Final Report on

“Optimization of
Biogas Plants using Digester Heating Technologies”

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Abstract

This report presents different biogas heating technologies being used around the globe for the effective temperature maintenance in the biogas reactors. Biogas plants with waste heat recovery from electricity production schemes and solar heated system have been studied and presented in this report.

For biogas plants with waste heat recovery from electricity production schemes, five designs have been identified and pros and cons of each design has been analyzed and presented. Similarly, for biogas with solar heated system, three systems have been identified and pros and cons of each system has been analyzed and presented. In addition, there designs for non-electricity scheme have been discussed.

It was determined that flowing water at velocity of 4 m/s using 5 HP water pump through a pipe of 1 inch diameter was necessary to keep the water temperature at 40 °C. The total number of coils was needed to be 19 with 1.25 inch of gap between them. For the heating purpose, it was calculated that 36 panels of dimension 4 ft x 10 ft would be required.
Acknowledgement

We are highly indebted to National Rural and Renewable Energy Programme (NRREP), Alternative Energy Promotion Center for giving us this opportunity to work on this project of optimization of biogas Plants using heating technologies. Our special thanks goes to Mr. Sushim Man Amatya, Program Officer, Biogas Energy, Alternative Energy Promotion Center and Mr. Sujesh Shrestha, Programme Consultant, Alternative Energy Promotion Center for their valuable suggestions to complete this project successfully.

This acknowledgement would be incomplete without mention of Mr. Mahaboob Siddiki, Executive director Global Green Energy (p) Ltd (GGEC) for his help in this project. We would like to thank Mr. Ashish Ghimire, Mechanical Engineer, Alliance Consultancy Pvt Ltd for his help in providing us with the useful information regarding the cost rate of the material used in the system. We owe our hearty thanks and appreciation to all the people who are directly or indirectly involved with this project in giving us valuable suggestions and recommendations during the project period.
# Table of Contents

Abstract .......................................................................................................................................................... 2  
Acknowledgement ........................................................................................................................................ 3  
Table of Contents .......................................................................................................................................... 4  

1. Introduction ........................................................................................................................................... 7  
   1.1. Background ....................................................................................................................................... 7  
   1.2. Objectives ......................................................................................................................................... 8  
   1.3. Scope ............................................................................................................................................... 8  
   1.4. Methodology ...................................................................................................................................... 9  
   1.5. Limitations of the study ..................................................................................................................... 9  

2. Literature Review ................................................................................................................................... 10  
   2.1. Biogas history and current status in Nepal ....................................................................................... 10  
   2.2. Biogas Digester Heating Technologies ............................................................................................ 12  

3. Waste heat recovery from electricity production schemes ..................................................................... 15  
   3.1. Design 1: Preheating the Substrate .................................................................................................. 15  
   3.2. Design 2: Heating the slurry from the base of the digester ............................................................... 17  
   3.3. Design 3: Heating the slurry from the inside walls of the digester ................................................... 19  
   3.5. Design 5: Digester with built in heat exchanger .............................................................................. 21  

4. Design of solar heated biogas plants ....................................................................................................... 23  
   4.1. Design 1: Solar Hut .......................................................................................................................... 23  
   4.2. Design 2: Use of solar water heater ................................................................................................. 24  
   4.3. Design 3: Heating the biogas by using reverse absorber type solar heater ....................................... 26  

5. Waste heat recovery from non-electricity production schemes .............................................................. 26  
   5.1. Design 1: Biomass Integration in the Bio-digester ............................................................................ 27  
   5.2. Design 4: Use of compost pile ......................................................................................................... 27  
   5.3. Design 5: Biogas Reactor using greenhouse technology ................................................................. 30  

6. Design Calculation .................................................................................................................................. 31  
   6.1. Design selection ................................................................................................................................ 31  
   6.2. Design conditions ............................................................................................................................. 31  
   6.3. Calculation for theoretical heating requirement ............................................................................... 32  
   6.4. Calculation of influent heating (QT) ................................................................................................. 32  
   6.5. Calculation of heat loss (QL) ............................................................................................................ 33  
   6.6. Calculation of total resistance to heat flow and heat loss ................................................................ 34
List of Figures

Figure 1: Temperature effect on Biogas Production

Figure 2: Preheating of substrate

Figure 3: On vessel heat exchanger (base heating)

Figure 4: On vessel heat exchanger (walls and base heated)

Figure 5: On vessel heat exchanger with base heated. The slurry is preheated by burning a portion of the produced biogas.

Figure 6: Heating system for a bio-digester under construction (Germany)

Figure 7: Schematic Diagram of Digester with built in heat exchanger

Figure 8: Bio-digester with External heating system (Karki et al, 2005)

Figure 9: Solar Hut (BSP-Nepal, 2005)

Figure 10: Cross-section of an active dome digester (Tiwari et al, 1992)

Figure 11: Solar panel is installed on the top of digester itself

Figure 12: Heat recovery unit (source: El-Mashad, 2003)

Figure 13: Biogas Digester with built in solar absorber heater (Abid et al, 2012)

Figure 14: Composting Pile (BSP-Nepal, 2005)

Figure 15: High altitude biogas reactor at Lukla/Mosi (BSP-Nepal, 2005)

Figure 16: BioDigester wrapped in insulating bag

Figure 17: Selected design

Figure 18: Heat transfer mechanism
1. Introduction

1.1. Background

Biogas plants are installed and used in many parts of Nepal, covering the Terai, the Hills and, to a lesser extent, the Mountain regions. The performance of biogas plants is affected by many factors, among which temperature is one of the key parameters impacting on the digester’s biological activity and, therefore, biogas production. Bacteriological methane production increases with temperature, and it has been observed that, in spite of increasing the hydraulic retention time in the hills and the mountains to compensate for the colder climate, biogas production is significantly reduced in these regions compared with the plants installed in the Terai, especially during the winter months.

