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Design, Construction and Production of Small Scale Energy Generation Plant using Indigenous Resources

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A B S T R A C T

Developing countries like Pakistan are in serious energy crisis. Renewable energy resources are the best alternative for conventional energy sources. The use of indigenous resources to produce bioenergy is an excellent solution to meet the energy needs of developing countries. The aim of the study was to design, construct and production of bioenergy generation from indigenous resources to fulfil bioenergy requirement for electricity, cooking and heating. This research introduces the Best Available Technology (BAT) and bioenergy plant was constructed with local materials at minimum cost to avoid economic burden on bioenergy production cost. An underground bio-digester unit with a volume of 10 cubic meter (7 m^3 bioenergy digester tank plus 3 m^3 bioenergy gas cap/holder) has been installed. The daily feed was approximately 160 kilogram of cow slurry (80 kg cow dung plus 80 litres/kg water). The retention period was approximately 44 days and the reported seasonal temperature was approximately 24°C - 32°C. The unit was thermally insulated, so the fluctuation in temperature was slightly about ±2°C. In experimental setup, indigenous biomass resources were mixed with water in a mixing chamber. Whole mixture enters into digester through the inlet pipe and regularly feed up to selected retention time. Anaerobic bacteria decompose the biomass in the digester and produce bioenergy. A simulation was performed to estimate relevant model parameters from experimental data. The proposed model can predict methane production behaviour from some key indicators (such as organic matter and VFAs) in the anaerobic digestion process. Results obtained from the experiment showed that the plant could generate average volume of 3.18 m^3 of bioenergy biogas at average pressure of 170 mbar in a day. Results also revealed that the rate of bioenergy generation increase with respect to time from 33 to 44 days of retention time, the pressure of bioenergy generated increase from 35 mbar to 175 mbar. From the results, it was observable that the more the pressure in the chamber, the more the volume of bioenergy generated; thus, at 175 mbars, it produced maximum volume of 3.2 m^3 of bioenergy.

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INTRODUCTION

The European (EU) Commission have introduced extended targets to complement the 20-20-20 goals (20% increase in energy efficiency, 20% increase in renewables and 20% reduction of CO_2 emissions) for 2020 [1]. The extended targets for 2030 include at least 27% of energy to be generated from renewable sources (RES) along with a 40.0 per cent reduction in greenhouse gas emissions relative to 1990 levels [2]. One part of reaching these goals is through the use of bioenergy generated from organic products.

The technology for producing bioenergy through anaerobic fermentation of organic materials is immediately available, renewable, rich/abundant and cheap [3]. In fact, many developing countries, like Pakistan, Republic of India, China, Nepal and many other Asian countries, thousands of bioenergy plants have been put into operation [3].

Pakistan and the most of the developing world are in an energy crisis. Pakistan is annually spending nearly US$ 7.0 billion on importing fossil fuels to meet its energy demands. The best alternative for fossil fuels and energy sources is the sustainable and renewable energy resources. In Pakistan, a large number of animals produce almost 0.651 billion kilograms of dung per day and only this amount of dung can produce 0.016 billion cubic meters of bioenergy per day and annually produce 0.021 billion tons of biological fertilizer [4]. So by installing bioenergy plants, Pakistan can overcome the energy crisis. It is low cost and can be operated with very small budget [4].

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The production of bioenergy by anaerobic digestion (AD) is an environment friendly process that uses organic waste produced worldwide. This technology can be used to treat a variety of waste streams, including municipal waste etc. It has major advantages over many other waste treatment methods. The main product of this treatment is a bioenergy, that is a renewable energy source, and the by-product is the plant residues which are used as fertilizer [5]. The performance of anaerobic digestion process is extremely dependent on the nature of the raw material and activity of the micro-organisms involved in various biodegradation stags [6].

The conversion of organic matter into bioenergy is divided into 3 stages: hydrolysis, acid formation and methane (CH_4) production. These three different stages may be carried out in parallel. Different bacteria groups are collaborating by forming an anaerobic food chain. In food chain the products of one group will be the substrates of another group. If the biodegradation rates at different stages are balanced, the process proceeds effectively [7].

As indigenous resources extraction technology is a renewable and reduces dependency on fossil fuels when appropriate techniques are used to generate energy efficiently and economically. Typical bioenergy has the highest methane (CH_4) composition (50-70%) and carbon dioxide (CO_2) in range of (30-50%), as well as traces of other gases with calorific values ranging from 20.0 to 25.0 MJ / m^3 [8].

The bioenergy content varies with the material that is degraded and the involved environmental conditions. Possibly, all of these organic waste materials contain sufficient amounts of nutrients needed for the growth and metabolism of anaerobic bacteria in the production of bioenergy. But, the chemical composition and biological availability of nutrients in these waste materials vary with species, factors that affect the age and growth of plants or animals [9]. Several waste materials have been used to produce bioenergy, including; industrial/municipal waste [10], animal waste [11–13], Agricultural waste or plant residues [14, 15], food processing/factory waste [16], etc.

Oyelaran and Tudunwada [17] determined the bioenergy potentials of corn cobs and melon shells. The results showed that the content of sulphur in the biocoal briquette decreases as the biomass increases. The best combustible values were given by the biocoal briquette sample with 40% corn cob, but because of its high calorific value, biobriquettes containing 10% corn cob may be preferred for industrial heating that needs a long boiling level/phase.

Benali [18] introduced an experimental investigation of the production of bioenergy from the cow manure as an alternative to fossil fuel for the consumption of energy. This experimental investigation was carried out by using a plastic keg bioenergy prototype plant with a capacity of 18 litres. The batch testing was performed and the plant's daily energy status was monitored for a period of 30 days. These wastes were filled into the digester at a ratio of 1.0:1.0 (1 part waste to 1 part water). Within the testing period, the mesophilic temperature ranges achieved were between 20-35° C. The production of bioenergy from cow manure fluctuates between 0.0 and 340 ml between the first day and the 30th day.

