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Feasibility Analysis of a Community Biogas Power Plant for Rural Energy Access

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Abstract— *In India there are a number of remote areas where electricity is yet to reach or even if electrification is there, lack of supply or no supply is having huge socio-economic impact. In such villages children are deprived of basic illumination for studies and women have to spend hours together searching for fuelwood and are exposed to smoke hazard due to the use of firewood and dung cakes for cooking. The lack of access to clean and efficient fuels or energy sources is a primary indicator of energy poverty in a country. Fortunately, with world's largest cattle inventory, India is having a very high potential for dung based bio-energy systems. Recently some of the state governments have imposed blanket ban on slaughter of cows and its progeny. Here, a community biogas power plant has been proposed as a solution to the problem of energy scarcity, as also that of financial viability of providing shelter to the retired cattle. It may also be a potential solution to the problem of rural unemployment. In this paper, for such a community biogas power plant an exhaustive analysis has been done with due consideration to the various costs involved and the possibilities of revenue generation to assess the financial viability of the project.*

Keywords— *Rural energy scenario, cow dung, biogas digester, community biogas power plant, payback period.*

I. Introduction

India has 70% of its people living in rural areas. Also, it has the largest share of world's cattle inventory which is more than 30%. Most of this cattle population is located in rural areas. Being an agrarian society, a large proportion of this rural population is engaged in self-owned farming, mostly at small scale, or works as farm labor. Biogas is one of the renewable energy resources and is produced from green energy crops and organic waste matters. In the sustainable energy discourse the biogas is considered to be an effective option which could be used to reduce reliance on fossil fuels. In addition to providing sustainable energy, biogas digesters are also low cost, efficient, and easy to maintain [1]. The proposed community biogas power plant model is self-sustainable. It can be run by the farmers as an energy cooperative, wherein the farmers could invest their retired cattle and also sell the dung produced by their household bovines. The plant can be operated and maintained by the villagers themselves and thus can generate employment opportunities for rural community.

II. Design of a Basic Unit of a Community Biogas Power Plant for an Indian Vilage

The basic unit of a biogas plant is considered to be of two-ton dung capacity. It is selected because it is found to be the most successful, based on the literature survey and field visits. It generates around 88 m^3 of biogas and 500 kg of bio-fertilizer per day. This plant can cater to around 230 households in a village with basic illumination and comfort. For a bigger village more number of such plants may be installed and for a smaller village, due to the lesser availability of dung, the plant size can be scaled down. The various components of the community biogas plant with a provision for vermicomposting and the pertinent design details are as follows:

A. Anaerobic Digester

The design of digester is based on BARC's Nisargrun biogas plant. In this the digestion happens in two stages i.e. primary and secondary and in thermophilic range by means of a solar water heater. Thus its performance is better than the KVIC model which is commonly used in India. Cow dung and water are mixed in the mixing tank and put in primary digester. After six days it goes to the secondary digester and actual gas production take place. Then digested slurry goes into the compost pit where it is dried naturally. The mixing room houses a mixing tank, mixer and an air blower. It's a square shaped room with side 2.7 m and height of 2.5m. It is made up of single brick wall as it doesn't have to take any load. Mixing tank is the commonly used 300-liter capacity plastic tank with diameter 0.64m and height 1m. For connections 8 inch diameters PVC pipe have been used. Primary and secondary digesters are constructed with bricks and concrete and the floating drum made of glass fibre is selected as it is easy to maintain.

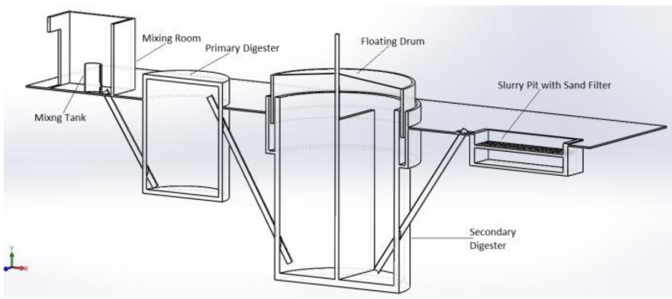

Fig. 1. Front sectional view of biogas digester from solid works.

B. Design of Primary Digester

Each day 2000 kg of cow dung and 2000 litres of water are fed to the primary digester and this slurry stays in it for six days. The volume of the primary digester has been obtained to be 24 cubic meter as follows.

$$Volume = Feed\ rate/day \times Retantion\ time = 4\ m^3/day \times 6\ days$$

Rohan N. Khedekar and Prashant Jain, "Feasibility analysis of a community biogas power plant for rural energy access," *International Research Journal of Advanced Engineering and Science*, Volume 1, Issue 3, pp. 125-129, 2016.