Currently, the main strategies to mitigate heat losses and maximize temperature in the digester in Nepal and other developing countries includes building biogas plants underground, which also buffers the potential harmful effect of sharp temperature changes; and locating the biogas plant in areas where it would receive direct solar radiation. In any case, biogas plants are, during part of the year, and in particular over the winter and during night time, working in the psychrophilic range (temperatures below 20°C). This results in the need of higher hydraulic retention time and lower gas production.

There is, therefore, great potential to develop new solutions for increasing the operating temperature of biogas plants up to the mesophilic (30-40 °C) or thermophilic ranges (40-55 °C), which will increase biogas production and reduce the hydraulic retention time required, resulting in lower active slurry volumes and therefore lower biogas plant volumes. This will, in turn, reduce the capital cost of the plant, although this effect may be somewhat offset by the cost of the heating equipment. However, the benefit of an increased, sustained gas production throughout the year will represent a significant improvement for the user. The increase in temperature will also have a positive effect in pathogen kill, which will produce safer slurry to be used as fertilizer. There are a number of options available to achieve higher digestion temperatures. In systems in which biogas is used for electricity production, recovery of waste heat from the engine would present a feasible alternative to heat up the digester, be it through an external heat exchanger where sludge is pumped through and re-circulated to the digester gaining the heat passed from the engine cooling water, or through an internal coil heat exchanger where the engine cooling water is pumped through transferring heat to the bulk of the digester. Another alternative, possibly more suited to those systems where biogas is not used for electricity production, would be the use of solar panels that heat up water that is pumped either to an
external or internal heat exchanger where heat is transferred to the sludge. Other options may include, among others, pre-heating the digester feed, other means of insulation or using a proportion of the biogas to heat up water that could then be used to transfer heat to the sludge.

1.2. Objectives

To assess, design, and recommend a suitable technological alternatives for digester heating in Nepal’s context.

1.3. Scope

I. Waste heat recovery from electricity production schemes:

   a. Carry out a study on existing alternatives for waste heat recovery from biogas electricity production systems for digester heating of large scale biogas plants in Nepal’s context (30, 35, 50, 65, 80, 100 m3 plants). The study shall include the following:

      • Literature review, estimation of the potential for biogas production increase with increased temperature, reduction of hydraulic retention time and increased pathogen kill for increased temperatures. The consultant shall recommend the optimum temperature range for digester operation.

      • Assessment, review of the various existing options and designs and recommendation of the most suitable and cost-effective one(s) for Nepal.

      • Identification of the suppliers of material, replacement parts and equipment required for the heating system nationally and internationally.

      • Provision of cost estimates and delivery lead time for all of the above.

II. Design and testing of a solar heated biogas plant

   i. Study report on the suitability of solar heated biogas plants in the different regions of Nepal. The report shall also produce of a cost-benefit analysis financial feasibility study to determine the viability of plants with solar heating and identify manufacturers of all equipment necessary. Literature review, estimation of the potential for biogas production increase with increased temperature, reduction of hydraulic retention time and increased pathogen kill. The consultant shall recommend the optimum temperature range for digester operation.

   ii. Provision of a full design specification (process, mechanical, civil) including all drawings and calculations (sizing of equipment, heat transfer calculations, materials, etc.) for a solar heated biogas plant. The design shall be adapted for installation in the modified GGC 2047 biogas plant of 6 m3.

   iii. Provision of all drawings related to the system
iv. Production of a control philosophy for the system.

v. Determination of the most suitable materials for the system, including any protective measures such as coating or others, especially for those that will be in contact with sludge or within the bulk of the digester to avoid corrosion.

1.4. Methodology

The overall objective of the project is to achieve the optimum temperature in the biogas digester by incorporating various types of heating system in the existing GGC 2047 model. To this regard, the major concern addressed is the long HRT, large digester volume requirement, and low rate of biogas generation. To carry out the project, MinErgy has proposed three qualified professional in the respective field. The biogas expert will lead the team, while the energy recovery and solar expert will provide their respective input to perform the respective task.

The entire project constitute of three different tasks;

a. Identification and technical analysis of large biogas plants with digester heating utilizing waste heat from electricity generation,

b. Identification and technical analysis to large biogas plants using solar thermal technology

c. Detail design of 35cum biogas plant using solar thermal technology

Identification and technical analysis digester heating system was carried out through desk study of multitudes scientific journals, national and international reports on biogas heating technologies. After the consultations with AEPC/NREEP, most suitable biogas heating technology was selected for detail design. Detail design consists of design of solar water heaters, design of heat exchangers and pump to maintain the temperature of digester at 40 degree centigrade. A software programme based on excel sheet has also been developed to assist design of solar thermal technology appropriate for various size of biogas plants.

1.5. Limitations of the study

Following are some of the limitations of the study;

- The study is focused on the desk literature review of different heating designs of biogas reactors whose practical effectiveness in Nepalese condition is yet to be explored.
- The biogas heating technologies are primarily analyzed based on its heat transfer effectiveness.
- It has been assumed that the bio digester will be fed with cow dung and water in equal ratio and subsequent calculation were based on that.
2. Literature Review

2.1. Biogas history and current status in Nepal

Nepal has a history of over 50 years of biogas technology development. The first historical biogas system was introduced in 1955 at St. Xavier’s School in Godavari, 20 kilometers southeast of Kathmandu by late Rev. B.R. Saubolle, S.J. His observation of the system’s performance and the people’s reaction to the technology was indeed noteworthy. After this pioneering venture attempted by Father B.R. Saubolle, it took almost 20 years to draw the attention of the Nepalese government towards biogas technology. On the auspicious occasion of the “Agricultural Year”, a biogas programme was launched by the government as a special program in 1975/76. The occasion also marked the disbursement of interest –free loan for big digester construction. Altogether 199 units of biogas systems were then established in the country. This marked the beginning of the growth in the implementation of biogas systems. Further momentum in the development took place in 1977 with the establishment of the Gobar Gas TathaKrishiYantraBikash Company (GGC), a pioneering and leading biogas system construction company in Nepal. The literature denotes that total 11,835 biogas plants were constructed till 1991.

