# Recycling Waste for Sustainable Development: A Business Point of View

Tony Mene –Akpata
Managing Director/Chief Executive Officer of Esiton Group

His Excellency, the Executive Governor of Kwara State, the Vice Chancellor of this great citadel of learning, the Dean of the Faculty of Engineering, the Head of Civil Engineering Department, Our Spiritual and Royal fathers, all Commissioners here present, Members of the Legislature, Judiciary, Local Government Chairmen, all Deans, Sub-deans, H.O.Ds and Lecturers present, the ever hardworking-to-discover students of this department, all students, friends and well wishers.

It is with great humility and gratitude that I stand here to address you on a topic I consider myself not an academic expert. In a country so blessed with highly qualified and seasoned Environmentalists and Experts, one wonders why a businessman is considered and invited to deliver this lecture to Professors, Doctors, and what have you? I hope my inefficiencies would be pardoned.

However, as a businessman, I will be presenting this paper from a business point of view rather than pretend to furnish you with adopted or should I say “stolen” academic theories that may not work but only sound good. I intend to let you in to some of our little secrets as a Waste Treatment Giant with over ten years of laboring experience to ensure our environment is safe for all.

Our Organisation, **Esiton Integrated Nigeria** Limited is committed to the provision of quick, efficient, dependable, highly sustainable and competitive environmental and engineering services. Esiton is a member and a recipient of the Nigeria Environmental Society (NES) Gold Service Award for outstanding contributions and commitment in the environmental sector. Esiton has won many other awards including the prestigious Central Bank of Nigeria (CBN) award in the Best Micro-Enterprenuer: Empolyment Generation Category.

Our interest ranges from Waste Management and Water Treatment to Sewage and Chemical Waste Treatment and presently we are diversifying into Petroleum Products distribution, Fisheries and provision of Fast Food Services. Along with the range of equipment and facilities, we are also actively involved in designs, fabrication and development of Raw Water, Sewage and Chemical Waste Treatment machineries of international standards.

## 1.0 Introduction

People hardly border about what happens to the things they put in the waste bins. Tons of refuse is produced by Nigerians annually! Unfortunately, most of these only ends up buried in landfills. More and more these landfills are closing down because they are too expensive to maintain. This is becoming a widespread problem across the country as various governments have struggled to find alternative ways to reduce the amount of trash accumulation.

### 1.1 Waste Management Strategy

The Waste Management Strategy is to minimize all wastes at the source. This involves waste collection, segregation, storage and transportation to the final disposal site. These steps reduce the complexity and handling precautions of wastes prior to the application of the treatment options. The waste management strategies is to first inventory and categorize waste, and then either minimize or treat it prior to final treatment or disposal.

### 1.2 Waste Inventory

An inventory of all waste types is needed to be compiled to ensure an easy segregation and effective waste management. The Department handling the waste shall be responsible for inventorying the waste using the Waste Tracking Log. The Waste Tracking Log has instructions for filling out the log such as: Name of facility/street/quarter/layout generating the waste, Quantity of waste in terms of Cubic metres, i.e. length x breadth x height, Name/Number of vehicle transporting waste, Disposal Method, Disposal Location and the Name of the Officer filling out the log.

### 1.3 Waste Segregation

This involves sorting and separation of waste on the basis of their characteristics. Some measures for the control, recording and disposal of waste for effective monitoring are:

(i) The provision of coloured bins. Proper labeling of bins with clear indication of waste to be collected in them.

(ii) Strategic placement of the various bins in offices, construction sites, food centres, markets, etc.

(iii) Proper storage of the segregates. This also involves effective delivery of the segregated bins to the waste disposal depot.

(iv) Treatment of the waste and

(v) Training workforce to segregate.

## 1.4 Waste Storage and Disposal

Appropriate transport containers/vehicles for the various kinds of waste are needed. To achieve effective waste storage and disposal we must consider the following:

(i) Properly covered, labeled and coloured collection bins are needed at all waste producing points.

(ii) All collection bins should be emptied as and when required into waste collection containers for transporting to the waste disposal depot.

(iii) All waste storage receptacles should be replaced promptly in the event of damage.

## 1.5 Waste Handling

It is necessary for all waste handlers to have and use the right and appropriate personal protective equipment (PPE).

(i) Hazardous waste should be assessed, monitored and handled under the supervision of trained and qualified Ministry of Environment's Health, Environment and Safety (HES) Officers.

(ii) All generated wastes should be tracked using the Waste Tracking Log from the point of generation to the final point of treatment.

## 2.0 Waste Management Hierarchy

Proper management of wastes begins with pollution prevention. Pollution prevention refers to the elimination, change or reduction of operating practices which result in discharges to land, air or water. This principle should always

be incorporated into the design and management of our roads, buildings, streets, industries and the planning of associated activities and not just an after thought. If the elimination of a waste is not possible, minimizing the amount of waste generated should be investigated. Responsible waste management can be accomplished through hierarchical application of the practices of source reduction, reuse, recycling, recovery, treatment and responsible disposal.

**2.1 Source Reduction:** This refers to the generation of waste through more efficient practices such as:
Material elimination, inventory control and management, material substitution, process modification and improved house keeping. A good way to reduce waste in our homes and campuses is buying food and other necessities in large quantities or in bulk. Grains and cereal are especially easy to purchase this way. Avoiding small individual packages of any product or consumable greatly reduces the amount of paper that you buy and throw away. Of course, don't buy large quantities if the food would spoil before it is used. You can reduce waste by giving preference to products that use less packaging.

**2.2 Reuse:** This refers to the use of materials or products that are reusable in their original form such as: chemical containers, oily waste for road construction and stabilization, burning waste energy for energy. We can easily find uses for things we discard. For instance, use old towels, rags, and sponges for most cleaning and wipe-ups. We could consider donating to charity some of the things we usually discard that could still be used. Are you still collecting bags every time you shop? STOP**!** It is advisable to invest in a set of reusable shopping bags. They hold more, they make carrying heavy loads much easier, they hold larger volumes than most plastic bags, they protect glasses and bottles better, and they last seemingly forever.

Invest in rechargeable batteries and a battery charger: You can run almost anything, from flashlights to digital cameras, with rechargeable batteries. In the long run it is cheaper and better for the environment.

**2.3 Recycling:** The conversion of waste into usable materials and/or extraction of energy or materials from wastes is the reason I am standing before you today. How can waste be turned into wealth? How do we stop the wastes and harness the gains in in wastes? What can the individual, state and federal governments do to ensure an efficient recycling?

**2.4 Treatment:** This refers to the destruction, detoxification and/or neutralization of residues through processes such as: biological methods (composting, tank based degradation), thermal methods (incineration, thermal desorption), chemical methods (neutralization, stabilization) and physical methods (filtration and centrifugation).

**2.5 Responsible disposal:** This refers to the depositing of wastes on land or in water using methods appropriate for a given situation. Disposal methods include landfilling, burial, surface discharge, land-spreading or land-farming and underground injection.

The waste management hierarchy "reduces, reuse, recycle, treat, dispose" actually expresses the order of importance of these ideas:

- Reduce needless consumption and the generation of waste.
- Reuse any item that can be reused or give it to a person or charity that can reuse it.
- Recycle whatever discards remain if you can and only dispose what you must.
- Treat any waste that cannot be reduced, reused or recycled.
- Responsibly dispose off any waste after proper treatment.

Please keep in mind that recycling is your least preferred option. Reducing the generation of waste so there is no waste left to recycle would be the ideal. The terms reuse and recycle have specific meanings, but they are often confused, switched, and misused, especially in commerce...

**3.0 What is recycling?**

Recycling is the process of collecting materials that are often considered trash and remanufacturing them into new products that can be resold and used again. This of course, is business in its entirety and if properly harnessed, can bring about the much needed human and capital development.

Recycling is processing used materials (waste) into new products to prevent waste of potentially useful materials, reduce the consumption of fresh raw materials, reduce energy usage, reduce air pollution (from incineration) and water pollution (from landfilling) by reducing the need for "conventional" waste disposal, and lower unwanted gas emissions as compared to virgin production.

Recycling is the process of turning one products useful part into a new product; this is done to conserve on the consumption of resources, energy and space used in landfills

Construction waste recycling is the separation and recycling of recoverable waste materials generated during construction and remodeling. The most important step for recycling of construction waste is on-site separation. Initially, this will take some extra effort and training of construction personnel. Once separation habits are established, on-site separation can be done at little or no additional cost.

### 3.1 Origin

Recycling has been a common practice for most of human history, with recorded advocates as far back as Plato in 400 BC. During periods when resources were scarce, archaeological studies of ancient waste dumps show less household waste (such as ash, broken tools and pottery) - implying more waste was being recycled in the absence of new material.

### 3.2 Why is recycling important?

Reducing and reusing are free market activities that are profitable investments of time and labour. Any astute entrepreneur will see the benefit of conserving factors of production.

Today, builders construct houses using less wood than similar houses built just 20 years ago. Using less wood makes financial sense, and any entrepreneur worth his profit will change his recipe to conserve wood through better design or by substituting less dear materials for wood products.

What about the lack of landfills nationwide? If landfills are truly in short supply, then the cost of dumping waste would quickly rise. People should begin to see the financial benefit to reducing their waste volume.

Recycling is more important than ever because just throwing away trash in a landfill or digging a hole and burying it is not a solution to the waste problem.

Most natural trash items like food can break down and decompose in a matter of weeks, leaving no trace of it in the environment. But for man-made products like glass, plastic bags and aluminum cans it may take months or years to break down.

The fact is many of our resources as well as our Earth is not renewable and we have to start taking control of our selves beginning with the world we live in. Global warming is no longer viewed as a theory by scientists and has sadly become a fact. The change needed must be in your actions today in order to ensure a bright (not too hot) tomorrow

Global warming, deforestation, acid rains, the endangerment of various species etc. have gone completely out of control in many areas around the globe. Various methods and suggestions are being offered to reduce the effects of these altogether and if possible, eradicate it completely. Recycling done on an everyday basis could actually help our planet Earth to a large extent.

### 3.3 What can be recycled?

There are thousands of items that can be recycled and reused as new products. Listed below are the most common items and from these, I wish to draw my reference:

(a) Plastic Recycling – Plastic bottles, shampoo and motor oil containers. There are over 50 different groups of plastics that are produced, and all are recyclable.

Do you know that the millions of table water plastic containers and sachet papers that liter the country and create drainage problems can actually be put into profitable use? We all know that interlock blocks are products of sand and cement. When plastics and pure water sachets are dried and grinded with a machine – which could even be a locally manufactured machine, particles are produced. The particles formed can replace sand in interlocking block making and mixed in the appropriate proportions with cement. This mixture can be used to produce the much desired and expensive interlocking blocks. You can imagine the volume of plastic and pure water sachet papers that will be grinded to form a tipper load of "sand". It further goes to show that all the plastics and sachet paper on this campus will not be enough to form the needed "sand". Let us go further to assume that all the roads in this campus are to interlocked as a way of giving them a face lift, all the plastic wastes generated here on campus will not be enough which therefore implies that we would have to move out into the town to scout for used plastics and pure water sachets. The multiplier effect of this is that the streets won't be littered anymore as students and indigenes will want to exchange their wastes for money.

(b) Glass Recycling – Glass bottles, mirrors and plain glasses can be recycled. Experts say recycling glass products uses 40% less energy than making glass products from all new materials. Even though not all glass containers can be recycled, it is still very easy to make new glass jars, and those can be recycled over and over again. The good news is that we have available markets for glass recycling in Nigeria. We have the Delta Glass Factory in Delta State, Loto Glass in Agbara and many more.

(c) Metal Recycling – Beverage cans, food cans, aerosol cans, Aluminium soda cans and scrap metal. Recycling metal can create new parts for cars and buildings, as well as containers for food. It may interest you to know that in the not-to-long completed Escravos Gas to Liquid (EGP-3) project, a lot of metal scraps were generated of which we, Esiton were responsible for the disposal. The Delta Steel Company in Delta State was a readily available to receive the waste as raw materials for their production work. Could you imagine if we had no one to recycle the volume of such waste? The whole streets of Warri would have been littered with metal scraps. The government needs to make our steel plants to function at full capacity. One only needs to buy off the scraps on the streets and re-sell same to the nearest steel plant and one is in business.

(d) Paper –It will also interest you to know that recycled paper uses fewer chemicals, bleaches and dyes. These papers and more can be recycled: Printer paper, newspaper, magazines, office paper, computer paper, envelopes, gift wrapping paper, cardboard, food boxes, shoeboxes, paper towel and toilet paper tubes, paper egg cartons etc. With the population growth of Nigeria, you will agree with me that more Nigerians would need tissue paper. If the cost of production reduces because of availability of cheaper raw materials occasioned by recycling then Toilet Roll Industries like Glory Lux in Delta State can afford to make their products affordable for all.

(e) Most of the garbage generated in the household can be recycled and reused. Organic kitchen waste such as leftover foodstuff, vegetable peels, and spoilt or dried fruits and vegetables can be recycled by putting them in the compost pits that have been dug in the garden.

(f) Electronics, Computers and Automobiles **--** Many electronics, computer and automobile parts can be reused or recycled into new parts or scrap metal. For instance, the Federal Road Safety Commission (FRSC) has in the Nigerian Muse of 16th November, 2007 put the number of vehicles on the Nigerian Roads at over 7 Million. With an average of four tyres to a vehicle and if we assume that all are brand new; we are looking at over 28 million automobile tyres. Interestingly, experts have put the life span of new tyres at 5 years. The implication is that without recycling by the year 2012 all these tyres and more will be dumped in overcrowded landfills or on the sides of our roads. It can only be imagined what our streets and roads would have looked like without some form of recycling going by the number of used tires that would have been generated. However, by recycling these tires can be broken down and reused for rubber tiles, shoe soles, foot mats, ropes and even black tar for road surfacing.

Used batteries can be put into profitable use by first extracting the acid and beat the inner compartments into useable sheets while the casing is melted for road asphalting.

### 3.4 What are the benefits of recycling?

Recycling benefits everyone and everything. Here are some benefits of recycling:

(a) Produces less harmful gases because industries burn fewer fossil fuels. Using the concept of recycling can help to reduce the global warming effect. Gas emissions occur due to the manufacturing, use and also the disposal of products that are not biodegradable. If the gas emissions reach dangerous concentration levels, it leads to changes in the temperatures, changes in the levels of the sea and other bizarre climatic conditions. Therefore, recycling can help reduce the need to manufacture paper, plastics, metals and glass. This would save energy needed to manufacture new products.

(b) Experts have shown that most often than not recycling programs cost less than waste disposal programs with all its attendant health, environment, social, agricultural and such like challenges.

(c) Recycling decreases soil erosion associated with mining and logging. Places like Auchi in Edo State and most part of the eastern states are presently suffering from severe erosion and both the Federal and State governments are doing all they can to see to it that the erosions are checked. But if only we realize early that except recycling is encouraged, other cities and states will with time suffer the same fate owing to deforestation associated with un-controlled mining and logging.

(d) It saves space in landfills. Recycling helps to limit the amount of glass, paper and plastic that must be produced. This will end with less garbage in landfills because it's being reused.

(e) Adds jobs to the economy. Besides, recycling also creates job opportunities for most people hence the slogan “Waste is Wealth”. You can receive money for turning in certain recyclable products and become self employed without any capital whatsoever.

(f) Recycling slows the consuming of natural resources such as wood, water and minerals. We reduce the amount of resources needed to make the same item compared to making it without recycling. Almost everybody reads newspapers and after some time discards such papers instead of selling them off to be recycled. Discouraging this practice would save many trees annually as these would not be cut down for the requirement of paper. We all know the importance of trees in the ecological cycle. Most companies therefore resort to recycled paper or the use of Internet to propagate their message. Experts say that one ton of paper saves at least 17 trees. Imagine the number of trees that recycling can save. So, avoid the unnecessary use of paper and if needed, use recycled paper.

(g) Saves the earth, saves animals and saves humanity. Using recycled products would also reduce the amount of materials (which are not biodegradable) that end up in the landfills. Materials that end up in landfills tend to decompose and cause the release of methane gas. This is very harmful for the environment; therefore such landfills are the main cause of the emission of methane gas into the atmosphere.

(h) Recycling Reduces Pollution and protects the environment. Pollution means the introduction of hazardous substances in the form of plastics, empty cans, chemicals and ordinary waste into the environment. If plastics are to be buried, these can last for at least 700 years. These substances contaminate our environment. Plastic waste is responsible for causing increased soil and water pollution. Plastic recycling is an effective solution to this problem.

(i) In fact recycling can prevent the creation of waste at the source. The benefits of recycling are many more to name, but to actually use these concepts in our everyday life would require awareness and also the urge to spread this message. So, whenever you can, just spread the word! Recycling will benefit everybody around the globe, including you! Recycling is key to life!

## 3.5 Legislation

### 3.5.1 Supply

For a recycling program to work in this country, having a large, stable supply of recyclable material is crucial. The Federal and State governments must propose and pass the following suggested laws that would create the enabling environment for proper recycling to take place in Nigeria.
Three legislative options can be used to create such a supply: mandatory recycling collection, container deposit legislation, and refuse bans.

**3.5.2 Mandatory Recycling Collection Law:** Mandatory collection laws will make it compulsory for the Federal, States and Local Government Areas to collect all wastes.

**3.5.3 Container Deposit Law:** Container deposit legislation involves offering a refund for the return of certain containers, typically glass, plastic, and metal. When a product in such a container is purchased, a small surcharge is added to the price. This surcharge can be reclaimed by the consumer if the container is returned to a collection point. This law will make it compulsory for sellers to receive returned containers and also pay the customer for returning same. You will agree with me that if this becomes operational hardly will you find containers and other categorized waste on our street not to mention this campus

**3.5.4 Disposal Ban Law:** A third method of increasing supply of recirculates is to ban the disposal of certain materials as waste, such as plastics, cellophane, used oil, old batteries, tires and garden waste. One aim of this

method is to create a viable economy for proper disposal of banned products. Care must be taken that enough of these recycling services exist, or such bans simply lead to increased illegal dumping.

**3.6.0 Government-mandated demand**

Legislation has also been used by some countries to increase and maintain a demand for recycled materials. The Nigerian Government can propose and pass the following suggested laws that would create the needed market for recycled products for the “Circle” in recycling to be complete. Four methods of such legislation exist and they are minimum recycled content mandates, utilization rates, procurement policies and recycled product labeling.

**3.6.1 Minimum Recycled Content Mandates:** This specifies that a certain percentage of a new product must consist of recycled material. If we insist that all plastics manufacturing firms use a given percentage of recycled plastics in the production of new plastics, we are sure that most of them would open up collection centres everywhere i.e. in every department, faculty, campus, town, city and state just to receive used plastics. Their involvement would probably at an easier and more affordable rate than should the government be involved in the collection directly.

**3.6.2 Utilization Rates:** By this, manufacturing firms are expected to either directly recycle to produce or contribute to other bodies/government to recycle for their eventual use. Both minimum recycled content mandates and utilization rates increase demand directly by forcing manufacturers to include recycling in their operations.

**3.6.3 Procurement Policies:** Many Governments have used their own purchasing power to increase recycling demand through what is called "procurement policies." The Nigerian government can apply these policies as either "set-asides," which earmark a certain amount of spending solely towards recycled products, or "price preference" programs which provide a larger budget when recycled items are purchased. Assuming Maclean toothpaste uses recirculates and is to sell for #200 while Close-up doesn’t use recirculates and would be sold for same price, the Nigerian government can subsidize the price of Maclean so that it sells for say #150. This first benefits the people because the price is reduced and secondly because the environment

is protected, purified and preserved because most of what would have constituted wastes, refuse and hazards have been recycled.

### 3.6.4 Recycled Product Labeling:

The final government regulation towards increased demand is recycled product labeling. The Nigerian government can legislate that producers label their products with the amount of recycled material in the product (including the packaging) so that you and I are better able to make educated choices. As students, for instance, you would prefer buying more environmentally conscious products that you know your waste is been utilized in their production thereby giving you more opportunity to sell your waste because the more you buy their products the more they buy your wastes. This will also prompt producers to increase the amount of recycled material in their products, and indirectly increase demand and the producers who hitherto never cared about recycled materials begin to care. Standardized recycling labeling can also have a positive effect on supply of recirculates if the labeling includes information on how and where the product can be recycled.

### 3.7.0 Establish stationary or mobile collection centres

Because schools often serve as focal points for local residents, they are ideal for stationary reuse and recycling drop-off points. A storage facility where people can drop off their reusable and recyclable products should be put in an easily accessible holding area, such as parking lots, supermarkets, car parks, markets, primary and secondary schools and even churches. On campus like this, bus stops, sit-out centres, libraries, departmental and faculty focal points are areas highly prone to refuse disposal. The school authority can either arrange for pickup of the collected waste/refuse/items by a local recycling centre or hauler or enlist volunteers to transport the collected materials to a nearby recycling centre or charity. For some very specific materials, such as computers and other electronics, you might need to make special arrangements with the engineering department/manufacturer/business that collects those particular items (sometimes called “take-back programs”).

The school authority will need storage space and well-labeled containers with covers at each pickup point where reusable or recyclables can be collected until the trailer/hauler arrives. Arrangements for convenient locations, such as supermarkets, car parks, markets, primary and secondary schools and even churches, to temporarily park the trailers/trawlers, and establish regular deposit schedules with your local recycling facility should be made.

### 3.8.0 Team up with a sponsor for waste reduction programs

Corporate or government organizations sometimes sponsor reuse or recycling drives or donate money or supplies to start a waste reduction program. The

government and school in particular can approach the producers of the major sources of waste on campus such as manufacturers of soft drinks, bottled/sachet water, food and beverages etc. for sponsorship and contributions.

However, corporate sponsors may be good sources for funding and advertising, but you might have to follow their guidelines and have the sponsor's name associated with your school or group.

### 3.9.0 Establish a "credit account" with a local recycling centre

If a school or group establishes a "credit account" with a local recycling centre, the monetary value of any recyclables dropped off there will be added to that account. Students and others can drop off recyclables and have the proceeds of those items posted to that account. That means your school or group will receive the money from those recyclables. Promoting the school or group that will be the recipient of the recycling effort is important as a motivator for participation and to ensure that credit is properly given to the school/student. Classroom activities and publicity should be utilized to reinforce recycling lessons and increase participation.

### 3.10 Recycle and Buy Recycled Too!

Finally no matter how you live, work, and play, we all produce waste. We can control this waste by reducing, reusing, and recycling it. While many people already recycle products at home, waste reduction opportunities exist anywhere we have waste. Recycling is one way to reduce waste; reusing products is another.

It is pertinent to mention that owing to time and space we have left out a vital recycling aspect of our job in Escravos. This involves recycling Sewage "human waste, shit, excreta). We have over the past ten years successfully recycled sewage into unharmful and profitable constituents. However, the full process and expertise involved shall not be a subject for today. It is hoped that probably in the future, an opportunity will arise for us to share our experience in that regards.

Selling your recovered materials is really only one part of the recycling process. Recycling involves separating reusable materials, collecting them, processing them, making them into new usable items, and then marketing and purchasing the new products. Also keep in mind the concept of "cycle" in the term "recycle". For there to be a complete cycle, the things you send to be

recycled must come back to you. So, look for recycled content products whenever you buy, otherwise you are not truly recycling. When people use products made from recycled materials, they are “closing the recycling loop.” Remanufactured material is critical to the success of recycling. If materials are simply collected and stored, we cannot achieve our ultimate goal of waste reduction. Start recycling today. Thank you and God bless.

# Strength and Sorption Properties of Some Selected Paper-Cement Boards in Ibadan Metropolis

Adefisan, O.O.[1] and Amiandamhen, S.O.[2]
femiadefisan@hotmail.com
1. Department of Agricultural and Environmental Engineering, Faculty of Technology, University of Ibadan, Ibadan, Nigeria.
2. Department of Forestry and Wildlife, Faculty of Agriculture, University of Benin, Benin City, Nigeria

## Abstract

Paper Cement Boards (PCBs) were obtained from four selected small scale manufacturers in Ibadan, Oyo State, Nigeria. Data on the production process, materials used for production and the paper-cement ratio in the mix were also collected from source. Strength and sorption properties were carried out on the boards. The properties of PCBs were compared with those of the commonly used fibre and gypsum board. One out of the four industries engaged in semi-mechanised production. Analysis of variance showed that boards made from mechanised process were significantly different from the other boards, but the difference between the other PCBs was not significant ($p < 0.05$). The results revealed that boards produced by mechanised process exhibited higher Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) of 3.06N/mm$^2$and 2140.13N/mm$^2$ respectively and 45.3% water absorption (WA) after 24h immersion. A comparison of the PCBs with gypsum and fibreboards did not prove the PCBs inferior in any of the properties evaluated. All the tested samples had low strength properties and high WA and are hence not suitable for structural purposes and exterior applications.

**Keywords**: Fibre Cement Composites, Paper Cement Boards, Strength Properties, Sorption Properties

## 1.0 Introduction

Fibre Cement Composites (FCCs) are from made from mixtures of processed fibres such as wood (Kraft pulp), glass, steel, Kevlar, asbestos, recycled papers etc. (Moslemi, 2008), cement and water. They are low-cost, environmentally friendly materials that can be machined using simple hand tools, made in myriads of shapes and are adaptable to modular housing construction. The incorporation of uniformly dispersed fibres in cementitious composites strengthen the cement matrix thus improving the structural performance in members under gravity loads, as well as in increasing shear and flexural strengths, toughness ductility, energy dissipation, and damage tolerance in members subjected to reversed cyclic loading (Bayasi and Gebman 2002; Jevtic et al., 2008). These technical benefits can be utilized both in semi-structural elements such as thin sheets, flat sheets, corrugated and cladding panel as well as in load bearing members (Oladele et al., 2008).

The integration of FCCs in housing construction because of their advantageous properties can serve as avenues for providing safe, affordable, environmentally-friendly shelter for the ever increasing world population. It is also a means of converting the abundant waste generated in paper mills / factories to wealth and thus help in cushioning the over-exploitation of dwindling timber resource in many developing countries like Nigeria.

A viable paper cement board cottage industry is currently flourishing within Ibadan, the capital city of Oyo State, Nigeria. These industries utilize waste from paper mills within Ibadan and its environs as raw materials for the production of FCCs. Characterization of these composites in terms of strength and sorption properties will be beneficial to the Nigerian populace who are now utilizing these items in building construction. This work seeks to examine the strength and sorption properties of some selected locally fabricated paper-cement boards within Ibadan metropolis.

## 2.0 Materials and Methods

Paper Cement Boards (PCBs) were sourced from four small scale factories in Ibadan, Nigeria, namely: (1) Dele Skylite Nigeria Limited, Apete, Ibadan (2) Mojim Nigeria Enterprises, Abidiodan, Iyana Church, Ibadan (3) Petopeg Ceiling manufacturers, Idito, Sango-Eleyele Road, Ibadan (4) Rasheed Asbestos Nigeria Limited, Iyana Offa, Lagelu, Ibadan. The Materials used by the respective companies for the production of PCBs were carton paper, cement, and water (paper-cement ratio: 50:50); carton paper, newspaper, cement, and water (paper-cement ratio: 60:40); any waste paper, cement, and water (paper-cement ratio: 40:60) and carton paper, cement, and water (paper-cement ratio: 50:50).

The production process entailed soaking of waste papers in cylindrical drums for a period of time depending on the nature of the paper, pulverization of the wet fibre by hammer milling, mixing of the slurry with cement, casting in a mould and curing for 28 days. Close examination of these factories revealed that one out of the four industries (Dele Skylite) engaged in semi-mechanised production process. Also, gypsum and fibreboards were purchased at a local market in Ibadan for comparison with the properties of PCBs.

### 2.1 Three Point Flexural and Impact Strength Tests

Test samples were cut into 50mm (width) by 150mm (length) and loaded perpendicularly to the direction of casting on a servo-hydraulic Universal Testing Machine (UTM) in accordance with ASTM D 1037-89 (1991). The Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) were thereafter estimated while the Internal bond strength for each test samples was evaluated from the results obtained from the flexural test as follows:

$$\text{Internal Bond Strength} = \frac{Force\ at\ Rupture}{Width\ x\ Length}\ (\text{N/mm}^2)$$

Impact test was based on repeated blows from increasing heights on the flat surface of the boards while noting the minimum height of the ball that caused the failure impact.

### 2.2 Water Sorption Test

The test specimens were cut into 50mm (width) and 50mm (length) square samples, weighed and thereafter immersed in distilled water at room temperature for 2 hours and 24 hours after which the samples were removed from the water, allowed to drain for a period of about 10 minutes and re-weighed. The percentage water absorption for each test sample was calculated as follows:

$$Water\ Absorbtion\ (\%) = \frac{M_1 - M_0}{M_0}\ x\ 100$$

$M_1$ = Final weight , $M_0$ = Initial weight

## 3.0 Results and Discussion

### 3.1 Density and Internal Bond Strength

The mean values of the densities and internal bond strength of the locally manufactured cement composites as compared with gypsum and fiberboards are shown in Figures 1 and 2. It was observed that for gypsum and fibreboards the densities had a direct relationship with internal bond strength with mean values ranging between 0.28 and 0.78g/cm$^3$ and 0.0052 and 0.0102N/mm$^2$

respectively. The density and internal bond strength of the paper cement boards however seemed to be a function of the composite mix, decreasing as the paper content increases. This agrees with the findings of Moslemi (2008) who found that increasing the quantity

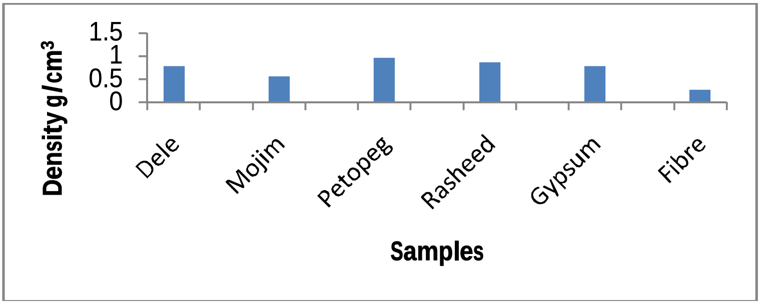



Fig 1: Densities of Selected Ceiling Boards

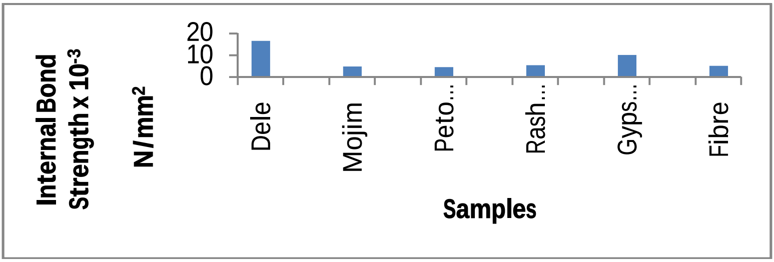



Fig 2: Internal Bond Strength of Selected Ceiling Boards

of fibres in a cement matrix decreases the density of the composites since fibres tend to have lesser density. Also, the pattern of variation in the locally manufactured paper boards revealed an inverse relationship between the density and internal bond strength. The mean densities and internal bond strength were between 0.56 to 0.97g/cm$^3$ and 0.0046 to 0.0165N/mm$^2$ respectively.

### 3.2 Strength Properties

The moduli of ruptures and elasticities (MORs and MOEs) and the impact strength of the paper cement boards as compared to those of fibreboard and

Gypsum board are presented in Table1 and Fig 3. The strength properties of the PCBs are generally low and are only suitable for non-structural applications (Olorunnisola, 2006). As shown, the mean MOR and MOE were

lowest in fibreboard with values of 1.13N/mm$^2$ and 164.42N/mm$^2$ respectively while the impact strength was highest with a value of 1.5Nm. This may be due to the fact that fibres increase the absorption of energy under impact load. Boards obtained from Dele skylite exhibited higher strength properties with MOR, MOE and impact strength values of 3.06N/mm$^2$,

2140.13N/mm$^2$ and 1.37Nm respectively. This observation is in line with the report of Mohr et al (2004) who noted

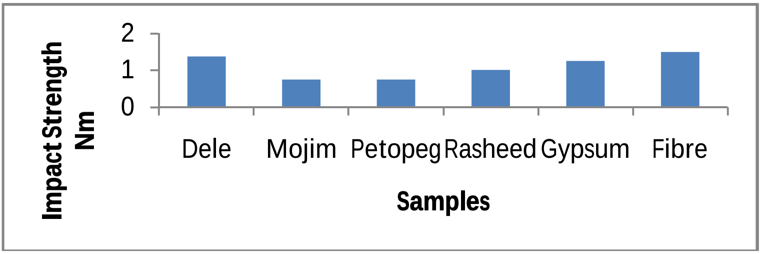



Fig 3: Impact Strength of Selected Ceiling Boards

Table 1: Moduli of Rupture, Elasticity and Water Absorption of Selected Fibre Composites within Ibadan Metropolis

| Fibre Composites | MOR (N/mm$^2$) | MOE (N/mm$^2$) | WA 2 Hr (%) | WA 24 Hr (%) |
|---|---|---|---|---|
| Gypsum | $4.8^{A}$ | $1106.3^{B}$ | $54.7^{AB}$ | $58.7^{A}$ |
| Fibreboard | $1.1^{C}$ | $164.4^{E}$ | $25.9^{BC}$ | $69.7^{A}$ |
| Dele Skylite | $3.1^{B}$ | $2140.1^{A}$ | $43.1^{ABC}$ | $45.3^{AB}$ |
| Rasheed | $1.6^{C}$ | $966.8^{CB}$ | $42.2^{ABC}$ | $45.5^{AB}$ |
| Mojim | $1.4^{C}$ | $799.7^{CD}$ | $63.5^{A}$ | $72.4^{A}$ |
| Pentopeg | $1.2^{C}$ | $569.2^{D}$ | $16.0^{C}$ | $18.6^{B}$ |

Means with the same letters are not statistically different

Table 2: Analyses of Variance of Moduli of Rupture and Elasticity and Water Absorption of Selected Fibre Composites within Ibadan Metropolis

| Source | Df | Mean Square MOR ($N/mm^2$) | MOE ($N/mm^2$) | WA 2 Hr (%) | WA 24 Hr (%) |
|---|---|---|---|---|---|
| Fibre Composites | 5 | 6.25* | 1335303.59* | 931.03 | 1186.23 |
| Error | 12 | 0.09 | 18168.25 | 340.51 | 420.6 |

- Significant at 0.05 level of probability

that the properties of fibre cement composites are largely controlled by the manufacturing process. Also, Soroushian and Marikunte (1990) reported that increasing the fibre content increased flexural strength and toughness as well as impact resistance. However, the strength properties of boards from Petopeg factory were the lowest with mean MOR, MOE and impact value of $1.22N/mm^2$, $569.23N/mm^2$, and 0.75Nm respectively. This may be attributed to the poor fibre quality employed in the manufacturing process.

Analysis of variance and Duncan's multiple tests revealed significant differences ($P < 0.05$) in the MORs and MOEs of the tested composites (Table 2). Except for composites obtained from Dele Skylite, the strength properties of products obtained from other factories were not significantly different from each other.

### 3.3 Water Absorption

The water absorption (WA) values are shown in Table 1. As shown, the paper cement and gypsum boards had high initial WA rate (2 hours) and a subsequently low WA rate after 24 hours. What this implies is that the PCBs are not dimensionally stable and thus are not suitable for exterior applications (Olorunnisola, 2006). This could possibly be due to the presence of air spaces and voids which are quickly filled up as a result of water uptake resulting in subsequent disintegration of the samples. Samples obtained from fibreboard absorbed more water (about 2.5 times) after 24hrs (69.66%) in comparison with results obtained after 2hrs (25.90%). This observation could be possibly due to the absorptive role of fibres.

Boards from Mojim factory had the highest water absorption with a mean value of 63.53% after 2hrs and 72.39% after 24hrs, while boards from Petopeg factory had the least water absorption with a mean value of 16.03% and 18.5% after 2hrs and 24hrs respectively. This observation is in line with those of Oladele et al. (2009) who noted that increase in fibre content enhances the water sorption of FCCs.

Statistical analyses revealed that the sorption properties of the tested composites were generally not significantly different (P < 0.05) from each other (Tables 1 and 2).

## 4.0 Conclusions

It can be deduced from this work that:

(i) The paper cement boards manufactured locally were not inferior to the commonly known gypsum and fibreboards in the properties evaluated.

(ii) The paper cement board are only suitable for non-structural application especially in interior applications.

(iii) Processing methods and product mix play significant role in composite performance in terms of strength and sorption properties.

(iv) Paper cement ratio of 50:50 proved to be effective in improving both strength and sorption properties of the boards.

## References


ASTM, (1991). American Society for Testing and Materials. Annual Book of ASTM Standards. Section 4. Construction. Volume 04.09 Wood. ASTM D 1037-89.

Bayasi, Z. and Gebman, M.(2002). Reduction of Lateral Reinforcement in Seismic Beam-Column via Application of Steel Fibres. ACI Structural Journal. Vol. 99, No. 6, pp.772-780.

. Jevtic, D., Zakic, D. and Savic, A. (2008). Modelling of Properties of Fibre Reinforced Cement Composites. Journal of Architecture and Civil Engineering. Vol. 6, No. 2, pp. 165-172.

Mohr, B.J., El-Ashkar, N.H. and Kurtis, K.E. (2004). Fiber-Cement Composites for Housing Construction: State-of-the-Art Review. 112-128pp

Moslemi, A. (2008). Technology and Market Considerations for Fibre Cement Composites. 11th International Inorganic-Bonded Fibre Composites Conference (IIBFCC). 2008. Pp. 113-129.

Oladele, I.O., Akinwekomi, A.D., Aribo, S. and A.K. Aladenika. (2009). Development of Fibre Reinforced Cementitious Composite for Ceiling Application. Journal of Minerals and Materials Characterization and Engineering. Vol. 8, No. 8, pp. 583-590.

Olorunnisola, A.O. 2006. Strength and water absorption characteristics of cement-bonded particleboard produced from coconut husk. Journal of Civil Engineering Research and Practice 3.1:41- 49

Soroushian, P. and Marikunte, S. (1990). "Reinforcement of Cement-Based Materials with Cellulose Fibers," Thin-Section Fiber Reinforced Concrete and Ferrocement, SP-124, American Concrete Institute, Detroit, 99-124.

# Impetus for Recycling Activities across the Globe: An Overview

*Adu, D.A.
Department of Science and Technology, Leadwell Academy, KM 4, Idiroko road, Ota, Ogun State
e-mail: dafe20062007@yahoo.com
and
Aremu, A.S.
Department of Civil Engineering, University of Ilorin, Ilorin, Nigeria
e-mail: aremu_adeniyi@yahoo.com
*Corresponding author

## Abstract

Solid waste is a prominent feature since the existence of life and the need to manage solid waste is felt all over the world. This paper presents an overview of solid waste generation rates and characteristics, as a spur to recycling activities across the globe. Disparity in generation rates and composition of solid wastes was observed across the globe. According to income groups, countries with higher income tend to generate more solid wastes per capita which have higher proportions of recyclables and inorganics, than developing countries. A typical solid waste stream from low-income, middle-income and high-income countries is composed of about 17%, 43% and 62% recyclable materials respectively. However low-income and middle-income countries still have under developed recycling plans. Therefore it suggested that governments in developing countries should build capacity among micro and small scale enterprises in order to derive maximum social, economic and environmental benefits from recycling.
Key words: Solid waste, composition, recycling, income groups

## 1.0 Introduction

Solid wastes are all the wastes arising from human and animal activities that are normally solid and are useless or unwanted (Tchobanoglous, 1993). As such solid waste is a byproduct from various aspects of a society. The term “waste” is subjective because the possessor determines at a particular moment what is considered a waste. However, one common point of concurrence for all definitions of solid waste in literature is the use of the word “solid” which typifies a non-liquid, non- gaseous material and “waste” which is a discarded material (Aremu, 2010).

Solid waste is multidirectional in context when viewed as a nuisance or resource with multiplier effects on various aspects of human endeavor. Solid waste management entails an understanding of waste generation, storage, collection, transport, processing, and disposal (Mihelcic and Zimmerman, 2010). Planning, design and implementation of solid waste management schemes vary from country to country and from city to city. Over the years several solid waste management methods have been fused together and coordinated to form an Integrated Solid Waste Management (ISWM) plan. The ISWM is a broad concept taking into consideration economic, environmental, social and institutional dimensions (Beukering et al., 1999).

The integration aspect lies in the trade-off between these four dimensions; economic, environmental, social, and institutional components. Actual integration takes place at the level of selection and combination of management options, participation of various stakeholders, interaction between the waste system and other relevant systems, and consideration of driving forces which influence the output and characteristics of wastes. The United Nations Environment Program (UNEP) equally endorsed a common approach to waste management known as the Integrated Waste Management (IWM) hierarchy. This hierarchy lists the options for the management of solid wastes according to decreasing priorities as waste reduction, reuse, recycling, composting, incineration, and landfilling. Accordingly, the IWM hierarchy seeks to list options to trim down the output of wastes and favour resource recovery from wastes.

## 2. 0 Output of solid wastes according to income levels

The output and characteristics of solid wastes can be regarded as a quantitative indicator of the use of resources, and the aftermath of production and consumption processes. Economic prosperity and population growth are major inputs that account for the output of wastes (Zia and Devadas, 2008; Ağdağ, 2009; Mihelcic and Zimmerman, 2010). The World Bank classified the economy of countries according Gross National Income per capita (July 2011 classification) as low income, $1,005 or less; lower middle income, $1,006 - $3,975; upper middle income, $3,976 - $12,275; and high income, $12,276 or more (http://data.worldbank.org). From this classification, 35 countries are regarded as low-income countries, 56 are lower-middle income countries, 54 are upper middle income countries, and 70 are high-income countries. Countries with low-and middle-income economies are referred to as developing countries while countries with high income economies are termed industrialized countries.

This criterion (economic status) forms a key indicator of a country's development and may reflect similar solid waste generation rate, composition and management technique of a group of countries in the same class. Some solid waste generation rates for low-income, middle -income and industrialized countries are shown in Table 1. The per capita solid waste generation rates is highest for industrialized countries, followed by middle income countries while low income countries have low per capita generation rates.

Table 1: Solid wastes generation rate based on income groups

| Type of waste and origin | Low income country | Middle income country | High income country |
|---|---|---|---|
| Mixed urban waste Large city(kg/capita/day) | 0.50 - 0.75 | 0.55 – 1.10 | 0.75 – 2.2 |
| Mixed urban waste Medium city (kg/capita/day) | 0.35 - 0.65 | 0.45 – 0.75 | 0.65 – 1.50 |
| Residential waste only (kg/capita/day) | 0.25 - 0.45 | 0.35 – 0.65 | 0.55 – 1.00 |

Source: Cointreau (2006)

Specifically the rate of generation of residential waste in industrialized countries is about one and half times more than middle income countries and double the amount generated by low income countries.

A summary of the characteristics of solid waste from different income levels is presented in Table 2. It was observed that a typical solid waste from a low and middle income country (developing country) contains more organic materials and less paper, hence the waste is normally high in moisture content and low in calorific heating value. On the other hand, solid wastes from industrialized countries contain more paper, metals and plastics, and less organic materials. The resulting solid waste therefore has a high calorific value and low density.

Table 2: Solid wastes composition and characteristics according to income groups

| Composition | Low-income country | | Middle income country | | High income country | |
|---|---|---|---|---|---|---|
| | * | ** | * | ** | * | ** |
| Paper | 2% | 1-10% | 14% | 15- 40% | 31% | 15- 40% |
| Metal | 2% | 1 – 5% | 2% | 1 – 5% | 8% | 3 – 13% |
| Plastics | 2% | 1 – 5% | 11% | 2 – 6% | 8% | 2 – 10% |
| Glass | 4% | 1-10% | 2% | 1-10% | 10% | 4-10% |
| Textile, rubber, leather, wood | 7% | N/A | 14% | N/A | 5% | N/A |
| Miscellaneous | N/A | 1-5% | N/A | 1-5% | N/A | 2-10% |
| Vegetable | 60% | 40–85% | 47% | 20 –65% | 25% | 20–50% |
| Others | 22% | N/A | 10% | N/A | 13% | N/A |
| Fines | N/A | 15–50% | N/A | 15 – 40% | N/A | 5 – 20% |
| **Density in trucks ( kg/m$^3$) | 250-500 | | 170-330 | | 120-200 | |
| **Moisture (%) | 40-80 | | 40-60 | | 20-35 | |
| **Calorific heating value (kcal/kg) | 800 - 1100 | | 1000 - 1500 | | 1500 - 2700 | |

*Source: www.inece.org **Source: Cointreau (2006)

**3. Implications of solid waste composition on recycling**

The previous sections show how waste generation rate and composition vary according to income levels. This information can be used to access materials/energy recovery options. Recycling, which is the extraction and recovery of valuable materials from scraps or other discarded materials, is employed to supplement the production of new materials. Basically, waste materials are reused, or remanufactured into new products. Recyclable solid wastes include textile, construction wastes, paper, plastic, ferrous and nonferrous metals, and glass. The plastic recycling industries shred plastics into pellets to manufacture other plastics and allied products. Some recycling factories process waste paper and cardboard to tissue paper, newsprint or bulk packaging materials. Waste glass is processed by glass or terrazzo companies, non ferrous metals are processed by aluminum smelters and tin is recovered from aerosol cans (Palczyski, 2002). Some products, such as paper, plastics, glass, can be recycled or reused over and over again, and many new products are being made from recovered materials ( http://www.greenrenewing.com).

Recycling activities in industrialized countries have become popular and some nations promote recycling through financial incentives and provision of market for these recyclables. In Europe, the European Union (EU) has launched a strong regulation on waste management which anchors around

recycling and recovery of waste. EU directives now require member States to introduce legislation on waste collection, reuse, recycling and disposal of their waste streams. A study of waste management activity of countries within the EU shows that Austria leads the group by recycling 69.86% of its waste (DEFRA, 2009). This is followed by Netherlands with 67.40% recycling/composting rate, Germany with 67.34% and Belgium with 60.62%.

Bulgaria and Malta have the least recycling rate of 3.93% and 4.85% respectively.

Most recycling activities in developing countries are performed by the informal sector with minimum input from the government (Cointreau-Levine, 1994; UNEP-IETC and CalRecovery, Inc., 2005). In some low-income countries, scavengers recycle about 10% of the waste stream because of the economic value, in addition to being an effective means of waste reduction (www.inece.org). In the middle and low income cities of East Asia/Pacific region, the informal sectors have also made enterprises from gathering, trading, and reprocessing materials (UNEP-IETC and CalRecovery, Inc., 2005).

Recycling of waste furnishes economic returns. The economic returns from some recycled goods in Argentina show that plastic wrap (chlorinated plastics with stretch ability) provides the highest economic return followed in decreasing returns by cardboard and paper, other plastics, and plastic soft drink bottles (McBean et al., 2005). In Turkey, the market price of recycled metal outstrips the revenue from other recyclables such as paper, cardboard, plastics, glass and compost. In Nssuka (Nigeria), the unit price of bones is the highest followed by batteries, tyres, aluminum, scrap metals and plastics respectively (Nzeadibe, 2009). Also Agunwamba (2003) observed that a well-planned recycling program in Nigeria could result in 78% savings in waste management cost and 79.5% landfill avoidance cost.

Aside from the economic gains of recycling, environmental benefits such as reduction of greenhouse gas emissions, and air and water pollution associated with production from virgin raw materials accrue from waste recycling. For example, the United States Environmental Protection Agency reported that in 2009, the United States recycled 80 million tons of wastes which is equivalent to a reduction of 178 million metric tons of carbon dioxide and savings of almost 1.3 quadrillion Btu of energy.

## 4. Conclusion

Solid waste is an inevitable consequence of human activities on earth. However, there is disparity in the generation rates and composition of solid

wastes across the globe. According to income groups, countries with higher income tend to generate more solid wastes per capita than lower income countries due to higher commercial and industrial activities. Solid waste arising from such income group has higher proportions of recyclables and inorganics, which generally have high calorific values. Solid wastes from developing countries are mainly organics with lower calorific value. Recyclable materials in low-income, middle-income and high-income countries comprise about 17%, 43% and 62% of the total waste stream respectively. Several social, economic and environmental benefits amass from solid waste recycling; hence it is recommended that well planned recycling programs should be incorporated into solid waste management plans.

## References

Ağdağ, O.N. (2009), "Comparison of Old and New Municipal Solid Waste Management Systems in Denizli, Turkey". Waste Management, 29 (1), 456-464.

Agunwamba, J.C. (2003), "Analysis of Scavengers' Activities and Recycling in Some Cities of Nigeria". Environmental Management, Vol. 32, No.1, 116-127.

Aremu, A.S. (2010) A GIS-AHP Optimization Strategy for Spatial Location of Municipal Solid Waste Bins in Ilorin, Nigeria. Unpublished Ph.D. Thesis, Department of Civil Engineering, University of Ilorin.

Beukering, P.V., Sehker, M., Gerlagh, R. and Kumar, V. (1999), "Analyzing Urban Solid Waste Management in Developing Countries: A Perspective on Bangalore, India". Working Paper No. 24. Collaborative Research in the Economics of Environment and Development (CREED).

Cointreau, S. (2006), "Occupational and Environmental Health Issues of Solid Waste Management". The International Bank for Reconstruction and Development/ The World Bank, Washington, D.C.

Cointreau-Levine, S. (1994), "Private Sector Participation in Municipal Solid Waste Services in Developing Countries". The World Bank, Washington, DC, U.S.A.

DEFRA (2009) Municipal Solid Waste Management in the European Union. Accessed on the 29th of May, 2012 from http://www.defra.gov.uk/statistics/environment/waste/wrfg08-munec/

http://data.worldbank.org/about/country-classifications/country-and-lending-groups. "Country and Lending Groups Data". Accessed on the 13th of May, 2012.

http://www.greenrenewing.com/waste-paper-trading-and-recycling-in-nigeria/. "Waste paper trading and recycling in Nigeria". Accessed on the 29th of May, 2012 .

McBean, E.A., Del Rosso, E., and Rovers, F.A. (2005), "Improvements in Financing for Sustainability in Solid Waste Management". Journal of Resources, Conservation and Recycling, 43, 391-401.

Mihelcic, J.R. and Zimmerman, J.B. (2010), "Environmental Engineering: Fundamentals, Sustainability, Design". John Wiley and Sons, Inc. U.S.A.

Nzeadibe, T. C. (2009), "Solid Waste Reforms and Informal Recycling in Enugu Urban Area, Nigeria". Habitat International, Vol. 33, 93-99.

Palczynski, R.J. (2002), "Study of Solid Waste Management Options for Africa". A Project Report Prepared for Africa Development Bank, Sustainable Development & Poverty Unit, Abidjan, Cote d'Ivoire.

Tchobanoglous, G., Thiesen, H., and Eliassen R. (1993), "Solid Wastes: Engineering Principles and Management Issues". McGraw-Hill, Inc., New York, U.S.A.

UNEP-IETC and CalRecovery, Inc. (2005), "Solid Waste Management, Volume II: Regional Overviews and Information Sources". United Nations Environmental Programme, Division of Technology, Industry and Economics, International Environmental Technology Centre, Japan.

www.inece.org. "Residential and Industrial (Solid) Waste Disposal Support Package, February, 1995". Accessed on the 20th January, 2007.

Zia, H. and Devadas, V. (2008), "Urban Solid Waste Management in Kanpur: Opportunities and Perspectives". Habitat International, 32 (1), 58-73.

# Meeting the Millennium Development Goals through Biomass Waste Reuse in Civil Engineering Construction – Case Study of Corn Cob Ash

O.A. Apampa[1], Y.A. Jimoh[2] & Popoola, M.O.[3]
[1,2]Department of Civil Engineering, University of Ilorin
[3]Department of Civil Engineering, Moshood Abiola Ploytechic, Abeokuta
[1]pampasng@yahoo.com [2]dryajimoh@yahoo.com

## Abstract

The aim of this paper is to establish a link between biomass waste reuse in civil engineering construction and socio economic well being of the country. It highlights the menace posed by biomass wastes in Nigeria, the mechanism for conversion of biomass waste to pozzolanic ash and the place of pozzolans in Portland cement concrete production. The paper goes on to review existing literature on the effective use of biomass waste as pozzolans worldwide, paying particular attention to corn cob – corn being the third most produced crop in Nigeria, and focussing on the data gap in the available literature. The paper concludes by identifying the Millennium Development Goals that would be achieved if efforts are made towards the effective utilization of corn cob as a pozzolan and calls on researchers to take steps in filling the critical data gap existing in this area.

