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# Research Article
# Engineering Design of Combined Septic Tank with Treatment Facilities for Partial Treatment of Wastewater

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## Abstract
**Background and Objective:** There are some wastewater treatment technologies using septic system, thus bringing about various designs which make most conventional septic tanks majorly serve the purpose of treating wastewater only to a safe level before its disposal. The present work, therefore aimed to depict engineering design of a rectangular septic tank attached to some treatment facilities to partially treat wastewater and also perform other pertinent functions. **Materials and Methods:** Two major processes were employed as dimensions needed for the proper drafting of the whole system were first calculated for using relevant standards and established figures from texts. Thereafter, AutoCAD and Autodesk Inventor were both used to render and model the two and three dimensional engineering drawings of the whole system combined together. **Results:** The results revealed that all the values gotten for each of the facility calculated for fall within the recommended values provided by relevant agencies. Taking for instance, the septic and sedimentation tank, the length to width ratio gotten is 2 and 3.5, respectively and falls between recommended range of 1.5-7.5. Also, the surface loading of the latter was gotten to be 12 $m^3$ $day^{-1}$ $m^{-2}$ which is less than the maximum recommended value of 40 $m^3$ $day^{-1}$ $m^{-2}$. All these results also agree with past similar research. The engineering drawings (both two and three dimension perspective) have clearly revealed the possibility of the conceptualized idea of the whole system to partially treat wastewater and perform other functions. **Conclusion:** This design is now an alternative technology in wastewater treatment and can be adopted to supplement water demand of places with limited access to water.

Key words: Septic tank, wastewater, treatment facilities, engineering, system

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

## INTRODUCTION

The innovation of septic tank was accredited to John Louis Mouras, a Frenchman 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[1]. Since discovery, septic systems have been an effective means of receiving all the waste discharged from buildings including wastewater (both domestic and industrial) and the wastes are retained in it for several years[2,3]. Septic systems are underground wastewater treatment structures, commonly used in rural areas without centralized sewer systems. A typical septic system consists of a septic tank and a drain field or soil absorption field[4]. According to Modi[5], septic tank is a combined sedimentation and digestion tank where sewage is retained for one day to two days.

As discoveries increases in science and technology, septic tank was discovered (not just as ordinary waste collectors) but can serves other functions like acting as digester where waste are decomposed to produce some mixture of gases since the condition in which the system is subjected to when in operation is anaerobic[6], as fertilizer raw material centre, since the remaining sludge and scums after decomposition could be extracted for fertilizer production and as a means of partially treating effluents entering into it, if properly connected to some treatment facilities which in turn reduced its toxicity to a safe point level[7,8]. This latter concept will help supplement water supply through treatment techniques where there are water scarcity in some parts of the world.

ASCE[9] defined wastewater as 'spent or used water of a household, community or industry which contains dissolved and suspended matter'. Wastewater is also water whose physical, chemical or biological properties have been changed as a result of the introduction of certain substances which render it unsafe for some purposes such as drinking. It consists of storm water runoff, industrial effluent and domestic wastewater[10]. Waste water can be collected by a reticulated sewage system and treated at a conventional wastewater treatment plant. Alternatively, it can be collected, treated and re-used on-site, thereby promoting more efficient water use[8,11]. Liquid wastes from industrial and domestic sources must first be treated to remove the bulk of contaminants before disposal or reuse, otherwise problems arise when excessive quantities of pollutants change the pH, increase bacterial growth and deplete dissolved oxygen resources[12].

The septic tank digests organic matter and separates floatable matter (e.g., oils and grease) and solids from the wastewater. Soil-based septic tank systems discharge the liquid (known as effluent) from the septic tank into a series of perforated pipes buried in a leach field, chambers, or other special units designed to slowly release the effluent into the soil. Alternative systems use pumps or gravity to help septic tank effluent trickle through sand, organic matter (e.g., peat and sawdust), constructed wetlands or other media to remove or neutralize pollutants like disease-causing pathogens, nitrogen, phosphorus and other contaminants[4]. Some alternative systems are also designed to evaporate wastewater or disinfect it before discharge. Gradually, this trend of septic tank design is changing as adequate effort must be made in order to fulfill one of the sustainable development goal which is 'Ensure availability and sustainable management of water and sanitation for all'. Unfortunately, this has been on the contrary as most areas worldwide are still with low water supply while others are without it. Nasr and Mikhaeil[13] reported that septic tanks may be used alone or in combination with other processes to treat raw wastewater to some certain degree as the tank itself provides primary treatment by creating inactive situation inside a covered, watertight rectangular, oval or cylindrical container, which is typically buried. Lasisi *et al.*[3] described a similar situation in their research which centres on redesigning of circular septic systems for energy generation and as irrigated farm water supply source. Therefore, the objective of the study is to present an engineering design of a combined rectangular septic tank with some treatment facilities to partially treat wastewater and also perform other pertinent functions.

