COMPUTER AIDED DESIGN OF BIOGAS PLANT FOR MODERN ABATTOIRS

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***Abstract*— There has been a considerable number of design works carried out on Biogas plants which are mostly devoid of computer approaches. Therefore, this paper present, modelling and software for the development of a biogas plant for abattoir. The software encompasses sub programmes that check for various conditions that have to be met for satisfactory operation of the plant during service condition. These include the stress or pressure developed with respect to the bearing capacity and strength of concrete. Input required were the number of cattle, sheep and goats slaughtered while output of the software is the design dimensions of the biogas plant. A Modern abattoir was use as a basis for the testing of the software. When tested, the software proved satisfactory for the purpose for which it was designed.**

Keywords- Abattoir waste, Biogas, Modelling and Software

I. INTRODUCTION

Biogas technology as an ecology-oriented form of appropriate technology based on the decomposition of organic materials by putrefactive bacteria at suitable stable temperature, had existed over a long period of time and is being modernized [1]. The recent global energy crises have generated interest in the use of animal waste as energy substitute for fossil fuel. The production of fuel gas (methane) from animal waste in an oxygen free atmosphere is one of the important possible alternatives and could help very much in preventing the indiscriminate cutting of trees and dumping of animal wastes especially in abattoirs. In most abattoirs, there are practices which posses serious health and environmental hazards on the immediate environment[1].

In order to alleviate problems of increasing energy need and environmental hazard caused by indiscriminate dumping of animal waste especially in modern abattoirs, the need for a biogas plant becomes necessary. Animal waste (dung and other visceral components) which can be rich in biogas are being wasted as a result of lack of utilization. According to (Kumar, 1998) biogas production is an alternative for the utilization of the energetic value of organic materials without destroying their manurial value [2]. Therefore the problem is that of production of alternative energy using abattoir waste such that the risk associated with indiscriminate dumping is possibly eliminated.

The gas is valued as a source of energy while the slurry is valued for its fertilizing properties (soil nutrients). Energy content of biogas can be transformed into various other forms such as mechanical energy (for running machines) and heat energy (for cooling and lighting) depending on the need and availability of the technology. Some of the common uses of biogas are: cooking, lighting, refrigeration and running internal combustion engines [2].

Biogas is composed mainly of 50-70 percent methane, 30-40 percent carbon dioxide and low amount of other gases [3]. Biogas is about 20 percent lighter than air and has an ignition temperature in the range of 650~750°C. It is an odourless and colorless gas that burns with clear blue flame similar to that of LPG [4]. Its calorific valve is 20 Mega Joules per meter cube (MJ/m^3) and burns with 60% efficiency in a conventional biogas stove.

A bio-digester can be made of various constructions materials and in different shapes and sizes. Construction of this structure forms a major part of the investment cost. Some of the commonly used designs are; floating drum digester, fixed dome digester deenbandhu model [5],bag digester plug, flow digester [6] and anaerobic filter [7].

Design, planning, and bills of engineering measurements presentation are not only time consuming but are also error prone which indirectly leads to high labour costs and delays. However, performing it with a software design can reduce the labour costs and time consumptions [8].

This study seeks an alternative source of energy as a supplement to the conventional fossil fuel products with the aim of designing a computer program (software) for a biogas plant of an abattoir.

II. MATERIALS AND METHODS

A. *Materials*

Biogas yield from biodigestion depends on the substrate composition, type of substrate, retention time and biodigester conditions. The composition of biogas generated should be determined before usage as fuel in internal combustion engines due to the consequence of traces of hydrogen sulphide. However, the situation where the biogas will be substitute for woodfuel for cooking or heating, the biogas will require no purification as the presence of trace gases will not have any effect on cooking or heating appliances [3].