## 1.0 Introduction
## 1.1 Background

The ability of any living specie to survive has always depended on its ability to respond appropriately to changes in its environment. Mankind is no exception. In Nigeria and many other developing countries, the challenges posed by the global climate change are being further compounded by the improper management of the challenges facing first generation city dwellers, principal among which is improper habits and systems of waste management and re-use, leading to increasing urban squalor, poverty and disease. With the rate of urbanisation in Africa estimated at 3.5 % annually and increasing (UNIDO, 2009), the problems are set to worsen except innovative ways of managing the environment through effective waste management and re-use are developed.

Table 1 below shows the per capita waste generation in some selected cities in Africa and the rate of collection.

Table 1: Solid Waste Generation and Collection Rates in African Countries

| City | Per capita annual waste generation (kg/year) | Households with garbage collection (%) |
|---|---|---|
| Abidjan/ Cote D'Ivoire | 365 | 70 |
| Ibadan/ Nigeria | 401 | 40 |
| Kinshasa/ Congo | 438 | Not Available |
| Bujumbura/ Burundi | 511 | 41 |
| Lome/ Togo | 693 | 37 |

Source: UNIDO,2009

It is clear from Table 1 above that with a huge population of some 160 million people and a high population growth rate of 2.5% (World Bank, 2012) waste generation in Nigeria is high and on the increase, collection rate is low, with organic waste comprising of biomass waste and municipal waste accounting for 56% of this (UNIDO, 2009).

### 1.2 Agricultural Production in Nigeria

In order to feed its huge population, Nigeria is necessarily a major producer of agricultural products, and is set to remain so for a long time to come considering the relatively high population growth rate. Indeed while oil and gas accounts for 80% of government earnings, agriculture actually contributes the highest amount to GDP at 40% (NBS, 2012), and is set to further increase on account of increasing realization that agriculture and not oil holds the key to Nigeria's sustainable development. Increased agricultural production will naturally lead to increased crop residues and increased biomass waste generation. Table 2 below gives the major food crops produced in Nigeria

Table 2: Major Food Crops in Nigeria (Source: FAOSTAT, 2010)

| Rank | Food Crop | Production (MT) |
|---|---|---|
| 1 | Cassava | 37504100 |
| 2 | Yam | 29148200 |
| 3 | Maize (Corn) | 7305530 |
| 4 | Vegetables | 5945600 |
| 5 | Sorghum | 4784100 |
| 6 | Millet | 4124560 |
| 7 | Citrus Fruits | 3488400 |

Substantial amounts of biomass waste are to be expected from the production of these agricultural products. But while cassava and yam peels are

immediately consumed by goats at the place of peeling, a large portion of corn is transported to cities, where they are consumed as roasted or boiled corn, the cob being discarded, often indiscriminately. Table 2 shows that corn is the third most produced food crop in Nigeria, and indeed Nigeria is the second highest producer of corn in Africa and the 13th highest in the world (FAOSTAT, 2010). With a corn to cob ratio of 0.15 (Halvorson and Johnson, 2009), over one million metric tonnes of corn cob are generated in Nigeria annually. Though some portion is used as feedstock for chicken feed, most of it still end up as biomass waste, constituting an environmental hazard in form of blocked stormwater channels and indiscriminate waste dump sites, particularly in the cities.

### 1.3 Menace of Wastes

Floods and epidemics, both of which are rooted in improper waste management practices are the major natural disasters afflicting Nigeria (Preventionweb, 2012). Table 3 below gives a listing of the top ten natural disasters reported in the country from 1983 to 2010 and the attendant losses in lives and money.

Table 3: Economic Damages from Natural Disasters (Source: Preventionweb, 2012)

| Year | Disaster Type | Lives Lost | Economic Damage (US$ x 1000) |
|---|---|---|---|
| 2000 | Flood | Not reported | 4,805.- |
| 2001 | Flood | Not reported | 3,000.- |
| 2001 | Epidemic | 340 | Not reported |
| 2003 | Flood | Not reported | 2,570.- |
| 2005 | Flood | Not reported | 147.- |
| 2005 | Epidemic | 561 | Not reported |
| 2010 | Flood | Not reported | 30,000.- |
| 2012 | Epidemic | 353 | Not reported |

Major flood disasters in Nigeria include the Ogunpa floods (Babasessy, 2012) and the perennial flooding of Lagos Island (Obasi, 2011). Obviously the more use that can be found for any biomass waste, the less likely it is to constitute a nuisance.

## 2.0 Biomass Waste as Pozzolans in Civil Engineering Construction

A number of biomass waste products are increasingly being identified as pozzolans that could partially replace cement in civil engineering construction thereby creating jobs, reducing the menace of wastes in the cities and rural area that cause floods and epidemics, and help in reducing $CO_2$ emissions associated with the production of ordinary Portland cement.

A pozzolan is defined by ASTM C 618-93 quoted by Neville and Brooks (2008) as "a siliceous or siliceous and aluminous material, which in itself possesses little or no cementing property, but will in a finely divided form – and in the presence of moisture- chemically react with lime, $Ca(OH)_2$) produced from the hydration of cement, at ordinary temperatures to form compounds possessing cementatious properties".

A number of work has been reported on biomass waste as pozzolans, locally and internationally. Rice Husk Ash has particularly been reported by researchers in the United States and Thailand – major rice producing countries of the world. For example while Muga et al (2005) reported Rice Husk Ash among other natural pozzolans that could lower overall $CO_2$ emissions and could be made available to developing countries as part of "appropriate technology", Subbukhrishna, et al, (2009) reported a method of producing industrial grade silica from RHA. Coutinho (2002) reported on Portuguese Rice Husk Ash as a pozzolan able to improve the durability and strength of concrete. In Nigeria, Alhassan (2008) investigated RHA as a chemical stabilizing agent in soils and reported and increase in CBR values at 6 – 8% RHA addition. Olonode (2010) carried out a comparative analysis of the cost of producing RHA and arrived at a figure of 45% of the cost of cement and posited that the cost of housing delivery in could be reduced if RHA blended cements were used in housing construction. Amu and Adetuberu (2010) worked on Bamboo Leaf Ash (BLA) just like Dwivedi et al (2006). While Dwiveldi tried to establish the pozzolanicity of BLA by the determination of free lime and by testing the compressive strength of blended cement/ sand mortar prisms, Amu and Adetuberu investigated BLA as a stabilizing agent for soils in highway construction and reported increases in maximum dry density, CBR and shear strength values, with increasing addition of BLA up to 6%, concluding that BLA is a technically viable pozzolan and stabilizing agent respectively. Locust bean pod ash widely used from time immemorial as a food spice, has recently been reported as a pozzolan (Adama and Jimoh, 2011). The cited reference reveals that the Nupe people of North central Nigeria had used an extracted liquid from the pod husk as binding agent for local clay tiles.

Corn cob ash has similarly been established by Adesanya and Raheem (2009a, 2009b) as pozzolan and went further to report on desirable qualities of concrete made with CCA blended Portland cement concrete. Other researchers have suggested that different pozzolans could be mixed depending on local availability e.g. corn cob ash with ground granulated blast furnace slag (Binici et al, 2009), and Adepegba (1990).

These research efforts are still collectively in the developmental stage and it is necessary to continue to build up the body of available knowledge in this field, especially in the areas of furnace technology, reaction kinetics and ash characterization. Lack of proper of these parameters are a probable of some of the contradictory results being reported in some literature, for example Turkel et al (2007) reported that "acid resistance of mortars made from Portland cement was better than the pozzolanic cement incorporated samples". This goes against the very nature of the reaction expected from a pozzolana cement going by its chemical composition. But on the other hand, Brunjes (2011) reported that a US company, Dynastone has built an entire business making acid resistant concrete pipes made from pozzolana cement.

## 3.0 The Mechanism of Pozzolanic Action

To qualify as a Pozzolan, ASTM C 618 – 93, quoted by Neville and Brooks (2008) requires that the material should contain a minimum of 70% of Silica (SiO2), Alumina ($Al_2O_3$) and Ferric Oxide ($Fe_2O_3$) all together. Table 4 gives the composition of a typical pozzolan.

Table 4: Chemical Composition of a Typical Pozzolan (Source: Raheem and Adesanya, 2009b)

| Chemical Constituents | Average Composition % |
|---|---|
| $SiO_2$ | 66.38 |
| $Al_2O_3$ | 7.48 |
| $Fe_2O_3$ | 4.44 |
| CaO | 11.57 |
| MgO | 2.06 |
| $SO_3$ | 1.07 |
| $Na_2O$ | 0.41 |
| $K_2O$ | 4.92 |
| **Total $SiO_2$+Al2$O_3$** | **73.86** |

Cement compounds are basically made of tricalcium silicate ($C_3S$), dicalcium silicate ($C_2S$) and tricalcium aluminate ($C_3A$), with $C_3S$ and $C_2S$ being the

main cementatious compounds. The approximate hydration reaction can be written thus (Neville and Brooks, 2008):
For $C_3S$:
$2C_3S + 6H \rightarrow C_3S_2H_3 + 3Ca(OH)_2$ (1)

For C2S:
$2C_2S + 4H \rightarrow C_3S2H_3 + Ca(OH)_2$ (2)

The hydration products being the calcium silicates hydrates (C-S-H) and hydrated lime Ca(OH)2.
This hydrated lime is what makes concrete susceptible to sulphate and acid attack and is key to understanding the mechanism of action of the pozzolan. The SiO2 content of the pozzolan gradually reacts with $Ca(OH)_2$ to form the more desirous calcium silicate hydrates in the following reaction:

2SiO2 + 3Ca(OH)2 → C3S2H3 + (other products of hydration) (3)

Thus improving both the quantity and quality of the C-S-H gel.

## 4.0 The Mechanism of Biomass Waste Ash Formation

Thermal conversion of biomass waste can be in the form of simple combustion, pyrolysis and gasification, and all three can be present in the same process depending on the path of the mass-loss kinetics. The temperature-decomposition profile and the kinetics of its thermal decomposition are rapidly determined by Thermogravimetry (Ledakowicz and Stolarek, 2002). The ash of interest here is the residue from mass-loss reactions and is schematically represented thus:

BIOMASS WASTE→MOISTURE + CHAR + VOLATILE

Pyrolysis of the Char is what gives rise to ash, schematically represented thus:
CHAR→VOLATILE + ASH
These volatiles are useful as sources of energy
Typical approach to the kinetics of thermal decomposition of biomass waste is dividing the volatile evolution into a few fractions – lumps, each of which is represented by a single first – order reaction. These lumps are assumed to be non-interacting and evolved by independent parallel reactions:
Biomass waste – volatile i i= 1,2,..n
If pyrolysis is performed at a constant rate β, the first order rate can be expressed in the following form

$$\frac{dV_i}{dT} = \frac{k_i}{\beta}(V^*_i - V_i) \qquad (4)$$

where $V^*_i$ is the ultimate yield of the ith volatile ($\tau \rightarrow \infty$), $V_i$ is the accumulated amount of evolved volatiles from lump i upto time $\tau$, $k_i$ is the rate constant, which depends on the Arrhenius equation

$$k_i = A_i \exp(-E_i/(RT)) \qquad (5)$$

At the peak temperature at which volatile evolution reaches maximum ($T_{max}$), the time derivative of the reaction rate should be equal to zero. The values of $T_{max}$ of the volatile lumps at different heating rates can be determined from peak resolution curves of derivative thermo-gravimetric (DTG).

A typical TG- DTG curve for biomass waste decomposition is as shown in Figure 1 below:

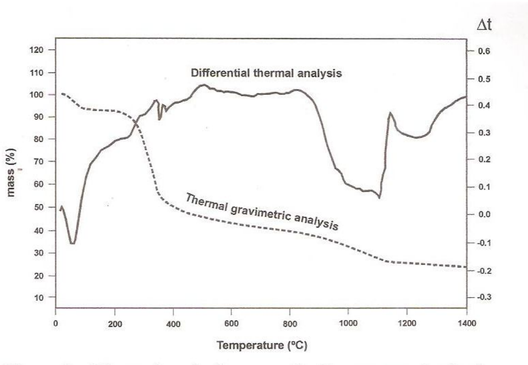



Figure 1: TG-DTG curves for Rice Husk Ash (Source: Coutinho,2002)

It can be seen from the figure that the highest rate of mass loss occurs around 400°C. However all available literature report a terminal temperature of 650°C for the production of the ash. The ash becomes crystalline at higher temperatures.

## 5.0 Carbon Dioxide Emissions from Cement Production

Figure 2 is a representation of the $CO_2$ emissions from the manufacturing of cement, showing that 46.3% of the $CO_2$ released is from the chemical reaction of the pyroprocess.

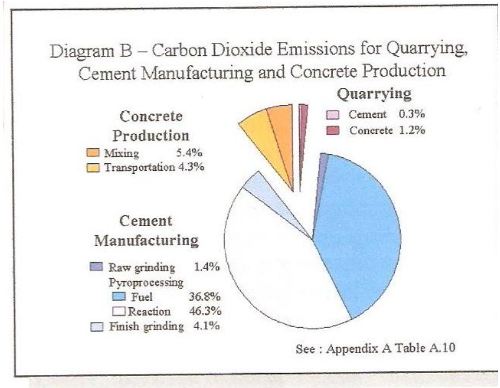



Figure 2: Distribution of CO2 Emissions in the Cement Concrete Industry (Source: USDoE, 2003)

The 46.3% CO2 emission during pyroprocessing is inherent in the nature of the raw materials undergoing chemical reactions. Improvement in furnace technology will have little effect on this category.

## 6.0 The Corn Cob Ash as a Pozzolan

As earlier stated, 7.3millions tonnes of corn are harvested annually in Nigeria, 50 % of this in the southwest, but an increasing percentage now being grown in the Savannah regions (North Central Zone) due to a shift from sorghum cultivation to corn (Iken and Amusa, 2004). With a corn to cob ratio of 0.15, over one million tonnes of cob are available, some of which are used as feedstock for chicken, but most of it going to waste. With increasing population and continuous demand for corn, these figures are set to increase, with attendant increases in cob waste and the attendant environmental hazards.

About 20million tonnes of cement worth 350 billion naira are consumed annually in Nigeria (Adeloye, 2011) contributing some 20million tonnes of carbon dioxide to the atmosphere in defiance of the Kyoto Protocol on climate change (USDoE, 2003).

Nigeria and other developing countries blessed with a large production base for corn cob can leverage on this to penetrate this 350billion naira market and to create jobs while reducing the menace of biomass waste in the environment and reducing GHG emissions into the atmosphere, especially considering that $CO_2$ emissions from biomass waste combustion are considered GHG neutral (Chungsangunsit et al, 2009).

## 7.0 The Knowledge Gap

The preponderance of available literature point to the technical viability of CCA as a pozzolan, but there is not enough hard data to evaluate the commercial viability, environmental sustainability or perform a life cycle assessment of CCA, vis-à-vis ordinary Portland cement.

It is instructive to note that some of the data lacking in the case of corn cob ash are already available for pozzolans derived from products in other parts of the world. For example, the following quote is from a report of the Institute of Concrete Technology: “each tonne of paddy produces about 400kg of husk, which on combustion, yield approximately 40kg of highly siliceous ash, and release 3800kca/kg of heat energy” (ICTECH, 2011). The ash yield of rice husk ash reported, here as 20% has been corroborated by Subbukrishna et al (2007) who reported it as between 18 and 20%. Also Muga et al (2005) have done an evaluation of savings in $CO_2$ emissions that could arise from the use of pozzolans made from rice husk ash, in building construction.

A number of research are recently being reported in Nigeria on several biomass waste as pozzolans, these include: palm fruit ash (Olonode, 2010), rice husk ash (Alhassan 2008), bamboo leaf ash (Amu and Adetuberu, 2010), locust bean pod ash (Adama and Jimoh, 2011), and corn cob ash (Adesanya and Raheem, 2009b). But in order to move these research efforts from the laboratory to the market place, it would be necessary to be able to make the kind of statement quoted above from the Institute of Concrete Technology about each of these biomass waste derived pozzolans. Being able to do so will go a long way in advancing the nation towards the attainment of the goals of the MDGs.

Critical data required in this regard include:

a) The yield of corn cob ash per corn cob (weight for weight)
b) The influence of furnace technology on the physical and chemical characteristics of CCA.
c) The quantity and cost of fuel consumed per gram of CCA.
d) Life Cycle Assessment of energy consumed and $CO_2$ emissions etc. for the CCA in comparison with the Portland cement clinker.
e) optimum blend of corn cob ash acting as a pozzolan, with ordinary Portland cement in the production of various grades of Portland cement concrete and hence the pozzolanic activity index of CCA at the respective levels of CCA replacement.
f) The potential of CCA for chemical stabilization of laterite soils for highway construction.

Here in lies a unique opportunity for Nigeria and other developing countries blessed with a large production base for corn cob to "kill several birds with one stone", namely:

i). Rid the cities of undesirable agro waste in form of corn cobs and thereby remove one cause of flooding, epidemics and other environmental hazards.
ii). Create employment through the processing of corn cob into useful ash and make one more move against poverty in line with the first objective of the MDG
iii). Reduce the amount of $CO_2$ emissions for each tonne of cement consumed in line with the international commitments of the Kyoto Protocol
iv). Reduce the cost of housing and civil engineering construction.
v). Develop a brand of cement with a low heat of hydration and therefore useful in the production of mass concrete and sulphate resistant concrete.

## 8.0 Biomass Waste Re-use and The Millennium Development Goals

### 8.1 The Millenium Development Goals

According to the United Nations Development Program (UNDP, 2012) the eight Millennium Development Goals are:

i) Eradicate extreme poverty and hunger
ii) Achieve universal primary education
iii) Promote gender equality and empower women
iv) Reduce child mortality
v) Improve maternal health
vi) Combat HIV-AIDS, malaria and other diseases
vii) Ensure environmental sustainability
viii) Develop a global partnership for development

Looking at the above stated goals, it may be clear that bio-waste reuse has a lot to do, not only with environmental sustainability, but also with eradication of extreme poverty and hunger and with developing a global partnership for development as will be discussed below:

### 8.2 Eradicating Extreme Poverty and Hunger through Biomass waste Reuse

Provision of affordable housing and creating new jobs through opening up new lines of business are sure ways to reduce extreme poverty. Various biomass wastes can be pyro-processed into ash to produce pozzolans.

Industrialized nations had for long taken advantage of the by-products of their industrial activities in producing various brands of cement. Blast furnace slag is one such example arising from steel making plants and used to produce various brands of cement including Hochofen in Germany and Cemsave in Britain (Neville, 1983). Fly ash arising from coal fired furnaces is another. In fact the Pantheon in Rome, in use since 135 AD with a 43 m diameter hemispherical dome, is made completely from volcanic ash blended cement without reinforcement (climatetechwiki, 2011).

In Nigeria, our steel plants are comatose, and there is hardly any coal fired furnace still burning. Yet pozzolans are one sure way of stemming the ever increasing cost of cement and by extension, the cost of housing and civil engineering projects. It has been estimated that cement cost alone accounts for 42% of the cost of a typical 2-bedroom bungalow (Olonode, 2010). The cost of cement has been on the increase in the year 2011, rising by as much as 50% at a point (Punch, 2011). The economic savings that could result from the effective use of pozzolans has been reported by various authors such as Brunjes (2011) and Olonode (2010). Adepegba (1990) reported that in Rwanda, lime-pozzolana cement costs only about 20% of the cost of Portland cement. Therefore the effective use of pozzolans in Nigeria, can bring down the cost of cement and by extension the cost of road pavement materials and civil engineering projects. Since the only category of pozzolans available to Nigeria are the biomass waste products, we must take full advantage of it.

### 8.3 Achieving Environmental Sustainability through Bio-Waste Reuse

Increased world wide concern with global warming has brought about an increased awareness of the advantages of converting the by-products of agricultural and industrial activities to advantageous use. The challenge in the construction industry is to reduce the amount of carbon released to the atmosphere through its activities, which are mostly generated in the cement/concrete industry. In the United States, 0.97 tonnes of $CO_2$ are generated for each tonne of cement produced, of which some 56% are from the chemical reactions released from pyro-processing (USDoE, 2003). This fact has contributed a great deal in sustaining interest in the use of pozzolans, since any credible substitution for cement is effectively a reduction in $CO_2$ emission.

Furthermore, management of biomass waste in Nigeria can be problematic, particularly when these find their way in to cities, as with wrapping leaves, plantain/banana peels corn cobs etc. causing flooding and subsequent collapse of some engineering structures. The challenge is to find useful purpose for these wastes, because a waste for which useful purpose has been found will no longer be indiscriminately disposed.

**8.4 Develop Global partnership for Development.**

The Kyoto Protocol (UNFCC, 2012) gives incentives to organisations and companies in the developed world to finance projects and schemes in developing countries that are aimed at reducing green house gas emissions. This world wide carbon credit market is estimated at 144 billion dollars and has the potential to create additional cashflow into developing economies almost as much as Overseas Development Assistance money (AFRONLINE, 2012). Based on this, a credible scheme to replace cement in whole or in part in the construction industry, using biomass waste thereby reducing overall GHG emissions, will likely attract partnerships and funding from international organisations. This would be in line with the 8th goal of the MDGs.

**9.0 Conclusion and Recommendation**

Nigeria, being a leading producer of agricultural produce generates a lot of biomass waste particularly corn cobs, which often cause problems for the country. The paper made a review of research efforts being reported on the pyro-processing of biomass wastes into pozzolans, that could be used to partially replace cement in construction industry an went on to establish a link between successful management of biomass waste and the attainment of the Millennium Development Goals. The paper ends by urging researchers in this line to move the research efforts towards gathering data, that would help in evaluating the commercial viability and environmental sustainability of each of these biomass waste derived pozzolans

**References**

Adama, Y.A., and Jimoh, Y.A.,(2011). Production And Classification of Locust Bean Pod Ash (LBPA) as a Pozzolan. Available at www.engineeringcivil.com [29 January 2012]

Adeloye, L (2011). Cement: New Investment yield 8.5million metric tonnes. Punch Newspaper feature article, June 10, 2011, pp26. Punch newspapers, Lagos Nigeria

Adepegba, O. (1990). Nigeria: Pozzolana – the cheap alternative to Portland cement. Seminar on Local Materials for Housing, Third International Seminar of the African Network of Scientific Institutions, Mauritius. Available at www.greenstone.org [December 25 2011]

Adesanya, D.A. and Raheem, A.A. (2009a). A study of the permeability and acid attack of corn cob ash blended cements. Journal of Construction and Building

Materials 24. Available at www.Elsevier.com/locate/conbuildmat [June 5 2011]

Adesanya, D.A. and Raheem, A.A. (2009b) Development of corn cob ash blended

cement. Journal of Construction and Building Materials 23. Available at www.sciencedirect.com [June 6 2011]

Alhassan, M. (2008) Potentials of rice husk ash for soil stabilization. A.U. Journal of Technology, pp 246 - 250. Available at www.journal.au.edu/au_techno. [November 26 2011]

Amu, O.O. and Adetuberu, A.A. (2010). Characteristics of bamboo leaf ash stabilization on lateritic soil in highway construction. International Journal of Engineering and Technology. Vol. 2(4) 2010. pp 212-219.

Babasessy, (2011). Flood devastates Ibadan (pictures) 30 feared dead, several homeless. On line news article of Nairaland forum. Available at www.nationalmirroronline,net [29 April 2012]

Brunjes, U (2011). Pozzolans. Trash to Treasure. Online publication. Available at www.

Chungsangunsit, T., Gheewala, S.H., and Patumsawad, S., (2009). Emission Assessment of Rice Husk Combustion for Power Production. Journal of World Academy of Science Engineering and Technology. Available on line at www.waset.org/journals/waset [4 March 2011]

ClimateTechwiki, (2011). Clinker substitute (slag, natural pozzolans, synthetic pozzolans). Available on line at www.climatetechwiki.org/technology/clinker-substitute [June 13 2011]

Coutinho, S. (2002). The Combined Benefits of CPF and RHA in improving the durability of Concrete Structures. Journal of Cement and Concrete Composites. 25 (2003) 51 - 59

Dwivedi, V.N., Singh, N.P., Das, S.S. and Singh N.B. (2006). A new pozzolanic material for the cement industry: bamboo leaf ash. International Journal of Physical Sciences Vol. 1 (3), pp. 106 – 111. Available on line at www.academicjournals.org/IJPS

FAOSTAT (2010). On line publication of the Food and Agricultural Organisation. Available at: www.faostat.fao.org/

Halvorson, A. and Johnson, J. (2009). Cob Characteristics in Irrigated Central Great Plains Studies. Agronomy Journal, 101: 390-399

Iken,J.E. and Amusa, N.A. (2004). Maize Research and Production in Nigeria. African Journal of Biotechnology Vol. 3 (6), p 302 – 307. Available on line at www.academicjournals.org/AJB

Kumar, P.S. (2011). Cementitious Compounds Formation Using Pozzolans and Their Effect on Stabilization of Soils of Varying Engineering Properties. Proceedings of the International Conference on Environment Science and

Engineering. Singapore. IPCBEE vol. 8 pp 212 – 215

Ledakowicz, S and Stolarek, P (2002). Kinetics of Biomass Thermal Decomposition. Proceedings of the International Conference of the Slovak Society of Chemical

Engineering. Tatranske Matliare, 27 -31 May 2002, pp 378 – 381. Available at www.chempap.org/papers/ [4 May 2012]

NBS, (2012). Information On Demand (Nigeria GDP figures). Available on line at www.nigerianstat.gov.ng [24 March 2012]

Neville, A.M., and Brooks J.J. (2008). Concrete Technology. Pearson Education Limited, Essex. First Edition.

Obasi, S. 2011. The Ravages of Lagos Floods. On line publication of Newswatch weekly magazine of 24 July 2011. Available at www.newswatchngr.com [24 March 2011]

OEE, (2001). Energy Consumption Benchmark Guide: Cement Clinker Production. A Publication of the Office of Energy Efficiency, Ottawa, Canada. Available on line at: www.oee.nrcan.gc.ca/publications/industrial/cement-clinker

Olonode, K.A. (2010). Prospect of Agro-By-Products As Pozzolans in Concrete For Low-Cost Housing Delivery in Nigeria. Proceedings of the International Conference of the Obafemi Awolowo University, Faculty of Technology. Vol. 1 pp. 217 – 221.

PreventionWeb, (2012). Nigeria – Disaster Statistics. Available at www.preventionweb.net/english/countries/statistics [29 April 2012]

Raheem, A.A., Oyebisi S.O., Akintayo, S.O., and Oyeniran, M.I. (2010). Effects of Admixtures on the Properties of Corn Cob Ash Cement Concrete. Leonardo Electronic Journal of Practices and Technologies, Issue 16, January – June 2010, pp 13 – 20.

Sinthaworn,S. and Nimityongskul, P. (2009). Quick monitoring of pozzolanic reactivity. Available at www.elsevier.com

Subbukrishna, D.N., Suresh, K.C., Paul, P.J., Dasappa, S., and Rajan, N.K.S. (2007). Precipitated Silica From Rice Husk Ash by IPSIT process. Proceedings of the 15th Biomass Conference and Exhibition, Berlin, pp 2091 – 2093.

Turkel, S., Felekoglu, B., and Dulluc, S., (2007). Influence of various acids on the physico-mechanical properties of pozzolanic cement mortars. Sadhana, Technical Journal, p 683 – 691.

UNDP, (2010). MDGs in Nigeria: Current Progress. Online publication of the United Nations Development Program. Available on line at www.ng.undp.org/nigeriamgds

United States Department of Energy (2003). Energy and Emission Reduction Opportunities for the Cement Industry. Technical Paper for Industrial Technologies Program. December 2003.Available at :

www.1.eere.energy.gov/industry/ [24 October 2011]

UNFCC, (2012). Kyoto Protocol to the United Nations Framework Convention on Climate Change. Available on line at www.unfcc.int/kyota_protocol/ [23 March 2012]

Yu, F., Ruan, R., and Steele, P. (2008). Consecutive Reaction Model for the Pyrolysis of Corn Cob. Transactions of the American Society of Agricultural and Biological Engineers. Vol. 51(3): 1023 – 1028

Zych, D., (2008). The Viability of Corn Cob as a Bioenergy Feedstock. On line material available at www.renewables.morris.umn.edu/biomass [25 march 2012]

# Reverse Osmosis Water Treatment System Application for Haemodialysis

**K. A. Akande (Ph.D)**

Faculty of Engineering and Technology, Department of Biomedical Engineering
University of Ilorin, P.M.B 1515, Ilorin, Kwara State, Nigeria, 240003
(E-mail: yemiakande@yahoo.com or akande.ka@unilorin.edu.ng)
Tel: +2348033440849 or +2348055275597

## Abstract

Over 15,000 new cases of end stage kidney failure requiring dialysis emerge each year in Nigeria and much more worldwide. Kidney diseases often develop slowly and the symptoms only appear at later stages when the patient already has advanced kidney failure and may even need dialysis or renal replacement therapy to live. Statistics showed that many Nigerians with kidney problems were not aware of their health challenges. Water treatment for preparation of dialysate is probably the most neglected area of renal replacement with dialysis. Quality of water contributes very significantly in morbidity and life threatening reactions in dialysis patients in both; an acute as well as in chronic diagnosis. Haemodialysis patients are exposed to between 25 to 30 times of water during their daily therapy compared to normal individuals drinking water needs. Contaminants enter the blood compartment of dialyzers (artificial kidneys) and accumulate in the body due to inability of these patients to excrete them via their kidneys. Hence, it is very important to provide good and well designed water treatment system for heamodialysis of patient with renal failure. This paper addresses how to design appropriate and efficient pure water treatment system using the application of reverse osmosis and other filtration equipment for haemodialysis and its waste products.

**Keywords:** reverse osmosis, haemodialysis, waste water treatment system, kidney failure, dialysis machines, and membrane.

## 1.0 Introduction

Kidney or renal failure can broadly be divided into two categories: acute kidney injury or chronic kidney disease. The type of renal failure is determined by the trend in the serum creatinine. Biochemically, it is typically detected by an elevated serum creatinine. In the science of physiology, renal failure is described as a decrease in the glomerular filtration rate (www.news-medical.net). Acute kidney failure usually occurs as the result of a sudden interruption in the blood supply to the kidney, or as a result of a toxic overload of the kidneys. Some causes of acute failure include accidents, injuries or complications from surgery where the kidneys are deprived of normal blood flow for an extended period of time. There are many causes of chronic kidney disease. The most common cause is diabetes mellitus, long-standing uncontrolled hypertension and glomerulonephritis (Adebayo, 2012). In Nigeria, there is little or no access to renal replacement transplant, meaning many people simply die. It affects between 20 and 25 per cent of Nigerians above the age 18. Fifty per cent of them do not know they have hypertension because they do not go for check-up (Aboderin, 2012). Kidneys remove waste products from the blood and also remove excess fluid. If the kidneys fail the filtering must be done by artificial kidney and blood pressure may have to be controlled by medication. The End Stage Renal Disease (ESRD) is when kidney function is so bad that one is likely to die within weeks or months unless special treatment such as dialysis or transplantation is given (www.edren.org). There are several different treatment options, such as Peritoneal Dialysis (PD), Continuous Ambulatory Peritoneal Dialysis (CAPD), Haemodialysis, and Kidney Transplant (Ward et al, 1982). According to a report from the Control Disease Center (CDC) of United States of America based on survey of Dialysis associated hepatitis and other disease, it was reported that 1 % centers used no water treatment, 50% used reverse osmosis, 13% used deionization, 33 % combination of reverse osmosis and deionization and 2% used other combination (Rajapurkar, 1994). During dialyses contaminants could enter the blood compartment of dialyzers and accumulate in the body due to inability of these patients to excrete them via their kidneys. Several reports have appeared in literature describing the toxic effects of various contaminants (Rajapurkar, 1994). These are shown in Table 1.

The use of bicarbonate dialysis is increasing common in haemodialysis due to recognition of complications of acetate dialysis both immediate as well as long term. In Japan almost100% and in Europe 40% patients are on bicarbonate dialysis. The bicarbonate concentrate has been documented to have increased susceptibility to microbial contamination (Rajapurkar, 1994). Hence, water used in mixing the concentrate must be free of contaminants. In order to remove all the contaminants indicated in Table 1, a well designed water treatment system is necessary.

Table 1: Toxic effects of water contaminants in haemodialysis patient

| CONTAMINANTS | TOXIC EFFECTS |
|---|---|
| Aluminum | Dialysis encephalopathy, Renal Bone Disease |
| Calcium / Magnesium | Hard water Syndrome, Hypertension, Hypotension |
| Chloramines | Haemolysis, Anemia, Methaemoglobinaemia |
| Copper | Nausea, Headache, Liver Damage, Fatal Haemolysis |
| Fluoride | Osteomalacia, Osteoporosis |
| Sodium | Hypertension, Pulmonary edema, Confusion, Headache |
| Microbial | Pyrexia Reaction, Chills, Fever, Nausea Shock |
| Nitrate | Methaemoglobinaemia, Hypotension, Nausea |
| High Iron | Haemosiderosis |
| Sulfate | Nausea, Vomiting, metabolic Acidosis |
| Zinc | Anemia, Vomiting, Fever |
| Aromatic Hydrocarbons | Potential Chemical Carcinogens |

## 3.0 Methodology

An extensive dialysis water treatment system is absolutely critical for haemodialysis. Since dialysis patients are exposed to immense quantities of water, which is mixed with dialysate concentrate to form the dialysate; traces of mineral contaminants or bacterial endotoxins can filter into the patient's blood. Because the damaged kidneys cannot perform their intended function of removing impurities, ions introduced into the bloodstream via water can build up to hazardous levels, causing numerous symptoms or death. For example aluminum, chloramines, fluoride, copper, and zinc, as well as bacterial fragments and endotoxins, have all caused problems in this regard (www.membranegroupindia.com). For this reason, the water used in haemodialysis is carefully purified before use. The type of membrane used and the location of some of the equipment in the water treatment processes determine the quality and efficiency of the system. In this paper Reverse

Osmosis method containing thin film composite membrane is used in the design of the water treatment system for heamodialysis. Typical equipments used in the water treatment system for haemodialysis are shown in Figure 2.

### 3.1 Reverse Osmosis Phenomenon

Reverse Osmosis (RO) is the phenomenon of osmosis which is defined as the passage of a solvent (e.g. pure water) through a semi-permeable membrane into a solution containing dissolved solutes called chemical contaminants, until the hydrostatic pressures on both sides of the membrane reach an equilibrium reach state as shown in Figure 1. The new solution side pressure is represented by water pressure and osmotic pressure. The term Reverse Osmosis implies the reversal of the equilibrium state to form pure water as shown in Figure 1.

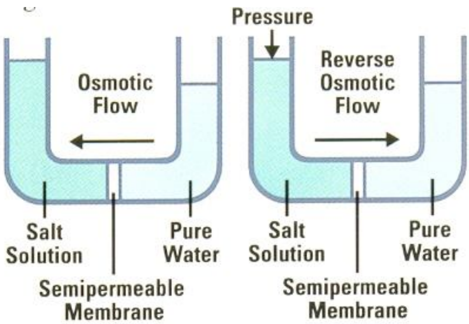



Figure 1: Differences between osmosis and reverse osmosis phenomenon

The typical membranes systems used in water treatment systems for dialysis is the thin-film composite membrane and cellulose acetate membrane systems. The thin-film composite membrane consists of ultra-thin membrane, polysolfone layer and non woven web. The thin-film composite FT30 reverse osmosis membrane gives excellent performance for a wide variety of applications and exhibits high rejection of contaminants with very stable long-term operation (Filmtec Technical Bulletin).

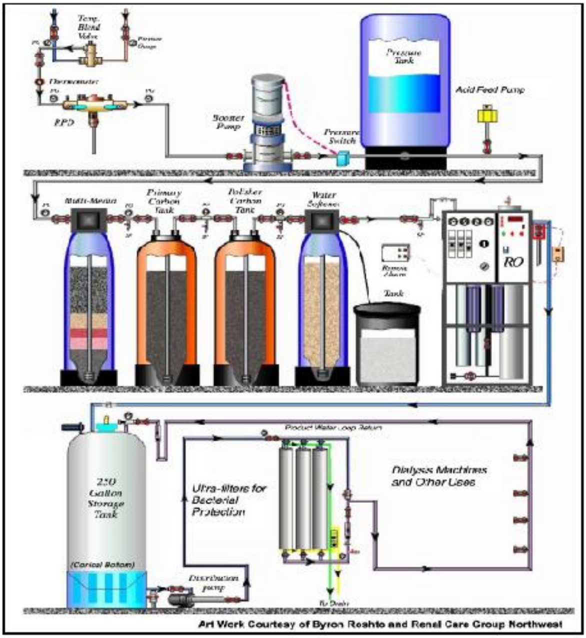
### 3.2 Water Treatment System Equipment Requirements for Haemodialysis

A typical design of water treatment system for haemodialysis is shown in Figure 2. Initially the water supply cold and hot is blended and temperature-adjusted. The water pressure is then boosted with the aid of pressure to maintain constant pressure required for the reverse osmosis machine. Then its pH is corrected by adding an acid or base. The supply water is passed through an automatic backwashed multi-media sediment filter. Multi-media sediment filter usually

contain anthracite in the top layer, sand in the second layer, garnet in the third and fourth layers, and gravel in the bottom layer.

Next the water is run through acid washed activated carbon tanks to adsorb organic contaminants such as chlorine and chloramines. It also adsorbs organic compounds which produce odor, taste and color or toxicity in water. The porosity of activated carbon offers an extremely high surface area to volume mass ratio. For example 2.2 pounds of 1,000 square meters per gram of a typical activated carbon, has about the same surface as 100 miles of two lane highway (Alamo Water Manual). Based on the known affinity of activated carbon, the carbon filter should remove the halogenated hydrocarbons (98%), aromatic hydrocarbons (100%), pesticides (100%), PCBs (100%), and phenols (98%) (Wathen, 1989).The location of activated carbon is very important. Activated carbon must not be placed before the RO system that uses acetate type of membrane because it will damage it. The supply water is then passed through an automatic backwashed water softener that uses processed pellet salt (Zeolites) instead of rock salt that can damage the RO membrane. The purpose of the water softener is to remove the hardness in the water. Next the water is passed through the RO unit that removes most of its contaminants before the pure water is stored in the storage tank with conical bottom. The conical bottom tank is for disinfecting purpose, which is enhanced with the upward facing designed sprinkler installed at the water inlet inside the storage tank. A stainless steel distribution pump is installed to distribute and re-circulate the stored RO water, passing through the ultra filtration system for bacteria removal and protection before the various dialysis machines points.

It is not recommended to use Deionizer (DI) for the polishing of reverse osmosis product water. This is because when DI is used in the dialysis application, may pose a major bacteria/endotoxins risk for the patient; have an ion exchange capacity which declines too rapidly, thereby causing leaching of materials used to construct the product water distribution system (Wathen, 1989). The ultraviolet (UV) light also poses a great risk in the system, though it kills bacteria, but the dead bacteria raises the endotoxins levels in the product water (Wathen, 1989)




*Monitoring Your Dialysis Water Treatment System* - June 2005
Northwest Renal Network - CMS Contract #500-03-NW16

Figure 2: Types of Water Treatment System Equipment for Haemodialysis

)

**4.0 Conclusion**

In designing a reverse osmosis water treatment for haemodialysis it is absolutely necessary to monitor equipment installed in the system. This is done by installing sample pots and oil filled pressure gauges before and after this equipment for monitoring pressure difference across the equipment. Reverse Osmosis system is built on a simple concept that happen to rely on very sophisticated components. Aside from its application in haemodialysis, reverse osmosis can also be used in different waste water recovery processes in many industries such as; oily waste water streams in automobile units, spent wash in distilleries, textile waste wash water, textile dye units, car wash, vegetable oil complex including refinery and solvent extraction units, par boiled rice mills, aircraft engine parts waste treatment, and double pass RO pyrogen free intravenous fluid.

## References

Adebayo, B. (2012). Nigeria: 15,000 cases of kidney failure occur yearly. www.punchng.com/.../nigeria-15000-cases-of-kidney-failure. (Accessed on 2/5/2012).

Aboderin, M. (2012). Renal disease major issue in Nigeria, Punch News Paper February 29, 2012

Alamo Water Inc., (1993). Water treatment system manual. Reference # AWR193.Association for the Advancement of Medical Instrumentation. Water treatment equipment for Haemodialysis applications (ANSI/AAMI RD62:2001). Arlington (VA). American National Standards. 2001.http://www.news-medical.net/health/Renal-Failure-What-is-Renal-Failure.aspx (Accessed on 2/5/2012).

Ward, R.A., Klien E., Wathen, R.L., Akande, K.A., Miller, S., Crick, J., Wells, P. (1982). Investigation of the Risks and Hazards with Devices Associated with Peritoneal Dialysis and Sorbent Regenerated Dialysate Delivery Systems. Food and Drug Administration, Department of Health and Human Services. USA. Contract # 223-81-5001. November, 1982.

Wathen, R. L. (1989). Rationale of water treatment equipment selection for haemodialysis application. Environmental Water Technology, Inc., Louisville, Kentucky. U.S.A www.edren.org/pages/.../dialysis-and-end stage-renal-failure. (Accessed on 2/5/2012).

www.news-medical.net/.../Renal-Failure-What-is-Renal-Failure. (Accessed on 2/5/2012).

www.membranegroupindia.com/dialysis-machine-water. (Accessed on 2/5/2012).

# Development of used oil filtering device for small scale production

[1]Aweda, J.O., [1]Badmos, A.Y., [2]Abdulkareem, S. A. and [3]Isa, Y.
[1]Mechanical Engineering Department, University of Ilorin, Nigeria
[2]Chemical Engineering Department, University of Ilorin, Nigeria
[3]Headquarters Nigerian Army Electrical & Mechanical Engineers, Lagos, Nigeria
*corresponding author: jacobaweda@gmail.com, joaweda@unilorin.edu.ng

## Abstract

The use of crystalline material for the filtration of used engine oil was carried out. The process of filtration involved the use of wire gauzes placed at both the input and output ends of the device and fine particle crystalline material (polymer material from used "pure" water sachets) packed in between them. Pouring a measured quantity of used engine oil under pressure through the device produced filtered oil that was free of metallic particles. The efficiency of the device was improved with the use of a finer particle size of the polymer material and pressure application of about $10Nm^{-2}$.

**Keyword:** polymer, crystalline material, used oil, water sachet

## 1.0 Introduction

Wastes are regarded as spent or unused materials which are either dumped or used in landfills. These wastes may pollute the air, land and water the effect of which may be difficult to manage or control. Much of the material thrown away as wastes can be diverted to other uses thereby decreasing the pressures on the management of disposal and lessening the negative impact it makes on the environment. Wastes are generated due to human activities, and can be in the form of solid, liquid or gaseous wastes or the three combined. Generally with the advancement in technology, most human and industrial wastes are renewable. The renewed bye products once more become useful through recycling or are reused for other purposes as reported in Pirog, (2005) and

Psoch et al (2004). Monier, 1993, opined that recycling of waste products helps preserve and save the environment while at the same time it generates and conserves fund.

Recycled oil can be used as burning fuel in turbines, incinerators, power plants, cement kilns, industrial heaters and manufacturing facilities such as asphalt and steel industries Posch et al, 2004, and Shi-Hee, 2002. It can also be reprocessed into base oil as lubricants for other purposes. This creates a valuable form of energy, which helps the economy by avoiding the over dependent on refined oil from the crude.

The American Circle of Clean Environment Association (ACCEA) predicted that the world is addicted to oil and that nearly 50,000 gallons of oil will be consumed every second in the next decade. The report of the International Energy Agency (IEA) suggested that if proper recycling is undertaken, it will safe close to 38% of the world oil and this will further add to the world crude oil reserve by 18 to 20 years of use.

United States Department of Defence compared making lubricating oil from virgin base oil and from used oil and concluded that, re-processing used oil through re-refining was both more environmentally friendly and cost effective.

The need for recycling of used oil will not only make the environment cleaner as observed by Shi-Hee et al (2002), but make fuel more available for electrical and other energy requirement in refineries more abundant. The work further stressed that through re-refining the production of lubricant oil from virgin crude oil will drop by 19.3% and a saving of about $9 - $10million annually will be made in European countries alone.

The report of United States Environmental Protection Agency (USEPA) supported the claim of Monier (1993) and further observed that if all the oil from automobiles, engines and nuclear plants in Europe and America are collected and used sent to re-refining centres, this practice will save the Governments close to $2Billion annually. This figure represents a good percentage of the annual budget dedicated to achieve a clean environment.

Bachelder, (2005) opined that the environmental impact of used oil on land, air, water, vegetation, and wildlife can be controlled through recycling. By doing this, it will enhance air quality, and proper waste management. This will further ensure protection of habitat, endangered species and biodiversity.

Indiscriminate disposal of waste products without recur to the devastating effect such an action can cause to the environment, has been a major concern to government agencies regulating environmental pollution. Efforts to reduce greenhouse emission through land use, transportation and energy related programmes and policies, Pitt, (2010). Recycling of used engine oil will contribute to the preservation of the environment, curtail excessive dependent on the refining of crude oil and provide job opportunities. Used engine oil recycling is viable and may be tagged waste-to-wealth venture if properly

executed. Currently, Riaz, (2008), estimated that in the United States of America, a saving of about $63 million is made annually through re-refining of used oil.

There are several other methods by which recycling can be carried out as suggested by Bachelder, (2005) and Riaz, (2008). Methods already in use include vacuum distillation, hydrogenation or clay treatment and propane de-asphalt methods. One method that is cost effective is the application of polymer material for recycling used engine oil as presented in this report. The polymer material of used water sachet, which is a waste product, is employed in this process.

## 2.0 Material and method

The material used for the filtering device is cast iron and was designed to withstand the stress from the compressor when put into use. Therefore, the device could withstand the loads due to bending and shear stresses. The yield stress determination in the members is determined thus:

$$\sigma_k = \sigma_0 - \frac{1}{3\left(\sigma_1 + \sigma_2 + \sigma_3\right)} \qquad 1$$

Where, $\sigma_1, \sigma_2, \sigma_3$ are principal stresses and $\sigma_0$ is the yield stress in simple tension.

$$\sigma_0 = \frac{\sqrt{\left(\sigma_1 - \sigma_2\right)^2 + \left(\sigma_2 - \sigma_3\right)^2 + \left(\sigma_1 - \sigma_3\right)^2}}{2} \qquad 2$$

## 2.1 Preparation of polyolefin material

A 3kg dry polymer material was melted in a 15litres of kerosene, used as solvent. The product was left in the molten state for about 25 to 30 minutes, with periodic check on the content not to allow it to burn out of kerosene. Constant steering of the content was carried out to have total dissolution of the polymer material in the heated kerosene. The heat source was removed when the mixture changed to a jelly like, milky coloured homogenous product. The mixture was then left at room temperature for 2 days. The hard thin outer surface layer that was formed was removed and the softer inner layer was crushed into particles on a crusher. The volumetric fluid moisture content was used to determine the fluid (kerosene) content in the un-dried polyolefin material using the following equation;

$$\theta = \frac{M_{wet} - M_{dry}}{P_w V_b} \qquad 3$$

Where, $M_{wet}$ and $M_{dry}$ –masses of crystalline material before and after drying
$P_w$ –density of kerosene
$V_b$ –volume of the crystalline material before drying
$\theta$ – volumetric moisture content
The dried crystalline material was sieved and separated into three sizes using sieve of different sizes (0.02, 0.05 and 0.7meshes).

**3.0 Experimental procedure**
The filtering device used for the experiment was aluminium alloy obtained through green sand casting and machined to shape on the lathe machine following the procedure in Haward, (1980). The device consists of 1-inlet lid, 2- polyolefin material chamber, 3-exit chamber, 4-pressure gauge, 5-pressure inlet and 6-used oil chamber as shown in fig. 1. The pressure gauge attached was used to monitor the pressure on the used oil as it passes through the polyolefin material.

Within the device compartment, wire gauze was placed inside the cone orifice (exit portion) and tightened to the chamber. The polyolefin material was placed on the wire gauze in the device cavity in the required quantity and was retained in position by the upper wire gauze. The second wire gauze, upper gauze, was placed at the lower end of the cylindrical oil chamber making the polymer material to be compacted in-between the two wire gauzes. The upper wire gauze was to ensure even spread of the used oil when poured on it and thus prevents channel formation on the polymer material. The lower gauze retained and supported the weight of both the polymer material (acting as filter) and the introduced used oil. As used oil was poured into the cavity, the inlet lid was tightened to the top of the device and pressure was applied using the air compressor.

**4.0 Test procedures**
After assembling, the device was placed on a tripod stand to support the weight, see fig. 2. The device was tested for full operation with the used oil and crystalline material in place. Used engine oil was then introduced into the device under pressure from the compressor (Model XCD340HA, 208/230

Volts, single phase, 60Hz, R-22) under the action of the applied pressure, the oil was forced to pass through the polymer material much faster. As the oil

passed down through the polymer material, the polymer material was soaked in oil which made the polyolefin material to increase in size. This increase in size led to the reduction in the size of the inter particle pores between the polymer material. This behaviour of the polymer material was responsible for the crystalline material ability to filter or retain tiny metal particles found particularly in used engine oil. This unique characteristics and behaviour of the crystalline material enabled the filtration of the oil by retaining the metal particles in the oil while only the oil was allowed to pass through the crystalline particles. The time interval between the time used engine oil was introduced into the device with the crystalline material in place and the time the first drop of the filtered oil was noticed at the exit orifice called the break through time (btt) was recorded.

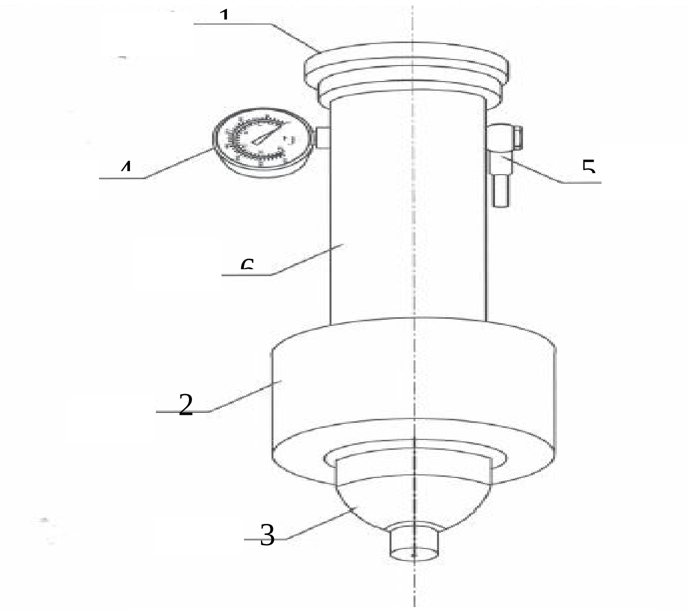



Fig. 1 Overview of the Filtration

1-inlet lid, 2- polyolefin material chamber, 3-filtered oil exit chamber, 4-pressure gauge, 5-pressure inlet and 6-used oil chamber

## 4.0 Results and discussion

### 5.1 Effect of polymer particle size

Different sizes of crystalline materials were used in the filtration of used engine oil. It was discovered that bigger particle sizes of crystalline material

absorbed more oil than the fine sized crystalline material. The fine sized crystalline material produced filtered oil freer of any grit than the large or coarse sized material. This phenomenon may be due to the closely packed or dense nature of the finer size material with very small space between the polymer materials as compared to the large sized material.