## MATERIALS AND METHODS

This study was carried out at the Postgraduate Central Research Laboratory of the Federal University of Technology, Akure from April-September 2018. Computer software programs were the major tools used and they include AutoCAD (Version 12) and Autodesk Inventor 3D CAD (Version 15). Other devices used are laptop, scientific calculator and design sheet. The research overall duration was for six months.

**Design summary:** Septic tank schematically designed in this study is a rectangular shaped tank that received all wastewater and slurry from a household having full plumbing system. The effluent from the combined constituents that flowed from the plumbing system into the septic tank (Fig. 1) leaves the tank into the treatment system unit which was designed to receive the effluent for further treatment before discharging it in to a service point for reuse. The septic tank is assumed to serve few colonies of houses whose plumbing system are all connected to the same disposal system such as hostels or residential quarters. The sludge in the septic tank continuously undergo anaerobic digestion process and generate biogas which could be used directly for cooking or be converted to electric energy through fuel cell or other scientific means. The slurry is also collected at regular intervals depending on the rate at which the septic tank get filled up. The slurry which contains nutrients and valuable trace elements essential to plants will be used as inorganic and mineral fertilizers.

**Design operation of the system:** The septic tank is designed to perform the function of energy generation, partial wastewater treatment and production of fertilizer from slurry for agriculture. As wastewater enters the tank, the rate of flow is reduced and heavy solids settle, forming sludge, grease and other light solids rise to the surface of the septic tank forming scum. The clarified liquid is then discharged to the treatment units which consist of sedimentation tank, aeration chamber, chemical mixing chamber, clear water tank and service tank for further secondary treatment processes. Figure 2 shows the flow diagram of the treatment processes.

**Septic tank design:** The capacity of the tank required is governed mainly by the number of people it serves and desludging interval. Indian Standard Code of Practice[14] 2470 gives the capacity of the tank as the summation of the volume of the clear effluent after settlement and volume of the sludge and scum deposited excluding freeboard. However, to achieve an appropriate capacity of this tank, some valid assumptions were made based on assertions made by some authors and agencies[5,15,16] and they are as follows:

- Tank will serve 200 persons
- Minimum daily consumption is 110 L per person per day
- Sewage flow is taken as 85% of daily consumption
- Minimum detention of the daily inflow is 24 h
- Sludge/scum accumulation rate is 70 L per person per year
- Desludging period is taken as 4 years interval

**Capacity of the tank:** The effective volume ($V_E$) of the septic tank in litres is calculated by adding volume of the clear effluent after settlement ($V_L$) and volume of the sludge and scum deposited excluding freeboard ($V_S$) as shown in Eq. 1:

$$V_E = V_L + V_S \quad (1)$$

$$V_L \text{ (L)} = P \times Q \times t$$

Where:
P = Number of users
Q = Sewage flow in litres/cap/day
t = Detention period in days

