. S., and Etim, R. K. (2020). "Microbial-induced calcite precipitation study on the plasticity and compaction characteristics of lateritic soil treated with *Bacillus megaterium* in Urea-$CaCl_2$ culture medium." ICSID 2020. *IOP Conf. Series: Material Science and Engineering*. 1036(2021)012031. https://doi.org/10.1088/1757-899X/1036/1/012031

Gadzama, E.W. (2021). *Evaluation of Compacted Lateritic Soil Treated with Sporosarcina Pasteurii for use as a Hydraulic Barrier in Municipal Solid Waste Containment Application*. Unpublished Ph. D. dissertation, Department of Civil Engineering, Ahmadu Bello University, Zaria.

Gautam, M and Soumya, B (2013) A Study of Bacterial Foraging Optimization Algorithm and its Applications to Solve Simultaneous Equations. *International Journal of Computer Applications, Volume 72– No.5*, pp 1-7

Ghosh S., Mukherjee S., Al-Hamdan A. Z. and Reddy K. R. (2013) "Efficacy of Fine-Grained Soil as Landfill Liner Material for Containment of Chrome Tannery Sludge" *Geotechnical and Geological Engineering*, 31: 493–500.

Hammes, F. N. Boon, J. de Villiers, W. Verstraete, and S. D. Siciliano, (2003). Strain-specific ureolytic microbial calcium carbonate precipitation, *Applied Environmental Microbiology* Vol. 69, pp. 4901-4909,

Hong, C S. and Shackelford, C. D. (2017) Characterizing Zeolite-Amended Soil-Bentonite Backfill for Enhanced Metals Containment with Vertical Cutoff Walls. *Geoenvironmental Engineering* GSP 274, pp 82-98

Hong, C.S., Shackelford, C.D., and Malusis, M.A. (2016). "Adsorptive behavior of zeoliteamended backfills for enhanced metals containment." *Journal of Geotechnical and Geoenvironmental Engineering* (published online 03/09/16; http://doi: 10.1061/(ASCE)GT.1943-5606.0001481).

Ijimdiya, T. S. (2010). *Evaluation of Bagasse Ash Treated Black Cotton Soil as Hydraulic Barrier in Waste Containment Systems*.Unpublished Ph. D. dissertation, Department of Civil Engineering, Ahmedu Bello University, Zaria.

Ijimdiya, T. S. and Osinubi, K. J. (2011)."Attenuative Capacity of Compacted Black Cotton Soil treated with *Bagasse* Ash." *Electronic Journal of Geotechnical Engineering*, Vol. 16, Bund. D, 419-429.

Ives, K. and Pienvichitr, V. (1965). "Kinetics of the filtration of dilute suspensions." *Chem. Eng. Sci.*, 20: 965-973.

Lee, G. F. and Jones, A. R. (1991a). Landfills and Groundwater Quality. *Groundwater* 29: 482–486.

Lee, G. F. and Jones, A. R. (1991b). Groundwater Pollution by Municipal Landfills: Leachate Composition, Detection and Its Water Quality Significance. *Proceedings of the National Water Well Association Fifth National Outdoor Action Conference*, Las Vegas, NV.

Li M., Cheng X., Guo H. (2013). Heavy metal removal by biomineralization of urease producing bacteria isolated from soil. *Int Biodeter Biodeger.76* 81-85. Doi: 10.1016/j.ibiod.2012.06.016/j.jhazmat.2005.02.017.

Liu, H. H., Bodvarsson, G. S. and Finsterle, S., (2002) "A note on unsaturated flow in two-dimensional fracture networks." *Water Resources Research*, 38 (9): 1176-1179.

Liu, Y. L., Sun, W. X., Du, B., Liu, J. G. (2018). The physical clogging of the landfill leachate collection system in China: Based on filtration test and numerical modelling. International Journal of Environmental Research & Public Health, 15, 318.

McGinley, P. M. and Kmet, P. (1984). *Formation, Characteristics, Treatment and Disposal of Leachate from Municipal Solid Waste Landfills*.Wisconsin Department of Natural Resources Special Report.

McGregor, R. (1999). "Remediation of a heavy metal plume using a reactive wall". *In Situ and on Site Bioremediation, The Fifth International Symposium*, Battelle, San Diego,CA, April 19-22.

Mitchell, J. K. (1993). *Fundamentals of Soil Behaviour*, 2nd ed., John Wiley & Sons, New York.