Fig. 2 Pictorial view of the set-up

## 5.2 Break through time (BTT)

Break through time is the time interval between the time used engine oil was introduced into the device with the crystalline material in place and the time the first drop of the oil was noticed at the exit orifice. With different particle sizes, different btt was obtained. The btt took longer period when finer particle size was used and lesser btt with coarse size. There was also a corresponding increase in the btt with increase in the quantity of the polyolefin material used as shown in fig. 3. For 0.05 and 0.07 mesh sizes, there was no significant

difference in the btt when the quantity was less than 500g, se fig. 3. As the quantity increased beyond 500g, 0.05 mesh size produced greater btt as compared to 0.02 mesh size. This trend may be due to the compact or dense nature of the fine sized crystalline material as compared to the coarse crystalline material, see fig. 3. The finer the particle size, the more time it took the process of filtration to complete. From fig. 3, the bigger the particle size the shorter the btt and consequently the less the time it took for the filtration to complete. It was also noted that the presence of kerosene in the crystalline material influenced the btt. The moist crystalline material containing a small amount of kerosene (the solvent) produced lesser btt than the dry material as is seen from fig. 4. This behaviour may be due to a high frictional effect on the surface of the dry material which reduced free flow of oil on the surface of the material when poured. The presence of kerosene in crystalline material was observed as having enhanced the btt.

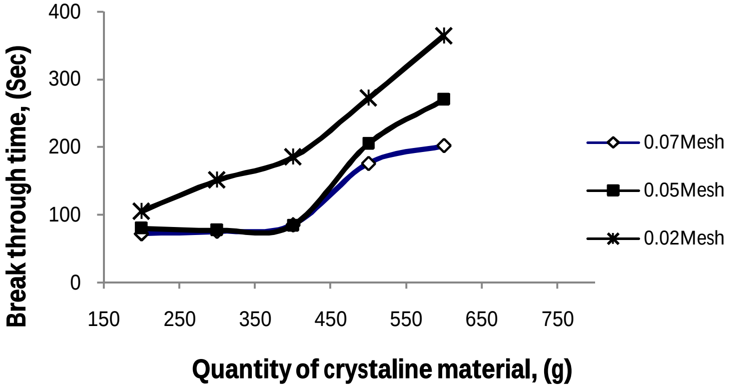



**Fig. 3 Effect of mesh sizes on break through time**

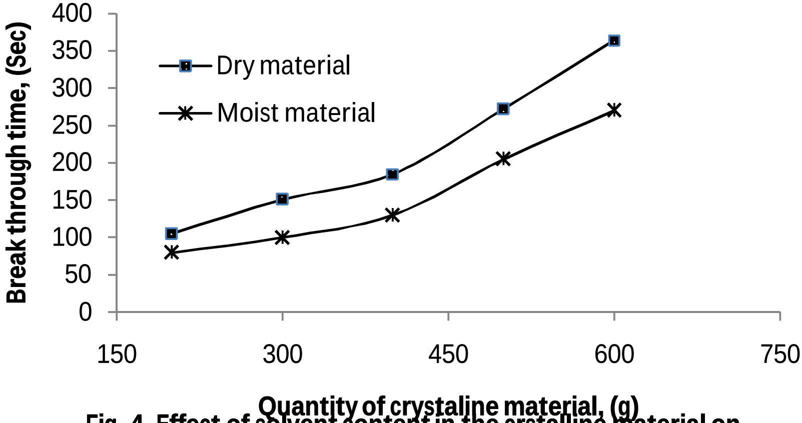



Fig. 4. Effect of solvent content in the crstalline material on btt

### 5.3 Pressure effect

With the application of pressure on the process of filtration, the value of btt decreases with increase in the values of applied pressure thereby, shortening the filtration time. At pressure level of $12Nm^{-2}$, the btt recorded was almost the same for all the mesh sizes used as is seen in fig. 5. Pressure value of $4Nm^{-2}$ produced btt of 158 sec, and this deceased to 70 sec at $12Nm^{-2}$ for 0.05 mesh size used as noticed in fig. 5.

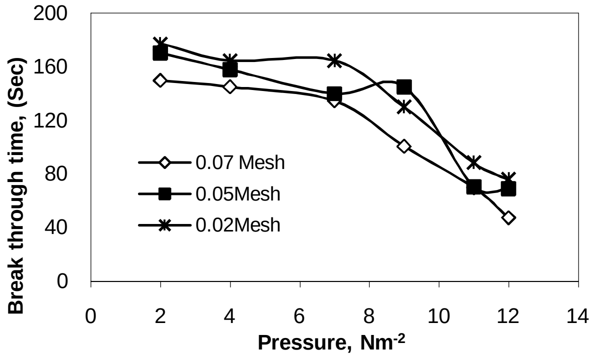



Fig. 5 Effect of pressure application on the break through time

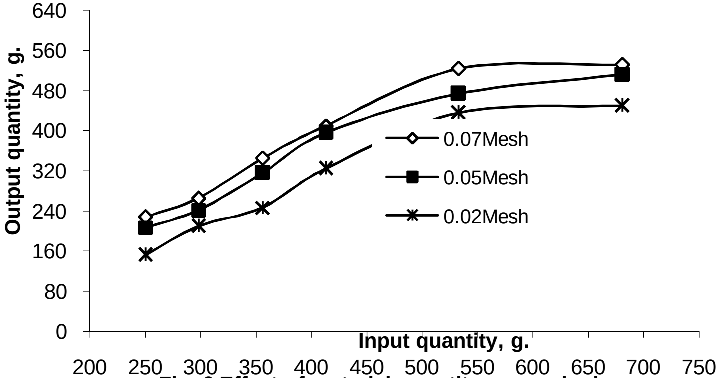



**Fig. 6 Effect of material quantity on mesh size**

## 5.4 Material turgidity

The polyolefin material absorbed some quantity of oil in the process of filtration thus slightly increasing in size (inflamed with oil). This increase in size consequently led to the narrowing down of the pores existing between the particles, thereby disallowing the metal particles present in the used engine oil from passing through the pores. It was observed that with different sizes of the mesh used, different volume of oil was absorbed by the crystalline material. At oil input of 350g there is an output oil of 246g and 345g respectively for 0.02 and 0.07 meshes sizes as shown in fig. 6. This increase continues until when about 500g of input oil was fed into the device. Shortly after this volume, there is a decline in the amount of oil retained by the crystalline material where 450g and 531g were output oil for a 680g input for 0.02 and 0.07 mesh respectively. This decline shows that maximum turgidity of the crystalline material is achieved where the material cannot retain more oil.

The quantity of oil absorbed increased with a decrease in particle size as in fig. 6.

## 6.0 Conclusion

The use of crushed crystalline material obtained from waste water sachet for the filtration of used engine oil was presented. The use of fine mesh size of the crystalline material was found to enhance the quality of filtered oil while the application of pressure reduced the btt thereby shortening the period of filtration. The pressure application of $10Nm^{-2}$ is optimum for the filtration of

used engine oil in a good time. In addition, if properly implemented, the process will generate funds and create job opportunities. It will also minimise the rate at which the used engine oil and waste water sachet pollute the environment and block the drainages.

## References

American Petroleum Institute, Oil Recycling Process, www.recycleoil.org/recyclingoil process/benefit.html. (Assessed on 17 (Assessed on 17 November 2008).

Bachelder, D. L., 2005, Re-refining waste oil, Safety kleen environment, vol. 7 (04), pp1-7.

Diene, D, 1988, Guide to oil waste management alternatives for used oil, sludge and waste resulting from used oil products, Project Research Institute, December, pp1-60.

Haward, E.D., 1980, Modern Foundry Practice, 3rd Edition Oldham Press Ltd, Uk.

Monier, V., 1993, Critical review and analysis of regeneration and incineration of waste oil, CS Press, UK.

Pirog, R., 2005, World oil demand and its effect on oil prices, www.fas/crs/misc/RL32530.pdf. Assessed on April 12, 2011.

Pitt, D.R., 2010, Harnessing community energy: The keys to climate mitigation policy adoption in US municipalities, Local environment: The international journal of justice and sustainability, Vol. 15(8), pp717-729.

Psoch, C., Wendler, B., Wozny, G., and Ruschel, B., 2004, Waste oil conditioning via microfiltration with ceramic membranes in cross flow, Journals of membrane science, vol. 245, issues 1-2, pp113-121.

Riaz Pervez, 2008, Oil demand and the future, American circle clean environment association, www.ace.com, assessed on January 8, 2008.

Shi-Hee Lee, Koo-Chun Chung, Min-Chul Shin, Jong-In Dong, Hee-Son Lee and Keun Ho Aun, 2002, Preparation of ceramic membrane and application to the cross flow microfiltration of soluble waste oil, Materials letters, vol. 52, issues 4-5, pp266-271.

Srijaroonrat, P., Julien, E., and Aurelle, Y., 1999, Unstable secondary oil/wateremulsion treatment using ultrafiltration: fouling control by backflushing, Journal of membrane science vol. 159, issues 1-2, pp11-20.

# Contributions of solid waste to malaria prevalence in Okelele, Ilorin East Local Government area of Kwara state.

[1]O. A. Mokuolu, [2]A. O. Coker, [3]M. K. C. Sridhar

[1]Civil Engineering Department, University of Ibadan,Ibadan, Oyo state, Nigeria.
[2]Professor,Civil Engineering Department, University of Ibadan, Ibadan,Oyo state, Nigeria.
[3]Professor,Department of Environmental Health Sciences, University of Ibadan, Ibadan,Oyo state, Nigeria.

## Abstract

Environmental control has been part of global reduction for malaria prevalence. However currently, its consideration for malaria control is very little. A community based study was conducted for malaria prevalence in Okelele, Ilorin East Local Government Area of Kwara State, Nigeria. A total of 200 households were studied which comprise of 501 children, age ≥ 14 years, 241 females, and 260 males. Data was recorded on the study profoma and entered into the computer using SPSS 17.0 software package. Data was then exported to DESIGN EXPERT for modeling using central composite for response survey. The results indicated that 29.9% were found to be positive with use of RDT, open drainage was found to be significant factor to malaria increase.
**Key words: Malaria, Solid waste, Open drainage**

## 1.0 Introduction

Malaria disease is transmitted to man by the bites from certain species of infected female anopheline mosquito (WHO, 2006)). Malaria is a serious problem in Africa where one in every five (20%) childhood deaths is due to the effects of the disease (Sachs and Malaney, 2002). There were an estimated 216 million episodes of malaria globally in 2010, of which approximately 81%, or 174 million cases, were in the African Region. There were an estimated 655 000 malaria deaths in 2010, of which 91% were in Africa. Approximately 86% of malaria deaths globally were of children under 5 years of age (WHO, 2011).

Mosquitoes may breed anywhere that standing water is available. Natural and man-made habitats include temporary flooded areas, tidal or fresh water wetlands, lakes, ponds, and rivers, municipal sewage or wastewater treatment plants, flooded basements of abandoned buildings, etc. Examples of smaller man-made potential breeding habitats include household articles and discarded trash such as tyres, drums, pails, garbage cans, plant pots, swimming pools, bottles, discarded automobiles and household appliances (Bourne, 2003).

Larval control measures are intended to reduce malaria transmission indirectly by reducing the vector population density near human habitations. As the larvae are exclusively aquatic, their distribution is determined by the locations of suitable water bodies (Walker, Lynch, 2007). One advantage of targeting larvae is that they cannot escape from their breeding sites until the adult stage and, unlike adult mosquitoes. Some of the main causes of malaria in the Sub Sahara African region are:

Poor sanitation in the sub region mainly: (i) stagnant water in the streets, gutters, etc.being choked without proper cleaning, (ii) Poor refuse dumping due to lack of waste management control (Kobina et al, 2010).

## 2.0 Methodology

The study was conducted in Okelele in Ilorin East local Government area of Kwara State. Okelele has a population of 36,191 based on 2006 census. It lies between longitude $04^o$ 32' and latitude $08^o$ 26' with estimated land area of $1.5Km^2$ . The relief flanking the flood plains around Okelele is between 290m and 305m above the sea level. ( personal Communication, Office of Surveyor General, kwara State Government, 2012).

A preliminary survey of the study site was conducted identifying the presence of environmental factors that could contribute to the high malaria burden of the area (morbidity and mortality). A multi-staged sampling procedure was thereafter adopted for the purpose of the conduct of household survey. Okelele area was divided into 5 clusters based on major enumeration parameters of the National Electoral Commission for that area namely, Lowin, Amuyankan, Omoboriowo, Jagun, and Baba Ladifa. From each of the clusters, 40 households were randomly selected. Members of the households selected were then interviewed using a structured questionnaire by the investigator and field assistants.

Malaria testing was done using the malaria rapid diagnostic test kit (RDT), Paracheck. This test kit is based on the identification of parasite Histidine rich protein II (HRP-2) that is present on the parasite cell wall.

A structured questionnaire was developed to obtain information on household characteristics. These include information on type of houses, household size, family income, use of malaria preventive measures among others. The parent/ guardian of each child were the respondents. Malaria prevalence was determined in children under 14years; representing the most vulnerable age group to the disease.

Data was recorded on the study proforma . The data was thereafter entered into computer using the SPSS 17.0 software package. The data entered were checked for errors and cleaned as appropriate before computation and data analysis. Data was exported to DESIGN EXPERT for modeling using central composite for response survey.

For all statistical tests, a p-value less than 0.05 were considered significant.

## 3.0 Results

A total of 200 households were studied. These comprised of 501 children, 241 females 260 males, giving a male to female ratio of 1.1:1. The average number of children ≥14years was 4per household. The ages of the children ranged from 8 months-14years, with an average of 6.8. The weight ranged from 5.5Kg to 53.0Kg with an average weight of 19.13kg.

Table1 Demographic characteristics of study population

| Characteristics | Frequency | Percent |
|---|---|---|
| **Sex** | | |
| Female | 241 | 48.1 |
| Male | 260 | 51.9 |
| Total | 501 | 100 |

Table 2 Malaria Prevalence with use of RDT

| | Frequency | Per cent |
|---|---|---|
| Positive | 150 | 29.9 |
| Negative | 351 | 70.1 |
| Total | 501 | 100 |

Table 3 Open drainage around the house

| | Frequency | Per cent |
|---|---|---|
| Yes | 163 | 81.5 |
| No | 12 | 6.0 |
| Total | 175 | 87.5 |
| Water bearing plants | 25 | 12.5 |

Table 4 Total volume of stagnant water

| Cluster | Total Vol. of stagnant water ($m^3$) |
|---|---|
| Lowin | 52.386 |
| Amuyankan | 33.052 |
| Omoboriowo | 2.2 |
| Jagun | Water bearing plants |
| Babaladifa | 7.569 |
| Total | 95.207 |

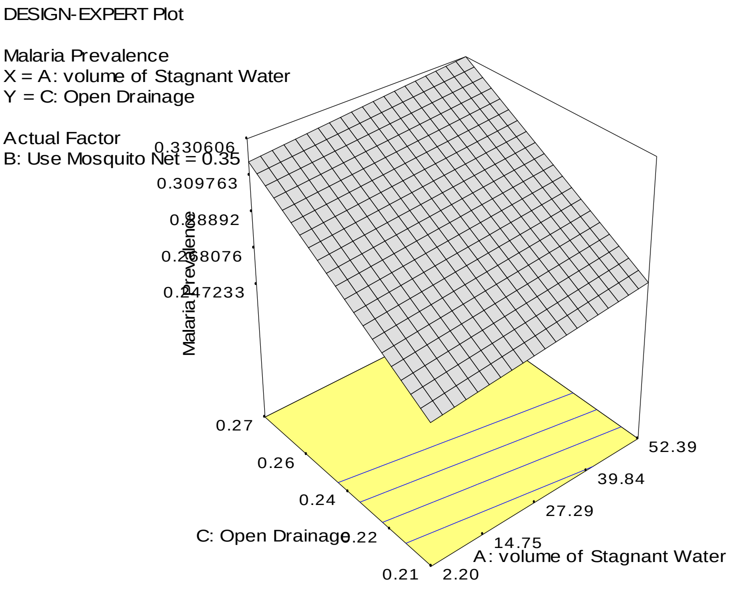



Fig. 1 Response survey contour map

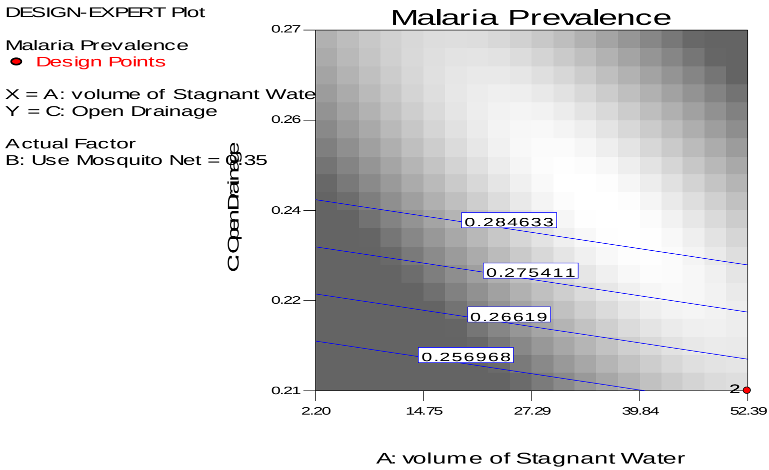



Figure 2. Model graph

## 3.1 Discussion of Results

The result shows open drainage to be significant factor to malaria prevalence in the study site. Castro et al, 2009 conducted a similar study in Dar es salaam, Tanzania. They concluded that Environmental management as part of an integrated vector management framework for malaria control is expected to reduce malaria transmission. Communal wastes blocking the open drainages because of poor sanitation of the site contribute largely to the high prevalence. Typical per capita solid waste generation rates for residential areas is 1.59Kg/person/day (Tchobanoglous George et al, 1977).

The population of Okelele is 36,191 based on 2006 census, implying a total of 57,544Kg solid waste generated per day is being indiscriminately dumped in the open drainages and other open spaces around the community.

## 4.0 Conclusion and Recommendation

Malaria prevalence of the study site is high considering period of study in November, a period of dry season when the prevalence is expected to be low.

Communal cooperation along with Government interventions is recommended.

Plate 1: Open drainage, a major problem as it is choked with solid waste.

## References

Bebra Bourne. 2003. Health & Management/ managing for West Nile virus infectio n/ Technique: collection and counting of mosquito larvae for West Nile virus control. http://wildlife1.wildlifeinformation.org/s/00Man/WNVOverviews/WNVIndTech/W

Castro C. Marcia, Atsuko Tsurata, Shogo Kanamori, Khadija Kennedy, Sixbert Mkude. 2009.Community based environmental management for malaria control: evidence from a small scale intervention in Dar-es-Salaam, Tanzania. Malaria Journal 8:57.

Design expert software version 6.

Kobina Odoro Agyapong, Gideon Kobla Nyarko, Augustus M Koomson, 2010.Malaria in the sub saharan Africa.Ghana Youth Engineering Center (Gyec)

Ogunleye, O.O., (2009) "Optimizing Raw Materials Formulation for Flexible Polyurethane Foam Production" An Unpublished Ph.D Thesis in the

Department of Industrial and Production Engineering. Faculty of Technology, University of Ibadan, Ibadan

Sachs J, Malaney P. 2002. The economic and social burden of malaria. Nature 2002. 415:680-685. PubMed Abstract Slobodan Trifkovic , Milan Pavlovic, Ljiljana Radovanovic, Jasmina Pekez, Eleonora

Desnica.2011. Analysis of projection of quantity medical waste generation in dependence on influencing factors. HealthMED - Volume 5 / Number 4.
SPSS, Inc. Statistical package for the social sciences version 17.0

Tchobanoglous George,Theisen Hilary, Eliassen Rolf, 1977. Solid Wastes Engineering

Principles and Management issues. Mcgraw-Hill Book company, pgs 71-73.

WHO 2006. Malaria vector control and personal protection: report of a WHO study group.
WHO 2011: World Malaria Report.

# Development of Pedotransfer Functions for Alfisols of Western Nigeria

C.J.Ejieji[a] and M.R. Baiyeri*,[b]

[a]Department Of Agricultural And Biosystems Engineering, University of Ilorin, Ilorin, Nigeria
[b]Department of Agricultural Engineering and Water Resources, Institute of Technology, Kwara State polytechnic, Ilorin, Kwara State, Nigeria
*Corresponding author
E-mail: emeka_ejieji@yahoo.com. baiyerimodupe@yahoo.com

Tel. Phone: 08033786327 ,08032127199

## Abstract

Modeling of water and solute transport in vadose zone helps to understand the complex nature of transport phenomena. A water retention curve is required for the simulation studies of water transport in unsaturated zone. Unlike direct measurement of water retention data, PTFs was developed to estimate water retention curve parameters from basic soil properties such as particle – size distribution and bulk density using multiple linear regression techniques and comparing the performances of the developed retention models {i.e. van Genuchten(1980) and Kosugi(1996)} using some evaluation criteria. Literature search was carried out to extract information on soil basic properties and water retention data from five (5) different locations in western Nigeria. Water content was predicted at selected water pressure head which combined water retention curve well. Both models performed well. Correlations is statistically significant at 0.05 levels. Prediction accuracy was evaluated by the coefficient of determination ($R^2$ ) and Root mean difference(RMSD) between the measured and the predicted values. The mean $R^2$ and mean RMSD are (0.421) , (0.102) and (0.475) and (0.098) respectively,

**Keywords: Pedotransfer functions, alfisols, water retention curve, van Genuchten parameter, kosugi parameter.**

## 1.0 Introduction

The quality of soil is under threat due to agricultural and industrial application on the earth. According to Hopmans et. al.(2002), the hydraulic properties of soils vary spatially from one location to another and are also scale dependent. Hence, it would be best to measure soil hydraulic parameters in the laboratory or field so that the variability in space and time can be sufficiently characterized. However, this difficult task is rarely accomplished because of the significant financial and time investments required for such measurement. To circumvent these practical difficulties with direct methods, researchers have shown keen interest in developing indirect methods (Mermoud and Xu, 2006), Khodaverdiloo (2011),in which the hydraulic properties are estimated from more easily measured or more readily available soil data (Wosten et al.,2001) .The basic idea behind these indirect method is often called Pedotransfer function (PTFs). Pedotransfer Functions (PTFs) is the Predictive function of certain soil properties from other more available and cheaply measured soil properties (Bouma,1989). PTFs predicts hard-to-measure soil hydraulic properties (such as retention parameter and hydraulic conductivities) using easily obtainable input information (such as soil texture, bulk density and organic matter). Pedotransfer Functions(PTFs) have attracted the attention of researchers for determining water retention curves from basic soil properties (Wosten et al., 2001), Bouman and Van Lanen, (1987): Bouma, (1989). Jurgen and Kneib (1981), in Moreira, Reghetto and Modeiros, (2002) from Germany introduced the term pedofunction, while Bouma and van Lanen (1986) used the term transfer function, which he later called pedotransfer functions.

Tieje and Tapkenhinrichs (1993), define PTF more narrowly in the context of soil water as a function that has arguments basic data describing the soil (e.g. particles-size distribution, bulk density, and organic C content and yields as a result the water retention function and hydraulic conductivity. Goncalves et al. (1997) use PTFs to estimate unsaturated hydraulic properties of Portuguese soils ranging from coarse sand to heavy clay

Vereeckan (1998) observe the existing PTFs according to point estimation for the prediction of hydraulic property value for specific values of the independent variable of the hydraulic curve; and estimation of parameters in algebraic functions or describing volumetric water content with the soil water pressure head (h) and the conductivity to soil water pressure head or water content K (h) or K (θ).

VOS et al., (2005) used 12 PTFs and Brazilian's database for prediction of bulk density, Guber et al., (2006) estimate the applicability of an ensemble of PTF for water regime simulation.

An effective commonly used parametric model for relating water content or effective saturation (θ) to the matric potential proposed by van Genuchten (1980) is,

$$Se = \frac{\theta - \theta r}{\theta s - \theta r} = \left[\frac{1}{1 + (\propto h)^m}\right]^m \qquad 1$$

Where; $S_e$ is effective saturation ($cm^3cm^{-3}$) ; h is soil water pressure (cm),$\theta_r$ is residual soil water content($cm^3 / cm^3$),where $\theta_s$ is saturated soil water content ($cm^3 / cm^3$) and θ is actual soil water content ($cm^3 / cm^3$)

α($cm^{-1}$), n and m are curve shape parameter of water retention

Thus, parameters required for the estimation of the model are θr, θs, ∝ and n. $\theta_s$, is sometimes known and is easy to measured, leaving only the three unknown parameters θr, ∝ and n to be estimated from the experimental data in many cases. θr represent the soil water content at some large negative value of the soil pressure head taken as θ at -1 5Mpa.(Cornelis et al., 2005)

Kosugi (1996), propose soil water retention curve as given below:

$$Se = \varphi\left[\frac{Ln\frac{h}{h_m}}{\sigma}\right] \qquad 2$$

Where; $\varphi$ = the complementary error function,h is soil water pressure head (cm), $h_m$ is matric potential under consideration ,$\sigma$ = A curve shape parameter representing surface Tension of the liquid.

Although most PTFs have been developed to predict soil hydraulic properties, they are not restricted to hydraulic properties. PTFs for estimating soil physical, medical and biological properties have also been developed.

The great advantage of PTFs used is the possibility of predicting soil hydraulic parameters directly

Despite the progress made in PTF development in general, evaluation of PTF has been carried out for Alfisols of western Nigeria region, Hence this study is carried out with the objective to develop Pedotransfer functions of alfisols of western Nigerian soil.

## 2.0 MATERIALS and METHODS:

### 2.1 Study Area

The study areas llustrated in Figure 1,are: Ilorin in Kwara State, Ibadan in Oyo state; Ikenne in ogun State, Ile-Ife and Ilora in osun. All located in the Western part of Nigeria (Figure 1). Ilorin is located approximately on latitude $8^0 28^1$N and longitude $4^0 40^1$E. Ibadan lies between longitude $3^0$ and $6^0 00^1$ East and latitude of $6^0$and $8^1$ North. Ile-Ife is located at $7^0$ $32^1$N and $4^0 32^1$E. Ikenne lies on latitude $6^0$ 52 $^1$N and $3^0 43^1$ and Ilora lies between latitude $7^0 50^1$N and $3^0$ and $4^0$East . The soil type in these study sites is Alfsols. Available data set on soil texture, bulk density and information on pairs of water retention versus pressure head from the study area ( figure 1) was collected as input data from different literature sources.These input data was divided into development and testing data set.

- Development Data Set
  - Ejieji and Ajayi (2001): Ilorin.Soil depth(0 – 100cm)
  - Ogunkoya, (2000): OGPRF1(15-60,90-105) and OGPRF4(45 -60 cm)

-

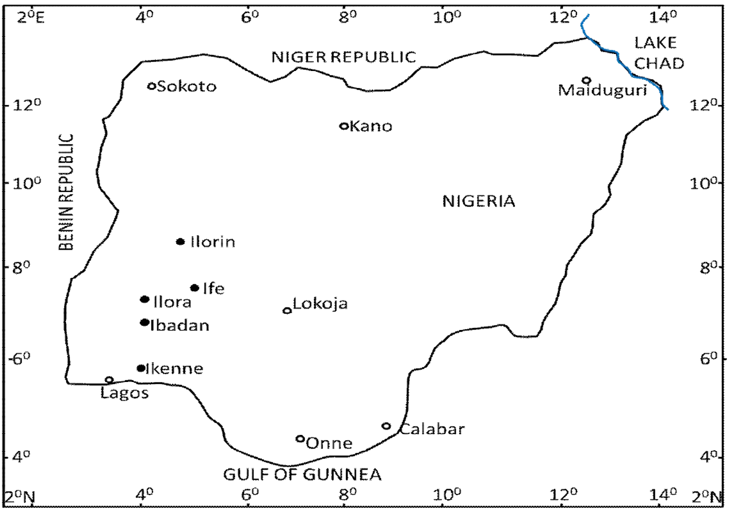



Figure 1: Location Considered in the Study (stations are Indicated in Solid Circles)

- Testing Data Set
  - Babalola (1981): DREXP (0 -120cm)
  - Babalola (1978): IB197896 (15 – 135cm)
  - Nbagwu (1984): Ilora(10c&20c
  - Ikenne (Ob,5b,c,10b,c &20b,c
  - (Ejieji and Ajayi (2001): Ilorin (15cm& 85cm)depth
-

## 2.2 PTF development and WRC estimation

Both water retention models (Eqn.1 and 2), were fitted to water retention data using the non linear optimization program SWRC- fit models to estimate the parameters;θr,θs,α,n,hm and σ of both water retention models. These parameters were related to basic soil properties . ( Sand,Silt,Clay and Bulk density) using multiple-linear regression techniques in order to develop PTFs coefficients. The most significant input variables were determined using stepwise regression method, and then linear,quadratic and possible interaction terms of these basic soil properties were investigated using the statistical analysis system.The PTF develop has the following general form;

$$P = \sum_{j=1}^{3} a_{1j} Sa^{j} + a_{2j} Si^{j} + a_{3j} CL^{j} + a_{4j} BD^{j} \qquad 3$$

Where, y = hydraulic parameter to be predicted $a_1$, $a_2$, $a_3$ are the regression coefficient. and $sa$, $sl$, $c$ and $Bd$ are the arguments of the PTF.

The following soil properties were investigated as argument, soil textural class (Sand, Silt , Clay) and bulk density.

## 2.3 Evaluation of the PTF Developed.

The performance of the PTFs in predicting the accuracy of the estimated data were evaluated using Correlation Coefficient (r), Root Mean Square Difference and Mean Error, expressed as,

$$r^2 = 1 - \frac{\sum_{1=i}^{n} \left(Y_i - Y_i'\right)^2}{\sum_{1=i}^{n} \left(Y_i - \overline{Y_i}\right)^2} \qquad 4$$

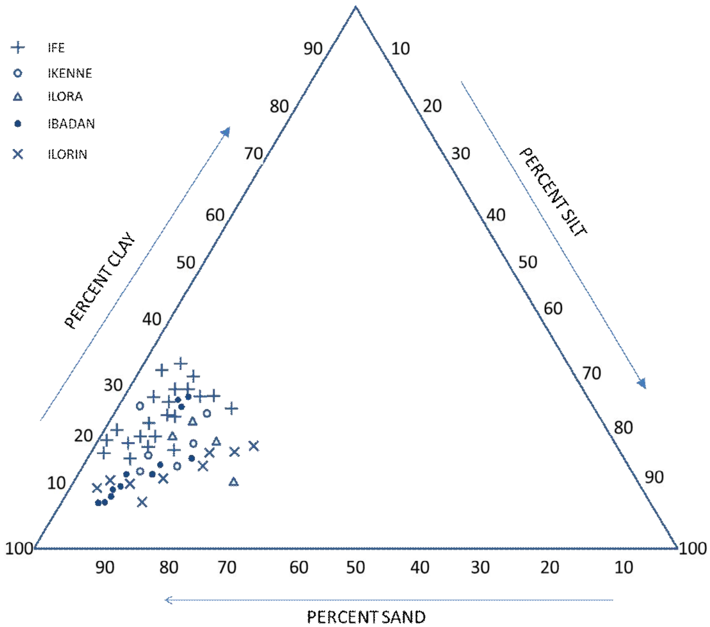



Figure 2: Textural Triangle showing Classes of Soil Used in the Study

$$\text{RMSD} = \sqrt{\frac{1}{n}\sum_{1-i}^{n}(Y_i - Y_i')^2} \qquad 5$$

$$\text{M E (Mean error)} = \frac{1}{n}\sum_{i-1}^{n}(y_i - y_i') \qquad 6$$

Yi denotes the measured value, $y_i'$ represent the predicted values, $\overline{Y_i}$ represent the average of the measured value $Y_i$ and N is the total number of observation.

Under or over prediction of PTFs for a given parameter are represented by positive and negative value of ME respectively. The RMSE ($M^3/M^{-3}$) is an indicator for over all error of the evaluated function and should approach zero for best model performance. The $R^2$ is a measure of the linearity between observed and fitted data. An $R^2$ value that approach unity means that the measured and fitted data pairs are linearly located around the line of perfect agreement .

## 3. Results and Discussion

The summary statistics of input parameter for development and testing data set (table 1 and 2) shows all values from testing data set were found to be within the ranges found in the development data set. The texture distribution in the data set were found to be typical of Afisols (figure 2),

Table 1 Statistics Variables used on the Development of the PTF

| **Statistics** | **Sand** % | **Silt** % | **Clay** % | **Bulk density** (g/cm$^3$) |
|---|---|---|---|---|
| Mean | 69.30 | 15.28 | 15.42 | 1.45 |
| SD | 21.06 | 14.54 | 6.48 | 0.09 |
| Max. | 84.16 | 25.56 | 20.00 | 1.51 |
| Min. | 54.44 | 5.00 | 10.84 | 1.38 |

Table 2 Statistics Variables used on the Testing of the PTF

| **Statistics** | **Sand %** | **Silt %** | **Clay %** | **BD (g/cm$^3$)** |
|---|---|---|---|---|
| Mean | 67.68 | 9.08 | 23.00 | 1.73 |
| SD | 8.7034 | 1.4705 | 7.8464 | 0.1258 |
| Max. | 80.10 | 10.30 | 29.20 | 1.74 |
| Min. | 60.50 | 7.00 | 11.90 | 1.71 |

Max.=Maximum,Min = Minimum, SD = Standard deviation

Table 3: PTF Coefficients for the van Genuchten model Parameters

| **Variables.** | **θs (X 10$^3$)** | **θr (X 10$^3$)** | **Ln (θr) (X10$^3$)** | **Ln (α) (X10$^3$)** | **Ln (n) (X10$^3$)** |
|---|---|---|---|---|---|
| Sa | 1148.558 | 1006.791 | 1777.279 | 23387.856 | 1155.391 |
| Sl | 24.862 | 53.237 | -10.338 | -2904.970 | 788.024 |
| C | -118.683 | 118.342 | 1594.381 | 8745.159 | 646.791 |
| Bd | -45814.946 | -54131.233 | -203263.896 | -413519.462 | -78947.056 |
| Sa$^2$ | -16.078 | -12.776 | -7.579 | -382.880 | -13.570 |
| Sl$^2$ | -6.668 | -0.879 | 44.722 | -188.188 | -42.910 |
| C$^2$ | 4.174 | -3.718 | -574.658 | 213.253 | -30.473 |
| Bd$^2$ | 28669.636 | 33657.841 | 123971.282 | 293113.198 | 44882.049 |
| Sa$^3$ | 0.072 | 0.057 | 0.535E-04 | 1.718 | 0.066 |
| SL$^3$ | 0.189 | 0.055 | 0.685 | 0.518 | 0.918 |
| CL$^3$ | -0.060 | 0.065 | 1.002 | 3.312 | 0.544 |
| Bd$^3$ | -5995.486 | -6943.141 | -25256.529 | -68444.442 | -8397.830 |
| **Std** | **0.030** | **0.050** | **0.482** | **1.097** | **0.306** |
| **R$^2$** | **0.790** | **0.631** | **0.690** | **0.790** | **0.885** |

- C, and Bd = Sand , Silt, Clay and Bulk density respectively

Table 3 and 4 contains the coefficients in the PTF,i.e.,$\alpha_i$ in equation (3), for the retention parameters.These coefficients were selected for their utility to predict Y (θr, ln(θr), θs,ln(α), ln(n),ln(σ) and ln(hm) as a function of the basic soil properties(Sa,Sl,Cl and BD). For each parameter, the argument were selected by stepwise regression forced through the origin.. Statistical information(Std and $R^2$) is also given in Table 3 and 4).Note that ln(θr),lnα and ln(n) improved the estimation by obtaining higher $R^2$ values for

van Genuchten model.These parameters which tends to be smaller for heavy soils was linearised by transforming it to logarithms.Vereecken et al.,(1989) reported that a logarithm transformation of n caused it's distribution to resemble the normal distribution more closely(also resulting in stronger correlations with basic soil properties).On the other hand, logarithm transformation of θs and θr in Kosugi model did not strengthen the predictions hence their actual values was used giving a better fit .Noticed that soil variables ( sand, silt clay and bulk density) are utilized in all the regressions. The performance of the PTFs was evaluated by the simple correlation coefficient between observed and predicted soil water content shown in Table 5 and 6 .The method yielded a better fit for ILORIN,DREXPandIB197896 locations, while the other locations gave a poor fit. Considering their R2 values and RMSD values.This indicate that the performance of the PTFs may be influenced by other factors such as the geographical source of the dataset use for it development,differences in measurement technigues,or other discrepancies that were not not considered in the analysis( Cornelis et al.,2001; Ghorbi Dastaki et al.,2010). The result of the PTFs developed in this study predict water retention parameter close to the prediction of Concalves et al.,(1997). Also,the estimate of van Genuchten – Kosugi models appears to be reliable for alfisols of Western Nigeria soils

Table 5 Root mean square difference, coefficient of determination and mean error( bias) of van Genuchten Model

| _ | _Location | RMSD | $r^2$ | ME |
|---|---|---|---|---|
| X | Ogunkoya (2000) (OGPRF1) | 0.050 | -0.211 | 0.077 |
| O | Babalola (1981) (DREXP) | 0.095 | 0.582 | -0.010 |
| Δ | Babalola (1978) (IB197896) | 0.072 | 0.710 | -0.001 |

| | | | | |
|---|---|---|---|---|
| + | Mbagwu, (1984) | | | |
| | Ikenne | 0.162 | 0.119 | -0.108 |
| | Ilora | 0.194 | -0.100 | -0.144 |
| * | Ejieji and Ajayi (2001) (Ilorin) | 0.036 | 0.924 | 0.009 |

(X) = Soil depth: 15-30, 30-45, 45 – 60, 90 – 105(+)Ikenne, soil dept.= (oa, ob, oc, (5a,b,c) (10a,bc) (20a,b,c)
(O) = Soil depth: 0-15, 45-60, 60-75, (Δ)=Soil depth: 45 – 135, +Ilora; (Oa,b,c), (5a,b,c) (10a,b,c) (20a,b,c)

Table 6 Kosugi Model

| | **Location** | **RMSD** | **$r^2$** | **Bias** |
|---|---|---|---|---|
| X | Ogunkoya (2000) (OGPRF1) | 0.046 | 0.170 | 0.010 |
| O | Babalola (1981) (DREXP) | 0.080 | 0.934 | -0.041 |
| Δ | Babalola (1978) (IB197896 | 0.076 | 0.643 | 0.073 |
| + | Mbagwu, (1984) | | | |
| | (Ikenne) | 0.161 | 0.181 | -0.113 |
| | Ilora | 0.195 | 0.036 | -0.154 |
| * | Ejieji and Ajayi (2001) ( Ilorin) | 0.029 | 0.888 | 0.017 |

(X) = Soil depth: 15-30, 30-45, 45 – 60, 90 – 105(+)Ikenne, soil dept.= (oa, ob, oc, (5a,b,c) (10a,bc) (20a,b,c)
(O) = Soil depth: 0-15, 45-60, 60-75, (Δ)=Soil depth: 45 – 135, +Ilora; (Oa,b,c), (5a,b,c) (10a,b,c) (20a,b,c)

## 4. Conclusion

The multilinear - regression analysis method was successfully applied to develop PTFs that predict the water retention curve and Van Genuchten-Kosugi parameter using different input predictors to estimate soil hydraulic parameters. This PTFs utilized some or all of the following predictors: sand, silt and clay percentages, bulk density. In the light of this research, the following conclusion was reached:

1 An increased in the number of predictors resulted in improved predictions by PTFs. The predictions made by Kosugi (1996) retention model in predicting the soil moisture content showed considerable improvement over Van Genuchten.

2 There is need to improve the performance of the PTF, by additional input information. However, care should be taken to avoid the use of predictors that are difficult to measure or are not commonly measured as this may put the idea of PTF in jeopardy.

3 More improvement was obtained in the prediction of natural logarithm of $\theta r$, n,$\alpha$, hm and $\sigma$.

4 Best prediction was obtain for ILORIN ,DREXP,IB197896 sites

Results shows that the use of PTFs to estimate unsaturated hydraulic properties requires a critical approach from the user. Future research should investigate for other soil types like locations with light structured soils.

## References

Bouma J., Van Lanen J.A.J. (1987): Transfer functions and threshold values: from soil characteristics to land qualities. In: Beek K.J., Burroughs P.A, McCormack D. E. (eds): proc. Int. Workshop Guality land evaluation. ISSS and SSSA, Washington, DC, ITC publ. N0 6. Enschede, the Netherlands.

Concalves,M.C., L.S.Pereira, and F.J.Leij, (1997): Pedo-transfer functions for estimating unsaturated hydraulic properties of Portuguese soils. European journal of Soil Science. 48: 387 – 400

Cornelis, W.M., M. Khlosi, R. Hartmann, M.V. Meirvenne, and De Vos Bruno, (2005). Comparison of unimodal Analytical expressions for the soil-water Retention curve. Soil Sci. SOC. AM. J. 69 : 1902-1911.

Ejieji,C.J.and A.S.Ajayi (2001). Relation of some soil water-transmission characteristics to some soil physical properties in a tropical alfisol.J.Agric.Res.Dev. 1: 9 – 15.

F.A.O(1983). Land evaluation for rainfed agriculture. Soil bulletin.No.52.Rome:F.A.O.

Ghorbani Dashtaki,Sh.,M. Hoaee, and H.Khodaberdiloo,(2010): Derivation and validation of pedotransfer functions for water retention curve using a variety of soil data. Soil use manage.(26): 68 – 74.

Guber,A.K.,Ya.A.Pachepsky,M.Th.vangenuchten,W.J.Rawls,J.Simunek,D.Jacques,T.J.Nicholson and R.E.Cady,(2006). Field scale water flow simulations using ensembles of pedotransfer functions for soil water retention. Soil Sci.Soc.Am.J.,5: 234 – 247.

Hopmans, J.W., D.R Wielsen, and K.L. Bristow, (2002). How useful are small-Scale Soil hydraulic properties measurements for large scale vadose one modeling. P.247-258 in D. smiles et al (ed.). headt and mass transfer in the natural Environment. The Philip volume Geophysical Manogr Ser. 129. AGU, Washington, D.C.

Mbagwu, J.S.C, R. Lal and T.W. Scott (1984). Effect of desurfacing alfisols and utisols in southern Nigeria. II changes in soil physical properties soil Sci. Soc. AM. J. 48. 834-838.

Ogunkoya, O.O., L.K Jeje and P.O Aina, (2000). Spatial variability of soil moisture in a small catchment in western Nigeria. The Nigeria Geographical Journal, New Series, ( 3 and 4): 183-195.

Olaolu B. (1978). Field calibrations and use of the neutron moisture meter on some Nigerian Soils. Soil Science 126 (2): 118-124.

Tietje, O.and M. Tapkenhinrichs, (1993). Evalution of pedotransfer functions soil sci. SOC. AM. J., 57: 1088 – 1095.

Vereecken, H. (1998). Pedotransfer functions for the Generation of Hydraulic Properties for Belgian Soils.Dissertationes de Agricultura.Katholieke Universiteit Leuven,Leuven.

VOS, B.D., M.V. Meiryenne, P. Quataert, J. Deckers, and B. Muys, (2005). Predictive quality of pedo transfer functions for Estimating bulk density. 172J. Ecol. Nat. Environ of forest soils. Soil sci. Soc. Am. J. 69: 500-510.

Wosten, J.H.M., Y.A. pachespsky, and W.J. Rawls., (2001). Pedotransfer functions: Bridging the gap between available basic soil data and missing soil hydraulic characteristic J. Hydrol. 251: 123-150.

# Comparative Study on the Design of Elevated Rectangular and Circular Concrete Water Tanks

*Ajagbe, W.O., **Adedokun, S.I. and *Oyesile W.B.

*Department of Civil Engineering, University of Ibadan, Nigeria
**Department of Civil Engineering, Ladoke Akintola University of Technology, Ogbomoso
*Author for correspondence: alpha_est1@yahoo.com

**Abstract**

Reinforced concrete overhead water tanks are used to store and supply safe drinking water. Design and cost estimation of overhead water tanks is a time consuming task, which requires a great deal of expertise. This study therefore examines the efficiency of Rectangular and Circular tanks. Tanks of 30m$^3$, 90m$^3$, 140m$^3$ and 170m$^3$ capacities were used in order to draw reasonable inferences on tank's shape design effectiveness, relative cost implications of tank
types and structural capacities. Limit state design criteria were used to generate Microsoft Excel Spreadsheet Design Program, named MESDePro for quick and reliable design. The basic tank's construction materials- steel reinforcement, concrete and formwork were taken-off from the prepared structural drawings. Results of the material take-offs showed that, for each of the shapes, the amount of each structural materials increase as the tank capacity increases. Also Circular-shaped tank consumed lesser individual material as compared to Rectangular ones. Hence, this will give Circular-shaped tanks a more favoured selection over the rectangular shaped tanks.

**Keywords**: Elevated water tanks, Design, Cost effectiveness, Limit state, Microsoft Excel Design Spreadsheet

## 1.0 Introduction

One of the most important needs of any community development is a safe and adequate supply of potable water. Unfortunately, there is still a shortage of clean water supply in rural regions of many developing countries. A large proportion of the rural population in such countries, rely on the availability of man-made wells, natural springs and rivers, and recently on limited piped water supply schemes. The majority of such sources are not at economical distances from the dwellings. The effectiveness of piped water supply depends on the availability of water storage tanks (Shirima, 1996). According to Patentscope (1998), in small towns or in rapidly growing urban areas it is common place to use concrete water reservoirs of 2 to 50 megalitres or even greater as "header" or "surge" tanks to store water pumped from a remote source. The stored water is then distributed to a specific community at a generally constant head.

Reinforced concrete overhead water tanks are used to store and supply safe drinking water. With the rapid speed of urbanization, demand for drinking water has increased by many folds. Also, due to shortage of electricity, it is not possible to supply water through pumps at peak hours. In such situations overhead water tanks become an indispensable part of life. As demand for water tanks will continue to increase in coming years, quick cost prediction of tanks before its design will be helpful in selection of tanks for real design. Quick cost prediction of tanks of different geometry and capacity is a difficult job and a time consuming task especially for less experienced design engineers (Pathak and Agarwal, 2003). Many times it is required to know the cost of a tank of known capacity and geometry before its detailed design.
This study attempted the achievement of some measure of the best practical solution, that is, the optimum design of elevated reinforced concrete water tanks for a specified performance in which the major objectives are to reveal the degree of effectiveness of the geometric shapes for the functional requirement, to assess the possible cost implications of each of the choices and to eventually generate Microsoft Excel Spreadsheet Design Programs as a tool for the rather quick assessment of various tank capacities.

## 2.0 Methodology

**2.1 Microsoft Excel Spreadsheet Design Program- MESDePro:** The generation of MESDePro- a versatile and adaptable design tool for elevated rectangular and circular reinforced concrete water tanks was prompted by the rigorous and lengthy manual design of reinforced concrete water tanks. The program considers no loop (or ring) design for the circular tank. Hence, if $H/(T \times R)^{0.5} > 1.29$, thick sections (or increased member-sizings) may be derived for the circular tank; where H is the tank height (or depth), T is its wall thickness and R is the tank radius. Moreover, the input values in the white-background cells are the only values to be adjusted to suit the desired requirements. A familiarisation study of the program would be very helpful,

coupled with the basic understanding of liquid retaining concrete structures' design principles-to have a better grasp of the embedded formula in the program. The choice of elemental design is made in the program instead of the whole-frame design modelling approach for design simplicity.

**2.1.1 Structural Layouts**: the rectangular and circular walls were considered to be propped cantilevers. Each of the propped cantilevers was made rigidly fixed to its base slab and was expected to be drawn inward at the top by the wall/top slab connecting reinforcements; in response to the outward hydrostatic loading on the wall. This was put in view based on the fact that continuity reinforcement must be provided at corners and at member-junctions to prevent cracking. The base slabs were typically a double overhanging single-spanned continuous slab, with wall point load and its applied fixed end moment at each overhang end. And the top slabs were laid out to be either two-way spanning or simply supported. The tank dimensions were deduced by the application of the related formula for solid shapes' volume calculations. Therefore, (L x B x H) for cuboid (or cube) was used for the rectangular tank and ($\pi$ x $R^2$ x H) for cylinder was applied for the circular tank; where L, B, H and R are Length, Breadth, Height and Radius respectively. For each tank, the preliminary member sizing were done for the walls, base slab and top slab. Water free-board was also provided for the possible volume increase above the require capacity in order to limit or check the overflow of the tanks. This was practically allowed to ease the reinforcing and construction of joints.

**2.1.2 Wall Loading:** The average water force or load, P in kN per metre width of the rectangular tank walls under flexural tension was derived as a point or concentrated load by calculating the areas of the triangular pressure diagrams of the water content on the walls, to be ($\rho$H) x H/2, where $\rho$ is the water density. By the centroidal consideration of loading of the pressure diagram, one-third distance from the base, up each wall, was chosen as the point of application of the concentrated load. The circular tank wall would be clearly in a state of simple hoop tension and its amount in kN per metre height of wall would be ($\rho$H) x D/2. And it would still act at one-third distance from the base up each wall. The wall total working loads for both options were assumed purely hydrostatic. And the inclusion of wind load in the working load was purely made to be dependent on tank elevation above the ground level, but would always be applicable in the design of its support. The wind load's application point, if considered, would be at one-half the tank's height and acting against the lateral water force. Hence, the resultant lateral force, from the combination of the water force and wind force; if applicable, would be one-half way between the two forces, that is, five-twelfth of the tank's height. For the purpose of this study, tanks elevated at 12 m and above were considered to be influenced by wind load.

**2.1.4 Base Slab Loading:** For each of the water tank options, the base slab's characteristic serviceability uniformly distributed load in kN/m per m run, was the sum of its dead load; the concrete self weight and its finishes, and its live load; that is, the weight of water to be contained. And the serviceability point load in kN per metre run, acting on each of the base slabs, at the extremes of the overhangs was derived by adding up the wall dead load; i.e. the base projection's weight and a calculated fraction of the top slab load. But some noticeable difference might be experienced in the calculations of the fractions of the loads from the rectangular and the circular top slabs.

**2.1.5 Top Slab Loading:** The top slab uniformly distributed load, in kN/m per metre run was calculated by adding up its combined dead load; that is, concrete self weight, waterproof finish and its live load (for tank access), to derive the characteristic serviceability load. Factors of safety of 1.4 and 1.6 were applied to the combined dead and live loads respectively before their sum was made to achieve the required ultimate design load for the top slab. The ultimate requirement, that is, stability would dictate its design and serviceability requirements; basically, deflection would be checked.

**2.1.6 Structural Analyses- General:** This entails the analyses of the loaded structural elements; walls, base and top slabs in order to determine their bending moments for the required design conditions. Serviceability loadings were considered for the general analysis to concentrate on crack width and reinforcement tensile stress limit except for top slab where this requirement would only be a check on the structural performance through measure of deflection. The maximum bending moment from the support and span for each condition was generally used and confirmed less than the moment of resistance, $M_u = 0.156 f_{cu} bd^2$, where $f_{cu}$ is the 28-day concrete characteristic strength, b is one metre width of slab, and d is the effective slab depth.

**2.1.7 Wall Analysis:** The Clayperon's three-moments equation approach was used for the propped cantilever walls of the water tanks to get their serviceability bending moments, that is, the fixed base of cantilever and span moments. The applied analysis approach is applicable to statically indeterminate beams or slabs (one way continuous spanned elements). Two spans are to be considered at a time. Its general expression is:

$$M_A L_{AB}/EI_{AB} + 2M_B(L_{AB}/EI_{AB}) + (L_{BC}/EI_{BC}) + M_C L_{BC}/EI_{BC} = -6A_{AB}X_{AB}/(L_{AB}EI_{AB}) - 6A_{BC}X_{BC}/(L_{BC}EI_{BC}) \quad \text{----- (1)}$$

Where $L_{AB}$ and $L_{BC}$ are the slab spans AB and BC respectively; $M_A$, $M_B$ and $M_C$ are the support moments at A, B and C respectively; $EI_{AB}$ and $EI_{BC}$ are the moments of rigidity of the spans AB and BC respectively; $A_{AB}$ and $A_{BC}$ are the diagram areas of span moments, $M_A$, $M_B$ and $M_C$, and $X_{AB}$ and $X_{BC}$ are the centroids of areas $A_{AB}$ and $A_{BC}$ respectively. The simplified form of the Clayperon's three-moments equation; as applied in the design is

$$M_A L_{AB} + 2M_B(L_{AB} + L_{BC}) + M_C L_{BC} = W$$

----------------- (2)

Where W is the combination or sum of all the applicable expression(s) for types of loading.

