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Redesigning Circular Septic System of Residential Buildings in Nigeria for Electricity Generation

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Abstract: *The conventional circular septic system was redesigned to help solve energy and electricity challenge in Nigeria at household level, the design involves three major stages which include ascertaining of design parameters in design calculations, using the ascertained parameters in drafting the two-dimensional engineering drawings and rendering of the three-dimensional drawing. The design calculation was done initially for both the septic and the soakaway units using the same capacity to get their depths. For the precast system, the depths for both the septic and soakaway chambers are 4.90 m and 4.25 m while for the cast in-situ system, the depths are 2.80 m and 2.46 m. The effective volume of both systems is 2.55* m^3 *while the probable biogas and electricity that can be generated are 0.098* m^3*/day and 7.22 kWh respectively. These dimensions were used for the engineering drafting. The engineering drawings show the plans and sections of the septic and soakaway systems with the biogas to electricity conversion process using gas engine or fuel cells. Three-dimensional rendering of the system was also performed to bring out a better view after being constructed. Some management measures were suggested to guarantee the normal and safe performance of the redesigned circular septic system which can now be adopted to recover methane gas purposely from household wastes for electricity generation and other economical uses in Nigeria.*

Keywords: *Circular, Septic System, Soakaway, Electricity, Methane Gas.*

1.0 INTRODUCTION

The conventional sewerage system followed by a sewage treatment and disposal plant, usually designated as off-site sewage disposal method is an expensive option and not affordable by low income communities and by small communities in rural and suburban areas which are not connected to a town or city sewerage system [1]. This resulted in the development of several alternative low cost on-site sewage disposal methods, with almost the same health benefits. One of such on-site sewage disposal method which is widely used is the septic tank [2]. The invention of the septic tank is credited to a Frenchman by the name of John Louis Mouras, who, during the 1860's constructed a masonry tank into which was directed various household detritus from a small dwelling in Vesoul, France, subsequently overflowing to an ordinary cesspool. After a dozen years, the tank was opened and found, contrary to all expectations, to be almost free from solids [3].

Septic tanks since invention have been used as a means of collecting wastes discharged from houses but as development in science and technology increases, it was discovered that the septic tank system can also function as a biodigester since the condition in which the system is subjected to when in operation is anaerobic [4]. The sludge and scum entering the septic tanks after undergoing decomposition by some micro-organisms emit some mixture of gases in different proportion. The mixture of gases (Methane and Carbon dioxide mainly) produced is what is called biogas**.** Methane which is a greenhouse gas has long been emitted to the atmosphere instead of being collected for other economical uses. Recently, the world especially developing countries are been faced with the problem of petroleum and coal combustion (which result in the emission of harmful gases into the atmosphere). This has led to various researches being carried out to access other sources of energy, like renewable energy which reduces or eliminates the emission of harmful gases. Solar energy, wind energy, hydro sources of energy and biogas are all renewable energy resources but biogas is distinct from other, because of its characteristics of use, control and collection [5].

WHO [6] defined septic tanks as any watertight chambers sited below ground level which receive excreta and flush water from flush toilets and other domestic sullage (collectively known as wastewater). The solids settle out and break down in the tank. The liquid remains in the tank for a short time before overflowing into a sealed soak away or drain field where it infiltrates into the ground. According to [2] septic tank is a combined sedimentation and digestion tank where sewage is held for one day to two days. During this period, the suspended solids settle down to the bottom. This is accompanied by anaerobic digestion of settled solids (sludge) resulting in reasonable reduction in the volume of sludge, reduction in biodegradable organic matter and release of mixture of gases like carbon dioxide, methane and hydrogen sulphide termed BIOGAS. Some of the gases evolve foul smell such as hydrogen sulphide during the digestion process, and the system is usually completely covered at the top with a provision of a high vertical vent shaft for the escape of these gases. Biogas does not have any geographical limitations or does it require advanced technology for producing energy, also it is very simple to use and apply [7].

Nigeria is a country with an estimated population of about 186 Million people, 65% of which are between the ages of 18 to 45 years. Only about 40 % of the population has access to electricity supply. The national grid is limited in reach [8]. There is limited extension of the grid to most communities, and it would take decades to reach most areas in Nigeria. This leaves a majority of Nigerians who live in most communities without access to electricity. Even the available electricity capacity is insufficient to meet existing power needs of the less than 40 % who have access to the national grid. Therefore, it has become a matter of necessity for exploitation and establishment of other energy resources to complement and supplement the limited power generation and supply available in Nigeria [9]. Nigeria receives a huge amount of solar radiation, has abundant wind energy resources, and large deposits of fossil fuel, as well as enormous hydro-power resources from Niger and Benue Rivers and other forms of renewable energy. However, of these about 80% of hydro-power remains untapped, the total 5.5 KW-hr/ m^2/day of solar radiation is not utilized, and wind energy resources remain unexploited [10]. This paper therefore reviews the existing conventional circular septic systems designed and constructed in Nigeria and further modified the design for biodegradation of household waste for electricity generation.

