**Final Report**

# Bio-gas yields
# from
## Toilet Linked Biogas Plants in Nausari / Valsad District, Gujarat, India

Report submitted to

**WASTE, Netherlands & FINISH Society, India**


**Submitted by**

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# Gas yields from toilet linked biogas plants in Nausari / Valsad Districts, Gujarat

## Contents

# Executive summary

Biogas from cow dung with or without toilet linkage is in practice for over 3 decades in India. It is supported by the Ministry of New & Renewable Energy, Government of India and State Governments.

However, the toilet linked biogas plant programme could not get required momentum, even though it has several advantages. Poor acceptability of the programme is mainly due to psychological taboos associated with human wastes and lack of adequate awareness and motivation to households.

To overcome the problem, the additional economic importance / advantages of toilet linked biogas plants over non-toilet linked biogas plants need to be demonstrated. The people with psychological taboos are often from the lower economic groups. The households requiring biogas for cooking purpose are from the same group. Therefore, the economic aspect is a prime motivator for creating social acceptance.

Toilet linked biogas plants have increased rate of biogas production over biogas plants without the toilet linkage. The percentage of the increase varies with number of users of the toilet in a family and the ratio of quantity of human wastes / quantity of cow dung. The higher the ratio, the higher is the rate of biogas production. In the present observations in 4 different villages covering total 16 families such increase has been recorded to vary between 25-32%.

Higher generation of biogas from toilet linked biogas plants is mainly due to complementary actions of different groups of bacteria present in human wastes and cow dung. Methanogenic bacteria are abundantly found in cow dung where as hydrolytic bacteria and acetogenic bacteria are copious in human excreta. Complementary actions of all these bacteria lead to increase production of biogas plant. Percentage of methane in the biogas from a toilet linked biogas plant is higher than the methane percentage in biogas from a non-toilet linked biogas plant, i.e. it has a higher calorific value. The results show that a family can have sufficient biogas with lower input quantities of cow dung. Cooking requirements will be met even with dung from 2 cows.

Plant nutrient values from slurries from toilet linked and without toilet linked biogas plants are being examined. Earlier, the samples were submitted to the Agriculture University for analysis. Their results were not acceptable as it mentioned in term of wet weight basis. It will be available by the end of this month. Effects of slurry on different vegetables and crops are being monitored. Such results may have good impact on its economic aspect and help social acceptability of the programme.

# Final report on Toilet linked biogas plant at Nausari /Valsad district

## 1. Introduction

Promotion of a family-size biogas plants with slurry management is a programme of the Ministry of New & Renewable Energy (MNRE), Government of India. It was implemented in different states in India, through State Nodal Agencies, since the early 1980s.

Later, in late 1980s, toilet linked biogas plants was also included under the programme for Central Financial Assistance by the Ministry. Financial support is provided by the MNRE, Government of India and State Government, Gujarat, through Gujarat Agro-Industries- a State Nodal.

The project on cow dung based biogas plants with toilet linkage is implemented in different villages in Nausari and Valsad districts in Gujarat by Vasudhara Dairy, Chikli. The project is implemented by WASTE, Netherlands and the Finish Society, India for technical and awareness/ motivation for linking of toilets to biogas plants with support from ICCO. A total of 1627 family size biogas plants have been implemented during 2012-13 and 2013-14. These plants are based on cow dung only yet with having a provision of connecting with toilet also, when households such desire. Additionally, 747 cow dung based biogas plants connected with toilets have been implemented during the same period. In the fiscal year 2014-2015 the Government has sanctioned 960 biogas plants to Vasudhara Dairy. The sanction letter was issued in October/ November 2014. There are several biogas plants under different stages of construction under the sanctioned target.

Linking toilets to biogas plants has so far been given little attention either by the State or Central Government. Its low acceptability is mainly caused by psychological taboos associated with human waste and lack of awareness and motivation programmes to households. Hence, there are only few toilet linked biogas systems and most people are not aware about use of human waste for production of biogas, improved health impact from sanitation and economic importance of biogas production from human wastes. The taboos can be reduced by considerable extent when

economic benefits of linking toilet with biogas plants is properly demonstrated to households coupled with awareness and motivation.

An assignment has been given by WASTE / the Finish Society to evaluate the biogas production from cow dung when the biogas plant is linked and not linked with toilets; the composition of biogas in terms of percentage of methane, carbon dioxide and hydrogen sulphide; comparative plant nutrients values in slurry of biogas plants from toilet linked and without toilet linked biogas plants; analyse the composition of the slurry resulting from toilet linked and non-toilet linked biogas slurry – including pathogens – and lastly evaluate the effects of toilet linked biogas plants on different crops and vegetable grown in the area. The latter research could not be completed as prior to harvesting a cyclone destroyed all crops in the area[1].

To evaluate the effects on biogas production with toilet linked biogas plants the following studies have been conducted:

- Comparative analysis of biogas production rates from toilet linked and non-toilet linked biogas plants
- Analysis of biogas for its methane and other constituents.
- Comparative analysis of plant nutrient values from toilet linked and non-toilet linked biogas plants
- Effects of yields of crops and vegetables when slurry of biogas plants is used in agriculture (not completed).

## *1.1 Location of the study*

Biogas plants are being implemented in several villages in the districts of Nausari. For study purposes four villages - Pathari, Adda (Navagam), Boriach, Unn - were selected. In each village 4 households were selected – 3 families with toilet linked biogas plants - and one family with no toilet linked biogas plant.

[1] A second report will be made available on subsequent, i.e. post-cyclone, research.

## *1.2 About biogas plants*

Deenbandhu Biogas plants of 2 $m^3$ with slight modification have been constructed. The modification is the Y shaped pipe in the inlet of biogas plant- one pipe is connected to the toilet and another to inlet chamber for cow dung mixing tank. The outlet chamber of the plant, also called expansion chamber, is connected to a storage chamber of slurry. After the chamber is filled it is taken out and stored till further use in agriculture lands.