The three main types of biogas that have been designed, tested are the fixed-domed, floating drum and Puxin digester. A fixed dome plant comprises of a closed dome-shaped digester with an immovable rigid gasholder and a displacement pit, also named 'compensation tank'. The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensating tank. Gas pressure increases with the volume of gas stored, i.e. with the height difference between the two slurry levels. If there is little gas in the gasholder, the gas pressure is low. When gas production starts, the slurry is displaced into the compensation tank. Gas pressure increases with the volume of gas stored and the height difference between the slurry level in the digester and the slurry level in the compensation tank.

Floating-drum plants consist of an underground digester and a moving gasholder. The gasholder floats either directly on the fermentation slurry or in a water jacket of its own. The gas is collected in the gas drum, which rises or moves down according to the amount of gas stored. The gas drum is prevented from tilting by a guiding frame. If the drum floats in a water jacket, it cannot get stuck, even in substrate with high solid content.

The Puxin biogas digester is a hydraulic pressure biogas digester, composed of a fermentation tank built with concrete, a gasholder made with glass fibre reinforced plastic and a digester outlet cover made with glass fibre, reinforced plastic or concrete. The gasholder is installed within the digester neck, fixed by a component; the gasholder and digester are sealed up.

The mesophilic temperature range for biogas production is 20–40 °C and considering the technology to be used at Nigeria which is in the tropics having an annual temperature of 23–32 °C shows that biogas plants will operate well within mesophilic temperature conditions [1].

The choice of the most suitable type of design and whether it should be constructed above or below the ground has to be made in order to decide on the needed materials for the design and development of the plant. Base on the review of literature, the fixed dome digester would be selected due to its benefits in terms of cost, durability and efficiency. Biogas plant constructed above the ground must be made of steel to withstand the pressure within while a plant below the ground can be made of bricks, cement and concrete. Therefore, it is generally simpler and cheaper to build the digester below the ground which also makes gravity feeding of the system much simpler. Maintenance is however more simpler for systems built above the ground. In addition, a black coating will help provide some solar heating.

The choice therefore is that the structure should be built below the ground since an abattoir is under focus and continuous batch feeding can at least be ensured. The materials needed for the construction of the plant below the ground include blocks, cement, stones, sand, woods, PVC pipes, paraffin wax, nails ceiling boards, binding wire and rods amongst others [9].

B. Methods

Many different designs of biogas digesters are available both in small and large scale operations throughout the world. In analyzing the design of the digester for a specific application, it is necessary to know the quantity of materials waste that is obtained from such a site. The temperature that is best suited for maximum biogas production is put at between 30–35°C [10]. Fermentation comes to a standstill when the internal temperature of the digester falls to 15°C. This has to be taken into consideration especially in some areas with tendency of having rainfall for several months in the year. While continuous operation of a plant depends on regular maintenance, maintenance is also dependent on the type of dome in usage, whether it is a fixed or a floating dome. When the floating dome is in use, its maintenance requires daily semicircular rotation of the gas holder to break the scum, and annual painting of the steel gas holders is necessary to protect them against corrosion. The fixed dome requires a lighter maintenance but regular checking for leakage and gas regulation are essential.

In this context, fixed dome below the ground biogas plants have been selected. It can be constructed almost entirely using locally available materials such as clay, brick, cement, bamboo, wooden supports, etc. This design exists in several sizes ranging from 4 to 20 m^3 [11].

In analyzing the design of the digester for a specific application, it is necessary to visit the location and determine the quantity of materials waste that is obtained from such a site. In this case, the Yola modern abattoir was visited over a period of seven days and the number of cattle, sheep and goats slaughtered daily were obtained thus forming the basis for testing of the design.

III. DESIGN SYNTHESIS AND ANALYSIS

A. Design Assumptions

The following design assumptions were made in respect to this study:

- The plant will fail only if the stress due to weight of the mixture exceeds the strength of the concrete.
- A cow produces an average of 10 kg visceral waste, whereas sheep and goat produce an average of 3 kg each.
- The average of these collected over a week gives daily estimated expected quantity.

It is also assumed that 36 kg of mixture occupies $0.03m^3$ capacity of the batch type digester.