**2.1.8 Base Slab Analysis:** The double-overhanging single spanned slab was initially directly analysed to get the equal cantilever moment; since the structure was symmetrical, by taking moments about a cut-section through either support. Dynamic span moment $M_{A\text{-}B}$ was determined as used for the wall analysis above.

**2.1.9 Top Slab Analysis:** The rectangular top slab was analysed as two-way spanning; as deduced from ratio of the long span to short span which was found to be less than 2. The circular top slab was assumed to be square. Their discontinuities on all edges had their midspan moments only to be calculated using $\beta_{sx}\omega L_x^2$ and $\beta_{sy}\omega L_x^2$ for the short and long spans respectively. The moment coefficients, $\beta_{sx}$ and $\beta_{sy}$ were obtained from BS 8110 (1997), while $\omega$ and $L_x$ are uniformly distributed load and the short span length respectively. Due to the discontinuity nature of their edges, there was zero value of the coefficients and hence, the support moments on each of the edges and no need for support design.

**2.10 Ultimate Limit State Design:** For all the designed elements, except the top slab where contact with the water content was assumed to be minimal, the ultimate limit state design though a critical strength or stability requirement assessment on the structure would not be the guiding design state. This fact was supported by Oyenuga (2005) that design for flexure in water retaining structures was just a little compared to the various checks for serviceability.

Hence, the top slab design was the only elemental design coordinated by the ultimate limit state considerations as for normal reinforced concrete work.
**Serviceability Limit State Design:** The limit state design procedure begins with the stating of the design maximum crack-width limit at the design outset. Serviceability requirements will dictate the elemental designs except for the top slab. Hence, for the top slab, which was expected to have little or no contact with the water content, crack-width limit would be of less importance but must be checked, at least for functionality and aesthetics. The serviceability limit state cases applied are: (i) flexural tension in mature concrete for a cracked section fulfilling the 'deemed-to-satisfy' condition of not exceeding the corresponding allowable reinforcement service stress as required for rectangular walls in normal calculations, (but used for both the rectangular and circular walls in the MESDePro- since both were designed as cantilevered walls and no hoop or ring design was considered for the circular wall), (ii) direct tension in mature concrete; for a cracked section fulfilling the 'cracked –width calculation' condition of not exceeding the stated design maximum crack-width limit: as required for the circular wall in normal calculations, but not used for the circular wall in the MESDePro since both were designed as cantilevered walls and no direct tension was assumed, (iii) flexural and direct tension in mature concrete; for a cracked section fulfilling the 'cracked-width calculation' condition of not exceeding the stated design maximum crack-width limit as required for both rectangular and circular base slabs, (but further limiting reinforcement service stress check was made in the MESDePro to improve its reinforcement provision), (iv) direct tension in immature concrete; to control the thermal and shrinkage cracking as required for both rectangular and circular walls, and base slabs, (v) transverse reinforcement provision: for longitudinal reinforcements' distribution in the continuous construction type for full restraint method of control of thermal contraction and restrained shrinkage. This would demand for no movement joints, but expansion joints at wide spacing might be desirable in walls and roofs that are not protected from solar heat gain or where the contained liquid is subjected to substantial temperature range (but this study generally assumed favourable conditions), and (vi) deflection calculation; to limit the element's depth required, not to exceed the depth provided for a singly reinforced section as required and used for the top slab.

## 3. Results

From the developed MESDePro-Outputs' Sheet, for the chosen capacities of 10 $m^3$, 30 $m^3$, 90 $m^3$, 140 $m^3$ and 170 $m^3$, the following design requirements for steel were derived:

Table 1: Design Reinforcements for 10 $m^3$ tank capacity

| Rectangular Tank | Circular Tank |
|---|---|
| Reinforced Concrete Walls: | Reinforced Concrete Walls: |
| R16 @ 125 mm NF | R16 @ 125 mm NF |
| R12 @125 mm FF | R12 @125 mm FF |
| R16 @125 mm EF | R16 @125 mm EF |
| Base Slab: | Base Slab: |
| R16 @ 125 mm T | R16 @ 125 mm T |
| R16 @125 mm B | R16 @125 mm B |
| R16 @125 mm EF | R16 @125 mm EF |
| Top Slab: | Top Slab: |
| R12 @ 300 mm T | R12 @ 300 mm T |
| R12 @ 300 mm B | R12 @ 300 mm B |

Table 2: Design Reinforcements for 30 $m^3$ tank capacity

| Rectangular Tank | Circular Tank |
|---|---|
| Reinforced Concrete Walls: | Reinforced Concrete Walls: |
| R16 @ 125 mm NF | R16 @ 125 mm NF |
| R12 @125 mm FF | R12 @125 mm FF |
| R16 @125 mm EF | R16 @125 mm EF |
| Base Slab: | Base Slab: |
| R16 @ 125 mm T | R16 @ 100 mm T |
| R16 @125 mm B | R16 @100 mm B |
| R16 @125 mm EF | R16 @100 mm EF |
| Top Slab: | Top Slab: |
| R12 @ 300 mm T | R12 @ 300 mm T |
| R12 @ 300 mm B | R12 @ 300 mm B |

Table 3: Design Reinforcements for 90 $m^3$ tank capacity

| Rectangular Tank | Circular Tank |
|---|---|
| Reinforced Concrete Walls: | Reinforced Concrete Walls: |
| R16 @ 125 mm NF | R32 @ 125 mm NF |
| R12 @125 mm FF | R12 @125 mm FF |
| R16 @125 mm EF | R16 @125 mm EF |
| Base Slab: | Base Slab: |
| R16 @ 100 mm T | R32 @ 200 mm T |
| R16 @100 mm B | R32 @ 200 mm B |
| R16 @100 mm EF | R25 @ 100 mm EF |
| Top Slab: | Top Slab: |
| R12 @ 200 mm T | R12 @ 200 mm T |
| R12 @ 200 mm B | R12 @ 200 mm B |

Table 4: Design Reinforcements for 140 $m^3$ tank capacity

| Rectangular Tank | Circular Tank |
|---|---|
| Reinforced Concrete Walls: | Reinforced Concrete Walls: |
| R32 @ 125 mm NF | R25 @ 100 mm NF |
| R16 @ 225 mm FF | R16 @125 mm FF |
| R20 @ 175 mm EF | R20 @100 mm EF |
| Base Slab: | Base Slab: |
| R32 @ 125 mm T | R32 @ 125 mm T |
| R32 @125 mm B | R32 @125 mm B |
| R32 @125 mm EF | R32 @125 mm EF |
| Top Slab: | Top Slab: |
| R12 @ 200 mm T | R12 @ 150 mm T |
| R12 @ 200 mm B | R12 @ 150 mm B |

Table 5: Design Reinforcements for 170 $m^3$ tank capacity

| Rectangular Tank | Circular Tank |
|---|---|
| Reinforced Concrete Walls: | Reinforced Concrete Walls: |
| R32 @ 125 mm NF | R32 @ 125 mm NF |
| R16 @ 225 mm FF | R16 @125 mm FF |
| R20 @ 175 mm EF | R20 @100 mm EF |
| Base Slab: | Base Slab: |

| | |
|---|---|
| R32 @ 125 mm T | R32 @ 100 mm T |
| R32 @125 mm B | R32 @100 mm B |
| R32 @125 mm EF | R32 @100 mm EF |
| Top Slab: | Top Slab: |
| R12 @ 150 mm T | R12 @ 150 mm T |
| R12 @ 150 mm B | R12 @ 150 mm B |

The followings are the amounts of construction materials derived from the material take-offs of the reinforced concrete water tanks designed, for the various capacities chosen.

Table 6: Amount of Reinforcements in kilograms

| Tank Capacity ($m^3$) | Rectangular (kg) | Circular (kg) |
|---|---|---|
| 10 | 1875 | 1045 |
| 30 | 3775 | 3115 |
| 90 | 17050 | 11555 |
| 140 | 26500 | 17850 |
| 170 | 32275 | 19950 |

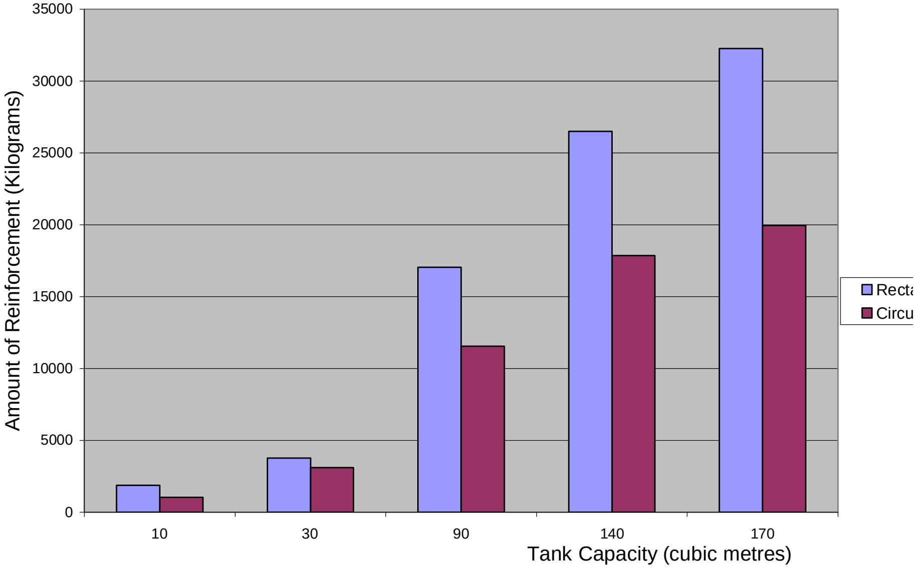



Figure 4.1: Amount of Reinforcement Against Tank Capacity

**Table 7: Amount of Concrete in cubic metres**

| Tank Capacity, ($m^3$) | Rectangular, ($m^3$) | Circular, ($m^3$) |
|---|---|---|
| 10 | 9 | 5 |
| 30 | 22 | 15 |
| 90 | 92 | 43 |
| 140 | 130 | 64 |
| 170 | 170 | 80 |

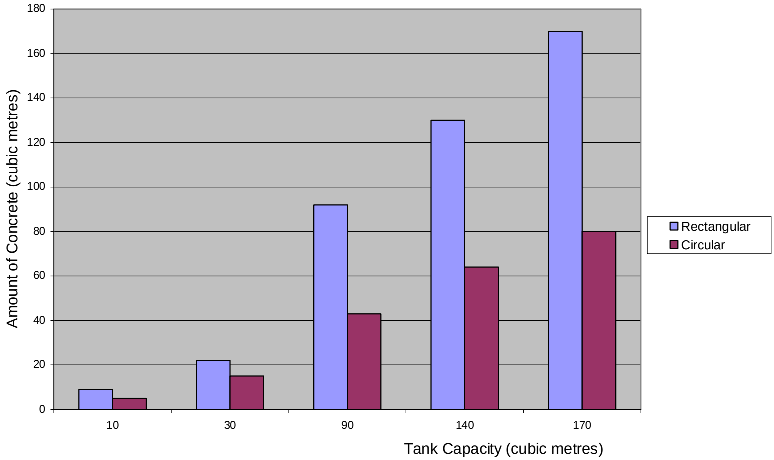



Figure 4.2: Amount of Concrete Against Tank Capacity

Table 8: Amount of Formwork in square metres

| Tank Capacity, ($m^3$) | Rectangular, ($m^2$) | Circular, ($m^2$) |
|---|---|---|
| 10 | 51 | 20 |
| 30 | 119 | 59 |
| 90 | 520 | 200 |
| 140 | 750 | 255 |
| 170 | 925 | 328 |

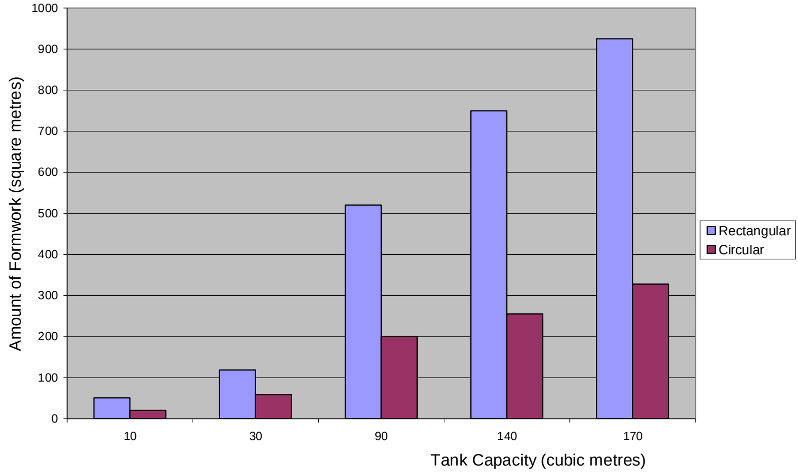



Figure 4.3: Amount of Formwork Against Tank Capacity

## 4. Discussion

From the above outputs, it could be deduced that as the capacities increase, the amounts of materials for the structure also increase. But, a rather non-perfect proportionality resulted; that is, a proportional increase in the capacity would not, necessarily lead to a proportional increase in any of the materials required. Moreover, the quantities of materials needed for the rectangular water tank were constantly more than those needed for the circular water tank, at each varied capacity.

Furthermore, assessing the relative reductions in the amounts of materials for the circular tanks when compared with those of rectangular tanks, it could be deduced that if the relative ease of putting up the shuttering; that is the formwork, would be significantly more challenged in the construction of the circular tanks, their presumed material-quantity advantage could be given up for a selection of rectangular tanks (though with potential increase in material-requirements). This could be considered if the said reduction in materials is relatively small or bearable. But, the final choice would depend on the client's desire and the pieces of advice of the professional(s) taking up the job.

## 5.0 Conclusion

Generally, the construction material-outputs for all water tank capacities would be based on the choice of the design considerations, with the sizes of their structural elements. Hence, there exists the possibility of having an equal-capacity and similar geometrically shaped water tanks but with some measurable difference in material requirements. For instance, a tank wall designed as a cantilever would come up with a relatively difference material-quantity when compared with its material requirements, if designed as a two-way spanning wall, (as for rectangular tank) or ring (or hoop) wall, (as for circular tank).

Hence, it could be concluded that the outcome of tank design and the possible cost implication of its material requirements- coupled with the relative ease of construction, would basically influence the choice of what geometric shape would be considered for the proposed water tank of any capacity -although, some other factors must still be assessed.

## References

Anchor, R. D. (1981) "Design of Liquid-Retaining Concrete Structures". London. Surrey University Press.

Anchor, R. D. "1992) "Design of Liquid-retaining Concrete Structures". Second Edition. London. Edward Arnold.

Anonymous (1998) "Construction of Liquid Retaining Structures". www.wipo.int/patentscope/en/

BS 8007 ( 1987) Code of Practice for Design of Concrete Structures for Retaining Aqueous Liquids.

BS 8110: Part 1 (1997) Code of Practice for Design and Construction-Structural Use of Concrete.

Charles, J. (2007) "Longtime Emblems of City Roofs, Still Going Strong" , The New York Times.

Durgesh, C. R. (2001) "Performance of Elevated Tanks in Mw 7.7 Bhuj Earthquake". Department of Civil Engineering, Indian Institute of Technology, India.

Elliott, D. (2006) "Wondering About Water Towers" New York Times.

Gray, W.S. and Manning, G. P. (1964) "Water Towers, Bunkers, Silos and Other Elevated Structures". London. Concrete Publications Limited.

Ludwig, A. (2008) "Tanks, Cisterns, Aquifers, and Ponds. For Domestic Supply, Fire and Emergency Use-Includes How to Make Ferrocement Water Tanks'. www.oasisdesign.net

Manning, G. P. (1967) "Reservoirs and Tanks'. London. Concrete Publications Limited.

National Public Radio (2006) "All Things Considered" New York.http://www.npr.org/templates/story/story.php?storyId=6567297(includes pictures)

Oyenuga, V. O. (2005) "Simplified Reinforced Concrete Design- A Consultant/Computer-based Approach''. Lagos. Asros Limited

Pall, A. and Pall, R. T. (2004) "Performance-Based Design Using Pall Friction Dampers- An Economical Design Solution". Paper No. 1955. 13th World Conference on Earthquake Engineering. Canada.

Pathak, K. K. and Agarwal, R (2003) "Cost Prediction of Overhead Water Tanks usingArtificial Neural Networks", IE (I) Journal , Vol. 84, pp. 153 – 158.

Reynolds, C. E. and Steedman, J. C. (1988) "Reinforced Concrete Designer's Handbook". Tenth Edition. London. E & FN Spon.

Shirima L.M. ( 1996) "Reinforced Blockwork Water Storage Tanks- Reaching The Unreached: Challenges For The 21st Century", 22nd WEDC Conference, New Delhi.

Slater, W.M. (1985) "Concrete Water Tanks in Ontario". Canadian Journal of Civil Engineering, Toronto.

Unified Facilities Criteria (2005) "Structural Design Criteria. For Structures Other Than Buildings" UFC 3-320-05A.

Wikipedia, the free encyclopedia . 2007: 'Concrete'

# Design and Fabrication of Polythene/Nylon Wastes Recycling Machine

Odusote, J.K.[1*], Muritala, A.A.[2] and Oyawale, F.A.[3]
[1]Mechanical Engineering Department, University of Ilorin, Ilorin, Nigeria
[2]Mechanical Engineering Department, Obafemi Awolowo University, Ile-Ife, Nigeria
[3]Industrial and Production Engineering Department, University of Ibadan, Ibadan, Nigeria
jamiukolawole@gmail.com/odusote.jk@unilorin.edu.ng/abduljamiukyahoo.com

## Abstract

The traditional methods of disposing polythene/nylon wastes have proved to be relatively expensive and unhealthy. Recycling of these non-biodegradable wastes will be more economical, healthy and safer for the environment. Thus, the objective of this research work is to design and develop a motorized polythene/pure water nylon recycling machine, using locally available materials. The machine is designed to use fixed and rotary blades, which are rotated by high-speed electric motor. Heat is provided for softening of the polythene prior to shredding by the blades. Tests were performed on the recycled machine to determine its possible output, and the results showed that 30-40 kg of recycled flakes was produced per hour at a machine speed of 2880 rpm. The flakes are used with recycled plastic wastes and/or virgin materials for production of coloured plastic product.

**Keywords: polythene/nylon, wastes, recycling machine, local materials**

## 1.0 Introduction

Plastics have become more popular materials for industry and its household uses have also increased tremendously. This has led to increase in the volume of plastic wastes of several types being generated in our society (Wilson, 1981). Most of these wastes are non-biodegradable and thus cannot be broken down by microbial action into simple inorganic forms like most other biodegradable wastes (Andrew and Subramaman, 1992).Most plastics and polythene/pure water nylon wastes are usually thrown in public drains, roads and open places to public view in most parts of the country. These wastes are used at times as a combustion aid for burning other organic refuse, and this liberates toxic vapours or gases that pollute the air and causes inconveniences to residents living near the landfill sights (New, 1986). Their values as reclaimed or recycled waste is considerably higher than their values as energy source (Andrew and Subramaman, 1992). Accordingly, well-known destructive techniques, such as incineration or pyrolysis (Leidner, 1981), seem quite wasteful, and hence, recycling of plastic wastes is the best method for solving both the environmental and economic problems associated with plastic waste disposal.

Based on the environmental awareness, need to conserve materials and energy, and growing demand to increase production economy (Mantia, 1993 and Bergland, 2003), recycling of plastic wastes is rapidly developing in almost every society. Many private industries and few government agencies are now engaging in recycling of plastic and polythene/nylon wastes. Recycling of plastic/nylon wastes could be achieved through chemical or mechanical recycling method. The chemical means involve solvent recycling process (Kampouris et al., 1995), flotation separation (Dilly-Louis, 1997) and selective dissolution techniques (Herberg et al., 1992). On the other hand, mechanical recycling involves the use of machines in converting the waste into recycle products, which can be re-used in new application (Jost, 1995). However, some of these machines are either non-available or expensive. Thus, the objective of this study is to design and develop a polythene/pure water nylon recycling machine from locally available materials, which will be cheaper and available.

## 2.0 Material and Methods

The polythene/nylon waste recycling machine consists of the following main components/units: the inlet-hopper/drum through which the wastes are fed into the machine, the recycling unit which consists of fixed blades and rotary blades performs the grinding and cutting operations. Three pieces of well sharpen fixed blades are firmly attached to the drum internally at a distance of less than 20 mm from the bottom of the drum. These blades are attached by sturds and bolts for easy removal and maintenance of the machine. Two pieces of rotary blades are welded to the spindle, which is attached to the shaft. The third unit is the driving unit, which consists of belts, bearing and pulleys transmit electric motor power to the drum and driving shaft. Figure 1 shows the assembly drawing of the recycling machine.

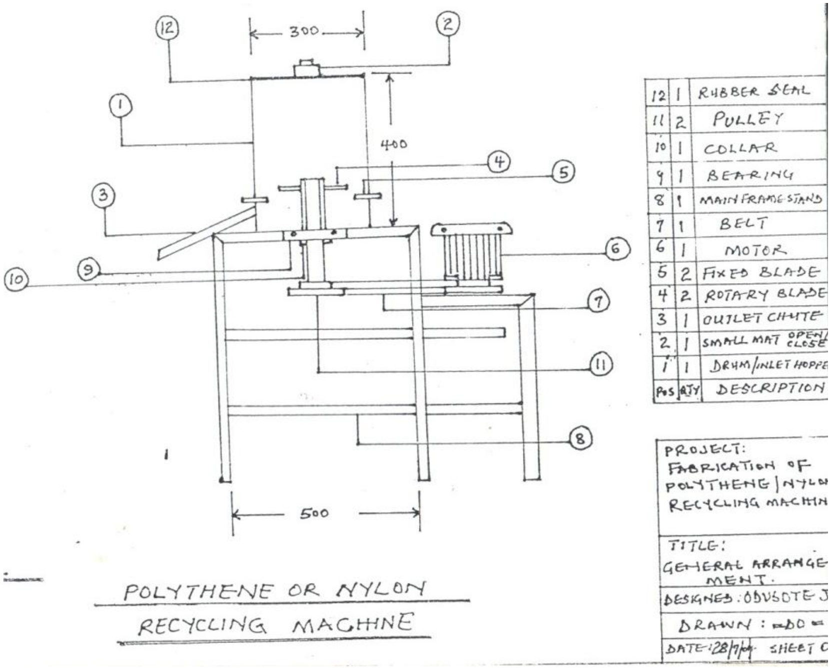



Figure 1. Assembly drawing of the recycling machine.

The inlet-hopper/drum, which determines the quantity of wastes to be loaded, is made of galvanized sheet based on its ability to withstand working stress, thermal conductivity and good wear resistance. Both the fixed and rotary blades are made of spring steel for good wear and corrosion resistance. A 3 KW electric motor is the power source and mover of the machine by shaft and belt drive. Heat is generated as the blades are rotating over one another during operation, and thus soften the nylon and then cut it into smaller pieces. The speed of the electric motor also contributes to the cutting rate of the machine.

## 2.1 Design Theory and Calculations

During the design process of the recycling machine, there are considerations for manufacturability, cost reliability and maintainability of the design product. The primary objective is to design a functioning product within given economic and schedule constraints.

### 2.1.1 Drum/Inlet Hopper designs

The drum is cylindrical in shape and its size can be obtained using the formula for obtaining the volume of cylinder, V, as given in Equation 1.

$$V = 2\pi r^2 h \qquad (1)$$

where r is the radius of the drum and h is the height of the drum. The drum wall thickness, t, is 6 mm, while the height is 400 mm and the diameter, D, is 310 mm. The value t/D for the drum is less than 0.05, which shows that its thinned wall, and thus reinforced with flat bars to increaseits ability to withstand any form of pressure.

### 2.1.2 Drum Shaft Design

The shaft is the rotating member having a circular cross section much smaller in diameter than the shaft length. Energy transmitting elements such as pulley, belts and bearings are attached to the shaft. The loading on the shaft can be various combinations of bending (almost always flunctuating), shock or axial, normal, or transverse shear. Thus, shaft design primarily involves the determination of the correct shaft diameter to ensure adequate strength and rigidity when the shaft is transmitting power under various operating and loading conditions. Strength, using yield or fatigue (or both) as a criterion; deflection; or the dynamics established by the critical speed are also considered in designing shaft (Hamrock et al., 1999).

The dimension of the shaft is:

Length = 760 mm

Diameter = 25 mm

The resultant internal moment at any section along the shaft may be expressed as:

$$M_x = (M^2_{XY} + M^2_{XZ})^{½} \qquad (2)$$

where $M_{XY}$ and $M_{XZ}$ are the bending moments in x-y and x-z planes respectively.

The force exerted on a shaft in the transverse direction (perpendicular to the shaft axis) produces a maximum stress of:

$$\sigma_b = M_b r / I \qquad (3)$$

$$\tau_{xy} = M_t r / J \qquad (4)$$

For a circular cross section, where r = d/2, I = $\pi d^4/64$ and J = $\pi d^4/32$, the bending stress according to Hall et al. (1982), will be given as:

$$\sigma_x = 32 M_b / \pi d^3 \qquad (5)$$

For torsional stress, the expression is:

$$\tau_{xy} = 16M_t/\pi d^3 \qquad (6)$$

For a solid shaft combining torsion and bending loads by applying the maximum shear equation modified by introducing shock, fatigue and column factors, the ASME code equation is given as:

$$d^3 = 16/\pi\sigma_s\,[(K_bM_b)^2 + ((K_tM_t)^2]^{0.5} \qquad (7)$$

where:

$\tau_{xy}$ = torsional shear stress (N/m$^2$)

$M_t$ = torsional moment (Nm)

$M_b$ = bending moment (Nm)

$K_b$ = combined shock and fatigue factor applied to bending moment

$K_t$ = combined shock and fatigue factor applied to torsional moment

$\sigma_b$ = bending stress

$\sigma_s$ = allowable stress

d = shaft diameter (m)

If the shaft diameter is known and safety factor, ns, is unknown, then,

$$n_s = \pi d^3 S_y/32\,(M^2 + T^2)^{1/2} \qquad (8)$$

where $S_y$ is yield strength.

### 2.1.3 Blades design

The recycling machine is designed to use both rotary and fixed blades as shown in Figures 1 and 2. These blades are well sharpened for effective cutting of the nylon waste. Two pieces of rotary blades were welded to the spindle, which is attached to the shaft. The fixed blades are attached firmly to the drum internally with sturds and bolt for easy removal and maintenance. They are attached very close to the bottom of the drum at a distance of about 1.5 mm in between each of them.

## 3.0 Result and Discussion

The product obtained after recycling the waste pure water sachets nylon by the machine is in form of flakes of different sizes. Although, the target is to obtain pellet of recycled waste or small grains similar to result of Kampouris et al, (1988) during recycling of polystyrene (PS) by solvent recycling process. However, the shredded nylon waste can be re-extruded with other plastic waste for production of coloured high density plastic or composite (Sasaki and Tomita, 1993).

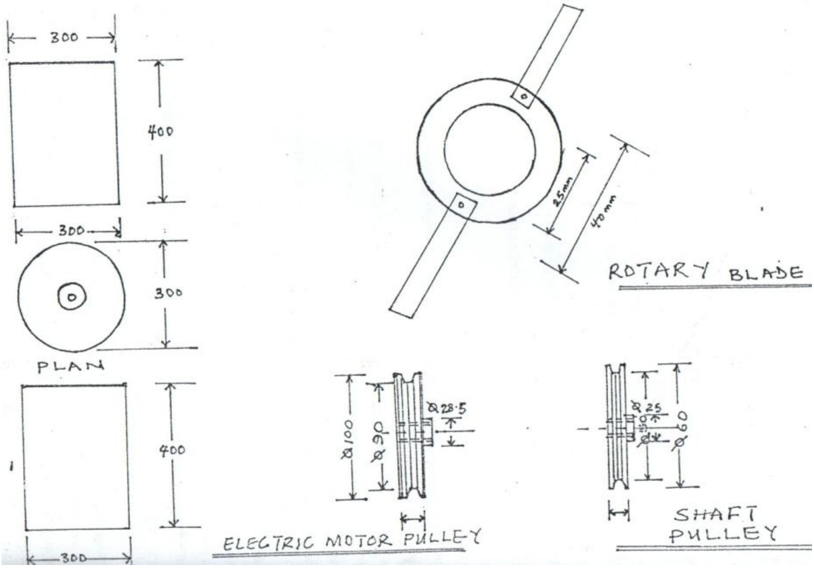



Figure 2. Rotary Blade and Pulley drawings.

The choice of other components such as bearing and belt depends on the diameter of the shaft and or its pulley, while the quantity of waste to be recycled, power required by the machine as well as the required speed rate of the machine will assist in the choice of the electric motor to be used.

**4.0 Conclusions**

The recycling machine designed produced about 20-30 kg of shredded nylon flakes as output per hour. The flakes can be re-extruded for production of coloured plastic products and composites. With this result, the primary objective of designing and fabricating a polythene/nylon wastes recycling machine using locally available materials has been achieved. The machine if successfully improved upon will assist in cleaning up our environment of non-biodegradable polythene/nylon wastes, which have constituted a serious

health and environmental problems in our society. The following recommendations are suggested to improve on the machine:

1. The properties of the polythene/nylon wastes should be well studied so as to carry our further work on the machine.

2. A heating unit as well as sieving unit should be introduced in the machine in order to be able to produce pellets of relatively same sizes from the machine.
3. Power requirement of the machine equipped with the heating unit must be determined to improve the efficiency of the machine.

## References

Andrew, G.D. and Subramman (1992), Emerging Technologies in Plastics Recycling, ACS Symposium series 513, Washington, D.C. USA.

Dilly-Louis, W., Seeligh, J. and Wolf, R. (1997), US Patent, 5,598, 980, Washington, D.C. USA.

Hall, A.S., Holowenko, A.R. and Laughlin, H.G. (1982), Theory and Problems of Machine Design, McGraw-Hill Inc., New York, 113.

Hamrock, B.J., Jacobson, B. and Schmid, S.V. (1999), Fundamentals of Machine Elements, 1st edition, McGraw-Hill Inc. 1st edition, New York.

Hegberg, B.A. Bremman, G.R. and Hallenbeck, W.H. (1992), Mixed Plastics Recycling Technology, Noyes Data Corporation, Park Ridge, New-Jersey.

Jost, K. (1995), Recycling Processes and Products, A Quick Read, 43.

Kampouris, E.M. Papaspyrides and Lekakou, C.N. (1988), Journal of Polymer Engineering and Science, 28 (8), 87.

La Mantia, F.P. (1993), Recycling of Plastics Materials, 1st Edition, Chemical Technology Publishing Inc., New York.

Leidner, J. (1981), Plastic Waste: Recovery of Economic Value, Marcel Dekker Inc., New York.

New, R. (1986), Plastics Waste Recycling in the United Kingdom, Dept. of Trade and Industry, Warren Spring Lab., United Kingdom.

Sasaki, K. and Tomita, T. (1993), Journal of Polymer Science and Technology, 50 (11), 855.

Wilson, D.C. (1981), Waste Management, Planning, Evaluation and Technologies, Clarendon Press, Oxford, United Kingdom.

# Stress-Strain Behaviour Model and Design of Plastered Straw Bale Wall

S.O. Ajamu[1] and A.A. Adedeji[2]

[1]Department of Civil Engineering, Ladoke Akintola University of Technology,
Ogbomoso, Oyo State Nigeria
soajamu@lautech.edu.ng
[2]Department of Civil Engineering, University of Ilorin, Ilorin Nigeria
aaadeji@unilorin.edu.ng

## Abstract

The structural behaviour of plastered straw bales depends on the properties of the materials with which the walls are made of. The constituent materials of plastered straw bale walls are basically the straw bale and the plaster. In this paper the stress-strain behaviour model and the design of lime-cement plastered straw bale wall is presented. To achieve this, the structural properties of the constituent materials such as compressive strength of plaster, creep of straw, and the load deformation test of the plastered straw bale wall were determined. The cement-lime plaster (with 10% lime) corresponding to mortar designation (i) in Table 1 of BS 5628-1:1992 of water to cement-lime ratio of 1:7 was applied. A creep of approximately 50mm was recorded after one week for the unplastered wall; the average mortar strength at 28 day was 3.92N/mm$^2$.

Stephen's analytical model was used to validate both the LIZA finite element model result and the laboratory stress-strain test result. It was observed that the ultimate applied stress on the plastered wall were 3.0 N/mm$^2$ for the laboratory test result and LIZA model while that of Stephen's model was 3.4N/mm$^2$. Within the range of elasticity of the plastered straw bale wall, Stephen's model could be used to predict the stress-strain behaviour of cement-lime plastered straw bale wall under concentric load. The designed strength of the wall is 667kN/m found to be adequate for most residential buildings.

**Keywords:** plants' wastes, stress-strain model, plastered straw bale wall, cement-lime.

## 1.0 Introduction

With increasing concern in regards to global warming and continuing depletion of earth's natural recourses, a new focus on environmental sustainability has arisen throughout the world. According to the Food and Agriculture Organization of the United Nations (FAO) report of November 17, 2005, Nigeria has the world's highest deforestation rate of primary forest. Between 2000 and 2005 the country lost 55.7 percent of its primary forest – defined as forest with no visible signs of past or present human activities. Logging, subsistence agriculture, and the collection of fuel wood are cited as leading causes of forest clearing in the West African countries (FAO, 2005).

In addition, modern construction materials such as steel, timber and concrete have greater embodied energy than many alternative options. Embodied energy is defined as the amount of energy which is required to produce a particular service or product. The construction industry is heavily focused on the use of concrete, steel and stone in Nigeria. It is however clear that this current trend is not sustainable. Concrete with its massive greenhouse gas emission, huge embodied energy and extensive use of natural resources; timber with danger of deforestation and loss of rainforest; and steel and stone with their consumption of natural resources; all have huge environmental implication associated with their use (Wilson, 1993). Thus in order to reach a level where Nigerians construct their building in a sustainable way, it is imperative that more environmentally friendly alternatives to the above mentioned materials be found and used whenever and wherever possible.

The need has arisen within Nigeria construction industry to focus on creating structures that require fewer non-renewable resources, both for their construction and their maintenance. One of the construction practices which has shown great assurance in meeting this new focus is construction using straw bale. Strawbale construction uses baled straw from wheat, oats, barley, rye, rice and others in walls covered by cement plaster. Strawbales are made from plants' wastes which farmers do leave on the farm. It is the dry plant material or stalk left in the field after a plant has matured, been harvested for seed, and is no longer alive. It is usually burned, causing severe air quality problems. The seed heads of the plants are what the farmer wants to harvest. Once they are removed, the stalks are baled into a great building material (Harvest homes, 2008).

However since there has not been a well developed building design code specific for strawbale buildings which can serve as guide and to eliminate some of the flaws associated with poorly designed/constructed strawbale buildings there is need for proper design and construction.

### 1.1 Production of Test Specimen

The specimens were produced using various proportions of water, sand, cement and hydrated lime. The water used for the plaster was tap water provided at room temperature. The quantity of water used for the mix was the volume of tap water added plus the volume of water contributed from the sand.

Because cement based plasters have been tested extensively, this study focused on testing cement and lime based plasters. The ratios of the binding materials (cement and lime) to sand were kept at 1:3 for all the batches.

Plaster cubes were produced with different proportions cement and lime and were tested after a variety of curing times. Load-deflection experiments were utilized to study the plaster stress-strain behaviour while cube experiments were utilized to study the influence of mix proportioning and curing time on the behaviour of low-strength cement-lime plaster.

Cube compression experiments were conducted to determine the compressive strength of some of the plasters. The cubes were tested in accordance with BS EN 12390-3: 2002. The load was applied to the cubes until failure, the ultimate load was recorded and the compressive strength was calculated for each of cubes. The strength of the plaster mix was taken as the average strength for three cubes of the same batch. Six different batches of mortar were prepared for the test according to variation in the percentage of lime addition to the cement. The result of the compressive test is as presented in Figure 1.

### 1.2 Load Deformation Test on Plastered Straw Bale Wall with Cement-Lime Mortar

#### Stacking of straws

After the bailing the guinea corn straw to form nearly rectangular shape, the bailed straws were stacked by placing them on each other, after which the dimension of the straw bale wall was 1050mm high by 450mm wide by 450mm long.

The stacked straw bale was compressed under a constant load for one week to allow for creep that could develop under service load, causing cracking of the plaster skin. After the creep, the final dimension obtained was 1000mm height 450mm width 450mm length.

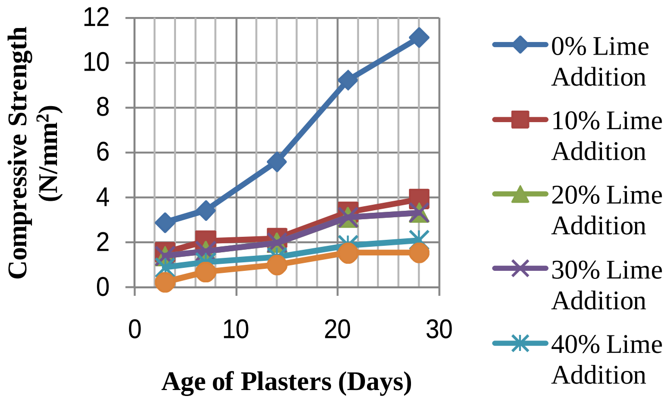



Figure 1: Plaster's strength at varying % replacement with Lime against the Age

## 1.3 Compression Testing of Plastered Bale Assemblies

There are currently no standards for testing straw bale assemblies, and as a result there is a lack of consistency in test methods, and a wide range of reported test results (Lerner et al., 2003). Also, the dimensional inconsistencies of straw bales make it difficult to reproduce results. A fabrication and testing method was used in this work. The specimens represent straw bale construction with consistent dimensions that permit repeatable testing.

Plastered straw bale wall was fabricated and tested in compression to failure. The results of the tests are compared to theoretical (model) predictions assuming the strength of the wall is governed by compressive failure of the plaster.

## 1.4 Load Deflection Test and Models

Experimentally there is a gap regarding the testing of eccentrically loaded specimen with only a few authors having conducted tests on specimens loaded concentrically in compression. There is also a gap regarding the theoretical analysis of the behaviour of plastered straw bale wall assemblies. These deficiencies are very significant to structural or building engineers. Therefore there is need for detailed understanding of the theoretical and experimental behaviour of the walls.

In this study, the specimen was fabricated such that both vertical and horizontal movements are not restrained at the top, while both vertical and horizontal movements at the bottom are restrained. The theoretical model for the load deflection behaviour of eccentrically loaded specimen was developed using LIZA Modeler for the wall height of 1.5m.

### 1.5 Assumptions

The plastered straw bale assemblies were assumed to act as composite sandwich panels under eccentric load with the following assumptions utilized for the analysis:

- Linear strain distribution across the width of the specimens was assumed. This assumes that there is no slippage at the straw/plaster interface, and that the straw does not undergo shear distortion.
- For the specimens presented, it is assumed that globally, plane sections will remain plane.
- Failure is a result of crushing of the plaster when plaster stress reaches f'cube at the extreme compression fibre;

### 1.6 Test Wall Specimen

In preparation for this test a wall of 1.5m height, 450mm width and 25mm plaster thickness was subjected to variable loading. The gradual deformations of the panel were measured with the strain gauge; the corresponding loads were also recorded. The diagrams of the test set up are as shown in Figures 2.

### 1.7 Plastering of Stacked Straw Bale Wall

After stacked straw were compressed, the cement- lime plaster (10% lime) corresponding to mortar designation (i) in Table 1 of BS5628-1:1992 was applied as shown in Figure 3a. The ratio of water to binding material (cement/lime) used for plastering of the straw bale wall was ratio 1:7, materials percentage were obtained by weight. The mortar strength of this mix at 28 day is 3.92N/mm$^2$. Ajamu and Adedeji (2010) reported that a plaster thickness of 25mm provides a maximum density for plastered straw bale prism and that at higher thickness values, the mass of the plaster begins to dominate. Plaster thickness between 20mm to 25mm proved to be stable.

### 2.0 Finite Element Model (FEM) of Plastered Straw bale Wall

By modeling the wall geometry and supplying the initial element properties for the LIZA's global properties for the wall (Figure 3) the graphic display generated from the FEM model of the wall panel and analysis result for different values of applied compressive loads are shown respectively in Figures 4(a) and 4(b).

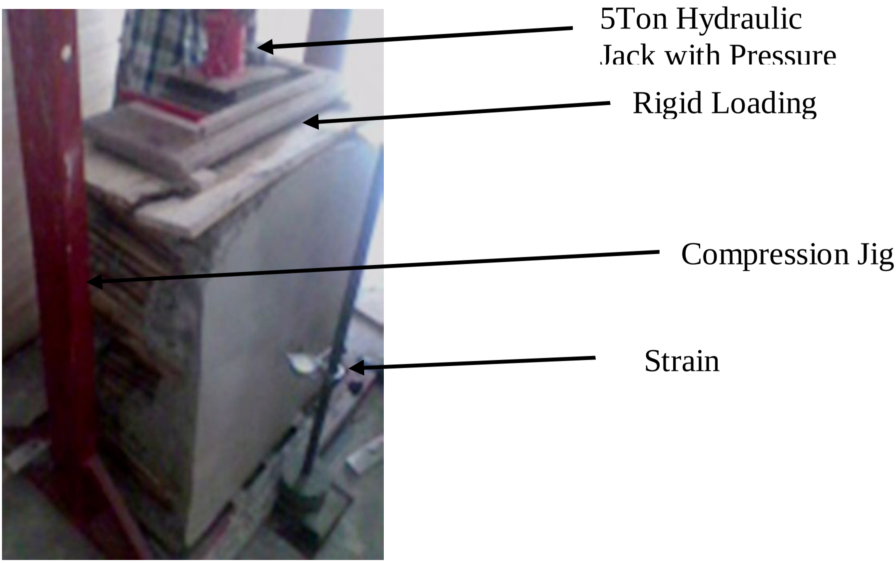



Figure 2: Plastered Straw Bale under Load with Strain Gauge attached

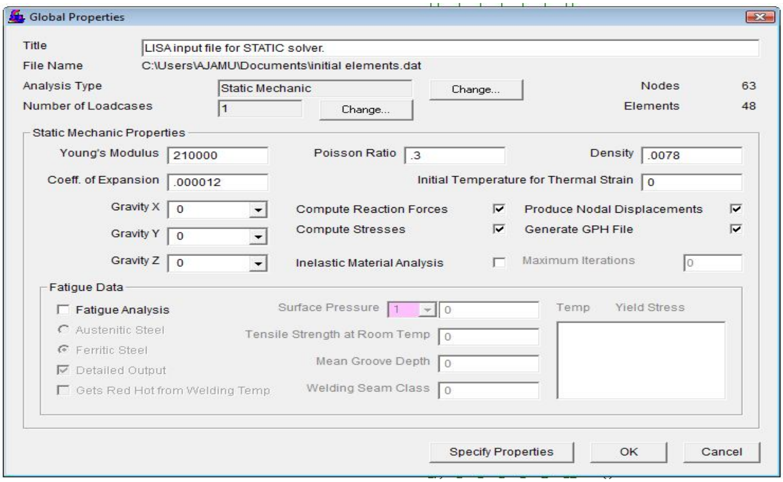



Figure 3: LIZA Interface for Global Properties Input

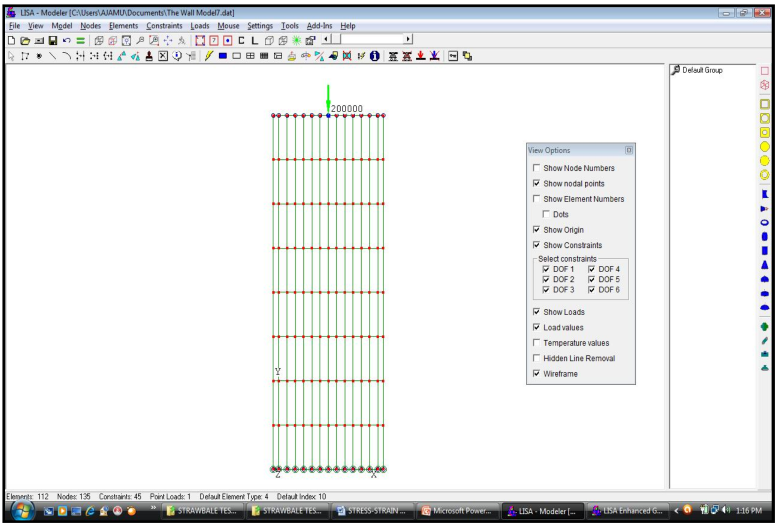



Figure 4(a): Concentric Compression FEM (200,000N Applied at eccentricity e = 0)

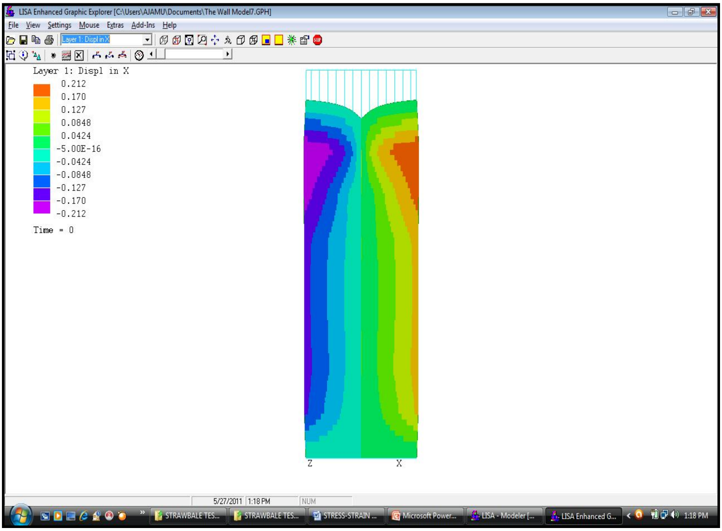



Figure 4(b): LIZA Graphic display of deformations due to 200,000N at e = 0

This was repeated for the different values of loads applied at eccentricity of zero.

## 2.1 The Plaster's Stress-Strain Relationship Model

Collins and Mitchell (1997) model was used directly by Tavio and Tata (2009) and was modified by Stephen et al, (2005) for low strength plaster

$$f_c = f'_c\left(\frac{764.8\varepsilon}{0.031+\left({}^{\varepsilon}/_{0.00253}\right)^{0.7547}}\right) \qquad (1)$$

Where: $f_c$ = compressive stress, $f_c'$ = ultimate stress, $\varepsilon_o$ = ultimate strain, $\varepsilon$ = strain at any given value stress $f_c$ Rearranging Equation 1 gives:

$$\varepsilon = \frac{f_c\left(0.031+\left(\frac{\varepsilon}{0.00253}\right)^{0.7547}\right)}{764.8 f'_c} \qquad (2)$$

Hence for a particular applied stress value (in N/mm$^2$) the corresponding strain value is gotten by iteration technique. A program is written in MATLAB to carry out the iteration.

$$= \frac{f_c\left(0.031 + \left(\frac{\varepsilon_{(i-1)}}{0.00253}\right)^{0.7547}\right)}{764.8 f_c'} \qquad (3)$$

The flow chart for the Newton-Raphson iteration technique used in the MATLAB program is as shown in Figure 6

Table 1: Stress-Strain Results - Laboratory Test and Model Results

| LOAD P (N) | DEFORMATION e (mm) (Lab. Test) | OBSERVED STRAIN | *STEPHEN'S MODEL | | LIZA FINITE ELEMENT MODEL | | | |
|---|---|---|---|---|---|---|---|---|
| | | | STRESS (N/mm$^2$) | STRAIN | LOAD P (N) | STRESS (N/mm$^2$) | DEFORMATION e (mm) | STRAIN |
| 0.00 | 0.000 | 0.00000 | 0.00 | 0.00000 | 0.00 | 0.00 | 0.000 | 0.00000 |
| 72,000 | 0.070 | 0.00014 | 0.29 | 0.00009 | 200,000 | 0.80 | 0.212 | 0.00042 |
| 150,000 | 0.128 | 0.00026 | 0.60 | 0.00023 | 250,000 | 1.00 | 0.265 | 0.00053 |
| 220,000 | 0.167 | 0.00033 | 0.88 | 0.00036 | 300,000 | 1.20 | 0.318 | 0.00064 |
| 300,000 | 0.265 | 0.00053 | 1.20 | 0.00052 | 350,000 | 1.40 | 0.371 | 0.00074 |
| 380,000 | 0.367 | 0.00073 | 1.52 | 0.00070 | 400,000 | 1.60 | 0.424 | 0.00085 |
| 450,000 | 0.436 | 0.00087 | 1.80 | 0.00088 | 450,000 | 1.80 | 0.477 | 0.00095 |
| 500,000 | 0.504 | 0.00101 | 2.00 | 0.00100 | 500,000 | 2.00 | 0.530 | 0.00106 |
| 600,000 | 0.580 | 0.00116 | 2.40 | 0.00130 | 550,000 | 2.20 | 0.583 | 0.00117 |
| 625,000 | 0.752 | 0.00150 | 2.50 | 0.00150 | 600,000 | 2.40 | 0.636 | 0.00127 |
| 750,000 | 0.895 | 0.00179 | 3.00 | 0.00180 | 650,000 | 2.60 | 0.689 | 0.00138 |
| 611,000 | 1.401 | 0.0028 | 3.44 | 0.0023 | 750,00 | 3.00 | 0.79 | 0.00138 |
| 586,000 | 2.802 | 0.00560 | 2.34 | 0.00140 | 800,000 | 3.20 | 0.849 | 0.00170 |
| 501,000 | 4.121 | 0.00824 | 2.00 | 0.00110 | | | | |
| 449,000 | 4.840 | 0.00968 | 1.80 | 0.00095 | | | | |

* Equation 3: Stephen et al, (2005) model for low strength plaster

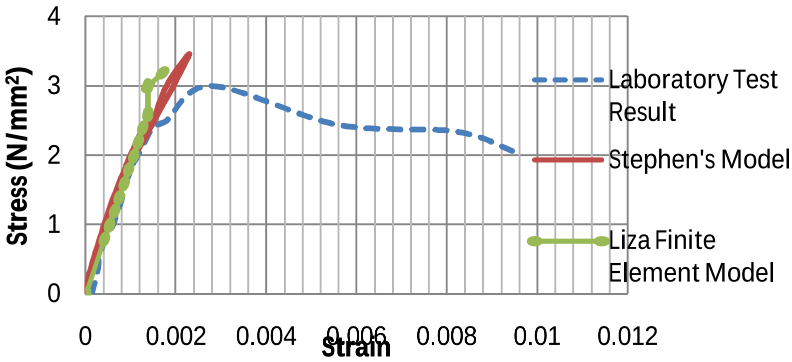



Figure 6: Stress-strain Curves

### 2.2 Design Ultimate Stress and Strength per unit Length of Wall

Figure 9 shows the free body diagram of the loading plate on the plastered straw wall. Equation 4 gives the expression for the design ultimate load which must not be greater than the capacity of the wall.

$$F_{ult} \leq 2f_c' L_p t_p + \varepsilon_{straw} E_{straw} A_{straw} \tag{4}$$

Figure 8: Schematic diagram of the test set up

The rigid loading plate produces equal compression of the plaster and straw as shown in Figure 9. The plastered bale fails when the plaster reaches its cube

strength fc', the plastered bale strength per unit length, $w_{bale}$ is therefore given as:

$$w_{bale} = \frac{(f_c' \times 2t \times L + F_{straw})}{L}$$

Where

$F_{straw}$ is the total force in the straw at failure

Where: $F_{ult}$ = ultimate load on the plastered bale assembly

$f'_c$ = average cube strength of the plaster material

$L_p$ = Length of plaster (500mm)

$t_p$ = Thickness of plaster (25mm)

$\varepsilon_{straw}$= strain in straw

$E_{straw}$ = modulus of elasticity in straw

$A_{straw}$ = load bearing area of straw

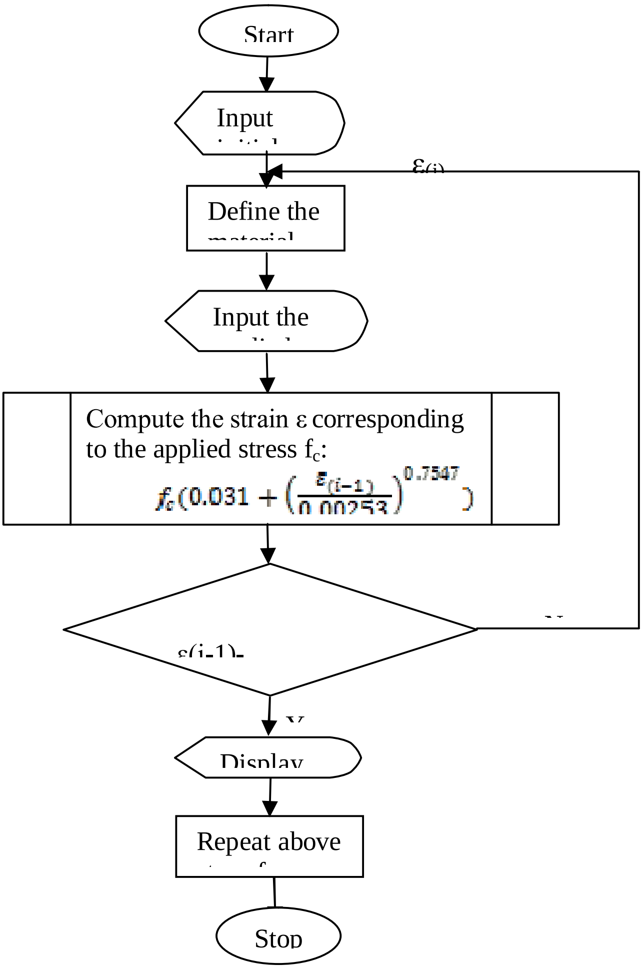



Figure 7: Flow chart of the MATLAB program

The average slope of the stress strain curve of Figure 6 for the laboratory test result gives Es (taken as $E_{straw}$) ≈1250 N/mm$^2$ while Adedeji (2007) gave an average value of the elastic modulus of unplastered straw bale as 737N/mm$^2$

Dividing both sides of Equation 8 by the load bearing area (500x500 mm$^2$) gives:

$$f_{ult} \leq \frac{2f_c'L_pt_p + \varepsilon_{straw}E_{straw}A_{straw}}{500x500}$$

$$3.0 < \frac{2 \times 3.92 \times 25 \times 500}{500 \times 500} + \frac{0.00179 \times 1250 \times 450 \times 500}{500 \times 500}$$
$$= 3.542N/mm^2 \qquad OK$$

Multiplying this result $f_k$ = 3.0N/mm$^2$ by L (=500mm) gives the plastered bale strength per unit length, $w_{bale}$ as expressed by Equation 4.9.

$$w_{bale} = 3.0 \times 500$$
$$= 1500N/mm \qquad or\ 1500kN/m$$

The validation of the plaster stress-strain model was done by utilizing the wall's experimental stress-strain behaviour results presented in Figure 7. Within the elastic range, the experimental results and LIZA model results show insignificant deference from the Stephen's model results for the stress-strain behaviour.