Produced biogas is passed through a 1.25 cm dia pressure pipe from digester to the gas burner in the kitchen. There is no moisture trap connected with the biogas plant. It is not required as the biogas pipe is connected vertically upward from biogas plant. Therefore, any moisture condensed in the pipe passes back to biogas plant. However, in some households it was seen that moisture gets condensed in pipe when there is bent in pipe, blocking smooth passage of biogas. In such cases, the pipe is opened from the burner and condensed water is drained out by households.

Biogas plants are made with Reinforced Concrete Cement (RCC). Therefore, there is no chance of leakage of biogas through the dome of plant. An innovative method in the construction of biogas plant is the use of pre-fabricated steel mold of whole upper part of biogas plant including out let. Fabrication of a steel mold is a onetime expenditure and it saves labour cost and requires much less time to construct a plant. Use of a mold prevents errors in the design/ dimension of biogas plant. One such mold is mentioned below. There is chance of leakage of biogas when the plant is constructed with bricks. In an exhibition cum seminar on NBA organized by the Government of Gujarat in September, 2014, FINISH was invited to show its biogas plant project. Chief Minister of Gujarat took interest with the toilet linked biogas plant being implemented by FINISH. She was impressed with the prefab mold of dome of biogas plant.

Photo 1 Chief Minister Gujarat being explained about toilet linked biogas plant (photo September 2014)

## *1.3 Design of Deenbandhu biogas plant*

The design of a Deenbandhu Biogas plant implemented under the project is as under. The design is approved by the Ministry of New Renewable Energy Sources, Government of India under its Central Financial Assistance programme.

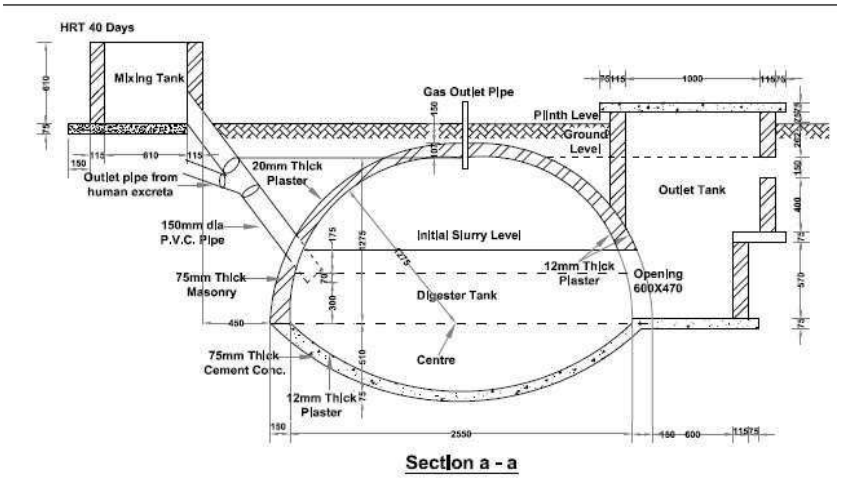



Fig. A section of 2 $m^3$ biogas plant linked with toilet.

**Photographs of toilet linked and without toilet linked biogas plants**


Photo 2 Toilet linked biogas

Photo 3 Outlet chamber with slurry tank being cleaned recently

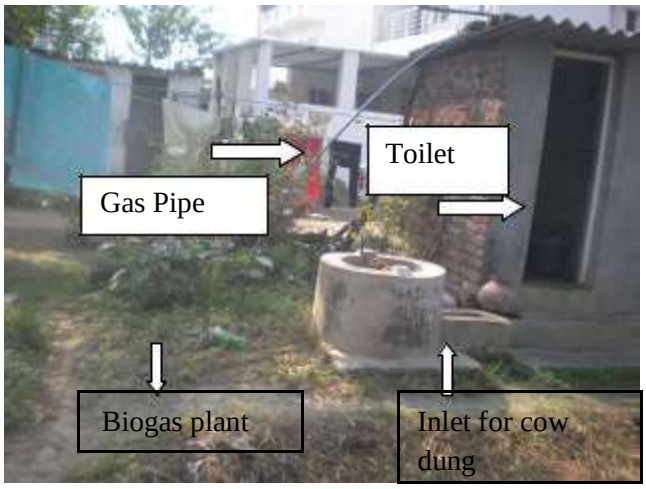



Photo 4 Toilet linked biogas plant

Photo 5 Toilet linked biogas plant


Photo 6 Toilet linked biogas plant

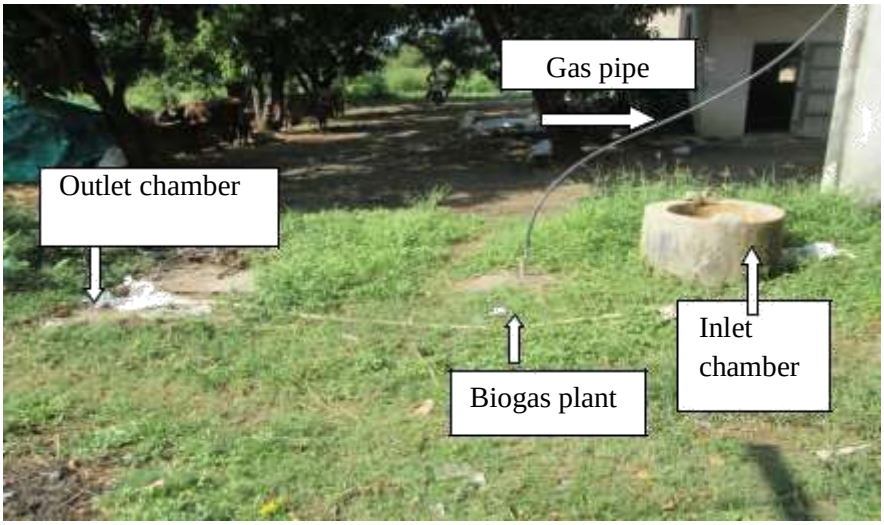



Photo 7 Cow dung based biogas plant without toilet linkage

**Biogas plants under construction at different stages**

Photo 8 Steel mold of biogas plant put for completing upper part of the plant

Photo 9 Biogas plant with completed dome. Inlet tank and Outlet chamber under construction.