B. Theoretical Background of Design

The complete anaerobic digestion of cow dung takes about 8 weeks at normal warm temperature. One third of the total biogas is produced in the first week, another quarter in the second week and the remaining part of the biogas production is spread over the remaining 6 weeks. Gas production can be accelerated and made more consistent by continuously feeding the digester with small quantity of visceral waste daily. This will also preserve the nitrogen level in the slurry for use as fertilizer. If such a continuous feeding system is assumed to be used ,then it is essential to ensure that the digester is large enough to contain all the materials that will be fed through in a whole digestion cycle. One solution is to use a double digester. Some methods of stirring the slurry in the digester is always advantageous: if not essential. If not stirred, the slurry will tend to settle out and form a hard scum on the surface which will prevent the release of biogas.

In hot regions it is relatively easy to simply shade digester to keep it in the ideal range of temperature but cold climate present more of a challenge. The first action is naturally to insulate the digester with straw or wood shavings. After which a layer of about 5~10cm thick, coated with water proof covering may be used. If this still proves to be insufficient in winter, then heating coils have to be added to the digesters.

C. Gas Collection

The biogas in an anaerobic digester is collected in an inverted drum. The walls at the drum extend down into the slurry to provide a seal. The drum is free to move to accommodate more of less gas as needed. The weight of the drum provides the pressure on the gas system to create flow. The biogas flows through a small hole in the roof of the drum. A non- return valve here is a valuable investment to prevent air being drawn into the digester, which will destroy the activity of the bacteria and provide a potentially explosive mixture inside the drum.

IV. MODELING ALGORITHMS

A. Algorithm Considerations

Since the computer program is an engineering analysis its algorithm was based on the conventional engineering approach. The requirements of the system are to be known first and it is based on these requirements that the system is to be analysed and designed. Checking is done to ensure that the plant can operate without failure, the pressure or stress developed must be less than the bearing capacity multiplied by the strength of the concrete and divided by a factor of safety.

B. Design of the Biogas Plant

The design of the biogas plant is the process of determining the correct dimensions and geometry of the digested parameters required to satisfy a given loading condition. This involves the use of model equations; some of the equations are given below :

Total weight of mixture is given by

$$w_t = (w_{vc} + w_{vs} + w_{vg}) \times 2 \qquad (1)$$

The factor 2 is a result of addition of an equal weight of water.

Force due to weight of mixture is

$$F = (av_{nc} \times 10 + av_{ns} \times 3 + av_{ng} \times 3) \times 2 \times 9.8 \qquad (2)$$

Experimentally it was found that 36 kg of visceral mixture would occupy 0.03m^3[1].

Diameter of the digester cylinder is

$$d = \left(\sqrt[3]{d_{cap}}\right)^{1.173} \qquad (3)$$

Volume of digester top dome

$$v_1 = \frac{\left(3r^2 + f_1^{\,2}\right) \times \pi f_1}{6} \qquad (4)$$

Volume of digester cylinder

$$v_2 = \pi r^2 h \qquad (5)$$

Volume of digester bottom dome

$$v_3 = \frac{\left(3r^2 + f_2^{\,2}\right) \times \pi f_2}{6} \qquad (6)$$

Surface area of digester top dome

$$s_1 = 2\pi p_1 f_1 \qquad (7)$$

Surface area of digester main cylinder body

$$s_2 = \pi d h \qquad (8)$$

Surface area of digester bottom doom

$$s_3 = 2\pi p_2 f_2 \qquad (9)$$

C. Determination of Safety in Operation

The mixture will acts on two surface areas; that of the bottom sphere and that of the cylinder hence the designed area will be

$$s_a = \pi d\left(0.5d + h\right) \qquad (10)$$

Pressure will then be

$$P = \frac{F}{\pi d(0.5d + h)} \qquad (11)$$

For safety of the plant without failure, the pressure or stress developed must be less than the bearing capacity multiplied by the strength of the concrete and divided by a factor of safety.