Later on, Biogas Support Programme (BSP) was launched in July 1992 with funding from the Directorate General for International Cooperation of the Netherlands (DGIS) of the Netherlands Government through the Netherlands Development Organization-Nepal (SNV/N). In 1996, the Government of Nepal established the Alternative Energy Promotion Centre (AEPC) under then Ministry of Science and Technology with the purpose of development and promotion of renewable energy technologies throughout the country. Since then AEPC has been able to establish itself as a national focal agency point for coordinating renewable energy related activities in Nepal, and it has been actively promoting the use of these energy technologies through implementation of a number of programmes and projects to meet the rural energy needs.

Government of Nepal (GoN) and the German Development Bank (KfW) also started funding the BSP from the Phase–III, which started in March 1997 and lasted till June 2003. Until Phase–III, BSP was directly implemented by SNV/N. BSP Phase–IV (July 2003-2010) was implemented after successful completion of the first three phases. As a substantial amount of the DGIS fund
was being left unspent, a Budget Neutral Extension (BNE) was made earlier- and phase IV was carried out until December 2010 and Interim Phase for the period from January 2011 to 15 July 2012. As of July 2012 the programme has reached 75 districts and some 2,800 Village Development Committees (VDCs), out of 3,915 VDCs in Nepal. Phase IV was implemented by Biogas Sector Partnership-Nepal (BSP-Nepal), an NGO and executed by AEPC. Likewise in the Interim Phase, AEPC took the role of Executing Agency whereas BSP-Nepal and Nepal Biogas Promotion Association (NBPA) as Principal Implementing Agency and Implementing Agency respectively. Currently, Biogas Program is being implemented under AEPC/NRREP from 16 July 2012 to 15 July 2017 supported by the Government of Nepal, DANIDA, the Norwegian Government, KfW, WB, SNV and DFID. However the year 2012 can be taken as the transition period of the Biogas programme.

Initially 11 biogas companies were established in F/Y 1991/92 under the Biogas Support Programme in Nepal. Now around 100 biogas companies and 17 biogas appliances manufacturing workshops have been established and pre-qualified for the biogas construction, installation and manufacturing biogas appliances purposes throughout the country. Primarily these companies are involved in the promotion of biogas while the national & local NGOs and District Environment and Energy Unit/Sections are also involved in the promotion of biogas in their respective areas. In tandem with this some of the micro finance institutions, banks and development projects are also promoting biogas in their working area. Further, under the Biogas Support Programme more than 6,012 technical persons (masons, supervisors, junior biogas technician, and biogas level-4 technicians) have been trained and produced during the programme period from 1992 to 15 July 2012.

The overall objective of BSP was to further develop and disseminate biogas plants as a mainstream renewable energy solution in rural Nepal, while better addressing poverty, social inclusion and regional balance issues and at the same time ensuring enhanced commercialization and sustainability of the sector. Biogas Support Programme is a development programme implemented with the public private partnership model in Nepal. And it is noteworthy that the programme modality has been replicated in 22 countries of Asia and Africa.

A successful development programme/project can be proven and announced only after its proper evaluation and impact analysis. Some tangible and superficial impacts can be seen and derived in a quantitative analysis during the project/programme implementation phase. But further, intangible, interrelated and interdependent impacts can be found only in the long run/after programme implementation. The result of impact analysis can demonstrate the cost and benefit of development activities or programme. It also supports the generation of new concepts and
ideas for further better programme implementation modality in future. The total number of plants constructed under the programme till 15 July 2013 is 290,000 including 7,500 plants from GSP and around 60,000 household biogas plants have been registered in Clean Development Mechanism (CDM). The success of a programme is not confirmed merely by quantitative figures of biogas plants only; various direct and indirect but important socio-economic benefits enjoyed by the users and as well as the nation through Biogas Support Programme must be taken into consideration. Every year AEPC conducts the biogas users’ survey to find out the impact of biogas plant. The survey shows socio-economic or environmental impact of only a limited number of biogas plants constructed during a certain time period; it does not reflect a complete socio-economic impact of the Biogas Support Program.

2.2. Biogas Digester Heating Technologies

To achieve the optimum biogas yield, the anaerobic digestion needs constant environmental conditions, preferably close to the process optimum. The digester temperature is of prime importance. In temperate areas, a heating system and an insulation of the digester are necessary. Hence, the needed temperature for digestion can be reached and a loss of energy by transmission is compensated.

Normally, because of the rather high involved costs, small-scale biogas plants are built without heating systems. But even for small scale plants, it is of advantage for the bio-methanation process to warm up the influent substrate to its proper process temperature before it is fed into the digester. If possible, cold zones in the digester should be avoided. In the following, a number of different ways to get the required amount of thermal energy into the substrate are described. In principle, one can differentiate between:

- **Direct heating** in the form of steam or hot water, and
- **Indirect heating** via heat exchanger, whereby the heating medium, usually hot water, imparts heat while not mixing with the substrate.

**Direct heating**

Direct heating with steam has the serious disadvantage of requiring an elaborate steam-generating system (including desalination and ion exchange as water pretreatment) and can also cause local overheating. The high cost is only justifiable for large-scale sewage treatment facilities.
The injection of hot water raises the water content of the slurry and should only be practiced if such dilution is necessary.

**Indirect heating**

Indirect heating is accomplished with heat exchangers located either inside or outside of the digester, depending on the shape of the vessel, the type of substrate used, and the nature of the operating mode.