Abubakar and Ismail [19] investigate the feasibility of cow manure for production of bioenergy. They observed averaged total bioenergy production and methane content were 0.15 Litre/kilogram and 47%, respectively. Alvarez and Lidén [20] studied the production of bioenergy from anaerobic digestion on animal farms, when used to produce domestic fuel and stabilize animal waste by using digested manure as fertilizer, and process is usually carried out under mesophilic conditions. The findings indicate that a mixture of llamacow- sheep manure is digested in the system at low temperatures (between 18 to 25°C). The methane (CH_4) content observed in the mixture of experiment was in the range of 0.07 to 0.14 (cubic meter/kilogram), with a methane (CH_4) concentration into bioenergy ranging from 47-55%.

Al Imam et al. [21] investigate the production of bioenergy from various fermentable materials such as cow manure, poultry waste and water hyacinth. In bioenergy generated from various fermentable materials, the percentage of methane (CH_4) content is almost the same. Castrillon et al. [22] studied the production of bioenergy from the animal dung by using the crude glycerine and food waste from the biodiesel industry as substrates. The methane (CH_4) concentration in bioenergy was found up to 78%. Westerholm et al. [23] examined five mesophilic laboratory scale bioenergy reactors, working semi-continuously for 640 days, as substrates for bioenergy production. The methane content with a substrate mixture of 85% whole stillage and 15% dung (based on volatile solids) was 0.31NL CH_4/g VS at an organic loading rate at 2.8 g VS/(L x day) and a hydraulic retention period of 45 days.

Borowski et al. [24] performed anaerobic digestion of urban sewage sludge with poultry droppings and pig manure. Experiments have shown that 30% addition of pig manure to sewage sludge effectively increased production of bioenergy by almost 40% relative/contrast to urban sewage sludge alone. Zhang et al. [25] evaluated the anaerobic co-digestion of food waste and animal dung to define the main parameters that evaluate the yield of bioenergy and CH_4. Higher lipid biodegradation and C/N ratio may be the key reasons for an increase in bioenergy production. Rico et al. [26] analyzed the efficiency of a CSTR digester with a volume of 1.5 cubic meter, processing the screened liquid fraction of dairy manure. The digested waste produced an attractive amount of bioenergy, 28.39% of the volume produced in the CSTR digester, which means to capture residual methane production, the digestive tank must be covered.

The main advantage of this process is that the bioenergy is used for cooking, vehicle fuel or for co-generation of electricity and heating; also reduce greenhouse gas emissions. This potential can be translated into a cumulative estimated capacity of approximately 48 billion cubic meters of bioenergy for power generation per year [27]. The uses of bioenergy for cooking and lighting in rural areas save a lot of wood and fossil fuel [28].

Bioenergy technology and other processes (including heat, ignition, pyrolysis and gasification) have recently seen as a good source of sustainable waste treatment, since waste disposals have become a main problem, especially for developing countries [29]. The effluent/sewage in this process is digester residue that is rich in important inorganic elements, such as (N_2) and (P) that are necessary for the growth of healthy plants. It is called organic fertilizer [30].

The production and use of bioenergy does not cause major pollution or health risks. The use of bioenergy instead of petroleum in combustion engines with power generation can eliminate emissions and environmental issues, including land subsidence and water decay due to oil loss. Although the use of biomass in rural communities is largely for cooking but it can also be used as a source of electricity production [31].

Bioenergy is upgraded through a cleaning process that removes CO_2 to increase CH_4 content and used as a transportation fuel. The most common method is to wash with an organic solvent or activated carbon for pressure swing adsorption [32]. With the aim of minimizing or reducing carbon emissions of transportation, a bi-objective non linear optimization model was also developed [33]. Bioenergy is also injected into the natural gas network for the same purpose as natural gas. Liquefied biogas can also be transported and used as LNG [32].

Tamoor et al. [34] conduct research to determine the impact of bioenergy and its social acceptability in Pakistan. Bioenergy is feasible solutions for meeting Pakistan's future energy needs. Bioenergy system was installed for almost three decades in Pakistan, but large market penetration was not achieved due to its high cost. More than 69.72% of peoples agree that the first step in producing bioenergy should be taken by government agencies. Approximately 70.35% of peoples were aware that bioenergy will enhance public health and 81.27% of peoples said that multiple job opportunities have been created by installing bioenergy plants.

The objective of this study is to provide technical knowledge about design, construction and production of small scale bioenergy plant to fulfil the cooking, heating and electricity requirement of the house by using animal manure. If produced gas is not used for cooking purposes then the plant can also run 1 HP generator to produce electricity.

METHODOLOGY

Bioenergy is produced by bacteria through the biological degradation of indigenous biomass resources under anaerobic conditions. The raw material (cow dung) [18] is collected from the animal shed and transported to the bioenergy plant installed at backyard of the house. Animal dung is mixed with same/equal amounts of water in a mixing tank/chamber. By this process slurry is formed. Whole slurry enters into digester through the inlet pipe and regularly feed up to selected retention time (44 days) [23]. When digester is partially filled with slurry, then induction of the slurry is stopped. During the selected retention time, anaerobic bacteria decompose or ferment biomass in the digester in presence of H_2O. Due to anaerobic degradation, bioenergy is formed and the dome of the digester begins to collect the bioenergy gas. As more and more gas starts to collect, the bioenergy exerted pressure, forces the waste slurry into the exhaust tank/chamber. The waste slurry flows from the outlet tank to the compost pit. Remove used slurry from compost wells and use it as a fertilizer. If the bioenergy gas supply is required, then the gas valve of the piping system, was opened. In order to obtain a continuous bioenergy supply, the prepared slurry can be supplied continuously to the operating plant.