**2.3 Load Bearing Plastered Straw bale Wall Design**

The strength of a plastered straw bale prism of 125mm x 165mm x 245mm having mortar thickness of 25mm is reported as $f_p$= 0.98N/mm$^2$ at 28 days by Ajamu and Adedeji (2010). As given above the strength of a plastered straw bale wall of 500 x 500 x 1000 mm is $f_w$= 3.0N/mm$^2$.

Hence $\emptyset = {f_w}/{f_p} = {3.0}/{0.98} = 3.06$

The strength of the plas straw bale prism is related to the strength of the plastered straw bale wall by equation 4.10

$$\sigma_w = 3.06\sigma_p \qquad (6)$$

**2.4 Design Vertical Load Resistance of Walls (N)**

BS5628 pt1 1992 gives the design vertical load resistance of a wall per unit length as:

$$N = \frac{\beta t f_k}{\gamma_m} \qquad (7)$$

Where

ß = capacity reduction factor allowing for the effects of slenderness and eccentricity and is obtained from Table 7 of the code

$f_k$ = characteristic strength of the masonry

$\gamma_m$ = appropriate partial safety factor for the material

t = the thickness of the wall.

For effective height of 3.0m and wall thickness of 0.5m, the code gives the slenderness ratio, $h_{ef}/t_{ef}$ = 6.0 and ß=1.0 for very small eccentricity of loading at the top of the wall.

$$Therefore, \quad N = \frac{1 \times 500 \times 3.0}{0.9 \times 2.5} = \frac{1500}{2.25}$$
$$= 667N/mm \ or \ 667kN/m$$

Hence, the design vertical load resistance of the wall per unit length, N is 667kN/m.

## 3.0 Observations

(i) From the test and the Stephen's model results it was observed that the applied stress on the plastered wall were 3.0 N/mm$^2$ for the laboratory test and 3.4N/mm$^2$ for the model. This difference could be due to non-uniformity in wall's plaster thickness at some parts of the wall.

(ii) The presence of straw in the cement-lime plastered straw bale wall reduces the stiffness and thereby causes the variations in strain obtained in the laboratory test and LIZA models compared to strain in Stephen's model which is based on plaster's strength alone.

(iii) The result from LIZA model is relatively higher than those obtained from Stephen's model.

## 4.0 Conclusion

- Within the range of elasticity of the plastered straw bale wall, Stephen's model gives a good prediction of the stress-strain behaviour of cement-lime plastered straw bale wall under concentric load.
- The cement-lime plastered straw bale wall can only support applied pressure not greater than 3.0N/mm$^2$.

- The designed plastered wall strength per unit length, $w_{bale}$ for the straw material and plaster used in this study is 667kN/m.

## References

Adedeji A.A. (2007): Introduction and design of straw bale masonry, Olad publishers Ent., Ilorin

Ajamu S.O. and Adedeji A.A. (2010): “Determination of Compressive Strength and Thermal Insulation Property of Cement Plastered Straw Bale Prism” First International Conference on Engineering and Technology Research of Faculty of Engineering and Technology Ladoke Akintola University of Technology, Ogbomoso (FET Conference 2010), 28th - 30th September 2010.

BS5628 Part 1 1992: Code of practice for use of masonry —Part 1: Structural use of unreinforced masonry.

BS EN 12390-3: 2002: Testing hardened concrete — Part 3: Compressive strength of test specimens

Collins, M, P., Mitchell, D. and MacGregor, J. G., (1993): “Structural Design Considerations for High-Strength Concrete”, Concrete International: Design and Construction 15 (5) (1993) 27-34.

Food and Agriculture Organization of the United Nations (FAO). “Nigeria has worst deforestation rate, FAO revises figures” retrieved on 23rd June 2009. http://news.mongabay.com/2005/1117-forests.html

Harvest homes (2008): “Straw bale building Primer”. www.harvesthomes.ca/building/straw_bale_primer.pdf

Lerner K and Donahue K (2003): “Structural Testing of Plasters for Straw Bale Construction” Research Report, Ecological Building Network, Sausalito, California, 23 pp.

Vardy, S., Tipping, T. and MacDougall, C. (2005) “Compressive Testing and Analysis of a Typical Straw Wall Plaster” Department of Civil Engineering, Queen’s University, Kingston, Ontario, Canada. www.springerlink.com/index/v2617u3114653136.

# Drought Analysis for Ilorin, Nigeria

Ogunlela A.O.* and Folowosele E.F.
Department of Agricultural and Biosystems Engineering
University of Ilorin
Ilorin, Nigeria.
Email:*aogunlela@yahoo.com

## Abstract

The occurrence of drought and its attendant effects on the environment, including agricultural programmes, have generated a lot of concern in Nigeria. This study was conducted in response to problems on drought damage and risk which could be reduced if adequate and precise drought forecasting mechanisms are put in place. Sixty six years of rainfall data (1946 – 2011) for Ilorin, were used in the analysis. Basic statistics were computed, including the mean, variance, coefficient of variation and skewness. The minimum daily rainfall ranged from 0.05 mm to 0.6 mm while the minimum monthly rainfall ranged from 0.25 mm to 76.8 mm. Four probability distributions were used: exponential, normal, log-normal and Extreme Value Type 1, including the Weibull plotting position. The extreme value distribution was the closest to the weibull (observed) plots for the daily and monthly events.
**Keywords**: Drought, frequency analysis.

## 1.0 Introduction

Precipitation is a principal component of the hydrologic cycle. Rainfall is the major form of precipitation in most regions of the world. Water availability is of paramount importance for industrial and socio-economic development. Shortage of water, or drought condition, affects humans, livestock, agricultural produce and the environment in general. Drought analysis is important in water resources planning and management and in socio-economic considerations. Drought definition and quantification are important in the analysis (Beran and Rodier, 1985; Wilhite and Glantz, 1985; Smakthin and Hughes, 2004). For example; the meteorologist views drought as below average precipitation in an area while the agriculturist views it as soil moisture deficit and the hydrologist, as below normal stream flow.

Since climate change affects hydrologic cycle, it affects drought events. Thus; changes in the frequencies of drought events may be one of the most

important consequences of climate change. Since drought events are associated with low or extremely-low rainfall periods, and rainfall attributes exhibit natural variability, drought event analysis in a stochastic framework provides a more realistic premise. This could be achieved using probability distributions (Haan, 1977; Mishra, et al., 2009). Some probability distributions are exponential, normal, log-normal and extreme value type 1 (Haan, 1977). Other methods that could be used include indices (Palmer, 1965) and simulation methods, with due recognition of spatial and temporal variability (Lana et al., 1998).The consequences of drought are mostly observed in arid regions, characterized by low rainfall and high evapotranspiration. Volgel and Kroll (1989) used probability-plot correlation coefficient to analyze low-precipitation frequency in Massachusetts. Keskin et al (2011) applied the standardized precipitation index in conducting meteorological drought analysis using artificial neural networks for five stations in Turkey.
A sizeable proportion of the population of Ilorin is engaged in agriculture and related activities. The purpose of this work was to conduct drought analysis for Ilorin: - to enhance agricultural activities and water resources planning in the area.

## 2.0 Materials and Methods

Ilorin, the study area and capital of Kwara state of Nigeria, is located on Latitude 8°30'N and Longitude 4°33'E. The wet season is from March to October, and the dry season, from November to February. Mean monthly temperature range from 25°C and 29°C and mean annual rainfall for Ilorin is 1222 mm (Akintola, 1986). Sixty six years of rainfall data (1946 – 2011) for Ilorin was obtained from Nigerian Meteorological Agency; Oshodi (1946 - 2002) and Lower Niger River Basin Rural Development Authority; Ilorin (2003 - 2011). Four probability distributions were used in the study: Exponential, Normal, Log-normal, Extreme Value Type 1.

The extracted low precipitation data were entered into Excel 2007 worksheet and basic statistics of mean, variance and standard deviation including coefficient of variation and skewness were computed for the untransformed and the logarithmically transformed data.
Weibull plotting formula was computed as:

$$pp = \frac{1}{T} = \frac{m}{n+1} \qquad \text{-------- (1)}$$

where, 'T' is the return period. 'm' the rank and 'n' the number of data points (66).

The exponential, normal, log-normal and extreme value type 1 distributions were used in this study due to their desirable properties. Return periods of 2 yrs, 5yrs, 10 yrs, 15 yrs, 20 yrs, 25 yrs, 30 yrs, 40 yrs, 50 yrs, 75 yrs, 100 yrs, 200 yrs, 500 yrs and 1000 yrs were used in the analysis. The pertinent equations are: (Haan, 1977; Barfield et al., 1981; Viessman, et al., 1989):

**Exponential:** $$F(x) = 1 - exp\left(\frac{-x}{\bar{x}}\right), x > 0 \quad (2)$$

$$X = -\bar{X}\, ln\left(\frac{1}{T}\right) \quad (3)$$

where; $F(x)$ is the cumulative distribution function for $x$; '$X$' is rainfall depth in mm; '$\bar{X}$' is the mean and 'T' is the return period in years.

**Normal:** $$x = \bar{x} + Z_T S_X \quad (4)$$

Where; '$x$' is the rainfall depth in mm; '$\bar{x}$' is mean; '$Z_T$' is standard normal deviate for return period T; obtained from Tables (Haan, 1977; Viessman, et al., 1989) '$S_X$' is standard deviation for $x$, in mm.

**Log-normal:** $$y = ln.x \quad \text{-------}(5)$$

$$y = \bar{y} + Z_T S_y \quad \text{--------} (6)$$

$$x = exp\,(y) \quad \text{--------} (7)$$

where; '$y$' is logarithmically-transformed rainfall depth; '$\bar{y}$' is mean of logarithmically transformed rainfall depth; '$S_y$' is standard deviation for $y$ and '$x$' is rainfall depth in mm. The other terms are as previously defined.

**Extreme Value Type 1:** $$\propto = \frac{\pi}{(\sqrt{6})(S_x)} \quad \text{--------} (8)$$

$$u = \bar{x} - \frac{0.5572}{\alpha} \quad \text{--------} (9)$$

$$y = -\ln[-\ln(1 - \frac{1}{T})] \quad \text{--------} (10)$$

Rainfall depth formulae: $$x = u + \frac{y}{\alpha} \quad \text{--------} (11)$$

$\propto$ and u are parameters of the distribution.

Rainfall depths were computed for the different return periods using the different probability distributions.

## 3.0 Results and Discussion

The statistics of Ilorin minimum daily and monthly rainfall depths for both untransformed and logarithmically transformed data (1946 to 2011) are shown in Table 1. The minimum daily rainfall ranged from 0.05 mm to 0.6 mm, with a mean depth of 0.237 mm and a standard deviation of 0.123 mm. The minimum monthly rainfall ranged from 0.25 mm to 76.8 mm, with a mean depth of 10.049 mm and a standard deviation of 13.163 mm. The coefficient

of variation, C.V., of minimum daily rainfall depth is 51.9 %, while that of minimum monthly rainfall depth is 130.9 %.

The following return periods (years) were used in the analysis: 2, 5, 10, 15, 20, 25, 30, 40, 50, 75, 100, 200, 500, and 1000. The return period depths for Ilorin minimum daily rainfall are shown in Tables 2 and 3, respectively. For the minimum daily rainfall; the depths (mm) ranged from 0.16 to 1.64; 0.24 to 0.62; 0.21 to 1.04; and 0.22 to 0.85 for the exponential, normal, log-normal and extreme value type 1 distribution, respectively. The corresponding values for the minimum monthly rainfall depths (mm) are: 6.97 to 69.42; 10.05 to 50.72; 4.26 to 402.62; and 8.11 to 75.54.

The plots of the rainfall depth and return periods for the various distributions are shown in figure 1 and 2 for the minimum daily and monthly events, respectively. The extreme value distribution was the closest to the weibull (observed) plots.

Table 1 Statistics for Ilorin Low precipitation data (1946 to 2011)

| | Min. daily rainfall | | Min, monthly rainfall | |
|---|---|---|---|---|
| | Untrans formed | Logarithmically Transformed | Untransform ed | Logarithmically Transformed |
| Min., mm | 0.05 | -2.996 | 0.25 | -1.386 |
| Max., mm | 0.6 | -0.511 | 76.8 | 4.341 |
| Range, mm | 0.55 | 2.485 | 76.55 | 5.727 |
| Mean, mm | 0.237 | 3.005 | 10.049 | 1.449 |
| Variance | 0.015 | 4.377 | 173.275 | 2.166 |
| Standard deviation, mm | 0.123 | 2.092 | 13.163 | 1.472 |
| Coefficient of Variation | 0.519 | 0.696 | 1.310 | 1.016 |
| coefficient of Skewness | 0.0000 1 | -0.00129 | 1.44175 | -0.00018 |

Table 2 Ilorin minimum daily rainfall return period depths mm (1946 – 2011)

| T (Return period in years) | Exponential Distribution | Normal Distribution | Log-normal Distribution | Extreme Value Type 1 | Weibull Plotting Position |
|---|---|---|---|---|---|
| 2 | 0.16 | 0.24 | 0.21 | 0.22 | 0.16 |
| 5 | 0.38 | 0.34 | 0.32 | 0.33 | 0.26 |
| 10 | 0.55 | 0.39 | 0.41 | 0.40 | 0.34 |
| 15 | 0.64 | 0.42 | 0.46 | 0.44 | 0.39 |
| 20 | 0.71 | 0.44 | 0.49 | 0.47 | 0.42 |
| 25 | 0.76 | 0.45 | 0.52 | 0.49 | 0.44 |
| 30 | 0.81 | 0.46 | 0.54 | 0.51 | 0.46 |
| 40 | 0.87 | 0.48 | 0.58 | 0.54 | 0.50 |
| 50 | 0.93 | 0.49 | 0.61 | 0.56 | 0.52 |
| 75 | 1.02 | 0.51 | 0.67 | 0.60 | 0.57 |
| 100 | 1.09 | 0.52 | 0.70 | 0.63 | 0.60 |
| 200 | 1.26 | 0.55 | 0.80 | 0.69 | 0.68 |
| 500 | 1.47 | 0.59 | 0.94 | 0.78 | 0.79 |
| 1000 | 1.64 | 0.62 | 1.04 | 0.85 | 0.86 |

Table 3 Ilorin minimum monthly rainfall return period depths mm (1946 – 2011)

| T (Return period in years) | Exponential Distribution | Normal Distribution | Log-normal Distribution | Extreme Value Type 1 | Weibull Plotting Position |
|---|---|---|---|---|---|
| 2 | 6.97 | 10.05 | 4.26 | 8.11 | 6.11 |
| 5 | 16.17 | 21.13 | 14.70 | 19.79 | 19.01 |
| 10 | 23.14 | 26.92 | 28.11 | 27.53 | 28.77 |
| 15 | 27.21 | 29.81 | 38.82 | 31.89 | 34.48 |
| 20 | 30.10 | 31.70 | 47.94 | 34.95 | 38.53 |
| 25 | 32.35 | 33.09 | 56.09 | 37.30 | 41.67 |
| 30 | 34.18 | 34.26 | 63.82 | 39.22 | 44.24 |
| 40 | 37.07 | 35.85 | 76.25 | 42.23 | 48.29 |
| 50 | 39.31 | 37.09 | 87.62 | 44.56 | 51.43 |
| 75 | 43.39 | 39.36 | 112.96 | 48.77 | 57.14 |
| 100 | 46.28 | 40.67 | 130.71 | 51.75 | 61.19 |
| 200 | 53.24 | 43.96 | 188.86 | 58.93 | 70.95 |
| 500 | 62.45 | 47.96 | 295.30 | 68.39 | 83.85 |
| 1000 | 69.42 | 50.72 | 402.62 | 75.54 | 93.61 |

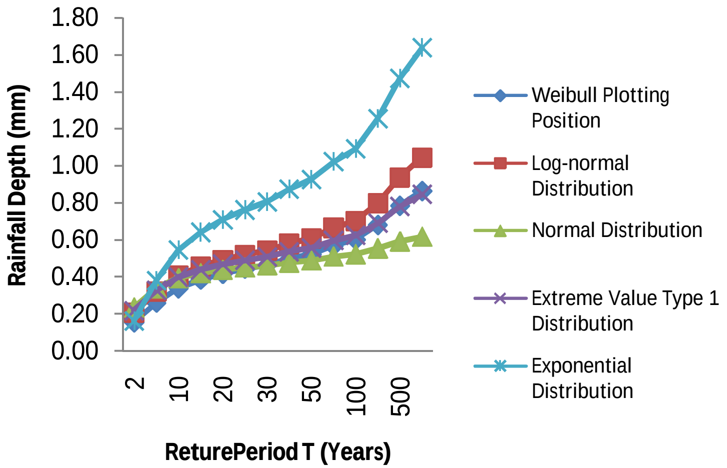



Figure 1. Ilorin minimum daily rainfall cumulative probability

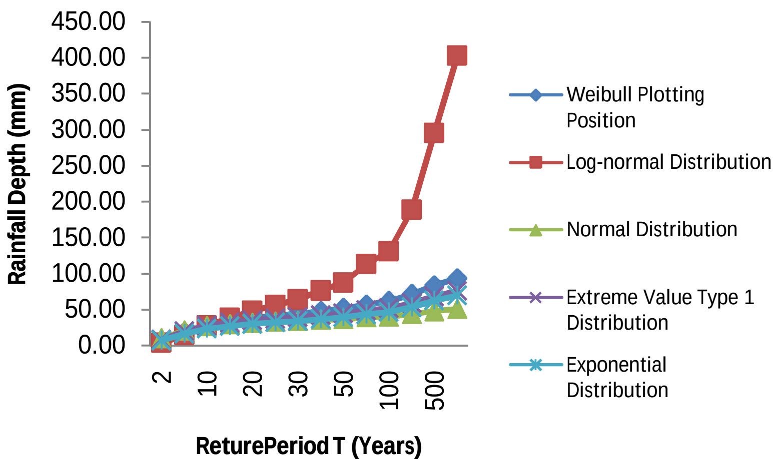



Figure 2. Ilorin minimum monthly rainfall cumulative probability

## 4.0 Summary and Conclusions

Sixty six years of low precipitation data (1946 – 2011) for Ilorin were used in conducting drought analysis for Ilorin Nigeria. Four probability distributions, i.e., the exponential, normal, log-normal and extreme value type 1, including the Weibull plotting position, were used in the analysis.

Fourteen return periods (years) were used: 2, 5, 10, 15, 20, 25, 30, 40, 50, 75, 100, 200, 500, and 1000. Basic statistics including minimum, maximum, range and mean; including variance coefficient of variation and skewness were computed. The extreme value distribution was the closest to the Weibull plots.

## References

Akintola, J.O. 1986. Rainfall Distribution in Nigeria. 1892 – 1983. Impact Publishers. Ibadan.

Barfield, B.J., Warner, R.C. and Haan C.T. 1981. Applied Hydrology and Sedimentology for Disturbed Arears. Oklahoma Technical Press.

Beran, M. A., Rodier, J. A. 1985. Hydrological aspects of drought. UNESCO-WMO Studies and Reports in Hydrology 39: 149.

Haan, C.T. 1977. Statistical Methods in Hydrology. Iowa State University Press, Ames. Iowa U.S.A

Keskin, M.E., O. Terzi, E.D., Taylan and D. Küçükyaman 2011. Meteorological drought analysis using artificial neural networks. Scientific Research and Essays. Vol. 6(21): 4469 – 4477.

Lana, X., Serra, C., and Bur gueňo. A. 1998. Spatial and temporal characterization of annual extreme droughts in Catalonia (Northern Spain). Int. J. Clim. 18: 93–110.

Mishra, A., Singh, V. and Desai, V. 2009. Drought characterization: A probabilistic approach.Stochastic Environmental Research and Risk Assessment 23(1): 41-55.

Oyegun, R. 1983.Water Resource in Kwara State, Nigeria Matanm Sons Printing & Publication Co., Ilorin

Palmer, W. C. 1965. Meteorological Drought. Research Paper No. 45. Washington, D.C.: U.S. Department of Commerce Weather Bureau.

Smakthin, V. and Hughes, D. 2004. Review, automated estimation and analysis of drought indices in south Asia-Working paper (83). IWMI, Colombo, Sri Lanka.

Viessman, W. Jnr, Knapp, J.W., Lewis, G.L. and Harbough, T. E. 1989. Introduction to Hydrology. Harper and Row Publishers, New York

Volgel, R.M. and C.N. Kroll. 1989. Low-flow frequency analysis using probability-plot correlation coefficients. Journal of Water Resource Planning and Management. Vol. 115 (3): 338 – 357.

Wilhite and Glantz, 1985. Drought Assessment , Management, and Planning: Theory and Case Studies, Netherlands: Kluwer Academic.

# Impact Indicator of Solid Waste Collection Effectiveness: A Case Study of Ilorin Metropolis, Nigeria.

Ogunlela A.O. and Abadunmi T.
Department of Agricultural and Biosystems Engineering
Faculty of Engineering and Technology
University of Ilorin; Ilorin, Nigeria
aogunlela@yahoo.com; taiwoabadunmi@yahoo.com

**Abstract**

Correlation of user satisfaction and community effect indices was used in obtaining an impact indicator of solid waste collection effectiveness in Ilorin metropolis, Nigeria. The research involved formal and informal interviews with stakeholders within the metropolis. Data collection was through the administration of questionnaire. The data and information obtained were analyzed and results indicated 12% of the total routes considered attained an "Excellent" level, 59% exhibited "Good" level and 29% still at the "Fair" level. The paper also discusses the need for a policy framework in achieving sustainable development through proper waste management.
**Keywords:** solid waste, impact indicator, collection effectiveness.

## 1.0Introduction

It is necessary to be able to measure system efficiency for effective management. Effectiveness indicates how well a task in a system is being done, thus aids in a proper planning and optimization. Solid wastes includes discarded paper pieces, cloth pieces, plastic, bottle, leaves and other materials usually found in the market places, road sides, residential and hospital areas, schools, manufacturing or production sites.

Solid wastes collection is best done in a planned way so that unhygienic conditions do not arise from the processes. Solid wastes improperly managed, have constituted great treat to the human health and the natural environment, which has called for attention (Tchobanglous et al, 1993). With increasing and changing habits, the quantities and varieties of solid waste generated have increased (Onibokun, 1999).

Basak (2004) suggested hygienic ways of collecting and removing solid wastes, emphasizing prompt disposal at dumping sites. Service coverage in most urban centers is inadequate, and no collection in many rural areas. Less

than 60 per cent of municipal wastes generated are collected in developing countries (Ogwueleka, 2003). In Nigeria, various government levels have taken measures to ensure proper collection and management of solid wastes but with little effects. Solid waste collection effectiveness plays an important role in ensuring environmental sustainability.
Sustainable development is an implied development without destruction. It means the judicious use of non-renewable resources for the present and future generations, which are non-renewable resources and must be used at a judicious rate, neither too fast nor too slow and to ensure that the natural wealth that they represent is converted into long-term wealth as they are used. Adewole (2009) examined conditions to achieve a sustainable development in waste management in Nigeria, as availability of land (for landfill), human resources, plant and equipment and other relevant tools. These tools, coupled with capital must be readily available. There is need to protect future for the next generation by cleaning up our environment of all types of waste, taking into consideration both physical and population development of the state. This study aimed at obtaining an impact indicator of solid waste collection effectiveness in Ilorin metropolis, Nigeria.

## 2.0Methodology

Ilorin, the study area and capital of Kwara State of Nigeria is located on latitude $8^0$ 29' N and longitude $4^0$ 37' E. The wet season spans from March to October, while the dry season, from November to February; with mean monthly temperatures from $25^0$C TO $29^0$C. The city is faced with wastes management challenges, mainly due to urbanization and population increase. The state government, in its efforts to proffer a lasting solution to the problem, launched the Clean and Green policy. O'lan klean-an, an environment management consortium, manages the waste collection and disposal in partnership with the Kwara State Waste Management Corporation (KWMC). Wastes are collected into Ro-Ro bins placed strategically in the metropolis. Figure 1 shows map of Ilorin metropolis indicating the distributed bins.However, since the purpose of this work was to investigate a potential method of obtaining a measurable impact indicator of solid waste collection effectiveness, the following variables were used, for proper planning and management optimization:

1. Satisfaction of the system users
2. Effect of the collection on the community and,
3. Societal values; the correlation of (1) and (2)

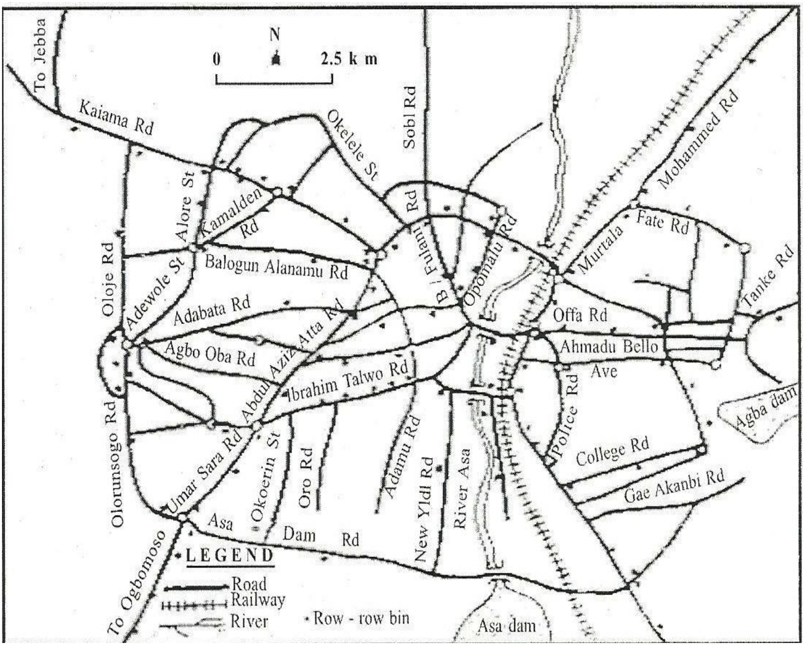



Figure 1: Map of Ilorin Metropolis showing locations of Ro-Ro bins
Source: Ministry of Land and Housing, Ilorin.

Data collection was through the administration of questionnaire, on-site field investigation, and oral interviews with targeted population, which were workers of solid wastes management and residents. The questionnaire was structured to investigate the user satisfaction and community effect ratings.
Table 1 shows the number of sampled locations per route. The point values in the questionnaire were used to measure the user satisfaction, given by (Versilind and Rimer 1981):

$$U.S.I \frac{\sum_{i=1}^{N} Ri}{N} \quad (1)$$

where:
U.S.I is the User Satisfaction Index; Ri is the sum of values for ith questionnaire, and N is total number of people interviewed. The user satisfaction rating used the following conditions for the point values: 20-clean, very good; 15-fairly clean; and 10-poor or dirty and irregular collection.

Table 1: Number of Sampled Location per Route

| Number of Route | Number of Location Sampled | Name of Route |
|---|---|---|
| 1 | 5 | From Fire Station To General Hospital. |
| 2 | 4 | From Omoda Roundabout To Ogidi village. |
| 3 | 7 | From Post Office Roundabout To Olunlade. |
| 4 | 6 | From Post Office Roundabout To Emir's Market Terminating @ 'C Police Division Roundabout. |
| 5 | 3 | From Yebumot Hotel To Offa Garage. |
| 6 | 7 | From Yebumot Hotel To Offa Garage. |
| 7 | 4 | From Unity Road through Taiwo Isale To 'C' Police Division, Oja |
| 8 | 5 | From Isale Oja To Pakata. |
| 9 | 8 | From Maternity to Emir's Market. |
| 10 | 8 | From Challenge via Govt. House to Ministry of Agric. Roundabout. |
| 11 | 2 | Illofa Road and its Adjourning Admiralty Drive. |
| 12 | 3 | Zulu Gambari Road - Yoruba Road –CBN Road-High Court Road |
| 13 | 1 | New Yidi Road. |
| 14 | 9 | Isale Oja Via Agbaka To Airport. |
| 15 | 2 | Pakata Roundabout To Adeta Roundabout. |
| 16 | 3 | Idi Ape To Omoda Roundabout. |
| 17 | 7 | From Olaolu Junction To Agbabiaka. |

Table 2 shows the results for five the locations in Route 1. Q signifies the question considered and R is the summation; $\sum Ri$ per location was used to measure the U.S.I in each location and subsequently, average user satisfaction index per route.

Further estimation of the collection adequacy was based on the street cleanliness. Scale of 1 to 5 was used to rate the cleanliness. Rating values were corrected for the presence of unusual materials left uncollected (Table 3). The collection effects on the community were estimated using the Community Effect Index, given as (Versilind and Rimer 1981):

$$\text{C.E.I}= \frac{\sum_{i=1}^{N}(S-P)i}{N} \qquad (2)$$

where:

S is street cleanliness rating (varying from 0 to 100), P is the presence of any special condition, and N is total number of streets rated. C.E.I has a maximum value of 100 indicating extremely clean street.

The measurement of the physical effects attributable to collection efficiency was based on the scale given as;

100 **-** Very clean street with no visible litter,
75 **-** Moderately clean street with only one accumulation of trash not set out for collection,
50**-** Litter scattered along most of the streets with several significant accumulations, 25**-** Heavy littered with enough trash to fill at least a Ro-Ro bin, 0 **-** Extreme condition, more trash than would fill one Ro-Ro bin.

The correction of rating value for presence of unusual materials/trash (P) was assigned the point value of 10 for any of the listed conditions and zero for none of the conditions.

The following were also considered in the ratings:

i. Littered vacant plots
ii. Health hazards
iii. Fire hazards
iv. Abandoned motor vehicles, and
v. Overflowing Ro-Ro bins.

Summation of corrected rating for each location estimated, with C.E.I., Average community effect index (A.C.E.I) indicated the mean C.E.I estimated for each route.

Table 2: User Satisfaction Rating for Route 1

| Route | Location | Point Value<br>Q1 Q2 Q3Q4 Q5 | R | ∑Ri | U.S.I | A.U.S.I |
|---|---|---|---|---|---|---|
| 1 | I | 20 20 10 20 20 | | 90 | | |
| | | 15 15 15 20 20 | | 85 | 175 | 87.5 |
| | II | 15 15 15 10 10 | | 65 | | |
| | | 15 15 15 20 20 | | 85 | 150 | 75 |
| | | 15 15 20 10 10 | | 70 | 155 | 77.5 |
| | V | 20 20 10 15 20 | | 85 | | |
| | | 15 20 10 15 20 | | 80 | 165 | 82.5 |

**Q**-Question, **R-** Sum, **∑Ri** – Summation of Values from ith questionnaire, **U.S.I-**User Satisfaction Index, **A.U.S.I-** Average User Satisfaction Index.
**Source -** field survey

Table 3: Community Effects Rating for Route 1.

| Route | Location | S | P | S-P | ∑(S-P) | C.E.I | A.C.E.I |
|---|---|---|---|---|---|---|---|
| 1 | I | 75 | 10 | 65 | | | |
| | | 50 | 10 | 40 | 105 | 52.5 | |
| | II | 100 | 0 | 100 | | | |
| | | 75 | 0 | 75 | 175 | 87.5 | |
| | III | 75 | 0 | 75 | | | |
| | | 100 | 0 | 90 | 165 | 82.5 | |
| | IV | 25 | 10 | 15 | | | |
| | | 75 | 75 | 90 | 105 | 52.5 | |
| | V | 75 | 0 | 75 | | | |
| | | 75 | 10 | 65 | 140 | 70 | 69 |

**S-** Street Cleanliness, P- Presence of any special condition, **(S-P) -** Corrected Rating,, **C.E.I -** Community Effects Index, **A.C.E.I -** Average Community Effect Index **Source -** Field survey

## 2.0 Results and Discussion

### Impact indicators

Routes/locations having high U.S.I and high C.E.I indicate a high efficiency in collection. Other correlations such as high U.S.I with low C.E.I, or vice versa, indicate deficiency in collection. Again, low U.S.I and low C.E.I depictextremely poor level, an unacceptable situation. Figure 2 shows the correlation and categorized impact indicators as follows

1. **Excellent level indicator**
   The collection efficiency has high U.S.I and high C.E.I. The indicator is that at this level continual surveillance to ensure non-decline of the collection efficiency. Routes $R_{12}$, $R_{13}$ fell into this category.
2. **Good level indicator.** The indicator signifies high U.S.I and low C.E.I or vice versa, indicating that the routes require improvement on the collection processes. The following routes fell into this class: $R_1$, $R_3$, $R_5$, $R_6$, $R_7$, $R_9$, $R_{10}$, $R_{11}$, $R_{14}$, and $R_{15}$.
3. **Fair level indicator**
   The Fair Level indicator has routes with lower C.E.I and U.S.I than for "Good Level". The routes in this condition require more attention

and if left unattended to, may eventually deteriorate. They are $R_2$, $R_4$, $R_8$, $R_{16}$, and $R_{17}$.

4. **Poor level indicator**

   None of the investigated routes fell into this condition. This indicator signifies low U.S.I and C.E.I values. Such areas would have needed a major attention which might involve changing collection crew, increasing frequency of collection and disposal, additional street sweeping and public awareness against indiscriminate dumping of wastes.

5. **Unacceptable level indicator**

   This is a situation/condition of extreme low U.S.I and C.E.I. values. No route fell into this class. A total overhaul of the quality of the collection processes would have been necessary.

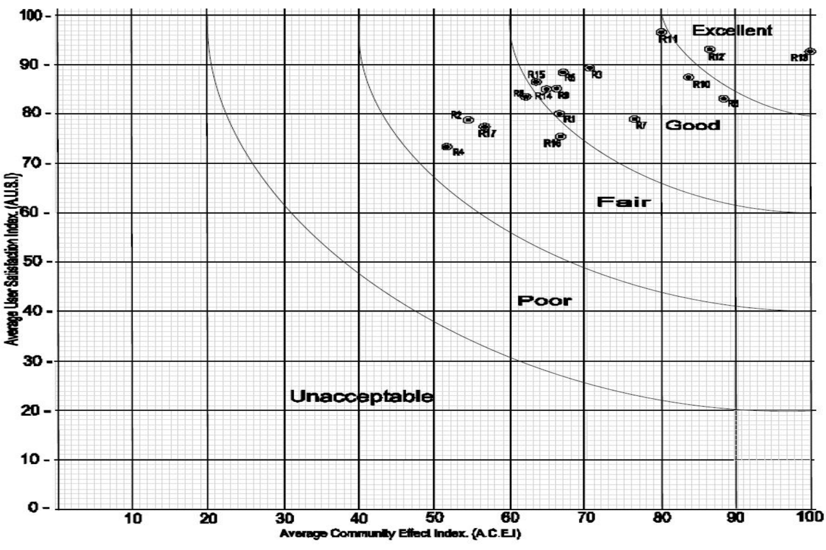



Figure 2: Correlation of User Satisfaction Index and Community Effects Index defining the Societal Value.

Impact indicator is an important tool needed for proper planning and optimization of system management. It is a panacea for environmental degradation. However, in achieving any level of sustainable development, especially in developing countries like Nigeria, there is need for management agencies and decision makers in this sector to be conversant with such an indicator. It conducts assessment, gives a vivid description of the state of a system, and can be used to make recommendation when carrying out an environmental risk assessment study. It must therefore be suitable for the socio-economic condition of the environment in which it is applied.

Collection effectiveness in Ilorin metropolis attains an average performance. Only 12 percent of the total route considered attained an “Excellent” level, 59 percent exhibited the “Good” level and 29 percent still, “Fair” level. Investigation shows that the task is going on well, but still requires better measures for sufficient collection coverage and disposal for optimum performance.

## 4.0Recommendation:

### Solid Waste Management Policy for Sustainable Development

Policy in wastes management is a broad approach, with social, economic, technological, political and administrative dimensions. It is not an issue, that can be easily compartmentalized and solved with innovative technology or engineering alone. It is particularly an urban issue that is related directly or indirectly to a number of issues such as urban lifestyles, resources consumption pattern, jobs and income levels, and socio-economic and cultural issues. Activities like minimization, reuse and disposal of waste, associated with urban waste need to be brought together on a common platform in order to ensure a long-term solution to waste management challenges.

A sustainable project which will incorporate the implementation waste sorting plant, and an aerobic composting plant is needed to serve the needs of the people. Facilities with high capacity to accepts both sorted and unsorted wastes, sorts the commingled waste on-site, separates the recyclables and stabilizes the organic components to produce compost of marketable quality should be proposed. Such a project can be complemented with numerous awareness campaigns that will focus on long-term waste management practices such as waste minimization, reuse/recycling, and sorting at the source programs.

One of the main objectives of the campaigns will be to enhance waste separation at the source, which will be needed to facilitate the operation of such plant, and more importantly, improve the quality of the by-products, compost, and recyclables, hence their marketability and subsequently, the sustainability of the project. It should also aim at increasing the awareness of the local populace on the importance of waste minimization, sorting and re-use as long-term strategies for the sustainable management of solid waste. It is therefore important to note that, there must be a balance between levels of development and the stock of natural resources, that is, development must be at a level that can be sustained without prejudice to the natural environment or to future generations.

## 5.0 Conclusions

The impact indicator of solid waste collection effectiveness in Ilorin metropolis indicated that routes $R_2$, $R_4$, $R_8$, $R_{16}$, and $R_{17}$ at "Fair" impact, still require more attention. Routes $R_1$, $R_3$, $R_5$, $R_6$, $R_9$, $R_{10}$, $R_{11}$, $R_{14}$, and $R_{15}$ at

"Good" impact, require minimum improvement and only Routes $R_{12}$ and $R_{13,}$ at "Excellent" impact, require continual surveillance to prevent a decline in the level of the service. Collection effectiveness in the metropolis is at an average performance, where only 12 per cent of the total routes considered attained an "Excellent" level, 59 per cent exhibits the "Good" level and 29 per cent still at the "Fair" level.

The operatives, professionals engineers, municipal agencies, and other stakeholders must make best efforts in planning and executing the system to keep with the increasing urban areas and population. Properly funding of the various agencies responsible for effective and safe waste management by the state governments is equally essential here. Policies in waste minimization, sorting and reuse/recycling and waste disposal for sustainable development, must also be made.

## 6.0Acknowledgement

We acknowledge members of Staff and Management of Ministry of Land and Housing; O'lan Klean-an Environmental Management Consortium and Kwara State Waste Management Corporation (KWMC), Ilorin, for their cooperation towards the success of this investigation.

## References

Adewole, A.T. (2009). Waste Management towards Sustainable Development in Nigeria: A case study of Lagos State, Nigeria. International NGO Journal, Vol. 4(4). pp. 173-179.

Basak, N.N (2004). Environmental Engineering; Tata McGraw-Hill Publishing Company Limited, New Delhi.

Ogwueleka, T.C. (2003). Analysis of Urban Solid Waste in Nsukka, Nigeria. Journal of Solid Waste Technology and Management Vol. 29(4): 239-246.

Onibokun, A. G. (1999). Managing the Monsters: Urban Waste and Governance in Africa. International Development Research Centre, Ottawa.

Tchobanglous, G; Theisen, H., and Vigil, S. (1993). Integrated Solid Waste Management, McGraw Hill Series.
Versilind, P. A. and Rimer, A. E. (1981). Unit Operations in Resource Recovery Engineering. Prentice-Hall Inc., Englewood Cliffs, New Jersey.

# Engineering Properties of Used and Unused Laterite Soils

**A.O. Adeboje, *O.S. Olaniyan and *O.S. Oladeji and *O.M.Osuolale
*Department of Civil Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria
**Department of Civil and Environmental Engineering, University of Lagos, Lagos, Nigeria
email – oluwaniretimi4sure@yahoo.com

**Abstract**

It is difficult to assess the strength parameters of lateritic soils from existing literature due to variability in test methods, degree of compaction and soil characteristics. This paper describes some significant engineering properties of both used and unused laterite soils, and also examines the reusability of laterite soil in construction of local houses. Disturbed samples of both used and unused laterite soils were investigated. The tests carried out are sieve analysis, atterberg limits, specific gravity, british standard compaction, air-dry moisture content, triaxial compression and compressive strength.

The results from the study revealed that the geotechnical properties of the unused laterite soil samples are better than that of the used laterite soil samples. The compressive strength of unused laterite soil is greater than that of used laterite soil hence they are more suitable, preferable and safer to be used for construction of local houses than the used laterite soil. The used laterite soil can however be re-used or reutilized to build local houses by addition of 0.5% portland cement. Futhermore, addition of 0.75% portland cement to the used laterite soil makes it stronger and more suitable for construction than the unused laterite soil.

**Keywords:** Laterite, compaction, geotechnic, reutilize, strength.

## 1.0 Introduction

Laterite as a soil group rather than a particular material is more commonly found in the leached soil of humid tropics. It is difficult to assess the strength parameters of lateritic soils from the existing literature due to variability in test methods, degree of compaction, and actual soil characteristics (Attoh – Okine and Fekpe, 1999). This paper thus describes some significant engineering properties of both used and unused laterite. It also examine the reusability of laterite soil in construction of local houses by comparing the

geotechnical properties of used and unused laterite soil. The effect of portland cement as addictive on the used laterite soil was also investigated.
The study involves collection of disturbed sample ( sample whose strata layer has been distorted) for the two types of specimen – the used and unused soils. The unused soil samples were collected from Igbo-Ile, Iresa Adu and the used soil samples were collected from General area, Ogbomoso. The tests carried out include grading size analysis, atterberg limits (liquid, plastic and shrinkage limits), specific gravity, british standard compaction, air-dry moisture content, triaxial compression and compressive strength.

## 2.0 Methodology

This research involves collection of disturbed sample for both the used and unused laterite soils. The tests carried out include sieve analysis, Atterberg limits (liquid, plastic and shrinkage limits), specific gravity, british standard compaction, air-dry moisture content, triaxial compression and compressive strength. Samples $A_1$ – $A_5$ represent unused laterite soils while samples $B_1$ – $B_5$ represent used laterite soils.
The specific gravity (SG) soil is given by the expression:

$$SG = \frac{(W2 - W1)}{W} \qquad 1$$

Where W = weight of water displaced by the soil
W1 = weight of density bottle (empty)
W2 = weight of bottle + soil

The experiments were conducted in compliance with BS 1377 (1990). The experimental procedures and full details are avalable in Adeboje (2003).

## 3.0 Discussion of Results

From the curves of the grain size analysis of both used and unused laterite soils, it can be deduced that the samples are well graded. The curves are given in Adeboje (2003). The percentage of soil material passing through No.200 BS sieve are (66.15 - 75.06) % and (10.72 - 13.11) % for unused and used laterite soil samples respectively. The percentage of soil material passing through No 40.BS sieve are (83.09 - 87.44) % and (33.03 - 37.34) % for unused and used samples respectively and the percentage of material passing through No.10 BS sieve are (92.42 - 94.26) % and (53.34 - 60.78) % for used sample. The values obtained from selected set of samples and sieve fall within acceptable limits. Both used and unused samples have constituents of silt, sand and gravel.

Federal Ministry of works and housing (1973) recommended liquid limit of 50% maximum, plastic limit of 30% maximum and plasticity index of 20% maximum for use in construction work. All the results obtained from this study fall within this range and satisfy the condition for construction. Except for sample $A_1$ and $A_2$ where the plasticity index is slightly higher than specification. Hence, all samples except samples $A_1$ and $A_2$ are suitable for construction work.

The addition of cement (a binding medium) to the used laterite soil at 0.25, 0.50 and 0.75, the strength of the used laterite soil increased as shown in Plate 1. It was deduced that the strength of the used soil samples were improved to equal that of the unused soil samples by the addition of 0.5% cement at specified age. The strength of the used soil samples were improved beyond that of the unused soil samples by the addition of 0.75% cement (see Table 1 and 2).

Table 1: Average Compressive Strength for Unused Laterite

| Age (Days) | Samples ID | Sample 1 Compressive Strength (kN/mm$^2$) | Sample 1 Compressive Strength (kN/ mm$^2$) | Average Compressive Strength (kN/mm$^2$) |
|---|---|---|---|---|
| 7 | $A_5$ | 2.20 | 2.10 | 2.15 |
| 14 | $A_5$ | 2.90 | 2.90 | 2.90 |
| 21 | $A_5$ | 2.30 | 2.20 | 2.25 |
| 28 | $A_5$ | 2.30 | 2.30 | 2.30 |

Table 2: Average Compressive Strength for Used Laterite

| Age (Days) | Samples ID | Sample 1 Compressive Strength (kN/mm$^2$) | Sample 1 Compressive Strength (kN/ mm$^2$) | Average Compressive Strength (kN/mm$^2$) |
|---|---|---|---|---|
| 7 | $B_5$ | 1.50 | 1.50 | 1.50 |
| 14 | $B_5$ | 1.70 | 1.80 | 1.75 |
| 21 | $B_5$ | 1.40 | 1.50 | 1.45 |
| 28 | $B_5$ | 1.40 | 1.50 | 1.45 |

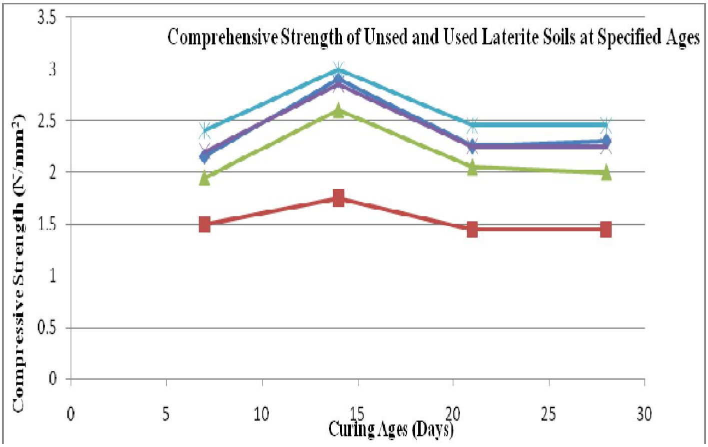



**Plate 1:** Graph of Compressive Strength against Curing Ages

From Plate 1, brown line represents the curve for the used laterite soil while the purple line represents the curve for the unused laterite soils (when cement has not been added). When the used laterite soil was stabilized, lemon, blue and sky blue lines represent the curves for stabilized used laterite soils at various percentages, that is at 0.25%, 0.50% and 0.75.

## 4.0 Conclusion

The geotechnical properties of the unused laterite soil samples are better than that of the used laterite soil samples because the used soil had earlier undergone leaching thereby altering its engineering properties. Since the used laterite soils had earlier undergone compaction, the values of its optimum moisture content, maximum dry density, plastic limits, liquid limit and shrinkage limit are lesser than that of unused soils. The results from compressive strength revealed that the strength of unused laterite soil is greater than that of the used laterite soil. By the addition of 0.5% of cement, the reduction in the strength of the used laterite soil was made up for (equalized) thereby giving a compressive strength which is comparable or equal to that of the unused laterite soil.

The unused or naturally existing laterite soils are preferable to be used for construction of local houses than the used laterite soil. The unused laterite soils are suitable and safe for the construction of local houses in Ogbomoso.

The used laterite soil can however be re-used or reutilised to build local houses by addition of 0.5% portland cement. Furthermore, addition of 0.75%

of portland cement to the used soil makes it stronger and even more suitable for construction even than the unused soil.

**References**

Attoh-Okine, N.O. and Fekpe, E.S.K. (1999). Strength characteristics modeling of lateritic soils using adaptive neural networks.

Gidigasu, M.D. (1974). Degree of weathering the identification of LateriteMaterialsfor Engineering Purpose, Elsevier Scientific publisher, New York.

Laa Archwichai, Winit Youngme, Surachai Somphadung, Somwang Changsuwan, Pansak Wannakao, Somyot Hokjaroen, Ladda Wannakao (2003). Engineering properties of lateritic soils from Khon Kaen and its vicinity, Thailand, Journal of Southeast Asian Earth Sciences, Volume 8, Issues 1-4, Pages 549-556.

Egwurube, J.A. (2001). Geotechnical properties of Tropically weathered Soils of Nigeria- A Review, Nigeria Journal of Tropical Engineering. (2).1 pp 55-60.

Adeboje, A. O. (2003). Comparative Evaluation of Engineering properties of used and unused Laterite soils in Ogbomoso". Unpublished B.Tech. Thesis submitttted to Department of Civil Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria.

BS (1990). Methods of Test for the Classification of Soils for the Determination of Basic Physical Properties", British Standards Institution, London.

Federal Ministry of Works and Housing, (1973). Highway Manual Part I: Road Design, Lagos.

O'Flaherty, C. A. (2002). Highways: The Location, design, Construction and maintenance of Road Construction, Fourth Edition, Butterworth – Heinemann, London.