Now if radius and height of the primary digester are r and h respectively and the height to radius ratio is 2.4, then

$$Volume = 24\ m^3 = \pi \times r^2 \times h = \pi \times r^2 \times 2.4\,r = 7.54\ r^3$$
$$\Rightarrow r = 1.471\ m\ and\ h = 3.531\ m$$

Adding an extra 10 % height to the digester for air and smooth processing we get the height as $h = 3.884\ m$.

For calculating thickness of digester wall, the maximum hydrostatic pressure at the wall will be the governing criterion. This is maximum at the bottom portion of the wall and will be,

$$hydrostatic\ Pressure = \rho gh = 2000 \times 9.81 \times 3.531 = 69.28\ kN/m^2$$

If the minimum thickness of the digester wall is t, then $t = p \times r/\sigma$, Where p is the maximum pressure, r is radius and σ is the tensile strength of the concrete brick wall which is 2 MPa, acting in the circumferential direction.

Thus thickness of the digester wall, $t = p \times r/\sigma = 69.28\ kN/m^2 \times 1.471\ m\ /2\ \text{MPa} = 50.95 \times 10^{-3}\ m{\sim}51mm$

In actual construction, brick width is 90 mm. Also a factor of safety is needed so the wall thickness has been taken as 150 mm.

C. Design of Secondary Digester

This has been done in the same way as for the primary digester. Retention time in secondary digester is 24 days. Internal radius and the height have been found to be 2.34m and 5.61m respectively. Adding an extra 10% to the height we get the height as 6.17m. The minimum wall thickness has been obtained to be 128.5 mm. The actual width of the brick being 90 mm and to adjust for factor of safety the wall thickness has been taken as 200 mm. In this design a water jacket has been provided around secondary digester for the floating dome. This will not only protect the floating drum from erosion but also be easy to maintain. The aesthetic looks and cleanliness are added advantage. Considering 250 mm of space for water and floating drum the internal radius of water jacket has been taken as 2.785 m. With a single brick wall and the plastering, the outer radius of the water jacket will be around 2.9 m.

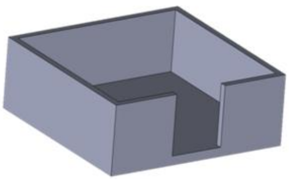

Fig. 2. Collection pit.

D. Collection Pit

Cow dung collected from farmers' homes and the in-house cow sheds comes to the collection pits. Taking the density of fresh cow dung as 960 kg per cubic meter [2] the volume of the collection pit required comes to be 2.083 cubic meter. Considering the allowance, a simple rectangular pit of area 2x2 square meter and height 1 m has been selected. The collection pit is made up of 100 mm thick single brick wall.

E. Slurry Pit

From the secondary digester the slurry comes out to the slurry pit. Daily output of the slurry being approximately 4m^3 and considering the allowance a rectangular area was selected for slurry pit with 2x4 m^2 and 1m height. For quick drying a provision for sand filter has been made as shown in the diagram. Also, a 0.5 horse power pump has been provided for removal of water from bottom of the pit.

F. Cow Shed

Based on the Livestock Census Report 2012 published by Government of India the number of bovines in an average village of India has been estimated as 485. Out of this 10% i.e. 48 have been assumed to be retired, stray or abandoned bovine who stay at the cow shed of the community biogas power plant. Design is made as per the Indian standards. For one bovine 1.2m x 2.2m floor area is needed with a shed height of 2.5m [3].

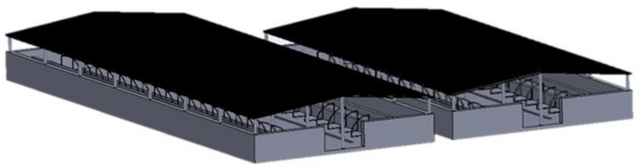

Fig. 3. Cow shed design is solid works.

G. Bio-Fertilizer Pit and Shed

Vermicomposting bed is made of single brick wall. Vermicomposting needs 45 days to complete and after drying 1-ton slurry is coming out of pit every day. So we require 45 pits each of 1-ton capacity. Each pit is 24 feet long and 3 feet wide and 2.5 feet high [4]. The surrounding pit wall is having a height of 6 feet. It doesn't have any load on it therefore its 150 mm thick single brick wall. Pits are arranged in 15 columns and 3 rows.