2.0 DESCRIPTION OF THE STUDY AREA

Nigeria is a country in West Africa. It is bordered in the North by Niger and the Sahara desert, West by Benin Republic, East by the Cameroun and Chad Republics and the South by the Atlantic Ocean. Nigeria is located within latitudes 4°N to 14°S and longitudes 3° E to 15°W. It comprises thirty six states and the Federal Capital Territory, where the capital Abuja is located. Nigeria has population of 185,989,640 people as declared by the National Population Commission in 2016. Nigeria, like the rest of West Africa and other tropical lands, has only two seasons. These are the dry season and the rainy season. The dry season is accompanied by a dust laden airmass from the Sahara Desert, locally known as Harmattan, or by its main name, The Tropical Continental (CT) airmass, while the rainy season is heavily influenced by an airmass originating from the south Atlantic ocean, locally known as the south west wind, or by its main name, The Tropical Maritime (MT) airmass. Figure 1 shows the map of Nigeria depicting all the states with the Federal Capital Territory.

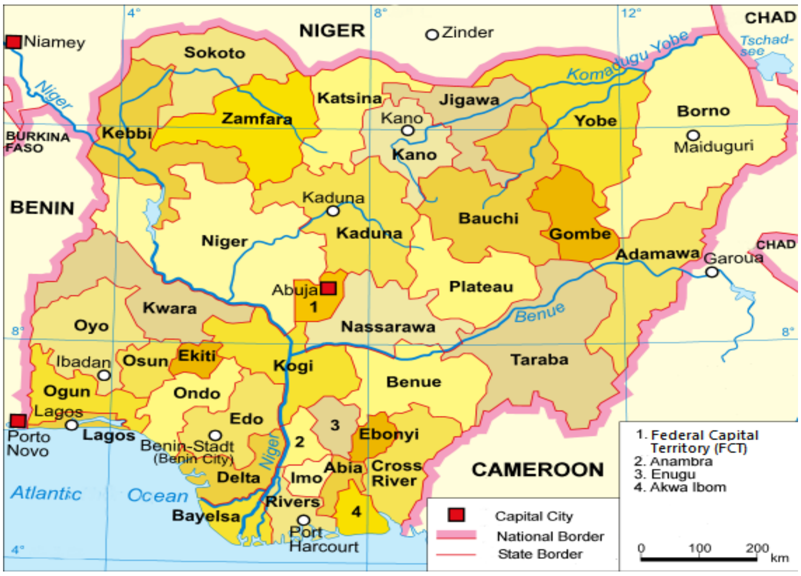

Figure 1: Map of Nigeria Showing Thirty Six States Including the Federal Capital Territory Abuja [11]

3.0 MATERIALS AND METHODS

Software programs were the major tools used for this research and they are AutoCAD (Version 12) and Autodesk Inventor 3D CAD (Version 15). Other materials/equipment used are Laptop, Computer, Scientific Calculator and Design Sheet.

Design Approach

Conventional (or Existing) design and construction of circular septic systems common in Nigeria was first evaluated and reviewed. This design was then worked upon in order to improve on its function and structure in order to get the desired design of septic system which can be used for electricity generation.

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Conventional Circular Septic System and its Design Operation

The design and construction of this system over the years have been widely done using two geometrical shapes: the rectangular shape and the circular shape and these two shapes have been generally adopted because of their ease of design and construction. Only few designers have worked on square shape and other forms of shapes in past years. Physical and biological processes are the two types of processes that occur in this conventional septic system. The schematic flow diagram of the conventional system is shown in Figure 2. The solid and liquid from the toilet flush cistern is conveyed into the septic system via a sewer, after which separation of the solids from the liquid take place as heavier solid called the sludge settles and fats, greases and other light materials float as scum on the surface while the liquid layer is formed in between the sludge and the scum layers called the effluent. Only one receptacle is provided for this system which makes it to have only inlet pipes (no outlet channel). This usually results in frequent disturbance and turbulence in the system and thus causing disruption in the tank operation.

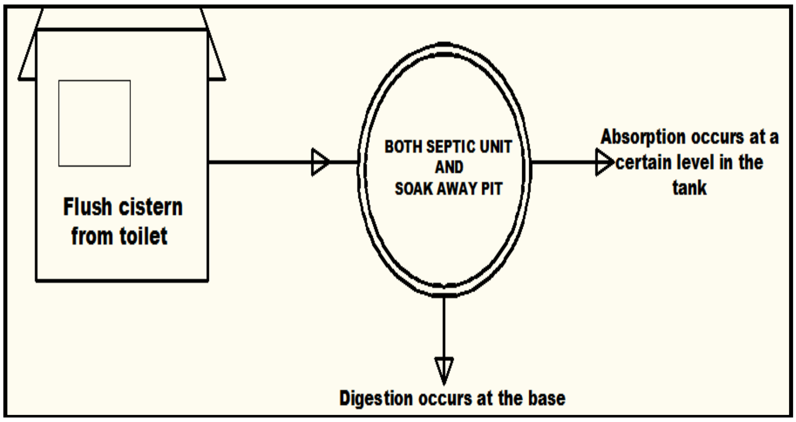

Figure 2: Flow diagram for the existing design

Engineering Drawing of Conventional Circular Septic System

The engineering drawing of the conventional circular septic system currently in use both in Nigeria and some other part of developing countries is shown in Figures 3 and 4. This system has some limitations in its design as it only considered the collection of the wastes from the house. It does not give any consideration on how the wastewater flowing with the solid matters will be discharged. The conventional engineering drawing shows the plan and section of the septic system (that is, the septic tank and the soakaway combined) in a single unit having just the de-sludging hole. This design lacks inspection hole where maintenance work can be carried out in case there is any technical fault in the system neither does it have a gas vent on it. Those constructed in houses has the pipe vent via which the gases is passed out connected to a small chamber before passing it to the septic system and these gases being released escape to the atmosphere which in turn affects the climatic condition of the surrounding and also causes air pollution. This system is limited in design hence the need for a better design.