$$V_S \text{ (L)} = P \times N \times S$$

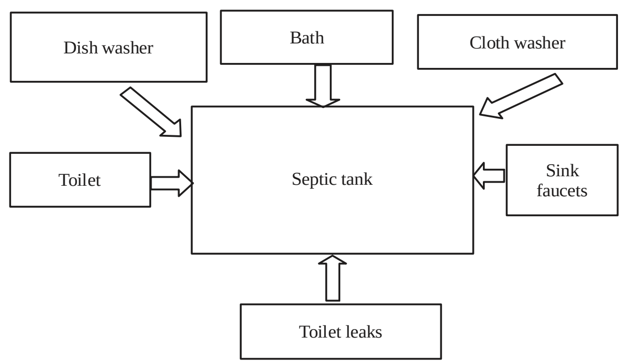


Fig. 1: Sewage inflow system

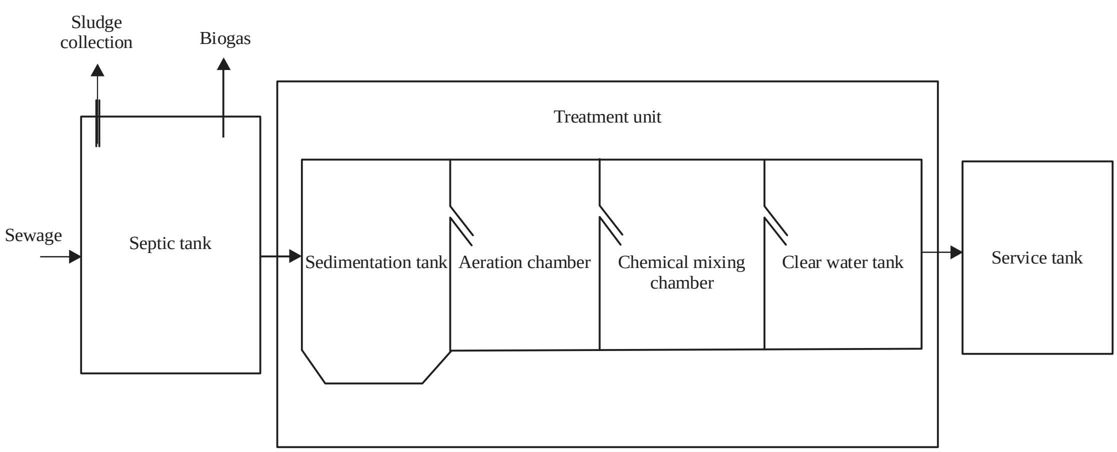


Fig. 2: Flow diagram of the treatment process

Where:

P = Number of people using the tank
N = Period between desludging in years
S = Sludge and scum accumulation rate in litre/year

The dimension of the tank was calculated by assuming the liquid depth to be 3 m (excluding free board), the surface area (A) which is product of the width (W) and length (L) is calculated using Eq. 2:

$$A = \frac{VE}{3} \tag{2}$$

Ratio 2:1 was used as length to width ratio to get the length and width of the septic tank.

**Potential biogas volume and power generation estimation:** The volume of biogas that can be produced varies from waste to waste. According to Mawufemo[8], the biogas production potential human waste varies from 0.068-0.085 $m^3$. To determine the amount of biogas that can be generated from the effective volume (i.e., total capacity) of the septic tank, the density formula in Eq. 3 is used to calculate the total mass of the effluent, sludge and scum in kg. Sharmin *et al.*[17] discovered that the density of human faeces is approximately the same as that of water in Eq. 3:

$$\text{Density} = \frac{\text{Mass}}{\text{Effective volume of septic system}} \tag{3}$$

The potential electricity that can be generated from the system was estimated using a model developed by Jewel[18] 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. 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) (Eq. 4):

$$E = B \times C \times F \times O \tag{4}$$

**Sedimentation tank design:** The design of the sedimentation tank was done following the methodology proposed by Modi[5]. The following steps are required in the design:

- Calculate the surface area
- Select the number of tanks
- Select a trial width for calculation and check length to width ratio; i.e. L:W
- Select a trial depth and check the length to depth ratio
- Assume/select a velocity of flow
- Design the launders at the specific intervals within the tank
- Check the weir loading rate

The following design considerations/assumptions are made:

- Detention period (for plain sedimentation) is between 3-4 h
- Velocity of flow should not be greater than 30 cm $min^{-1}$ (horizontal flow)
- Length to width ratio of the sedimentation tank is 1.5:1 to 7.5
- Surface overflow rate (for plain sedimentation) is between 12000-18000 l/d/$m^2$ tank area
- Floor of tank should be provided with a slope of 1% from the outlet end towards the inlet end

**Aeration chamber design:** The aeration tank is at the heart of the treatment system as bulk of the treatment occurs there by employing microbes/bacteria for the process. The main function of the aeration tank is to maintain a high population level of microbes. The design of aeration chamber combined the methodology proposed by some researchers and agency[19-21].