It is important to design the bioenergy plant by maintaining the high hydrostatic pressure of the inlet tank than the outlet tank. If raw material of bioenergy plant is insufficiently supplied, then the production of bioenergy will be lowered. In that situation, the bioenergy gas pressure may not sufficient to completely dispose the slurry into the outlet tank.

A simulation is performed to estimate relevant model parameters from experimental data. The proposed model can predict methane production behaviour from some key indicators (such as organic matter and VFAs) in the anaerobic digestion process.

EXPERIMENTAL SETUP

Design of bioenergy plant

A survey is conducted in the rural area of district Faisalabad and found that most houses have animal in the range of 6 to 10 livestock. One house is selected have 8 cows; each cow producing 10 kg manure per day; then, total manure is 80 kg. The average maximum bioenergy produced from cow manure/kg is reported to be $0.05m^3$ [35]. Total biogas production for 80kg manure would be 4 m^3. Let us defined 80%the efficiency of bioenergy plant, then total biogas production would be 3.20 m^3. To determine the size of the small scale household bioenergy plant, the following relations are used: The digester size is volumetric rate of slurry× retention time (days). Daily input material is the mixture of the cow dung and water that is added to bioenergy digester in one day. For 80 kg manure per day, 80 litters of water is added to make slurry. The mass of total slurry per day would be 160 kg. Plant capacity is given by the following equation [36].

$$V_d = V_f \times T_r \tag{1}$$

where V_d is volume of bioenergy plant digester, V_f is volume of slurry feed in bioenergy plant digester and T_r is slurry retention time. We V_f as follows:

$$V_f = M/\Psi \tag{2}$$

where M is the mass of dry material and Ψ is density of dry material. Density of dry dung in slurry feed in digester is given by

$$\Psi = 80 \text{ kg/m}^3 \tag{3}$$

Having 1kg of fresh dung, resulted in 0.16 kg of dry dung because wet dung contained 84% moisture. Therefore, the dried mass of 80 kg manure would be 12.8kg, then the volume of biogas generated is:

$$V_f = M/\Psi = 12.80/80 = 0.16 \text{ m}^3 \text{ per day} \tag{4}$$

For retention time of 44 days, the working volume of digester (V_d) should be 7 m^3. From the calculation, it is concluded that the minimum capacity of the digester of bioenergy plant for production of 4 m^3 of bioenergy/day is approximately 7 m^3. If the digester is designed cylindrical shape having height and diameter of 1 m and 3m, respectively. There is no strict rule to relative the values of diameter and height of the digester, an appropriate size for a 7 m^3 bioenergy digester tank. Biogas cap of digester hold almost 75% volume of the total biogas produced. Volume of gas cap is determined by the following relation:

$$V = \frac{1}{6}\pi h(3r^2 + h^2) \tag{5}$$

where “r” is radius of the base of the cap that is equal to radius of digester (1.5m) and “h” is the height of the cap (0.75 m), plug in values in equation (5), the volume of cap would be 3m^3.

Construction of bioenergy plant

Plant layout

After design and selecting the size and location of the bioenergy plant, construction work of plant start with process of layout works. In this activity chalk, stakes, stones or other materials is used to mark the size of the plant on the ground. First a wooden stick plug on the ground in the middle of the digester. Then, follow these steps:

- Level the ground surface, and then determine the centre line of inlet tank, digester and outlet tank called hart line.
- To determine the reference level, it is best to use the ground surface level as a reference level. Top of the dome (outer) is just on this level.
- Select outer radius of the well/pit 1.84 m includes (digester radius 1.5m + wall thickness 23 cm + 1 cm thickness of cement plasters + space for footing projection at least 10 cm).
- A cord is attached to stick for the radius of proposed digester and circumference are marked by rotation of the rope/cord end in a circle which indicates the area to dig.
- Then a suitable arrangement is marked for all components of bioenergy plant include (inlet tank, outlet chamber, inlet-pipe, compost pits and gas piping).
- From centre point or midpoint where the centreline intersects the perimeter line, draw a tangent-line and measured the length equal to half the width of the output plus thickness of the wall (for the outlet tank/chamber) and the half size of the manhole (30 cm) plus the wall thickness, both sides of the tangent line.
- Marked the manhole, which has inside dimensions approximately (60×60 cm).
- Draw horizontal parallel lines of points on either/both sides of tangent-line that intersect the (outer) dome.
- Check size/dimensions diagonally make sure the corners are accurately at 900 (degree).

Construction of digester

In digester foundation, lay gravel or broken stones (bats) on the floor and then fill them with concrete. The base/foundation is 15cm thick. Straight iron rod or tube (0.5 "GI Pipe and 169 cm long) should be placed vertically in the centre of the digestion well, and the vertical pipe provides the symmetry of the bioenergy plant.

- Wire or rope is attached to the vertical fixed pipe/bar. The length of the string is equal to the radius of the digester (150 cm). Add 1 cm to the length of the rope or wire to make room/space for cement plastering. Each brick on a circular wall is completely separated (150 + 1) cm from the vertical bar.
- After at least one day of cured or healing the foundation, the circular walls began to build. The first three rows of bricks must be placed to make a 9 inch (23 cm) wide base. It is vital that the first two rows are placed on a firm, untouched level. The subsequent rows of bricks are then placed for their length, so the wall thickness is maintained at 9" (23 cm). It’s not important to build the pillars in wall.
- After 12-18 hours, backfilling should be carried out to solidify the cement mortar. The backfill between the bioenergy tank wall and the pit side must be compacted by adding water and gentle compaction. Poor compaction can cause cracks in the round walls and domes of the digester.
- Cement mortar for walls has a ratio of (cement) 1 part to (sand) 4 parts (1: 4) up to (cement) 1 part to (sand)

5 parts (1: 5), depends on the sand quality.