Photo 10 Complete biogas plant with Inlet tank and outlet chamber under construction

Photo 11 Almost complete biogas plant only outlet chamber is to be covered with slabs

# 2. Methods for the study

## *2.1 Loading of biogas plant with cow dung*

Daily loading of cow dung by each household was measured. Households were requested to maintain same quantity of loading every day. Yet, it was difficult to fix loading quantity for each family, due to difference in practice and requirement of gas by households. Loading rate also varied with the size of the bucket for loading. In each household cows are available; their number varies between 2 and 9. Excess quantity of cow dung is used for making cakes or in agriculture fields. Loading rate of cow dung varied between 15 kg to 36 kg per day in different households. Required quantity of cow dung is mixed with equal amount of water in the inlet tank and mixed with stirrer before it is put into biogas plant. Loading of biogas plant is done by 8 AM every day. The number of persons in households using toilets connected with biogas plants varies between 2 and 8.

## *2.2 Measuring biogas*

The capacity of all biogas plants is 2 $m^3$. In each village 4 families are selected- 3 families with toilet linked biogas plants and one family without toilet linked. A gas flow meter of flow rate 2 $m^3$/ hour is fixed with gas burner for cooking with each selected family. The gas outlet pipe from biogas plant is connected to the inlet point of the gas meter; outlet point of the gas meter is connected to the gas burner (Photos 12-15).

Daily reading of the gas meter gave amount of gas used in the burner. Daily consumption of biogas in a family varied considerably. Sometimes households make a meal only once in a day as they may be invited by relatives / friends for a meal. Similarly, consumption of biogas can be high in a family as they may have invited relatives / friends for a meal. In any case, no household with a toilet linked biogas plant was found using LPG for cooking purpose.

There may be surplus biogas inside the biogas plant. To measure total biogas, at an interval of 3-4 days total biogas was burned through the gas burner and the gas reading was taken. It gave the reading of total produced biogas till that time. Based on the readings, total gas produced from those with and without toilet linked biogas units was recorded. These readings were measured continuously for 27-43 days for each biogas plant in different villages. The reading of the gas meter was taken after 2 PM each day when cooking was completed in family.

Average gas production rate was calculated considering total amount of cow dung fed into biogas plant and total gas produced during the period of measurement in different villages. For a village, the number of days of observation was same for all the biogas plants. Calculation was made for biogas production rate against per 25 kg of cow dung for all the biogas plants. Based on the calculation percentage rate of increase or decrease in gas production was calculated.


Photos 12 -13 Gas meters attached to gas burners used for cooking


Photos 14 -15 Gas meters attached to gas burners used for cooking

## *2.3 Analysis of biogas*

Analysis of biogas (percentage of methane, $CO_2$ and $H_2S$) from with and without toilet linked biogas plants were carried out through the Pollucon Laboratory, Surat, Gujarat - a NABL accredited laboratory. Samples of slurry from both the sources were analysed for different

chemical and microbiological parameters like pH, TS, VS, TKN, P, K, faecal coliform and helminths through the concerned departments of the Navsari Agriculture University, Navsari, Government of India, Gujarat.

### *2.4 Analysis of physic-chemical and microbiological parameters*

Analysis of physic-chemical and microbiological parameters of slurry from toilet linked and without toilet linked biogas plants are being carried out by Navsari Agriculture University.

### *2.5 Effects of slurry on yields crops and vegetables*

To evaluate effects of slurry on yields of different crops and vegetables, experimental agricultural fields have been selected. 5 agricultural plots each having 100 $m^2$ areas have been selected- one plot each for wheat, brinjal, cauliflower, chilly (capsicum), tomatoes. Turnip and carrot were not used due to possible contamination through coliforms and helminthes. In these fields, no slurry or inorganic fertilizer has been used previously.

## 3. Observations

### *3.1 Measurement of biogas production in Pather Village*

In Pather village, 4 families were selected for the study:

i. Mr. Arwind Bhai Sukhabhai Patel
ii. Manubhai Fikabhai Patel
iii. Bhupendra Bhai Patel
iv. Bhalchardra Bhikha Bhai Patel

First 3 of the above families have toilets linked with biogas plants whereas the last family has its toilet not linked to the biogas unit. The reading of gas measurement in the village was taken for 24 days. For a family quantity of cow dung put into biogas plant was fixed. It was as per the practice and requirement of biogas by the family. The quantity was measured and recorded.

Initially there were five biogas plants taken under the study. One meter was found not working on 24$^{th}$ Day. Readings of the meter was totally discarded. Therefore, readings of only 4 biogas plants only were taken into consideration.

Biogas production from fixed quantity of cow dung (25 kg) was calculated from each biogas plant considering total amount of cow dung fed into the plant and total produced biogas plant during 24 days of experiment. The following is the summary of biogas generation along with quantity of cow dung used in different biogas plants (Table 1). Details of gas production per day from each biogas plant are mentioned in Annexure 1 Table 5.

**Table 1 Pather village**

| Sl. no. | Name of household | Toilet linked or not linked | If linked, no. of users of toilet | No. of cattle in the family | Quantity of dung used daily | Total quantity of cow dung put into plant in 24 days | Final reading of gas meter $m^3$ Initial reading of all the Gas Meters was 0 | Calculated production of biogas per 25 kg of cow dung $m^3$ |
|---|---|---|---|---|---|---|---|---|
| 1 | Arwind Bhai Sukhabhai Patel | Toilet link | 4+1 | 4+2 | 24 kg | 576 kg | 24.32 | 1.05 |
| 2 | Manubhai Fikabhai Patel | Toilet link | 4+2 | 3+2 | 25 kg | 600 kg | 31.38 | 1.30 |
| 3 | Bhupendra Bhai Patel | Toilet link | 4+1 | 1+2 | 15 kg | 360 kg | 18.23 | 1.26 |
| 4 | Bhalchardra Bhikha Bhai Patel | Without toilet | NA | 4+2 | 30 kg | 720 kg | 21.18 | 0.73 |

The average biogas production from 3 toilet linked biogas plant against 25 kg cow dung comes to an average of 1.20 $m^3$ against 0.73 $m^3$ from without toilet linked biogas for the same quantity of cow dung, i.e. there is 39% increase in gas production.