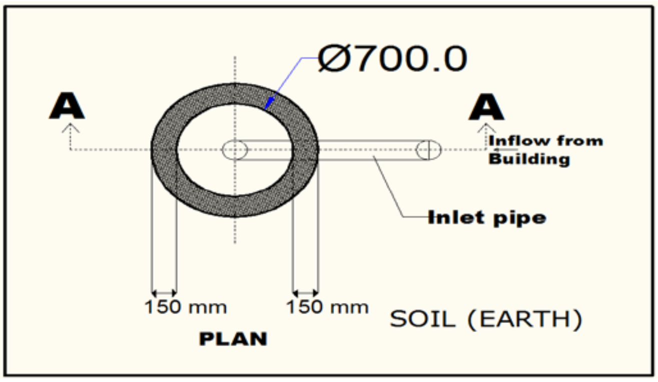

Figure 3: Plan of a typical conventional circular septic system

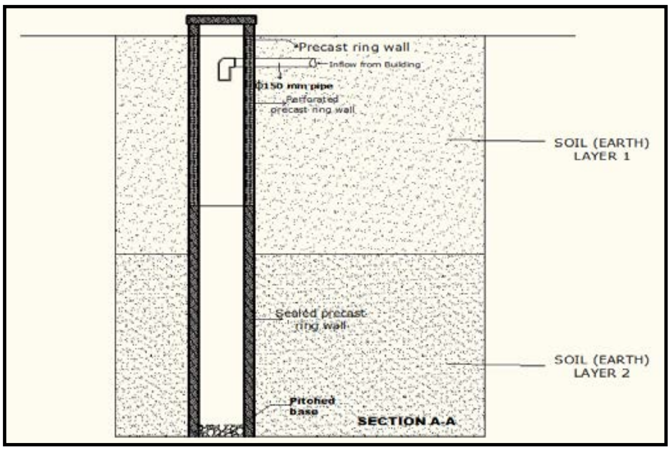

Figure 4: Section of a typical conventional circular septic system

The Modified Septic System and its Design Operation

The design of the circular septic system was modified to further improve on the conventional circular septic system and to maximize its usage for biogas and electricity generation. Two types of processes occurred in this modified system just like the conventional system since both are operated under anaerobic condition. The two processes are physical and biological processes. The schematic flow diagram of the proposed system is shown in Figure 5. The solid and liquid from the toilet flush cistern are conveyed together into the septic system via a sewer just like the existing (conventional) system. After, the separation of the solids from the liquid take place as heavier solid called the sludge settles and fats, greases and other light materials float as scum on the surface. The liquid layer is formed in between the sludge and the scum layers called the effluent. The effluent is retained for a minimum of 24 hours after which it is conveyed into the soak away tank via the outlet pipe. A screen is introduced before the outlet pipe to prevent the scum from being transported with the effluent into the soak away pit. Effluent in the soak away is discharged into the soil through the perforated rings thus preventing turbulence in the system. The breakdown of the solid matters by bacterial action will yield mixture of gases. This mixture of gases emitted from both the septic unit and the soak away pit are then collected for further use.

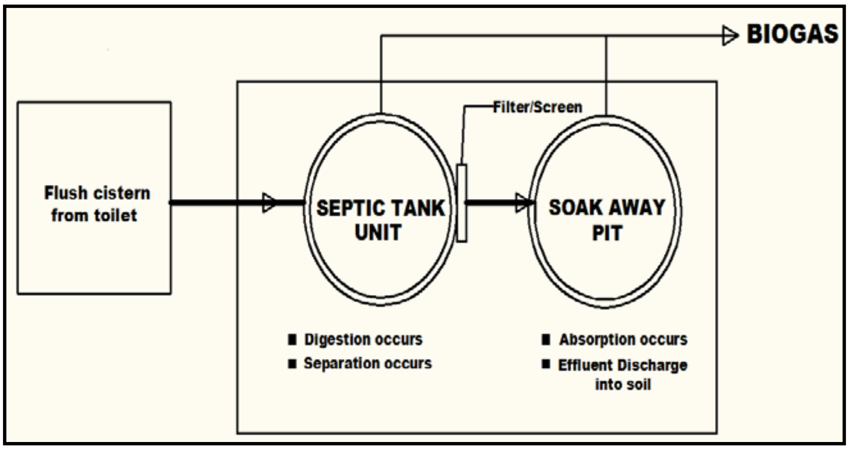

Figure 5: Flow diagram showing the modified circular septic system design

Design Parameters

In redesigning the conventional circular septic system, some parameters are considered that are paramount and can affect the outcome and subsequently the proper construction and performance of the septic system. They are as follows:

a) **Population (P):** This is the number of users contributing to the usage of the septic tank.
b) **Quantity of Water used per person per day (Q):** This is the total amount of water to be used per person per day and it depends on the capacity and type of the sanitary facilities installed.
c) **Retention Time of Effluent (t):** This is the minimum time for the effluent to be retained in the septic tank before being transported to the soak-away unit or drainfield. It is usually taken as 24 hours.
d) **Desludging Period or Frequency Removal of Sludge and Scum (N):** This is the number of year(s) between each removal of the sludge and scum from the septic system. It is usually taken as 1 year for developed countries, 3 years for developing and 5 years and more for undeveloped countries.
e) **Rate of Sludge Accumulation (S):** This is the quantity of sludge that accumulates after decomposition has occurred over a given period of time. This depends on some factors such as diet condition of each individual, the standard of living of each country etc.
f) **Sizing factor (F):** Sizing factor is a factor relating to the ambient temperature. The digestion process occurs less readily at lower temperatures. At temperature more than 20 ºC throughout the year, the sizing factor ranges from 1.0 – 1.3 depending on the period of desludging. At temperature less than 20 ºC throughout the year, the sizing factor ranges from 1.5 – 2.5 depending on the period of desludging also.

Design Calculation (Using statistics of household in developing countries as case study)

[12] carried out a study on population distribution of household by sizes in Nigeria, it was affirmed that the average number of people living in a household in Nigeria ranges from 2 to 6 persons. Based on this study carried out, this design calculation takes into consideration the maximum number i.e. six (6) people with full plumbing facilities that includes the bathroom wastes, toilet wastes, kitchen wastes. Other forms of sanitary facilities that are installed for luxury and aesthetics purpose are excluded in this design.

Two codes of practice are considered namely the British standard code of practice and Indian standard code of practice for design and construction of septic tanks.

The British Standard Code of Practice gives the capacity (C) in litres, as

C = 180P + (values between 1000 – 1500), (1)

Where: P is the contributing population

The formula used in the Indian Standard Code of Practice gives the capacity (C) in litres, as the summation of the volume of the clear effluent after settlement (V_L) and volume of the sludge and scum deposited (V_S) [13].

Unlike the British formula, the Indian system allows for the rate of sewage flow, the rate of sludge accumulation, the frequency of sludge removal and the effect of surge due to simultaneous discharge from sanitary fixtures to get the capacity of the whole system [14].

Assumptions

For proper design, some assumptions were used based on past designs found in literatures.

i. The effluent minimum retention time is never less than a day.
ii. The quantity of water used per person per day for kitchen use, bathing, urinating and defecating is 75 litres
iii. De-sludging period is taken as 5 years interval
iv. Rate of sludge accumulation is taken as 70 litres per person per annum. (This value was selected based on the diet of an average African adult which results in him passing out 300 – 500 g of feaces per day under normal circumstances).
v. Sizing factor is taken as 1 as it relates with the ambient temperature. Digestion process occurs less readily at lower temperatures and so the effective capacity for sludge storage has to be increased.

Using the British Standard Code of Practice formula, we have the capacity to be 2580 litres (2.58 m^3) while using the Indian Standard Code of Practice formula give capacity of 2550 litres (2.55 m^3).

Comparing the two formulas used to get the capacity of the system, the Indian system of design was selected for further calculation owing to the fact that, the British formula only considers the contributing population as its only parameter. Calculation was done further to get both the depth and diameter of the septic tank unit and the soak away unit using necessary equations as specified by the Indian code. Precast rings and cast in-situ was used as walling material in both units.

Probable Biogas Volume Estimation

The volume of biogas that can be produced varies from waste to waste. According to [4], the biogas production potential human waste varies from 0.068 – 0.085 m^3. In determining the amount of biogas that can be generated from the effective volume (i.e. total capacity) of the septic system, the density formula in Equation 2 is used to calculate the total mass of the effluent, sludge and scum in kg.

$$\text{Density} = \frac{\text{Mass}}{\text{Effective Volume of Septic System}} \quad (2)$$

Potential Electricity Generation Estimation

The potential electricity generation estimation was done using a model developed by [15]. Electricity generation was modeled by taking the estimated biogas production and assuming it was used in an engine-generator set, with a capacity factor of 0.95 and conversion efficiencies output of 200 kW. In addition, 25 % of the output of the engine-generator was assumed to contribute to operating the conversion process of the system itself known as parasitic load [15]. Considering the total biogas generated per day and the calorific value of biogas, it can be estimated that the amount of electricity (E) generated per day will be the product of the biogas produced per day (B), the calorific value of biogas (C), the capacity factor of the engine-generator set (F) and the 25 % of the generator conversion efficiencies output (O) (Equation 3).

$$E = B \times C \times F \times O \quad (3)$$

2-D and 3-D Engineering Drawings of the Redesigned Septic System

The engineering drawings (both two and dimensional) were drawn based on the design calculation carried out. Other dimensions used for the drawings are based on the dimensions of the locally fabricated precast rings produced here in Nigeria. The 3-Dimensional drawings help appreciate the design and assist in any further construction and test work.

4.0 RESULTS AND DISCUSSION

Design Calculations Results

From the computation carried out, the values gotten for both the septic tank and soakaway units are shown in Tables 1 and 2.

