Design of Biogas Plant for Rural Households in India (A Case Study from Rajabhat Khawa)

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Abstract : The dry manure fuel is used for harnessing electric power and helps us to reduce the environmental emissions by accomplishing energy security and sustainable development. This paper presents a strategy for an approximate power production potential of dry manure fuel in a country. In addition to this strategy that has been applied to develop a plan for production of authentic power in India. The recent study reveals that about 7300 Mt/ year of dry manure fuel is initiated in the village known as Rajabhat Khawa, North Bengal, West Bengal. The study contains a domestic biogas plant, which if acquired can reduce the biomass consumption by a sizeable percentage. From extensive research, a family with between 5 to 10 cows can produce a minimum of 2.5 m^3 of gas which is sufficient for lighting and cooking for an average rural household of six people .This will lead to a better standard of living through ameliorate household income from milk, meat, organic fertilizer, employment of biogas masons and preservation of environment by saving the metric ton of trees being fell for firewood and charcoal.

Index Terms: Biogas, Biomass, Energy, Rajabhat Khawa, Rural Household.

I. INTRODUCTION

1.1 Renewable energy sources and economic growth

The dissipation of electricity is increasing in India without a break due to rapid urbanization, industrialization and increasing population .In order to achieve energy security for long term, the installed capacity has to be increased at the same pace (800 GW by 2031-2032) in the country (World Bank, 2011). The native energy sources (fossil fuels) are not sufficient enough to meet growing power requirements. Moreover, these resources do not produce clean energy and their use, results in environmental degradation (Chaurey et al., 2004; Hiloidhari and Baruah, 2011) (ref 1.). Therefore, the fossils fuels cannot inherently be exploited to meet the targets of financial growth in India. But it may be noted that the financial growth of a country depends upon the energy scenario, which needs to be reformed in the country. Due to this, the use of alternatives and renewable energy sources becomes vital and unavoidable.

About 68.84% of India's populations live in rural villages where there are almost no alternatives to biomass fuel. Cooking takes a lot of round wood and the need to cook with cheap smarter charcoal in urban areas increased the situation of the rural people to engage in charcoal production for sale to urban centers. Biomass usage prevents people from working as they have to spend large amounts of time to search for and collect wood. It also causes respiratory problems and eye sickness due to carbon monoxide and smoke besides destroying the natural habitat for coexistence.

1.2 Sustainability of biomass resources

Biomass is a one of the renewable energy source, which is the most extensively used for heat and power demand all over the world. A no. of economically viable technologies is accessible for transformation of biomass into the energy (Mckendry, 2002) (ref 2.). Besides, these sources are comparatively cheap as compared to conventional resources. Due to this, the biomass power is considered to be economic to produce and provide on the regular basis. The agricultural department produces a major part of superfluity biomass in India (India Council of Agricultural Research (ICAR,2014; Hilodhari et.al.,2014)(ref 3). The agricultural biomass is generally produced during harvesting and processing of various crops. Generally, this biomass is burnt in the open field due to deficiency of time for preparing the fields for the next crop. This results in disposal problems for this superfluous product causing environmental pollution at local and global level.

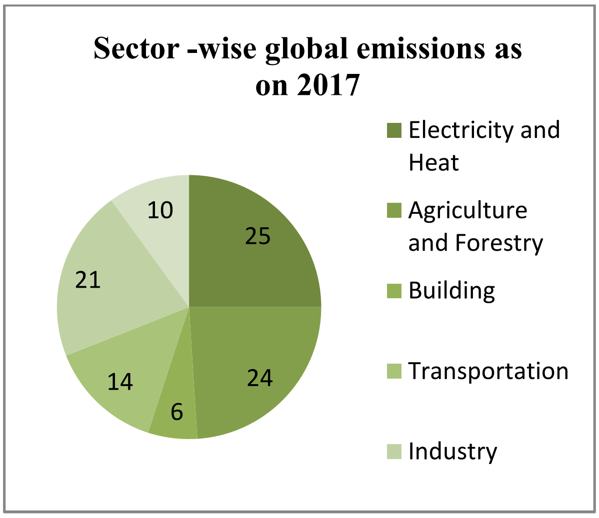

Fig.:1. Global emissions as on 2017.

