Energy, environment and economic analysis of biogas system

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ABSTRACT

An attempt has been made to estimate embodied energy from the building materials used in construction of various type of biogas plants, energy pay back time and potential carbon dioxide (CO₂) mitigation using renewable energy and different biomass for domestic cooking in India. Analysis of money pay back time has also been carried out. Using the data available in literature survey and the simple frameworks presented in this paper results of some typical calculations are presented and discussed.

Key words: Embodied Energy; Energy pay back time; Biogas; Carbon dioxide

INTRODUCTION

Biogas plants may be classified in several ways depending upon the plant design and mode of working. One common way to classify them is movable drum type and fixed dome type. These models in India are popularly known as the KVIC or the conventional type, the Janta and Deenbandhu model. These type models have their own merits and demerits though the fixed dome plants based on Chinese design are expanding fast in numbers. Digesters can also be vertical and horizontal displacement types depending on the orientation of digester. Horizontal displacement type plants faceless problems of scum formation than vertical types. The horizontal plants are suited for high ground water level or rocky areas. These are not recommended when retention time is 30 days¹².

A life cycle analysis for each energy service analyzed will start with identification of the primary energy source and progress through the appropriate steps for energy conversion and transportation up to the final devices providing energy service³. Fig 1 shows the overview of the life cycle analysis of a biogas system.

A model was developed⁴ for biogas production rate and period to achieve optimum temperature that is the functions of the temperature of the slurry. A life cycle costing technique⁵ was carried out taking into account the time value of the money to meet as much as electric energy demand as possible by an optimal decentralized mix of photovoltaic, biogas generator and biomass gasifier generator. Kandpal et al.⁶ developed and disseminated renewable energy technologies such as biogas plants and improved cookstoves and box type solar cooker to make efficient utilization of bio-fuels for domestic cooking in India and to reduce carbon dioxide (CO₂). The potential numbers of biogas plants, improved cookstoves and box type solar cooker were estimated⁷. A distributed energy systems was discussed⁸ based on renewable energy resources like solar, wind, hydro and bio-waste and compared on the basis of energy pay
back time. Embodied energy of building materials in India had been presented and comparative analysis\(^9\) were also carried out to gauge the energy efficiency of the walling elements and to identify the most suitable option\(^10\). An approach was developed\(^11\) to reduce the size and cost of the biogas system. A brief history of building materials, energy consumption in manufacture and transportation of some common and alternative building materials was described\(^12\) and its implication on environment.

A survey has been carried out in Punjab Agricultural University, Ludhiana, Punjab\(^13\). From the survey, the data so were collected used in analysis of biogas system has been worked out for different capacities and different KVIC models viz. horizontal and vertical digester biogas plants. In present study, an effort has been made to estimate the embodied energy from the building materials used in construction of the biogas plants\(^9\). The embodied energy is the amount of energy required to produce the materials in its present form\(^14\). Energy pay back time (EPBT) has been evaluated using embodied energy and energy output.

Economics and cost analysis has also been carried out\(^15\). Finally analysis of potential CO\(_2\) mitigation using renewable energy and different biomass has been carried out and results are discussed.

**Methodology**

Various biogas plants models for different plants size have been surveyed in the country\(^13\). The data so collected were used in carrying out the analysis in this paper. The embodied energy has been evaluated of building materials used to construct plant\(^9\). One cubic metre biogas is equivalent to 20 MJ\(^16\). The biogas production rate varies with climate conditions. Based on average conditions, with cattle dung as feed it is possible to get yield of 0.4 gas/day/m\(^3\) of digester volume of movable drum type plant\(^2\). The biogas is available for 300 days in a year.