Table 1: Summary of the precast and cast in-situ septic tank dimensions

S/N	Parameters calculated	Results	units	Results	Units
		Precast		Cast In-situ	
1	Effective volume of septic tank	1.70	m^3	1.70	m^3
2	Depth of the septic tank	4.90	m	2.80	M
3	Diameter of rings	0.70	m	0.92	M
4	Number of rings needed	8	Nos	Whole units	Nos
5	Height of the precast ring	0.6	m	2.80	M
6	Thickness of the precast ring	0.15	m	0.15	M

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Table 2: Summary of the precast and cast in-situ soakaway dimensions

S/N	Parameters calculated	Results	units	Results	units
		Precast		Cast In-situ	
1	Infiltration Area	13.64	m^2	13.64	m^2
2	Depth of the soakaway	4.25	m	2.46	M
3	Diameter of rings	0.70	m	0.92	M
4	Number of rings needed	7	Nos	Whole units	Nos
5	Height of the precast ring	0.6	m	2.80	M
6	Thickness of the precast ring	0.15	M	0.15	M

From Tables 1 and 2, there are some variations in the values gotten as a result of different techniques employed in the design. Table 1 present both summary of the precast and cast in-situ septic tank dimensions. It can be observed from the table that with the same effective volume, the precast septic tank has a deeper depth of 4.90 m than that of the cast in-situ septic with 2.80 m, but with a less diameter of 0.70 m. Also, the thickness of wall ring considered for both systems are the same. Table 2 present both summary of the precast and cast in-situ soakaway dimensions. It was also observed that with the same infiltration area for both systems, the precast soakaway has a higher depth of 4.25 m but a lesser diameter of 0.70 m while the cast in-situ soakaway system has a smaller depth of 2.46 m but a higher diameter of 0.92 m. The results indicate an inverse relationship between the depth and the diameter of both units.

Engineering Drawings

The two-dimensional was drawn using values from Tables 1 and 2 to show the plans, sectional elevations and ring details for both the precast septic system and the cast in-situ septic system. They are presented in Figures 6 to 8. The drawings show the house from where all the wastes flow from via the inlet/receiving pipe of 150 mm diameter buried inside the soil into the septic unit. Sedimentation and digestion processes will occur thereafter inside the unit. In the process, the wastes form into three different layers namely the sludge (the solid matters), the effluent (the liquid waste) and the scum. The cover of both septic units have on them the inspection holes for carrying out maintenance work and gas outlets via which the gases coming out can be trapped, gas collector chamber for collecting the gas, pressure gauge for recording the gas pressure, thermometer for measuring the septic tank surrounding temperatures and de-sludging pipe for removing the sludge when the septic tank has exceeded the active volume level.

The outlet pipe receives the effluent from the septic unit after it has reached about two-third of the unit and the flow is done by gravity into the soakaway unit. The soakaway unit just like the septic unit also has a gas outlet pipe attached to its cover. The gas outlet for the soakaway unit was linked with the septic unit gas outlet to trap any gas escaping from the septic unit into it. Both were then passed into the gas collector chamber.

The Gas Collection Mechanism

The amount of gas evolving from the septic system is of interest in this study. Since most gases have small densities, it is usually not practicable to collect the gas and find its volume. For gases that are not particularly soluble in water, it is possible to collect the evolved gas by displacement of water from a container. The setup for the collection of biogas over water involves a big rubber container and a transparent gas collection calibrated plastic container filled with water to a certain level and inverted inside the big reservoir of water inside the rubber container. The gas to be generated will be collected by attaching one end of a pipe to the container and inserting the other up into the inverted gas collection calibrated plastic. Weights are placed in equilibrium state on the calibrated plastic containers to hold in the inverted position. As the biogas is generated, it will displace water from the plastic. The volume of biogas generated can be determined by the amount of water displaced by the biogas inside the calibrated plastic container (Figures 7 and 8).

The Electricity Conversion

The biogas generated will be passed into the electrical engines for power generation (which will be procured). Two engines can be used for the gas to electricity conversion depending on the choice of the designer viz the internal combustion engine coupled with the generator and the fuel cell engine. The engine generator set is the internal combustion engine which uses the biogas generated from the septic system as fuel while stacks of fuel cells generates reasonable amount of direct current (DC) electricity [16].