Moses, G. (2012). *Hydraulic and Contaminant Transport Performance of Compacted Bagasse Ash Treated Foundry Sand for Use in Waste Containment Facilities* An unpublished Ph.D dissertation presented to the Postgraduate School, Ahmadu Bello University, and Zaria, Nigeria.

Moses, G. and Osinubi, K. J (2015). "Attenuative capacity of compacted bagasse ash treated foundry sand." *Jordan Journal of Civil Engineering*, 9(3):266-277

Muhammad, N. (2004), *Hydraulic, Diffusion, and Retention Characteristics of Inorganic Chemicals in Bentonite*. A published PhD dissertation in Department of Civil and Environmental Engineering, College of Engineering, University of South Florida.

Neretnieks, I. (2002) "A stochastic multi-channel model for solute transport – Analysis of tracer tests in fractured rock." *Water Resources Research*, 55 (3-4): 175-211.

Nikolova-kuscu, R., Powrie, W., Smallman, D.J., 2013. Mechanisms of clogging in granular drainage systems permeated with low organic strength leachate. Canadian Geotechnical Journal, 50, 632, 2013.

Nitin, K J. and Dipak, A. (2014) Comparative Analysis of Bacterial Foraging Optimization Algorithm with Simulated Annealing. *International Journal of Science and Research (IJSR)* vol 3 Issue 3, pp 10-13.

Oluremi, J. R. (2015). *Evaluation of Waste Wood Ash Treated Lateritic Soil for Use in Municipal Solid Waste Containment Application*. Unpublished PhD Thesis Department of Civil Engineering, Ahmadu Bello University, Zaria.

Osim, A. R. (2017). *Compacted Cement Kiln Dust Treated Black Cotton Soil as Suitable Liner and Cover Material in Waste Containment Facilities* An unpublished Ph.D dissertation presented to the Postgraduate School, Ahmadu Bello University, and Zaria, Nigeria.

Osinubi, K. J., Eberemu, A. O., Ijimdiya T. S. and Etim, R. K. (2021). "Unconfined compressive strength of compacted tropical soil bio-treated with *Bacillus megaterium*." In: Hossain Z., Zaman M., Zhang J. (eds.) *Finding Solutions of the 21st Century Transportation Problems Through Research and Innovations. GeoChina 2021*. Sustainable Civil Infrastructures. Springer, Cham. https://doi.org/10.1007/978-3-030-79638-9_4

Osinubi, K. J., Eberemu, A. O., Ijimdiya, T. S., and Yohanna, P (2020a). "Interaction of landfill leachate with compacted lateritic soil treated with Bacillus *coagulans* using microbial-induced calcite precipitation approach." *Journal of Hazardous, Toxic, and Radioactive Waste*. 24(1), 040190249. https://doi.org/10.1061/(asce)hz.2153515.0000465

Osinubi, K. J., Liman, A.S. and Moses, G. (2014) Batch Equilibrium Analysis of Compacted Cement Kiln Dust Treated Lateritic Soil. *Geoenvironmental Engineering* GSP 241,pp 181-191.

Osinubi, K. J., Yohanna, P., Eberemu, A. O. and Ijimdiya, T. S. (2019a). 'Evaluation of hydraulic conductivity of lateritic soil treated with Bacillus coagulans for use in waste containment applications.' *Proceedings of the 8th International Congress on Environmental Geotechnics (ICEG 2018)*, "Towards a Sustainable Geoenvironment" Edited by Liangtong Zhan, Yunmin Chen and

Abdelmalek Bouazza, 28th October – 1st November, Hangzhou, China, © Springer Nature Singapore Pte Ltd., Vol. 3, pp. 401–409, On-line: https://doi.org/10.1007/978-981-13-2227-3_50.

Osinubi, K.J and Moses, G. (2015). "The influence of compactive effort on the desiccation-induced volumetric shrinkage of compacted bagasse ash treated foundry sand as hydraulic barrier material." *Jordan Journal of Civil Engineering*, 9(4): 411-420

Osinubi, K.J and Moses, G. (2015). "The influence of compactive effort on the desiccation-induced volumetric shrinkage of compacted bagasse ash treated foundry sand as hydraulic barrier material." *Jordan Journal of Civil Engineering*, 9(4): 411-420

Osinubi, K.J., Eberemu, A.O., Ijimdiya, T.S., Yakubu, S.E., Gadzama., E.W., Sani, J.E., Yohanna, P. (2020b). "Review of the use of microorganisms in geotechnical engineering applications." 2,207. https://doi.org/10.1007/s42452-020-1974-2

Osinubi, K.J., Oluremi, R J., Eberemu, A.O and Ijimdiya, T.S (2017a) Interaction of landfill leachate with compacted lateritic soil–waste wood ash mixture. Proceedings of the Institution of Civil Engineers. http://dx.doi.org/10.1680/jwarm.17.00012.

