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Embodied Energy Calculation of Small-Scale Biogas Plants in Rural Areas of Bangladesh

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Abstract- *Installation of a biogas plant consumes a significant amount of energy, especially in transportation and manufacturing of various biogas plant construction materials. Energy conservation has become one of the crucial issues of today's world for reducing greenhouse gases emission into the atmosphere and for reducing the costs of materials. This paper has focused on some parameters relating to embodied energy in a biogas plant, particularly in the Bangladeshi context. Energy consumption in the production and transportation of necessary biogas plant materials (such as brick, cement, sand, etc.) and other materials used for construction has discussed. Data were collected from 20 small-scale biogas plants (2.4 m^3, 3.2 m^3, 4.8 m^3) located in different rural areas of Rajshahi, Bangladesh. It is found that the embodied energy of 2.4, 3.2 and 4.8 m^3 biogas plants are 9.4 GJ, 11.4 GJ, and 22.7 GJ respectively. Around 59-63% of total energy is costs by brick, 29-33% by cement, 1.5% by sand, 3-5% by PVC pipe, 1% by HDPE pipe and 0.5% by steel used to install the plants. It is also found that the energy required for the production of the construction materials was 83-85% of the total energy needed while transportation energy was 16-17%.*

Keywords: Embodied energy, Biogas plant, Consumption, Transportation

1. INTRODUCTION

The energy situation in Bangladesh is severely critical at present. The country is blessed with plenty of biomass sources which has been used for extracting energy by generating biogas for many years. Animal manures being easily accessible in rural areas are much used to produce biogas to be used for cooking. Rural people generally meet up the energy needs from traditional biomass fuels comprising of animal dung (20%), wood and wood wastes (35%), and agricultural residues (45%) [1]. About 8.65 million tons municipal waste, 102.6 million tons Cattle dung from 25.5 million cows and buffaloes, and 12.9 million tons poultry waste from 291.5 million chickens and ducks are produced in Bangladesh per year [2]. Such a large amount of these wastes can create a tremendous economic value which can be fruitfully utilized to produce biogas for cooking, heating and electricity generation. Besides, the production of biogas from organic waste significantly avoids emitting methane and nitrous oxide in the environment. According to the intergovernmental panel on climate change, nitrous warms the atmosphere 310 times more than carbon dioxide, and methane does so 21 times more [3].

The energy in biogas plants can be classified into two segments. (1) Maintenance/servicing energy of a biogas plant during its useful life, and (2) capital energy that goes into the production of a biogas plant (embodied energy) using different materials. Both types of energy consumption are required to study for the complete understanding of biogas plant energy needs. The embodied energy of biogas plants can vary over full limits depending upon the choice of construction materials and techniques. Embodied energy can be divided into (1) consumption of the energy in the production of necessary biogas plant materials, (2) energy required for transportation of biogas plant materials, and (3) energy needed for assembling the various materials to form the plant. This paper deals with two following aspects of embodied energy.

1. Energy consumption in biogas plant materials
2. Energy in the transportation of biogas plant materials.

It is expected that the information provided in this paper will help in selecting the proper size of energy efficient biogas plant based on embodied energy, thereby reducing the cost of materials.

2. ENERGY IB BIOGAS PLANT MATERIALS

2.1. Burnt Bricks

These are very commonly used for any type of masonry. In Bangladesh "Brick" is an essential construction material as there is lack of stones and other alternative building materials at a comparable cost. It is estimated that total brick production in Bangladesh is 17 billion per year [4]. The standard brick size is 240 mm × 115 mm × 70 mm in Bangladesh [5]. They require a considerable amount of thermal energy during the burning process. Most commonly used fuels for brick burning in Bangladesh are Coal, coal cinder and firewood. Generally, 0.20 kg of coal or 0.30 kg of firewood requires the burning process of each brick. This process translates into thermal energy of 4.25 MJ per brick or 1.21 MJ/kg (considering the weight of 1 brick= 3.5 kg) has been considered (Table 1) for the computation of energy content of biogas plant construction.