Mathematically

$$P < \frac{b_{cap} \times f_c}{n} \qquad (12)$$

Equating the expressions gives

$$\frac{F}{\pi d(0.5d + h)} < \frac{b_{cap} \times f_c}{n} \qquad (13)$$

D. Algorithm of the Software

The algorithm of the program was:

- Start and Show Main Menu.
- Select from Menu.
- Based on selection go to File, Design, Administrator, Report or Help.

- If File, select Exit to end the program. Return to Main Menu or End.
- If Design, select New to design a new system or select Modify to modify an already designed work. Return to Main Menu.
- If Administrator, select User Password to select type of User and input password. Return to Main Menu.
- If Report, select Report to view/print the bills of engineering measurement of already design work, Return to Main Menu.
- If Help, select About Program to know brief information about the program or select Help Content to open Help content files. Return to Main Menu.

Fig.1. shows the main program flowchart of the software while Fig.2. shows a simplified flowchart of design process.

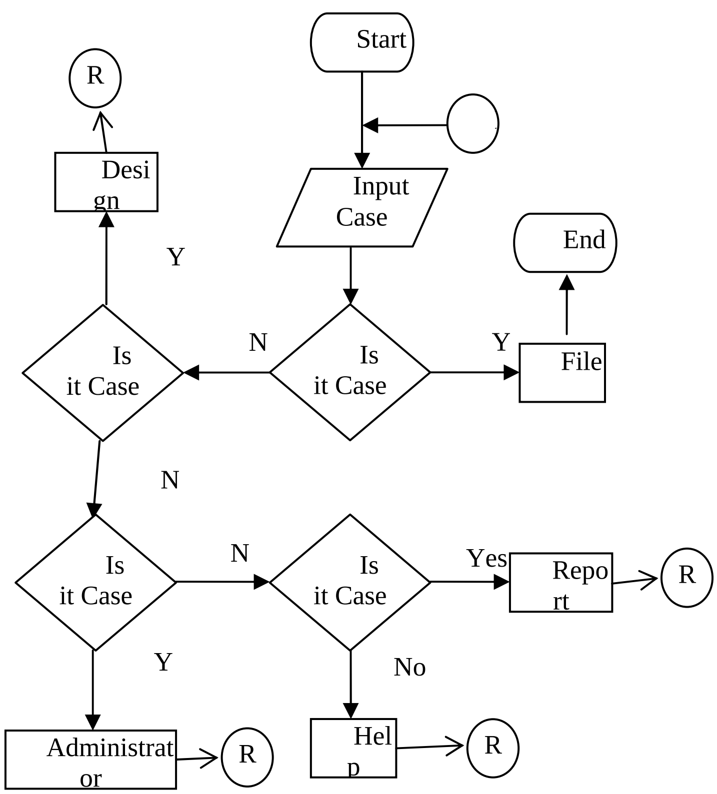

Fig.1. Main Program Flow Chart

<u>Key</u>
Case 1 = File. Case 2 = Design.
Case 3 = Administrator. Case 4 = Report.
Case 5 = Help.