The International Panel on Climate change (IPCC) has announced that the emission of green house gases (GHGs) such asCO_2,NO_2,SO_2, CO ETC can be classified by the economic activities that lead to their production.

It has been delineated that the use of burning fossil fuels for heat, electricity and power generation is the vital cause for emission of these gases. The major source of GHGs in the atmospheric environment isNO_2. Therefore, curtailment of emissions from the agricultural sector depends upon a no of parameters such as crop yield, climatic conditions, type of soil and the cultivation methods. Therefore, the outpouring of GHGs can be supervised substantially by eliminating the burning of the crop remnants in addition to production of power from fossil fuels.

BIOGAS CONCEPT

Biogas is engendered through a process of anaerobic digestion of organic materials from human and animal waste, agro- industrial waste and other biomass materials. The energy acquired from waste materials like plants, animals and humans is what is advert to as biomass energy.

Table 1: Composition of biogas

Composition of biogas	Percentage	Properties and Remarks
Methane	55-70	Key source of energy, lighter than air and has ignition temperature of approximately 700°C with specific gravity of 0.86 and a flame factor of 11.1. Its flammability in air is 6-25%(safer and other gasoline)
Carbon dioxide	30-45	Green gas. Use for photosynthesis
Nitrogen, hydrogen sulphide and others	1-5	

The calorific value of biogas is approximately 20 MJ/m^3 (4700Kcal/m^3) and methane is responsible for the energy acquired from biogas depending on the biological process and type of biomaterial. An average dairy cow produces about 55 kg of solid waste each day, which adds to 20 metric ton of dung per annum. Unmanaged livestock waste can create negative environmental impact. The methane created through anaerobic digestion of manure has proven to be 21 times more damaging than CO_2 exacerbate to climate change. Around 3.0 kw/h of electricity could be engendered daily from the dung and urine of just one cow.

POTENTIALS OF BIOGAS

Duggal, (2002) (ref 4.) found out that biogas contains 400-6000 calories/m^3 thus providing a convenient source of energy at low cost. A comparison of biogas with other forms of fuel energies and results are shown in the table.

Table 2: Composition of Biogas with other forms of fuel energy

Energy	Alcohol	Petrol	Crude Oil	Gasoline Gas	Charcoal	Electricity
Quantity	1.1 litre	0.8 litre	0.6 litre	1.5 m^3	1.4 kg	2.2 kwh

Table shows the Brobdingnagian potentials of the biogas as energy source. Biogas system can be designed for individual family or community use.

Factors that affect Biogas Production:

Rai, (2002) (ref 5.) says the ideal temperature for methane producing bacteria is about 35°C, just about blood temperature. Low temperature decreases gas production and virtually stops at 10°C. Plants built underground conduce to have stable temperatures within daily allowable fluctuation of 1°C and in Rajabhat Khawa the minimum is 1.7°C . The organic matter that is to be digested in the digester in the postulated time is called retention time and is called retention time. The more the temperature the faster the bacteria use the food in the slurry and the sooner it needs substitution. The bacteria produced by methane is anaerobic, thus air should be excluded. Bacteriology multiplication depends on the sort of dung and the temperature level. The chief nutrients of anaerobic bacteria are carbon (in the form of carbohydrates) and nitrogen (as proteins, nitrates, ammonia, etc) for energy provision. The required ratio according to (Mathur and Rathore, 1992) (ref 6.) is 25-30:1. At any given time, the bacteria will find its own pH level and this is usually 7-8, but can have $\pm$0.5. This is checked using a litmus indicator paper. Suitable solid content (dry matter concentration) is 7-9%. More water results in moreCO_2, while more solid content result in scum formation all affecting gas production, therefore need for control and balancing. Toxic and harmful substances result from medications and type of feeds given to the animals, but the effect is so minimal that can be ignored.

DESIGN METHODLOGY

1.1 Field Survey

The raw material required for the plant sustainability was carried out by assessment of number of cattle per household. For construction preliminary surveys were done to identify the availability of water and local material to evaluate the condition of proposed sites. The number of persons per household was found to be seven and they showed willingness to use biogas. The analysis and design was based on the information obtained from other scholars like Rai, (2000) and field data. The average number of cows per household was found to be 10, and the quantity of dung per cow was experimentally estimated to be 10Kg/ cow per day, during worse period dry season. For the design purpose, this study adopted 6 persons per household as per the population census of 2011. The success of a biogas plant in the rural areas primarily depend on the selection of the plant design, size site, materials of construction, type of plant, method of construction and acceptability. Monitoring its operation, repairs and maintenance are required for optimum working and utilization.