Therefore, energy output annually for horizontal and vertical type biogas models at different digester capacities are mentioned in Table 1\(^13\). Embodied energy is calculated by the following relation:

\[
\text{Embodied energy} = \sum m_i e_i \quad \ldots(1)
\]

Where

- \( m_i \) = mass of materials used in constructing biogas plants in kg
- \( e_i \) = energy density of the material in MJ/kg

Energy output in MJ/day is calculated as

\[
\text{Energy output} = HV \times S \times G \quad \ldots(2)
\]

Where

- \( HV \) = Heating value of fuel in MJ/m\(^3\)
- \( S \) = Digester capacity in m\(^3\)
- \( G \) = Rate of gas production in m\(^3\)/day per digester capacity (m\(^3\))

And Energy output/year = \(HV \times S \times G \times 300\) \ldots(3)

Energy pay back time (EPBT) can be calculated using:

\[
\text{Energy pay back time (EPBT)} = \frac{\text{Embodied energy (MJ)}}{\text{Energy output (MJ/year)}} \quad \ldots(4)
\]

The Table 1 shows embodied energy and EPBT in MJ and in years respectively.

Cost analysis\(^5\) also has been carried out to yield net profit in Indian rupees (Rs.) per day\(^6, 15\) and Money pay back time in years. Based on the effective heat produced a 1 cubic metre biogas plant could replace, in a month, fuel equivalent of 13 kg of LPG\(^14\). If the unit cost of LPG at present is Rs. 24 per kg then, the cost of biogas is Rs. 10.4/day/m\(^3\) of plant digester capacity.

Initial cost is calculated by the following relation:

\[
\text{Initial cost} = \sum c_i Z_i \quad \ldots(5)
\]

Where

- \( Z_i \) = quantitiy of materials
- \( c_i \) = unit cost of materials in Indian Rupees

The total life cycle cost \( (T_c) \) is given by:
Table 1: Embodied energy, energy output and energy pay back time (epbt) for horizontal and vertical digester type biogas plants

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Digester capacity (m3)</th>
<th>Energy output (MJ/day)</th>
<th>Horizontal type biogas plants</th>
<th>Vertical type biogas plants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Embodied energy (MJ)</td>
<td>Embodied energy (MJ)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>EPBT (years)</td>
<td>EPBT (years)</td>
</tr>
<tr>
<td>1</td>
<td>2.83</td>
<td>22.66</td>
<td>31939.4</td>
<td>26412.91</td>
</tr>
<tr>
<td>2</td>
<td>4.25</td>
<td>34.0</td>
<td>37471.1</td>
<td>31122.91</td>
</tr>
<tr>
<td>3</td>
<td>7.08</td>
<td>56.64</td>
<td>45452.6</td>
<td>38374.09</td>
</tr>
<tr>
<td>4</td>
<td>14.02</td>
<td>112.16</td>
<td>86585.8</td>
<td>74734.20</td>
</tr>
</tbody>
</table>

Table 2: Total life cycle cost (Rs.) and Money Pay Back Time (MPBT) for Horizontal and Vertical digester type biogas plants

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Digester capacity (m3)</th>
<th>Horizontal type biogas plants</th>
<th>Vertical type biogas plants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>T_b (Rs.)</td>
<td>T_b (Rs.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MPBT (years)</td>
<td>MPBT (years)</td>
</tr>
<tr>
<td>1</td>
<td>2.83</td>
<td>41830.8</td>
<td>35772</td>
</tr>
<tr>
<td>2</td>
<td>4.25</td>
<td>54176.4</td>
<td>47586</td>
</tr>
<tr>
<td>3</td>
<td>7.08</td>
<td>65252.4</td>
<td>58242</td>
</tr>
<tr>
<td>4</td>
<td>14.02</td>
<td>104760.0</td>
<td>92398</td>
</tr>
</tbody>
</table>