2.2. Cement

Cement is another significant material consumed in bulk quantities for biogas plant construction. Use of coal in the rotary kilns and energy required in crushing and grinding the clinker are the causes of energy consumption by cement. Locally available ordinary Portland 42.5 grade cement is selected in this work for construction of plants. Both the dry and wet processes are employed for the manufacturing of cement in Bangladesh, which causes energy consumption of 8 MJ/kg and 4.5 MJ/kg of cement, respectively. The value of 6.25 MJ/kg of cement given in Table 1 represents the average value of 8 and 4.5 MJ, which has been used in the computation of energy in this paper. An earlier study on energy in buildings in India [6] showed 5.75 MJ/kg energy for cement manufacture.

2.3. Sand

In Bangladesh generally, sand is used for construction works, collected from various rivers. The production cost of sand is mainly the cost of labor and machinery used. Earth-particle and clay-free sand have been used in this work. Sand is generally calculated in m^3, and as it is available in nature, its energy consumption can be considered as zero. Hence the only energy costs for sand production is labor and machinery which has been taken as 0.05 MJ/kg (Table 1) in this paper. A report by the Indian Institute of Technology, Delhi has given the embodied energy of sand 0.08 MJ/kg [7].

2.4. Connecting Pipe

15-centimetre diameter higher thickness Poly Vinyl Chloride (PVC) pipe is used in this work to connect the inlet to the digester and hydraulic chamber to the slurry pit. These pipes are locally available, having a thickness of 4-6 mm. The embodied energy of PVC has been taken (Table 1) as 104.15 MJ/kg in this work.

2.5. Gas Passing Pipe

High-density polythene (HDPE) pipe has been used in this work for passing the gas from biogas plant to outside area. This pipe is also locally available in the market having about 3-millimetre thickness and 2-centimetre diameter. Energy consumption of HDPE pipe has been considered as 90 MJ/kg, which is shown in Table 1.

Table 1. Energy in biogas plant materials.

Materials	Embodied energy MJ/kg
Brick	1.21
Cement	6.25
Sand	0.05
PVC pipe	104.15 [7]
HDPE pipe	90 [8]
Steel	42 [9]

2.6. Other Materials

A 2-centimetre diameter brackets welded galvanized pipe made of steel with 2-centimetre diameter gate valve was used to fix it on the zenith of the semi-spherical digester. For making this unmovable, two steel wire pieces were welded together on both sides of the pipe of about 30-centimetre long at the height of 3-centimetere from the bottom. The pipe is available in the local market and gets it welded at a local welding shop. Energy consumption of steel has been taken (Table 1) as 42 MJ/kg.

3. ENERGY IN TRANSPORTATION

Transportation of materials is one of the significant factors in the cost and energy of a biogas plant construction. The bulk of the construction materials in rural areas are transported using trucks in Bangladesh. The transportation distance may vary depending upon the location of the construction site. In rural areas, the materials travel anywhere between 5 to 300 km. Materials such as sand are transported from a distance of 10–50 km while bricks, crushed aggregates, PVC pipes, etc. have to travel about 5–50 km before reaching the construction site in rural areas of Bangladesh. In this work, the average distance was considered as 50 km for sand and brick transportation while the cement was transported from 300 km distance.

Cement and steel travel longer distance that are> 200 km to reach the plant location. Most of the cement industries are situated in urban areas like Dhaka, Bangladesh. Natural sand consumes about 0.05 MJ/ft^3 or 0.0011 MJ/kg (considering, 1 cubic feet sand = 43.30 kg) for every one km of transportation distance. Similarly, bricks require about 0.004 MJ/kg per km travel. Cement was also transported using trucks, diesel energy of 1 MJ/ton/km was spent during transportation.

The energy in the transportation of other materials such as HDPE pipe, PVC pipe, and steel pipe has been ignored as these materials are required in small quantities and generally transported along with brick or cement. Table 2 represents the summary of transportation of biogas plant materials.