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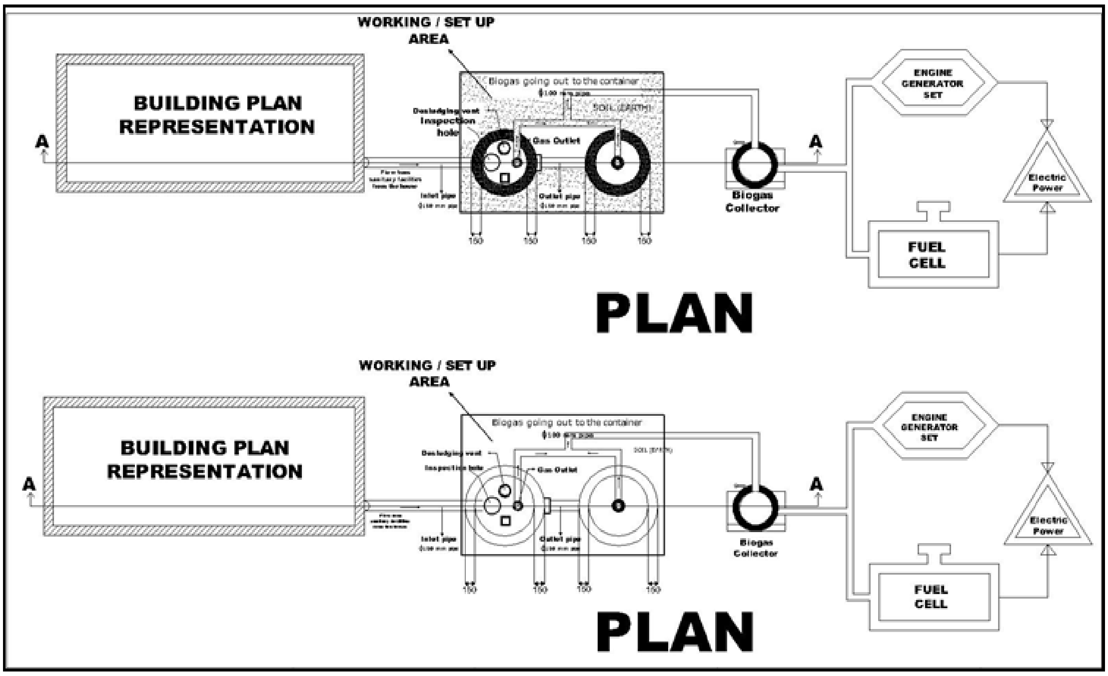