Readings for toilet linked biogas plant includes gas production from human waste as well. Based on the literatures available, it is 0.03 $m^3$ per person per day. For one day, this gas production would be around 0.12 $m^3$ per day for 4 persons in a family. Calculation is made for biogas production with 25 kg of cow dung for comparison point of view. To know the additive effect, from this figure under each head of toilet linked biogas production, biogas production from human waste in one day i,e. 0.12 $m^3$ needs to be deducted. Therefore, gas

production rate from toilet linked biogas plant against 25 kg of cow dung and after deducting gas production from human wastes it comes to 0.93 (Fam. 1), 1.18 (Fam. 2), and 1.14 (Fam. 3) $m^3$ for the household. On an average, it is 1.08 $m^3$. There is only 0.73 $m^3$ gas production from 25 kg of cow dung. Thus, there is an additive effect. The additive effect is 32% .

## *3. 2. Measurement of biogas produced in the Village Adda*

In Adda village the following households having biogas plants were studied:

i. Ashwin Bhai Chandrakant Bhai Patel
ii. Kusum ben
iii. Mahesh Bhai
iv. Ganga Ben

Biogas measurement through gas meter was taken continuously for 41 days in all the families. Biogas plant of Ganga Ben was without toilet- working as control. In rest three families biogas plant was connected with toilet. The following table gives total quantity of cow dung fed into each biogas plant and corresponding produced biogas (Table 2). In this village also cow dung put in biogas plant by households was measured and same quantity was fed every day. Biogas production from fixed quantity of cow dung (25 kg) was calculated from each biogas plant taking into account total amount of cow dung fed into the plant and total produced biogas plant during 41 days of experiment.

**Table 2 Adda village**

| Sl. no. | Name of household | Toilet linked or not linked | No. of users of toilet | No. of cattle in family | Quantity of dung used daily | Total quantity of cow dung put into plant in 41 days | Total Gas produced $m^3$ | Calculated production of biogas per 25 kg of dung – $m^3$ |
|---|---|---|---|---|---|---|---|---|
| i | Ashwin Bhai Patel | Toilet link | 3+1 | 2+2 | 30 kg | 1,230 kg | 59.09 | 1.20 |
| ii | Kusum ben | Toilet link | 4+ 2 | 3+2 | 24 kg | 984 kg | 49.64 | 1.26 |
| iii | Mahesh Bhai | Toilet link | 4+1 | 2+2 | 25 kg | 1,025 kg | 52.65 | 1.28 |
| iv | Ganga Ben | Without toilet | NA | 4+2 | 30 kg | 1,230 kg | 45.77 | 0.93 |

Average biogas production from three toilet linked biogas plants per 25 kg of cow dung fed is calculated to be 1.24 $m^3$ against the 0.93 $m^3$ gas production for without toilet linked for the same quantity of feed material. Thus, there is 25 % increase in gas production when linked with toilet. Details of the per day gas readings for 41 days are annexed (Annex 1- Table 6)

## *3. 3. Measurement of biogas in the village Boraich*

In Boriach village gas meters were installed in the following households:

i. Suresh Bhai Ram Bhai Patel
ii. Indira Ben Patel
iii. Mani Ben Thakur Bhai Patel
iv. Thakur Bhai Patel

The biogas plant of Thakur Bhai Patel is without toilet linkages. All rest three are toilet linked biogas plants. Capacity of each plant is 2 $m^3$. For all families, gas meter was attached to the gas burner for cooking. Reading of gas meter was taken for 43 days continuously. The readings primarily gave the quantity of biogas consumed by the family. In a family consumption varied considerably. Sometimes families made only one meal due to invitation by friends/ relatives for a meal. Similarly, sometimes consumption was high as they reciprocated. There could be a surplus biogas inside plant. Therefore, after an interval of 3-4 days all biogas was burnt through cooking burner and gas was measured. It gave the reading of total produced biogas till that day.

Biogas production from fixed quantity of cow dung (25 kg) was calculated from each biogas plant considering total amount of cow dung fed into the plant and total produced biogas plant during 43 days of experiment. Total produced biogas under total feed material is summarized as in Table 3.

**Table 3 Village Boraich**

| Sl. no. | Name of household | Toilet linked or not linked | No. of users of toilet | No. of cattle in family | Quantity of dung used daily | Total quantity of cow dung put into plant in 43 days | Total Gas produced $m^3$ | Calculated production of biogas per 25 kg of dung – $m^3$ |
|---|---|---|---|---|---|---|---|---|
| I | Suresh Bhai Ram Bhai Patel | Toilet link | 3 | 1+2 | 20 Kg | 860 kg | 46.55 | 1.35 |
| Ii | Indira Ben Patel | Toilet link | 5 | 2+2 | 20 Kg | 860 kg | 51.58 | 1.49 |
| Iii | Mani Ben Thakur Bhai Patel | Toilet link | 4 | 2+2 | 20 Kg | 860 kg | 49.32 | 1.43 |
| Iv | Thakur Bhai Patel | Without toilet | NA | 4+2 | 25 Kg | 1075 kg | 46.90 | 1.09 |

Average biogas production from 25 kg cow dung from three biogas plants linked with toilet is 1.42 $m^3$, whereas gas produced from without toilet linked biogas plant against the same quantity of feed is 1.09 $m^3$. Thus, there is an adjusted increase in biogas production of 30.27%. Details of the per day measurement of gas from all four households are presented in Table 7 (Annex 1).