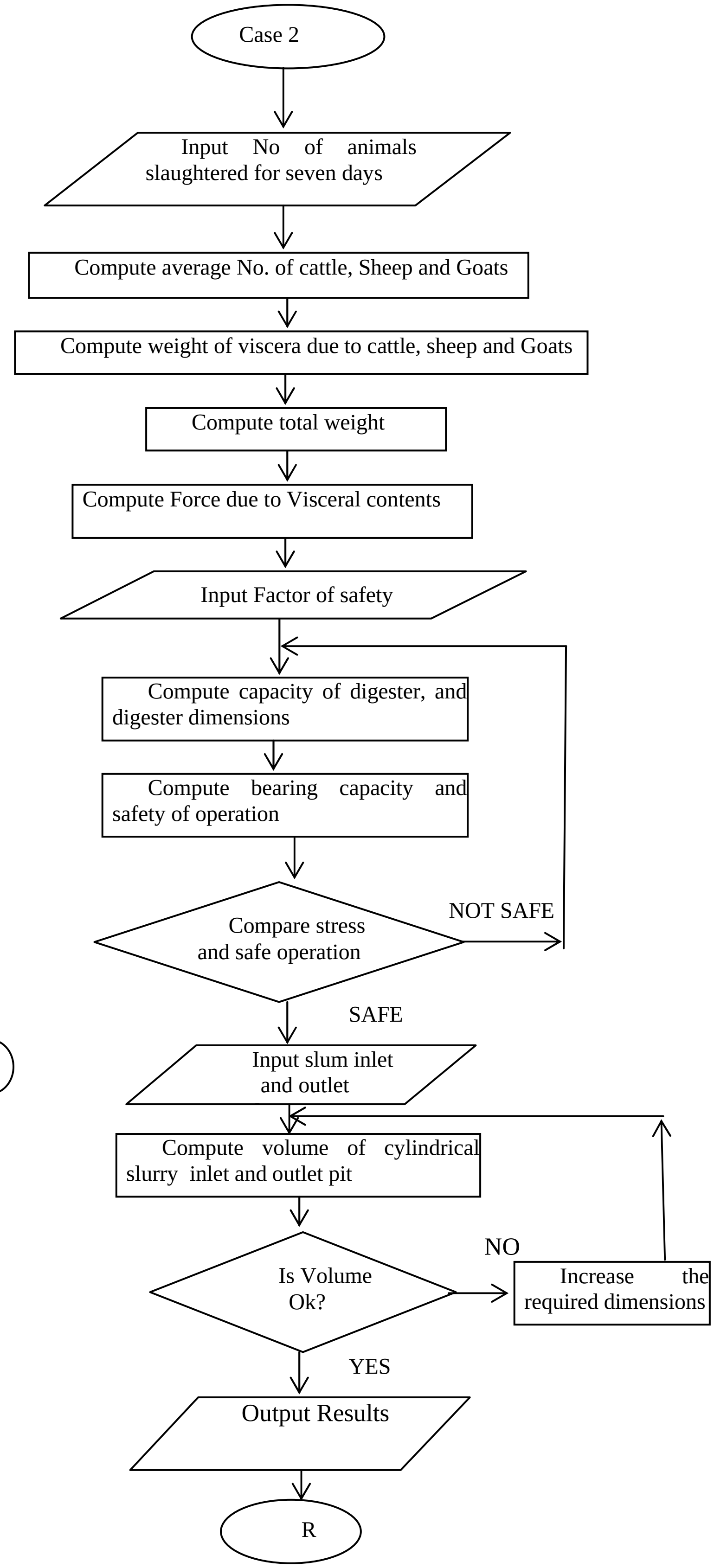

Fig.2. A simplified flowchart of design process.

The algorithm of Design (New) was:

- Input general requirements number of animals slaughtered.
- Compute weight of viscera due to cattle.
- Compute weight of viscera due to sheep.
- Compute weight of viscera due to goats.
- Compute total weight of cattle, sheep and goats viscera.
- Compute force due to visceral contents.
- Compute capacity of the digester.
- Compute Digester Dimensions based on capacity.
- Compute bearing capacity and safety of operation.
- Compare stress and safety operation.
- If above is ok continue else add capacity to digester and recomputed digester dimensions.
- Specify dimensions slum inlet and slurry outlet pits.
- Compute their volumes.
- Safe results.
- Generate Report if required.
- View Report and print if required.
- Return to main menu Show results.

The algorithm of Design (Modify) was:

- Select Name from available database (already designed work).
- Open and re modify data.
- Do same as Design (New).
- Save and Return to Main Menu.

The algorithm of Administrator. (User Password) was:

- Select type of User.
- Input name and password.
- Confirm Password.
- Save and Return to Main Menu.

The algorithm of Report (Design Report) was:

- Select design name from Database (already designed work).
- Select type of bills of engineering measurements.
- View/Print the Report.
- Return to Main Menu.

The algorithm of Report (Prices of materials) was:

- Select type of Material.
- View/Print the Report.
- Return to Main Menu.