The parameters used for the sizing and operation calculations are given as follows:

- $Q_o$ is the primary effluent flow rate ($m^3$ $day^{-1}$)
- So is the primary effluent biochemical oxygen demand (BOD) concentration, (mg $L^{-1}$) (or g $m^{-3}$)
- V is the aeration tank volume ($m^3$)
- X is the aeration tank MLSS (suspended solids conc.) (g $m^{-3}$)
- F:M is the food to microorganism ratio, (kg BOD $day^{-1}$ $kg^{-1}$ MLVSS)
- HRT is the hydraulic retention time (h)
- VL is the volumetric loading (kg BOD $day^{-1}$ $m^{-3}$)
- Vol. (%) is the volatile solids (%) in the aeration tank mixed liquor suspended solids

Volumetric loading, food to micro-organism ratio (F:M) and hydraulic residence time (HRT) usually has typical value of 0.3-0.7, 0.2-0.4 and 4-8, respectively for determining the size of activated sludge aeration basins conventional plug flow activated sludge process.

**Engineering drafting of the whole system:** The engineering drafting showing both the two and three dimensional of the septic tank system, sedimentation tank, aeration tank, chemical dosing chamber and the clear water tank were drawn based on the design methodology adopted. The 3-Dimensional drafting helps the design aesthetically and gives it a better view of construction.

## RESULTS AND DISCUSSION

The dimensions obtained for the septic tank system, sedimentation tank and the aeration units are summarized in Table 1 and 2.

**Engineering drafting and modeling:** The plan and section view of the whole system are presented in Fig. 3 and 4 while the three dimensional model prepared using Autodesk Inventor 3D CAD are presented in Fig. 5 and 6.

The dimensions obtained for both the septic system and sedimentation tank in Table 1 revealed that the design is adequate for communities and areas with up to 200 users as they fall within acceptable range provided in EPA guidelines manual. For the sake of structural stability in the design, the septic tank was reinforced at all the corners and at the midpoints of the longer side of the tank. For the sedimentation tank, some assumed parameters were used to derive other such as quantity of sewage to be treated, the capacity/volume of the tank, the area of flow section and the length and width of the tank. The length to width ratio was gotten to be 3.25 which is okay, as it falls between the recommended range of 1.5-7.5, also the surface loading (overflow rate) of the tank was gotten to be 12 $m^3$ $d^{-1}$ $m^{-2}$ which is less than the maximum recommended value of 40 $m^3$ $d^{-1}$ $m^{-2}$. These results falls with in the range of values given by the United State Environmental Protection Agency (USEPA)[22] and similar to those obtained by Ajibade *et al.*[23]. The effective volume of the aeration tank was obtained. The assumed depth was used to derive the length and the width of the aeration tank using a length to breadth ratio of 1.5:1.

Table 1: Septic tank and sedimentation dimensions

| Parameters considered | Septic tank | Sedimentation | Units |
|---|---|---|---|
| Effective volume of tanks | 74.70 | 9.30 | $m^3$ |
| Depth of the septic tank | 3.00 | 2.10 | M |
| Length of septic tank | 7.00 | 4.50 | M |
| Width of septic tank | 3.50 | 1.40 | M |
| Freeboard | 0.40 | 0.30 | M |
| Thickness of the wall | 0.25 | 0.25 | M |
| Surface loading | N/A | 12.00 | $m^3$ $d^{-1}$ $m^{-2}$ |

N/A: Not applicable

Table 2: Aeration tank dimensions

| Parameters considered | Results | Units |
|---|---|---|
| Effective volume of aeration tank | 22.41 | $m^3$ |
| Retention time of aeration tank | 7.20 | Hrs |
| F:M of aeration tank | 0.30 | kg BOD $day^{-1}$ $kg^{-1}$ MLVSS |
| Depth of aeration tank | 2.10 | M |
| Width of aeration tank | 2.70 | M |
| Length of aeration tank | 4.00 | M |