- The digester wall height is measured from the finished concrete floor.
- When the round wall height reaches 30.0 to 35.0 cm, place inlet pipe for manure or cow dung. The pipe place just on the opposite side of the manhole opening. The pipe has a slope of at least 45° from the ground. Make sure that the length of this inlet pipe is sufficient to form the inlet floor, at least 15 cm above the level of slurry overflow at the outlet chamber.
- Opposite of the inlet pipe feedstock, a 60cm×60cm wide opening should left in the digester wall used as a manhole. Digested slurry is passes/flow through the manhole to the exit chamber
- When the construction of digester wall is complete. The inside of wall is coated with smooth layer of cement mortar has a ratio of cement to sand is 1:3.

Dome construction

When construction of round or circular wall is complete, a bioenergy gas holder (spherical dome shaped) is starting to construct.

- First make the dome shape with the help of mud and supporting structure. Construction of dome must be completed quickly without any interruptions with concrete have ratio 1 part cement, 3 parts sand and 3 parts crush (1:3:3). Concrete mixture not more than 30 minutes old. Any delay in construction result the leakage b/w main pipe of gas pipe line and dome.
- The bioenergy gas-tightness or air tightness of the bioenergy gas holder/retainer is important for the efficient operation of any bioenergy digester. If gas escapes through pores, we will not be able to get full efficient system and whole investment will be wasted.
- After 7-10 days, the mud of the mould and supporting structure is removed by or through the manhole. When all mud has been removed, inner surface of the gas holder is washed or cleaned with iron brush and water.
- After cleaning the following plaster layers are applied, which make the digester gas holder completely gastight.
- Layer-1: Flat/Plain cement and water flush (Cement: 1 part and water: 3-5 parts), applied with broom.
- Layer-2: 10.0 mm (1 cm) thick plaster layer with cement sand mortar (Cement: 1 part and Sand: 3 parts) applied with plastering trowel.
- Layer-3: 3 to 5 mm (0.3 to 0.5 cm) thick layer of cement sand punning (Cement: 1 part and Sand: 2 parts) with plastering trowel.
- Layer-4: 3 mm (0.3 cm) thick plaster layer with cement and acrylic emulsion paints (paint: 1 to cement: 10 ratio) applied with plaster trowel.
- Layer-5: 10 mm (1 cm) wide Painting layer cement and acrylic emulsion paint (Paint: 1 to Cement: 2 ratio) applied with painting brush.
- Plaster coat/layer are well set before applying the next one. Gap of 1-2 days for the 3rd and 4th coat/layer is excellent for gas tightness. Minimum cover of 40 cm (16.0 inch) compacted mud/clay are compulsory on the dome.
- If we use a bioenergy gas cap of steel or metal to cover the digester tank, this is the most expensive part of the entire installation. In order to keep the price as low as possible, people normally minimize the size of the drum, so it does not contain a entire day bioenergy gas production, this gas is used all over the day and the drum will never allowed bioenergy plant to reach its full capacity. But they have advantage that they properly bioenergy gas tight and there is no chance of leakage.

Outlet tank/chamber

The excavation of outlet tank/chamber and manhole are completed simultaneously with the digester. The manhole and the digester have a common foundation. When we build the outlet tank, follow the steps below.

- The digging depth (total 48+2+7.5 cm) is the inner depth of outlet (48) + thickness of cement plaster (2 cm) + thickness of flooring (7.5 cm) from ground level. The length (228 cm) and width (175 cm) of excavation is inner dimension length (180 cm) and width (125 cm) plus the wall thickness (9 inch or 23 cm on both side) plus the thickness of plaster layer (1 cm on both sides).
- Outlet walls are starting to construct vertically. First, placed bricks on the four corners of the outlet wall, fixed the ropes to guide the bricks. The inner wall of the tank is finished with a smooth cement plaster layer (cement: 1 and sand: 3). There is no need for plaster outside the walls of the outlet tank.
- Always build an overflow on a long wall. The overflow point (10 cm×10 cm) in the outlet tank is at least 5 cm above the ground. This is because surface runoff is prevented from entering into the outlet from the surrounding area during the rainy season.

Construction of inlet chamber/tank

The inlet tank/chamber is typically constructed when the structure of the outlet chamber/tank is completed. There are some facts to consider when building an inlet tank to feed cow manure in the digester.

- The base of the inlet tank is level, well rammed and hard. A rectangular bottom of the inlet tank/chamber (70×70 cm, height 30 cm) was constructed on the rammed surface. The height of the base is determined such that the bottom of inlet chamber is at least 15cm above the level of the overflow of the outlet tank.
- Circular marking is marked on the finished surface by means of a 30cm radius of rope or thread to determine the inner circumference of the tank.

- Before starting to construct the inlet round wall, we need to hold the mixing device in position and place the pivot in the center of the inlet base. When the height of the circular inlet reaches 45 cm, an iron bracket is installed for tightening the mixing device. Steel parts in contact with the slurry require proper galvanization.
- The height of the inlet tank/chamber (including the bottom of the inlet) is recommended to be 90 cm, but in some cases it exceeds 100 cm.
- When the circular wall is constructed, the inlet tank is coated with cement mortar on both sides, and the cement sand ratio is 1:3.