### 3. 4. Measurement of biogas from biogas plants installed at Village Unn

The following families with biogas plants were selected for the present study.

i. Soma Bhai Patel
ii. Chhiba Bhai Patel
iii. Amrit Bhai Patel
iv. Mahesh Bhai Mangan Bhai Patel

The biogas plant of Mahesh Bhai is not linked with toilet. Rest of the plants have toilet connections. Fixed and known quantity of dung is put into the biogas plant daily. Such loading is done around 8 AM and biogas is measured. The reading of gas measurement was started on November 24, 2014 and is still going (at the time of report preparation). So far readings for 21 days have been taken. Also in this case for each family production of biogas was calculated against 25 kg of cow dung after calculating total quantity of biogas against known total quantity of cow dung fed. Summary of the total gas production against each biogas plant is as follows (Table 4). Details of the readings of biogas meters are presented in Annex 1 (Table 8).

**Table 4 Village Unn**

| Sl. no. | Name of household | Toilet linked or not linked | No. of users of toilet | No. of cattle in family | Quantity of dung used daily | Total quantity of cow dung put into plant in 21 days | Total Gas produced $m^3$ | Calculated production of biogas per 25 kg of dung – $m^3$ |
|---|---|---|---|---|---|---|---|---|
| i | Soma Bhai Patel | Toilet link | 8 | 5 | 20 kg | 420 | 31.07 | 1.84 |
| ii | Chhiba Bhai Patel | Toilet link | 4 | 3 | 15 kg | 315 | 18.69 | 1.48 |
| iii | Amrit Bhai Patel | Toilet link | 2 | 2 | 15 kg | 315 | 16.06 | 1.27 |
| iv | Mahesh Bhai Patel | Without toilet | 9 | 7 | 36 kg | 756 | 35.17 | 1.16 |

**Analysis of biogas production rate**. Average biogas production per 25 kg of cow dung from toilet linked biogas plant is 1.52 $m^3$, whereas from without toilet linked biogas plant it is 1.16 $m^3$ for the same quantity of cow dung. Thus, the gas production increase is 31.01%.

## *3.5 Analysis of composition of biogas*

Biogas samples from toilet linked and without toilet liked were analysed through Pollucon laboratory, a NABL accredited laboratory. The following is the result of analysis:

| Sl. No. | Source | Methane % | Carbon Dioxide % | Hydrogen sulphide ppm |
|---|---|---|---|---|
| 1 | With toilet linked biogas plant | 63.8 | 31.4 | 55.37 |
| 2 | Without toilet linked biogas plant | 60.4 | 33.9 | 72.82 |

The analysis shows that toilet linked biogas has higher percentage of methane and lower percentage of carbon dioxide and hydrogen sulphide.

### 3.6 Analysis of physic-chemical and microbiological parameters

To analyse different physicochemical and microbiological parameters from slurries from toilet linked and without toilet linked biogas plants, samples were submitted to Navsari Agriculture University. The parameters were- TS, VS, TKN, P, K, Helminths and feacal coliform and Total Coliform. Samples were resubmitted to the Navsari Agriculture University for testing different chemical and microbiological parameters.

During the experiment on wheat, only slurry from toilet linked biogas plant of the farmer was analysed. The average results of analyses are as follows.

| Parameters | Slurry (toilet linked biogas plant | Slurry (without toilet linked biogas plant) |
|---|---|---|
| Total Solid (%) | 59.27 | 62.83 |
| Dry weight basis | | |
| Total N (%) | 1.34 | 1.01 |
| Total P (%) | 0.55 | 0.39 |
| Total K (%) | 0.16 | 0.12 |

Analyses of slurry from toilet linked biogas plant used for wheat plot at Valsad

| Parameters | Value |
|---|---|
| Total Solid (%) | 65.61 |
| Total N (%) | 1.29 |
| Total P (%) | 0.69 |
| Total K (%) | 0.18 |

**Microbiological analyses**

Microbiological analyses of samples were carried out for fresh slurry as well as after sun dried. There were 3 samples analysed at different period during the experiments. The following is the results:

| Parameters | Slurry from toilet linked biogas plant | | Slurry from without toilet linked biogas plant | |
|---|---|---|---|---|
| | Fresh slurry | Sun dried slurry | Fresh slurry | Sun dried slurry |
| Total Solids (%) | 59.56 | 91.63 | 52.87 | 90.85 |
| Helminths eggs | Absent | Absent | Absent | Absent |
| Coliforms (per gram) | Present | Absent | Present | Absent |

Helminths eggs were absent in all samples. Coliforms were present in wet slurry. However, sundried slurry was tested to be free from coliforms also.

## *3.7 Effects of slurry on yields of vegetables / crops*

To assess the effects of slurry from toilet linked biogas plants on vegetables and crops, 5 agricultural plots each having 100 $m^2$ areas have been selected. One plot each for wheat, brinjal (eggplant), cauliflower, chilly (capsicum), tomatoes. Turnip and carrot were not used due to possible contamination through coliforms and helminths. In these fields, no slurry or inorganic fertilizer has been used previously. Wheat has been sown till date as atmospheric is still high not suitable for wheat. Plot for wheat is ready. It is expected to be sown in next 2 days. Results of the experiment will be available in next 2-3 months. However, results from wheat will be available only in last month of March or early April. Some of the photographs of the plots are as follow:

Photo 16. Brinjal plants in the experimental field

Photo 17 Experiment plot for Cauliflower plants

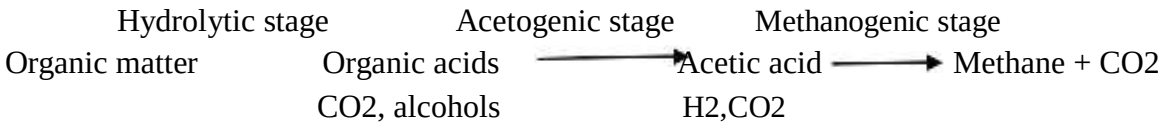
Photo 18 Experimental plot for Tomatoes plants

# 4 Technical explanations of the results

From the Tables 1-4 it is evident that rate of production of biogas from toilet linked biogas plant is higher than the biogas plants without toilet linked. Percentage of such increase in varies from 25 to 31 % in different sets of experiments in different villages. Such variation in increase is comparable with the number of users to toilets in a family. It clearly shows that there is additive effect on biogas production when toilet is linked with cow dung based biogas plants. There are technical explanations to justify such increase in biogas production.