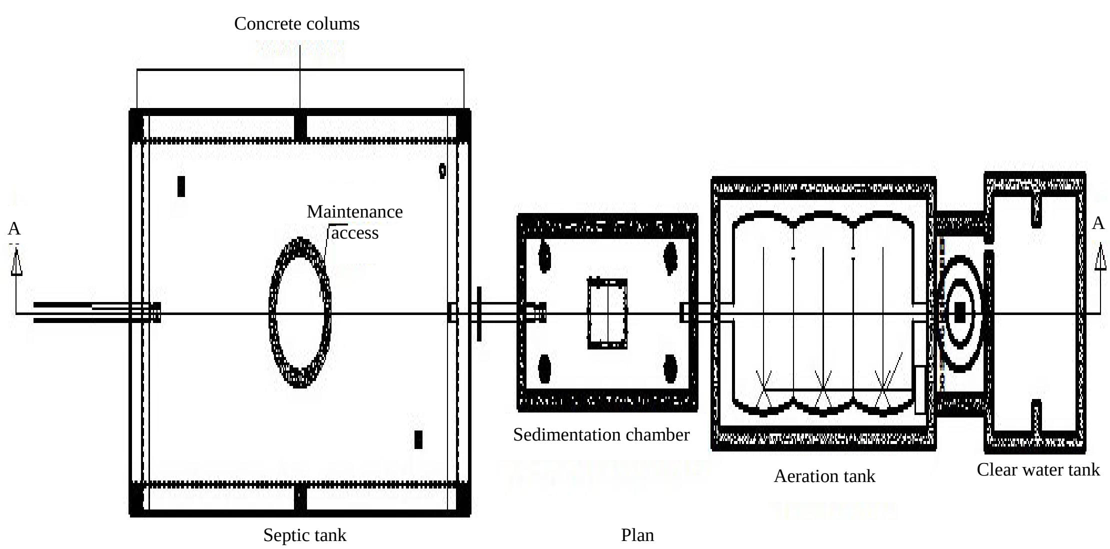


Fig. 3: Septic tank and treatment facilities plan view

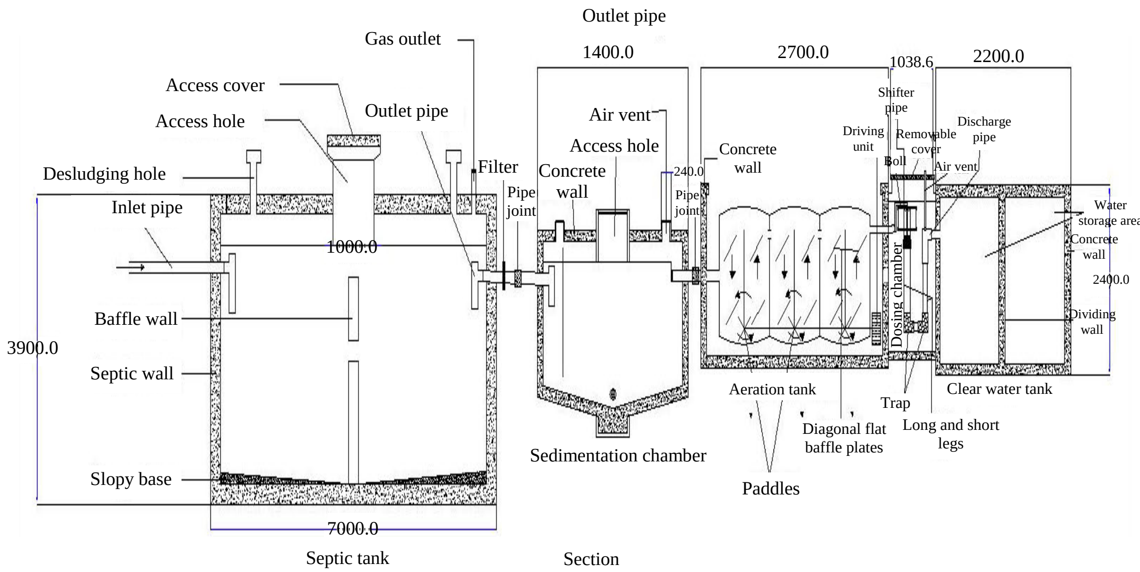


Fig. 4: Septic tank and treatment facilities sectional view

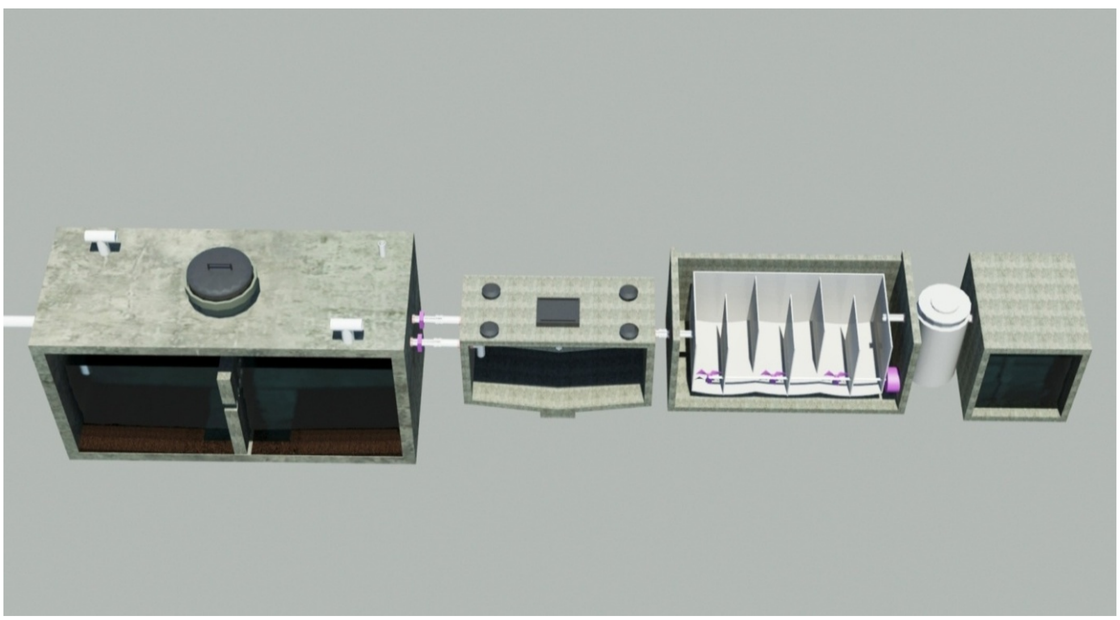

Fig. 5: Septic tank and treatment facilities 3-dimensional view

**Septic and sedimentation system description and operations:** Fig. 3 and 4 showed the engineering drafting of the whole system with each part of the system having a unique function. The septic tank is a receptacle that will receive the mixture of solid matters and wastewater coming from different sewer systems. It is rectangular in shape having an inlet pipe of 300 mm for receiving the incoming waste and an outlet pipe for discharging the wastewater leaving the septic tank into the sedimentation chamber. It also has a baffle wall for separation of solid matter from the wastewater for some period of time. On the top cover of the septic tank is a maintenance access or manhole for carrying out regular maintenance work on the tank when necessary. Also, two desludging holes for removal of the solid matters after some period for fertilizers production and a gas outlet for collecting the gases produced under the anaerobic

