MONITORING OF BIOGAS PLANTS (PHASE 1)

For
Gesellschaft für Technische Zusammenarbeit (GTZ)

Sustainable Energy for Development (SED)
Bangladesh-German Technical Cooperation

Bangladesh

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Acknowledgement

It was a pleasure to work on this assignment, in the field and in the office, meet a small section of the Bangladesh biogas stakeholder community and try to get good, forward pointing recommendations elaborated. The biogas sector of Bangladesh was impressive for me. It is a challenge and my wish to contribute to its further development.

I am very thankful to all I met and particularly to the GTZ staff for their commitment and help.

Christopher Kellner

Summary

The technical evaluation was in conjunction with Grameen Shakti (http://www.grameen-info.org) executed by visiting 14 randomly selected biogas plants in Maona, about 80 km north of Dhaka, all built within the last two years. The plants ranged in terms of their nominal sizes from 2 to 9 m^3 (gas production per day) and construction volumes from 4 to 18 m^3. Most of the plants operated on water cleaned chicken manure basis, 4 were fed with cow manure. During the evaluation another 20 plants of different ages were briefly seen. The conclusions drawn cannot be generalized for the entire biogas sector of Bangladesh.
All plants where in operation except two. In relation to construction volume and ambient temperature the majority worked far below their potential,. Main technical weakness was the piping systems and cumbersome feeding. In 5 cases, where the gas production was high, the gas use was too little to consume all the gas. All the plants, which were directly connected to stable floors performed best. The use of the effluent as fertilizer was in most cases not existing, which is partially caused by the young age of most digesters. In the first years of operation the digesters discharge mainly watery effluent. All water discharged is nutritious for plants but either flows in water bodies or infiltrates in the underground water body via deep compost pits, causing obviously pollution. It can be assumed that also in future the handling and use of the fertilizer will be an area, which requires more concentration.

The locally produced biogas burners are reasonably well designed but there is room for improvement without increasing the cost. The recently introduced copy of a burner developed in Nepal is cheaper as it requires less material, but the dimensioning of jet, primary air, mixing pipe, burner head volume, area of burner holes and distance to bottom of pot are not harmonized with each other and with the average gas pressure and average methane concentration in the gas, leading to inefficient combustion, H_2S smell in the kitchen due to insufficient combustion temperature and wasteful operation. The gas use options for most farmers are insufficient. Some plants were linked to several households against a monthly flat rate payment for the gas. Negative impact of overcharging wash water from chicken houses in digesters was neither observed nor could any negative impact be proven by measurements as liquids and solids separate in the digester. The water functions as a transport agent, sending the feed material in the digester. After separation of liquids and solids in the biogas settlers the water is discharged quickly.

Before going in faster and wider dissemination the following measures need re-consideration and engineering:

- The standard designs of inlet and outlet have to be adapted to optimize use of building material and to provide convenient feeding and convenient access to liquid digested slurry.
- Some calculations in the English language (metric) version of the latest *Biogas Technology Guide* of GS have to be controlled, redone and changed.
- The piping systems have to be improved for more reliability.
- All construction personnel have to know how to lay all optional piping systems (GI, PVC, fixed or flexible).
- To concentrate only on underground GI piping system, contradicts the good practice of connecting many users, as then gas distribution would become too expensive and complicated.
- The method of conducting pressure tests on digesters and piping systems has to become general know how of all personnel active in the field (also for personnel which is otherwise *non-technical*).
- The installation of one pressure gauge for each biogas plant in the kitchen of the owner should be considered to become a standard feature.
- Measures dealing with condensation water like water drains and gas pipes sloping back to the digester have to become obligatory. To expect form the user to dismantle the pipe and drain condensation water out is not realistic. Otherwise the flexible hosepipe installations are at least in the first 5 years well performing.
- The use of fertilizer needs more concentration on and input from the project implementer’s side.
- Strategically on farm experiences with effluent used as fertilizer by the plant owner are more important than commercialization of liquid or dried sludge. The farmer has to be convinced of the product first before it can be sold.
- A system of practical filed advisors should be established, to visit farmers and practically support them to establish *slurry gardens* and multiple uses of effluent around the digesters.

- The awareness to be created around slurry utilization has to differentiate between nutritious water and liquid sludge. The water should be used to irrigate all kind of crops with different means like pumping, channels and watering cans whereas the sludge can be dried in shallow trenches in gardens so that seeping nutritious water is picked up by surrounding crops.

Furthermore two larger scale plants (126 m^3 and 252 m^3 digester volume) and a digester at a small slaughterhouse were visited.

Among these the Muslim Mission in Faridpur was the project where the benefits of the technology were best utilized. On the gas side there is electricity generation, a bakery, large scale cooking for a orphanage and final drying of the slurry fertilizer to become a marketable organic fertilizer The system to dry fertilizer in a rotating biogas heated drum and its final packaging is impressive but investment cost, running cost, marketing and benefits have to be clearly observed before copying such systems. The large subsidy component (UNDP 90%) in this project may question the expectation that many farms should or could look similar to this one.

Raj Farm in Faridpur provides numerous opportunities for learning and fine-tuning for GTZ SED in terms of electricity generation, options for gas use, use of liquid fertilizer on the farm and handling of sludge and the dried sludge as final product. More farms with similar learning opportunities have to be identified.

Future activities on biogas extension in Bangladesh should include systematic regular stakeholder coordination. The topics to be tackled are:

- Securing long-term performance of all biogas plants due to Sustainable After Sales Service Execution (SASSE).
- Improve viability of biogas systems (use and/or sale of gas and fertilizer).
- Appropriate credit systems instead of subsidies.
- Self-propelling commercialization of biogas technology.
- Utilization of biomass conversion potential in larger scale.
- Multiple uses of anaerobic digestion technologies (sanitation, organic solid waste, agro-industrial waste water).
- International networking.

Abbreviations

Btu	British Thermal Units
CDM	Clean Development Mechanism
DEWATS	Decentralized Wastewater Treatment Systems
GI	Galvanized Iron
GS	Grameen Shakti
GTZ	Deutsche Gesellschaft fuer technische Zusammenarbeit
Ha	hectare
H_2S	Hydrogen Sulfate
IDCOL	Infrastructure Development Company Limited
kcal/h	kilocalories per hour
KJ	Kilo Joule
kW	kilo Watt
LED	Light Emitting Diode
^0C	Degree Celsius
PVC	Poly Vinyl Chloride
SASSE	Sustainable After Sales Service Execution
SED	Sustainable Energy for Development
TS	Total solid
VG	Volume gas

1 Background

Within the framework of Bangladesh-German Technical Cooperation Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) supports within its Programme „Sustainable Energy for Development (SED)" the dissemination of biogas plants which are larger than the commonly understood *household biogas plants*. About 96 biogas plants, mainly larger than 5-m3 gas production per day, have been built since mid of 2005 in cooperation with the executing partner Grameen Shakti (GS), financed via a revolving fund.
As in Bangladesh the biogas sector has gone through a history with ups and downs, it is of course the wish of each program not to repeat mistakes and rather learn from the mistakes of others than of own ones.

The history as well as the performance of biogas plants operated in Bangladesh are sufficiently described and documented in recent times. The respective sources are referred to in the *references*, and for the sake of easy readability of this paper their contend is not repeated.

The survey focused on its objective:
Randomly selected agro-industrial biogas plants are assessed on their performance and recommendations for design and approach adaptations aiming at long term good performance and improved cost benefit ration are made.

2 Method

A checklist has been elaborated which aims at evaluating the biogas plant with only minimized involvement of the user. The rational of this was the experience that questions which ask for the feeling of some one, figures (non- recorded) may show a trend but can not be as accurate as measured data.
Most important data was the gas production of the plant, measured as rise of liquid level in the displacement tank over time. In some cases biogas had to be released first, to show the digesters gas production and in one case the overflowing liquid could be measured quite precisely. The fertilizer utilization was assessed based on observation and if necessary supported with questions. The position of the practical 0-line as opposed to the theoretical 0-line was calculated out of the actual gas pressure and the level difference between slurry level and overflow point. The piping system was pressure tested to identify leakages and opened in the kitchen to see if there are water blockages or cranks in the pipe. A detailed analysis of the stoves was only done twice as there were only two types of stoves. All other questions mentioned in the check list were placed and asked in order to have an idea of the context, why a certain performance of an individual plant was identified.

The construction method for the digesters was discussed with personal of Grameen Shakti.

To get more information on the stove, an intensive visit to two stove producer workshops was paid. Also an experiment was conducted to modify a stove following a path mixed out of theory application and empirical experiments.
While working on the existing literature it was realized that there are unclear definitions and misunderstood modes of calculation. Thus an assessment of the design work as documented by Grameen Sakti in the Biogas Technology Guide, covering both, the IDCOL - household and the Grameen Shakti larger biogas plant designs was briefly done and is discussed. (The English version of the book was completed and handed over only at the end of the evaluation period)

It has to be noted that the survey does not represent a reflection of the biogas sector in Bangladesh in general but looked only in one segment. The findings can not be generalized, the recommendations contain however elements, which may be useful to be considered in the entire biogas sector of Bangladesh.

3 Findings

3.1 Gas tightness

All biogas plants build under the Grameen Shakti – GTZ Program were gastight with one exception (number 67 on GS list). This plant was not used anymore. It looked in the first place that this is due to lack of feeding material. But if the plant was tight and is not used it should stand idle with its maximum pressure of gas in it. But this was not the case.

3.2 Cracks

One GTZ plant, build (2006) beside a small open slaughterhouse is most likely cracked. It had obviously undergone a repair already immediately after its establishment. This was however not reported to the GTZ office. It could be measured that the digester discharged gas exactly at the crank where the gastight spherical dome changes to the cylindrical shape which is equivalent to the bottom of the outlet tank.

3.3 Gas production

Most plants produce more gas than needed. Particularly when the concreted chicken house is directly connected to the inlet the gas production is high. Only in one case the high gas produced corresponded with high gas consumption and was also close to the nominal gas production capacity of the digester ($9m^3$, number 69, Md Mojibur Rahman, Pathar Para, Maona). In that case 10 families each paid lump sum 400 Taka for the gas connection per month. It was obvious that this plant was viable also without any financial return generated by the fertilizer.