The algorithm of Help (Help Content) was:

- Show Help files available .
- Select a file.
- View/Print the file.
- Return to Main Menu.

E. Main Features and Usage of the Software

The software is a menu-driven computer based program. It is a very robust and powerful data handling system for the design of a biogas plant (digester). The use of the software is however not restricted to the design, it can also modify an existing design and store it. It is a comprehensive package designed to be user-friendly it is composed of many sub-routines and forms. These forms are discussed below.

frmAbout: This form gives brief information about the software and the computer.

frmAdministrator: This form checks and allows the administrator to be able to add/modify the database.

frmDesignWork: This form is the one responsible for the design. In essence, it is the most important form. It comprises of many frames and commands that do provide the platform to input data..

frmStartUp: This form gives the user the opportunity to select what he wants to do, i.e either designing a new design or modifying an existing one.

frmClose: This form shows the user that he has end the program.

pop_design_estimate: This is a form that allows the user to select design to show it bills of engineering measurements.

pop_Modify: This form allows for modification of already designed work. It is a link to the database so that when a design is selected it can display the already given parameters which could be modified

The first step in the use of the software is that the designer need to know the total daily number of cattle, sheep and goats slaughtered in a given abattoir over a period of seven days. These values are then inputted on the interface provided by the software during design process. Then the factor of safety will be inputted. The estimated dimensions of the rectangular slurry inlet and cylindrical slurry outlet pit are provided on the interface of the software by the user. The software automatically displays the various design parameters required for the development of the biogas plant.

F. Software Requirements

The Software has the following minimum system requirements:

a) Computer: An IBM-compatible computer with a Pentium class processor of 166 MHz and above.

b) Memory: 64 MB RAM (128 MB or higher recommended).

c) Hard Disk Space: minimum of 40 MB.

d) Video Screen Type: 800 x 600 resolution, 256 colours (High colour 16-bit recommended).

e) Operating system: Windows 98, Windows Me, Windows 2000 and Windows XP.

f) Office Application: The system must have the Microsoft Access installed for the program to function properly.

In addition, peripherals like Laser printer, Ink jet printer or any other type of printer is recommended for producing an output. A zip or flash drive is also recommended to backup the database of this application program.

V. VALIDATION AND CONCLUSIONS

Testing of the software to determine its workability was carried out with the data obtained from the Yola Modern Abattoir in Adamawa state, Nigeria. From the results displayed in Table 1. comparisons of the software parameters indicate that the variation between the actual design and the values obtained from the software falls within the range of -9% to 15%. It can be concluded that the project has been able to demonstrate computer simulation of the design process of a Biogas Plant for modern abattoirs, using a Computer Aided Design program. Similarly, the interactive feature seen in the design process of this nature, has a wide advantage over the traditional manual design method. Thus, many designs of these plants can be completed within the shortest possible time by employing the use of this software.

The software designed also has the facility that will help in documentation since design is saved in a database. When modification is required it can also be done with ease.

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TABLE 1. COMPARISON OF PARAMETERS

S/no	Parameters	Software Design (m)	Actual Design (m)	Variation
1	the digester cylinder body	1.3375	1.4000	4%
2	height of the digester cylinder body	0.8453	1.0000	15%
3	radius of the digester cylinder body	0.6688	0.7000	4%
4	height of the digester top dome body	0.2675	0.2500	-7%
5	radius of the digester top dome	0.9698	1.0000	3%
6	height of the digester bottom dome	0.1338	0.1500	11%
7	radius of the digester bottom	1.7390	1.6000	-9%
8	the total volume of digester	1.4812	1.5000	1%
9	total surface area of the digester	8.1395	8.0000	-2%
10	the volume of rectangular slurry inlet	12.0000	12.0000	0%
11	volume of cylindrical slurry outlet pit	2.6550	2.7000	2%
12	distance of inlet pipe from bottom of digester main cylinder	0.2100	0.2000	-5%
13	distance of outlet pipe from the bottom of the digester main cylinder	0.6340	0.7500	15%