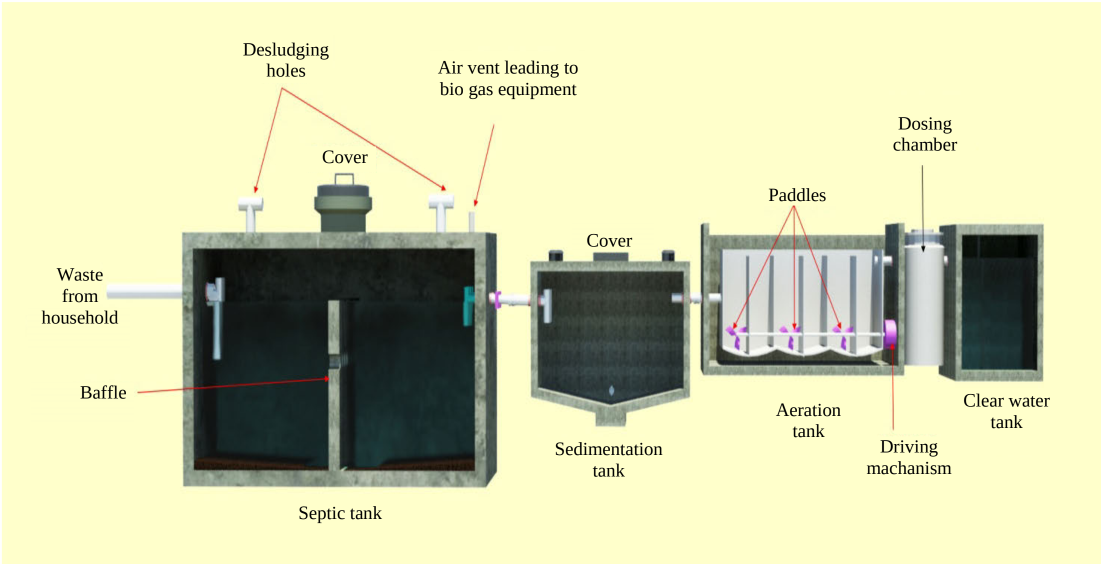


Fig. 6: Well-labeled septic tank and treatment facilities 3-dimensional view

digestion of the solid matter for energy production are both provided. The septic tank wall is made of masonry blocks joined together with concrete columns at the edges and middle to provide the wall with adequate strength. Sedimentation tank is the next chamber and it is connected to the septic tank. This chamber is designed to further separate the suspended particles flowing alongside the effluent from the septic tank heavier than water by gravitational settling. It also helps to remove organic and residual inorganic solids, free oil and grease. Its main primary purpose in this design is to produce a clarified effluent. The wall of the chambers is made of concrete. On the top of the chamber is an access hole for carrying out maintenance work and four circular air vents for trapping air into the system. It also has an inlet and outlet pipe for both entrance and exit of water with suspended matter and clarified effluent, respectively. All these mentioned functions of the designed system are in agreement to those provided in the guidelines by the Pipeline Newsletter Summer Issue of the National Environmental Service Centre (NESC)[16] on 'Home Aerobic Wastewater Treatment: An Alternative to Septic Systems', NEIWPCC[19], Metcalf and Eddy[20] and USEPA[22] Onsite Wastewater Treatment Systems Manual.

**Description and operations of other treatment facilities:** The aeration tank is connected to the sedimentation chamber and it was included in the system to supply oxygen required to meet the demand of the micro-organisms and also provides adequate mixing and agitation so that the mixed wastewater suspended solids are held in suspension and are available for the biological activity. The aeration tank designed and drawn is a mechanically operated aeration tank. It is operated by means of mechanical devices such as paddles to allow the absorption of oxygen from the atmosphere by the continuously changing surface of the wastewater due to agitation. This mechanical aeration is also known as surface aeration. This system is preferred to the diffused air aeration system because it has higher oxygen transfer capacity, absence of air compressors, air piping and filters. The aeration tank wall is made of concrete. It also has long relatively narrow parallel interconnected channels by means of thin dividing walls. At the bends, one end of each pair of channels, partially submerged vertical paddles are provided. The paddles are not truly vertical but are slightly inclined from the vertical and are so arranged that they rotate about vertical shafts. The rotating paddles give a forward movement to the wastewater in the channels and also set up a wave action due to the spiral flow of the wastewater which brings the wastewater in intimate contact with the atmospheric oxygen (Fig. 3, 4). The designed dosing chamber consists of a dosing siphons system. They are useful devices for dosing fixed, finite volumes of liquid at flow rates ranging from some cubic meters per seconds to several hundred cubic meters per second. Modern siphons as used in this design are made of corrosion resistant materials, have no moving parts, require no power source, easy to install and require very little maintenance. They are cost-effective alternative to pumps in many situations, especially in remote areas and other sites where electricity is difficult to obtain. For the clear water tank, a large rectangular reservoir was designed for momentary collection of treated wastewater for storage before pumping it to the elevated storage tank for further reuse. The tank wall of this design is made of concrete and it has a small dividing wall protruding from the centre of the side wall for stability purpose. The whole system connected together is well depicted in three dimensional views (Fig. 5, 6). The engineering drafting and three dimensional modeling follows same trend as those prepared in recent research works carried out[3,8].

The design of septic tank with some connected treatment facilities has been illustrated diagrammatically with sufficient information. The system when adopt constructed can treat wastewater to a reasonable degree as the overall output of the effluent when tested will greatly show significant reduction in polluting constituents present in the wastewater.

## CONCLUSION

The design has shown the possibility of using septic tank in conjunction with some other treatment facilities to partially treat wastewater and in addition get some other benefits like biogas generation during decomposition and fertilizer production from the accumulated sludge after decomposition. Pertinent procedures and operations of the system have been aesthetically presented in drawings for better view. Hence, this design can be adopted by government, public sectors and some private establishments in supplementing water demand of places with limited access to water, epileptic power supply and low crop yields.

## SIGNIFICANCE STATEMENT

This study described a new blend of engineering design of septic tank system with some treatment facilities to explore further the extent of its usefulness in treating water partially. In the process, the multi-functionality of the system to benefit human activities was also brought to light. In this way, the design can be adopted for areas with limited access to water to supplement their demand. Also, energy could be generated from biogas produced in form of heat and electricity through proper conversion. Finally, farmlands where the crop yield is low can immensely benefitted as slurry gotten from the decomposed sludge can be extracted and used as fertilizers to improve crop yield.

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