Table 2. Energy in the transportation of biogas plant materials.

Type of material	Energy (MJ/kg)		
	50 km	100 km	300 km
Bricks	0.2	0.4	1.2
Cement	0.3	0.6	1.8
Sand	0.055	0.11	0.33
Other materials	-	-	-

4. CONSTRUCTION

A fixed dome design biogas plant has been promoted for this program as this is the most user-friendly and available in the rural areas. In this work, three types of size 2.4, 3.2 and 4.8 m3 have calculated. There are three major parts of a biogas plant- inlet chamber, digester and slurry pit. Also, an important part is the hydraulic chamber. All the assumptions (Table 3) and calculation were done according to Infrastructure Development Company Limited (IDCOL) biogas plant design standards [10].

Table 3. Assumptions for biogas plant construction.

For volume	For geometrical dimensions
$V_c \leq 5\%\ V$	$D = 1.3078 \times V^{1/3}$
$V_s \leq 15\%\ V$	$V_1 = 0.0827\ D^3$
$V_{gs} + Vf = 80\%\ V$	$V_2 = 0.05011\ D^3$
$V_{gs} = V_H$	$V_3 = 0.3142\ D^3$
$V_{gs} = 0.5\ (V_{gs} + V_f + V_s)\ K$	$R_1 = 0.725\ D$
Where K = Gas production	$R_2 = 1.0625\ D$
rate per	$f_1 = D/5$
m^3 digester volume per day.	$f_2 = D/8$
For Bangladesh K = 0.4	$S_1 = 0.911\ D^2$
m^3/m^3d.	$S_2 = 0.8345\ D^2$
h = 800 mm water volume (1	$V_1 = [(V_c + V_{gs}) - (\pi\ D^2\ H_1)/4]$
mm = 10 N/ m^2)	$h = h_3 + f_1 + H_1$

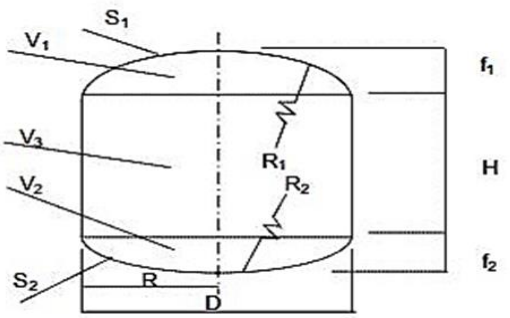

Figure 1: Geometrical dimension of the digester.

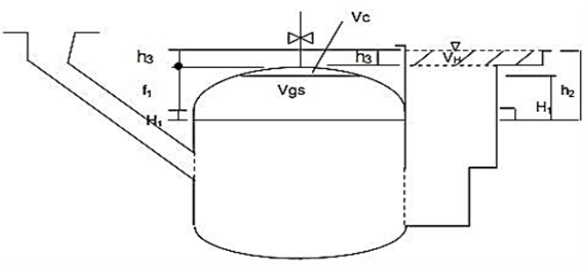

Figure 2: The Geometrical dimension of the hydraulic chamber.

Figure 3: Installation of a biogas plant.

For the calculation of constructional materials, strict general and civil and geometrical assumptions were considered. Figure 1 and 2 represent various dimensions of installed biogas plants and Figure 3 is the actual plant installed for this work. There were three types of structure in each plant, which are brick masonry, concrete slab and brick soling. For brick masonry structure, 100 square feet area requires 2.5 bag cement, 480 brick, and 11 cubic feet sand. For the concrete slab, 100 cubic feet volume requires 12.5 bag cement, 850 brick, and 45 cubic feet sand. And for brick soling, 100 square feet area requires 300 brick. 1 bag cement = 50 kg, 1 brick = 3.78 kg and 1 cft sand = 43.30 kg. By considering these values, all the calculations have done. Table 4 represents the amount of biogas plant construction materials.