Osinubi, K.J., Oluremi, R J., Eberemu, A.O and Ijimdiya, T.S (2017a) Interaction of landfill leachate with compacted lateritic soil–waste wood ash mixture. Proceedings of the Institution of Civil Engineers. http://dx.doi.org/10.1680/jwarm.17.00012.Daniel and Benson, 1990;

Osinubi, K.J., Oluremi, R J., Eberemu, A.O and Ijimdiya, T.S (2017) Interaction of landfill leachate with compacted lateritic soil–waste wood ash mixture. *Proceedings of the Institution of Civil Engineers*. http://dx.doi.org/10.1680/jwarm.17.00012.

Ozcoban, M.S., Tufekci, N., Tutus, S., Sahib, U. and Celik, O. (2006). "Leachate removal rate and effect of leachate on the hydraulic conductivity of natural (undisturbed) clay." *Journal of Scientific and Industrial Research* 65. 264-269.

Page, A. L., Miller, R. H., and Keeney, D. R., (1982). "Methods of Soil Analysis. Part 2. Chemical and MicrobioloGical Properties." 2nd Edition, American Society of Agronomy, Inc., Soil Science society of America, Inc., Madison, Wisconsin, 1159 pp.

Passino, K. M. (2002) "Biomimicry of Bacterial Foraging for distributed optimization and control," *IEEE Control System Magazine*. 22(2):52-67.

Peterson, S. R., and Gee, G. W. (1985). "Interactions between acidic solutions and clay liners: Permeability and Neutralization." In: Johnson AI, Frobel RK, Cavalli NJ, Pettersson CB (eds) Hydraulic barriers in soil and rock, ASTM STP 874. American Society for Testing and Materials, Philadelphia, 229–245.

Petrov, R., Rowe, R., (1997). "Geosynthetic Clay Liner (GCL) — chemical compatibility by hydraulic conductivity testing and factors impacting its performance." *Canadian Geotechnical Journal* 34, 863–885.

Petrov, R., Rowe, R., (1997). Geosynthetic Clay Liner (GCL) — chemical compatibility by hydraulic conductivity testing and factors impacting its performance. *Canadian Geotechnical Journal* 34, 863–885

Rowe, R. K. (2005). "Long-term performance of contaminant barrier systems." *Geotechnique*, 55(9), 631-678.

Rowe, R. K. and Booker, J. R. (1989) "A semi-analytic model for contaminant migration in a regular two or three dimensional fracture network: Conservative contaminants." *International Journal of Numerical and Analytical Methods*, 13 (5): 531-550.

Rowshanbakhta, K., Khamehchiyara, M., Sajedib, R. H., and Nikudela, M. R. (2016). "Effect of Injected bacterial suspension volume and relative density on carbonate precipitation resulting from microbial treatment." *Journal of Ecological Engineering*, 89, 49-55. https://doi.org/10.1016/j.ecoleng.2016.01.010

Sani, J. E. (2019). *Microbial- Induced Improvement of Lateritic Soil with Bacillus pumilus for Use in Waste Containment Systems*. Unpublished Ph. D. Thesis Civil Engineering Department, Ahmadu Bello University, Zaria.

Scalia IV, J. (2010) "State of Geosynthetic Clay Liner research at University of Wisconsin Madison and thoughts on emerging global geoenvironmental challenges and opportunities." *The First US-India Workshop on Global Geoenvironmental Engineering Challenges New Delhi, India, November 7, 1 – 5*.

Shackelford, C. D. (1994). "Waste-Soil interactions that alter hydraulic conductivity" *Hydraulic conductivity and waste containment transport in Soils.ASTM STP 1142*, David F. Daniel and Stephen J. Trantwein (eds.), American society for Testing and Materials. Philadelphia.

Shackelford, C. D. and Daniel, D. E. (1991a). "Diffusion in Saturated Soil, I: Background," *Journal of Geotechnical Engineering*, ASCE, 117(3): 467-484.

Shackelford, C. D. and Daniel, D. E. (1991b). "Diffusion in saturated soil. II: Results for compacted clay", *Journal of Geotechnical Engineering, ASCE*, 117 (3): 485-506.