Plants which were not directly connected (5) to a stable floor, where all poor in performance, had little gas, and the users gave reasons why the chicken manure was not regularly fed. On top of this, such farms where rather messy.

All the new plants from the IDCOL program where not directly connected to stables or some sort of a solid pavement. The inconvenience of loading was obvious and also mentioned by the owners.

3.4 Direct stable connection

Most directly connected biogas plants received large amounts of water. The water did neither have any negative impact on the gas production nor could it be seen that the water flows in and pushes out sludge. The opposite was the case, most of the sludge remained in the digester and only the water ran through faster through the digester into the outlet tank. There were absolutely no problems with this, except that one can not call the watery overflow *sludge*. It also makes no sense to discharge this water into a drying bed and infiltrate it and remain with some traces of organic matter. This water has to be used for irrigation. It is nutritious irrigation water. This has been observed in many countries before and is also suggested in the context where biogas plants are used as settlers in sewage treatment and in Decentralized Wastewater Treatment Systems (DEWATS). Water enters uncontrolled without causing a problem. The rule of mixing water and animal manure in a certain ratio **is theoretical** and can be applied for planning. **But the practice is different**. The farmer will operate in accordance to what is easily manageable and when the dung goes in with less water it will be less water and when cleaning the stable will take place with more water, it will be more water entering the digester. The important finding is that this does not have negative side effects on the digestion process and does not matter.

Problems of scum cannot appear as long as a biogas plant has its manhole through the outlet and the digester dome is gastight. High pressure will build up from time to time and part of the swimming layer will be discharged. In that case a swimming layer appears in the outlet tank.

Fluctuations in chicken population are common in all farms, leading to fluctuations in gas production as well.

3.5 Piping System

All piping systems seen in the GS - GTZ digesters were made from flexible PVC pipe. Leakages could not be detected. The problem of condensation water settling in spots where the pipe hangs down was frequently seen. In one case the gas did not arrive in the kitchen as the owner could not help himself in releasing the condensation water. It can be assumed that in older plants the piping system is among the core reason for decreasing performance. The lifetime of such a piping system is in the range of four to five years. In practice the piping will not deteriorate quickly but start to become brittle and porous un-remarked and the digester will decrease its performance gradually.
One piping systems made from ½” galvanized steel pipes (IDCOL plant) was pressure tested during the technical assessment exercise and was leaking practically in all joints. The water drain was not at the lowest point so the pipe had also water in. It can be concluded that a laymen did the piping. Consequently GS was asked to redo this piping system and when it was pressure tested again, two days later, it was still heavily leaking even though it was obviously completely worked on. The water drain was now correctly leveled. All the other three IDCOL plants seen had also signs of poor piping system installation. Practically almost all joints have been re-sealed by the owners with packing tape or insulating tape. Such repair is of almost no effect. As soon as the gas pressure rises a little bit the gas will find its way out. Leaking piping systems have to be re-done. Unfortunately this repair method is even explained as a remedy against leaking pipes in the Biogas Technology Guide. Further observation was that locally produced ball valves are of poor quality and do not allow forceful tightening of joints. They also corrode very fast and cannot be recommended for biogas use at all.

3.6 Gas consumption

Four of the measured plants had gas distribution to more households. It is a common scenario in Bangladesh that *natural gas* is distributed to households and people pay a monthly flat rate of 400 taka for that. On that background it was interesting to see that the same can be done with gas from a biogas plant. It is feasible in areas with high population density where the households are near each other and where the respective biogas plant has surplus gas. As a rule of thumb a small family will consume around one m^3 biogas per day for their cooking, but one limiting factor for this gas consumption concept is if many houses in the vicinity have biogas plants. That case had been observed and under this condition there is no neighbor who helps to consume the gas. Other limiting factors are the winter – summer fluctuation in gas production or the uneven gas consumption of the end users.
All the 23 plants in the Dhaka Slum Area were based entirely on sewage as a raw material and distributed the gas to three consumers each. Even though the piping systems were leaking and it can be assumed that the plants can not store gas even when the stoves are switched off, the three consumers were able to do some cooking and also commercial tea preparation was practiced and seen on many of them.

3.7 Biogas burners

The majority of the households had a Nooria burner. Furthermore there were some new burners, which are obviously copies of the burner used in Nepal. At one site there were older versions of Nooria burners, which were equipped with different burner heads.

The performance of a biogas burner depends on many parameters. For good operation these parameters need consideration. As biogas technology is matter of variations, it is important that their range of the variations is known so that a rational decision is made which average value has to be addressed. The constant parameters, which are actually the dimensions of the stove, should respond to this average so that stoves and other gas consumption accessories can be standardized.

The existing burners are based on trial and error tests and are all over dimensioned. This (over dimensioning) leads to satisfactory cooking but also to unnecessary much gas consumption and slight smell disturbances in the kitchen during cooking.

3.8 CO_2 concentration in biogas

The only gas ingredient, which could be measured, was the CO_2 concentration in the gas. It is important to know that for the dimensioning of biogas burners. The table shows chicken based digesters in comparison to cow manure based ones. Interestingly the measured figures contradict figures found in some reference literature.

	Chicken Manure	Cow Manure
CH_4 = Methane	65%	61%
CO_2 = Carbon dioxide	34%	38%
H_2S = Hydrogen sulphate	traces	traces

3.9 Energy conversion

All owners except one, had grid electricity. The main reason for people to have a biogas plant was to improve the farm hygiene. This was in all cases accomplished where the digester inlet was directly connected to the chicken house. Energy was not the driving motivation to have a digester but a welcome side effect. And the fertilizer is rather mainly an item to be disposed off than something from which a benefit is expected or can be realized. It is a characteristic of the egg producing farms that they are not cycle oriented. The feed is not produced on the farm, but bought, so it is rather coincidental if the farm has enough land to use the overflow as fertilizer and/or for irrigations. The orientation is clearly on maximizing egg production… the marketing is well organized… here lays the focus of the farmer. There are no signs that the people had a serious energy problem, which was now solved by biogas. Considering wider uses of biogas was not an option as electricity is a really convenient form of energy, even if it costs something. This is different for large farms where the waste is enough to justify after digestion the production of electricity from the gas. Electricity is such a universal user-friendly form of energy, that this conversion option changes the scenario entirely.

A project with a renewable energy dissemination objective can only fulfill its purpose effectively in areas without electricity and piped gas connection. The opportunities for good use of larger amounts of gas on continuous regular basis are very limited. A biogas project has to be viable and the core element to achieve that is a good and continuous use of all the energy produced. Correctly designed and implemented – especially in the case of specialized farms - biogas plants are part of the environmental treatment chain of livestock waste.

3.10 Integration in the farm – non-standardized structures

Most biogas plants are 10 to 20 m away from the chicken house and the dung is fed by gravity in the inlet. The inlet structure is a round mixing chamber which due to the inflow hole from the side and can actually not be utilized for mixing dung with water. Most channels have sand traps integrated as the chicken dung contains 3 % sand or silt, which should under no circumstances enter the digester. There are two parameters, which influence the success of sand separation. One is the water contend in the mix of dung and water (the more the water the better the separation) and the other the retention time of the mix in the trap. In the observed plants all sand traps are different. It looks that the execution of this important job is left to the mason.

When the plant inlet is not connected to the stable, all feeding is depending on the laborer and the farmer. In that case also the sand separation is questionable. Sand separates better when more water is mixed with the dung the more the water the faster the separation takes place. It looks that the *biogas technology textbook rules* (mix dung and water 1:1 or 1:2) are not comprehensive enough and should be matter of reassessment.

3.11 Retention time

Retention time is expressed in days and is the digester volume divided by the volume of daily feeding. The water being mixed with the dung is normally part of this equation. The planner uses this figure to decide on the size of a digester under given condition. In practice a fixed dome plant does not operate like that pragmatically. In a digester liquids and solids are separating out and the middle water layer will be discharged first, as it has the lowest viscosity. This physical law can be used as an advantage so that the discharge of water is encouraged and the retaining of solids in the digester is extended to receive maximum exploitation of the digestible carbon hydrogen chains in the digester. When solids have accumulated and all water is driven out the sludge starts being discharged. That may happen only after a year of operation, depending, however, on many factors. When gas accumulates to the maximum pressure, the digester will discharge parts of the swimming layer.

Regarding the digesters visited the average hydraulic retention time of settled solids and liquids cannot be judged. Grameen Shakti defines in its *Biogas Technology Guide* the hydraulic retention time required in agricultural digesters as 45 days.

There is definitely a large difference between the digesters which require the transportation of dung and water by hand which may have retention times of over hundred days and those operated by gravity where the retention time can fall below thirty days. A long retention time will indicate an underutilization of the digester volume whereas a short one can lead to discharge of non stabilized digester water. The latter was however not observed in any case.

3.12 Overflow utilization

Among the researched digesters there was mainly no overflow utilization. In one case there were traces of experiments and in one case it was reported that the discharge is utilized. Farmers had dug out sometimes very deep ponds to fetch the overflow, but most digesters discharged only water, which then infiltrated via the compost pits in the underground water body.

The overflow from many other plants was not considered at all and was discharged in nearby rivers or ponds. Tools to encourage overflow utilization where not in place. Only at the two large biogas plants seen in Faridpur the fertilizer utilization was either practiced (Muslim Mission, drying and packaging and selling of solid and own use of liquids) or serious matter of theoretical consideration (RAJ poultry, drying and composting of solids component and own utilization of liquid component).

3.13 Drawings, plans and literature

The Grameen Shakti biogas activities have obviously recently undergone some changes. The plants are not as outlined on the drawings in the actual construction book. The book for instance considers making in the *"Grameen Model"* outlet tanks round, whereas in the field they are squared. Two recently constructed digesters had a round outlet tank and their disadvantage was that they had large lids. Furthermore the new digester design is lower leveled in the ground so that the overflow point is 20 – 30 cm below the natural surface.

The natural surface level around a biogas plants changes due to the construction in case the dug out soil is not transported away but just distributed on the spot.