1. Floor heating systems have not served well in the past, because the accumulation of sediment gradually hampers the transfer of heat.
2. In-vessel heat exchangers are a good solution from the standpoint of heat transfer as long as they are able to withstand the mechanical stress caused by the mixer, circulating pump, etc. The larger the heat-exchange surface, the more uniformly heat distribution can be effected which is better for the biological process.
3. On-vessel heat exchangers with the heat conductors located in or on the vessel walls are inferior to in-vessel-exchangers as far as heat-transfer efficiency is concerned, since too much heat is lost to the surroundings. On the other hand, practically the entire wall area of the vessel can be used as a heat-transfer surface, and there are no obstructions in the vessel to impede the flow of slurry.
4. Ex-vessel heat exchangers offer the advantage of easy access for cleaning and maintenance.

**Substrate heating using heat exchanger**

In countries with higher temperatures and longer sunshine hours, solar-heated water can be a cost-effective solution for heating. Exposing the site of the biogas plant to sunshine, e.g. by avoiding tree shade, is the simplest method of heating.

**Internal and external heating systems**

External heating systems have a forced flow on both sides. Due to the turbulent flow patterns of both media, very good heat transportation can be reached. Therefore, the surface of the heat exchanger can be comparatively small. Nevertheless those systems cannot be recommended for non-agitated digesters.
The proper dimensioning of an internal heating system seems to be more difficult because of the different currents due to pumping, agitation, thermo-convection and the inflow of biomass. Under-floor heating systems have been very popular, as they have no disturbing parts in the digester itself. Due to sedimentation and the resulting worsening of heat transportation into the digester, under-floor heating is no longer recommended. With the growth of digester volumes and the need of bigger heating systems, it is also more difficult to build under-floor heating big enough to provide the necessary heat.

Heating coils installed at the inner wall of the digester are a rather new practice. Heating coils made out of steel are much more expensive than heating coils out of plastic material (PE). Materials developed during the last years make such a system more stable while not increasing the costs of the heating system.

Another option is to construct two digesters connected in series, the first heated, the second unheated. The first digester can be used as sedimentation tank, in which the substrate is heated up. The second digester is well isolated to reduce loss of heat.

NOTE: There are prevalent practices of painting the dome of biogas digester with black paint for absorption of solar heat. This method also helps increase the temperature of the digester to some extent. Instead of paint, charcoal can be used to cover the dome. Charcoal also helps retain the heat for some time. This method had been reported to be in practice by some institute in Solan, India.

There are different ranges of temperatures which have direct effect on the anaerobic digestion process. Due to this reason, we divide temperature into three groups. These temperature ranges have different retention type of biogas production. So the table explained these two parameters briefly as shown:

<table>
<thead>
<tr>
<th>Thermal Stage</th>
<th>Process Temperatures</th>
<th>Minimum Retention Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psychrophilic</td>
<td>&lt; 20°C</td>
<td>70 to 80 days</td>
</tr>
<tr>
<td>Mesophilic</td>
<td>30 to 42 °C</td>
<td>30 to 40 days</td>
</tr>
<tr>
<td>Thermophilic</td>
<td>43 to 55 °C</td>
<td>15 to 20 days</td>
</tr>
</tbody>
</table>
3. Waste heat recovery from electricity production schemes

Five designs have been selected and studied for the electricity production biogas schemes. Pros and cons of each of those designs has been presented below along with their schematic diagrams.

3.1. Design 1: Preheating the Substrate

In this design the inlet manure slurry is preheated before it enters the digester. For preheating the slurry, the water used for cooling the generator will be used incorporating Waste Heat Recovery as shown in the figure above. The heat exchanger used in the process is a cross flow type named as Shell and Tube Heat Exchanger.

From the outside, the heat exchanger just looks like a large cylinder, while inside the water is circulated across a series of manure pipes. The water is heated by circulating it across several heat sources. The primary heat source for this water loop comes from the waste heat off the engine-generator that burns the biogas. Heat is added to the water from the engine-generator in two ways. First, the water is run through a separate heat exchanger to collect heat from the exhaust of the internal combustion engine. Next, the water is circulated through the coolant system of the engine block. If the engine is not able to provide enough heat, there are additional boilers that can provide the needed heat. (Boissevain, 2012)

The schematic figure of such system is drawn below:

![Figure 1: Preheating of substrate](image-url)
<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Design</td>
<td>The slurry may clog in the pipes and the system needs extra measures</td>
</tr>
<tr>
<td>Occasional maintenance and monitoring</td>
<td></td>
</tr>
<tr>
<td>Shell and tube heat exchanger can withstand high pressure and temperature</td>
<td></td>
</tr>
</tbody>
</table>
3.2 Design 2: Heating the slurry from the base of the digester

This design is similar to design 1 except introduction of heating arrangement of the base of the digester by employing running hot water from the generator. Its schematic diagram along with its pros and cons has been shown below:

![Schematic Diagram](image)

**Figure 2**: On vessel heat exchanger (base heating)
<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple in design as it has no disturbing parts inside the digester</td>
<td>Accumulation of sediment at the bottom hinders proper transfer of heat from the heated base to the slurry</td>
</tr>
<tr>
<td></td>
<td>The heat exchanger has to withstand high pressure from the slurry and biogas inside the digester, circulating pump etc. Therefore, the heating coils have to be made up of steel which is much expensive compared to plastic material.</td>
</tr>
</tbody>
</table>
3.3. Design 3: Heating the slurry from the inside walls of the digester
In this design outgoing gas from the digester is used to produce a flare to heat the incoming substrate while heating the base of the digester as well as heating the incoming substrate in the shell and tube heat exchanger. Its schematic diagram is presented below along with its pros and cons.