Shackelford, C. D., C. H. Benson, T. Katsumi, T. B. Edil, and L. Lin. 2000."Evaluating the hydraulic conductivity of GCLs permeated with non-standard liquids."J. Geotext. Geomembr.18 (2–4): 133–161. https://doi.org/10.1016/S0266-1144(99)00024-

Shackelford, C. D., C. H. Benson, T. Katsumi, T. B. Edil, and L. Lin. 2000. "Evaluating the hydraulic conductivity of GCLs permeated with non-standard liquids."J. Geotext. Geomembr.18 (2–4): 133–161. https://doi.org/10.1016/S0266-1144(99)00024-

Sivakumar, D. (2011). "A study on contaminant migration of sugarcane effluent through porous soil medium"*International Journal of Environmental Science and Technology*, 8 (3): 593-604.

Stibinger J. (2016). Approximation of clogging in a leachate collection system in municipal solid waste landfill in Osecna (Northern Bohemia, Czech Republic). *Waste Management*, 63, 131.

Strawn, D. G., Bohn, H. L., and O'Connor, G. A. (2020) *Soil chemistry*.5th Edition. Wiley Blackwell.

Sudicky, E. A. and Frind, E. O., (1982). "Contaminant transport in fractured porous media: Analytical solutions for a system of parallel fractures." *Water Resources Research*, 18 (6): 1634-1642.

Sura, N. K., and Hiremath. L. (2019) "Isolation of Bacillus megaterium and its commercial importance." *International Journal of ChemTech Research*. 12 (4): 30-36. http://dx.doi.org/10.20902/IJCTR.2019.120405

Tang, Q., Wang, H. Y., Chen, H., Li, P., Tang, X. W., Katsumi, T. (2016). Long-term hydraulic conductivity of compacted clay permeated with landfill leachates. *The 15th Asian Regional Conference on Soil*

Mechanics and Geotechnical Engineering. Japanese Geotechnical Society Special Publication. 1845-1848. doi:10.3208/jgssp.CHN-52.

Touze-Foltz, N., Duquennoi, C. and Gaget, C.E., (2006). Hydraulic and mechanical behavior of GCLs in contact with leachate as part of a composite liner. Geotextiles and Geomembranes 24. 188–197.

Wen. K., Li, Y., Amini, F., and Li, L. (2020). "Impact of bacteria and urease concentration on precipitation kinetics and crystal morphology of calcium carbonate." *Acta Geotechnica* 15:17-27. http://doi.org/10.1007/s11440-019-00899-3

Whiffin, V. S., van Paassen, L. A., and Harkes, M.P. (2007) "Microbial carbonate precipitation as a soil improvement technique." *Geomicrobiology Journal*. 24 (5) 417–423.

World Health Organization (2006) *Guideline for Drinking Water Quality*, World Health Organization: Geneva; 2006.

Xiao, Y., Zhao, C., Sun, Y., Wang, S., Wu, H., Chen, H., Liu, H. (2020) "Compression behaviour of MICP-treated sand with various gradations." Acta Geotechnica. https://doi.org/10.1007/s11440-020-01116-2

Xie, H., Wang, S. and Qiu, Z. (2017) An analytical model for contaminant transport in a vertical cut-off wall and an aquifer system. *Proceedings of the 2nd Symposium on Coupled Phenomena in Environmental Geotechnics (CPEG2)*, Leeds, United Kingdom, 6 – 8 September. Session: Surface containment, Paper #92, Pp. 1 – 6.

Xie, M., Liu, D., Tang, Y., Feng, M., Yi, X., 2020. Study of the clogging properties of mixed leachate. Pol. J. Environ. Stud. 29 (5), 1–9. https://doi.org/10.15244/pjoes/114257

Yohanna, P. (2021). *Evaluation of Lateritic Soil Treated with Bacillus Coagulans in Bio-Cementation for use as a Hydraulic Barrier in Municipal Solid Waste Containment Application*. Unpublished Ph. D. dissertation, Department of Civil Engineering, Ahmadu Bello University, Zaria.

Yu, Y., Rowe, R.K., (2013). "Effect of grain size on service life of MSW landfill drainage systems." *Can. Geotech. J.* 50, 1.