Many elements in the literature and reports written contradict with the reality. The contract to be signed with the customer mentions elements, which contradict the long-term experience of Grameen Shakti and are just introduced and then made mandatory without that they have stood the test of time.

- This is for instance the case for is the *mixing device,* which is not required when the plant is directly connected to the chicken house.
- Also the slurry pits are mentioned as mandatory despite that the pit design is an environmental thread.
- The contract also talks about *proper functioning of the plant* which should rather be *the prove of a biogas plant to be gastight*.
- The gas storage capacity is represented in the outlet tank only whereas in the digester it is in some cases larger and in other cases smaller than the outlet tank.
- Chicken and cow manure digesters differ in their dimensioning but are identical in their nominal size. Then they should not differ in the gas storage capacity but they do.
- For the digester sizes 1.6; 2; 2.4; 3.2 and 4.8 the outlet tanks are **oversized** and do not correspond to the gas space in the digester below the 0-line. This technical mistake ranges between 23 and 52%. It is obvious that the requirements of designing fixed dome digesters have not been mastered.

VG_1 and VG_2 should be identical volumes. The dome volume above VG_1 contains gas but under full utilization of the digester capacity this gas cannot be discharged. In the calculation of the gas storage capacity during the design phase these volumes are to be identical. In case VG_2 is larger than VG_1, only a small section of the additional volume can be used an as then the 0-line rises the shape of that camber has to be flatter. Rising only VG_2 leads to unnecessary cost increase. Rising only VG_1 leads to a lowering of the 0-line and would sometimes empty the outlet tank completely.

- For digester sizes 6; 9; and 12 m^3 the outlet tank is 28 to 36 % **undersized**, but this has no operation consequences as the inflowing dung due to direct stable connection does some of the hydraulic displacement. So this approach is to the favor of the customer as it saves investment cost.
- The table *maintenance of plant and distribution pipe* is not based on sufficient practical experience and monitoring and communicates concepts which are insufficient (fixing leaks with tape…)

Independent of written documents it was observed that also advice given to farmers is governed by partially wrong concepts.

4 Conclusion

A number of technical suggestions in accordance to the findings are discussed here. There is no final recommendation how the standard biogas plant in the program should look. Instead there are a number of options and their strength and weaknesses are discussed.

4.1 Gas tightness

More pressure tests on different biogas plants have to be conducted. It has to be assured that the plant is checked independent from the piping system. Each plant, which is found not being gas tight, has to be emptied and inspected. There are two possibilities for no gas tightness: either the dome is cracked or the surface cover diffuses gas. It is next to impossible to repair a cracked dome in a way that it is able to cope with the changing pressure and respective expansion of the dome (Extensive test of a German research institute (University of Applied Science, Hildesheim, Profeesor Ringkamp, 1988) have shown that under pressure the digester surface expands). Tests with fiberglass lining as a remedy could be made. Regarding a diffusing surface it depends on the sealing method previously applied. In case of waxing an additional wax layer on a completely dried surface is recommended. In case of application of acrylic emulsion paint the surface has to be repainted.

4.2 Cracks

In case of the plant at the slaughterhouse it is necessary to empty the plant and understand the cause of the crack. As there are signs of serious cracking there may be a problem with the foundation. In that case the plant has to be rebuilt completely.

4.3 Gas production

An overproduction of biogas can be considered as a positive problem. It has to be addressed with more gas consumption. Reducing the feeding is not an option to be considered, as the main purpose of an overfed plant is clearly sanitation and therefore this performance should not be endangered. The option of connecting more families to the biogas plant is an excellent consideration and should be further encouraged. To have such systems reliably working, the piping systems have to be of good quality and measures to control them have to be in place.

The owner of a biogas plant does not know the production status of the digester. This information gap can be addressed by the installation of a pressure indicator in the kitchen. This is a low cost improvement of the situation and stimulates the owner to know the digester better. It also gives information if the plant is gas tight.

4.4 Direct stable connection

All biogas plants should be build in a way that feeding them is as convenient as possible. This will increase the gas production. For long-term operation convenience of loading has higher priority than saving investment cost. Cleaning a chicken house with water is then at the same time feeding the biogas plant. It is necessary that the sand in the chicken droppings be removed. For this purpose a standard sand trap has to be installed. The sand trap should provide a retention time of 10 seconds to provide enough time for all the sand to settle down.

The dung channel should be as short as possible so that the digester level does not drop unnecessarily. This is also advantageous for the construction under high water table conditions, requires less digging and makes gravity distribution of effluent a bit easier.

In case of cattle raring the animals are often kept on a brick paved floor. The inlet of the biogas plant should be directly connected to this pavement so that the urine enters the digester by gravity.

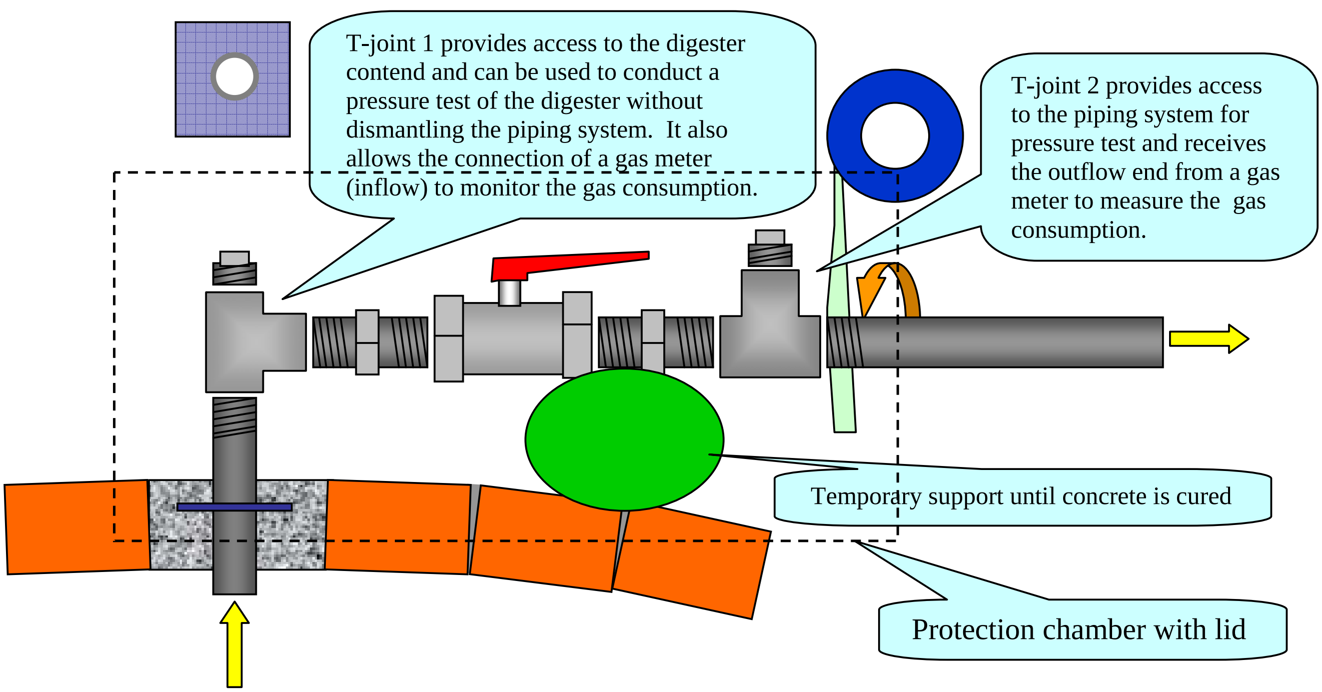
Fodder residues mixed with the dung can be washed in the digester and will increase the gas production (the lignin structure of the grass will be discharged through the large (manhole) outlet).

In case it is preferred to charge the digester with little water only, a poking stick can be used to press the material down. During the digestion process the material gets more watery.

4.5 Piping system

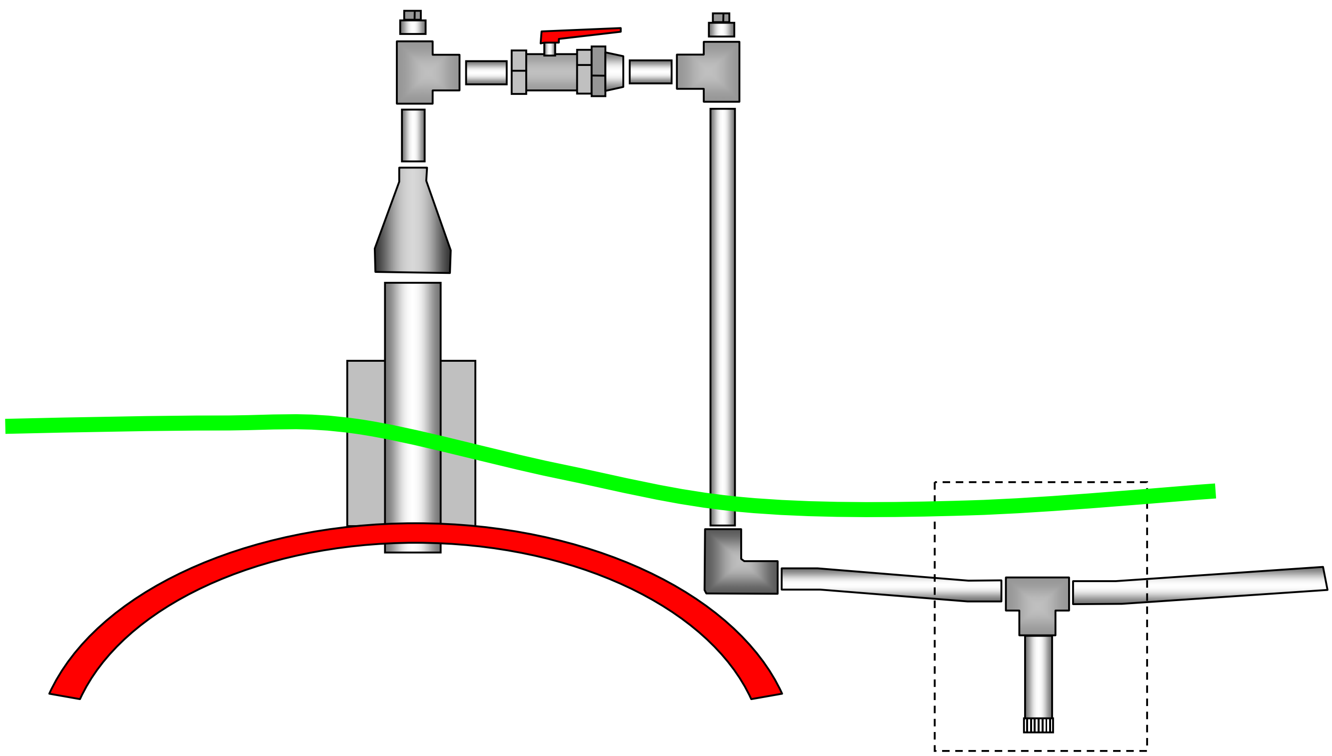
The piping system is the weakest part of the digester systems seen. The flexible PVC pipe is a low cost solution. Weaknesses seen were mainly the formation of condensation water. **More care and more technical options** are required to improve this element. It has to be considered that a reliable piping system made of galvanized steel pipes would be an expensive option, which reduces the target group to be reached commercially with the technology. Such a piping system would in conjunction with the existing design of a gas outlet pipe require a water drain in each case.
Several options for piping system solutions are discussed here:

- Best solution of a gas piping system starts already with the digester design. When the overflow of gravity fed digester is 10 cm lower than the gas outlet pipe, which is inserted in the dome, the entire piping system can be kept under ground and in case the room where the gas is used is higher than the digester, can be laid as either galvanized steel pipe or PE plastic pipe or aluminum reinforced pipe (multi layered) entirely under ground. If that can be done with a constant slope facing backwards to the digester, such a piping system does not need water drain as condensation water can flow back to the digester. The gas outlet pipe can be a standard set of fittings, which leads together form a maintenance and testing unit. The following sketch shows how under such conditions the gas outlet pipe should be designed. If executes in ¾" fittings, it is more durable than in ½" :



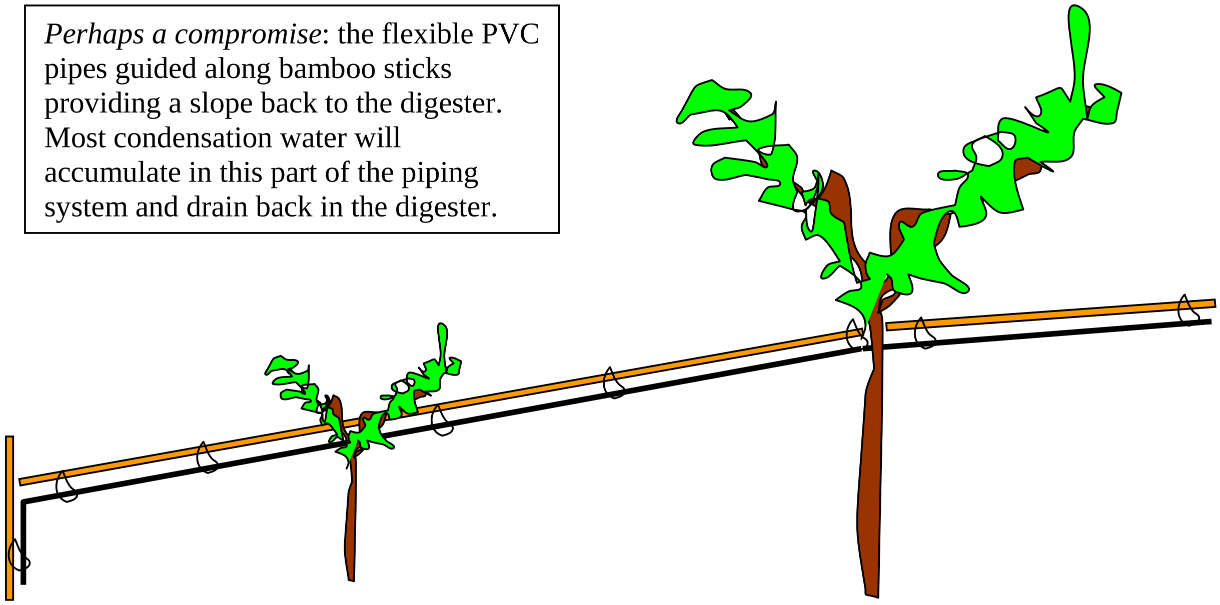
The gas outlet pipe is made from an 18 cm piece of pipe to which a disc or square metal piece is welded this secures gastight fit in the surrounding concrete. It is advisable to grease the thread in advance, to prevent corrosion. This piece of metal should last as long as the concrete structure of the digester, as replacing it is cumbersome. The standard fittings should already be mounted on the pipe so that when the piping system is placed, stresses and forces on the young concrete work as it might occur with the construction of a steel piping system are avoided. Thus the gas outlet pipe is composed of ***T-joint - main valve - T-joint***. This set up is a recommended feature for subsequent maintenance and monitoring of the system. Under normal operation the T-joints are closed with plugs. All threads are sealed with tape, applied in approximately ten layers.

- Another option would be the installation of a riser pipe in conjunction with the standard gas outlet pipe and respective reducer fittings, with a valve which immediately goes back under ground and sloping from there to a water drain. The 2” gas outlet pipe has this over dimensioned size to avoid clogging in case the liquid inside the digester rises to this level. If possible a union, which ideally would be a part of the valve itself, should be incorporated. Also here the incorporation of two T-joints to allow convenient monitoring and measuring the gas consumption is advisable.

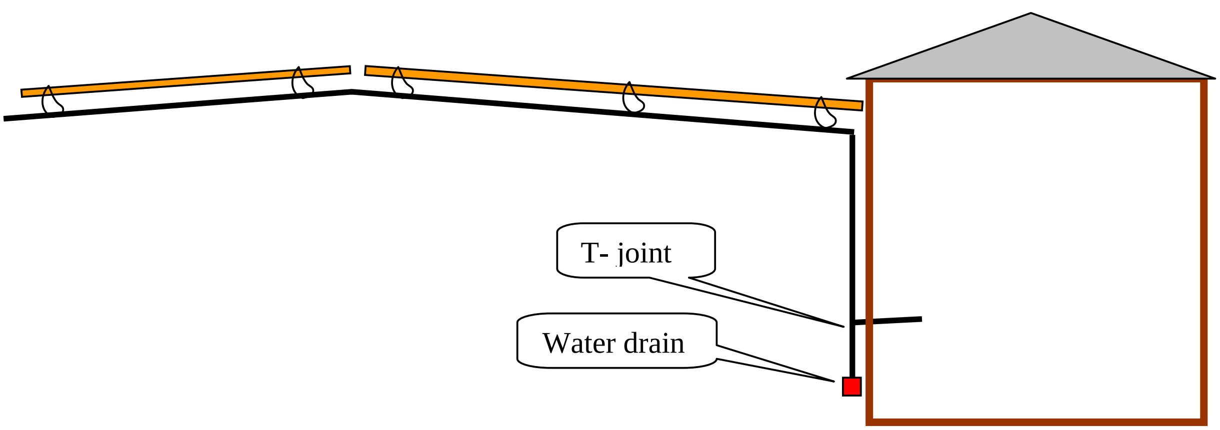


- For larger piping systems it is difficult to install a reliable network from steel pipes and secure its long-term reliable operation. This would require many check points and intermediate valves to cut off parts of the pipe network in case problems arise. The overview, where the pipe is laid would get lost after some time. Rural land is matter of frequent change and the danger that a pipe is knocked and ruptured is given. Under such consideration the frequently found solution of flexible PVC pipes being guided through trees and across roads looks appropriate and minimizes at the same time the cost. It was observed that the pipe fits very tight on the respective fittings, which is a big advantage. It is advisable to make a systematic distribution plan for the pipes and follow certain logic for its division.

- Also for shorter piping systems the actual solution of a flexible hosepipe can be accepted. It is however necessary to address the condensation water problem. Biogas is generated in a wet environment and is therefore water saturated. To reach saturation the amount of water in the gas depends on the gas temperature. The warmer the gas the higher the water contends. This water condenses as soon as the gas touches a colder surface. The same way the water is released from the gas, it can happen the other way round that the gas may be colder than a piping system and if this pipe is moist from inside, the gas will pick this moisture up and saturate. Coming to a cold surface this moisture is again released. The condensation water problem therefore depends on the weather, direct sunlight, and gas use during the day and/or during the night.
- All depressions in a piping system are potential points of water accumulation. The probability of condensation water is higher closer to the digester and smaller closer to the stove. Once the water condenses and is allowed to trickle back into the digester, the danger of condensation water later in the piping system is reduced. As the temperature conditions in and around the pipe cannot be influenced, it is necessary that condensation water leave the pipe. This is best addressed with a piping system, which slopes upwards from the digester towards the gas consumption points, as long as the situation allows. A situation where the owner of a biogas plant frequently has to maintain the piping system by draining out the water should be avoided. Even though there are situations where the owner can perfectly handle this, there may be many others where this maintenance requirement is the beginning of the end. One option to address the condensation water is to consequently slope the pipe for as long as possible towards the digester, by tying it to parallel running bamboo sticks.
- In case a compromise with a flexible hosepipe is tolerated in the piping system the owner has to receive clear instructions how to maintain this piping system. Sealing leakages with tape should not be advised or practiced. In case a pipe is ruptured there should be a repair set in form of a coupling and spare piece of pipe at hand. Water in the system can be detected early once the user has received training (user training) where this issue is addressed. The technology provided, should in principle avoid instructions for users as much as possible and address respective issues, which may arise technically. This is the only way to minimize failures.



If it is unavoidable that the pipe slopes down and forms a lowest point a T-joint and a water drain have to be installed.



- Piping systems have to be put more in the focus of teaching and training. Trainees have to practice the different options and know how to assure quality and also how to best teach users to maintain the system. They must know how to make a pressure test and must learn that *quick, hasty* repair measures are not sufficient. There must be awareness that <u>only a consequent quality concept is acceptable</u>. For this a service person, who in the context of Grameen Shakti is at the same time an outpost to receive credit repayment, is equipped with all maintenance tools and spare parts, control tools (pressure indicator) and know how.