Figure 6: Plan views of the precast and in-situ circular septic system

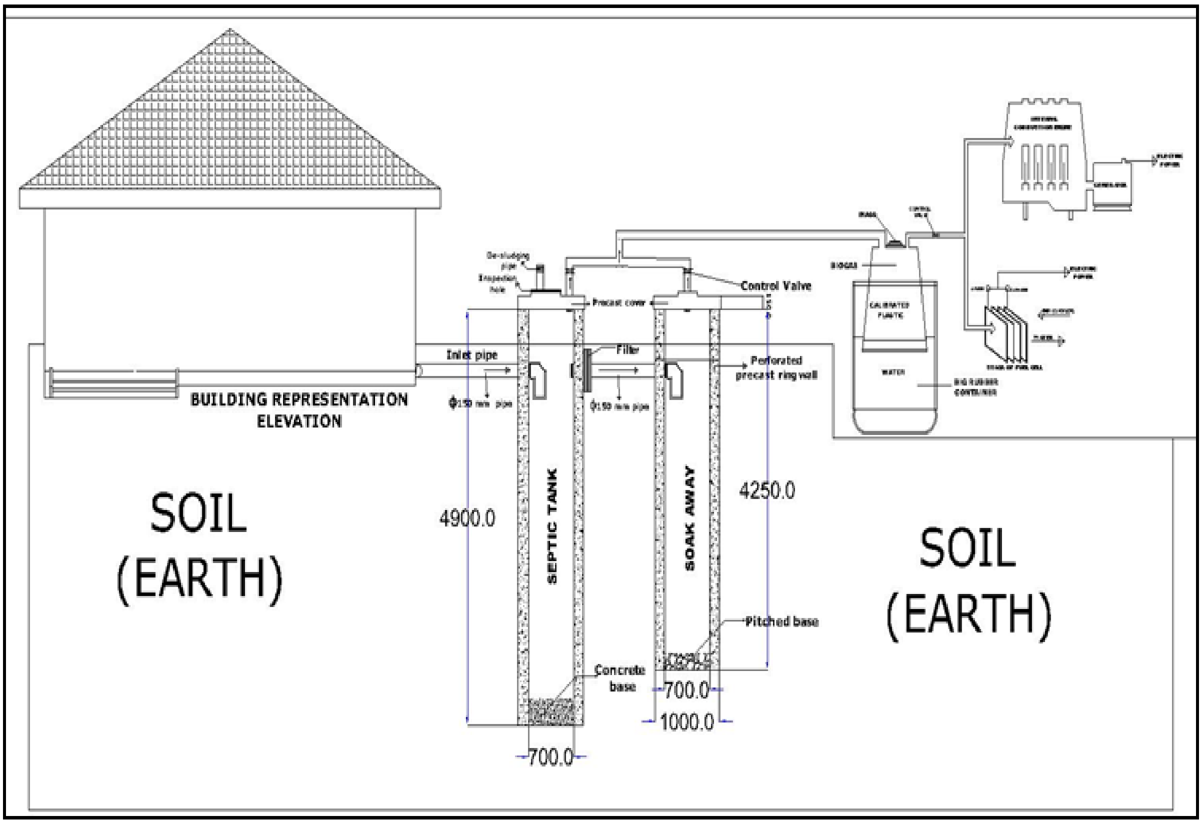

Figure 7: Sectional view of the precast circular septic system

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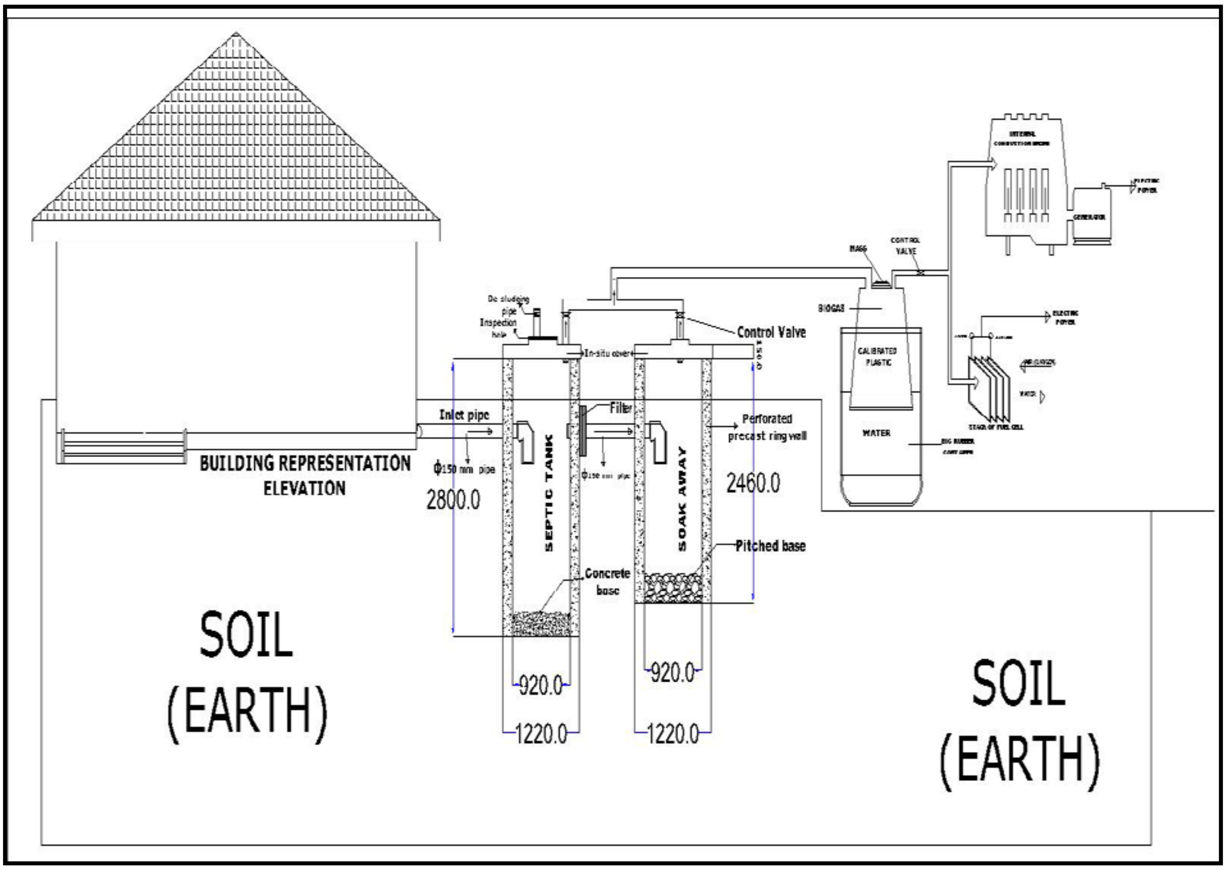