It can be explained in two sub headings

i. Biogas is produced from any substrate by the action of at least three groups of bacteria that act as a relay system, i.e., one group's metabolite product is the substrate of another group. It can be summarized as follows:




Hydrolytic stage by hydrolytic bacteria is the 1st group followed by Acetogenic bacteria and the last group is Methanogenic bacteria. In cow dung methanogenic bacteria- responsible for methane gas formation, are abundantly found, where as there is little presence of hydrolytic and acetogenic bacteria. In case of human excreta hydrolytic bacteria are abundantly found. Acetogenic bacteria are also present in this waste, but methanogenic bacteria are either absent or rarely found. Therefore, in case of biogas plant solely based on human waste, cow dung is mixed once at the start that acts as inoculums for methanogenic bacteria.

Therefore, by mixing human wastes with cow dung there is complementary action by different groups of bacteria to produce biogas. It has been observed that when toilets are used by higher no. of users or when there is higher human waste / cow dung ratio, there is higher rate of production of biogas. Therefore, rate or enhanced biogas production varies with number of user of toilet.

ii. Per tonne cow dung, 40-45 $m^3$ biogas is produced, whereas per tonne of human excreta, 85-90 $m^3$ biogas is generated. There is no experiment on biogas generation from human excreta on weight basis. However, there are references of production of 0.03 $m^3$ biogas per person per day. Quantity of human excreta per person in India is taken as 300 g. Based on this figure, biogas generation per tonne of human excreta comes to 90 $m^3$. This is an explanation of increased biogas generation when mixed with human excreta.

Composition of biogas in term of methane, carbon dioxide and hydrogen sulphide vary with the nature of feed materials. In case of human wastes based biogas, methane composition is 65-66 %. In case of cow dung based biogas plant percentage of methane is 60-61. Under the present study percentage of methane from cow dung and toilet linked biogas plants are 60.4 and 63.8 % respectively. Obviously, toilet linked biogas has higher calorific value than non-toilet linked biogas.

# Annex 1 Detailed gas readings per village

**Table - 5**

Village Pather - Day wise measurement of biogas against each biogas plant

| Sl. no. | Date | Arwind Bhai Sukhabhai Patel | Manubhai Fikabhai Patel | Bhupendra Bhai Patel | Bhalchardra Bhikha Bhai Patel |
|---|---|---|---|---|---|
| 1 | 4.8 2014 | Initial reading-00 $m^3$ | Initial reading-00 $m^3$ | Initial reading-00 $m^3$ | Initial reading-00 $m^3$ |
| 2 | 5.8.2014 | 0.67 | 1.42 | 0.60 | 0.89 |
| 3 | 6.8.2014 | 1.98 | 2.73 | 1.24 | 1.36 |
| 4 | 7.8.2014 | 2.95 | 4.22 | 1.88 | 2.52 |
| 5 | 8.8.2014 | 4.04 TGB | 5.69 TGB | 2.25 TGB | 3.65 TGB |
| 6 | 9.8.2014 | 4.99 | 7.06 | 3.53 | 4.49 |
| 7 | 10.8.2014 | 6.18 | 8.38 | 3.90 | 5.25 |
| 8 | 11.8.2014. | 7.02 | 9.85 | 4.35 | 6.05 |
| 9 | 12.8.2014 | 8.20 TGB | 11.22 TGB | 5.48 TGB | 6.98 |
| 10 | 13.8.2014 | 9.25 | 12.66 | 5.92 | 7.96 |
| 11 | 14.8.2014 | 10.52 | 13.99 | 6.06 | 8.05 |
| 12 | 15.8.2014 | 11.50 | 15.23 | 7.21 | 9.04 |
| 13 | 16.8.2014 | 12.49 TGB | 16.25 TGB | 8.90 TGB | 10.00 TGB |
| 14 | 17.8.2014 | 13.52 | 17.33 | 10.80 | 10.64 |
| 15 | 18.8.2014 | 14.61 | 18.79 | 13.82 | 11.67 |
| 16 | 19.8.2014 | 15.61 | 20.32 | 14.00 | 12.75 |
| 17 | 20.8.2014 | 16.67 TGB | 21.62 | 14.50 | 13.77 |
| 18 | .21.8.2014 | 17.94 | 22.94 TGB | 14.90 | 14.60 |
| 19 | 22.8.2014 | 18.93 | 24.25 | 15.40 | 15.47 |
| 20 | .23.8.2014 | 19.90 | 25.75 | 15.81 | 16.75 TBG |
| 21 | 24.8.2014 | 21.15 TGB | 27.05 | 16.58 | 17.76 |
| 22 | 25.8.2014 | 21.99 | 28.95 | 16.99 | 18.75 |
| 23 | 26.8.2014 | 22.85 | 30.18 | 17.58 | 20.03 |
| 24 | 27.8.2014 | 24.32 TGB | 31.38 TGB | 18.23 TGB | 21.18 TGB |