4.6 Gas consumption

It is very important to assure that all gas produced is also consumed. Over produced gas escaping through the outlet tank should be an exception but not the rule. The negative climate impact of methane escaping in the atmosphere endangers the CDM credibility of biogas programs in general.

Particularly for the scale of plants targeted by the SED project, larger than 6-m3 daily gas production, this is a serious issue. A larger gas store does not address gas escape. It helps a bit to harmonize gas production and gas consumption, but at the end a higher production can only be addressed with more consumption of gas.
6 m^3 biogas per day are equivalent for the entire cooking energy for 24 people.
The same gas could bring 150 L water to the boiling point.

There are several options for more gas consumption:

1. Connect in each household a well readable pressure indicator and train people to use it. This will encourage finding more uses for the gas. Raising the awareness that in particular the long night period, where no gas is used, should be used for some gas consumption.
2. Discuss with users what other items could be cooked on a regular basis, e.g. to establish a small business like a teashop.
3. Connect to each biogas plant the optimum number of households (4 people per m^3 expected gas production).
4. Establish in each household also an institutional burner for larger pots. There are occasional feasts or needs to cook with larger pots.
5. Encourage the use of gas lamps (it has to be stated that the trend shows that biogas lamps loose their former attractiveness since solar home systems and LED technology reach the rural areas. The long-term performance of biogas lamps is often not satisfactory, they are more *heater* than *lighter*. In the context of daily use biogas lamps are rather rare).
6. Look for new options of gas use like gas ironing, chicken breeding and incubation, par boiling of rice, electricity generation and water pumping with H_2S removal. Biogas can in principle replace all stationary used liquid, gaseous and solid fuel.

The search for better gas consumption and mainstreaming such options should be a long term focus for the GTZ project.

4.7 Biogas burners

The parameters to be considered in the construction of a household burner are:

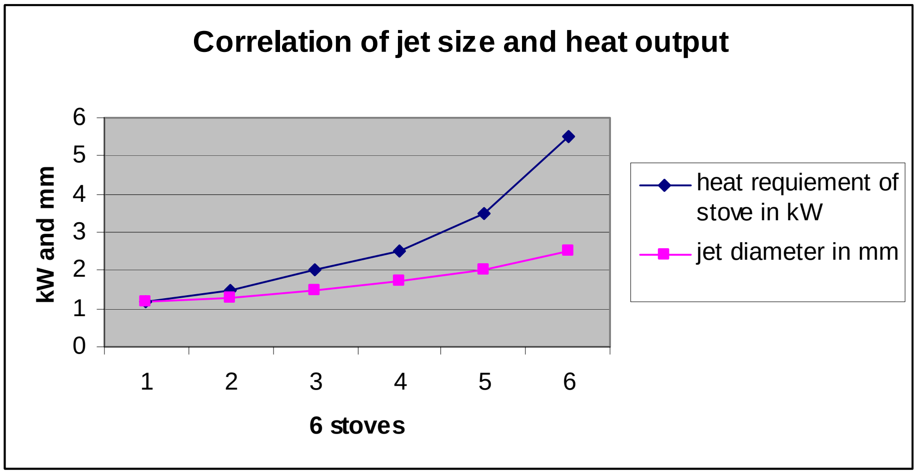
Parameter	**Purpose**	**Respective finding**
Methane contend in biogas	Most important to estimate the calorific contend of the gas	Chicken manure plants 67% Cow dung plants 61%
Most likely range of gas pressure under flowing conditions	Flow of gas in the nozzle	The maximum pressure in all researched digesters ranged between 87 and 131 cm water column. An orientation at an average pressure of 50 cm WC is the guiding figure. A gas valve regulated by the user is a pressure reducer as for the performance of the stove the gas under running conditions is decisive.
Nozzle size	Determines together with parameters 1 and 2 the amount	Nozzles are in general too large, leading to huge, but not very hot

	of energy consumed over time	flames.
Contact area with primary air in mixing pipe	The closer the primary air to the stichomythic mixture, the smaller and hotter the gas flame	Insufficient primary air in burners, leading to a large flame which is 50 -100 ^{0}C cooler than the flame receiving the optimum primary air. The flame cools down further by 200^{0}C when touching the pot.
Mixing pipe	Mixing all different molecules as good as possible. A Venture jet is doing that most reliably.	The burner head is too small to accommodate the required amount and size (area) of holes to operate efficiently. Consequently the mixture of gas and primary air run off in high speed. As the ignition speed of biogas is low the flames tend to lift off.
Area of burner head holes	The area has to be big enough to allow a slow exit of the gas mixture as biogas has a slow ignition speed. Otherwise the flame tends to lift off. The area of burner head holes should be 50 times the area of the nozzle.	In relation to total gas mix the area of the opening holes are too small. Also after fine-tuning less gas and more primary air the gas exit holes have to be increased
Distance between flame tip and bottom of the pot	Fuel should be allowed to combust completely before its converted form of energy is used. Using it during the conversion leads to incomplete combustion.	Flames are usually surrounding the pot which is decreasing the efficiency as the flame cools down from 800^{0}Cto 600^{0}C and combusts incompletely, resulting in slight H_2S smell.

As SNV is actually addressing the burner issue by testing burners at 3 different international institutes, it is wise, to wait for the fed back form those institutes actually researching the burner efficiency. The final product for mass dissemination should then be developed and address the following requirements:

Purpose	Gas consumption	Thermal power at 50 cm water column and 67% methane concentration				Nozzle diameter,
	l/h	kW	MJ/h	kcal/h	BTU/h	mm
Double household burner smaller pots	200	1.2	4.32	1032	4096	1.2
Single household burner	250	1.5	5.40	1290	5120	1.5
Double household burner larger pots	334	2	7.20	1720	6826	1.7
Large burner, household	416	2.5	9.00	2150	8533	2.0
Medium burner, institution	500	3	10.80	2580	10239	2.5
Large burner, institution	667	4	14.40	3440	13652	3
Double tea burner cooker for the requirements of a small tea shop	400	2 * 1.2	2 * 4.32	2 * 1032	2* 4096	2 * 1.2

There is a direct correlation between gas pressure, energy contend and jet size on the one hand and thermal power output on the other.



The graph describes the correlation between jet size of a stove and the heat output. The efficiency of a gas stove can go up to 60%. With a biogas stove this can only be realized if a maximum of primary air is provided and can be utilized by the stove. This depends on the physical dimensions of the mixing device, burner head, area of holes and distance of the bottom of the pot to the holes.

The gas valve should be easy to operate and long term reliable (this has been improved recently in the Nooria stove by copying the valve used in the Nepal stove design. It has to be observed if the closing mechanism in form of an O-ring is a long lasting solution).

Most of the common English language biogas literature does not describe the scientific construction of biogas stoves (except the FAO docs and the teaching material form BRTC, China).

4.8 CO_2 concentration in biogas

The research on CO_2 concentration in biogas should be continued. A correlation between water entering the digester and CO_2 concentration has not been followed up, but could be matter of further research. To some extend water flowing through the digester carries out parts of the CO_2 as well as H_2S leading to a better performance of all appliances. A similar effect can be expected from a *manhole size inlet structure* in which the hydrolysis (acid phase) of freshly fed material takes place. In this phase the CO_2 concentration of the gas produced here is relatively high. A digester with an inlet structure providing a retention time of ½ a day and wastewater flowing through it normally has a higher CH_4 concentration in the gas. Also the H_2S contend of the gas could be reduced by that (this has not been measured).

4.9 Energy conversion

A renewable energy extension program has to focus on areas with the potential and the need for this form of energy. In Bangladesh there is a wide electricity grid to towns and Upazilla (peri-urban) areas. There is also a network of natural gas pipes, which also reaches many households. Both energy forms are in relation to the high demand in shortage. This shortage will further rise. It is difficult for Bangladesh to assure its energy provision. Biogas in small and medium scale should be extended particularly in areas without electricity and natural gas grid. Larger-scale digesters with

electricity conversion can be built in areas with or without electricity link. They would contribute to reduce the consumption of the respective primary energy forms. The existing biogas operated generators are all asynchrony generators. They need an own independent electric grid, which consumes the electricity in the range of their output potential.
In larger scale operations of 100 kW electricity production (at least 4500 m^3 biogas per day) or more, synchronized generators could be utilized and supply the electricity into the grid. This requires a higher technical standard and can be looked into in the future. There would also be an option to produce biogas from municipal organic waste in a biogas plant near an electric power plant and utilize the gas in the power plant complementary to the natural gas

4.10 Integration in the farm – non standardized structures

The operation of a biogas plant has to be convenient. The digester must be rather *of help* for the farmer than *a burden*. It should be easier to push the dung into a digester than to load it in buckets or wheelbarrows and transport it to the digester or at any other location of the farm. The inlet of a biogas plant belongs to the point where the organic waste is easiest available. There is often the opinion that for cost saving the digester should be rather close to the kitchen for a shorter piping system. This form of priority setting may decrease the investment cost, but increases the running cost and is therefore a daily threat for the digester to receive less feeding. The farmer does not need an innovation on his farm, which is cumbersome to operate. Integrating a biogas plant in the farm means to link it as short as possible to the cowshed or chicken house and build the overflow as close as possible to the point where the effluent can be utilized as irrigation water and fertilizer. The ideal inlet is in the stable and is operated by splashing a bucket of water over the dung and pushing it with a broom it into the inlet. Any mixing device should be avoided. All metal structures being in contact with air, dung, urine and water will sooner or later corrode. From there onwards the biogas plant will be operated without the mixer anyway, so why not from the onset? There is theoretically a large fear that solid organic matter should not enter the biogas plant. This fear in unrealistic, since nowadays most fixed dome plants have a manhole size connection to the outlet tank. (Older biogas plant designs and particularly floating drum designs had small outlet pipes and were therefore sensitive for swimming layers. Another example are the two slightly different fixed dome standards built in Vietnam, which base on technical drawings made in the early 80ies). Provided that the dome of the digester is gastight, all swimming particles forming a scum will sooner or later be discharged, once the maximum pressure in the digester is reached. In any well operating biogas plant this is quite frequently the case. Thus the swimming particles are discharged into the outlet tank. For better integration of the digester on the side of fertilizer utilization, it is helpful if the outlet tank is accessible. This allows the user to take out the more solid swimming layers as well as the discharged water.