ETIM PROGRESS 3 SEMINAR

ORIGINALITY REPORT

40%	20%	35%	2%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Roland Kufre Etim, Thomas Stephen Ijimdiya, Adrian Oshioname Eberemu, Kolawole Junwolo Osinubi. "Compatibility interaction of landfill leachate with lateritic soil bio-treated with Bacillus megaterium: Criterion for barrier material in municipal solid waste containment", Cleaner Materials, 2022 Publication	19%
2	www.issmge.org Internet Source	3%
3	P Yohanna, K J Osinubi, A O Eberemu, T S Ijimdiya, A T Salawudeen. "Evaluation of compacted lateritic soil – bacillus coagulans induced calcite precipitate for landfill application using bacterial foraging optimization algorithm", IOP Conference Series: Materials Science and Engineering, 2021 Publication	3%
4	K J Osinubi, P Yohanna, A O Eberemu, T S Ijimdiya. "Unconfined Compressive Strength	2%

of Lateritic Soil Treated with Bacillus Coagulans for use as Liner and Cover Material in Waste Containment System", IOP Conference Series: Materials Science and Engineering, 2019
Publication

5	www.researchgate.net Internet Source	1 %
6	www.ejge.com Internet Source	1 %
7	Roland Kufre Etim, Thomas Ijimdiya Stephen, Adrian Oshioname Eberemu, Kolawole Junwolo Osinubi. "Compatibility interaction of landfill leachate with lateritic soil bio-treated with Bacillus. Megeterium: Criterion for barrier material in municipal solid waste containment", Cleaner Materials, 2022 Publication	1 %
8	K J Osinubi, A O Eberemu, T S Ijimdiya, R K Etim. " Microbial-Induced Calcite Precipitation Study on the Plasticity and Compaction Characteristics of Lateritic Soil Treated with Bacillus Megaterium in Urea-CaCl Culture Medium ", IOP Conference Series: Materials Science and Engineering, 2021 Publication	1 %
9	mafiadoc.com Internet Source	1 %

10	ascelibrary.org Internet Source	1 %
11	repository.futminna.edu.ng:8080 Internet Source	1 %
12	link.springer.com Internet Source	1 %
13	J. R. Oluremi, A. O. Eberemu, T. S. Ijimdiya, K. J. Osinubi. "Absorption and Diffusion Potential of Waste Wood Ash-Treated Lateritic Soil", Geo-Chicago 2016, 2016 Publication	<1 %
14	epdf.pub Internet Source	<1 %
15	dokumen.pub Internet Source	<1 %
16	Submitted to Federal University of Technology Student Paper	<1 %
17	RC Chaney, KR Demars, TE Cotten, MM Davis, CD Shackelford. "Effects of Test Duration and Specimen Length on Diffusion Testing of Unconfined Specimens", Geotechnical Testing Journal, 1998 Publication	<1 %
18	kubanni-backend.abu.edu.ng Internet Source	<1 %

19	www.xpublication.com Internet Source	<1 %
20	ia800504.us.archive.org Internet Source	<1 %
21	www.scribd.com Internet Source	<1 %
22	Roland Kufre Etim, Adrian Oshioname Eberemu, Thomas Stephen Ijimdiya, Kolawole Juwonlo Osinubi. "Coupled Effect of Cementation Solution, Curing Period, Molding Water Content, and Compactive Effort on Strength Performance of Biotreated Lateritic Soil for Municipal Solid Waste Containment Application", Journal of Hazardous, Toxic, and Radioactive Waste, 2023 Publication	<1 %
23	www.mdpi.com Internet Source	<1 %
24	"Finding Solutions of the 21st Century Transportation Problems Through Research and Innovations", Springer Science and Business Media LLC, 2021 Publication	<1 %
25	trepo.tuni.fi Internet Source	<1 %
26	nepis.epa.gov	

	Internet Source	<1%
27	www.tandfonline.com Internet Source	<1%
28	Kolawole J. Osinubi, Adrian O. Eberemu, Thomas S. Ijimdiya, Mutiu A. Oyelakin. "The Impact of Biocalcification on Strength of Semi-Arid Zone Sand of Northeastern Nigeria", Geo-Congress 2023, 2023 Publication	<1%
29	ia600504.us.archive.org Internet Source	<1%
30	R. Kerry Rowe. "Eleventh Canadian Geotechnical Colloquium: Contaminant migration through groundwater—the role of modelling in the design of barriers", Canadian Geotechnical Journal, 1988 Publication	<1%
31	iosrjournals.org Internet Source	<1%
32	www.bosaljournals.com Internet Source	<1%
33	Adrian O. Eberemu, Agapitus A. Amadi, Joseph E. Edeh. "Diffusion of municipal waste contaminants in compacted lateritic soil	<1%