TBG – Total gas was burned through cooking burner

**Table 6: Adda Village: Details of readings of biogas in four families**

| Sl. no. | Date | Ashwin Bhai Patel | Kusum Ben | Mahesh Bhai | Ganga Ben |
|---|---|---|---|---|---|
| 1 | 1.9.2014 | Initial reading- **28.09 $m^3$** | Initial reading- **35.86 $m^3$** | Initial reading- **19.90 $m^3$** | Initial reading- **23.06 $m^3$** |
| 2 | 2.9.2014 | 29.35 | 36.99 | 20.53 | 23.40 |
| 3 | 3.9.2014 | 32.04 | 38.36 | 22.14 | 25.49 |
| 4 | 4.9.2014 | 34.08 TBG | 39.59 | 23.41 | 26.56 |
| 5 | 5.9.2014 | 36.64 | 41.17 | 25.04 | 27.61 |
| 6 | 6.9.2014 | 38.68 | 42.68 | 26.62 | 29.21 |
| 7 | 7.9.2014 | 40.27 | 44.15 | 27.89 | 30.62 |
| 8 | 8.9.2014 | 41.88 | 45.56 | 29.07 | 31.86 |

| | | | | | |
|---|---|---|---|---|---|
| 9 | 9.9.2014 | 43.90 TBG | 46.76 TBG | 30.30 | 33.41 |
| 10 | 10.9.2014 | 45.85 | 47.11 | 31.09 | 34.11 |
| 11 | 11.9.2014 | 47.83 | 49.44 | 32.24 | 35.85 |
| 12 | 12.9.2014 | 49.57 | 50.77 | 33.00 | 37.17 |
| 13 | 13.9.2014 | 51.57 | 51.98 TBG | 34.24 | 38.17 |
| 14 | 14.9.2014 | 52.61 | 53.12 | 35.15 | 39.63 |
| 15 | 15.9.2014 | 54.85 TBG | 54.66 | 36.30 | 40.66 |
| 16 | 16.9.2014 | 56.35 | 55.72 | 37.49 | 41.76 |
| 17 | 17.9.2014 | 57.95 | 56.85 | 39.18 | 43.09 |
| 18 | 18.9.2014 | 58.36 | 58.32 TBG | 41.04 | 44.41 |
| 19 | 19,9.2014 | 59.49 | 59.65 | 42.54 | 45.44 |
| 20 | 20.9.2014 | 60.35 TBG | 60.99 | 43.87 | 46.58 |
| 21 | 21.9.2014 | 61.33 | 62.38 | 45.58 | 47.96 |
| 22 | 22.9.2014 | 62.60 | 62.95 | 46.24 | 48.30 |
| 23 | 23.9.2014 | 63.89 | 64.07 | 47.55 | 50.06 |
| 24 | 24.9.2014 | 65.39 | 65.20 | 49.03 | 51.44 |
| 26 | 25.9.2014 | 65.51 | 66.56 TBG | 50.28 | 52.32 |
| 26 | 26.9.2014 | 66.03 | 67.90 | 51.80 | 53.54 |
| 27 | 27.9.2014 | 68.04 TBG | 69.22 | 52.85 | 54.09 |
| 28 | 28.9.2014 | 69.82 | 70.46 | 54.08 | 54.97 |
| 29 | 29.9.2014 | 71.56 | 71.36 | 55.65 | 55.21 |
| 30 | 30.9.2014 | 72.70 | 72.30 | 56.86 | 56.60 |
| 31 | 1.10.2014 | 74.95 TBG | 73.25 TBG | 59.14 | 57.84 |
| 32 | 2.10.2014 | 75.76 | 74.31 | 59.84 | 58.60 |
| 33 | 3.10.2014 | 77.82 | 75.48 | 61.42 | 60.11 |
| 34 | 4.10.2014 | 79.10 | 76.55 | 62.35 | 60.99 |
| 35 | 5.10.2014 | 80.71 TBG | 77.75 | 64.05 | 62.36 |
| 36 | 6.10.2014 | 81.88 | 78.63 | 65.70 TBG | 63.20 |
| 37 | 7.10.2014 | 82.60 | 80.12 | 67.02 | 64.42 |
| 38 | 8.10.2014 | 83.40 | 81.42 TBG | 68.49 | 65.31 |
| 39 | 9.10.2014 | 84.64 TBG | 82.92 | 69.88 | 66.69 |
| 40 | 10.10.2014 | 85.87 | 84.02 | 71.03 | 67.84 |
| 41 | 11.10.2014 | 87.18 TBG | 85.50 TBG | 72.56 | 68.83 |
| Actual gas production (final reading minus initial reading) | | **87.18 – 28.09 = 59.09 $m^3$** | 85.50 - 35.86= **49.64 $m^3$** | 72.56 – 19.90= **52.66 $m^3$** | 68.83 – 23.09 = **45.77 $m^3$** |

**Table 7: Village Boriach : Details of measurement of gas from four households**

| Sl. No | Date | Suresh Bhai Ram Bhai Patel | Indira Ben Patel | Mani Ben Thakur Bhai Patel | Thakur Bhai Patel |
|---|---|---|---|---|---|
| 0 | 11.10.2014 | Previous Reading-87.18 | Previous Reading 72.56 | Previous Reading 85.50 | Previous Reading -68.83 |
| 1 | 12.10.2014 | 88.14 | 73.38 | 86.67 | 69.63 |
| 2 | 13.10.2014 | 89.26 | 74.46 | 88.15 | 71.01 |