Is a biogas plant directly connected to chicken house, a sand trap in the wastewater stream is mandatory. It should provide for the wastewater stream a retention time of 10 seconds. When all dung is washed in the digester the dung and water, which has accumulated in the sand trap are scooped out into the digester and the sand is removed with a shovel.

The amount of water entering a digester can be limited by an instruction but the limitation should not be communicated in a dogmatic form. Fluctuations in water provision can be tolerated. In practice some farmers allow 5 times the suggested amount of water into the digester without that this causes any harm or reduced gas production.

4.11 Retention time

Grameen Shakti defines in its Biogas Technology Guide the retention time required in agricultural digesters as 45 days. For cow dung a mix of 1:1 with water and for chicken manure a mix of 1:2 with water are suggested.

Taken this as the real condition this is under the given average ambient temperatures of about 25° C on the high side. It should be observed how well the discharged effluent is broken down. In the field the hydraulic retention time varies between 20 and 200 days. This may look odd but is quite normal as it all depends on the user's habits. Plants with the short retention time will still produce a lot of gas as the water, which is discharged first, is mathematically part of the RT calculation. As plants with more water entering separate liquids and solids distinctively. The retention time for the solid components may well be over 100 days in such digesters too. Seeing the vide variation in real field conditions, the planning of digester sizes may be in the first thought oriented on the retention time, but other criteria like

- Space available,
- Funds available and
- Need for gas storage
- Expected future developments on the farm

may very well be parameters for planning and decision making as well. This in mind, gives the customer the choice of selecting a plant of the next larger or the next smaller category, so that it's not only the number of animals determining the size of the plant.

4.12 Overflow utilization

Effluent utilization is in many biogas programs a matter of concern. In the digestion process the carbon (C) is removed from the original charged material whereas nitrogen (N) remains in the material. Thus the C/N becomes narrower. The agricultural soil also contains C and N and consequently has a C/N ratio. Only if the C/N of added organic matter or organic fertilizer is narrower than the one present in the soil, the material is a growth enhancer and shows its fertilizing effects as in comparison to a plot where the biogas effluent is not applied. In the composting process under aerobic conditions a lot of nutrients are lost either in gaseous form or as seep.

What is the background that farmers are often reluctant to use the effluent form biogas plants in accordance to the potentials of it?

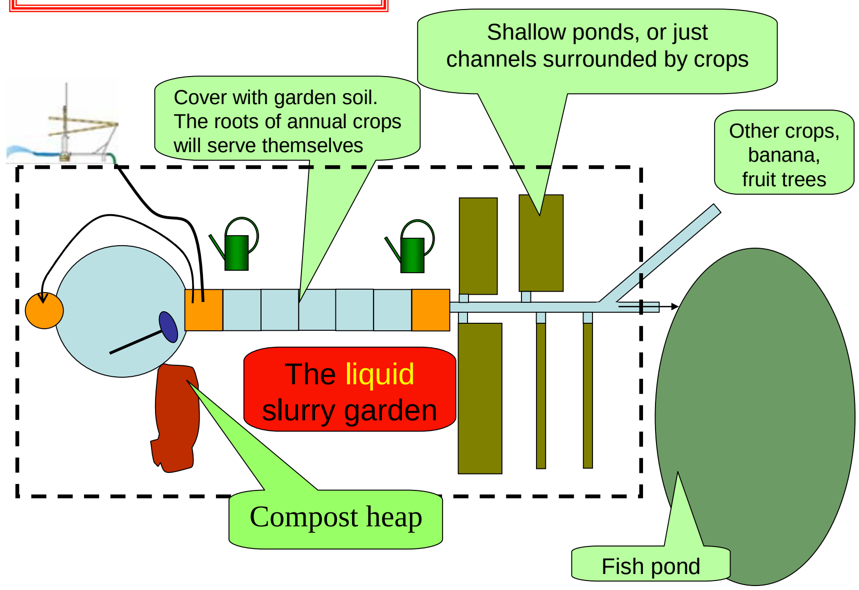
The farmer will be convinced to utilize the overflow as fertilizer if he is pleased by the relation of work input in comparison to results on crops. A fertilizer promotion therefore has to focus on convenient utilization of the effluent and showing good results.
Organic fertilizers require much more work from the farmer than the comparative chemical fertilizers. Applying 90 kg nitrogen per ha means to distribute 200 kg substrate. The same N provided in form of slurry from a biogas plant (TS 8%) would require the distribution of 35 000 kg per ha. On a non-mechanized farm this is not feasible. Thickening the slurry to a compost material of a TS of 40% would lead to the loss of 50% of the nutrients but would reduce the transportation requirements to 7 000 kg per ha, which is still 35 times the labor as if chemical fertilizer is used. The focus of slurry utilization should therefore be within the vicinity of the biogas plant. Small successes from the fertilizer will encourage the farmer to make more and better use of the fertilizer. It cannot be expected that farmers use slurry without being convinced that the effort is worth it.
Advice and support should focus on small easy achievable successes, which encourage the farmer to use it more consequent and better.
The transfer of advice to farmers needs particular attention. Theoretical input in classroom condition has very little impact. An approach of farmers visit and shared practical implementation could be elaborated and tried. Advisors with practical experience in ***slurry gardening*** could be hired and be trained to work on biogas farms. They would receive their payment partially from the farmer and partially on pilot basis from the project. Such an advisor will move on from one biogas plant owner the next and establish fertilizer utilization gardens around the digester. The objective of such measures would be that demonstration gardens show the practical options of fertilizer utilization and their effects to the respective farmer and also to others. The methods of slurry utilization should

cover all thinkable options. The advisor and the farmer or his employees or family members execute all work. ***Convenience*** should be the guiding principle for slurry use. The following options are possible:

- Change the outlet chamber in a way that it is easily accessible and liquid slurry can be taken out conveniently. The impact on the possibility to use gas can be neglected latest after a period of learning. Also the installation of a pressure indicator as suggested would reduce the overuse of slurry out of the displacement tank. Particularly when the plant is directly connected to the stable floor there is a high probability that the water in the digester is rather abundant than too little.
- Establish vegetable garden beds in the immediate vicinity of the biogas plant (*slurry garden*, or *paradise garden*).
- Purchase, make or provide tools which make slurry handling easier: buckets, watering can, swimming pool cleaner and dipper.
- Establish a fence around the slurry vegetable garden.
- Establish, if possible, channels in which the overflow can be guided to crops, trees, plantations outside the fenced slurry garden.
- Introduce treadle and/or electric pump to use liquid overflow where it cannot reach by gravity, also in irrigated rice fields.
- Establish compost heaps (composting should be done in humid climates on heaps and in arid climates in sealed pits but only solid slurry (8% TS) should enter such pits. More watery sludge should be used to water the crops) shallow drying pits for the sludge component, surrounded by useful vegetation. The sludge drying should be easily accessible and made in a form that plant roots absorb seeping water.
- Plant out the slurry garden with various plants considering marketing of the products.
- Maintain the garden to maximum productivity.
- Use the dried slurry outside the garden and also around trees.
- Use the liquid slurry to clean out chicken houses as a form of water recycling.
- Test and observe all ideas of slurry utilization.
- Establish a beautiful, presentable ***paradise garden***.

The sketch shows an example of slurry utilization with an outlet chamber design, which encourages slurry utilization. The limiting factors for slurry utilization are its high water contend and the transport requirements. Therefore the suggested system is oriented to cope with theses weaknesses. A long stretched displacement tank with two easily movable lids allows slurry discharge at two different locations in the garden.

8 methods to use slurry



For larger scale digesters the principles for slurry utilization should be:

- Liquid and solid components are separated,
- The liquid is used on the farm
- The solids are dewatered on the farm, stored on compost heaps and used on more distant parts of the farm or finally dried in the dry season and packed in bags to be sold.
- If liquids are taken out of the displacement tank regularly the solids will slowly thicken in the displacement tank and can be removed in the dry season when it is easier to dry it completely to a level that packaging and or transportation is feasible.

Selling liquid slurry may in exceptional cases be attractive if there is for instance a specific clientele who wishes to buy the overflow in drums or bottles. But it is not advisable to rely on this as the nutrients contend is low and the transportation of water is high.

The use of slurry as fish feed is a very appropriate option for Bangladesh as fishponds are very common. Experiments to identify the optimum dosage have to continue. Recommendations for slurry use must consider their TS contend as otherwise misunderstanding is created. The effluent should be separated by solid and liquid and the solid part could be used as fish feed. Liquid effluent produces algae which are applied as fish feed, too.
For cow manure biogas plants the use of urine in the digestion process is important to have finally an effective effluent. Even if used as fish fodder, higher nitrogen content due to urine utilization is advisable.
Watery slurry should not infiltrate in the underground water body but be used for irrigation as liquid fertilizer for all crops.

The table gives the variation of nutrients in the total solid of biogas slurry. The wide variation originates in case of cattle manure from the urine being part of the feeding or not. In case of chicken manure the nutrient contend depends on the method the chicken manure is stored and finally fed. Fresh feeding will lead to higher nutrient recovery.

Table 3.9: Concentration of nutrients in the digested slurry of various substrates! (Source: OEKOTOP, compiled from various sources)

Type of substrate	N	P_2O_5	K_2O	CaO	MgO
	—% TS—				
Cattle dung	2.3 - 4.7	0.9 - 2.1	4.2 - 7.6	1.0 - 4.2	0.6 - 1.1
Pig dung	4.1 - 8.4	2.6 - 6.9	1.6 - 5.1	2.5 - 5.7	0.8 - 1.1
Chicken manure	4.3 - 9.5	2.8 - 8.1	2.1 - 5.3	7.3 - 13.2	1.1 - 1.6

4.13 Drawings, plans and literature

As described in paragraph 3.13 the Grameen Shakti concept is in a transition phase where a new approach for faster biogas technology dissemination is being prepared. It is advisable to increase the intensity of communication among all involved in order to come out with excellent concepts, designs and products. In the preface of the *Biogas Technology Guide* it is mentioned that this publication will be further improved in conjunction with field experiences.