Table 4. Amount of biogas plant construction materials.

Type of material	2.4 m^3	3.2 m^3	4.8 m^3
Brick (kg)	4090	4820	10100
Cement (kg)	350	475	925
Sand (kg)	1342	1667	3117
PVC pipe (kg)	5	5	5
HDPE pipe (kg)	1.5	1.5	1.5
Steel (kg)	1	1	1

5. ENERGY CALCULATION

Calculation of total energy for the installation of biogas plants has been done using Table 2, Table 3 and Table 4. From energy calculation (Table 5) of biogas plants, it is seen that 59-63% of total energy costs by bricks, energy costs for cement is 29-33%, sand is 1.5%, PVC pipe is 3-5%, HDPE pipe is 1%, and steel is 0.5% of total energy. It is also seen that the energy required for the production of the construction materials was 83-85% of the total energy required while transportation energy was 16-17%. Figure 4 represents the percentage of energy in various construction materials with plant size.

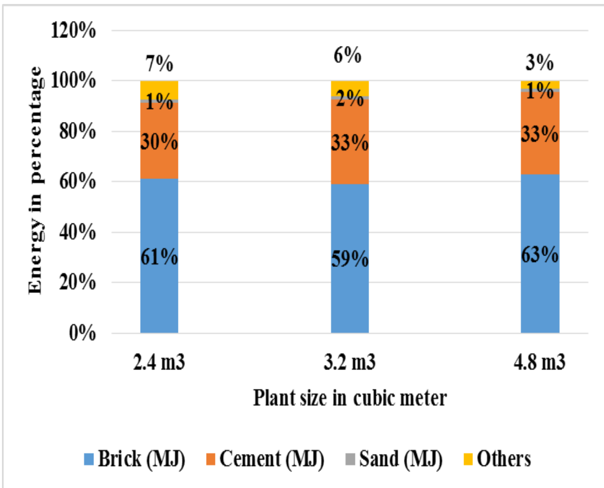

FIGURE 4. Energy costs by various biogas plant materials

Table 5. Summary of energy in MJ of different biogas plant materials.

Type of material	$2.4\ m^3$		$3.2\ m^3$		$4.8\ m^3$	
	Production	Transportation	Production	Transportation	Production	Transportation
Brick (MJ)	4948.9	818	5832.2	964	12221	2020
Cement (MJ)	2187.5	630	2968.8	855	5781.3	1665
Sand (MJ)	67.1	73.81	83.4	91.7	155.9	171.4
PVC (MJ)	520.8	-	520.8	-	520.8	-
HDPE (MJ)	135	-	135	-	135	-
Steel (MJ)	42	-	42	-	42	-
Total (MJ)	9423.1		11492.9		22712.4	

6. DISCUSSION AND CONCLUSIONS

To Embodied energy in necessary biogas plant construction materials has been discussed in this paper. The paper focuses on production and transportation energy consumption of different biogas plant construction materials. The energy needed for assembling the various materials to form the plant was not considered in this paper. The plants were newly installed to calculate embodied energy; thus, the depreciation energy losses were neglected. The following conclusions emerge.

1. Energy requirements of various biogas plant construction materials are five times greater than their transportation energy.
2. Bricks and cement consume the maximum amount of total embodied energy, which is almost 90-95%.
3. Brick is the primary energy consumption factor of all the materials used.
4. 3.2 m^3 sized plants require comparatively less energy than the other sized plants described.

The results of the paper give useful tips for selecting an energy-efficient biogas plant size leading to a considerable reduction in embodied energy. Even though the results pertaining to Bangladeshi conditions, many other developing nations have similar construction practices, where these results can be conveniently extrapolated and used.

7. REFERENCES

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8. NOMENCLATURE

MJ = mega joule
GJ = Gigajoule
Kg = kilogram
MJ/kg = mega joule per kilogram
PVC = polyvinyl chloride
Ft^3 = cubic feet