1.2 Components of Biogas Plant

A complete biogas plant will have the gas generation sub-system (the digester), feed and slurry handling sub-system (the inlet and outlet of the slurry), gas distribution and utilization sub-system (the pipe work and terminal appliances).

1.3 Selection of Model, Design and Construction

This was based on technical, economic and social considerations. The size to use depends on the availability of biodegradable materials and amount of gas required. The factors of interest this case were quantity if cow dung and the use o gas (cooking and lighting), and hydraulic retention time. Construction time and labour resources required to build a biogas plant vary depending on several factors. The most important consideration is the availability of people interested in carrying out this kind of work. A biogas digester an apparatus which is used to control anaerobic decomposition was proposed to be constructed of brick masonry. A sealed tank or pit holds the organic materials, and some means to collect the gas that is produced. Many different shapes and styles of biogas plants have been experimented with horizontal, vertical, cylindrical, cubic, and dome shaped. This project adapted the dome shaped shown in figure. The bottom line is that the construction should be simple with low demand of materials, cheap labour and low in cost and easy to build. The foundation is constructed using the plain concrete slab of M20.This can take a dead load of 250kg/cm^2. The wall (Plastered) should be impenetrable to avoid percolation of water from the sides. The slurry mix tank (inlet chamber) is also provided using masonry construction. The size is decided in such a way that it can hold charging material for at least one day. It is fitted with a pipe which leads into the digester. The outlet chamber/manure pit/ drying bed are constructed having an outlet pipe leading the digested slurry from the digester into the chamber where it is removed and utilized as manure. The gas is lead out from the top of the dome to a pipe network for consumption.

DESIGN AND DIMENSIONS

Calculations

The number of cows per household as found on average = 4.

The amount of dung per cow = 10 kg given the fact that the cows move far from home to graze. However, with zero grazing practice a dairy cow produces about 55 kg of dung day. The amount of dung to be used for the design therefore= 4×10= 40kg per day.

Gas requirement per day

Size of household = 4 persons on average, (India population Census, 2011) (ref 7.)

Cooking

Quantity of gas required for cooking per person = 0.227m^3.

Therefore, required gas per day per household= $0.227\times4=0.908\text{m}^3$ of gas.

Lighting

Quantity of gas required for lighting per candle lamps (i.e 60 ≈watts electric bulb) = 0.125m^3 per bhp-hour (Rai, 2000). Assuming 3 lamps are required per household for hours per day, required gas per day per household = $0.125\times3\times3=1.13\ \text{m}^3$ of gas.

Total volume of gas required

Gas required for Cooking + Lighting =0.908+1.13 $=2.0308\text{m}^3$ of gas. Take 2.03m^3 of gas for design. Basing on the amount of gas required per day, 1 kg of fresh dung produces 0.05m^3 of biogas, (Duggal, 2002) (ref 1.), this implies for $2.03\ \text{m}^3$ = 2.03/0.05=40.6 kg of dung day.

Number of cows=40.6/10 = 4.06 cows≈4 cows. This is adequate compared to household average of 2.

Plant Capacity

For the purpose of this project, the fixed dome type biogas plant was preferred. According to Rai, (2000) the digester volume is given by the formula:

$V_d=V_f t_r$ …………………………… (1)

Where V_d= digester volume, V_f= Volume of the fluid (slurry) in the digester, and t_r=hydraulic retention time. But also,

$V_f=\frac{M}{\Psi}$……………………(2)

Where, M= mass of dry input and Ψ= density of dry material in the fluid.

Density of dry dung in the fluid is given by; Ψ= 50 Kg/m^3.

Using eqn (2), Volume of daily slurry charge, V_f= Mass/Density

1 kg of fresh cow dung = 0.18 kg of dry dung (measured from the field). Therefore 40.6kg= 40.6×0.18=7.2 kg of dry weight of dung per day. Wet dung contains about 82% water.

Volume of fluid, V_f= 7.2/40.6= 0.177≈0.178 m^3/day.