RESULTS AND DISCUSSION

Simulation

The model simulations were compared with experimental data of an anaerobic digestion in a pilot-scale up-flow anaerobic fixed dome type digester. The macroscopic performance of digester and methane production is shown in Figure 1 (Data, blue line). During the pilot test, VFA (volatile fatty acid) did not accumulate and methane content in the bioenergy is about 65% in the digester. The changes in the dynamics of the variables are the effect of changes in the slurry input flow. The simulation results are shown in Figure 1 (Model, red line). The model correctly reproduces the behaviour of the variables, so organic matter and methane gas are well predicted. However, VFA behaviour shows some differences. It is noteworthy that the model simulation follows the effect of disturbances forced by input flow.

The data showed that the increase in organic loading rate corresponds with an increase of VFA, organic matter and methane gas, and also, a decrease of biomass concentration. On the first three days of treatment, the model has a poor prediction, and the estimated value of organic matter is too high, but the estimated value of methane is too low. This performance is difficult to explain from a biochemical viewpoint because after day three, the same variables of the model correctly follow the dynamics of the experimental data. In these first days, the model seemed to be slower than the process.

VFAs are the main intermediate products of anaerobic digestion. They are considered to be good indicators of the performance of anaerobic digestion processes. They are directly related to the final product methane. In our model, the VFA simulation follows the data. However, some experimental data are insufficiently predicted (for example, days 14, 15 and 22). This may be due to the simplicity of the model. It is likely that some substances in the waste material during acidification step are converted to VFA, and the model does not consider this.

The major advantage of the model is its ability to predict the methane production using few input variables (such as organic matter and VFA). This reduces the number of variables that have to be monitored in a process of anaerobic digestion.

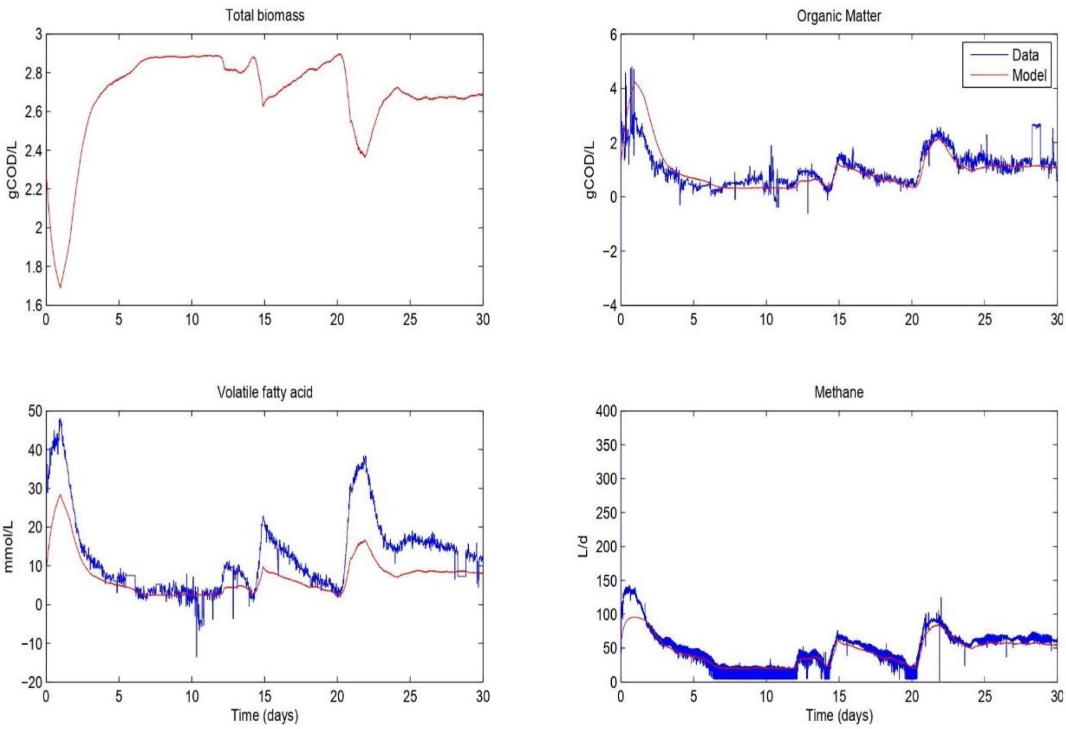

Figure 1. Behaviour of total biomass, organic matter, volatile fatty acid and CH_4

This simulation approach is widely accepted for estimating the different conditions in anaerobic digesters [37, 38].

Bioenergy production and pressure

The exact/precise amount of the produced bioenergy gas depends on various factors. First, the quantity of animal waste varies depending on the animal, the animal feed, the season/period of the year (winter or summer), whether animals live in stable or/and free from grazing. Daily mix 80 kg cow dung with 80 kg water and regularly feed up to 44 days in digester. During these days anaerobic bacteria decompose or ferment biomass in the digester in presence of H_2O. In the case of anaerobic degradation, bioenergy is formed and the dome begins to collect in the digester. After 9 days, production of gas will start and will be collected in the dome. After 33 days the pressure of gas in the digester will be reached upto 35 mbar as shown in Figure 2.

The complete bioenergy gas formation process will be completed in 44 days. During these days the pressure is increased from 35 mbar to 175 mbar as shown in Figure 3. This is the total pressure of the 4 m^3 gas formed in the digester of bioenergy plant installed at the backyard of the house. For reference, the production of bioenergy plant is similar to the production bioenergy plant installed in Libya. Benali [18] investigated the production of bioenergy from cow dung. No bioenergy was produced for the first 8 days, because it takes longer for the cow dung to decompose, after which bioenergy is produced. This is predicted due to the lack of growth of methanogenic bacteria. The bioenergy production from cow manure started on the 9th day of the retention period with an average bioenergy production of 30 ml, then increased to 100 ml on the 10th day. On the 13th day, 160 ml of bioenergy was produced. After the completion of retention period the total production of bioenergy was 340 ml. Tamoor et al [39] conduct a study for production 4 m^3 bioenergy and the production of that bioenergy plant similar to the production of bioenergy in this research.