![Diagram of the digester with heat exchanger](image)

**Figure 3**: On vessel heat exchanger (walls and base heated)

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entire wall is subjected to heat transfer as heat exchanger are attached to the entire wall of the digester.</td>
<td>The heat exchanger has to withstand high pressure from the slurry and biogas inside the digester, circulating pump etc. Therefore, the heating coils have to be made up of steel which is much expensive compared to plastic material.</td>
</tr>
<tr>
<td>The positioning of heat exchanger on the walls allow free passage of slurry in the digester.</td>
<td>This design is inferior to in-vessel type as heat exchanger are attached to the walls of the biogas digester which lead heat to be lost to the surrounding and unhomogenous heat transfer to the slurry.</td>
</tr>
<tr>
<td>Heating is not uniform and manure is subjected to localized heating.</td>
<td></td>
</tr>
</tbody>
</table>
3.4. Design 4: Slurry is preheated by burning a portion of the produced biogas

![Diagram of Design 4](image)

**Figure 4:** On vessel heat exchanger with base heated. The slurry is preheated by burning a portion of the produced biogas.

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helps minimizing the thermal shock as heat exchanger performs better. More biogas can be extracted at the expense of a small portion of the produced biogas.</td>
<td>If the heating mechanism of produced gas is not maintained properly, it may lead to inefficient operating condition.</td>
</tr>
<tr>
<td></td>
<td>On-site personnel must be needed to inspect the system regularly.</td>
</tr>
</tbody>
</table>

**Recommendation:** The system efficiency can be increased if we install the digester under the ground so that it will be well insulated.
3.5. Design 5: Digester with built in heat exchanger

In this design hot water from generator is made to flow inside the digester by running a coil through it. Its schematic diagram is shown below:

![Figure 5: Schematic Diagram of Digester with built in heat exchanger](image)

For this design five options are available which are explained below with their pros and cons.

**Options available for all designs from 1 to 5**

**Option A: Heating the biogas digester by running hot water from the generator through a heat exchanger at its base.**

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple in design as it has no disturbing parts inside the digester.</td>
<td>Accumulation of sediment at the bottom hinders proper transfer of heat from the heated base to the slurry.</td>
</tr>
</tbody>
</table>
### Option B: Heating the biogas digester by ex-vessel heating

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allows easy access to periodic cleaning and maintenance</td>
<td>In terms of heat transfer efficiency, this system is not appropriate as most of the heat is lost to the surrounding.</td>
</tr>
<tr>
<td></td>
<td>Non-uniform heating of the manure.</td>
</tr>
</tbody>
</table>

### Option C: Heating the biogas digester by employing on wall heat exchanger

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entire wall is subjected to heat transfer as heat exchanger are attached to the entire wall of the digester.</td>
<td>The heat exchanger has to withstand high pressure from the slurry and biogas inside the digester, circulating pump etc. Therefore, the heating coils have to be made up of steel which is much expensive compared to plastic material.</td>
</tr>
<tr>
<td>The positioning of heat exchanger on the walls allow free passage of slurry in the digester.</td>
<td>Heating is not uniform and manure is subjected to localized heating.</td>
</tr>
<tr>
<td>This design is inferior to in-vessel type as heat exchanger are attached to the walls of the biogas digester which lead heat to be lost to the surrounding and unhomogenous heat transfer to the slurry.</td>
<td></td>
</tr>
</tbody>
</table>

### Option D: Heating the biogas digester through in-vessel heat exchanger

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniform heating of the manure can be expected due to its positioning.</td>
<td>Corrosion problem. So, the coils should be made of corrosion resistant materials making it expensive.</td>
</tr>
</tbody>
</table>

In this design, heat exchanger is kept inside the digester itself to heat the manure inside the digester pit. The hot water coming out of the generator is run in a closed system kept inside the digester.
4. Design of solar heated biogas plants

Three solar heated biogas plants design have been studied and analyzed to compare their effectiveness to each other. They are explained below:

4.1. Design 1: Solar Hut

A black plastic hut is made over the dome of a biogas digester so that solar radiation is absorbed by the hut and consequently rising the temperature of the digester.

![Solar Hut Diagram]

**Figure 6: Solar Hut (BSP-Nepal, 2005)**

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple in design and less costly as it requires an erection of a simple hut with black cover on the top.</td>
<td>Heat transfer from the hut to the digester will be not be efficient enough to maintain high yield of biogas during a cold climate.</td>
</tr>
<tr>
<td></td>
<td>Susceptible to vandalism or theft.</td>
</tr>
<tr>
<td></td>
<td>Life span of the hut which needs to be replaced periodically.</td>
</tr>
</tbody>
</table>
4.2. Design 2: Use of solar water heater

Option 1

![Cross-section of an active dome digester (Tiwari et al, 1992)](image)

**Figure 7**: Cross-section of an active dome digester (Tiwari et al, 1992)

In this design the slurry inside the digester is kept underground and heated via heat exchanger using the hot water from the solar water heaters so as to maintain the desired temperature for better production of biogas.

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficient system if enough sunlight is available as it serves to increase the digester’s reaction temperature and/or reduce reactor’s volume.</td>
<td>If water gets overheated, unnecessary reactions take place within the digester. Extra stirrer may be required.</td>
</tr>
<tr>
<td>Occasional maintenance and monitoring</td>
<td>Low temperature in the night may freeze the heat transfer fluid in the solar collector.</td>
</tr>
<tr>
<td>Simple design and easier to make.</td>
<td>Water used to cool the generator or in solar water heater needs to be filtered so as to prevent scaling.</td>
</tr>
<tr>
<td></td>
<td>Initial capital investment can be an obstacle to its successful implementation.</td>
</tr>
</tbody>
</table>

**Option 2: Solar panel is installed on the top of digester itself**
**Figure 8:** Solar panel is installed on the top of digester itself