H. Balloon storage

Flexible balloon of capacity 50 m^3 is used to store biogas generated from the digester. Standard material for biogas balloon is neoprene rubber. Balloon has 3.4 m diameter and height is 5.5 m. It is placed in vertical orientation and it is enclosed by sheet metal room which is having length and width of 4 m each and a height of 6 m. It is cylindrical type balloon storage and has one inlet and outlet valves and one drain valve as accessories.

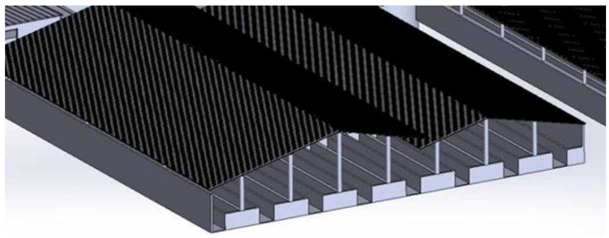

Fig. 4. Bio-fertilizer pit with shed.

I. H_2S Scrubber

It is H_2S scrubber cum moisture separator with a capacity of 10 m^3/hour. H_2S Scrubber in MS Epoxy coating with 1 time charged cartridge consist of iron chips mixed with steel wool a proprietary catalyst. They are 2 m in height and 0.4 m in diameter. Suitable for stripping H_2S and moisture from biogas for feeding into gen-set and burner.

First biogas is pass through iron chips and steel wool to absorb some amount of H_2S in it, then biogas is pass through pressurised water column such a way H_2S is removed.

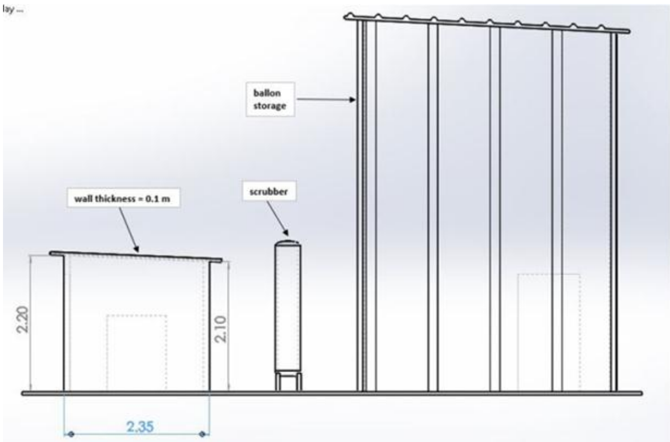

Fig. 5. Balloon storage, scrubber and generator design in solid works.

J. Generator Room

The generator room houses an IC engine coupled with a generator. It's a modified diesel engine with a compression ratio reduced to less than 12, a spark plug and a carburettor added to it. It runs on 100% biogas. A generator with 30 KVA capacity has been selected. Accessories of the system are control panel, MCB, auto change over and wagon trolley. It generates 25 kW of electrical power. Generator room is around 3.8 m long and 2.4 m wide and 2.2 m high, wall thickness of the room is 0.1 m.

I. Mixer

Mixer is mounted on the mixing tank for mixing cow dung and water. Capacity of the tank is 300 litres so we need to make 13 batches of cow dung slurry. Mixer is a fabricated unit made up of sheet metal paddles welded together on a shaft which is connected to a one horsepower motor. It takes around 3 hours to mix and feed slurry to the digester.

J. Air Blower

In primary digester cow dung slurry is fed in, and with the help of blower air is blown in. Hydrolysis and acidogenesis these two steps take place in primary digester and microbes require oxygen to carry out the reaction. Cow dung and water produce 4 ton of slurry and it has 10% total solid content, so it has 400 kg of solid content and in it around 50% is carbohydrate; so it has around 200 kg of carbohydrate. A small chemical analysis will give the capacity of blower required for this process. Microbes convert carbohydrates into acetic acid and three molecules of hydrogen are released with two molecules of carbon di-oxide. Chemical reaction is given below.

$$C_6H_{12}O_6 + H_2O + \frac{1}{2}O_2 --> 2\,CH_3COOH + 3\,H_2 + 2\,CO_2$$

From this equation it's obvious that 0.0889 kg of Oxygen is required to process each kg of carbohydrates i.e. the air requirement per kg of carbohydrates will be 0.0889/0.23 or 0.386 kg. Air requirement in terms of volume will be 0.386/1.15 i.e. 0.3356 m^3 or 11.85 cubic feet. Thus every day for 200 kg of carbohydrate the air required will be 11.85* 200 i.e. 2370 cubic feet [5]. Air blower of capacity 0.5 HP power is selected; it has air capacity of 400 cubic feet per minute.