Figure 8: Sectional view of the in-situ circular septic system

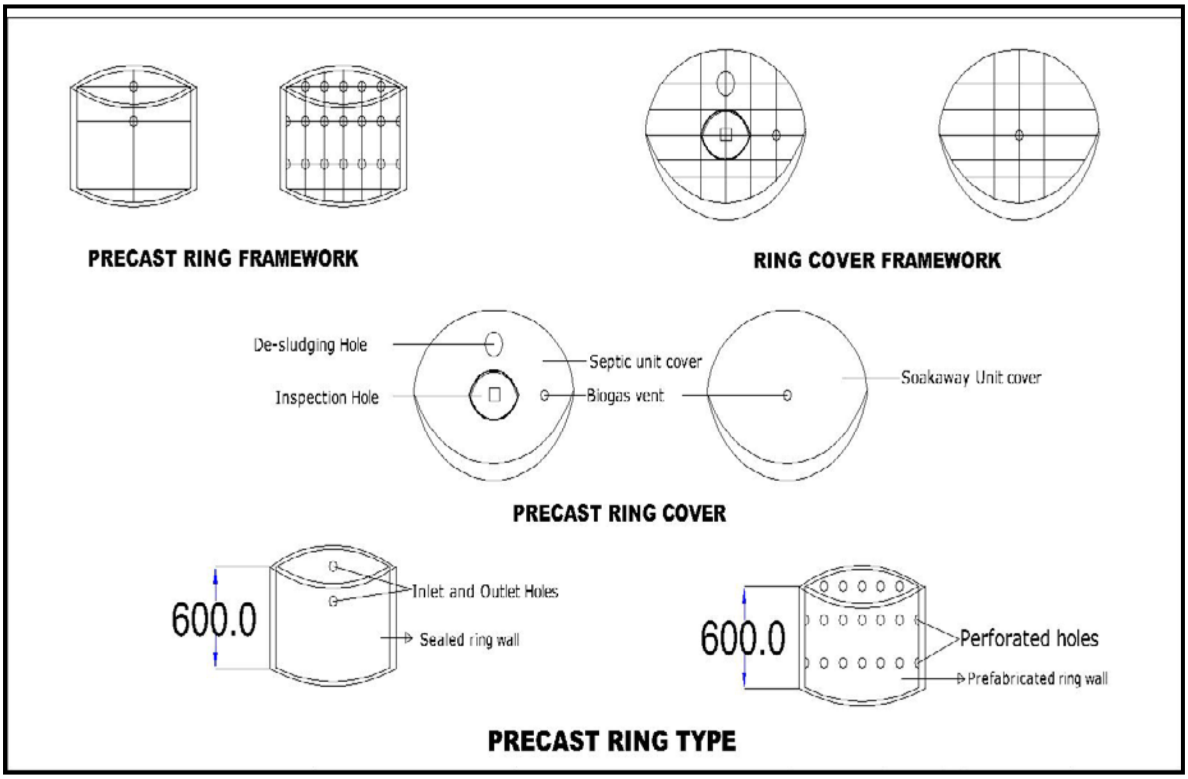

Figure 9: Precast ring details of the circular septic system

Three-Dimensional Modeling

The three dimensional drawing of the circular septic system was prepared using Autodesk Inventor 3D CAD to give a better view and perspective to prospective installers or constructors. Figure 10 shows the labelled sectional view of the system.

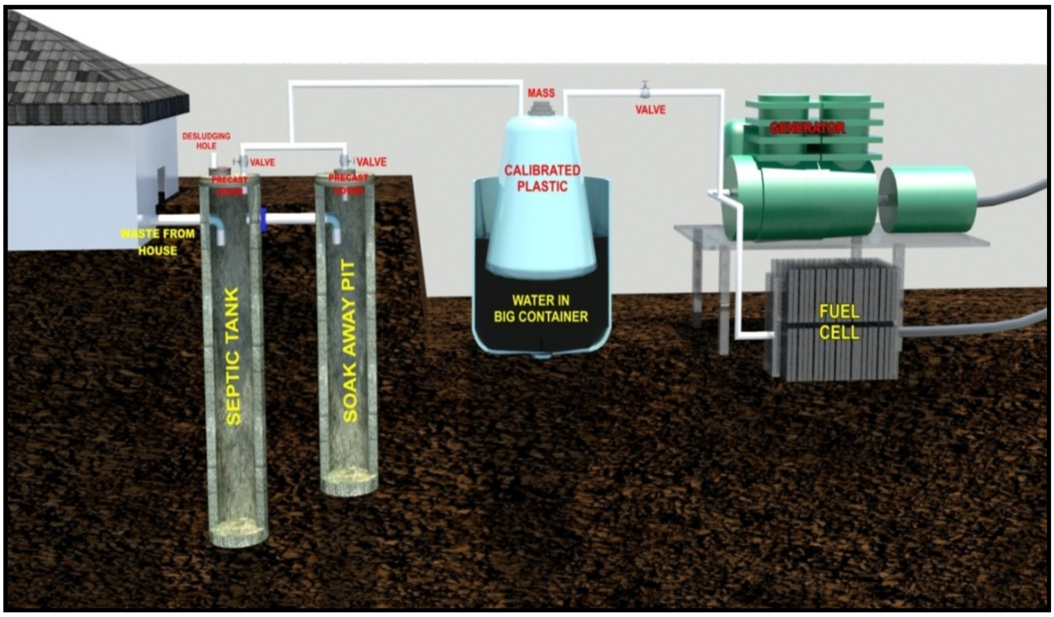

Figure 10: Sectional view of the 3-dimensional drawing

Management of the Modified Circular Septic System

Prospective and current septic system owners and users must ensure that their systems are maintained properly. Even a well-designed and properly operating septic tank system will eventually fail if it is not also maintained. Regular maintenance can prevent failures such as clogging of the septic tank inlet and outlet pipes and sewage backup into the home.

To guarantee the normal and safe performance of the redesigned septic system for electricity generation, owners/users of the system should undertake the following maintenance procedures as follows:

i. The septic tank should be pumped out at least once every three to five years depending on the tank size, amount of solids entering the tank, and habits of the users to prevent clogging of the soil surrounding the soak away receptacles.
ii. When the septic tank is de-sludged, it should not be washed or disinfected in order to continue the digesting process when the tank is put into use again. A small quantity of sludge must be retained to serve as a starter.
iii. The junctions and valves should be checked regularly to prevent leakage and in case there is any leakage, appropriate material should be used to seal it.
iv. Septic tank non-safe products such as cigarette butts, sanitary napkins and disposable diapers that do not easily degrade and which can also clog the septic inlets/outlets pipes should be avoided.
v. Leakage of biogas around the covers and gas distribution tank should be checked regularly to prevent loss of biogas which is the essence of the redesign.
vi. Electricity generating machines should be serviced regularly to prevent sudden breakdown of the system.

5.0 CONCLUSION

A modified/redesigned circular septic system for electricity generation has been considered in this study. Three major stages of work were carried out namely the design calculations, two dimensional engineering drawings and three dimensional engineering rendering to bring out a better view after being constructed. This improved circular septic system design can now be adopted and used instead of the old system so as to recover methane gas purposely from household wastes for electricity generation and other economical uses. This on the long run will shield the environment from greenhouse gases effect.

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