# Integrated Sustainable Waste Management: A Means of Achieving Vision 20:2020

AbdulWahab Ogunbiyi
Mechanical Services, Lagos State Ministry of Works & Infrastructure
The Secretariat, Ikeja Lagos, Nigeria (wahogun@yahoo.co.uk)
Johnson O. Agunsoye
Metallurgical & Materials Engineering Department,
University of Lagos
Akoka, Lagos, Nigeria (jagunsoye@unilag.edu.ng)
Olasunkanmi M. Ojowuro
Ministry of Physical Planning and Urban Development
The Secretariat, Ikeja Lagos, Nigeria (sojowuro@yahoo.com)
Adeshola O. Openibo-Adebosin
Operations Department, Lagos State Ministry of Transportation The Secretariat, Ikeja Lagos, Nigeria (adeshola.openibo@yahoo.com)

## Abstract

This paper briefly examines the relationship between man and solid waste generation, it impact on the environment and needs for man to manage waste. It also briefly discussed methods of managing waste in Nigeria so far and the attendant results achieved . Integrated Sustainable Waste Management (ISWM) focussing on relevant aspects is also discussed, benefits and roles of ISWM for the nation enumerated. Its also highlight how to get the relevant parts of ISWM adopted in Nigeria so as to make waste management sustainable and contributory toward the achievement of the vision 20:2020 discussed.

**Key words**: Relationship, Man and solid waste, Impact on the environment, ISWM, Vision20:2020.

## 1.0 Introduction

Every human activity, natural or life induced ones leads to waste generation. Every form of waste becomes a pollutant to the environment, creating imbalance in the eco-system. Waste, though unwanted, is a companion of man from cradle to grave. It cannot be avoided but can be managed and controlled to prevent it from causing ecological problems. If properly managed, it can also be a great economic values to man

Due to peculiar characteristics of solid waste, it is the first that easily comes to mind whenever waste is mentioned. This is so because solid waste does not flow away or evaporate from its point of generation. Solid waste does not also dissolve or diffuse into its surrounding medium such as water or air. It remains in the immediate environment and competes with man and the environment. Other form of wastes, liquid or gas flow away or diffuse into other media thereby competing with global environment but not with immediate environment. Solid waste is an individual commodity at generation but becomes a global commodity after generation as it competes with everyone in its environment[1]. Another characteristic of solid waste is its potential to become a pollutant to the three bodies of the environment. As solid, it pollutes the land, as it disintegrates (depending on the chemistry of the solid waste material), it pollutes both water and the air. All these have made the solid waste the next, apart from the natural pollutants, the source of ecological problems to man. **Hence, man needs to manage the waste**. Several studies and experience have also shown that if wastes, solid waste in particular, are not properly managed, they will grow to such a level that will prevent human beings from carrying out their daily activities, dangerously affect human lives and the environmental bodies[2].

## 2.0 Solid Waste Management and Establishment of Waste Management Bodies

The history of solid waste management in Nigeria is closely tied to the history of local governments, as it is all over the world. From time immemorial, the sanitary officers are not working for anybody other than Local Government and are not known for any function other than cleanliness of the environment with solid waste management as major. The management and enforcement are all entrusted to the hand of this tier of Government by the constitutions of Federal Republic of Nigeria[3]. Local government authorities started having problem in handling this statutory responsibility as urbanization started. Urban cities were growing too rapidly leading to unbearable pressure on existing service facilities. This problem became a monster which rendered all efforts of local authorities abortive and became source of embarrassment to the state and federal governments as heaps of refuse were clothing the entire landscape.This embarrassment reached the peak during FESTAC 77 when Lagos, the then federal capital city, was described as the dirtiest capital city in the world[4]. This led to the emergence of the first waste management agency in Nigeria established by the Lagos State Military Government in 1977 as a Lagos State Government agent to carry out the duty of collection,

transportation and disposal of waste throughout the state. The body was then called Lagos State Refuse Disposal Board and has transformed to what is today called, Lagos Waste Management Authority (LAWMA).
Another shake up in solid waste management matter, in Nigeria, came up in 1988 as tonnes of hazardous waste dumped in Koko south-south Nigeria by a foreign company. This led to a further and higher effort from Governments both at Federal and State levels. Several bodies like Federal Environmental Protection Agency (FEPA) and corresponding States Environmental Protection Agencies (SEPAs) were set up as a result, assigned with the responsibility of proper management and protection of environment. Solid waste management is one of the major duties of the bodies[5]. No state in the country today, is without State Environmental Protection agency (SEPA) and one or more bodies in use for managing solid waste in the state – Kwara State inclusive. Each government provide these bodies with equipment and infrastructures and also spend huge sum of money yearly, by way of budgetary allocations, for their operations.

### 2.10 Waste Management and Environmental Impact

To some extent, solid waste management situations, in many states of the federation and FCT in the new millennium have improved. Streets and roads in cities are fairly clean while market and public places are no more dump sites, round-about junctions and under bridges are fairly cleared of solid waste regularly.

However, streets and road-shoulders in some cities are still dotted with naked wastes as collection points; Canals and streams are yet to be places of resorts to cities dwellers or sources of attractions to visitors as they are lined up with waste; solid waste still being used for land reclamation; wastes are openly burnt as a means of management in corners of the urban centres; many illegal dump sites are still in operation in cities; in some cases, collection and transportation equipment are worse than the waste they carry while the workers have direct body contacts with waste of all sort (hazardous and non-hazardous); approved dump sites are not adequately equipped, they are opened and freely accessible to scavengers, pests and animals of any kind and people of any interest, open fire burning during dry season; **solid waste treatment facilities are lacking; many infrastructure built are poorly operated or totally abandoned**; same method of collection and disposal is used to manage wastes even though they have different properties; major methods of management is land filling; **a larger percentage of wastes are not actually managed but only moved from one location to another**. Huge amount of money is expended every year to bury materials of high energy and economic value, polluting the global environment, disturbing eco-systems equilibrium thereby causing ecological problems of all kinds (e.g. global warming/climate change, flood/erosion, food and water contamination, e.t.c.)

## 3.00 Causes of Failure

Causes of failure to achieve desired goals in solid waste management are many but can be grouped into three main folds[1]. These are faults due to governments; faults due to the citizens and faults due to our foreign partners. Until recent time, waste management has solely been government duty (100%). Governments set up the waste managers and authorities. They financed and control every day operations and activities. Government also makes policies that guide the administration and operation of these authorities. Infrastructure and equipment are provided by the government. In carrying out these functions, the following errors are committed by governments:

**(i) Waste Manager**: This is the man that heads waste management authority/organization. He is appointed by government which in many instances has been by **favour and not by competency**. This, at many instances affects operation/administration of the body adversely as he does not understand many hot issues of the industry. The frequency and un-ceremonious ways by which the manager is hired and fired from office hardly allow him to settle and meaningful contributions. Since his or her removal is always with immediate effect, he hardly has anything to pass to the in-coming manager and hence the new one has to begin his work from zero point.The cumulative effect of these is low performance by the authority and poor environment.

**(ii) Finance:** Government finances the waste management bodies (100%). Funding under this system depends on budgetary provisions and funds availability at a particular time and not as per needs. This therefore makes the body, in many instances, to suffer and render poor services. At other instances, it creates room for fraud and poor accountability. Also, investment does not flow into the industry which makes it impossible for the body to expand and meet up with ever increasing duties. Lack of adequate finance does not allow the industry to acquire the necessary equipment, infrastructure and services for the ever challenging job.

**(iii) Infrastructures:** Because of the need to manage solid waste in the society, government just set body/bodies but could not put in place required infrastructure. In carrying out statutory responsibility, the body goes out to use any thing that can be found around notwithstanding level of efficiency and fitness, e.g. creation and use of illegal dump sites. In many instances, this leads to low productivity, environmental pollution and damages to equipment. Because of excessive pressure from the government and the people for the job, waste management bodies often over use their infrastructures.

**(iv) Equipment and Technology:** It said that **'right equipment makes waste management easy'** and in like manner **'wrong equipment makes waste management difficult'**. It means that no matter any technology/method adopted amongst the popular waste management methods-recycling, land filling, incineration, etc**-right equipment is the way out**. Most of waste management bodies in Nigeria lack right equipment for the job they do. In fact, **major problem of most of them is hinged on equipment**. Associated with this is low level of technology to sustain the few equipment, machines and tools imported for the purpose. Government in many instances worsen the situation by importing brands of equipment without any advice from competent professionals. This has always lead to low performance of the equipment and frequent break down which at last cut short the designed service life of such equipment.

**(v) Policy:** Little progress has been made to translate policy and law into plan, action and practice. There is a low level of awareness across all sectors of the economy and there seems to be no common purpose between the Regulators and the Regulated. Frame-work policy of government on research and development in solid waste management is not adequate. No single body, by policy, is been institutionalised to look at what material from the waste can be used for anything despite the efforts of other great nations of the world on recycling processes of waste. None has also been put in place to research into development/type of any tool that can be used in the industry, while it has been said that **indigenous equipment is the best tool for managing solid waste.**

### 3.11 Faults from Citizens

Waste generation is by everybody but the duty of clearing and management has been made to be that of government. Every citizen feels unconcerned to anything related to waste. This attitude of the citizens made the bodies responsible for waste management not to receive from the people the kind of cooperation which can in turn can lead to morale boosting of the operators and managers for better environment. Kind of supports which other bodies such as sport and entertainment receive from private bodies like banks, insurances, communication services, etc have never been extended to waste management bodies though waste generation is by everybody.

Payment for the service, where asked, is never responded to very positively, yet we hate seeing waste around us.

### 3.12 Faults Due to Foreign Partners

Right from inception, foreign partners from developed nations have been participating in the waste management in Nigeria in one form or the other. All equipment, from collection to transportation and disposal are from developed nations. Establishment of waste management authorities have also been with their advice and services. Foreign consultants have always been involved in all World Bank loans and grants on solid waste management projects in Nigeria. Equipment and infrastructure for these projects (World Banks) have always been approved by them. As problem is overwhelming on projects executed by two parties, none is free from faults. **Foreign partners should also remember that waste generation in Nigeria is by all of us, since Nigeria is a big market for most of their goods and services**.

### 4.00 Pragmatic Solution

Causes of failure in Nigerian Solid Waste Management Industry, as shown above, are multi-dimensional, required solution should be multi-dimensional too. Hence a concept named **Integrated Sustainable Waste Management (ISWM)** is considered as the required solution if sincerely adopted. Really, there is no way of managing solid waste that is not known for years[6], but the failure to apply them accordingly is the major problem. ISWM is therefore designed to manage the waste of a given nation not only for aesthetic environment but for overall sustainability of waste management [7]. The concept works with three dimensions and two terms that takes into account: technical, finance/economy, socio-cultural, environmental, institutional and political aspects that do influence sustainability of the system. These are outlined below:

**4.10 Terms**:

The two main terms of the concept are ‘sustainable’ and ‘integrated’. These are defined as:

(i) **Sustainability** in the context of ISWM is defined as: A system that is appropriate to

the local conditions from a technical, environmental, social, economic, financial, institutional and political perspective and capable of maintaining itself over time without exhausting the resources. This is a key factor in a waste management system. It is important and is advisable to consider this factor whenever a waste management system is being planned, analyzed or monitored.

(ii) **Integrated** refers to: the integration of different aspect of sustainability (technical, environmental/public health, financial etc.), different waste management operations and their relations with other urban systems such as drainage, energy, telecommunications, water, agriculture, etc.

**4.20 Main Dimensions**

The concept has three main dimensions of sustainability that need be integrated. They are Stakeholders, System Elements and Aspects. The functions of each member are as stated below:

**(a) Stakeholders**

The range of stakeholders include the government, community–based organizations (CBOs), non-governmental organizations (NGOs), private sectors (formal and informal), donor agencies (World Bank, UNO and their agencies).

Involvement of stakeholders leads to more responsible behaviours, increase environmental awareness, and a higher willingness to pay among the users of waste management services. The idea aims at supporting the weak and underprivileged groups, to have a say in planning and implementation of a waste management system.

**(b) System Elements**

These are simple waste management principles we do know but never practice properly in Nigeria. These are: (i) Waste generation /prevention (ii) Primary collection (iii) Waste separation (iv) Resource/Energy recovery (v) Treatment and (vii) Disposal. These are really the jobs the concept is out to carry out.

**(c) Aspects**

**(i)** The six different aspects being use by the concept to bring about integrated sustainable waste management system are: (i) Technical; (ii) Environmental; (iii) Finance; (iv) Socio-economic; (v) Institution and (vi)Politics. They are the guiding principles of the concept and are very influential in the success of the concept.

**5.00 ISWM and Vision 20:2020**

Application of ISWM brings about a waste management alliance that will make waste management activities effective and self-sustaining. Every sector and machinery of the society is involved. All-beneficiary-contribute principle is used in the ISWM instead of the polluter pays principle, because in many cases cost-based-tariff levels are not affordable for low-income groups. All groups that benefit from the waste management system should financially contribute to its operation and maintenance. Citizens are usually the direct users of waste management services as their living environment improves by it. The private sector involved in resource recovery and recycling benefits, because it has access to the valuable waste materials and makes profits out of these. Governments benefit for reduced health care related costs and reduced costs of urban management, especially the cost of drinking water supply and treatment, and of drainage. Every great nation of the world practices these ISWM and continuously developing the required infrastructures and equipment of the system to achieve a sustainable clean environment without wrecking the nation's budget. They create wealth and decent employment that contribute to their national growth. On August 1, 2007, the Presidency released a vision for the country tagged "Vision 20:2020". It was conceived by Mr. President with the objective of making Nigeria: 1. One of the 20 largest economies in the world; 2. Consolidate its leadership role in Africa and 3. Establish itself as a significant player in the global economic and political arena by the year 2020. In order to achieve these objectives of the vision, the President in his wisdom, set up a seven-point-agenda (SPA). The agenda has the following: (i) **Power and Energy**; (ii) **Food Security and Agriculture**; (iii) **Wealth Creation and Employment**; (iv) Mass Transportation; (v) Land Reform; (vi) Security; and (vii) Qualitative and Functional Education Using ISWM in managing the waste of a nation, the following benefits are derivable and are means of achieving the three key items of the agenda:

(i) **Turning waste generated in the society into raw materials for industrial use:**

Many industries across the country depend on recovered materials from waste as primary raw materials for their production. Examples of these are plastic industries, metal producing factories, polystyrene and low density plastic industries, carpet industries, etc. They save costs, wealth creation, through the use of recovered materials as base raw materials to their production. Recovering of these materials also create employment for the people.

(ii) **Recovering Embedded Energy in Waste:**

Solid waste, apart from solar energy, constitutes the most abundant available energy reservoir on the Earth. It is a good source of alternative energy resources worldwide, consisting about 90% of biomass and plastics, which are of high calorific values. For example, energy embedded in **1,700mt** of wet domestic waste generated per day in Kwara State is calculated to be about **7,300,000 kWh**. Across the country, a total of **120,000mt** of wet domestic waste is generated daily containing about **500,000,000 kWh** of energy. This is available 24/7 round the year in all states of the federation. Recovering this energy will improve the short fall of energy per capital in Nigeria, which another key item of the agenda. Energy per capital in Nigeria is **142.263 kWh** and the country is ranked **178th** in the world energy/capital ranking among **216** countries [8] Listed in the ranking.

(iii) **Recovering Embedded Agric Nutrient in Waste:**

Domestic solid waste consists organic and non-organic materials. The organic component is made up of nutrients from plant/soil and when return to the soil they provide better nutrient to plant/soil than any syntactic additive. From the **1,700mt** of wet domestic waste generated per day in Kwara State, compost manure of about **712.3 $m^3$** can be recovered. **A** total of **50,280$m^3$** organic manure can be recovered from **120,000mt** of wet domestic waste generated daily in Nigeria. The products are able to provide nutrients to plants on the soil and also able to develop bad soil structures like that of the desert and is means of achieving the agenda.

(iv) **Reduction of Environmental Pollution for a Sustainable Environment**

For instance, in Nigeria where 90% of waste generation ends up in dump sites, embedded energy as stated above turn to landfill gases[9]as energy cannot be created nor destroyed but transformed from one form to another. From waste disposed in Kwara landfill sites, it is estimated that about **107,936,500$m^3$** of landfill gases emitted to the environment annually and total across the country is **14,000,000,000$m^3$**. Most of these gases, which include water vapour ($H_2O$), Carbon dioxide ($CO_2$), Methane ($CH_4$), Nitrous oxide ($N_2O$) and Perfluorocarbons (PFCs), are green house gases that cause reduction in ozone layer thereby making the earth to be heated more (global warming) and leading to climate change. Managing solid waste by ISWM methods prevents this incident for environmental sustainability.

(v) **Creating Wealth and Economic Opportunities:**
By the current energy tariff of **N10.00/kwh/month** in Nigeria, Power Holding Company of Nigeria (PHC) will be making, monthly, about N**70,300,000** in Kwara and **N5,000,000,000** nationwide if the embedded energy in the domestic waste generated is recovered. For PHCN to generate the same quantity of energy stated above from oil daily, about **4,412 barrels of crude oil** is required in Kwara and, **300,000 barrels** nationwide. Going by international market price of USD100/barrel and exchange rate of N150/USD, economic values per day are: **N66,178,570** for Kwara and **N4,500,000,000** nationwide. Application of ISWM in solid waste management in Nigeria could create wealth, employment and economic opportunities to the teaming population.

(vi) **Reducing the volume of waste and land space for disposal**:
Landfill is basically a burial ground for waste materials. After removing materials and emended energy, the waste that will be sent to the land fill would be less than 20% of total waste generated in Nigeria [1]. This would safe land that is today polluted by land filling activities and make it available for agriculture and other purposes.

## 5.10 How to Adopt ISWM in Nigeria

Solid waste management has become a very big industry through the ISWM system having many infrastructures and equipment for operation. It has also become a big business that **requires big and sincere investment** for Nigeria to have a good share in the global market as shown in fig.1 below.

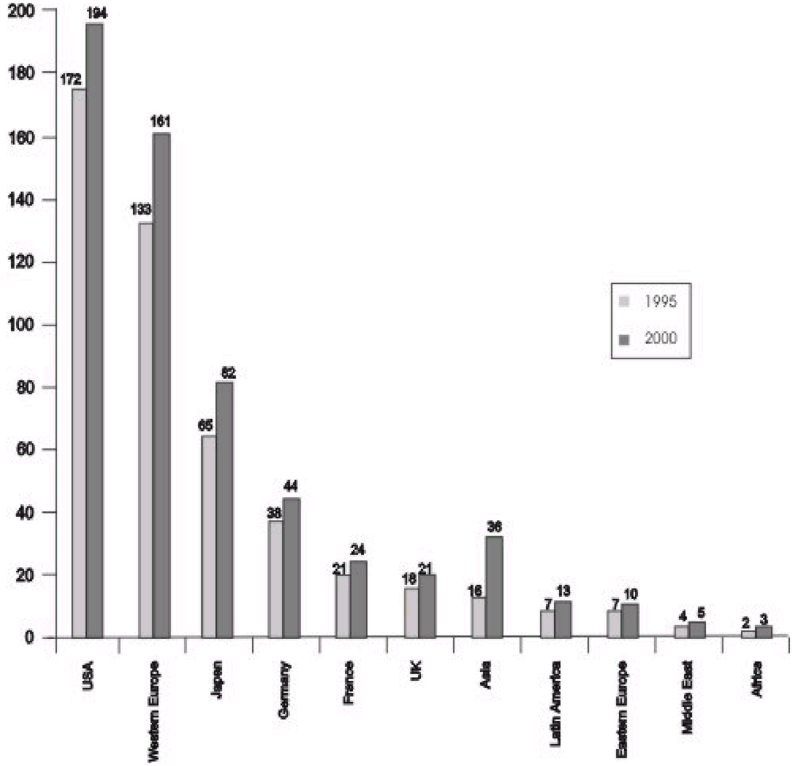



**Figure 1: Global Solid Waste Industrial Market Sharing for 1995 & 2000**

As many of the equipment and infrastructure that are available in the industry, locally developed ones are rated best. This will give room for continuous development since the materials (Solid waste) keep on increasing both in quantity and complexity[10]. Many infrastructure and equipment of this concept that may look complex and unattainable in the country today can be possible through application of research and development. Current research works on development of machines and equipment by the Environment Division of the Nigerian Society Engineers, which Lagos has keyed into, attested to the fact that about 55% of **"CombiTech technology"** which can be used to derive the energy & nutrients embedded in solid waste, as stated above, can be fabricated in Nigeria. Establishment of collaborative programmes between our research bodies and experts in the field from developed nations will accelerate the work.

Waste management system has a better prospect in Nigeria during the civil rule than the military rule as governors are indigenes of their respective states. Assessment/accountability therefore, does not end with the tenor of office and environment is part of the indices with which to appraise the performance of a particular government.

The essential thing is the right thought towards the right change. Fortunately one of them (Governor Babatunde Raji Fashola (SAN) of Lagos State) has earlier said "To make any reasonable progress towards meeting the objectives of both the MDGs and Vision 2020, we must fundamentally alter the way we think. Too often, we have allowed ourselves to be branded negatively. This attitude must change because, as a nation thinketh, so is she" [11].

The following are therefore the thought for the right change in the Solid Waste Management Industry in Nigeria, the industry in which lot of funds and resources have been committed with no result for world to judge:

(i) Integrating resources, technologies, politics, and persons for adoption of ISWM in Nigeria;

(ii) Every waste should be considered and handled as a raw material that has economic value from which one product or the other can be produced;

(iii) Every infrastructure and equipment built for waste management system should be intended towards producing one product or the other from the waste and should be based on home technologies that will not only be maintained locally but be further developed upon by the future generations;

(iv) All bodies committed to waste management activities should **update and develop research activities** that will address the issues of solid waste management in a multidisciplinary ways as discussed above;

(v) Every developed nation has one business or the other in Nigeria, and as such contributes in the waste generation in one way or the other. Hence, they are parts of problems in Nigeria and should be parts of solutions.

(vi)

## 6.0 Conclusion

Waste is an unwanted companion of man that cannot be avoided but if properly managed can be a source of economic and environmental sustainability to him.

Failure in turning solid waste generated by 150 million people to any product of economic value is the major problem of Solid Waste Management Industry in Nigeria. Factors responsible for this are multi-dimensional and the required solutions are in adoption of Integrated Sustainable Waste Management (ISWM) concept, which is a means of achieving Vision 20:2020 in Nigeria.

## References

E. Uhuo, A.Ogunbiyi, F. Jimoh: "Global Warming and Solid Waste Management in a Developing Nation: The Case of Southern Nigeria" at the 24th International Conference on Solid Waste Technology and Management, Philadelphia, P.A, USA. March 2009;

C.O. Folayan: "Key note address on the investiture ceremony of Engr. Abdul wahab Ogunbiyi, mnse as the 7th National Chairman of the environmental division of Nigerian Society of Engineers" April 2010

Kunle Awotokun: "Local Government Administration Under 1999 Constitution Department of Local Government Studies" Obafemi Awolowo University, Ile-Ife, Nigeria

Olushola Popoola: "The Evolution of Solid Waste Management Practices in Lagos State; The Past, Present And The Future". Invited paper delivered at a 4-day Lagos Megacity 2015 project, Feb. 2004

A. Ogunbiyi 2006: 'The Local Government and its statutory roles in Solid Waste Management: Problems, Prospects and Pragmatic Options: Case Study of Lagos State'. Proceeding of the fourth annual conference of the Senate on the Nigerian Environment July 2006;

Eldon D. Enger, Bradley F. Smith (5th Edition): Environmental Science-Solid Waste Management and Disposal;

William M. Eberle: Integrated Sustainable Waste Management – Solid Waste Management Fact Sheet No 19;

NationMaster.Com: Energy per capital statistics 2003-2008

A. Ogunbiyi and A. O. Adebosin: "The Future Engineers' Roles and Responses to the Challenges of Climate Change in Preserving the Environment" Presented At The 2011 of The Civil Engineering Synergy Conference University of Ibadan. April 2011;

A. Ogunbiyi: "Development of Infrastructure and Machinery for Commercialization and Sustainable Environmental Engineering Services in Nigeria: A Case Study of Solid Waste Management Industry" Presented at the National Conference and Annual General Meeting of The Nigerian Society of Engineers Institute of Environmental Engineering (Environment Division) 2nd - 5th September, 2003;

OMOBA: Back page of the Punch, Friday January 2, 2009.

# Waste Segregation and Its Effect on Medical Waste Management

[1]O. A Mokuolu, [2]H.O Olawumi [3]B.F Sule
[1]Environmental Unit, University of Ilorin Teaching Hospital, Ilorin, Nigeria.
[2]Department of Haematology and blood transfusion University of Ilorin Teaching Hospital, Ilorin, Nigeria.
[3]Professor, Department of Civil Engineering and Director, NACHRED University of Ilorin, Ilorin, Nigeria.

## Abstract

An institutional based study was carried out at the University of Ilorin Teaching Hospital to determine her waste management practices and proffer solutions to the observed inadequacies. Information on knowledge and practices on hospital waste management was obtained using structured questionnaire, and in depth interview of a cross section of staff, infection control officers, waste handlers and off site vehicle drivers. The result shows average daily waste generated was 554kg/day (202.21tons/year). Average waste generation rate per bed per day was 1.68kg/bed/day. Generation by waste type is 4.5% pathological, 20% infectious, and 1.6% were sharps, while 73.9% were non-infectious or general waste. Non practice of waste segregation makes the entire waste generated risk waste. Training and retraining of staff on waste management is recommended.

## 1.0 Introduction

Waste segregation is the Separation of different types of waste at the point of generation and keeping them isolated from each other. Management of such waste involves safe handling from point of generation to disposal.

The most appropriate way of identifying the categories of health care waste is by sorting the waste into colour-coded plastic bags or containers. WHO recommended colour coding for biomedical and healthcare waste are: red for highly infectious waste, yellow for other infectious waste, yellow marked "SHARPS" for sharps waste, brown for pharmaceutical waste, lead box labeled with radioactive symbol for radioactive waste, and black for general or non infectious waste(Pruss et al, 1999).

Management of medical waste has caught the attention of Government all over the world.

In March 2009, 240 people in the Indian state of Gujarat contracted hepatitis B following medical care delivered with previously used syringes later discovered to have been acquired through the black market trade of unregulated health care waste (Harhay et al 2009).Further investigation found evidence from a 2004 study conducted by the Indian Clinical Epidemiology Network suggesting that more than 30% of the 3–6 billion injections administered each year in India were done with used equipments.

Studies in Pakistan showed that around 2.0 Kg of waste/bed/day is produced out of which 0.1-0.5 can be categorized as risk waste.

Over the past two decades, health-care waste has been identified as one of the major problems that negatively impact both human health and the environment when improperly stored, transported and disposed. For many years, the World Health Organization has advocated that medical waste be regarded as special waste, and it is now commonly acknowledged that certain categories of health-care waste are among the most hazardous and potentially dangerous of all waste arising in communities (Mehtap Dursun et al 2011). Harhay et al 2009, in their study commented that Medical workers were undertrained, uninformed, and had limited access to waste segregation systems.

## 2.0 Methodology

Information on knowledge and practices on hospital waste management was obtained using structured questionnaire, and in depth interview of a cross section of staff, infection control officers, waste handlers and off site vehicle drivers. In addition all wastes generated in the 42-day study period were sorted into categories and at the point of collection and weighed .The total quantities of wastes generated were tabulated according to the wards or units from which they were obtained.

## 3.0 Results

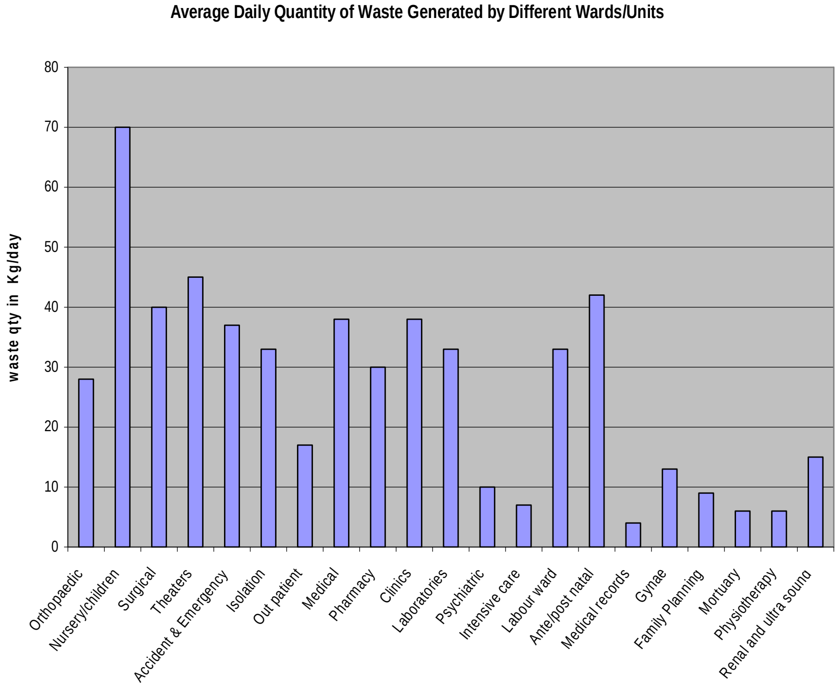
Average daily waste generated was 554kg/day (202.21tons/year). Table 1 shows average daily generated according to ward/building. Average waste generation rate per bed per day is 1.68kg/bed/day. Generation by waste type is 4.5% pathological, 20% infectious, and 1.6% were sharps, while 73.9% were non-infectious or general waste.

TABLE 1 Average dasily quatity

| **WARD** | AV. DAILY QUANTITY (KG/DAY) |
|---|---|
| Orthopedic | 28 |
| Nursery/children ward | 70 |
| Surgical wards | 40 |
| Theaters | 45 |
| Accident and emergency | 37 |
| Isolation | 33 |
| Out patient | 17 |
| Medical | 38 |
| Pharmacy | 30 |
| Clinics | 38 |
| Laboratories | 33 |
| Psychiatric | 10 |
| Intensive care | 7 |
| Labour ward | 33 |
| Ante and post natal | 42 |
| Medical records / Admin. | 4 |
| Gynae | 13 |
| Family planning | 9 |
| Mortuary | 6 |
| Physiotherapy | 6 |
| Renal and ultra sound | 15 |
| **TOTAL** | **554** |

### 3.1 Discussion of results

This study revealed that 26.1% of total waste generated from the hospital are hazardous and therefore require special attention for their disposal. This is a little higher than WHO classification of 10-25%. Segregation of waste is not practiced hence this lower quantity of hazardous waste when lumped together with other categories of waste makes the entire waste emanating from the hospital unsafe.




## 4.0 Conclusion and recommendations

Wastes emanating from healthcare activities can have adverse effects if not properly managed. Segregation of hospital wastes involves separating different types of waste at the point of generation and keeping them isolated from each other. It is the most important step in the entire process of hospital waste management. There is the need for special attention to be given to the relatively small quantities of infectious and hazardous waste, thereby reducing not only the risks but also the cost of handling, treatment and disposal. Training and retraining of medical personnel is recommended to enforce waste segregation.

## References

Harhay O Michael. Scott D. Halpern, Jason S. Harhay, and Piero L. Olliaro. 2009. Health care waste management: a neglected and growing publichealth problem worldwide. Tropical Medicine and International Health volume 14 no 11 pp 1414–1417

Nosheen Arshad, Shamail Nayyar, Fatima Amin, and Khawaja Tahir Mahmood. 2011. Hospital Waste Disposal: A Review Article. J. Pharm. Sci. & Res. Vol.3(8), 2011,1412-1419.

Hassan M Manzurul , Shafiul Azam Ahmed, K Anisur Rahman, and Tarit Kanti
Biswas.2008. Pattern of medical waste management: existing scenario in Dhaka City, Bangladesh BMC Public Health 2008, 8:36

Mehtap Dursun, E. Ertugrul Karsak, and Melis Almula Karadayi, 2011. A Fuzzy MCDM Approach for Health-Care Waste Management.World Academy of Science, Engineering and Technology 73 2011

Gautam V, Thapar R, and Sharma M, 2010. Biomedical waste management: Incineration Vs.environmental safety. Indian journal of medical microbiology 28(3): 191-2.

Habib-Ullah J, Khan MA,2011. Proposed Model for Healthcare Waste Management. Pak J Med Sci ;27(4):901-905.

Pruss, A., Giroult, E and Rushbrook, D. (1999) Safe management of waste from healthcare activities. Geneva: World Health Organization.

# PID Slip Control of Antilock Braking System incorporating Passive Suspension Dynamics

Samuel John
Department of Mechanical Engineering,
School of Engineering, the Polytechnic of Namibia,
Windhoek, Namibia
Email: sjohn@polytechnic.edu.na

## Abstract

An Antilock Braking System (ABS) controller is developed and tested on two road conditions; dry asphalt and dry gravel road conditions. Two external disturbances are introduced to these road conditions. The two external disturbances simulate a sinusoidal road profile and an inverse step function. The sinusoidal road scenario is frequently encountered on gravel roads and the inverse step function simulates a typical pothole situation. The results revealed that the inverse step scenario has a much longer stopping distance than the sinusoidal road profile.

**Keywords** PID, ABS, slip control, friction model, passive suspension, road disturbance, ride comfort

## 1. Introduction

The antilock-brake system has been in use in automobile since the early 50s (Solyom, 2002). The control algorithm has been mainly by table rule-based method, this method has a number of short-comings: firstly, the slip tends to oscillates around the peak friction point, creating a chattering effect and this hampers the performance of the ABS. Secondly, several road tests are required in order to get the controller tuned, which is usually carried out by a trial and error method. This process is expensive and time consuming (Solyom, 2002). In the current work we propose model based design, inline with current research trend (Gao, 2006). This method cuts down on the cost of design and implementation process. The proportional-integral-derivative (PID) controller has been a success story in industrial applications (Jiang and Gao 2001, Yoo 2006). In his work, Solyom (2002) proposed a slip tracking approach, in which the design objective is for each wheel to follow a reference trajectory for the longitudinal wheel slip. A quarter-car model was used for his analysis. A gain scheduled PI(D) controller was implemented for his design. Braking from an initial speed of $30\,m/s$ the vehicle achieved a stopping distance of between $36m$ to $41m$, which is a considerable improvement to currently available ABS. Secondly, tuning of the controller did not take as long as commercial ABS. However, the transient condition was slightly unstable.

The PID control method has been known to behave poorly when systems are highly non-linear and hence (Jiang and Gao, 2001) have proposed a 'nonlinear PID' (NPID). This so called NPID incorporates a non linear function to the linear PID as the major modification to the linear PID. The method of gain scheduling implemented for the NPID is same for the linear PID. A comparison between the two control methods by Jiang and Gao (2001) revealed that the NPID has a better robustness to linear PID when tested on ABS stopping distance, road conditions and tyre conditions. The NPID performance was on the average 25% improvement over the linear PID.

This paper presents some simulation results using Matlab®/ Simulink® to demonstrate the effectiveness and robustness of an ABS PID controller. The model is tested on dry asphalt and dry gravel road conditions using two external disturbances namely; sinusoidal and an inverse step input conditions.

The rest of the paper is arranged as follows: Section two presents the mathematical background for the quarter-car model with a passive suspension system, section three discusses the PID controller design while the simulation results are presented in section four. Finally in section five we draw some conclusions from the results obtained.

## 2. Dynamic Model Development

### 2.1 Vehicle and wheel dynamics

The quarter-car model shown in Figure 1 below was used to develop the mathematical equations governing the vehicle and wheel dynamics. This model has been adopted due to its extensive use by researchers (Solyom 2002, Yoo 2006, Peterson 2003).

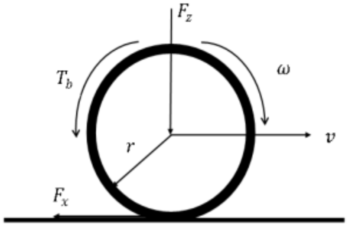



Figure. 1: Free-body diagram of a quarter car model

From Newton's second law of motion the equations describing the vehicle, tyre and road interaction dynamics during braking are given as (Poursamad, 2009):

$$\dot{\omega}_w = \frac{1}{J_w}\left(-T_b - B_w\omega_w + rF_x\right) \tag{1}$$

$$\dot{v}_x = -\frac{1}{m}\left(F_x + B_v v_x - mg\sin\theta\right) \tag{2}$$

$$\dot{T}_b = \left(-T_b + K_b P_b\right)/\tau \tag{3}$$

where $m$ is the total mass of the quarter-car and the wheel, $v_x$ is the longitudinal velocity of the vehicle, $J_w$ is the rotational inertia of the wheel, $r$ is the radius of the tyre, $\omega_w$ is the angular velocity of the wheel, $\theta$ is the angle of inclination of the road, $F_x$ is the tractive force between the tyre and the road, $F_z$ is the normal force exerted on the tyre, $\mu$ is the friction coefficient. Further more $T_b$ is the effective braking torque, $k_b$ is the braking gain, $P_b$ is the braking pressure from the pedal, and $\tau$ is the hydraulic time constant. $B_w$ and $B_v$ are the viscous friction of the wheel and vehicle respectively. The longitudinal wheel slip $(\lambda_x)$ is defined by the equation:

$$\lambda_x = \frac{\left(\omega_v - \omega_w r\right)}{\omega_v} \tag{4}$$

where $\omega_v$ is the equivalent angular velocity of the vehicle.

The friction coefficient between the road and the tyre influences the braking or traction of the vehicle. Several friction models exist in the literature, representing the relationship between the friction coefficient and the slip. A review of various friction models used in developing vehicle dynamics for ABS control are presented in John and Pedro (2006), Li et al (2006) and Svendenius (2003).

The tyre slip $(\lambda_x)$ as defined by equation (4) shows that a locked wheel $(\omega_w = 0)$ will occur when $\lambda_x = 1$, and free accelerating wheel $(\omega_w = \omega_v)$ will mean $\lambda_x = 0$. In the next section, we will develop the equations for the suspension system

## 2.1 Passive suspension system

A passive suspension system is used in the current work, it is represented by the two-degree-of-freedom of the springs and dampers shown in Figure 3. Their main purpose is to either store or dissipate energy Wang (2001).
Using this model, we can generate the equations for the passive suspension system as follows:

$$m_2\ddot{z}_2 = K_2(z_2 - z_1) - b_2(\dot{z}_2 - \dot{z}_1) \quad (6)$$

$$m_1\ddot{z}_1 = K_2(z_2 - z_1) + b_2(\dot{z}_2 - \dot{z}_1) - K_1(z_1 - z_0) - b_1(\dot{z}_1 - \dot{z}_0) \quad (7)$$

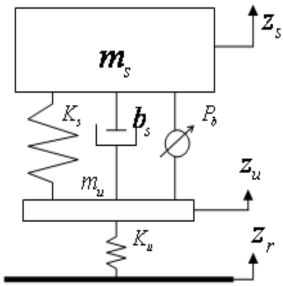



Figure 3: Quarter car suspension model

If $m$ is the total mass of the quarter car, then;

$$m = m_2 + m_1 \quad (8)$$

$$F_z = mg - K_1(z_1 - z_0) - b_1(\dot{z}_1 - \dot{z}_0) \tag{9}$$

where $m_2$ and $m_1$ are the sprung mass (Vehicle) and unsprung mass (tyre) respectively. $K_2$ and $K_1$ are the spring constants, $b_2$ and $b_1$ are the damping coefficients, $z_2$ and $z_1$ are the displacement of the car body and the wheel respectively while $z_0$ is the road surface disturbance.

The frequency response of the suspension system was determined and the natural frequency of the wheel is found to be 12.5Hz and that of the vehicle to be 1.85Hz. These values are considered when tuning the ABS controller to avoid resonance effects at the frequency level of 12.5Hz. Two disturbances are investigated: a sine wave road disturbance described as:

$$z_0(t) = A_m \sin \omega_v t \tag{10}$$

And an inverse step function road disturbance given as

$$z_0(t) = -h \tag{11}$$

where $A_m$ is the height of the bump, $\omega_v$ is the angular velocity of the vehicle and $h$ is the depth of the inverse step function.

## 3. Controller Implementation

### 3.1 Controller performance specifications

Current research focuses on slip control ( Yoo 2006, Peterson 2003), and the goal of the controller is to follow a pre-determined trajectory of the slip, this will be our reference input, and the performance of the controller will be measured against its ability to meet the following criteria:

i) good tracking of the desired slip $(0.1 \sim 0.2)$ (Chikhi et al, 2005);
ii) stopping distance $\leq 50m$ from initial speed of $80km/h$ (Dietsche and Klingebiel, 2007);
iii) disturbances attenuation and
iv) nominal stability

### 3.2 Controller design

The PID controller sums up the error, integral of the error and the derivative of the error. These three terms are then carefully tuned using the proportional gain and the time constants of the integral and derivative terms. This is presented by equation (12):

$$u = K_p\left(e + T_i\int e + T_D\dot{e}\right) \tag{12}$$

Where $e, \int e$ and $\dot{e}$ represent the error, the integral of the error and the derivative of the error respectively. $K_P$ is the proportional gain, $T_I$ is the integral time constant and $T_D$ is the derivative time constant, while $u$ is the control output.

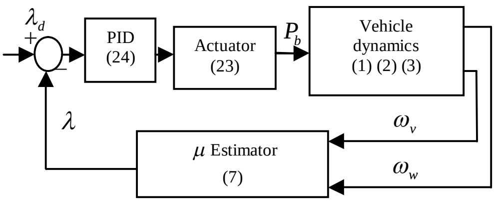



Figure 4: Schematic diagram of ABS

The schematic diagram of the ABS is shown in Figure 4. This was implemented in Simulink® and the simulations are presented in section 4.

### 4. Simulation Results and Discussion

Simulations were conducted using the numerical values in Table 1. Figure 6 presents the simulation results of braking on dry asphalt without any road disturbance. The stopping distance of the vehicle and wheel is 27.63m. In Figures 7 and 8, we have the simulation results of braking on dry asphalt with sinusoidal road profile and an inverse step function scenarios respectively.

Table1. Parameters of the quarter-car model

| Parameters | Parameters |
|---|---|
| $m_1 = 55\,kg$ | $r = 0.3\,m$ |
| $m_2 = 395kg$ | $K_1 = 24\,kN/m$ |
| $J = 1.6\,Nms^2/rad$ | $K_2 = 200\,kN/m$ |
| $B_v = 6\,N\,s/m$ | $g = 9.8\,m/s^2$ |
| $B_w = 4\,N\,s/rad$ | $\lambda_d = 0.2$ |
| $b_1 = 120\,Ns/m$ | $T_b = 1200\,Nm$ |
| $b_2 = 1350\,Ns/m$ | $h = 0.2m$ |
| | $A_m = 0.05m$ |

The stopping distance on the sinusoidal road profile is 27.74m while the inverse step function scenario has a stopping distance of 29.25m.

Figures 9-11 presents the simulation results on dry gravel road condition. On the flat surface, a stopping distance of 37.83m was achieved, whereas for the sinusoidal and inverse step input scenarios, stopping distances of 37.95m and 38.19m were achieved. The flat surfaces for both dry asphalt and dry gravel road conditions exhibit good slip tracking and stopping distances as expected. The results for the two road disturbances achieved good stopping distances, with the sinusoidal profile having a better slip tracking. The pothole scenario on the other hand experienced uncertainties for about 1 sec after the impact from the inverse step input. With respect to the ride comfort of the passengers, the pothole scenario had the worse performance.

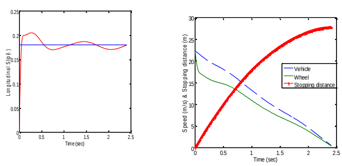



Figure 6: Dry asphalt

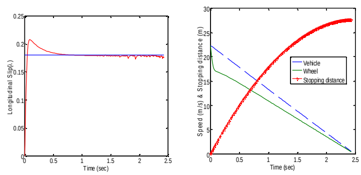



Figure 7: Sinusoidal dry

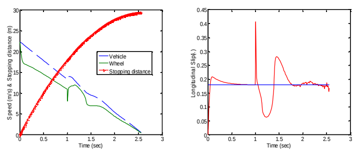



Figure 8: Inverse step dry asphalt

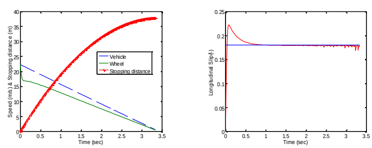



Figure 9: Dry gravel road

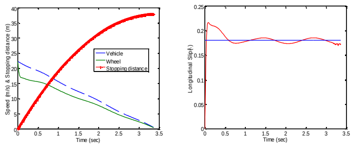



Figure 10: Dry sinusoidal

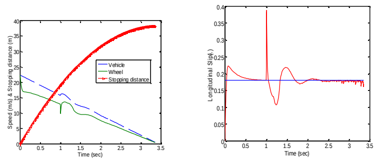



Figure 11: Dry inverse step

## 6. Conclusion

## 7.

This study investigated the performance of an ABS using a PID controller on dry asphalt and dry gravel road conditions under two road disturbances; sinusoidal and inverse step input.

From the above results, the inverse step function situation which simulates a pothole scenario has longer stopping distance compared to the sinusoidal situation in both road conditions. The passive suspension system absorbed most of the vibration from the disturbances thereby enhancing the ride comfort of the passengers.

In conclusion, the PID controller performances meet all the design specification requirements as stated in section 3.1 under the induced road disturbances.

## References

Bakker E., Pacejka H.B. and Lidner L.,(1989), “A New Tyre Model with an Application in Vehicle Dynamics Studies”, SAE 890087, pp.83-95.

Chikhi F., El Hadri A. and Cadiou J.C., (2005), “ABS control design based on wheel-slip peak localization”, Fifth Int. Workshop on Robot Motion and Control, June 23-25,2005

Dietsche K. and Klingebiel M,(2007), ‘Automotive Handbook’ 7th Edition, Robert Bosch GmbH, Plochingen, July 2007 pp 820 -849.

Gao Z. (2006), “Active Disturbance Rejection Control: A Paradigm Shift in Feedback Control System Design”, Proc. American Control Conf. Minneapolis, Minnesota, USA, June14 -16 2006. pp 2399 – 2405.

Jiang F. and Gao Z. (2001), “An application of nonlinear PID control to a class of truck ABS problems”, Proceedings of the 40th IEEE conference on decision and control, 2001, pp 516 - 521C.M.

John S. and Pedro J.(2006), "Review of Tyre/Road Friction Coefficient Estimation for ABS Controller Design" Fifth South African Conference on Computational and Applied Mechanics, 2006, pp 432 – 440.

Li L., Wang F-Y, and Zhou Q. (2006), "Integrated longitudinal and lateral tire/road friction modelling and monitoring for vehicle motion control", IEEE Trans. On Intelligent Transportation systems, Vol. 7, No 1, March 2006.

Lin J. and Ting W. (2007), "Nonlinear Control Design of Anti-lock Braking Systems with Assistance of Active Suspensions", IET Control Theory Appl., Vol. 1, No. 1, January 2007. pp343 – 348.

Petersen I. (2003), "Wheel Slip Control in ABS Brakes Using Gain Scheduled Optimal Control With Constrains", PhD Thesis, Department of Engineering Cybernetics, Norwegian University of Science and Technology Trondheim, Norway.

Poursamad A. (2009), "Adaptive feedback linearization control of antilock braking systems using neural networks", Mechatronics (Elsevier) vol. 19, pp767 – 773.

Solyom S. (2002), "Synthesis of a Model-based tyre Slip Controller". Technical Report Licentiate thesis ISRN LUTFD2/TFRT-3228-SE, Department of Automatic Control, Lund Institute of Technology, Sweden.

Solyom S., Rantzer A. and Kalkkuhl J. (2004), "A benchmark for control of antilock braking systems", Technical article, Department of Automatic Control, Lund Institute of Technology, Sweden.

Svendenius J. (2003), "Tyre models for use in braking applications", PhD Thesis. Department of Automatic Control, Lund Institute of Technology, Lund Sweden.

Wang F.(2001), "Design and synthesis of active and passive vehicle suspensions", PhD Thesis, Department of Engineering, Control group, Queens' College, University of Cambridge, U.K., Sept. 2001.

Yoo D.K. (2006), "Model based wheel Slip Control via constrained optimal algorithm", MSc Thesis, School of Electrical and computer Engineering, RMIT University, Melbourne Australia.

# The Sustainability and Viability of Locust Bean Pod Extracts/Ashes in the Waste Agricultural Biomass Recycle for Pavement Works.

AdamaA.Yand Jimoh Y.A
**Department of Civil Engineering, University of Ilorin Nigeria**
**yaj@unilorin.edu.ng.com; dryajimoh@yahoo.com.**

## Abstract

This paper reports the analysis of the sustainability of employing the derived products from locust bean pod wastes in the development of pavements. Liquid (extract) and powder (ash) were respectively produced from boiling in water and burning (in incineration) of the locust bean pod husks, characterised and applied as chemical stabilizer for AASHTO classified A-7-6 poor subgrade soils. The feeds stock of the locust bean ash and the improvement of the mechanical properties (CBR and unconfined compressive strength) of the soils were analysed to determine the sustainability of the recycle of agricultural biomass waste for pavement works. The viability as a road soil stabilizer was also assessed with the durability test according to BS 1924 Clause 5.1. The percentage increase of the soaked CBR recorded was in the range of 8 - 46 % at a stabilizer content of not more than 12 %. Only the stabilized soils were able to survive beyond the first wet/dry cycle (6 - 12). A 25 % ash was produced from 100 % of the incinerated locust bean pod husk. The continuous natural germination of locust bean plants in the tropical and sub-tropical regions from where the ash was derived indicated the sustainability of the recycled waste agricultural biomass.

## 1.0 Introduction

The corresponding increase in Waste Agricultural Biomass (WAB) with increased agricultural production has become one of the major sources of environmental pollution within the localities. However with the recent efforts in research and development, much of the wastes have been found to have potentials for re-use, and already strongly advocated in the construction industry in the United States of America, and especially in the road transport sector where great demand for recycled materials has to be institutionalised to replace sands and tons of earthen materials needed annually for road construction. The WAB includes rice husks, saw dust, palm kernel shells, locust bean pod etc. which constitutes examples of the precious resource of recycled material in focus which can reduce pressure on natural resources and ensures economic development and improved living standards, especially in the rural areas which are predominantly farming population. This could also be in line with strategies for poverty alleviation through income generation activities for obtaining material or energy to support livelihood, Sri Lanka; 2010. The focus of this paper is to show the sustainability and viability of production of chemical stabilizers from Locust Bean Pod husk which is a waste product hitherto consigned to spoil heaps. The feedstock of the agricultural product of the liquid extract and ash, when analysed on stabilization for unsuitable sub grade soils in road pavements would be useful for evaluation for viability of recycling; and sustainability if the source remains reliable the year round.

## 2.0 Material and Methods

### 2.1 The WAB from the locust plant (tree).

Locust bean tree occurs naturally in a belt between 5° N and 15°N, from the Atlantic coast in Senegal to Sudan and the northern Uganda. The belt is widest in West Africa (to a maximum of 800km) and narrows towards the east. About 201,000 ton of the locust bean fruit is being produced in northern Nigeria annually,Sina and Traore (2002), which is the source of the raw waste agricultural biomass (WAB) when the harvested fruits were ripped, opened and the yellowish pulp and the seeds removed to result in the empty pod husk of the locust bean pod. The pods make up 39% by weight of the fruits while the mealy yellowish pulp and the seeds together make up the remaining 61%. See plate 1 and 2 respectively for the plant (tree) and the locust bean fruits.


Plate 1: Locust Bean (ParkiaBiglobosa) Tree


Plate 2: Close up view of Locust Bean fruit.

Two main forms of the products were produced from the Locust bean pod; the solution and the powder from incineration burning, respectively designated as the LBPE (solution) and LBPA ash (powder) forms.

### 2.2Locust Bean Pod Extract in solution (LBPE).

The Locust bean pod husks extract is a liquid form prepared by placing and boiling the pod husks in water in the ratio of 1:4 by weight to attain appreciable concentration of LBPE. Higher or other concentrations could be attained by varying the ratio. The mix is boiled to a temperature of 75 $^{o}$ C. In other words, a 250 kg of Pod boiled in 1000kg of water would result to approximately 1000litres of the LBPE solution.