K. Solar Flat Plate Collector

The digester is working in thermophilic range of temperature that is from 45ºC to 55ºC. For maintaining this temperature inside the digester the use of a solar flat plate collector has been suggested that will be able to heat 2000 litres of water each day to the desired temperature. For achieving this temperature, the heat required will be

$$Q = m*C_p*(T_o – T_i) = 2000*4.187*(50-24) = 217.72 \text{ MJ}$$

For this 217.72 MJ i.e. 60.478 kWh of energy per day, taking an efficiency of the flat plate collector as 62% [6] and average solar radiation incident on tilted surface in Mumbai as 6.578 kWh/m^2 per day, the area of the collector will be

$$A = 60.478/ (6.578*0.63) = 15 \text{ m}^2 \text{ approximately.}$$

In rainy season a gas geyser will be needed to heat the water using some amount of biogas. Area of one collector is 2x1 m^2, so a total of 8 collectors will be needed in parallel connection.

L. Gas Flow Meter

The gas flow meter is needed to monitor the flow rate and quantity of biogas produced each day. It is connected in series between scrubber and the I.C. Engine. It is basically a rotameter with a working range of 1-30 m^3/hr.

III. Financial Analysis of the Community Biogas Power Plant

A. Capital Cost

The capital cost consists of the cost for civil construction, and the cost of other components and systems that would need to be procured. The construction cost figures have been obtained from a civil engineer, experienced in designing and construction of such projects.

TABLE I. Capital cost of the plant.

Description		**(Cost) Rs.**
Biogas Digester Construction		
Earth work in excavation for foundation.		43,675
Hire and labour charges for shoring work (including necessary close planks, walking framing, piling, strutting, etc.		68,495
Earth work in filling in foundation with silver sand.		3,933
Silver sand dressing and filling in bed.		6,262
PCC or cement concrete with graded jhama khoa (30mm) excluding shuttering.		29,177
Ordinary cement concrete (mix-1:1.5:3) with grade stone chips (20mm normal size) excluding shuttering and reinforcement.	Foundation	47,995
	Walls	4,40,033
Hire and labour charges for shuttering with centring & necessary using approved stouts props and thick hard wood planks of approved thickness with required bracing for concrete slab, wall etc.		1,89,281
Reinforcement for reinforced concrete work in all sorts of structures including distribution borr and		14,23,234

Rohan N. Khedekar and Prashant Jain, "Feasibility analysis of a community biogas power plant for rural energy access," *International Research Journal of Advanced Engineering and Science*, Volume 1, Issue 3, pp. 125-129, 2016.

strip, binders etc.	
Total	**22,52,085**
Bio-Fertilizer Pit Construction	
Hire and labour charges for shoring work (including necessary close planks, walking framing, piling, strutting, etc.	1,13,645
P.C.C or cement concrete with graded Jhama Khoa (30mm) excluding shuttering.	2,71,400
Roof sheets	1,15,200
Total	**5,00,245**
Cow Shed Construction	
Hire & Labour charges for Shoring work (including Necessary Close Planks, Walking Framing, Piling, Strutting, etc.	2,03,206
P.C.C or Cement Concrete with Graded Jhama Khoa (30mm) excluding shuttering.	1,56,860
Roof Sheets	1,18,080
Total	**4,78,146**

……. continued

Description	**(Cost) Rs.**
Auxiliary Constructions	
Collection pit	17,748
Generator Room	44,528
Total	**62,276**
Cost of Other Component and Accessories	
Biogas generator	4,00,000
H_2S scrubber	85,000
Balloon storage	76,000
Mixer (1 hp)	6,500
Air blower (0.5 hp)	7,000
Flat Plate Collector [7]	2,34,300
Gas Flow Meter	25,000
Total	**8,33,800**
Grand Total	**41,26,552**
Government Subsidy (Less)*	**8,75,000**
Capital Cost	**32,51,552**

**Government Subsidy*

The Government of India has many schemes to promote renewable energy generation by providing subsidy. As per the guidelines given by MNRE, a biogas plant with a capacity of 20 kW to 100 kW is eligible for a subsidy of Rs. 35,000 per kW. The plant designed in this work has a capacity of 25 kW, so its eligible for a subsidy Rs. 8,75,000.