When dome is filled with bioenergy gas, the bioenergy exerted pressure on the slurry and forces the waste slurry into the outlet chamber. If the gas supply is required, open the gas valve of the piping system. In order to obtain a continuous bioenergy supply, the prepared slurry can be supplied continuously to the operating plant. First process will be complete in forty-four days, after that the gas formation is done in 24 hours because anaerobic process is completed. When we enter the slurry on 45th day, the slurry enters on 1st day drain into outlet chamber because bioenergy exerted pressure on the waste slurry and the slurry enters on 2nd day will produce the gas. Similar when we enter the slurry on 46th days, the slurry enter on 2nd day drain into outlet chamber. And the slurry enters on 3rd day will produce the bioenergy gas. (The composition (ingredients) of raw bioenergy is shown in the following Table 1.

Figure 3. Final bioenergy pressure

Figure 2. Bioenergy pressure after 33 days

Bioenergy up-gradation

However, bioenergy contains significant amount of (CO_2), (H_2S) and water vapour, practically not used as fuel. The presence of CH_4 makes bioenergy combustible, while CO_2 is non-flammable, limiting its compressibility by making it difficult to store in cylinders. The presence of H_2S and water vapor in bioenergy also enhances/improves the corrosion and reduces the calorific value of the fuel [40].

Therefore, bioenergy must be enriched by removing carbon dioxide, hydrogen sulfide and water vapor prior to compression, making it suitable for cooking or use in engines.

There is a significant impact on the environment from pollution and emissions caused by production and operation. Therefore, the development of an efficient and effective approach to environmental impact assessment is essential. The key innovation is the development of an

TABLE 1. Composition of raw bioenergy

Content	Unit	Raw Bioenergy
Methane (CH_4)	(%)	58.23
Carbon Dioxide (CO_2)	(%)	34.01
Hydrogen sulfide (H_2S)	(ppm)	988
Oxygen (o)	(%)	2.81
Moisture	(%)	4.01

improved multi criteria decision making model using a novel hybrid approach, namely the group fuzzy entropy and cloud technique, similar to the ideal solution theory for order of preference [41]. Graphene oxide nanocomposite (FA-GO) coated with folic acid is used as an adsorbent to remove heavy metals, including cadmium (Cd^{2+}) and copper (Cu^{2+}) ions from water [42].

Water scrubbing

Water scrubbing/washing involves the physical absorption of CO_2 and H_2S in water under high pressure. Carbon dioxide present in raw bioenergy reacts with water and forms carbonic acid. This is the cheapest and simplest bioenergy upgrade method using pressurized water as the absorbent. Use a 4.5-inch diameter, a 6foot and 2-inch long PVC pipe to develop a water scrubber/washer for raw bioenergy. Water is supplied from the upper side of the scrubber (6 inches down from the top) and sprayed through the nozzle. Raw bioenergy is fed from the bottom of the scrubber (up to 6 inches from the bottom), thus providing a 5 foot height for scrubbing/ washing of raw bioenergy with water. The raw bioenergy enters directly from the bioenergy plant. Bioenergy is uncompressed. The washed water is drained from the bottom of the scrubber, where a U-bend is provided for storing water and preventing the outflow of bioenergy. Scrubbed bioenergy emerges from the top of the scrubber. The composition (ingredients) of purified bioenergy is shown in the following Table 2.

TABLE 2. Composition of purified bioenergy

Content	Unit	Water Scrubbed Bioenergy
Methane (CH_4)	(%)	86.57
Carbon Dioxide (CO_2)	(%)	7.03
Hydrogen sulfide (H_2S)	(ppm)	115
Oxygen (O)	(%)	1.69
Moisture	(%)	3.48

Bioenergy production and consumption comparison

Experiment was carried out at an ambient temperature range of 24 to 32 ° C and the retention period is 44 days. Daily bioenergy production and consumption is shown graphically in Figure 4. This figure shows the maximum bioenergy produce by bioenergy plant is 3.2 m^3 and 3.17 m^3 is the gas consumption of the house on date (May 14, 2019). It is observed that peak gas demand of the house is primarily met by small scale bioenergy plant and system have potential to make the house self-reliance in terms of gas required for cooking and heating requirement. If produce gas is not used in cooking and heating, then the plant also operate a 1 HP electric generator for 7 hours a day. Because it required 0.45 m^3 bioenergy per hour.

Figure 5 shows the temperature curve of the water tank, feed slurry and ambient temperature for different seasons (242 days). The results showed that even if the ambient temperature reaches a minimum of -25 °C, the temperature of the bioenergy digester remains within 27 ± 2 °C. Therefore, the system is capable of constant temperature fermentation in the different local season's conditions.

For cow manure, the pH fluctuates between 5.2 and 7.6 from the first day to the twentieth day, after which it starts to steadily or slowly decrease for the remaining days of the retention time. The pH of cow manure decreases because of high volatile fatty acid (VFA). The