For the next edition some elements could be further elaborated:
The technology has to consider convenience of operation for the farmer in all aspects. This regards particularly the daily feeding and the fertilizer utilization. There should be encouragement for more gas use and the use of a pressure indicator in the kitchen. The aspect of quality has to be risen to a higher level. Quality has to include performance of the system and this should not bank entirely on the user or operator. More convenience in operation already incorporated in all design elements is a way to exclude the human factor as a reason for failure. Particularly the piping system needs fresh re-thinking.
The differentiation of chicken and cow dung plants with slight differences in digester volumes are confusing, not stringent and not significant. The fluctuations on the farm as far as number of animals, digester temperature and change in gas requirement and consumption, retention time and water entering are matter of permanent change. By nature a family size biogas plant is only approximately an optimum. So dealing in all aspects with approximate averages is sufficient and makes the program and quality control easier.
Regarding the chapters on slurry utilization the methods for transport and the utilization in liquid or solid form could be described.
Special emphasis should be put on the correctness of the technical drawings and correctness of figures and measurements.
The aspect of long term maintenance and self maintenance needs further re-thinking.

5 Recommendations

The recommendations have given here focus on the GS-GTZ program. There is automatically an overlap of these suggestions to other biogas activities.

GTZ - SED should:

- Continue monitoring existing biogas plants and assess their performance with the help of the tested checklist.
- Develop quality control system, which aims at judging the quality on the performance of the respective system.
- Further improve the checklist to deliver precise data with little effort.

- Involve itself in biogas stakeholder communication and coordination.
- Provide backstopping on technical developments.
- Encourage the GS program to concentrate more on areas without electricity and natural gas provisions.
- Develop strategy to assure long term follow up for all biogas plants installed. This element needs commercialization as otherwise the program will depend on donor support.
- Identify locations for larger scale biogas plants with multiple feed material and electricity generation.
- Provide advice on biogas burner fine-tuning and production to have efficient low cost standards.
- Introduce other gas end uses (ironing, brooder, larger burners, fridges…) and support the installation of a pressure indicator at each plant.
- Continue activities on electricity generation with biogas with relevant partners
- Support the establishment of a limited number of demonstration biogas plants, which show best practice in all biogas related aspects (technical perfection, gas use, slurry use).
- Identify means and ways to sustainable upgrade the 23 biogas plants in the slum area (godfather role).
- Repair the slaughterhouse biogas plant (also under the aspect of learning).
- Encourage commercial appliance sector to widen its portfolio to deal with slurry utilization appliances as well.

Grameen Shakti should:

- Reconsider the piping system in general to achieve more operation security as highest priority (gas tightness, condensation water, lifetime, corrosion…). Options with PE pipes and GI and plastic pipes are feasible. Main focus is consequent work execution and training.
- Reconsider recent design changes under the aspect of convenience and user friendliness in operation, long term performance, technical precision of drawings (design, volume of gas store). With these changes investment cost per biogas plant can be reduced.
- Consider a standard width of all displacement tanks in all sizes of digesters, changing only the length. Change depth of displacement tanks within limits not to raise pressure above 120 cm WC.
- Make pressure tests on existing plants, particularly on the IDCOL design as both, the inner lining of the digester and the piping system have been changed (compared to former standards).
- Reconsider the effluent utilization to achieve maximum recovery of nutrients. Access to outlet tank and encouragement to use the outlet tank as fertilizer store. Avoid infiltration of overflow water in underground water body.
- Encourage effluent utilization on own farm with highest priority and commercialization of dried sludge overflow with second priority based on convincing results on the farm. This increases the confidence in the product on the side of the farmer and the customer for the fertilizer.
- Introduce on pilot basis a system on individual advice on slurry utilization with interested farmers. The perspective would be to create slurry advisor jobs and commercialize the service. The focus of this service should be on plants of up to 10-m3 gas production per day.
- Reconsider the biogas terminology to be more precise (*digester volume* is precise, daily gas production is hypothetical and was correct in less than 20% of the measured cases).
- Consider changing all measurements to metric and providing training consequently in metric terminology.

- Consider simplifying the digester standardization. The differences of chicken and cow dung plants are confusing for the masons, not stringent and not significant. The fluctuations on the farm as far as amount and age of animals, digester temperature, amount of water entering the plant, change in gas consumption are so large and unpredictable, that the application of average sized digesters is sufficient.
- Focus to develop methods for maximum benefit recovery on all biogas plants. This has to have higher priority than building many biogas plants (quality is more important than quantity). This priority setting allows harmonizing biogas extension with the Grameen Bank business development approach.
- Consider a quality control system, which goes beyond comparing the executed work with the data on the drawing. In the interest of the end-user quality is the relation between *promise and reality* and that is a function of *performance*.
- Fine-tune systems of follow up, after sales service, user training, instruction manual, user information, advertisement and awareness creation.
- Establish extension unit for commercial biogas plant repair and rehabilitation.

Recommendations for the wider biogas stakeholder community, including GS and GTZ:

Future activities on biogas extension in Bangladesh should include systematic regular stakeholder coordination. The topics to be tackled are:

- Securing long-term performance of all biogas plants due to Sustainable After Sales Service Execution (SASSE). The instrument required goes beyond a guarantee period. The long-term performance is a weakness in many biogas programs in other countries as well.
- Improve viability of biogas systems (use and/or sale of gas and fertilizer). It is not sufficient that there is a theoretical potential for being viable. The practice has to prove it the farmer has to feel it.
- Appropriate credit systems instead of subsidies. The involvement of the Grameen movement gives good opportunity to adapt proven credit provision methods to renewable energy technology dissemination.
- Self-propelling commercialization of biogas technology. The dissemination has to aim at mainstreaming biogas as a normal technology. For chicken farms it may even become obligatory.
- Utilization of biomass conversion potential in larger scale. Converting manure alone will cover only a small section of the potential for anaerobic digestion. Bangladesh is located in a tropical humid zone and has ample growth of organic matter. This is a good base for multiple use of the technology.
- Multiple uses of anaerobic digestion technologies (sanitation, organic solid waste, agro-industrial waste water treatment). Technology innovations have to be tackled as pilots. This is the area where support as well as international know how are required.
- International networking. The technology is developing fast in many countries in the world. Only good international linkage and communication can help to learn form successes and failures of others.

The entire report and particularly most of the recommendations are also given in form of two power point presentations, handed over to SED/GTZ which can be used as reference information.

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7 Annex

Annex 1 TERMS OF REFERENCE

1.0 BACKGROUND

In areas of promotion and dissemination of sustainable energy technologies (SETs), Bangladesh has made significant progress in sub-sectors such as solar home systems (SHS), of which about 120,000 units have been installed and commissioned. While the SHS initiative, with diversifications such as small solar home systems (SSHS) goes on, the current and future programs have now targeted the promotion and dissemination of **bio-mass technologies**, including improved cook stoves (ICS) and **bio-gas plants**, where significant 'baseline' works already exist in the country. **About 25,000 biogas plants** were cumulatively installed in the country over the last thirty-two years, since demonstration of the first biogas pilot project in the mid-Seventies, and a new project initiated by the Government of Bangladesh in the late Nineties through Institute for Fuel Research & Development (IFRD) - an institution under Bangladesh Council of Scientific & Industrial Research (BCSIR). This is when also a baseline capacity building initiative was carried out by imparting hands-on training of a large number of bio-gas engineers and bio-gas masons by IFRD. Many public and private sector institutions and also NGOs are being benefited by the human resources development already made under this programme.

Large new bio-gas programmes have been launched in Bangladesh in the recent past through initiatives of Grameen Shakti (GS) with a target to implement about **200,000 Bio-Gas Plants** in the country in next 10-15 years. Also, an international NGO - SNV, of the Netherlands, which has achieved a commendable success in Nepal, having implemented about 150,000 bio-gas plants in that country, has now taken up a programme to launch about 64000 units farm household level bio-gas plants (<4 m^3 size) in Bangladesh, whereby financial supports are being provided from the EU, including those from KfW, Germany. The fund manager of the programme is the Infrastructure Development Company Limited (IDCOL) of Bangladesh.

The target set by GS in terms of the number of biogas plants is no doubt an ambitious one, compared to the practically achievable progress. Till date, about 1000 biogas plants have been implemented under this new programme by GS. It is of course usual, based on experience, that in implementing such new programmes in rural areas, initially slow **'induction periods'** are encountered, given by various initial 'take-off' problems, in financial (e.g. delayed disbursement of the committed funds), social (e.g. delayed creation of a market that needs to be developed through creation of awareness/interest of potential bio-gas plant owners), technical (relatively long construction period) and also logistic (difficulty and/or delays in transportation of construction materials to construction site) terms. Very soon, however, a period of rapid growth is usually reached, followed by a 'saturated' or slowed down growth again before such a programme reaches its set target.

GTZ through its programme *Sustainable Energy for Develoment* (SED) is complementing the mentioned biogas initiative. Through implementing partners such as Grameen Shakti SED supports the dissemination of larger biogas plants that meet the requirements of **agro-industries** such as poultry, dairy farms and slaughterhouses, as well as institutions like boarding schools.

2.0 OBJECTIVES

While the **progress and performance of bio-gas plants implemented so far**, as reported by financial beneficiaries and the implementing agencies, such as Grameen Shakti, are reported to be going on fairly well, **a professional field-level monitoring of the plants installed and commissioned** is absolutely essential.

IDCOL, as the fund management institution of the SNV programme, has its own in-house monitoring system, but concentrates on bio-gas plants for its target group, i.e. rural households. SED needs its own comprehensive and **neutral monitoring through engagement of an international biogas expert** to assess the impact of the bio-gas dissemination activities in agro-industries. The **technical and functional aspects** of the plants installed need to be monitored and fed back to SED, **with appropriate recommendations if and when required,** so that 'course-correction' can be made in time.