B. Operation and Maintenance Cost

The operating cost consists wages to labour, running cost of mixer and air blower, cost of cattle food, purchase cost of cow dung from villagers and cost of worms for vermicomposting. The computations for these recurring costs have been given in the following table. As is customary, the abandoned bovine which stays at the plant cow shed will be fed with the ordinary fodder at a cost of around Rs.16 per day. The bovine population in the village comprises of cattle and buffalo, adult and calves with a dung production capacity of 5 to 15 kg per bovine per day. So, an average dung production capacity of 10 kg per bovine per day has been considered. Dung collection efficiency for household bovines has been assumed to be 40% as the villagers would like to use it for dung cakes for cooking. The air blower runs for 3 hours a day. The worms for vermicomposting need to be purchased only for initial 6 months. Thereafter the plant will become self-sufficient with regards to worms. Two skilled and 2 unskilled labours will be needed to operate and maintain the plant for a four-hour shift each. Wages for these workers have been taken from the government regulations for wage payments.

Engine and air blower will need lubrication and careful maintenance. For the engine for a daily running of 6 hours, a lifespan of 18000 hours, engine oil change interval of 220 hours i.e. 10 times per year, the cost of oil has been estimated as Rs. 30,000 per year.

TABLE II. Operating and maintenance cost.

Description	**Rs.**	**Calculation**
Operation Cost per Year		
Cattle feeding cost	2,77,400	Rs. 16/day/cattle*48 *365
Cost of cow dung purchased from villagers	2,97,840	Rs. 0.5/kg*Average dung 10 kg/bovine* 365*Collection efficiency 40%
Mixer and air blower running cost	4,198	0.75 kW * 3 hr/day * Rs. 5/kWh * 365
Worms' cost for vermicomposting	25,740	2.854 kg * Rs. 50/kg * 180 days
Workers' wages (28,200*12)	3,38,400	(2 labour * Rs.310/day * 365) + (2 labour * Rs.160/day *365)
Total	9,43,578	
Maintenance Cost per Year		
Cost of lubricating oil per year for 10 oil changes	30,000	Rs. 3000 * 10
Total Operation and Maintenance Cost	**9,73,578**	

IV. REVENUE GENERATION FROM BIOGAS PLANT

TABLE III. Revenue generation from plant.

Particulars	**Value**	**Calculations/ Remark**
Amount of Electricity Generated		
Amount of dung fed to the plant per day	2000 kg	Fed both by household bovines and cattle at the plant
Total volume of biogas produced	88 Nm^3	2000 * 0.044 (at a rate of 0.044 m^3/kg)
Total electricity produced from biogas	149.6 kWh	88 Nm^3 * 1.7 (at a rate of 1.7 kWh/Nm^3)
Amount of Bio-fertilizer Produced		
Material input to digester per day	4000 kg	2000 * 2 (Dung: water = 1:1)
Slurry produced	3800 kg	4000 * 0.95
Slurry weight after drying	1026 kg	3800 * 0.27 [4]
Amount of bio-fertilizer produced	513 kg	1026 * 0.5 [4]
Revenue Generation per Year		
Sale of electricity	Rs. 3,00,322	149.6 kWh * 5.5 Rs. /kWh * 365 days
Sale of Bio-fertilizer	Rs.8,42,602	0.513 Ton/day *4500 Rs. /Ton *365 days
Revenue Generation through REC	Rs.1,90,021	149.6 kWh * 3.48 Rs. /kWh * 365 days
Revenue through Carbon Credits	Rs. 40,250	For electricity generation and Bio-fertilizer
Total Revenue Generation	**Rs. 13,73,195**	

Rohan N. Khedekar and Prashant Jain, "Feasibility analysis of a community biogas power plant for rural energy access," *International Research Journal of Advanced Engineering and Science*, Volume 1, Issue 3, pp. 125-129, 2016.

V. RESULT AND CONCLUSION

In the above analysis the capital cost of the community biogas power plant has been obtained as Rs. 32,51,552 while the Operation and Maintenance is cost Rs. 9,73,578. The recurring incomes through the sale of electricity and the bio-fertilizer are Rs. 3,00,322 and Rs.8,42,602 respectively. Based on these values and assuming a plant life of 25 years and simple payback period for the project has been computed as 8.14 years. The internal rate of return based on the same data has been obtained as 10.3 %. This payback period and the IRR may be said to be fair, as the community biogas power plant has rural energy access as its objective and not the profit.

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Rohan N. Khedekar and Prashant Jain, "Feasibility analysis of a community biogas power plant for rural energy access," *International Research Journal of Advanced Engineering and Science*, Volume 1, Issue 3, pp. 125-129, 2016.