| | | | | | |
|---|---|---|---|---|---|
| 3 | 14.10.2014 | 90.22 TBG | 75.70 TBG | 89.38 TBG | 72.00 TBG |
| 4 | 15.10.2014 | 91.01 | 76.58 | 90.47 | 73.03 |
| 5 | 16.10.2014 | 92.72 | 77.59 | 91.42 | 74.10 |
| 6 | 17.10.2014 | 94.27 | 79.25 | 92.79 | 75.24 |
| 7 | 18.10.2014 | 95.16 | 80.57 | 93.51 | 76.12 |
| 8 | 19.10.2014 | 96.29 TBG | 81.97 TBG | 94.50 TBG | 76.92 TBG |
| 9 | 20.10.2014 | 97.05 | 82.77 | 95.82 | 77.70 |
| 10 | 21.10.2014 | 98.43 | 83.66 | 97.08 | 78.27 |
| 11 | 22.10.2014 | 99.52 | 85.02 | 98.34 | 78.88 |
| 12 | 23.10.2014 | 100.07 | 86.33 | 100.00 | 79.14 |
| 13 | 24.10.2014 | 101.24 TBG | 87.83 TBG | 100.72 | 80.08 |
| 14 | 25.10.2014 | 103.43 | 88.85 | 101.70 TBG | 80.66 |
| 15 | 26.10.2014 | 104.84 | 90.03 | 102.60 | 81.65 |
| 16 | 27.10.2014 | 105.53 | 91.51 | 103.78 | 82.79 |
| 17 | 28.10.2014 | 106.69 | 92.50 | 104.81 | 84.04 |
| 18 | 29.10.2014 | 107.67 | 93.97 | 106.00 | 85.32 |
| 19 | 30.10.2014 | 108.88 | 94.81 | 107.45 | 86.40 |
| 20 | 31.10.2014 | 109.74 | 95.75 TBG | 108.65 TBG | 87.50 TBG |
| 21 | 1.11.2014 | 110.53 | 97.19 | 109.75 | 88.51 |
| 22 | 2.11.2014 | 111.80 TBG | 98.88 | 111.14 | 89.64 |
| 23 | 3.11.2014 | 112.45 | 99.81 | 112.05 | 90.52 |
| 24 | 4.11.2014 | 114.13 | 101.25 | 112.98 | 91.92 |
| 25 | 5.11.2014 | 115.50 TBG | 102.35 TBG | 114.45 | 92.57 |
| 26 | 6.11.2014 | 116.70 | 104.00 | 115.20 | 94.98 |
| 27 | 7.11.2014 | 117.60 | 105.11 | 116.18 | 95.43 |
| 28 | 8.11.2014 | 118.68 | 106.15 | 117.21 | 96.40 |
| 29 | 9.11.2014 | 119.23 | 107.26 | 118.14 | 97.38 TBG |
| 30 | 10.11.2014 | 120.15 TBG | 108.00 TBG | 119.45 TBG | 98.75 |
| 31 | 11.11.2014 | 121.37 | 109.58 | 120.66 | 100.01 |
| 32 | 12.11.2014 | 122,22 | 110.78 | 121.69 | 101.28 |
| 33 | 13.11.2014 | 123.24 | 111.89 | 123.09 | 102.70 |
| 34 | 14.11.2014 | 124.23 | 113.43 | 124.30 | 104.17 |
| 35 | 15.11.2014 | 125.29 TBG | 114.43 | 125.44 | 105.50 |
| 36 | 16.11.2014 | 126.31 | 115.37 | 126.47 | 106.60 |
| 37 | 17.11.2014 | 127.58 | 117.09 | 128.07 | 108.24 |
| 38 | 18.11.2014 | 128.65 | 118.33 | 129.43 | 109.31 |
| 39 | 19.11.2014 | 129.65 TBG | 119.22 TBG | 130.50 TBG | 110.69 TBG |
| 40 | 20.11.2014 | 130.86 | 120.25 | 131.69 | 111.95 |
| 41 | 21.11.2014 | 132.04 | 121.99 | 132.56 | 113.07 |
| 42 | 22.11.2014 | 133.01 | 122.70 | 133.40 | 114.36 |
| 43 | 23.11.2014 | 133.73 | 124.14 | 134.82 | 115.73 |
| Actual gas production (Final reading minus previous reading) | | **133.73 - 87.18= 46.55 $m^3$** | **124.14 – 72.56 = 51.58 $m^3$** | **134.82 – 85.50= 49.32 $m^3$** | **115.73 – 68.83= 46.90 $m^3$** |

TBG Total gas burned through cooking burner and measured.

**Table -8 Biogas measurement in the families of Village Unn**

| Sl. No | Date | Soma Bhai Patel | Chhiba Bhai Patel | Amrit Bhai Patel | Mahesh Bhai Patel |
|---|---|---|---|---|---|
| 1 | 23.11.14 | Previous Reading **134.82** | Previous Reading **133.73** | Previous Reading **124.14** | Previous Reading - **115.93** |
| 2 | 24.11.14 | 136.04 | 134.69 | 124.86 | 117.11 |
| 3 | 25.11.14 | 138.24 | 136.00 | 125.89 | 119.90 |
| 4 | 26.11.14 | 139.83 | 136.74 | 126.42 | 121.02 |
| 5 | 27.11.14 | 141.20 | 137.92 | 127.30 | 122.81 |
| 6 | 28.11.14 | 142.65 | 138.71 | 127.86 | 124.62 |
| 7 | 29.11.14 | 144.71 | 140.02 | 129.09 | 126.46 |
| 8 | 30.11.14 | 145.77 | 140.80 | 129.80 | 127.49 |
| 9 | 1.12.14 | 146.96 | 141.39 | 130.23 | 129.52 |
| 10 | 2.12.14 | 148.04 | 142.05 | 131.00 | 131.05 |
| 11 | 3.12.14 | 150.89 | 143.55 | 132.15 | 134.00 |
| 12 | 4.12.14 | 151.48 | 144.02 | 132.75 | 135.75 |
| 13 | 5.12.14 | 153.58 | 145.23 | 133.49 | 137.90 |
| 14 | 6.12.14 | 154.86 | 145.93 | 134.39 | 139.00 |
| 15 | 7.12.14 | 155.78 | 146.87 | 135.05 | 140.98 |
| 16 | 8.12.14 | 157.75 | 147.61 | 135.84 | 142.34 |
| 17 | 9.12.14 | 158.80 | 148.05 | 136.09 | 144.89 |
| 18 | 10.12.14 | 160.99 | 149.48 | 137.10 | 145.55 |
| 19 | 11.12.14 | 161.93 | 150.00 | 137.61 | 146.53 |
| 20 | 12.12.14 | 162.95 | 150.42 | 138.76 | 147.99 |
| 21 | 13.12.14 | 164,40 | 151.09 | 139.32 | 149.38 |
| 22 | 14.12.14 | 165.89 | 152.42 | 140.20 | 151.10 |
| **Total gas produced (Final reading minus previous reading)** | | **31.07 $m^3$** | **18.69 $m^3$** | **16.06 $m^3$** | **35.17 $m^3$** |