Schematic of system configuration; 1- solar collector, 2- Agitator, 3- Heat exchanger, 4- auxiliary heater, 5-control; 6-pump, 7-heat recovery unit, 8-extra gas volume (Source: El-Mashad, 2003)

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>The system can be installed in undersized space as separate place is not needed for solar collector.</td>
<td>The addition of heat recovery unit and a separate chamber for it increases the system cost.</td>
</tr>
<tr>
<td>Inclusion of heat recovery unit enhances the efficiency of the system.</td>
<td></td>
</tr>
</tbody>
</table>

*NOTE:* Solar water heaters can be used in place of electricity systems for heating the biodigester. The pros and cons would be similar
4.3. Design 3: Heating the biogas by using reverse absorber type solar heater

![Diagram of biogas digester with built-in solar absorber heater](image)

Figure 9: Biogas Digester with built in solar absorber heater (Abid et al, 2012)

1 – Cylindrical methane tank
2 – Reverse absorber heater
3 – Pyramidal support
4 – Thermo insulating material
5 – Aluminum foil
6 – Metallic absorber
7 – Slurry
8 – Inlet
9 – Outlet
10 – Tap
11 – Partition
12 – Horizontal axes, cylindrical
13 – Horizontal glass cover
14 – Inclined glass cover

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>The convective and radiative heat losses in this type of solar air collector are reduced due to the down facing of the absorber.</td>
<td>Difficult to mount the biogas digester on the top of the solar system.</td>
</tr>
<tr>
<td>Suitable only for small biogas system.</td>
<td></td>
</tr>
</tbody>
</table>

5. Waste heat recovery from non-electricity production schemes

Three designs have been selected for non-electricity production scheme. They are explained separately below:
5.1. Design 1: Biomass Integration in the Bio-digester

Using a biomass stove to heat the substrate inside the bio-digester is one of the various possibilities of using external heating devices to the biogas production system.

In this system, water is heated by using biomass stove to produce hot water which can be employed for direct as well as indirect heating of the substrate inside the biogas digester. In direct heating, one can guide the produced hot water directly into the digester and through indirect heating one can heat the digester by employing a heat exchanger to exchange heat between the hot water and the substrate inside the digester. The substrate may be subjected to unnecessary dilution in case of direct heating. However, this system contradicts with the definition of environment friendly technology as burning biomass for heat generation results in GHG emissions.

5.2. Design 4: Use of compost pile

In this design, it is recommended that putting composting pile on the top of biogas digester dome can be an effective measure in increasing the temperature of the digester. The compost can be farm residues which when composted on top of the dome releases heat by metabolism. The heat
is then trapped by using straw over the compost pile which is further covered by black plastic cover which not only trap the released heat but also aid in the absorption of solar radiation.

**Figure 11**: Composting Pile  (BSP-Nepal, 2005)

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locally available organic wastes can be used as a compost to provide heat to the digester</td>
<td>Compost pile gives unpleasant odor and makes the surrounding look dirty.</td>
</tr>
<tr>
<td>The heat entrapment can be done by using simple black plastics or rice straws.</td>
<td></td>
</tr>
</tbody>
</table>

*Note:* A well-designed indoor compost system, >10 gallons in volume, will heat up to 40-50°C in two to three days. In outdoor systems, compost invertebrates survive the thermophilic stage by moving to the periphery of the pile or becoming dormant. Regulations by the U.S. Environmental Protection Agency specify that to achieve a significant reduction of pathogens during composting, the compost should be maintained at minimum operating conditions of 40°C for five days, with temperatures exceeding 55°C for at least four hours of this period. Most species of microorganisms cannot survive at temperatures above 60-65°C, so compost managers turn or aerate their systems to bring the temperature down if they begin to get this hot.
Ms Mamie Wong carried out experimental trials in the winter of 1983 in functioning plants in Kathmandu to enhance biogas production at low temperatures with special emphasis on composting. She presented her findings at the COSTED/UNESCO sponsored workshop on Microbiological Aspect of Biogas Production held in Kathmandu (Biogas Newsletter, Number 16, 1983). It was discovered, for example that composting heaps piled on the top of an underground Chinese-type plant could enhance gas production in winter by over 54 percent compared to an uninsulated plant (BSP Nepal, 2005).
5.3. Design 5: Biogas Reactor using greenhouse technology

In this system, the biogas digester is kept inside a manmade greenhouse in order to absorb solar radiation and maintain high temperature inside the digester. Two biogas digesters of 6m³ were built by SNV/BSP in 2000 in high altitude region of Lukla and Khumjung. SNV/BSP staff indicated that the state of art greenhouse technology for such scale would cost Nrs 75,000. (BSP Nepal, 2005)

![Figure 12: High altitude biogas reactor at Lukla/Mosi (BSP-Nepal, 2005)](image)

Option 1: Biogas digester wrapped in an insulating bag

![Figure 13: BioDigester wrapped in insulating bag](image)
6. Design Calculation

6.1. Design selection
As per the terms of reference of the project as provided by AEPC, detailed heating system design of electricity production and non electricity production schemes was needed. Therefore, in the first phase of the project designs were selected for both electricity and non electricity systems. However, after consultation with AEPC detailed designs of electricity systems wasn’t pursued further owing to its less usage in context of Nepal. Therefore, a heating system was selected and designed completely for non electricity scheme after consultation with AEPC.

A non electricity biogas system where hot water from solar water heater is circulated through a pipe inside the digester has been selected. The pipe runs on the wall of the digester which will transfer its heat to the surrounding substrate due to the temperature difference between hot water and the manure.