### 2.3 Locust Bean Pod Husks Ash (LBPA)

The Locust bean pod ash is a solid/powder residue prepared by burning large mass of the locust bean pod husk in the incinerator at temperatures of up to 500 $^{o}$C for a period of about 2 hours, as normally applied for rice husk ash from the rice husk(Ghani et al, 2008). The residue was then left to cool and sieved through IS Sieve 44µm to obtain a fine powdery form which was used for required chemical analysis. Some degree of confinement of the biomass during combustion was ensured in order to achieve the desired temperature control that plaid an important role in the combustion process. The ratio of the LBPA residue to the pod produced from the combustion process was 1:25 by weight. In other words, from the 1kg of the pod husk burnt,the weight of the ash produced was 0.04 kg.

The test to confirm the ash material (substance) as a Pozzolanwas conducted with the determination of the percentage of the various chemical compounds

present in the ash and compared with the American Society for Testing and Materials (ASTM) classification requirements (benchmarks) of the elements of Pozzolanas presented in table 1. Table 2 presents the chemical analysis of the LPBA as well as the LBPE.

Table 1 Chemical and Physical Requirements of Pozzolans

| **CHEMICAL REQUIREMENTS** | **MINERAL ADMIXTURE CLASS** | | |
|---|---|---|---|
| | **N** | **F** | **C** |
| Silicon dioxide, Aluminium dioxide and Iron oxide($SiO_2$+$Al_2O_3$ +$Fe_2O_3$) , Minimum % | 70 | 70 | 50 |
| Sulphur Trioxide ($SO_3$), Maximum % | 4.0 | 5.0 | 5.0 |
| Moisture content , maximum % | 3.0 | 3.0 | 3.0 |
| Loss on Ignition , maximum % | 10.0 | 6.0 | 6.0 |
| Available alkalis as $Na_2O$, maximum% | 1.5 | 1.5 | 1.5 |
| **PHYSICAL REQUIREMENTS** Fineness, maximum % retained on 325-Mesh (44μm) sieve. | 34 | 34 | 34 |

***ASTM Specification C618-92a Chemical and Physical Specifications (1994)**

Table 1: Chemical composition of Locust bean pod extract and the ash(powdery)

| | $Na_2O$ **(%)** | $K_2O$ **(%)** | MgO **(%)** | $Pb_2O_5$ **(%)** | $Fe_2O_3$ **(%)** | $Al_2O_3$ **(%)** | CaO **(%)** | $SiO_2$ **(%)** | L.O.I **(%)** |
|---|---|---|---|---|---|---|---|---|---|
| **A** | 14.4 | 9.1 | 9.9 | 5.1 | 20.3 | 5.5 | 32.2 | - | - |
| **B** | 1.2 | 5.6 | 2.0 | 5.8 | 11.5 | 13.1 | 15.7 | 39.0 | 6.00 |

**A is the solution (LBPE) while B represents the Pozzolan (LBPA)**

## 3.0 Results and Discussions

The results of the particle size distribution and chemical analysis of Locust Bean Pod Ash (LBPA) confirms that the ash is a pozzolan(% $SiO_2$ + % $Al_2O_3$ + % $Fe_2O_3$ = 63.57 > 50 %; LOI = 6 %) and can be classified as Class ‘’C’’

Pozzolans on the ASTM classification system. As such, it can be recommended for use as a chemical stabilizing agent in weak soils for road construction (Adama and Jimoh2011). The LBPE on the other hand cannot be

considered as a pozzolan(% $SiO_2$ + % $Al_2O_3$ + % $Fe_2O_3$ = 38% < 50; the Class C). However successful application of the extract as water proofing of mud walls for buildings has been reported in Nupe land of Nigeria.Infact the is one of the major motivation of this study.

### 3.2. Application of LBPE and LBPA for road works.

#### 3.2.1 LBPE as waterproofing solution in building.

The application of LBPE for road works was not substantially proved in this paper. However its usefulness in protecting the exposed faces of lateritic soil walls is an indication of the essence of the economic worth of recycling the husk, a WBA from locust bean pod.The LBPE is a good water proofing chemical for the soil and block walls of buildings in the Nupe speaking area (Dokko Township) of Niger State, Nigeria for the past 50 years, Adama 2008.

#### 3. 2. 2 Analysis of soil samples treated with LBPA for strength improvement.

Some poor road soils sampled from ch.3+100, Ch. 6 +950, ch.22 +150, ch.33+200 and Ch. 43+100 of the exhausted borrow pit of the Niger state Ministry of Works were used to determine the application of the locust bean pod stabilizer for road works.The particle size distribution of the soil samples are summarized in table 3, while that of the consistency limits and the AASHTO classification are shown on table 4 accordingly. The Particle size distribution charts are displayed in Figs.3-7 respectively for the samples.

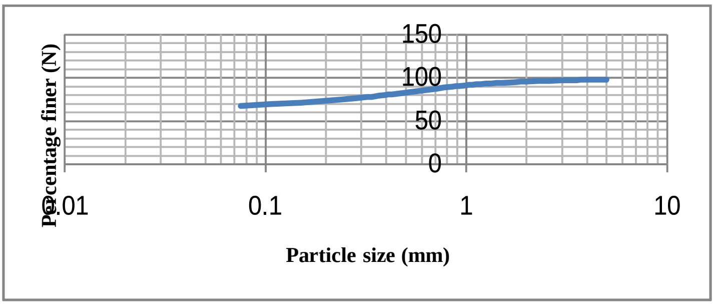



Fig. 3. Particle size distribution curve of Soil Sample from Ch3+100

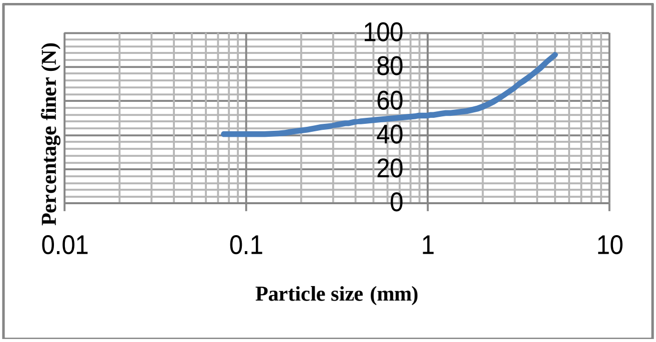



Fig. 4.Particle size distribution curve of Soil Sample from Ch6+950

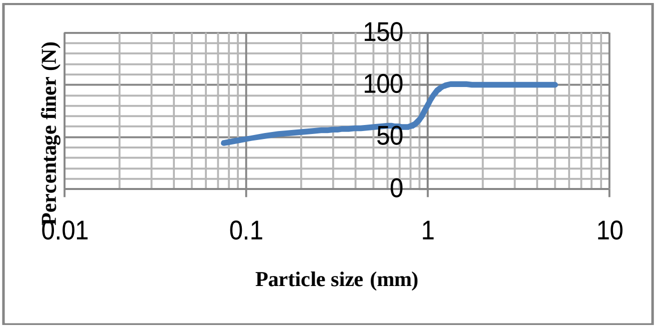



Fig.4. Particle size distribution chart (Ch22+150)

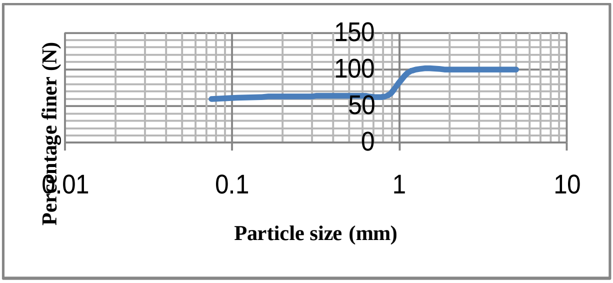



Fig.5. Particle size distribution chart (Ch33+200)

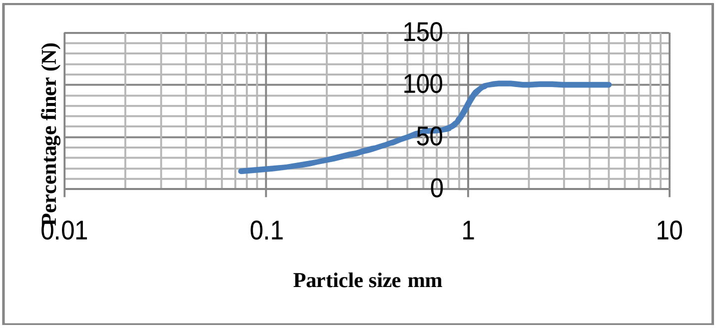



Table 6.The geotechnical index & classification properties of the studied soils

| S/ No. | Location | Consistency limits LL (PI) | | Particle size, % passing (mm) 2.0 No.10 | 0.425 NO.40 | 0.075 No.200 | *AASHTO Classification |
|---|---|---|---|---|---|---|---|
| 1 | Ch. 3+100 | 48 | 21 | 95.7 | 81.1 | 67.5 | A-7-6(15) |
| 2 | Ch. 6+950 | 39 | 23 | 56.6 | 48.1 | 40.5 | A-6(4) |
| 3 | Ch. 22+150 | 44 | 20 | 100 | 58.4 | 44.1 | A-7-6(5) |
| 4 | Ch. 33+200 | 49 | 21 | 100 | 63.8 | 59.6 | A-7-6(11) |
| 5 | Ch. 43+100 | 43 | 24 | 100 | 44.6 | 16.8 | A-7-6(5) |

*AASHTO Classification Chart tables 15.1 and 15.2; Wright and Paquent (1987) **3.2.2 (a)CBR**

The CBR test was carried out on natural soil samples and on samples treated with the stabilizer; Locust Bean Pod Ash (LBPA), at respective optimum moisture and AASHTO energy level according to BS1337 (BSI, 2000). Only representative samples from three locations (2 of A-2-6 and 1 of A-6) were tested with varying LBPA contents to establish the optimum values desired for stabilization. Results are shown in table 4 and figs 6 and 7.

**3.2.2(b). Unconfined compression and durability.**

Samples treated with LBPA were cured in a moist room for seven days before the compression tests were carried out. Table 7 gives the summary of the durability test. The percentage loss in weight after 6 -12 wet/dry cycles of heat treatment (in the oven). The un-stabilized soil samples collapsed in water immediately on soaking

TABLE 4.10: Durability Test Results

| Wet and Dry Cycles | Cumulative % lossed (Ch22+150) | Cummulative % lossed (Ch 33+200) | Cumulative % lossed (Ch 3+100) |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 1 | 0.03 | 0.07 | 0.07 |
| 2 | 0.97 | 4.69 | 2.97 |
| 3 | 1.06 | 6.24 | 3.31 |
| 4 | 1.50 | 7.10 | 4.47 |
| 5 | 3.60 | 8.30 | 4.72 |
| 6 | 3.93 | 9.53 | 6.41 |
| 7 | 4.03 | | 6.54 |
| 8 | 4.61 | | 6.93 |
| 9 | 5.03 | | |
| 10 | 5.14 | | |
| 11 | 5.22 | | |
| 12 | 5.59 | | |

Table 4.CBR – stabilizer content of the LBPA pozzolan.

| **LBPA Content (%)** | **Ch. 6+950 (A-7-6)** | | **Ch. 22+150 (A-6)** | | **Ch. 33+200 (A-7-6)** | |
|---|---|---|---|---|---|---|
| | **Soaked (%)** | **Uu-soaked (%)** | **Soaked (%)** | **Un-soaked (%)** | **Soaked (%)** | **Unsoaked (%)** |
| 0 | 18.0 | 22.0 | 11.0 | 19.0 | 11.0 | 21.0 |
| 2 | 20.0 | 24.0 | 14.0 | 21.0 | 12.0 | 24.0 |
| 4 | 23.0 | 29.0 | 18.0 | 25.0 | 14.0 | 27.0 |
| 8 | 27.0 | 35.0 | 22.0 | 27.0 | 17.0 | 29.0 |
| 12 | 24.0 | 25.7 | 15.0 | 21.0 | 13.0 | 23.5 |
| Range of % increase on stabilization | 11 - 50 | 8 – 46 | 28-100 | 10 – 42 | 9 – 54 | 12 – 34 |

LBPA=Locust Bean Pod Ash

### 3.3Feedstock of LBPE and LBPA for Viability and Sustainability analysis.

The feedstock for both the LBPE and LBPA was established at the ratio of 0.25 (1/4), while the corresponding increase in the CBR, the strength decision making parameter in road soil suitability was varied from 9 – 100 % for un-soaked road soil but 8 – 46 % for soaked condition. Indeed, the entire LBPE in solution as mud/soil wall waterproofing against rain is fully applicable. This implies that at least 25 % can act as water proof as well as stabilizer derived from a hitherto WAB can result to an improved soil from unsuitability for road soils to a meaningful level for pavement works. Thisfact assures that some or additional source of stabilizer for industrial production, which could be viable, is available. Also the fact that locust bean pod husk will continually being produced implies that the production of LBPE and LBPA would be sustainable. Locust bean, as a natural plant in the tropics and sub tropics of northern and south of the sub Saharan Africa is a continuous source of soil wall water proof and chemical stabilizer as long as living exists.

## 4.0 Conclusion

Locust bean pod can be recycled for re-use as a chemical stabilizer (liquid and ash forms) for improving weak sub grade soils. The material is sustainable

since it is renewable and thus does not have the tendency to get exhausted if adopted for re-use as a stabilizer in road works.

## References

Adama Y.Andrew (2008): Production and classification of LBPA as a Pozzolan, Ph. D Proposal in civil engineering, university of Ilorin, Nigeria.

Adama Y.A and Jimoh Y.A (2011): Production and classification of LBPA as a Pozzolan. www.engineeringcivil.com.

BSI (2000) BS 1377 British Standard Method of testing soils for civil engineering purposes.

BSI (2000) BS 1924 British Standard Method of testing soils for natural and stabilization clause 5.10

W.A Wan AbKarimGhani, M.S Firdaus Abdullah, C.J Loung, C.J Ho, K.A Matori (2008): *Vol. 5, No. 2, 2008, pp.111-117* International Journal of Engineering and Technology. wanaz@eng.upm.edu.my

National cleaner production centre, Sri Lanka (2010): Report II Waste Biomass Quantification and Characterization.

Sina, S & Traore S.A. (2002): Parkia biglobosa (jaccq) R.Br.ex G.Don. (Internet) record, Prota Network Office Europe, Wageningen university, P.O.Box 341, 6700 AH Wageningen, Netherlands.www.prota.org.

ASTM Specification C618-92a (1994): Chemical and Physical Specification. The American Society for Testing and Materials (ASTM).

# A study of Waste Paper and Coconut Fibre as a Reinforcing Material in Cement Sheets

A.M. Olawuyi and A.A. Jimoh
Department of Civil Engineering, University of Ilorin, Nigeria

**Abstract**

This research is aimed at investigating the use of waste papers and coconut fibers in the production of non-hazardous and low cost roofing materials using Portland cement as the binder. The global need for affordable housing has stimulated extensive research on cementitious matrix composite hence coconut fibre being incorporated with waste papers and cement for the purpose of producing affordable roof ceilings.

Three categories of samples were produced; cement ratio to waste papers and coconut fiber being kept constant while waste paper to coconut fiber is slightly varied. The mixing ratio in the form "cement : waste papers : coconut fiber" are, Group 1 (1:1:0.1, 1:1:0.2), Group 2 (1:2:0.2, 1:2:0.4) and Group 3 (1:3:0.3, 1:3:0.6).

The ingredients were manually mixed and placed in a formwork dimensioning 300mm x 300mm x 5mm, well compacted, pressurized with a load of 150Kg for 72hours and cured in moist air for 28 days.

The tests carried out include Flexural strength, Water Absorption test, Swell test, Specific Gravity, Moisture content, Impact test, Fire resistivity test, Electric conductivity test were all carried out on the produced samples.

Water absorption capacity increased with increasing ratio of waste papers and coconut fibers. 65.64% to 73.07% for group 1, 95.59% to 102.34% for group 2 and 109.51% to 129.95% for group 3. The result of the swell test conducted on the samples yielded a minimum 1.96% swell to a maximum 8.51%.

**Keywords:**Waste papers, coconut fibers, cement, Roof ceiling

## 1.0 Introduction

The use of environmental and agricultural waste materials and recycling of raw materials has been an efficient technique used to solve problems of environmental degradation, resources depletion and high cost of production (Marquita, 1998).Basically, there are two classification of fiber in the reinforcement of concrete namely synthetic fibers and natural fibers. Usually, synthetic fibers come from the family of polymer and some of the examples are glass fiber, polypropylene and Kevlar. Natural fibers can be extracted from bamboo, coconut fruit, sisal, jute, vegetable fibers etc. (Ghavani, 1984, Sobral, 1990 and Barbosa et al, 2000).

Waste papers are widely available all over most of the world.However, the widespread use of papers encourages deforestation on one hand and pollution on the other hand as waste papers are not properly managed thereby giving the need for rapid intervention by Government and Individual to find solutions through research.
The major component, (chrysolite) used in the production of asbestos cement is harmful to humans from the health point of view. Therefore, this gives an urgent need for the design and construction of roofing material which will eliminate such treat to human lives.

## 2.0 Methodology

The following were the methods and principles used in the course of the research;

i. Collection and processing of materials (Waste papers, coconut fibers, cement, water and formwork).
ii. The following tests were carried on the materials used. They include bulk density, specific gravity, moisture content and water absorption tests for the construction materials.
iii. The construction of samples for testing. Activities carried out includes batching, mixing, placing, compacting, pressurizing and curing.
iv. Tests carried out on samples includes Flexural test, Water Absorption test and Swell test.
Additional tests include electrical conductivity test, Shock absorption test and fire resistance test were also carried out.

## 3.0 Results

Below are the result of the test obtained from the test and analysis carried out;

Table 1: Properties of Coconut fiber

| Properties of Coconut fibers | | | |
|---|---|---|---|
| | Minimum | Maximum | Average |
| Length (mm) | 45 | 163 | 111.34 |
| Diameter (mm) | 0.29 | 0.40 | 0.36 |
| Bulk density (g/cm$^3$) | 0.22 | 0.46 | 0.34 |
| Water Absorption (%) | 43.33 | 48.33 | 45.55 |
| Specific Gravity | 0.40 | 0.42 | 0.41 |
| Moisture Content (%) | 5.26 | 11.70 | 8.98 |

Table 2: Properties of Waste papers

| Properties of Waste papers | Minimum | Maximum | Average |
|---|---|---|---|
| Bulk density (g/cm$^3$) | 0.40 | 0.48 | 0.45 |
| Water Absorption (%) | 80.66 | 90.66 | 85.56 |
| Specific Gravity | 0.68 | 0.74 | 0.71 |
| Moisture Content (%) | 5.00 | 11.11 | 7.22 |

The following table shows the mix proportioning of the samples produced;

Table 3: Table showing mix ratios and mix properties of Specimen used

| Specimen | Mix ratio | Mix properties (g) | | | | Specimen actual size (mm) | | |
|---|---|---|---|---|---|---|---|---|
| | | Cement | Waste paper | Coconut fibre | water | Length | Breadth | Width |
| 1A1, 1A2 | 1:1:0.1 | 212.13 | 212.13 | 21.21 | 425 | 300 | 300 | 5.10 |
| 2A1, 2A2 | 1:1:0.2 | 196.03 | 196.03 | 39.21 | 425 | 300 | 300 | 4.96 |
| 1B1, 1B2 | 1:2:0.2 | 136.20 | 272.59 | 27.24 | 341 | 300 | 300 | 5.21 |
| 2B1, 2B2 | 1:2:0.4 | 123.28 | 246.57 | 49.31 | 340 | 300 | 300 | 5.00 |
| 1C1, 1C2 | 1:3:0.3 | 100.50 | 301.50 | 30.10 | 370 | 300 | 300 | 4.70 |
| 2C1, 2C2 | 1:3:0.6 | 90 | 270 | 54.00 | 370 | 300 | 300 | 4.82 |

### 3.1 Water Absorption Test

Water absorption test were carried out on the test samples to determine water absorbing capabilities. This was done by soaking the samples in water.
The table below shows the effect of water with respect to time with which the samples were soaked in water.

$$\% \quad Absorption = \frac{m_s - m_d}{m_d} \times 100$$

Where; $m_s$ = mass of soaked samples and $m_d$ = mass of dry samples

Table 4: Effect of Water Absorption over Time

| Specimen | Mass of dry specimen(g) | WA after 24hrs soak (%) | WA after 48hrs soak (%) | WA after 72hrs soak (%) | WA after 96hrs soak (%) | WA after 120hrs soak (%) | WA after 148hrs soak (%) | Absolute water absorption of specimen (%) |
|---|---|---|---|---|---|---|---|---|
| 1A1 | 298 | 63.09 | 1.23 | 1.02 | 0.3 | 0.0 | 0 | 65.64 |
| 2A1 | 270 | 70.37 | 2.17 | 0.43 | 0.1 | 0.0 | 0 | 73.07 |
| 1C1 | 178 | 105.62 | 2.46 | 1.33 | 0.1 | 0 | 0 | 109.51 |
| 2C1 | 180 | 125.56 | 3.20 | 1.19 | 0.2 | 0.1 | 0 | 129.95 |

### 3.2 Percentage thickness swell of specimen

The thickness of each specimen was taken by the aid of vernier calliper before and after the absorption test was carried out. The table below shows the results obtained

$$\% \ Swell = \frac{t_f - t_i}{t_i} \ x \ 100\%$$

Where;

$t_f$ = $Final\ thickness\ after\ immersion\ in\ water$
$t_i$ = $Initial\ thickness\ before\ immersion\ in\ water$

The table below shows the results obtained from the test;
Table 5: table showing percentage swell of samples produced

| Samples | Mix Ratio | Initial thickness (mm) | Final thickness (mm) | *Swell (%)* |
|---|---|---|---|---|
| A1 | 1 : 1 : 0.1 | 5.10 | 5.20 | 1.96 |
| A2 | 1 : 1 : 0.2 | 5.10 | 5.31 | 3.92 |
| B1 | 1 : 2 : 0.2 | 5.26 | 5.47 | 3.85 |
| B2 | 1 : 2 : 0.4 | 5.06 | 5.40 | 6.02 |
| C1 | 1 : 3 : 0.3 | 4.70 | 5.12 | 8.51 |

### 3.3 Flexural Test

The flexural strength of the samples was determined by carrying out flexural tests on the samples produced.
Dimension of plates: 300mm x 300mm x5mm
Method used: Three Point loading system
Flexural Strength,

$$\sigma = \frac{1.5PL}{BD^2}$$

$\sigma$ = Modulus of Rupture

P = ultimate load applied to failure *(N)*
L= length of specimen *(mm)*
B= breadth of samples *(mm)*
D= depth of samples *(mm)*

The results obtained were shown in the table below;

| Samples | Mix Ratio | Ultimate Load (N) | Maximum deflection (mm) | Flexural Strength ($N/mm^2$) |
|---|---|---|---|---|
| A1 | 1 : 1 : $^1/_{10}$ | 26.477955 | 34 | 1.59 |
| A2 | 1 : 1 : $^1/_5$ | 22.55 | 16.22 | 1.353 |
| B1 | 1 : 2 : $^1/_5$ | 16.71 | 29.00 | 1.09 |
| B2 | 1 : 2 : $^2/_5$ | 11.77 | 27.12 | 0.80 |
| C1 | 1 : 3 : $^3/_{10}$ | 11.78 | 29.8 | 0.79 |
| C2 | 1 : 3 : $^3/_5$ | 9.81 | 3.39 | 0.58 |

### 3.3.1 Loading and Deflection of Samples.

The deflection rate of each sample was recorded with respect to loading using a dial guage. The table below shows the result obtained.

Table 7: Table showing the rate of deflection to loading.

| | Deflections (mm) | | | | | |
|---|---|---|---|---|---|---|
| Load (N) | 1:1:2/10 | 1:1:1/10 | 1:2:2/10 | 1:2:4/10 | 1:3:6/10 | 1:3:3/10 |
| 1.96133 | 0.5 | 0.2 | 0.6 | 2.1 | 3 | 0.34 |
| 2.942 | 0.9 | 1.1 | 2 | 3.1 | 4.2 | 0.45 |
| 3.92266 | 1.2 | 1.29 | 2.7 | 4.2 | 5.6 | 0.5 |
| 4.90333 | 2.1 | 1.3 | 3.2 | 7 | 8.4 | 0.79 |
| 5.88399 | 2.3 | 1.5 | 4 | 9 | 10.5 | 1.05 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 6.86466 | 2.5 | 2 | 4.5 | 11 | 12.1 | 1.23 |
| 7.84532 | 2.7 | 2.6 | 5.7 | 12 | 15 | 1.48 |
| 8.82599 | 2.9 | 2.7 | 6.18 | 14 | 17.2 | 2.4 |
| 9.80665 | 3 | 2.8 | 7.5 | 16 | 20.1 | 3.35 |
| 10.7873 | 3.1 | 3.6 | 8.5 | 21 | 24 | |
| 11.768 | 3.2 | 3.8 | 10 | 27 | 26 | |
| 12.7486 | 3.8 | 4 | 12.1 | | | |
| 13.7293 | 3.83 | 4.5 | 13.68 | | | |
| 14.71 | 4 | 5.1 | 15.1 | | | |
| 15.6906 | 4.1 | 6.1 | 18.1 | | | |
| 16.6713 | 4.4 | 7.1 | 29 | | | |
| 17.652 | 5.1 | 7.2 | | | | |
| 18.6326 | 5.5 | 7.24 | | | | |

### 3.3 Additional test on produced samples

**Flame Test**

The aim of the test is to know the fire resistance ability of the produced samples. The results were obtained by visual inspection.

| Samples | Resistance offered against fire |
|---|---|
| $1 : 1 : {}^{1}/_{10}$ | Burn slightly, smoke emission |
| $1 : 1 : {}^{1}/_{5}$ | Burn slightly |
| $1 : 2 : {}^{1}/_{5}$ | Tendency of burning Increased |
| $1 : 2 : {}^{2}/_{5}$ | Low resistance to burning |
| $1 : 3 : {}^{3}/_{10}$ | Actively burn in fire |
| $1 : 3 : {}^{3}/_{5}$ | Actively burn in fire |
| Asbestos Sheet | Burn sluggishly with minimal smoke emission |

### Electrical Conductivity Test

All the samples produced were subjected to electrical continuity test and it was discovered that electric current could not pass through the samples as they are perfect insulators when dry.

### Impact Test (Shock Absorption Test)

This test was carried out dropping the samples produced from a predetermined height. Impact test is carried out in order to know the ability of the samples to resist shock.

| Height (m) | Produced Samples | Asbestos Sheets |
|---|---|---|
| 0.50 | Intact | Intact |
| 1.00 | Intact | Shatter |
| 2.00 | Intact | Shatter |
| 3.00 | Intact | Shatter |
| 3.50 | Intact | Shatter |

All the samples offered a good resistance to shock on impact on the ground which better compared to asbestos sheets.

### 3.4 Cost Analysis

In order to ascertain the cost effectiveness of the samples produced, cost analysis were carried.
Note: The cost of materials are based on current market price as at May, 2012.

**Unit cost of Coconut fibre reinforced Papercrete**
Cost of procuring 1 bag of cement = ₦1,850
Cost of Transporting 1 bag of cement = ₦100
1Bag of Cement = 50 Kg
1 Pack of Old newspaper = ₦25
Average weight of a pack of newspapers = 280g
Cost of production factor for newspapers = ₦0.09/g
Cost of production factor for cement = ₦0.04/g
Volume of waste papers and coconut fibre sheet = 300mm x 300mm x 5mm=450,000 $mm^3$ ($450cm^3$)

Unit cost producing 450 $cm^3$ sheet= (212.12 x 0.04) + (212.12 x 0.09) = ₦27.57
Unit cost of papercrete sheet = ₦0.06/$cm^3$

**Unit cost of Asbestos sheet**
Cost of producing a single sheet = ₦900
Cost of transport = ₦100
Volume of Sheets = 120cm x 120cm x 0.6cm = 8640$cm^3$
Unit cost of sheet (N/$cm^3$ ) = 1000/8640 = ₦0.12/$cm^3$

## 4. Discussion of results

| Physical property | Fibre reinforced papercrete | Asbestos sheets |
|---|---|---|
| Thickness of sheet (mm) | 5mm | 6mm |
| Bending load to failure (N) | 26.5 | 46.38 |
| Water absorption (24 hours) | 65.64 | 18.2 |
| Density of sheet (g/$cm^3$) | 0.71 | M |
| Effect of shock when dropped from a height of 3.5m | Absorbs shock and remains intact | Shatters on impact |
| Fire resistance | Undesirable with increase in waste paper-coconut fibre ratio | Good |
| Deformation Character | Deflects steadily under influence of an ultimate load | Collapses under the influence of an ultimate load |
| Electrical insulation | Good | Good |
| Cost of 1000$cm^3$ sheet | ₦ 60.15 | ₦ 120.00 |

## 5. Conclusion

The coconut fibre reinforced sheets produced with mix ratio of $1:1:{}^{1}/_{10}$ (Cement: Waste papers : Coconut fiber) by weight had the maximum flexural strength of 1.59N/$mm^2$ and a Water Absorption capacity of 65.64%. The sheets produced have good shock absorption capacity hence enabling ease of transportation over long distances and rough terrain without breaking. The cost of producing coconut fibre reinforced papercrete is about half the cost of asbestos sheet.The sheets produced are good electrical insulators.

However, it is important to know that the fibre reinforced sheets offered undesirable resistance to fire. It is hereby recommended that sheets should be coated with fire resisting materials for the purpose of extending failure time during fire outbreak.

## References

ASTM Standards (1965), "Concrete and mineral Aggregate", part 10, American Society for Testing and Materials.

Bashar S.M.(2009), "Papercrete as Infill Materials for Composite Wall system"

Ekwebe T.C. and A.A. Jimoh (2011), "Investigation of use of Coconut Fibre and Sawdust in the production of Roofing sheets". Department of Civil Engineering, University of Ilorin, Nigeria..

Marquita K.H (1988), "Understanding Environmental Pollution", The Press Syndicate of the University of Cambridge, Triumpyton Street, united Kingdom, pp21 – 32.

Majid Ali, "Coconut fibre – A Versatile Material and its Applications in Engineering", Conventry University and The University of Milwaukee Centre for By-products Utilization, Second International Conference on sustainable construction materials and Technologies, June 28 – June 30, 2010, UniversitaPolitecnicadelle Marche, Ancona, Italy.

Mohammad Hisbany Bin Mohammad Hashim (2005), "Coconut Fiber Reinforced Wall Panelling System". Thesis Master of Engineering (Civil-Structure), Faculty of Civil Engineering, UniversitiTeknologi, Malaysia.

Natural Fibre Reinforced Concrete (NFRC). http://www.3-co.com/Pro/Principles/Special%20Concrete/nfrc.htm accessed on 28/6/2012.

Neville, A.M and Chatterton. M. (1979), "New Concrete technology and Building Design", Longman Inc., New York, pp 101 – 107.

Ransom W.H, "Building failures", Second edition E & FN Spon, pp 14 – 15.

Toledo Filho R.D., Ghavami K. and England, G.L (2005), "Free, restrained and drying shrinkage of cement mortar composites reinforced with vegetable fibres". Cement and concrete composite, 27(5), pp 537-546.

S. NAGATAKI ET AL (1972), "Durability of Building Materials and Components", volume one, E & FN Spon, London.

Tara Sen, H.N. Jagannatha Reddy, (2011), “Application of Sisal, Bamboo, Coir & Jute Natural Composite in Structural Upgradation”.

Technical Teachers Training Institute, Chandgarh (1992), “Civil Engineering Materials”, 11th edition, Tata, McGraw Hill publishing company limited, New Delhi, pp 294 – 297.

Walton D. U, (1987) “Building Construction”, Macmillan Publishers Ltd, London and Bashing Stoke,pp 97 – 102.

# Recycled Waste Tyres for Road Construction: A Review

**A. R. Anwar and Y. A. Abdulkareem**
Department of Civil Engineering University of Ilorin, Ilorin, Nigeria

## Abstract

Recycled wastes for road construction applications were briefly discussed as well as the application of waste tyres for civil engineering works. the impact of tyre stockpile on environmental degradation was highlighted. Previous researches done on waste tyres for road constructions providing information on the geotechnical characteristics and environmental impact of such applications were reviewed. Some established properties and case histories where scrap tyres are used for road constructions were presented.

## 1.0 Introduction

Recycling waste materials has been encouraged since 1965 by the United State Congress through its passage of the Solid Waste Disposal Act (SWDA). The Act was amended in 1970 by the Resources Recovery Act (RCA) which called for the procurement of products with recycled material content and for the elimination of the requirement to use only virgin materials in products and process (Ashekrana, 2004). Many waste materials that can be recycled for road construction industry are available. Some of which are: Bottom Ash which is a coarse, granular, incombustible by-product of coal burn usually collected from the bottom of furnaces (FHWA, 1998). It is primarily composed of silica, alumina, and iron, with smaller percentages of calcium, magnesium, sulphates, and other compounds. The chemical composition is primarily determined by the source of the coal (FHWA, 1998). Typical maximum dry density of bottom ash is usually 10 to 25 percent lower than those of naturally occurring granular materials. However, the optimum moisture content (12% - 24%) is higher than for naturally occurring granular materials. The friction angle of 38° to 42° is similar to that of sand and other conventional fine aggregate sources. Its California Bearing Ratio (CBR) value ranges from 40% to 70 % which is comparable to high quality gravel base materials (FHWA, 1998). Bottom ash is used in a number of ways in road projects which includes its use as a fine aggregate substitute in hot mix asphalt wearing surfaces and base courses, as granular base material, in stabilized base applications, as structural fill materials in highway embankments, and in flowable fill mixes.

Roofing shingles are also recyclable waste in road construction industry which are usually black in colour with a specific gravity of approximately 2.6. They are typically comprised of approximately 35% asphalt, 45% sand, and 20% percent mineral filler (Newcomb et al., 1993). This combination of asphalt binder and aggregates make roofing shingles a potential recycled material that could be used in asphalt concrete.

Crushed Concretes are also important recyclable waste obtained from demolition of concrete structural elements such as buildings roads, runways, bridges etc. It was found that Recycled Concrete Aggregates concrete, when compared to Virgin Aggregate concrete, has approximately 82% in compressive strength, 96% in tensile strength, 81% in flexural strength, and 86% in modulus of elasticity for laboratory prepared samples (Chini, 1999). Won (1999) reported that continuously reinforced concrete pavement (CRCP) sections utilizing 100% recycled coarse and fine aggregates performed well and showed no distresses such as spalling, wide cracks, punch-outs, or meandering cracks (Ashekrana, 2004). Frabizzio (1999) reported that jointed concrete pavement (JCP) containing recycled concrete coarse aggregate appears to have more transverse cracks when using natural gravel or carbonate aggregates. This was attributed to a greater tendency for shrinkage cracking in recycled pavements where unique curing requirements are often neglected (Ashekrana, 2004).

Adama and Jimoh (2011) reported locust bean pod ash produced from the waste of locust bean as pozzolan (Apampa, 2011). Adesanya and Raheem (2009a and 2009b) introduced corn cob ash as pozzolan (Apampa, 2011).

Scrap tyres are waste scrap vehicular tyres removed permanently as they are old to be safe for further use on roads. They are usually recycled and used through burning for electric power generation, production of cement in cement kilns, energy to run pulp and paper mills, recycling at tires-to-energy facilities and then for civil engineering applications. In U. K approximately 48,000 tonnes are produced yearly (Used Tyre Working Group, 2001). Of the aforementioned quantity 60% are recovered, 25% of which are retreaded, 22% are recycled, and 8% for energy generation and 3% are used in engineering for landfill purposes. Approximately 2 billion waste tires are reported to be stockpiled across the United States, and 250 million are generated annually (Edward and Mullen, 2004). The U.S. Environmental Protection Agency

(EPA) estimated in 1990 that 11 % of the waste tires generated annually in the U.S. were converted into energy; while 7% were recycled into new products and 5% were exported out of the U.S (U.S. Environmental Protection Agency, 1991).

Waste tire stockpiles contribute to environmental and health hazards by producing air pollution from tire stockpile fires and enabling environment for breeding of potential disease carrying mosquitoes and vermin. The retained water by the waste tires creates a conducive environment for breeding mosquitoes. They also produce hazardous tire fires, which pollute the air with large quantities of carbon smoke, hydrocarbons and residue (Edil and Bosscher). They cause fire outbreak through ignition that can occur due to the rise in temperature caused by exothermic reactions. Potential causes of initiation of exothermic reactions are as follows: (1) oxidation of exposed steel wires, (2) oxidation of rubber, and (3) consumption of liquid petroleum products by microbes. Oxidation of exposed steel wires is the primary cause of exothermic reactions (Humphrey, 1996). Mixing of tire shreds with soil impedes the oxidation process due to the reduction in the contact area of the exposed steel wires to oxygen and the formation of a non-combustible insulating layer that increases the critical ignition temperature (Wallingford, 2005). Tire fires release heavy metals and other hazardous compounds that run into streams and seep into shallow wells. The toxic runoff from a tire fire results in the death of all life in nearby water resources. The heavy metals produced by burning tyres are as follows:

- Arsenic
- Chromium
- Lead
- Manganese
- Nickel
- Mercury
- Cadmium
- Oil

Fig. 1 shows the application of tyre bales in raising the profile of Diehl Road. Fig.1a shows the road before the project and the ongoing project is presented in Fig.1b. Fig.1c shows the road section after the completion of the construction.

Fig.1a. Diehl Road before raising the profile

Fig.1b. Tyre bales being placed to raise Diehl Road

Fig.1c. Diehl Road after raising the profile

Many researchers have been dedicating their times in fine tuning the employment of the scrap tyres in road construction with a view to reduce the environmental adverse impact of the tyre stockpiles and benefitting from the economic advantage of using such waste. Scrap tyres proved efficient as an engineering material in road construction especially as a lightweight fill on roads founded on weak soils.

In 1992 Hossain et al investigated the feasibility of developing a chunk rubber asphalt concrete mix design for low volume road construction using local aggregate, shredded tire rubber chunks and a cationic emulsion.

Glenn and Rich (1994) documented seven sites in Minnesota that used tyres as lightweight fill and found that when subjected to high acidic conditions environmentally harmful substances can be released. They proposed a guideline that tyres should be used at unsaturated zones.

Humphrey et al (2000) presented two case histories where shredded tyres were used as a lightweight fill for highway embankments on weak marine clay. In the first project tire shreds were used as lightweight fill and bridge abutment backfill for the approach embankment for the North Abutment of the Merry meeting Bridge in Topsham, Maine. In the second project tire shreds were used for two approach embankments for a new bridge over the Maine Turnpike in Portland, Maine. The tire shreds proved efficient for use as lightweight fill for highway embankment on weak marine clay and similar applications. Aggregates Information Service releases series of articles named digest with aim of providing information to increase efficiency of the aggregates utilization which will contribute to the reduction of dependence of construction industry on virgin aggregates and to focus on the increased exploitation of secondary and recycled materials. In 2002 released an article referred as DIGEST No.76 Version1.1 that highlighted the constraints of using scrap tyres for civil engineering applications. Traffic loading can cause deflection of pavements containing tyre shreds, Health and Safety implications relating to steel reinforcement belts, Tyre voids can be filled with unwanted particles if immersed in water, Tyre fires cause problems and finally Oxidation of tyres and steel belts can lead to the production of heat.

Khan and Shalaby (2002) reported the performance of lightweight road embankment on soft soil using large size tyre shreds of about 300mm in the base course. They developed layered elastic-isotropic deflection model based on one-dimensional constrained compression laboratory tests on three sizes of the tire shreds. They then suggested some design guidelines based on the laboratory testing, numerical model and field performance of the road. They discovered that large size tire shreds can be an economical alternative compared to the small size tire shreds in the construction of the tire shred embankment.

In 2004 Hoppe and Mullen presented a report of research work sponsored by Virginia Transportation Research Council in collaboration with the U.S. Department of Transportation. They developed an experimental project of constructing road embankments using shredded tyres. After 10 years of monitoring the engineering and environmental performance the project proved acceptable. They concluded that the use of shredded tyres does not have adverse effect on environment. Large tire shreds intermixed with sandy soil discouraged an exothermic reaction within an approximately 6 m high embankment. Vertical soil pressures exerted by shredded-tire embankments (50/50 volumetric ratio of tires to soil) on the foundation soil are approximately one half of the corresponding stresses exerted by conventional embankments. Shredded-tire embankments may be expected to settle at approximately twice the magnitude of conventional embankments. The use of surcharge for a period of at least 6 months appears to be effective in minimizing future settlement. Measurement of the shredded tire material quantity by volume delivered does not adequately reflect the cost of construction (Hoppe and Mullen, 2004).

Sugmin et al (2005) evaluated the use of tyre shred – sand mixture for test embankment construction. They found that the mixture discouraged exothermic reaction, was less compressible and had higher shear strength as compared with the pure tyre shred. The road was monitored for one year after opening to traffic. It was found that the settlement was within the acceptable limit, No differential settlement was observed. Sample ground water was analysed for metals and found to be well below the standard limits prescribed for secondary drinking water (EPA, 2002). No internal heat generation was observed and no potential slope stability problem was observed.

Winter et al., (2005) presented the steps to be followed during bale tyre based road construction over weak soils. The steps included: excavation and preparation; placement and alignment of bales; filling of voids; pavement construction and drainage with special attention given to the stages that deviate most from conventional construction, namely placing and alignment of the bales and filling of the voids between.

Lech and Philippe (2007) studied the mechanical behaviour of tyre chip-sand mixtures in a series of CD triaxial tests. Pure tyre chips specimens show a linear stress-strain relationship. Randomly distributed tyre chips/shreds have 3 to 5 times lower shear strength than horizontally oriented chips. The strength and dilatancy of the mixture depends highly on the tyre content. For small tyre content, the shear strength of the mixture is smaller than for the sand only. The tyre-chips soil mixture has high shear strength at relatively large strains. At optimum tyre content, the maximum deviatoric stress corresponds to the axial strain of about 8%. The mixture conserves a high post-peak shear resistance as well. The reinforcement effect of the tyres is getting reduced with high density of the sand and with confining pressure. They suggested that for a practical application one should avoid compacting the composite backfill to a very dense state as the reinforcement effect of the tyres is getting reduced with high density of the sand and with confining pressure.
Steve (2008) prepared a report of research work sponsored by Alaska Department of Transportation to evaluate different recyclable wastes so as to solve the problem associated with the constructing infrastructure in Arctic and sub-arctic regions of Alaska where the available fill material are very high in moisture, and /or frozen, and/or too fine to be employed as sound engineering material. They found that tyre bales can be employed for the intended purpose as tyre bales require minimal handling and can be found within the region of

interest. Placement of tire bales is fast but requires heavy equipment. Leachates obtained from tyre bales happen to be less than that from similar

volumes of shredded tires. Tire bale construction provides insulation, shear resistance, seismic protection, and contributes for utilization of local fill.

Prasad and Raju (2009) modelled flexible pavement on expansive soil in laboratory with gravel/flyash as subbase course with waste tyre rubber as a reinforcing material. Gravel subbase shows better performance as compared to flyash subbase with different percentages of waste tyre rubber as reinforcing material. And maximum load carrying capacity associated with less value of rebound deflection is obtained for gravel reinforced subbase compared to flyash reinforced subbase.

Anbazhagan et al., (2011) performed an experimental testing program with the goal of evaluating the optimum dosage and the aspect ratio of tyre crumbs with soil and sand. Two typical locally available soil samples are considered for the study, one is red soil and other one is sand. Based on this study it is observed that the static properties of maximum and minimum density, angle of internal friction [Φ (phi)], and maximum dry densities are slightly decreased when increase in the percentage of mix of the tyre crumbs. Decrease in Φ values when compared to dry sand is very minimal. OMC does not follow any trend with percentage of tyre crumbs. Increase in the tyre crumb percentage will decrease the maximum dry density values. Engineering properties of tyre sand mixture are not altered much, but compaction character of tyre crumbs and red soil mix alter much from its original values.

Krishna and Aravind (2011) evaluates engineering properties of tyre shreds and variation of these properties with the size of the shreds. In spite of the wide variation in engineering properties, shredded scrap tire properties meet or exceed the minimum requirements for a drainage material in landfill covers. The effect of the size of tire shred on the properties of shredded tires is not clear; however, the shred size ranging from 0.5 inches to 5.5 inches can possess satisfactory properties to serve as the drainage material in landfill covers. However, site-specific testing using the actual tire shreds is recommended to accurately determine the engineering properties and to design an effective and inexpensive tire shred drainage layer for a landfill cover system.

**Properties of tyres**

The use of scrap tyres in civil engineering projects is getting global acceptability as they posses some properties fit for such applications. Scrap tyres have been used in civil engineering as lightweight fill material for road

construction as they are relatively lightweight, inexpensive, non-biodegradable, very porous, contains good vibration damping properties, and is easily compacted (Glenn and Rich, 1994). Their low density makes them attractive for use as retaining wall backfill as they produce lower horizontal stresses than soil thereby making the wall thickness thinner (Reid and Winter, 2004). Tyres are also used as landfill material.

The major properties of interest to civil engineers are:
**Light weight:** the compacted dry density of shredded tyre is about one third of a typical soil (Humphrey et al., 2000). This makes them suitable as lightweight fill for embankments where foundation soils are weak. Their low density makes them attractive for use as retaining wall backfill as they produce lower horizontal stresses than soil thereby making the wall thickness thinner (Reid and Winter, 2004).
**Hydraulic conductivity:** whole and shredded tyres posses' high hydraulic conductivity making them fit for where free draining fill is required (Reid and Winter, 2004).
**Durability:** non toxic, non biodegradable and resistant to wide variety of chemical and climatic conditions (Reid and Winter, 2004).
**Thermal resistivity:** about 7 to 8 times that of typical granular soils making them fit for use as insulation materials. Others are good vibration damping properties and inexpensiveness (Reid and Winter, 2004).

**Table1: Properties of tyre**

| **Property** | **Typical values** |
|---|---|
| Compacted density | 600 – 700 KG/m3 |
| Angle of friction | 19 – 26 degrees |
| Cohesion | 1 – 5 KN/m2 |
| Compressibility | 20 – 50% (at 21 – 147 KN/m2) |
| Hydraulic conductivity | 1 x 10-2 – 1 x 10-3 m/s |
| Poisson ratio | 0.2 - 0.35 |
| Resilient modulus | 1 – 2 N/m2 |
| Specific gravity | 1.1 – 1.27 Kg/m3 |
| Thermal conductivity | 0.15 - 0.23 W/mK |

Source: Reid and Winter, 2004

## Application in Civil Engineering

Scrap tyres are used in civil engineering projects for the following applications:

- Lightweight fill
- Backfill to structures
- Drainage for roads
- Landfill engineering
- Fluvial and coastal erosion control
- Artificial reefs
- Noise absorption bunds
- Insulating layers
- Absorption layer for hydrocarbons in ground remediation
- As a constituent in asphalt and concrete
- As a constituent in sport and safety surfaces
- As constituent in building products (Reid and Winter, 2004).

## Forms of tyre for civil engineering use

Tyres can be used in number of forms as a function of their sizes such as whole tyres, tyre bales, shredded tyres, chips or granulate.

**Table 2: Sizes of tyres for civil engineering application**

| Name for fraction | Minimum size | Maximum size |
|---|---|---|
| Powder | 0 | 1 |
| Granular | 1 | 10 |
| Buffings | 0 | 40 |
| Chips | 10 | 50 |
| Shreds (small) | 40 | 75 |
| Shreds (large) | 75 | 300 |
| Cut | 300 | Half tyre |
| Whole tyre | - | - |
| Bale | - | - |

Source: Reid and Winter, 2004

## Case studies

### 1. Unsurfaced Roads, East Sussex

Tyre bales were used in the construction of 180m unsurfaced road that developed deep ruts due to 4 wheel axle traffic load. The excavated soil was replaced by tyre bales with a 150 mm layer of crushed natural stone to form the road surface. This resulted in savings of about 75% in the cost of materials and a significant reduction in the overall cost of the repair. (Reid and Winter, 2004).

### 2. Landfill Site Haul Road, Fochabers

200m long road was constructed as an extension to the existing haul road which was required to service a new landfill cell fochaber. The area is prone to flood due to seasonal variation of underground water level. Two trial sections of 16 and 18m in length were constructed using tyre bales. The rest were built with cobbles. The road is used by 30 to 40 vehicles per day with gross weight ranging from 10 to 20 tons. The road has been monitored for more than a year but no failure is observed. The water running up from the projected tyre from the shoulder was collected for visual signs of pollution but no sign of pollution observed (Reid and Winter, 2004).

### 3. Road Embankment Over Peat in Sutherland Finland

A serious settlement was observed along the length of a road embankment placed on peat in 2002. The road settled about 0.2m below water table. Tyre bale was used in reconstructing the road that will be opened for heavier loads from timber plantation transportation observed (Reid and Winter, 2004).

### 4. Drainage and Liner Protection Layer, Newland Park Landfill

Supplementary drainage and liner protection layer for the Newland Park Landfill in Wicomico County, Maryland (1 .4 million tires).

### 5. Highway Embankment Fill, Portland

Lightweight fill for a 32-ft high highway embankment constructed on weak clay in Portland, Maine (1.2 million tires) (California Environmental Agency, 1999).

6. **Drainage Layer For Landfill Cap, Rockingham**
   Drainage layer for landfill cap over a Superfund site in Rockingham, Vermont (800,000 tires) (California Environmental Agency, 1999).

7. **Landslide Stabilization Fill, Oregon**
   Lightweight fill to stabilize a landslide on U.S. Route 42 near Roseburg, Oregon (580,000 tires) (California Environmental Agency, 1999).

8. **Rigid Frame Bridge Backfill**
   Lightweight backfill for a rigid frame bridge in Topsham, Maine 1100,000 tires Turnpike(California Environmental Agency, 1999).
9. Chautauqua Co. Dept. of Public Facilities has completed five projects using tyre bales as a lightweight subgrade replacement for roads over soft ground (Figure 4) (Winter et al., 2005).

## Conclusion

1. Literature on application of recycled post consumer tyres has been reviewed.
2. Some established properties of tyres have been presented
3. It has been seen that the use of recycled tyres makes road construction cost effective
4. The use of tyres for road construction does not have significant environmental degradation
5. Scrap tyres are efficient for road applications
6. Where the road is to be laid on weak soils, scrap tyres prove effective as light weight fill.
7. It is recommended that used tyres that are currently thrown away and which are used as bonfire at road intersections during protests in this country should be researched and put into more profitable use.

## References

Aggregates Information Service (2002). The Use of Post-Consumer Tyres as Aggregate. Digest No. 76 Version 1.0

Anbazhagan, P., Mamatha, M., Soumyashree, P., Sushyam, N., Bharatha T. P. and Vivekanand, R.W. (2011). Laboratory Characterization of Tyre Crumbs Soil Mixture for Developing Low Cost Damping Materials. International Journal of Earth Sciences and Engineering, Vol. 04, No 06, pp. 63-66.

Apampa, O.A. (2012). Investigation of Corn Cob Ash as a Pozzolan and Chemical Stabilizer for Pavement Materials. A PhD Proporsal Submitted to the Department of Civil Engineering Uiniversity of Ilorin, Ilorin, Nigeria.

Ashekrana A. S. M. (2004). Evaluation of Recycled Material Performance in Highway Applications and Optimization of their Use. A PhD Dessertation (Civil Engineering), Texas Tech University

California Environmental Agency (CEA), Integrated Management Board (IMB) (1999). Tyre Shreds: Solutions for Civil Engineers

Chini, A. R., Kuo, S., Armaghani, J. M. and Duxbury, J. P. (1999). Performance Test of Recycled Concrete Aggregate in a Circular Accelerated Test Track. Conference Paper, Annual Meeting of Transportation Research Board.

Edil, T.B., Bosscher, P.J., "Evaluation of Shredded or Whole Tires and for Highway Application and Development of Engineering Criteria" A proposal to the Wisconsin Department of Transportation.