The objective therefore reads:
Randomly selected agro-industrial biogas plants are assessed on their performance and recommendations for design and approach adaptations aiming at long term good performance and improved cost benefit ration are made.

3.0 TASKS

The following would be the tasks of the international biogas program-monitoring Expert:

- **Assess whether the field-level physical progress of implementation** of the bio-gas plants are in line with the information as provided by bio-gas plant implementing agencies

- **Assess whether all essential technical components of the installed bio-gas plants** have been established as per approved design in a functional, easy/user-friendly manner

- **Assess that based on international experience of the monitoring expert, technical mistakes made elsewhere (e.g. in other developing countries of Asia, Africa etc.) are not repeated in Bangladesh**, whereby professionally proven corrections/modifications may also be recommended before large scale replication of such mistakes are made. These recommendations are essential, if identified, irrespective of the fact whether the design of the implemented bio-gas plants have been approved in Bangladesh

4.0 TERMS OF REFERENCE (TOR)

Based on above tasks, the international biogas-monitoring Expert will have the following terms of reference for the phase-I monitoring of bio-gas plants ('Reconnaissance Monitoring of Bio-Gas Plants - Phase-I):

1. **Statistically sample at least ten (10) percent** of the bio-gas plants implemented for monitoring (about 25 plants)

2. **Balanced geographic distribution** of the bio-gas plants sampled for monitoring is desired

3. **Examine all essential technical aspects of construction as per design** for fixed dome bio-gas plants, approved for Bangladesh. Should the best professional experience and judgment be indicative of the fact that **any material/component and/or design used for construction of the Bio-Gas plants may not be appropriate and/or may fail in terms of its eventual operation and/or its sustainability**, **provide GTZ with such identifications with appropriate recommendations** that will be pragmatic and possible to implement in the context of Bangladesh, **keeping in mind also the cost factors** as already allocated in the **project budget** for construction of such bio-gas plants in Bangladesh

4. **Examine the installed and commissioned bio-gas plants on their proper operations** (**routine bio-gas production in digesters**, **riser constructions/pipe dimensioning and lay-out etc., including appropriateness and operation of the 'downstream' equipment (such as bio-gas burners, bio-gas lights etc.)**

5. **Interview the bio-gas plant owners on their operational satisfaction** in technical terms and evaluate and report them professionally. Also report technical trouble-shootings, if any, faced by the plant owners since the installation & commissioning of the bio-gas plants and how resolved (if done), either by the plant owners or by the implementing agency

5.0 FINAL OUTPUTS

The international bio-gas monitoring Expert shall submit the following outputs to GTZ:

- An Inception Report containing Expert's methodology and modifications of the Terms of Reference (TOR) on bio-gas plant monitoring, as stipulated under Section 4.0, if felt necessary, based on his international experience that may be appropriate in the context of Bangladesh. This is to be submitted within about fifteen (15) days of signing the Contract with GTZ, incorporating results of initial meetings with the bio-gas plant implementing agencies.

- A Final (Monitoring) Report containing all findings, analysis, evaluations and recommendations, if any, of the Expert

6.0 TIME SCHEDULE

It is estimated that the bio-gas monitoring work (Phase-I) can be completed with submission of the above two outputs within two months from signing the contract and receipt of the mobilization advance by the Expert.

Annex 2 The cooperating team

The team, which cooperates with the author, consists of the GTZ counterparts

Dilder Ahmed Taufiq	Chief of operations
Dr. Engr. M. Khaleq-uz-zaman	Senior Adviser
Dr.-Ing. Khurshed-Ui-Islam	Senior Adviser
A.N.M. Zobayer	Programme officer
Otto Gomm	Team Leader

External cooperators are:

Md. Abdul Gofram	Biogas Consultant, Grameen Shakti
Shaik	University of Flensburg
Sekender	Grameen Shakti
Md. Shah Aam	Stove producer
Members of the	Institute of Fuel Research and Development

Annex 3

Time schedule of activities

Date	Activity	Time	Names of location	Names of Person
10.06.07	Arrival in Bangladesh	19.00	Dhaka	
11.06.07	Orientation meeting Organize checklist		GTZ office	Otto Gomm
12.06.07	Departure to Singapore	01.00	Singapore	
	Asia Biogas Markets		Singapore	
13.06.07	Asia Biogas Markets		Singapore	
14.06.07	Speech on Biogas in developing Countries		Singapore	
15.06.07	Return to Bangladesh			
Saturday 16.06.07	Preparing checklist and questionnaire			
17.06.07	Office, purchase of missing tools, meeting with biogas stakeholders completing and printing questionnaire	09 – 11 12 – 13 13 – 16 17 – 18	GTZ office	Gofram Dr.-Ing. Khurshed-Ul-Islam
18.06.07	Field trip Testing questionnaire and check list		Maona	Zobayer
19.06.07	Field trip		Maona	AN.M. Zobayer
20.06.07			Faridpur	AN.M. Zobayer Dr.-Ing. Khurshed-Ul-Islam
21.06.07			Maona	AN.M. Zobayer
Friday 22.06.07				
Saturday 23.06.07				
24.06.07	Field		Maona	AN.M. Zobayer
25.06.07	Stove producers		Dhaka	AN.M. Zobayer Gofram
	Field	4 IDCOL Plants	Maona	
27.06.07	Field	Slaughterhouse		AN.M. Zobayer Alam, Khaleq
28.06.07	Data processing See gas stoves		Dhaka	AN.M. Zobayer Dr.-Ing. Khurshed-Ul-Islam
Friday	Workshop		Dhaka	

29.06.07	preparation			
Saturday 30.06.07	Workshop preparation		Dhaka	
01.07.07	Visit to slum area		Dhaka	Gofran, Zobayer
02.07.07	Modification of stove		Institute of fuel research and Development	Dr.-Ing. Khurshed-Ul-Islam
03.07.07	Slurry Workshop		Grameen Shakti office	
04.07.07	Preparation of Debriefing Workshop			
05.07.07	Debriefing Workshop		Dhaka	Biogas stakeholder community
06.07.07	Journey back to Nepal			

Annex 4

Checklist, Questionnaire

The filled checklist is transferred to an excel sheet where the raw data are calculated to performance data. The instrument is still matter to further modification and adaptation for further use as monitoring instrument within the Biogas extension Project of SED.

Questionnaire Biogas Plant Evaluation, Bangladesh, June 2007

	Legend
It is suggested to run the questionnaire in its original order from up to down	Measured data
Inserted activities and measurements to be taken, aim at gathering quantified data.	Actvities
The construction company has to make a technical drawing available for each digester to be analyzed	data calculated by computer program
Tools required: Tape measure, watch, spirit level, pressure indicator, thermometer, CO2 meter (not essential),	Data taken from, drawing

Criteria	Answer or measured data	Unit
Name of surveyor		
Running number at Grameen Shakti		
Is the digester in operation and use?		
pressure		cm WC
precise time		
Stop using gas, close main valve		
Stop feeding		
Assure access to overflow point		
level difference overflow - liquid (spirit level)		mm
level difference liquid to fixed point e.g lid		mm
precise time		
In case of overflow measure flow and time		cm^3
time of flow		minutes
gas production per minute		cm^3/minute
gas production per day		m3/day
Precise time		
Date		
Name of location		
Name of owner		
Name(s) of interviewed person(s)		
Farm enterprise and other forms of income		
Name of responsible person constructing/company		
Type of digester		
Nominal Size		
Digester Volume		m^3
Gas storage capacity		m^3
Maximum pressure as on drawing		cm WC
factor for sludge density	1.04	
Max gas pressure		
Year of construction		year
Time in operation		months
Burning gas since when		months

Feeding practices		
What is fed?		
Chicken manure		average kg/day
Cow manure		average kg/day
Paunch manure		average kg/day
Water		average kg/day
Toilet waste		Person
other feeding material		average kg/day
fluctuations since operation		
other info on feeding		
Expected gas production (company)		
Encountered problems with digester (customer)		
Observations (surveyor)		
Remedies to solve the problems		
How often does company visit the site		
What was repaired by whom?		
Temperature of digester		^0C
General conditions of outlet tank		
Signs of moisture leakage		
conditions of covers		
inner length		cm
inner width		cm
inner depth to overflow point		cm
Volume of outlet tank		m3
Volume of gas used today from store		m3
% of gas utilization at this point in time		%
Inlet pipe diameter		inch
Inlet structure		
Inlet diameter		cm
Distance source of material to inlet		
Signs of feeding		
Signs of not feeding		
Sand separation		
Smell problem		
Outlet cover		
Quality of overflow in outlet		
Moisture signs in outlet tank side wall		
Overflow position in the farm		
Overflow level compared to grass		
Concept of use of overflow		
Evidence of concept		
Earnings from overflow		currency/time
Any use of overflow reported		
Users own experience with overflow		
Gas use		
Type of gas use		
Number of burners		
Optical assessment of piping system		
Check again level in outlet tank to reference point		mm

Level rise		mm
Check time again		
(the more minutes passed, the better the measurement)		minutes passed
Fraction of day		
Gas produced in measured time period		m3
24 hour production		m3
practical 0-line above theoretical 0-line		cm
Underutilization of gas store		%
Gas appliance performance		
Open main valve		
Pressure		cm WC
time		
Max pressure these days (1)		cm WC
Max pressure these days (2)		cm WC
Average max pressure		
Ask user to light gas at stove		
assess stove performance		
assess stove design		
Brand name, specification		
Position of stove		
Jet size 1		
Jet size 2		
Primary air		
flame performance		
Observation		
Distance to pot		
hottest flame temperature at normal adjustment		^{0}C
Jet 1 without pot		
Jet1 with pot		
Jet 2 without		
Jet 2 with		
CO2 concentration		%
Piping system description		
weaknesses,		
remedies, how often condensation water problem		
earnings from gas sale		taka/month
Pressure test (to be conducted if problems are assumed		
time, date 1		
pressure reading 1		
time, date 2		
pressure reading 2		
if there is overflow:		
time, date 3		
pressure reading 3		
Final evaluation		
Performance regarding gas production in relation to nominal		%
Performance regarding gas storage		%
Performance regarding gas use (estimated)		%
Performance on the fertilizer side (estimated).		%