![Figure 14: Selected design](image)

6.2. Design conditions
Following listed are the basic design conditions that have to be met for the proper heating of the manure in the digester.
Desired manure temperature | 40°C |
---|---|
Volume of biogas digester | 35 m³ |
Average temperature of manure | 20°C |

### 6.3. Calculation for theoretical heating requirement

Total digester heating requirement, \( Q_1 = Q_T + Q_L \)

where \( Q_T \): Rate of heat transfer to raw manure influent

\[ Q_T = \dot{m} \times c \times (T_2 - T_1) \]

\( \dot{m} \): mass of influent added
\( c \): specific heat of influent
\( T_2 \): Desired digester slurry temperature
\( T_1 \): Current slurry temperature

Now

Volume of manure, \( V = 23.45 \) m³

Density of water, \( \rho_1 = 998.2 \) kg/m³

Density of cow dung, \( \rho_2 = 0.13 \) kg/m³

Average density of manure = \( \frac{\rho_1 + \rho_2}{2} \)

\[ = \frac{998.2 + 0.13}{2} \]
Mass of manure, \( m = \text{volume} \times \text{Density} \)
\[
= 23.45 \times 499.165 \\
= 11705.2 \text{ Kg}
\]

Specific heat of cow dung, \( c_1= 2.79925 \text{ KJ/Kg}^{0\text{C}} \)
Specific heat of water, \( c_1=4.186 \text{ KJ/Kg}^{0\text{C}} \)

Average specific heat of manure= \( (c_1+ c_2)/2 \)
\[
= (2.79925+4.186)/2 \\
= 3.49 \text{ KJ/Kg}^{0\text{C}}
\]

Current Slurry temperature= \( 20^{0}\text{C} \)

Desired temperature of slurry, \( T_2=40^{0}\text{C} \)

\[
Q_T=\dot{m} \times c \times (T_2 − T_1) \\
= 11705.2 \times 3.49 \times (40-20) \\
=817022.96 \text{ KJ}
\]

6.5. Calculation of heat loss (\( Q_L \))

\[
Q_L = \frac{(T_2 − T_3)}{R_{th}}
\]

Where

\( R_{th} = \text{total resistance to heat flow} \)

\( T_3 = \text{Ambient temperature} \)
\( T_2 = \) Desired digester slurry temperature

### 6.6. Calculation of total resistance to heat flow and heat loss

<table>
<thead>
<tr>
<th>Structure</th>
<th>Area ((m^2)), A</th>
<th>Thickness ((m)), L</th>
<th>Thermal conductivity ((W/m-k)), K</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall</td>
<td>11.75</td>
<td>0.15</td>
<td>1.7</td>
<td>Concrete</td>
</tr>
<tr>
<td>Roof</td>
<td>0.15</td>
<td>0.15</td>
<td>1.7</td>
<td>Concrete</td>
</tr>
<tr>
<td>Floor</td>
<td>4.66</td>
<td>0.35</td>
<td>1.295</td>
<td>20 cm Stone</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15 cm concrete</td>
</tr>
</tbody>
</table>

Total resistance to heat flow = \( \frac{L}{K \times A} \)

Where, \( L = \) Length of path flow

\( K = \) Thermal conductivity of the material of the path

\( A = \) Area normal to path flow

Resistance to heat flow due to wall, \( R_1 = \frac{L}{K \times A} \)

\[
= \frac{0.15}{1.7 \times 11.75}
\]

\( = 0.007 \)

Resistance to heat flow due to roof, \( R_2 = \frac{L}{K \times A} \)
\[
R_3 = \frac{L}{K \times A}
\]

Resistance to heat flow due to floor, \( R_3 = \frac{L}{K \times A} \)

Equivalent thermal conductivity of concrete and stone, \( k = k_1 + k_2 \)

\[
k = 1.7 + 1.295 = 2.995
\]

Therefore,

\[
R_3 = \frac{0.35}{2.995 \times 4.66}
\]

\[
= 0.025
\]

Heat loss through wall, \( Q_1 = \frac{\Delta t}{R} \)

\[
= \frac{(40-25)}{0.007}
\]

\[
= 2141.86 \text{ J}
\]

Heat loss through roof, \( Q_2 = \frac{\Delta t}{R} \)

\[
= \frac{(40-25)}{0.6}
\]

\[
= 25 \text{ J}
\]

Heat loss through floor, \( Q_3 = \frac{\Delta t}{R} \)

\[
= \frac{(40-25)}{0.025}
\]

\[
= 600 \text{ J}
\]

Total heat loss, \( Q_L = Q_1 + Q_2 + Q_3 = 2766.86 \text{ J} \)
Total heat requirement = $Q_T + Q_L$

$$= 2766.86 + 817022.96$$

$$= 819789.8 \text{ J} \ldots \ldots \ldots \text{(i)}$$
6.7. Calculation of heat transfer to manure

Heat transfer from hot water from solar water heater to manure inside the digester

![Diagram of heat transfer mechanism]

**Figure 15:** Heat transfer mechanism

Calculation of heat transfer coefficient in flow convection

Coefficient of viscosity of water at 40°C, \( \mu = 0.0006532 \text{ Kg/m-s} \)

Density of water at 40°C, \( \rho = 992.2 \text{ kg/m}^3 \)

Specific heat of water at 40°C, \( C_p = 4186 \text{ J/Kg}^\circ\text{C} \)

Thermal conductivity of water, \( K = 0.6305 \text{ W/m-K} \)

Maximum temperature of water, \( T_{max} = 80^\circ\text{C} \)

Temperature of manure, \( T_m = 20^\circ\text{C} \)

\[
Re = \frac{\rho \times V \times D}{\mu}
\]

\[
= \frac{992.2 \times V \times D}{0.0006532}
\]

\[
= 151893.466 \times V \times D
\]
\[ Pr = \frac{0.0006532 \times 4186}{0.6305} \]

\[ = 4.33 \]

Now

Nusselt Number, \( Nu = \frac{h \times D}{k} = 0.023 \times (R_e)^{0.8} \times (Pr)^{1/3} \)

or, \( h = 0.023 \times 0.6305 \times (1518983.466 \times V \times D)^{0.8} \times 4.33^{1/3} \)

Heat transfer from water, \( Q = h \times A \times (T_{\text{max}} - T_m) \)

\[ = 0.023 \times 0.6305 \times (1518983.466 \times V \times D)^{0.8} \times 4.33^{1/3} \times \Pi \times D \times L \times (T_{\text{max}} - T_m) \]

Now

Total height of wall, \( H = 1 \text{m} \)

Diameter of inlet pipe= 20 cm=0.2 m

Taking number of coils as 18 and total height of digester is 1 m.