Edward J. H. and Mullen, W. G. (2004). Final Report Field Study of a Shredded-Tire Embankment in Virginia. Sponsored by Virginia Transportation Research Council in collaboration with the U.S. Department of Transportation.

Environmental Protection Agency (UPPA) (2002). Secondary Drinking Water Regulations: Guidance for Nuisance Chemicals.

Federal Highway Administration (FHWA) (1998). User Guidelines for Waste and By-Product Materials in Pavement Construction. Report No: FHWA-RD-97-148.

Glenn M. E. and Rich L. 1994, Using Shredded Waste Tyres as a Lightweight Fill Material for Road Subgrades

Hossain M., Sadeq M., Funk L. and Maag R. (1992). A Study of Chunk Rubber from Recycled Tires as a Road Construction Material. Proceedings of the 10th Annual Conference on Hazardous Waste Research, Kansas State University, Pp 188 – 197

Humphrey, D.N., Whetten, N., Weaver, J., and Recker, K. (2000). “Tire Shreds as Lightweight Fill for Construction on Weak Marine Clay,” Proceedings of the International Symposium on Coastal Geotechnical Engineering in Practice, Balkema,Rotterdam, pp. 611-616.

Informational Bulletin (2006). Tire Bales as Road Fill. Version 1.

Khan, R. A. and Shalaby A. (2002). Performance of a Road Base Constructed with Shredded Rubber Tires. *Annual Conference of the Canadian Society for Civil Engineering*

Krishna R. R and Aravind M. (*2001)***.** *Seventeenth International Conference on Solid Waste Technology and Management*, *Philadelphia, PA, USA*

Lech B. and Philippe G. (2007). Characteristics of Tyre Chips-Sand Mixtures from Triaxial Tests. Archives of Hydro-Engineering and Environmental Mechanics, Vol. 54, No. 1, pp. 25–36

Prasad, D. S. V. and Prasada Raju G. V. R. (2009). Performance of Waste Tyre Rubber on Model Flexible Pavement. ARPN Journal of Engineering and Applied Sciences, VOL. 4, NO. 6, pp 1033–1044

Reid, J.M and Winter, M.G. (2004). The Use of Post – Consumer Tyres in Civil Engineering. Used/Post – Consumer Tyres, Editors M C Limbachiya and J J Roberts, 195 – 202. London Thomas Telford

Sungmin Y., Monica P. ,, Nayyar Z.S. , Bumjoo K. (2005). Construction of a test embankment using a sand–tire shred mixture as fill material

U.S. Environmental Protection Agency (1991). "Markets for Scrap Tires",

Used Tyre Working Group (2001). Statistics, www.tyredisposal.co.uk

Winter, M. G., Johnson, P. E. and Reid, J. M. (2005). Tyre Construction of Road Foundations on Soft Ground Using Lightweight Bales. Proceedings of International Conference on Problematic Soils. Eastern Mediterranean University, Famagusta, N. Cyprus. Pp. 775 – 782

# Waste Recycling for Sustainability Economy- Is There Any Waste?

Y. A. Jimoh* M. O. Ogundipe, A. Y. Adama, Yusuf I.T &Apampa, A.H.
Department of Civil Engineering, University of Ilorin, Ilorin Nigeria
Corresponding author e-mail :dryajimoh@yahoo.com, yaj@uniliorin.edu.ng

## Abstract

This paper discusses the misnomer inherent in labelling materials as waste; while still having economic and other values. The perception that alternative values are possible after further processing is enough not to referto them as waste. It can conveniently be linked to a stop over on a trip prior to final destination. The use of hitherto agricultural biomass to develop concrete pavement and stabilisation of soils for road works was enumerated with four agricultural bye products of sawdust, palm kernel shell, locust bean pod and corn cob. Apart from the economic view point, the environmental quality enhancement and wellness of human beings (from evolution of $O_2$ – plant (vegetation) photosynthesis) are added benefits and values. It was therefore suggested that the materials be referred to as Materials for Further Treatments (MfFT) rather than wastes.

**Keywords:** wastes recycling, sawdust concrete, locust bean pod ash, pozzolana, palm kernel shell aggregates, concrete and corn cobs.

## 1.0 Introduction.

There are many ways of defining/identifying wastes; i) unwanted and useless material, worthless and of no value to the possessor Wachukwu and Eleanya, 2007; ii) an inescapable bye product of human activity and economic growth (www.sviva.gov.il, Mcleod et al. 2006); iii) a mirror that reflects various aspects of a society JICA, 2005, etc. Being a product of human activities, wastes do occur in the three states of matter; gas, liquid and solid. The solid wastes are much more generated from the primary occupation of life (farming/vegetation) and whose sustainability is more assured, because they are vegetative and continuous gift of nature /life cycle. Many other authors and or agencies have some other definitions for waste, which is related to solid waste in particular, Tchobanoglous et al., 1993, USAPA United States Environmental Protection Agency,
http://www.epa.gov/epawaste/hazard/dsw/compendium.htm.

Despite the different versions of general definition of waste and the impending confusion, the two keywords are ‘unwanted / useless material’ as perceived by ‘the possessor’. But the big question is; should an object or material be discarded by a person (or groups) but still found valuable to or by some other group be called a waste? It is my proposition in the paper that better and appropriate word be coined for waste recycling.
It is proved in the paper that the enormous economic and other values abound in the biomass waste dumps in civil infrastructure development, especially as applicable in highway and pavement.

## 2. Re-use of Biomass Wastes for Pavement Works.

### 2.1 From sawdust to sawdust concrete

Sawdust is a wood based waste produced after timber logs have been converted to commercial or construction purposes. About one third of wood harvested yearly by the logging and lumbering industry ends up as waste ETL, 1999. Plates 1a – 1c present thetimber logs, the commercial timber elements and the sawdust waste respectively. The wastes are in the form of logging residues, wood and back chips and the saw dust.

Plate 1a: Timber logs ready for sawing.

Plate 1b: The stockpile of the commercial structural timber elements after sawing.

The common uses of sawdust are for packaging functions, heat generation for home cooking and industrial based fuels including conversion to exotic purposes.

Plate 1c: Heap (stockpile) of Sawdust.

The use of wood bye products in construction works has been extensively reported,Washa 1956, Ahmed 1991, Sakai 1992, Ramirez 1992, Schroeder 1994 and ETL 1999; but however limited to structural works at low compressive strength. Its use as coarse aggregates for concrete mixesand cement bound base/sub-base course for road works, have proved to reduce amount of waste needing disposal and significant savings in construction costs. Lightweight sawdust concrete at nominal mixes 1:1:2, 1:11/2:3 or richer make suitable Grade 7 concrete with low thermal conductivity, strength and

environmental appropriateness, Ogundipe 2005, Ogundipe and Jimoh 2009, 2011.

## 2.2 Palm kernel shell aggregates in concrete.

Palm kernel shell is the hard endocarp of palm kernel fruit that surrounds the palm kernel seed of the oil palm tree (Elaeisguineensis) (Abiola, 2006). The palm kernel tree is native of West Africa as well as widely spread throughout the tropics and sub-tropics. It grows to about 9 metres in height and characterized with a crown of feathery leaves that are up to 5 mm long, followed by the development of cluster of egg-shaped red, orange or yellowish fruits, each about 3 cm long. Palm kernel shells are obtained as crushed pieces after threshing or crushing to remove the palm seed after the production of palm kernel oil. In the process of extraction from the ripe, fresh fruit bunches at the mills, solid residues and liquid wastes are generated (Olutoge, 1995). These bye products include empty fruit bunches, fibres, shells and effluent with various uses; such as for prevention of the fibres from insect attacks, in weaving baskets, and as source of energy for domestic cooking. It is estimated that the palm kernel shell constitutes about 34.5% of a single ripe, fresh fruit (Aragbaiye, 2007). Palm kernel shells are derivable in large quantities and their disposal has continued to constitute major environmental problems. Plates2a and 2bshow the palm kernel fruits and the waste dump after the oil processing. A relative advantage of recycling palm kernel shell as PKS concrete at various mixes and traffic level in comparison with an asphalt pavement is adequately displayed in table 1. Further remarks were also made;

(a) The recycle of palm kernel shells as alternate coarse aggregate for light weight concrete at nominal mixes of $1{:}1^1/_2{:}3$ and 1:1:2 produced rigid pavement for freeways. The compressive strength of the lightweight palm kernel shell concrete increases with age and as the mix proportion increases and up to a value of 12.0–21.2 $N/mm^2$.

Plate 2a: Palm kernel fruits

Plate 2b: Palm kernel shell dump at Igbaye, Oyo State, and Southwest Nigeria

(b) The use of PKS concrete is a cheaper method for provision of rigid pavement as freeways for high stresses imposed by the overloaded goods vehicles. Environmental pollution caused by indiscriminate dumping of

PKS as waste can be reduced when used as alternative coarse aggregates in pavement works.

## 2.3 Locust bean pod ash and extract.

Locust bean pod is a Waste Agricultural Biomass (WAB) which is obtainable from the fruit of the African locust bean tree (ParkiaBiglobosa). The harvested fruits are ripped open while the yellowish pulp and seeds are removed from the pods. The empty pods are the waste raw material. The pods make up 39 % by weight of the fruits while the mealy yellowish pulp and seeds make up 61 %. See plate 3a – 3c.The Locust Bean Pods used in this research were sourced from Doko town in Niger state of Nigeria, usually as a waste product of agricultural processing of the locust bean fruits during harvest.

Two products from the locust bean pod waste are liquid (when boiled-in-water as locust bean pod extract, LBPE) and ash (burnt in an incinerator at a temperature of up to 500$^{o}$C (incineration), referred to as locust bean pod ash (LBPA). The chemical composition of LBPA as presented in Table 2 is an ASTM Class C pozzolana, when compared with the specification of table 3 Adama and Jimoh (2011).The LBPA is the solid /powdery residue of the incineration process which was left to cool and satisfying the percentage passing IS Sieve 44µm to obtain the fine powdery form needed for the chemical analysis.

The two products (LBPE and LBPA) have proved to be useful in the development of stabilized flexible pavement and rigid concrete pavement Adama and Jimoh (2011, 2012).


**Plate 03: Locust pod husks attached to external walls at Doko in Niger state, Nigeria.**


www.engineeringcivil.com

**Plate 04: African Locust Bean (Parkia Biglobosa) Tree**


**Chemical composition (%) of Locust bean pod ash**

### 2.4 Corn cob ash pozzolana.

The corn cob is the waste after extracting the seeds from the ear of maize. It is another source of rich energy or carbon. Based on an annual production of maize (corn) of about 7.31 million tonnes by Nigeria as2nd highest in Africa and 13th in the world (FAOSTAT, 2010) and corn: cob ratio of 0.15 (Halvorson and Johnson, 2009), the feedstockpile would become a major environmental nuisance. Hence, the various further treatment for civil and other infrastructural facilities; as a pozzolana, stabilizer for unsuitable road soils, etc. would be appropriate as an economic and MDG vector especially in the rural communities, Apampa et al., 2012. Fig. 4a -4c are the maize waste generation process in terms of the plant, green maize and the fruited cob.

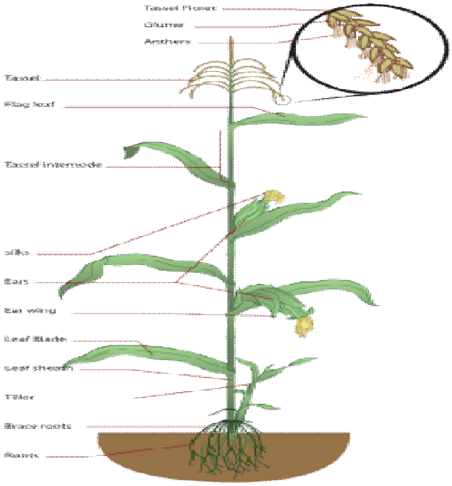


Plate 4a: Maize plant

Fig 4b: The green maize. Plate 4c: Maize grain that produced the cob when removed.

Corn Cob Ash (CCA) can be produced from the burning and processing of the Cobs, which has a potential use as pozzolana and other uses.

## 3. Discussions.

### 3.1 Stock feed of the biomass waste.

Table 5 gives a summary of the outcome of the further processing of the biomass waste for the four plants considered in this submission. The waste materials either in raw (untreated) and or burnt /boiled forms, were found to be useful and adequate respectively as light weight aggregates and or for production of lightweight concretes (Yusuf and Jimoh 2011, Ogundipe and Jimoh 2012). At high proportions of the cementitious binder when used as coarse aggregates (nominal mixes of 1:11/2:3 or richer) the strength properties of the concrete is of good quality for rigid pavement or cement base road course. Also ash powders identified as ASTM ClassC Pozzolana, the possible uses are suitable while in some instances the products are appropriate for chemical stabilisation of weak sub-grades, Adama&Jimoh 2011, Apampa 2012).

#### 3.1.1 Feed stock from agricultural wastes

The biomass stock feed generated was determined to be in the range 15 - 39 % of the original useful plant or the crop. This figure seems significant to be neglected in any material sourcing schemes. It is not economical to so declare that portion as waste, hence the need for further treatment for alternate use.

### 3.2. Place of concrete in rigid pavement.

Rigid pavement has been identified as very strategic in the long term provision of road structures because the very low maintenance cost and frequency implies a much better total life cycle costs when compared with the flexible for the same level of traffic. The initial high cost of development of a concrete road notwithstanding, the flexible roads need more frequency of maintenance. Besides the concrete pavement either as rigid pavement or small element pavement, is more appropriate on very poor,weak and settlement prone sub-grades. It is a surer strategy of responding to the effect of excessive traffic induced stresses from the excessively overloaded axles of trucks on the freeways.

### 3.3. Health/ wellness

Another important benefit derivable from recycling biomass waste is in the area of health. The elimination of the waste dumps and substantial reduction or elimination of emission of greenhouse gas (GHG)from the direct burning of biomass waste in the open air is desirable for survival of human beings. Also the generation of $0_2$by plants through the process of photosynthesis continually is a reliable source of oxygen; one of the much desirable element for sustainable living of human beings.

### 3.4The new description of wastes

As can be seen from the facts enumerated in preceding sections, the stock of derived materials (e.g. pozollana, stabilizer, etc.) and the respective usefulness indicated that the hitherto wastes have value afterwards. What is being depicted is similar to the issue of problem soil, which was also correctly disclaimed as not purely problem soils. The soils are as good as the user understands them Omotosho (2009).

## 4.0 Conclusions and Recommendations.

In the paper, it has been enumerated that a) much of the material (about 30 %), normally generated from processes of plants and vegetation are erstwhile classified as waste b) such materials still have values and worth either as raw or when subjected to further treatments under intensive heat as Pozzolana with attendant reduction in the amount of cementitious binder in concrete production c) the generated powdery substances do also serve as chemical stabilizer for unsuitable road soils, and d) can serve as an effective vector in enhanced economic emancipation of the rural farmers who hitherto throw or burn the materials at the end of harvest season. Based on the potential benefits

derivable from further treatment, the materials are therefore not waste but material for further treatments. The materials have sustainability elements because they derive from plants and vegetation, the continuous product of life cycle.

## References

Adama A. Y (2012); Production and Classification of LBPA as a Pozzolana, Ph. D. progress report No. 2 and Seminar Series No. , Faculty of Engineering &Technology, University of Ilorin, unpublished.

AdamaA. Y and Jimoh Y.A (2011); Production and Classification of LBPA as a Pozzolan.www.engineeringcivil.com.

Adama A. Y and Jimoh Y.A (2012); Effect of Locust Bean Pod Ash on Strength Properties of Weak Soils, Paper under Review, AU Journal of

Apampa A. H, Jimoh Y. A and (2012), paper submitted for the 4th Annual & 2nd International Conference of Civil Engineering, University of Ilorin, Nigeria.

Aragbaiye B. A. (2007); Palm kernel shell as a composite material in concrete, B. Eng civil report, university of Ilorin, Ilorin Nigeria, 63 pp. unpublished.

FAOSTAT (2010), Food and Agricultural Organisation, online publication at www.faostat.fao.org/.

Halvorson A. and Johnson J. (2009); Cob Characteristics in Irrigated Central Great Plains Studies. Agronomy Journal, 101: 390 - 399.

JICA (Japan International Cooperation Agency) 2005; Supporting Capacity Development in Solid Waste Management in developing countries http://www.jca.gov.jp, last accessed 6th December 2006.

Macleod, D., Meyers G. D and Anbari, M. A (2006), An International Waste Conversion: Measures for Achieving Sustainable Development; Waste Management & Research, Vol.24, p505 – 513.

Ogundipe, O .M. (2006);An Investigation into the Use of Sawdust for Rigid Pavement Works; M. Eng. (Civil) Thesis, University of Ilorin, Unpublished, 132 pages.

Ogundipe, O .M. and Y. A. Jimoh (2009); Durability-based appropriateness of Sawdust Concrete for Rigid Pavement, Journal of Advanced Materials Research, Vol. AMR 337.11, 11 -16.

Ogundipe, O .M. and Y. A. Jimoh (2011); Strength-based appropriateness of Sawdust Concrete for Rigid Pavement, Journal of Advanced Materials Research, Vol. AMR 367.13, 13 -18.

Olutoge, F. A. (1995); A Study of Sawdust, Palm Kernel Shell and Rice Husk Ash as Full/Partial Replacement for Sand, Granite and Cement in Concrete. M. Sc. Project, University of Lagos, Nigeria, 56 -62 pp, Unpublished.

Omotosho, Olujide (2009), Problem Soils! Problem Soils!! Are Soils Really The Problem?, Engineering Guide, Engineering Guide People, Vol.2 December, 42 – 53.

Ramirez Tim (1992); Steel Slag Aggregates in Bituminous Mixtures - Final Report, Pennsylvania Department of Transportation.

Shroeder R.L. (1994); The Use of Recycled Materials in Highway Construction; Public Roads, Vol. 58, 32 - 41.

Sakai K. (1992); Properties of Granulated Blast Furnace Slag Cement Concrete; Proceeding 4th Int. Conf. on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Istanbul, Turkey.

www.sviva.gov.il

Tchobanoglous G, Thiesen H and Eliassen R. (1993), Solid Wastes: Engineering Princples and Management Issues, McGraw-Hill, Inc., New York, U.S.A.

USEPA (2006), Municipal Solid Waste Management in the United States: 2005 Facts and Figures. Executive Summary; United States Environmental Protection Agency, Municipal and Industrial Solid Waste Division, Office of Solid Wastewww.epa.gov/osv/nonhaz/municipal/index.htm Accessed on the 16th of February, 2008.

http://www.epa.gov/epawaste/hazard/dsw/compedium.htm

Wachukwu, K.C and Eleanya, E. U. (2007), Health Impact Assessment of Solid Waste Disposal Works in Port Harcourt, Nigeria; Journal of Applied Sciences, Vol. 22, No.7, 3562-3566.

Washa G. W. (1956); Properties of Lightweight Aggregates and Lightweight Concrete; Journal of the American Concrete Institute, No. 4, Vol. 58, 375 - 382.

www.sviva.gov.il/Environment/Static/... Integrated_management_1.doc; accessed on 6th December 2008.

# Design of Waste Stabilization Pond for Institutional Waste Treatment

O.T. Amoo[1*] & T.S Abdulkadir[1], B.F. Sule[1]
[1]Department of Civil Engineering, P.M.B 1515, University of Ilorin, Ilorin,Nigeria
* Corresponding author: taye2236@yahoo.com

## Abstract

The greatest challenge in the water and sanitation sector over the next two decades will be the implementation of low cost sewage treatment that will at the same time permit selective reuse of treated effluents for agricultural and industrial purposes. This report presents the outcome of the model studies of waste stabilization ponds for sewage treatment at the University of Ilorin, Main Campus. The pilot scale study demonstrate the effectiveness of Waste stabilization pond (WSP) for the treatment of sewage and its potential as a viable means to recover a variety of resources including: treated effluent for irrigation, organic humus for soil amendment and energy in the form of biogas which are some of it intervention to recycle precious resources while still meeting the sanitation needs.

**Key words: Sewage, Reuse, Waste stabilization pond (WSP), Treated Effluent, Biogas, Recycle.**

## 1.0Introduction

Wastewater reuse is an important alternative for water supply. It may be more attractive in arid areas where water is scarce and water losses are high. Municipal wastewater is the best resources for water reuse in terms of its quality and low variability. It can be classify into Indirect Reuse and Direct reuse. Indirect Reuse: - in which water is taken from a river, lake, or underground aquifer that contains sewage. The practice of discharging sewage to surface waters and withdrawal for reuse allows the processes of natural purification to take pace. Direct Reuse:- which is the planned and deliberate use treated wastewater for some beneficial purpose. Direct reuse of reclaimed waters is practiced for several applications without dilution in natural water resources.

Recycling Waste is one of the commonest ways of managing waste in developed countries. It involves the production of a useful material from waste garbage through recycling parts of it. (Malcom R.,1994). A method of wastewater treatment is the construction of waste stabilization pond (WSP) system, which essentially is an earth basin to retain wastewater within which natural stabilization process occurs. (WHO,1987). Integrated resources management in the cities of the future or eco-cities represents a major paradigm shift in the way new cities will be built or older ones retrofitted. The aim is to achieve a change from the current unsustainable status to sustainability, meet zero greenhouse emission targets, reuse and recycled water and recover resources, including nutrients (Novotny et al., 2010). It is vital to revise our models of development, especially in terms of holistic management of wastewater. The traditional linear approach to water management often does not recognize or understand, as it should, the interactions between wastewater reuse and costs. With increasing water scarcity and soaring energy costs and coupling with the effect of global warming and climate change reinforce the need for an holistic approach to managing wastewater and water- along with nutrients- in an integrated system that fits with growing urban development. (Bieker et al.,2010).

Proper management of wastewater quality has become an important and complex issue because of increases in both water requirements and in water pollution in recent years. An inadequate water quality management policy may cause severe impacts on the environment and the economy. Therefore, analysis and selection of a best wastewater treatment must be carefully performed with the best available techniques. WSP systems could be an excellent alternative for the production of effluents that can be reused for irrigation (WHO, 1989). It provides savings in energy costs for industries. Return flows from irrigation are reusable source for agricultural or industrial uses. When use for agricultural uses suitable treatment is required because it is highly contaminated with salt and chemical matters. It is also useful for fertilizers, pesticide and herbicides.

In developing countries like Nigeria, There are only a few locations where WSPs' are in use. The Ahmadu Bello University Main Campus at Samaru, Zaria, has a functional WSP system. The campus has a centrally planned wastewater disposal system and the effluent from the pond has been satisfactory. A central waste treatment plant is in use for the residents in Wuse, Garki and Apo village in Abuja F.C.T. There is also, one in Lagos at FESTAC Estate but records of its performance are not available (Bilewu, 2004).

However, in warmer climates (the Middle East, Africa, Asia and Latin America) ponds are commonly used for large populations (up to 1 million). Many countries in Africa also use WSPs for wastewater treatment (e.g., Tanzania, Kenya, Malawi, Uganda, Zambia, Botswana and Zimbabwe). Many of these systems have been performing below the required standards, due to lack of proper operation and maintenance (Kayombo *et al*., 1998).

## 2.0 Materials and Method

### 2.1. Population Determination

The population estimates for the University up to the year 2010 was 31,162 people. A yearly population growth rate of 1.52% was found from the analysis of past population's records for the University community. This was use for the project's population projection for 20 year design period.

### 2.2 Volume of Sewage generation

Wastewater production can be mathematically represented as $= (W_c \times N)85\%$

Wher $W_c$ = water consumed per person (taken as 150L/day) N = Nos. of people contributing to the same sewer line

It is taken here that the actual low in each pipe is 85% of the water consumption

Discharge, Q = wastewater produced × peaking factor Peaking factor, P.F = 3.0 for dwelling houses and 1.5 for offices.

### **2.3 Effluent Limits**

Effluent limits represent the maximum amount of pollutants allowed to discharge from wastewater to its final destination (waterway, reservoir for reuse, etc.). These limits vary from one country to another due to geographical, climatic and socio-economical reasons. Table 2 shows effluent limit in Nigeria.

Table 1: shows estimate of wastewater production for the various locations on the University campus.

| Dwelling categories | Population | Discharge Volume (l/day) | peaking factor | % Contribution |
|---|---|---|---|---|
| Senior Qrts | 1600 | 612,000.00 | 3 | 7.50 |
| Junior Qrts | 1120 | 428,400.00 | 3 | 5.25 |
| Unilorin Primary School | 1172 | 224,145.00 | 1.5 | 2.75 |
| Unilorin Secondary School | 1236 | 236,385.00 | 1.5 | 2.90 |
| Unilorin Administrative Building | 2960 | 566,100.00 | 1.5 | 6.94 |
| Unilorin Academic Area | 6720 | 1,285,200.00 | 1.5 | 15.75 |
| Unilorin Physical Fitness Area | 3948 | 755,055.00 | 1.5 | 9.25 |
| Unilorin Bank layout | 820 | 156,825.00 | 1.5 | 1.92 |
| Clinic Area /Student village | 2800 | 535,500.00 | 1.5 | 6.56 |
| Male Hostel area | 2676 | 1,023,570.00 | 3 | 12.54 |
| Female hostel area | 6110 | 2,337,075.00 | 3 | 28.64 |
| TOTAL | 31162 | 8,160,255.00 | | 100.00 |

Table 2 Effluent Limitation Guidelines in Nigeria for all Categories

| Parameters | Model Maximum | Surface Water Discharge Limit | Limit for Land Application |
|---|---|---|---|
| BOD | 9.5mg/L | 50mg/L | 500mg/L |
| Suspended Solids | 122mg/L | 30mg/L | - |
| Dissolved Solids | 288 | 2000mg/L | 2,000mg/L |
| pH | 7.6 | 6-9 | 6-9 |
| Temperature | $35^oc$ | $<40^oc$ | $<40^oc$ |

Source: Federal Environmental Protection Agency, Lagos, Nigeria, (1991) 2.4 Composition of sewage

Samples of fresh sewage were collected over a week between 8th – 15th of June, 2010 at designated manholes along the University functional areas. The BOD of the influent wastewater samples was determined by the BOD Track equipment at the Water Monitoring Control Laboratory of Kwara State Ministry of Water Resources, Ilorin. The results of the analysis of the samples collected in selected areas are presented in Table 3

## 2.5 Design of a Wastewater Stabilization Pond System

### 2.5.1 General

A series of wastewater stabilization ponds whose first stage comprises two anaerobic ponds in parallel, followed by two facultative ones in parallel is adopted. These are to be followed by as many maturation ponds in series to achieve the required effluent coliform count. In the case considered, the river into which the ponds will discharge is used for irrigation and watering animals; the prevailing wind direction which lies at south west direction on the campus necessitated the orientation of the ponds.

### 2.5.2 Population to be Sewered

The first step is to determine the population to be sewered in 20 years time.

Estimated population in 20 years: $31162 \times (1.015)^{20} = 41971 \approx 42{,}000$ people

### 2.5.3 Measured and Assumed Parameters

**a) General parameters**

Population in 20 years - 42 000

Water supply per capita - $150\ L/d$

Volume of influent to pond system per day $\left(42\,000 \times 150 \times \frac{0.85}{1000}\right) = 5355\ m^3/d$

Mean probable number (MPN) of coliforms in the influent $1.8\ x\ 10^8/100\ mL$

Mean air temperature during the coldest month 26.9°C

Mean water temperature during the coldest month 21.5°C

Civil Engineering Parameters

Embankment slope, pond side 1/3 (= 33%)

Land side 1/1.5 (= 67%)

Freeboard, all ponds = 0.5 m

(Compacted soil vol./original vol.) x 100 = 90%

**b) Anaerobic Ponds**

The influent load in terms of $BOD_5$ per day is:

Assumed $BOD_5$ per capita 45 g/d

$No\ of\ people\ \times\ BOD_5/person-day\ =\ 42\,000\ \times\ 45\ =\ 1890\,000\ g\ BOD_5/d$

$BOD_5$ of sewage $[=\ 45/(150\times 0.85)]$ per capita = 0.353 g/L = (353 mg/L)

Volumetric loading of anaerobic ponds for T > 25°C $(l_v)$ = 300g$BOD_5$/m$^3$

Digested anaerobic sludge production per capita per year - 0.04 m$^3$

Anaerobic pond depth chosen 4 m

$BOD_5$ reduction in the anaerobic ponds - 50%

Anaerobic pond do not contain algae, they are design to remove negligible pathogenic agents. ∴ Percentage removal of coliform in the anaerobic ponds - disregard

**c) Facultative ponds**

Base on design formula suggested by Gloyna(1976)Ultimate BOD ($BOD_u$), = 1.4 $BOD_5$

Digested sludge production per capita per year 0.03 m$^3$

Facultative pond depth chosen to be 1.70 m

Percentage removal of coliform in the facultative ponds 99%

**d) Maturation ponds**

FEPA (BOD) Surface water discharge limit(Table 3)
$\leq$ 50mg/L
Effluent land limit (Table 3)
$\leq$ 500/100 mg/L
∴Coliform count final effluent of the maturation ponds $MPN' \leq 400/100\, ml$
Bacterial removal rate,
$K' = 0.3d^{-1}$
Maturation pond depth chosen to be
= 1.0m

### 2.5.4 Design of Anaerobic Ponds

The Anaerobic pond was design on the basis of volumetric BOD loading (lv, $g/m^3d$), given by Mara and Pearson (1986) equations:

$$l_v = \frac{L_i \times Q}{V_a} \qquad (1)$$

where $L_i$ = influent BOD, mg/l (= 0.353g/m3)
$l_v$= volumetric BOD loading = 300 g BOD5/m3-d.
Q = flow, $m^3/d$ (5355m3/d)
$V_a$ =Anaerobic pond volume, $m^3$
Hence, total volumes of anaerobic pond ($V_T$) = (liquid plus sludge)
$V_T$ = In luent load/volumetric loading = (2)

**Retention time** ($q_a$) $= \frac{V_a}{Q} =$ (3)

$$\frac{Volume}{depth} = Surface\ Area \qquad (4)$$

Using a trapezoidal shape, the side of the trapezium at half-depth is:
$\sqrt{\text{Area}} = \sqrt{2888} = 53.7$ m side length and by simple geometry:

Side
$length \pm 2\, x\, (half\ liquid - plus - sludge\ depth)\ x\ inverse\ slope$

Chosen appropriate data from measure and assumed parameter (section 2.5.3) and substituting in eqn.1 – 5.

∴ The anaerobic ponds dimension gives: length =69m and breath=42m for the top layer

### 2.5.5 Design of Facultative Ponds

For comparison purposes, the facultative pond was designed using three methods: the McGarry and Pescod (1970), Gloyna (1976) equations and Mara (1998) equation. These are given as:

a) The McGarry and Pescod design principles recognizes the high correlation between maximum applied area or surface loading, $L_{s,o}$ and the minimum ambient monthly air temperature, $T_a(^0C)$

$$L_{s,0}(kg\frac{BOD_5}{ha}.d) = 60.3 \times 1.0993^{Ta} \qquad 6)$$

b) The Gloyna equation is: $V = 3.5 \times 10^{-5}\, Q\, L_U\, \theta^{(35-T)}\, ff'$ 7)

Where: V =pond volume ($m^3$); Q= wastewater flow (L/d); Lu =ultimate influent BOD (or COD) (mg/.L);$\theta$ = temperature reaction coefficient; T = pond water temperature (°C);
$f$ = algal inhibition factor;$f'$ = sulphide or other immediate chemical oxygen demand.

Note: The two facultative ponds was designed to removed 50% of the influent load with each pond volume to be half of the total expected volume, while eqn. 6 can be subjected to a factor of safety of 1.5 which can be substituted in eqn. 8 to gives the surface area ($m^2$)

$$\text{Applied surface area (m2)} = \frac{\text{ultimate BODu (kg BOD/d)}}{\text{design loading } (L_{s,0})} \qquad 8)$$

c) The design based on (Mara, 1998) equation gives:

$$A = \frac{Q}{DK_1}\left(\frac{L_i}{L_e} - 1\right) = \frac{Q}{DK_1}\left(\frac{L_1 - L_e}{L_e}\right) \quad (9)$$

where: A = Area of the pond in $m^2$ , Q = volumetric flow rate i.e. Daily flow of wastewater (L/d), D = Depth of the pond (m) , T = Average temperature of the coldest month. $L_i$ = BOD of the influent, $L_e$ = BOD of the effluent, the rate constant (k) varies with temperature because it is temperature sensitive. $K_T = K_{20}\theta^{T-20}$ (10)

where $K_T$ and $K_{20}$= Biodegradation rate constant value (at temperature T°C and 20°C) ($d^{-1}$)

Using (Mara 1998) $K_1$ for raw wastewater is 0.3$d^{-1}$ and the value should be in the range 50 - 70 mg/L for pond depth of 1 - 1.5m.selecting the required data from measure and assumed parameter (section 2.3.3), these can be substituted to give the ponds dimension in eqn.6 – 10. The conservative surface area values of 34,000 $m^2$ employed the ratio 1.5 Length: Breadth ratio to give facultative: Length= 143m Breadth = 93m, depth = 1.8

### 2.5.6 Design of Maturation Ponds

The daily average evaporation loss is about 6.3mm/day for Ilorin (Amoo,2011). This has a bearing on the concentration of the bacteria in the effluent passing to the maturation ponds. A modified form of (Gloyna, 1971): was used to design the maturation ponds. Since the ponds was assumed to have the same volume and therefore, the same retention time. The effluents from the two facultative ponds are combined and flow into the first maturation pond.

$$\frac{N_e}{N_i} = \frac{1}{(K'R+1)^n}$$

$$\frac{400}{1.1\times10^6} = \frac{1}{(2R+1)^n} \quad (11)$$

Rearranging gives: $\log(2R + 1) = \frac{\log 2750}{n}$ (12)

Where: $N_i$ is the bacterial population in the effluent from the facultative pond, $N_e$ is the bacterial population after R days, K' is the die-off constant ($d^{-1}$), R is the retention time (d) while n is the number of ponds. Solving eqn.12 to obtained retention time R, for different pond's number which range from n= 1-5, gives: R=2.98 days, n = 4 and total area ($m^2$) = 30000$m^2$

The individual pond volumes are 7650 $m^3$.Since the depth is to be 1 m, the area of each pond at half-depth is 7650 $m^2$. Employing four ponds of each length to breadth in the ratio 1.5L: B gives each of the maturation ponds to be length 113m by 72m breadth.

## 3.0 Recommendation and Conclusion

The traditional linear treatment systems must be transformed into the cyclical treatment to promote the conservation of water and nutrient resources reduces pollution of rivers and other surface water. Using organic waste nutrient cycles, from point-of-generation to point-of-production, closes the resource loop and provides an integrated approach for the management of valuable wastewater resources.

The University presently has no effective system in place for treating the entirety of waste water generated by the residential estates, hostels and cafeterias etc. The current septic tank usage is vulnerable to overflow, creation of foul odour, susceptible to contagious disease and an unaesthetic environment.

The results of model test for the treatment process showed a reduction of the BOD from 353mg/L to 14.1mg/L and a significant reduction of the microorganism such as the faecal coliform. The effluent from the treatment process could be discharged to a water body without damaging the environment thereby conserves soil nutrients and reducing the need for artificial fertilizer for increases crop yields. The study has demonstrated that WSP system is a viable option of natural treatment of sewage for the University because the availability of vast land area for its construction, low capital costs, easiness of maintenance and potential longer life-cycles. .

## References

Amoo O.T (2011).Analysis ,Design and Model Studies of a WSP for Treating Sewage at University of Ilorin. M.Eng. Project Report, Civil Engineering Dept. University of Ilorin, Nigeria.

Bilewu, O. S. (2004). A Comparative Study of Series and Parallel Models of Stabilization Ponds for Wastewater Treatment. M.Eng. Project Report, Civil Engineering Dept. University of Ilorin, Nigeria.

Bieker S, Cornel P and Wagner M (2010),:Semicentralzed Supply and Treatment Systems: integrated infrastructure solutions for fast growing urban areas. Water Science &technology, 61(11),2905-2913

FEPA, (1991) Standards for Environmental Pollution Control in Nigeria, Federal Enviromental Protection Agency, Lagos, Nigeria.

Gloyna,E.F (1971). Waste Stabilization Ponds:World Health Organization monograph series No 60: 58- 60.

Gloyna E.F. (1976): "Waste Stabilization Pond Design; in Ponds as a Wastewater Treatment Alternative, Water Resources Symposium No 9, University of Texas, Austin, Texas, USA.

Kayombo.S, Mbvelte T.S.and Katima,J.H.(1998):WSP & CW Research Project Prospective, College of Engineering and Technology, University of Dares Salaam, Tanzania p (22)

Malcolm R,1994: A guide to Environmental Law, London, sweet & Maxwell, vii. EC Directive 91/156

Malcolm R,1994: A guide to Environmental Law, London, sweet & Maxwell, vii. EC Directive 91/156

Mara, D.D. and Pearson, H.W. (1998). Design Manual for Waste Stabilization Ponds in Mediterranean Countries. European Investment Bank. Lagoon Technology International. Leeds, United Kingdom. URL: http://www.irc.nl/url/7354

McGarry M.G. and Pescod M.B. (1970): Stabilization Pond Design Criteria for Tropical Asia. Proc.2nd Int.Conference on Waste Treatment Lagoons, Kansas City, pp.114-132.

Novotny V (2010), water energy nexus- towards zero pollution and GHG emissions of future (eco) cities. Water infrastructure for sustainable Communities (Hao X, Novotny V,and Nelson V, eds), IWA Publishing, London, pp 35-58.

WHO (1987) Wastewater Stabilization Ponds:Principle of Planning and Practice.''WHO- EmbroTechnical Publication, No. 10, Eastern Mediterranean, Alexandria, Egypt.

WHO (1989) Health Guidelines for the Use of Wastewater in Agricultural and Aquaculture Technical Report series No. 778, World Health Organization, Geneva.

# Comparison the Compressive Strength of Stabilised Termitarium Brick with Conventional Concrete Bricks Produced in Namibia

[1]Kamara Victor S and [2]Katale David P.
Department of Civil Engineering, School of Engineering, Polytechnic of Namibia, Windhoek, Namibia:
[1]vkamara@polytechnic.edu.na
[2]dkatale@polytechnic.edu.na

## Abstract

The fluctuating high cost of cement, which has limited the development of affordable housing has, because of its unique engineering properties, necessitated an in-depth look into termitarium as an alternative to the production of standard bricks for the construction of affordable housing in developing countries. This paper revealed findings on whether stabilised terrnitarium can compete with the compressive strength of the standard 7 MPa concrete brick found in Namibia and most developing Africa countries. Laboratory tests were conducted on three (3) design mixes, prepared, cured and crushed under standard conditions. As done in Bricks Cement Institute (BCl) in Windhoek, the same proportion of cement was mixed with termitarium so as to compare results with the same amount of cement in sandcrete/concrete bricks produced locally. This paper revealed that the termitarium mixed with same amount of cement as used by BCI in their mix can compete with the 7MPa brick produced by BCl.

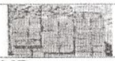
**Keywords:** Termitarium, compressive strength, mix design

## 1. Introduction

Namibia is situated between latitudes 17° and 29°S, and longitudes II ° and 26°E. Namibia and considered to be the thirty-fourth largest country in the world (825,418km$^2$) with a population of 2,147,585 (July 2011 est.) with temperature ranging from 7$^o$C to 35$^o$C. Because of the climatic condition in most part of the country, varying shapes and sizes of habited and abandoned termite moulds do exist, more especially along the Namibian coast line. With the present quest for arable land, the spread of such moulds limit the usage of such land, hence the need to look at alternative use of such moulds that will benefit society especially vulnerable and less privileged communities. According to recent surveys, one of the areas where soil in such moulds can be beneficial is in the construction of affordable or low cost housing especially traditional Africa houses that spans far back as in the 18th and 19th century. Survey conducted by one of the authors revealed that most of the traditional African houses, that have been in existence for decades and sometime centuries with little or low maintenance, are one way or the other made of termitariurn (Amsterdam, 2009).

Like any similar engineering investigation, soil samples of habited and abandoned termite moulds were collected, cured and tested. Moist content and other engineering parameters were investigated in both scenarios and differences in engineering properties were deduced (Anderson et al, 2009). This finding revealed technical information of habited stabilized terrnitariurn and the compressive strength was compared with that of standard bricks widely used in the construction industry in Namibia. (See Table 1). Wide ranges of brick strengths are available in Namibia. However, this finding will only focus on comparing the stabilised termitarium brick with the 7MPa cement brick that is widely used in the local construction industry. Research on the properties of termitarium is relatively new and this finding opens the way for extensive research on the viability of using such material in the construction of avoidable housing in tropical countries.

Table 1: Specification of bricks widely used in Namibia

| Product | Super Bricks | Standard Bricks | Hollow Blocks | Split Rock Face |
|---|---|---|---|---|
| |  |  |  |  |
| Strength | 7MPa (S7) & 14MPa (S14) | 7MPa (S7) 14MPa (S14) | 4MPa | 14MPa |
| Size (L x W x H) | 217mm x 100mm x 100mm | 222mm x 105mm x 70mm | 440mm x 220mm x 190mm | 222mm x 105mm x 70mm |
| Weight | 4.7kg / unit | 3.7kg / unit | 24kg / unit | 3.7kg / unit |
| Application | Single Wall 42 bricks / m² Double Wall 84 bricks / m² | Single Wall 55 bricks / m² Double Wall 110 bricks / m² | 11 units / m² | Single Wall 55 bricks / m² Double Wall 110 bricks / m² |
| Units per stack | 288 | 384 | 32 | 396 |
| Colour | Plain | Plain | Plain | Natural Plain, Black, Red & Plum |

## 2. Laboratory Investigation

### 2.1 Description of soil structure and size

Visual inspection of the soil revealed the soil to be "powder like". The termites make use of very fine grained soils (smaller than 4mm). The soil on the inside of the mound is moist and can easily be compacted.

## 2.2 Site description of termite moulds

At the Windhoek, the region contains scattered trees and strubs with relative humidity ranging between 70 – 80%
- 80% during most of the moist months of February to April, and relatively low during the rest of the year (10 - 20%). Temperatures are quite costant throughout the year with mean temperature of ± 21°C. Annual rainfall averages 350 - 400mm with evaporation rates ranging between 300-3200mm per year. Lithic liptosols (composed of lithic sandstones that contain lithium) are the dominant soil in this area with schi t rock mostly ob erved in the area. The dominant moulds found in this area are those of the hodoterrnes Mossambicus species of termites. The e species thrive in areas with average annual rainfall of less than 750m111. The site contain varying sizes of moulds. The size of these moulds depend largely on the number of occupants in a colony i.e. the more termites, the bigger the size of the mould. Results revealed that the number of individual termites living in a colony and the size of the mould are related by:

$$\text{In}N = 7.893+1.09h \quad (1)$$

Where *N*, *h* are the total number of individuals and height of mould (in metre) respectively. Also the varying sizes of these moulds depends on the number of female occupants within the terrnitarium i.e. the higher the female population, the more eggs been laid, hence larger brood.

## 3. Laboratory Preparation

The samples were then collected, categorized (labeled A - D) and crushed by hand using a mortar and pestle and placed in bags. Tests were then conducted on the terrnitarium samples to determine certain engineering properties. Sieve Analysis, Liquid Limit, Plastic Limit and Bulk Density tests of materials were embarked upon. Three mixed designed were developed with the following percentages as shown in Table 2

Table 2: percentages by volume of cement used per mix

| Mixes | Percentage by volume of cement | Content |
|---|---|---|
| 1 | 25 | - |
| 2 | 7 | terrnitarium |
| 3 | 7 | Soil sample D |

The sieve analysis and bulk density was done on soil sample D. This sample was used to produce a third mix of cubes for testing. This was done to have a comparison that would be able to give an answer on whether terrnitarium actually does increase the strength.
The mixes for the cubes were made. The cubes were cured in a water bath. After 7, 14 and 28 days of curing, five cubes from each mix were crushed to determine the compressive strength.

## 3. Laboratory Test Results

### 3.1 Sieve analysis test per sample

Sieve analysis was performed to determine the size of soil particles and the distribution of the sizes in the soil. Typical example of the results obtained the group is shown in Table 3. All other results are not shown here.

Table 3, Sieve analysis results for sample A used to in mix 1 and mix 2

| Sieve Size (mm) | Mass retained (g) | Mass Passed (g) | Percentage Pass (%) |
|---|---|---|---|
| 4.750 | a | 1000 | 100.00 |
| 2.360 | 3 | 997 | 99.71 |
| 2.000 | 24 | 973 | 97.31 |
| 1.180 | 149 | 824 | 82.41 |
| 0.600 | 208 | 616 | 61.61 |
| 0.425 | 93 | 523 | 52.31 |
| 0.300 | 126 | 397 | 39.71 |
| 0.150 | 213 | 184 | 18.41 |
| 0.075 | 126 | 58 | 5.81 |
| < 0.075 | 51 | 7 | 0.71 |
| Σ | 993 | | |

### 3.3 Liquid limit tests per sample

The liquid limit expressed as a percentage by weight of the oven dried soil and the boundary between the plastic and the liquid states on sample A were conducted... It was done to determine the boundary between the plastic and liquid states. The liquid limit is read off at 25 taps. using the equation (2) and replacing $x$ with 25, the answer received will be the value of the corresponding moisture content.

Moisture Content, $\omega = -3.685 \ln' x' + 29.57$ (2)
$= 17.71$ %

A typical example of the liquid limit results are shown in Table 4 for sample A.

Table 4 Liquid limit results for sample A used in mixes 1 and 2

| Tin # | Sample Number | Number of Taps | Wet Mass, Mw(g) | MD+MT(g) | Mass of Tin, MT (g) | Dry Mass, MD(g) | Mass of Water (g) | Moisture Content (%) w |
|---|---|---|---|---|---|---|---|---|
| A18 | 3 | 33 | 6.952 | 16.057 | 10.146 | 5.911 | 1.041 | 17.61 |
| A21 | 4 | 30 | 4.35 | 14.156 | 10.424 | 3.732 | 0.618 | 16.56 |
| A23 | 5 | 23 | 6.569 | 18.357 | 12.775 | 5.582 | 0.987 | 17.68 |
| A24 | 6 | 10 | 5.723 | 15.854 | 11.124 | 4.73 | 0.993 | 20.99 |
| A26 | 7 | 19 | 4.932 | 15.223 | 11.012 | 4.211 | 0.721 | 17.12 |
| A29 | 8 | 36 | 5.202 | 15.516 | 11.117 | 4.399 | 0.803 | 18.25 |
| A30 | 9 | 7 | 8.639 | 20.022 | 12.868 | 7.154 | 1.485 | 20.76 |

## 3.4 Laboratory results on bulk density of samples

The bulk densities which give the ratio of mass versus volume of a solid or a liquid for samples A and D were determined. The purpose of determining the bulk density was to be able to convert the required volumes of soil to a measurable mass. It is easier to weigh the mass required than it is to measure off the required volume Laboratory results of the bulk density are as shown in Table 5.

Table 5 Values recorded to obtain the bulk density

| $V_i$ | $M_l$ | $M_e$ |
|---|---|---|
| 0.001882 | 3.142 | 0.854 |

From Table 5, the corresponding values were substituted into equation (4) below the bulk density was calculated

$$M_{,} = M_J - Me \tag{3}$$

$$= 3.142 - 0.854 = 2.288 \text{ kg}$$

and

$$\text{Bulk Density} = M_s/V_e \tag{4}$$

$$= 1216 \text{kg/m}^3$$

### 3.5 Laboratory results of the plastic limit

The test for the plastic limit did not yield any results as the sample kept disintegrating into smaller particles.

### 3.6 Laboratory results on test cubes of samples

This forms the most important component of this research since it provides answer to the research question. Test results are as shown for 7 and 28 days strength for mix 1.

Table 6 7 day strengths for Mix 1

| Cube Number | Stress (MPa) | Mass (Kg) | Mass in Water (Kg) | Saturated Density Kg/m $^3$ |
|---|---|---|---|---|
| 1 | 11.69 | 7.325 | 3.968 | 3.357 |
| 2 | 6.7 | 7.271 | 3.851 | 3.420 |
| 3 | 10.9 | 7.214 | 3.827 | 3.387 |
| 4 | 16.74 | 7.229 | 3.853 | 3.376 |
| 5 | 18.61 | 7.315 | 3.397 | 3.918 |
| Average | 12.928 | | | |

Sample Standard Deviation = 4.776 , Sample Variance = 22.812

Table 7 28 day strengths for Mix 2

| Cube Number | Stress (MPa) | Mass (Kg) | Mass in Water (Kg) | Saturated Density Kg/m $^3$ |
|---|---|---|---|---|
| 1 | 6.800 | 7.215 | 3.84 | 3.375 |
| 2 | 7.667 | 7.772 | 4.327 | 3.445 |
| 3 | 8.57 | 7.633 | 4.247 | 3.386 |
| 4 | 8.003 | 7.537 | 4.196 | 3.341 |
| 5 | 8.922 | 7.731 | 4.136 | 3.595 |
| Average | 7.992 | | | |

Sample Standard Deviation = 0.825 Sample Variance = 0.681

## 4. Discussion of the Results

### 4.2 Laboratory Results

In Tables 6 and 7, relationship between compressive strength and mix design with respect to the type of soil sample used to make the cube are shown.

### 4.2.1 Comparison

1. Mixes 1, 2 & 3

Comparing mix 1 with mix 2 and mix 3, the following can be deduced: the compressive strength obtained for mix 1 is more than double the compressive strength reached by mix 2 and almost six times the compressive strength reached by mix 3. This is due to the fact that the amount of cement used in mix 1, is almost four times the amount of that used in mix 2 and mix three. Hence the amount of cement is the main variable causing the change in compressive strength. However, using that amount of cement is not economically viable, as using that much cement in a mix would make the brick expensive to produce.

Mixes 2 & 3

Comparing mix 2 with mix 3, the following can be deduced: the compressive streneth of mix 2 is almost double the compressive strength of mix 3. Mix 2 and mix 3 have the same mix design, the *only* difference being the soil that was used. The termitarium was used in mix 2 and normal sand was used in mix 3. Therefore, using mix 2 can be cheaper than using the mix used to produce the standard cement brick in Namibia.

The only problem with using mix 2 is the termitarium. Termitarium is not readily available. Terrnitariurn can only be formed by termites. Therefore to mass produce the brick would not be viable, as it would be impossible to acquire enough terrnitarium to be able to match the production of local brick manufacturers. Therefore, to make the use of mix 2 viable, soil that resembles all the properties could be used instead.

## 5. Conclusions and Recommendations

### Conclusion

From the compressive strength results of mix 2, comparing that to the stated strength of 7Mpa for the local brick manufacturers, it can be concluded that the terrnitarium can compete with their bricks regarding compressive strength. This is due to the fact that the local brick manufacturer adds coarse aggregates and an additive to further strengthen their bricks.

According to the SANS 1215 :2008 code, for a brick to meet the compressive strength requirements, an average strength of 8Mpa for 5 test samples and an individual strength of 7Mpa must be reached. It can be concluded that mix 2

has met the compression requirements stated by the SA S 1215: code.

**Recommendations**

The following can be recommended for further research:

i. perform tests on the shear strength, permeability and linear shrinkage of the brick as stated in the SANS 1215 :2008 code, to determine if the brick is viable for construction;
ii. similar tests can also be conducted for abandoned termites mould and results compared;
iii. Future research to be conducted on cost analysis between the termitariurn brick and the standard cement brick and
iv. Further research on durability and sustainability of the termitarium brick and compare that with standard cement brick.

**References**

Amsterdam, E. V. (2009). Construction Materials for Civil Engineers. Lansdowne: Juta and Co, Ltd 2000.

Anderson, W., Basson, D. G., Cupido, 1. c., Husselmann, M. F., Karnana, E. M., Ndanyengwa, L M., (2009). Investigation into the engineering properties and the viability of using termitarium as material for the production of bricks for the construction ofcffordable and sustainale housing in Namibi.

British Standards. 1- 2. (1990). Methods for testing of soils for civil engineering purpose (Part 2: Classification tests)

SANS 1215 :2008 Code for a brick to meet the compressive strength requirements, 2008