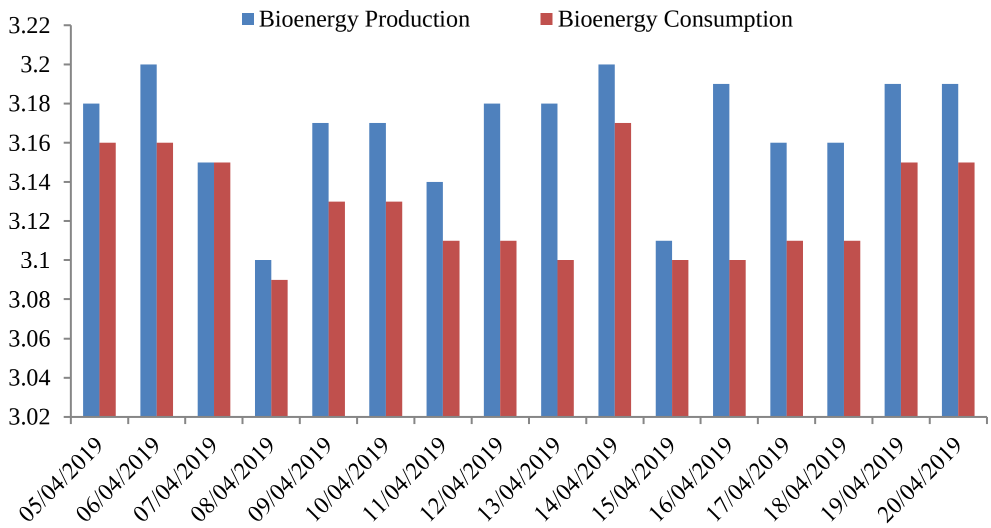

Figure 4. Bioenergy production and consumption

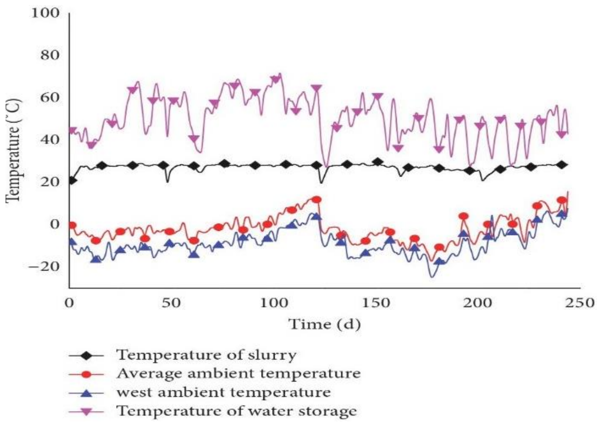

Figure 5. Feed slurry temperature, ambient temperature and water tank temperature in Centigrade over different heating seasons

steadily or slowly decrease explains the significant transition in the stage of bioenergy production from hydrolysis to acidogenesis, where the slurry becomes acidic and forms the substrate then after bioenergy is produced.

ECONOMIC ANALYSIS

One of the traditional and common methods for assessing the feasibility of the energy system is the levelized cost of bioenergy production. Levelized cost is the net present value of the energy system's total life cycle costs (including capital cost, component replacement cost, O/M cost, and the cost of fuel) divided by the amount of energy generated over the lifecycle of the system. The levelized energy cost is often used to compare the cost of energy production from various options and therefore to select the best technology. Levelized energy cost (LCOE) relies on feedstock handling cost, digester operating and maintenance (O/M) cost, digester capital cost when considering the energy system under consideration.

This research used the levelized cost estimation approach of the different energy technologies described in Mainali and Silveira [43] for economic analysis. All cost data is taken from the local market and expressed in US dollars (2020). With the 10% discount rate over the life span technology, the amortisation of the capital investment was done and the overall price growth rate of 5% was assumed.

Levelized cost of bioenergy

Table 3 describes the capital cost of construction and installation of a bioenergy digester, operating cost, cost of replaceable items and their service life, and other key assumptions.

The operating and maintenance (O&M) cost of bioenergy production represent/reflect the cost of the different inputs to the bioenergy system, i.e. labour and maintenance cost, cost of water for mixing different indigenous materials, monitoring and supervision cost, slurry storage and disposal cost, cost for distribution and utilization of gas, and administration needed for the operation of the system. Bioenergy plant maintenance costs are considered to be the replacement cost of gas pipes sockets, valves, etc. It is estimated that the annual operating cost of the bioenergy plant is 5% of capital investment cost. The cost of fuel includes the cost of energy needed to operate the water pump and the cost of purchasing raw materials (transportation of raw materials).

TABLE 3. Technical and economic parameters and specifications of a bioenergy plant

Specification/Description	Values
Construction cost of a 10.0 cubic meter (7.0 m^3 bioenergy digester tank plus 3 m^3 bioenergy gas cap/holder) bioenergy plant (US dollars)	460
One Heat exchanger (US dollars)	60
Life span of heat exchanger (year)	8
One Water pump (US dollars)	24
Life span of water pump in year	4
Valves and pipes for bioenergy plant (US dollars)	30
Accessories and pipes for gas distribution (US dollars)	90
Installation and transportation cost (US dollars)	150
Bioenergy plant feedstock handling cost ($/ton)	6
Bioenergy plant service life (years)	25
Levelized cost of bioenergy production ($/kWh)	0.014

The estimated/projected cost of constructing a 10 cubic meter bioenergy plant is approximately $664 (including the civil construction costs of the bioenergy digester, heat exchanger, water pump, valves and pipes, and accessories,). Considering the cost of material and labour in local market, the construction cost of bioenergy plant was estimated.

For reference, the cost of a bioenergy plant of similar size in Vietnam was $890 [44]. The overall cost of the bioenergy production system, including the cost of the distribution pipeline is $814. The levelized cost of production of bioenergy can vary from $0.014 /kWh. Capital costs for bioenergy digesters and gas engines have a major impact on the total cost of bioenergy production.

Now we discuss the impact on bioenergy and electricity production costs due to changes in raw material handling costs, bioenergy digester and generator capital costs. Depending on how the livestock is raised, the cost for feedstock managing or handing varies. If the livestock can be herded to a centralised farm or stable, then collecting / processing cow dung would be relatively easy. On the other hand, sparse grazing practises, would dramatically increase handling costs. The handling cost can also vary from $1.14 to $6.14 per ton depending on the situation.