Diameter of base of digester, \( D = 254 \text{ cm}=2.54 \text{ m} \)

Total Length of coil, \( L = \text{Number of coils } \times \Pi \times D \)

\[ = 14 \times \Pi \times 0.254 = 111.7 \text{ m} \]

Heat transfer \(, Q = h \times A \times \Delta t \)

\[ = 0.023 \times 0.6305 \times (1518983.466 \times V \times D)^{0.8} \times 4.33^{1/3} \times \Pi \times D \times L \times \Delta t \]

\[ = 0.023 \times 0.6305 \times (1518983.466 \times D)^{0.8} \times 4.33^{1/3} \times \Pi \times D \times L \times \Delta t \ldots (ii) \]

Equating equation (i) with equation (ii), we get
Optimum heat requirement can be reached if we can allow water to flow through pipe of 1 inch diameter at velocity 4 m/s with spacing 1.25 inch in between them.

**6.8. Solar water heater design**

Quantity of water needed to heat the system = 5,000 L

Mass of water = volume x density = 5,000,000 ml x 1 g/ml

= 5,000,000 g = 5,000 kg

Assuming the initial temperature of water to be 15 degree

Desired temperature of water is 80 degrees

Change in temperature = ΔT = (80-20) = 60 °C

Heat gained by water = Q_S = mC_p ΔT = 5,000 x 1.16 x 60

= 348 kWh

Average solar radiation on a horizontal surface in Kathmandu = S_R = 5.24 kWh/m²

Calculating the collector yield of the panel:

\[ C_Y = \text{Average solar radiation} \times \text{collector efficiency} \times \text{system efficiency} = S_R \times \eta_C \times \eta_{\text{Sys}} \]

Thus, \[ C_Y = 5.24 \times 60\% \times 85\% \]

= 2.67 kWh/m²

And, the collector array = \[ C_A = \frac{Q_S}{C_Y} \]

= 348/2.67 = 131 m²

Using standard panel size of dimension: 4 ft x 10 ft = 40 ft² = 3.72 m²

Thus, we can calculate the number of panels required as \[ N = 131/3.72 \]

Hence, Number of panels = 35.22 = 36 panels.
6.9. Heat exchanger material analysis

Stainless steel has been selected as the pipe material. Following are the reasons for using stainless steel in heat exchange equipment:

1. Resistance to corrosion
2. High temperature resistance to oxidation and scaling
3. Good strength characteristics in low and high temperature service
4. Maintains excellent heat transfer properties
5. Resistance to fouling due to corrosion
### 6.10. Cost Estimation

<table>
<thead>
<tr>
<th>Parts</th>
<th>Quantity</th>
<th>Rate (Rs)</th>
<th>Total cost (Rs)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>solar panel (No)</td>
<td>31, 134m²</td>
<td>13,500 per m²</td>
<td>18,09,000</td>
<td>Flat bed</td>
</tr>
<tr>
<td>Water pump (No)</td>
<td>1</td>
<td>30,000</td>
<td>30,000</td>
<td>5 HP</td>
</tr>
<tr>
<td>pipe (Kg)</td>
<td>559</td>
<td>105/kg</td>
<td>58,695</td>
<td>Stainless steel</td>
</tr>
<tr>
<td>Storage tank (No)</td>
<td>31, 420 kg</td>
<td>76/kg</td>
<td>31,920</td>
<td>Wrought iron</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>19,29,615</strong></td>
<td></td>
</tr>
</tbody>
</table>

Total cost was for the heating system has been estimated to be NRs. 19 lakhs 29 thousand and six hundred fifteen.
7. Conclusion and Recommendation

7.1. Conclusion

Heating of manure in the biogas digester to the mesophilic range ensures that the yield of biogas increases appreciably. The heating technology of biogas digester was designed so that the temperature of manure in the digester is always maintained at 40 °C. The heating design of biogas plant of 35m³ was completed with determination of optimum pipe diameter, solar panel required to heat the water to required temperature and velocity of the hot water flow in the pipe. It was determined that flowing water at velocity of 4m/s using 5 HP water pump through a pipe of 1 inch diameter was necessary to keep the temperature of water at 40 °C. The total number of coils was needed to be 19 with 1.25 inch of gap between them with total required length of pipe being 137 m.

Likewise, solar panel was designed which will ensure necessary supply of hot water at 80 °C. It has been 351 panels of dimension: 4 ft x 10 ft = 40 ft² = 3.72 m² was needed for the purpose. Solar panels were designed from the calculation of amount of water needed to maintain the system at 40 °C for continuous hours. Finally, costing of the system was done with cost estimation of water pumps, solar panels and stainless steel for the pipe and storage tank of the hot water. Total cost of the system has been estimated to be around Rs 19 lakhs.

7.2. Recommendation

Throughout the study, some important points have come in light which ensures better effectiveness of the heating system. Following recommendations are listed for the more efficient implementation of the bio gas heating technologies:

- Integration of water boiler in the system will allow the continuous heating of the digester manure.
- Addition of insulation on the walls and roofs of the digester will improve its efficiency while increasing cost of the system at the same time. Therefore, proper optimization of insulation thickness and material is necessary.
- Use of temperature sensors in the system allows effective control of temperature of the digester.
8. References