	treated with bagasse ash", Environmental Earth Sciences, 2012 Publication	
34	catalog.libraries.psu.edu Internet Source	<1 %
35	ijest.org Internet Source	<1 %
36	Edil, T.B.. "A review of aqueous-phase VOC transport in modern landfill liners", Waste Management, 2003 Publication	<1 %
37	www.ajol.info Internet Source	<1 %
38	www.matec-conferences.org Internet Source	<1 %
39	Hong, C.S.. "Non-reactive solute diffusion in unconfined and confined specimens of a compacted soil", Waste Management, 200901 Publication	<1 %
40	Yuze Wang, Charalampos Konstantinou, Sikai Tang, Hongyu Chen. "Applications of microbial-induced carbonate precipitation: A state-of-the-art review", Biogeotechnics, 2023 Publication	<1 %
41	insis.vse.cz Internet Source	<1 %

42	www.physiologyweb.com Internet Source	<1 %
43	B. R. Phanikumar, M. Uma Shankar, Manikanta D. "Interaction of diesel oil contaminants with laterite soil and bentonite treated by sawdust -landfill liner", Geomechanics and Geoengineering, 2022 Publication	<1 %
44	www.cambridgenigeriapub.com Internet Source	<1 %
45	Carla Ribeiro Machado e Portugal, Carolyn Fonyo, Carlos Cardoso Machado, Richard Meganck, Todd Jarvis. "Microbiologically Induced Calcite Precipitation biocementation, green alternative for roads – is this the breakthrough? A critical review", Journal of Cleaner Production, 2020 Publication	<1 %
46	ojs.wiserpub.com Internet Source	<1 %
47	repository.up.ac.za Internet Source	<1 %
48	www.jstage.jst.go.jp Internet Source	<1 %
49	www.pokka.co Internet Source	<1 %

50	acikbilim.yok.gov.tr Internet Source	<1 %
51	bbrc.in Internet Source	<1 %
52	coek.info Internet Source	<1 %
53	journals.vgtu.lt Internet Source	<1 %
54	ri.conicet.gov.ar Internet Source	<1 %
55	Charles D Shackelford. "Laboratory diffusion testing for waste disposal — A review", Journal of Contaminant Hydrology, 1991 Publication	<1 %
56	Pramod Kumar Sharma, Muskan Mayank, Chandra Shekhar Prasad Ojha. "Numerical analysis of breakthrough curves and temporal moments for solute transport in triple-permeability porous medium", ISH Journal of Hydraulic Engineering, 2018 Publication	<1 %
57	R. Kerry Rowe, Toshifumi Mukunoki, Richard J. Bathurst. "Compatibility with Jet A-1 of a GCL Subjected to Freeze–Thaw Cycles", Journal of Geotechnical and Geoenvironmental Engineering, 2006	<1 %

	Publication	
58	Roque, A.J.. "Calculating hydraulic conductivity of fine-grained soils to leachates using linear expressions", Engineering Geology, 20060526 Publication	<1 %
59	Umar Sa'eed Yusuf, Matawal Danladi Slim, Elinwa Augustine Uchechukwu. "Hydraulic Conductivity of Compacted Laterite Treated with Iron Ore Tailings", Advances in Civil Engineering, 2016 Publication	<1 %
60	cyberleninka.org Internet Source	<1 %
61	eprints.utm.my Internet Source	<1 %
62	scholarsmepub.com Internet Source	<1 %
63	silo.pub Internet Source	<1 %
64	www.ocrwm.doe.gov Internet Source	<1 %
65	www.roads.maryland.gov Internet Source	<1 %
66	Agapitus A. Amadi, K. J. Osinubi. "Transport parameters of lead (Pb) Ions migrating through saturated lateritic soil–bentonite	<1 %

column", International Journal of Geotechnical Engineering, 2017
Publication

67 Anna Norris, Neelufar Aghazamani, Joseph Scalia, Charles D. Shackelford. "Hydraulic Performance of Geosynthetic Clay Liners Comprising Anionic Polymer–Enhanced Bentonites", Journal of Geotechnical and Geoenvironmental Engineering, 2022 <1%
Publication

68 Agapitus Ahamefule Amadi, Adrian Oshioname Eberemu. "Delineation of compaction criteria for acceptable hydraulic conductivity of lateritic soil-bentonite mixtures designed as landfill liners", Environmental Earth Sciences, 2012 <1%
Publication

Exclude quotes	On	Exclude matches	Off
Exclude bibliography	On		