Let Hydraulic Retention time to be 30 days (~8~50 days, Rai, 2000).

From equation (1), volume, V_d=0.178×30=5.34m^3………………… (3)

Actual digester volume = 1.1 V_d (10% more to provide allowance for disengagement of gas)

Actual volume of digester therefore= 1.1 × 5.34= 5.874m^3

Using United Nations data for fixed dome type biogas plant, the gas production rate in tropical climate range from 0.4 to 0.5 m^3/day per 1m^3 of digester volume. Taking an average of 0.45m^3, 2.03m^3 gas required per day =2.03/0.45 will need 4.51m^3 of digester volume; m^3 is adequate.

Digester Dimensions

Height to Diameter ratio = 0.9, (U.N 1984).

H/D=0.9,H=0.9D

But V=0.785D^2H

5.87=0.785×0.9D^3

Dimensions: D=2.02 m; H=1.83 m.

Table 3: Plant Capacity in terms of Cost

Plant Capacity (m^3)	Daily Fresh dung (kg)	Fresh Slurry (l)	Number of Cows	Number of People	Cost in India ($) US
1	**25**	**50**	**2-3**	**3-4**	**1800**
2	**50**	**100**	**4-6**	**6-8**	**2160**
3	**75**	**150**	**6-9**	**9-12**	**2700**
4	**100**	**200**	**8-12**	**12-16**	**3240**
5	**150**	**300**	**12-18**	**18-24**	**3888**

Adapted from the International Network for Sustainable Energy, 2006 (ref 8.)

Cost of owning and running a biogas plant per day on average is, with a life of expectancy of 20 to 30 years. The initial cost may be well above the average income of the majority of the rural population. There is need for government intervention inform of biogas loans, plastic digesters and also training of biogas technicians for construction and maintenance.

Durability and Reliability

The average recorded life expectancy of a model is important in deciding which model is best suited to rural households in India. The user would expect to invest in a model with the longest life expectancy. The average life expectancy of the fixed dome plants was found to be form 20-30 years. Structurally the dome shaped has the required strength to carry the soil above and avoid the need for structural design and strict supervision during construction. It also requires minimum repair and maintenance, (Singh et. al., 2005) (ref 9.).

Benefits of Biogas

1. Cheap and reliable source of domestic energy.
2. Reduce foreign currency expenditures on electric appliances.
3. Methane being a green gas, its domestic use of cooking and lighting will greatly reduce its release to the atmosphere.
4. Thousands of metric tons of round wood cut for firewood and charcoal will be spared leading to natural conversations of the environment, in line to MDG 7.
5. Sickness due to the use of firewood and charcoal will be history.
6. There will be job creation in form of construction and maintenance of biogas plant (MDG 1)
7. Will lead to improved economic status of the population as the energy and time spared from collecting firewood may be diverted to other activities like farming which will reduce hunger.
8. May encourage cattle keeping which economically will provide milk, meat and also be used for ploughing.
9. Effluent use as fertilizer will be lead to improved agricultural output which is in line to MDG 1(Eradication of extreme poverty and hunger)

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

Based on the findings of this project work, the following conclusions and recommendations have been reached:

1. At a cost of US $ 2000 and 4 herds of cattle, a family of 4 people can acquire a biogas plants to meet their daily cooking and lighting energy for between 20 to 30 years, (Sashul and Naimul, 2006)(ref 10). The average of 10 cows is adequate.
2. The fixed dome type biogas plant was chosen because of low cost and cheap technology.

3. The size of the plant digester volume was determined to be 5.874 m^3.
4. The major economic activity of the rural populance in the study area is cattle keeping and subsistence farming which provides disposal system for the by- product of the biogas plants in form of manures/fertilizers.
5. The situation on the ground warrants the implementation of a biogas energy initiative as the major domestic energy for cooking and lighting.

RECOMMENDATIONS

It is recommended that:

1. Biogas being cheap, reliable and easy to be construct can be sustainable, and as such is a necessary technology which needs exploration to benefit the rural population.
2. There is need to sensitize people about the use of biogas as a cheap, reliable source of energy.
3. Government should come in to promote the use of biogas through financing of the construction at a community level or initiate the creation of biogas loans. This can be a good supplement to the ongoing rural electrification programme.
4. Need for training technicians in biogas technology as it is a new thing.

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