Table 3: Amount of Fuel consumed and CO₂ emissions per year

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Fuel Consumed/yr (mt/yr)</th>
<th>Heating value (kJ/kg)</th>
<th>Device Efficiency (%)</th>
<th>%Carbon Content</th>
<th>CO₂ emission (mt/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal (coak)</td>
<td>1182.27</td>
<td>29000.00</td>
<td>70</td>
<td>85.2</td>
<td>3693.40</td>
</tr>
<tr>
<td>Firewood</td>
<td>10582.71</td>
<td>15119.00</td>
<td>15</td>
<td>48.68</td>
<td>18889.43</td>
</tr>
<tr>
<td>Dung cake</td>
<td>18591.68</td>
<td>8606.00</td>
<td>15</td>
<td>48.68</td>
<td>33184.91</td>
</tr>
<tr>
<td>Agriculture residue</td>
<td>12436.84</td>
<td>6286.00</td>
<td>15</td>
<td>48.68</td>
<td>22198.94</td>
</tr>
<tr>
<td>Kerosene</td>
<td>786.89</td>
<td>38125.00</td>
<td>80</td>
<td>80</td>
<td>2308.20</td>
</tr>
<tr>
<td>Gasoline</td>
<td>697.67</td>
<td>43000.00</td>
<td>80</td>
<td>80</td>
<td>2046.51</td>
</tr>
<tr>
<td>LPG (propane + n butane)</td>
<td>600.00</td>
<td>50000.00</td>
<td>80</td>
<td>83.45</td>
<td>1835.90</td>
</tr>
<tr>
<td>Methane (Natural gas)</td>
<td>600.00</td>
<td>50000.00</td>
<td>80</td>
<td>75</td>
<td>1650.00</td>
</tr>
<tr>
<td>Biogas</td>
<td>2000.00</td>
<td>20000.00</td>
<td>60</td>
<td>42.24</td>
<td>3097.60</td>
</tr>
</tbody>
</table>

$T_b$ = Initial cost + present worth of operation cost and maintenance + human labour cost in Indian Rupees (Rs.) ...

Money pay back time (MPBT) = $T_b$ / cost of biogas per unit time ...

Total life cycle cost ($T_b$) and Money pay back time (MPBT) in years of horizontal and vertical type biogas plants for various digester capacities are tabulated in Table 2. The EPBT values of horizontal and vertical biogas plants have been determined and are plotted.

The EPBT values of horizontal and vertical biogas plants have been determined and are plotted.
It is observed from the figure 2-3 that EPBT is minimum at 10 m$^3$ digester capacity of biogas plant. Therefore, 10 m$^3$ digester plant size produces (E) = 24000 MJ energy per year [14]. This total energy consumption (E) is considered as standard and the amount of fuel consumption per year is calculated as:

$$ E = \frac{HV \times n}{C} $$  \hspace{1cm} (4)

By considering different fuels (coal/firewood/dung cake/agriculture residue etc.), the CO$_2$ emissions for each fuel is calculated. In order to estimate CO$_2$ emissions from different fuel for the same energy consumption, the following expression is adopted

$$ Q_{CO2} = m \times c $$  \hspace{1cm} (5)

---

**Fig. 1:** Overview of the life-cycle analysis of a biogas system

**Fig. 2:** Variation of energy pay back time (EPBT) with digester capacity of horizontal type biogas plant

**Fig. 3:** Variation of energy pay back time (EPBT) with digester capacity of vertical type biogas plant
RESULTS AND DISCUSSION

The figures 2-3 represent the variation of EPBT along with different digester size of biogas plants. From the graphs, it is observed that EPBT decreases significantly with increase in the digester capacities of plants.

Figures 4 - 5 show graphs for MPBT of horizontal and vertical type models variation in along

CONCLUSIONS

From the analysis the following conclusions can be drawn:
1. EPBT decreases as the biogas plant size increases.
2. MPBT also decreases in same manner with increase the plants size of various models.
3. Biogas is non-commercial and environment friendly renewable source of energy (fuel).
4. The pollution emitted by biogas is comparatively very low as compared to other biomass fuels

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REFERENCES