For levelized biogas production cost with feedstock handling costs from $1.14 to $6.14 per ton and digester capital costs (19 to 51% change in bioenergy digester capital cost), a sensitivity study was conducted to show to at what level the levelized bioenergy cost varied with these changes. Depending on the fluctuations in the feedstock handling cost (FHC), the levelized cost of bioenergy generation would be $0.01/kWh and $0.027/kWh. Levelized costs also increase, but only slightly, if capital costs by 50%. A fivefold increase in feedstock handling cost, as a results an increase in levelized costs of about a half, showing the significance of proper handling and management of feedstock.

CONCLUSION

This work offers a new approach to sustainable technologies and their potential in developing countries such as Pakistan. The growing demand for sustainable energy is forcing people to explore and develop new technologies for bioenergy production. Regarding the raw material of anaerobic digestion, it utilizes the waste material in this way that it solved the problem of waste reduction and energy production. A simulation is performed to estimate relevant model parameters from experimental data. The nonlinearity of the model will bring difficulties in parameter identification, but it can be overcome by using the cascade structure of the model. The proposed model can predict methane production behavior from some key indicators (such as organic matter and VFAs) in the anaerobic digestion process.

By use of this study, it seems that 10 m^3 bioenergy plant installed at backyard of the house fulfil the cooking and heating requirement of the medium sized family. Results obtained from the test showed that the plant could generate average volume of 3.18 m^3 of bioenergy biogas at average pressure of 170 mbar in a day. Results also revealed that the rate of bioenergy generation increase with time and from 33 to 44 days of retention time, the pressure of bioenergy generated increase from 35 mbar to 175 mbar. From the results, it was observable that the more the pressure in the chamber, the more the volume of bioenergy generated; thus, at 175mbars, it produced maximum volume of 3.20 m^3 of bioenergy. If produce gas is not used in cooking and heating, then the plant also operates a 1 HP electric generator for 7 hours a day. Because it required 0.45 m^3 bioenergy per hour.

The results show that even if the ambient temperature reaches a minimum of -25 °C, the temperature of the bioenergy digester remains within 27 ± 2 °C. Therefore, the system is capable of constant temperature fermentation in the different local season’s conditions.

The concept of using animal waste (cow dung) in a fixed bioenergy plant for bioenergy production offers effective waste management and resource development with positive measures for the economy, improved air quality and sustainable energy security.

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Persian Abstract

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چکیده

کشورهای در حال توسعه مانند پاکستان در بحران جدی انرژی قرار دارند. منابع انرژی تجدیدپذیر بهترین گزینه برای منابع انرژی مرسوم هستند. استفاده از منابع بومی برای تولید انرژی زیستی یک راه‌حل عالی برای تأمین نیازهای انرژی کشورهای در حال توسعه است. هدف از این مطالعه طراحی، ساخت و تولید تولید انرژی زیستی از منابع بومی برای تأمین نیاز به انرژی زیستی برای برق، پخت و پز و گرمایش بود. این تحقیق بهترین فناوری موجود را معرفی می‌کند و نیروگاه انرژی زیستی با حداقل هزینه برای تولید مصارف محلی ساخته شده است تا از بار اقتصادی در هزینه‌های تولید انرژی زیستی جلوگیری کند. یک واحد هضم‌کننده زیستی زیرزمینی با حجم ۱۰ متر مکعب (مخزن هضم‌کننده انرژی زیستی ۷ متر مکعب به علاوه کلاهک / نگهدارنده گاز انرژی‌زای ۳ میلی‌متر مکعب) نصب شده است. خوراک روزانه تقریباً ۱۶۰ کیلوگرم دوغاب پهن گاو (۸۰ کیلوگرم کود گاو بعلاوه ۸۰ لیتر در کیلوگرم آب) بود. مدت زمان نگهداری تقریباً ۴۴ روز و دمای فصلی گزارش شده تقریباً ۳۲-۲۴ درجه سانتی‌گراد بود. واحد عایق حرارتی بود، بنابراین نوسان دما در حدود ۲ درجه سانتی‌گراد بود. در نصب آزمایشی، منابع زیست‌توده بومی در محفظه مخلوط با آب مخلوط شدند. مخلوط کامل از طریق لوله ورودی وارد هضم می‌شود و به طور منظم تا زمان نگهداری انتخاب شده تغذیه می‌کند. باکتری‌های بی‌هوازی زیست‌توده موجود در هضم را تجزیه کرده و انرژی زیستی تولید می‌کنند. یک شبیه‌سازی برای تخمین پارامترهای مدل مربوطه از داده‌های تجربی انجام شد. مدل پیشنهادی می‌تواند رفتار تولید متان را از برخی شاخص‌های اصلی (مانند مواد آلی و اسیدهای چرب فرار در روند هضم بی‌هوازی پیش‌بینی کند. نتایج به دست آمده از آزمایش نشان داد که گیاه می‌تواند به طور متوسط حجم ۳/۱۸ متر مکعب بیوگاز زیست انرژی را با فشار متوسط ۱۷۰ میلی‌بار در روز تولید کند. همچنین نتایج نشان داد که میزان تولید انرژی زیستی با توجه به زمان ۳۳ تا ۴۴ روز از زمان ماند افزایش می‌یابد، فشار انرژی زیستی تولید شده از ۳۵ میلی‌بار به ۱۷۵ میلی‌بار افزایش می‌یابد. از نتایج، مشاهده شد که هرچه فشار در محفظه بیشتر باشد، حجم انرژی زیستی تولید شده بیشتر است. بنابراین، با ۱۷۵ میلی‌بار، حداکثر حجم ۳.۲۰ متر مکعب انرژی زیستی تولید کرد.