ID China bio-gas experimentations
法国发起发展组织昆明办公室“沼气池优化管理”研究

INSULATION OF FIXED-DOME DIGESTERS
固顶式沼气池保温功效研究

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1 ABSTRACT 摘要

As part of its commitment to provide continuous support to the more than 2500 families using a biogas digester build by Initiative Développement China (ID), the NGO has engaged in a one year study focused on optimising the management of biogas digesters.

One issue that biogas digesters have to face in climates with a cold season is the reduction of gas production due to the sub-optimal temperature of the digester. In the climate of northern Yunnan, where ID China has implemented household biogas programs since 2008, the average winter gas production is typically a third to a tenth of the average summer production.

In China, where fixed-dome digesters are the most common type, government and non-government programs widely teach the households to place an insulation of organic material above the digester during the winter season. This advise, which is supposed to limit the temperature drop of the digester, is followed by a large number of families.

To test the insulation efficiency in practise, ID China ran a series of temperature measurements from September 2012 until July 2013. Three households were selected; each providing two digesters for the experiment. In each household, one of the digesters was covered with insulation, while the other was left free of any cover. One household used a cover of manure, the second a layer of corn straw, the third household a corn straw compost. Each couple of digesters were managed similarly for all other aspects but the insulation. The temperatures of both digesters were measured every three weeks and compared. The results show that the positive impact of the insulation is little or negligible, and in any case not exceeding 1°C. After the 15th of March, the effect of the insulation seems even counter-productive.

Another strategy for increasing the temperature is to build a greenhouse over the biogas digester. ID China has built such a pilot greenhouse in 2010. Temperature measurements of this digester were taken from January until July 2013 and compared with the temperature of a neighbouring digester, which was not covered by any material. Paradoxically, winter temperatures of the greenhouse-covered digester were up to 3.2°C lower. Summer temperature however were increased by up to 2.7°C. However, the specific design of the greenhouse and the management by the beneficiary may have played an important role. It was learned from this study that the beneficiaries would favour the practical uses of the greenhouse (growing vegetables, drying clothes or beans; requiring to leave the door open) over the potential heating of the digester (requiring to leave the door closed). Such considerations should be taken into account by organisations planning coupled bio-digester/greenhouse construction programs.

In two of the experiments, the biogas production was monitored with gas flow meters. Typical daily productions varied between 0.2–1.0 m^3 in the summer falling to 0.05–0.1 m^3 in the winter.

The results of this study indicate that, contrary to the common belief, corn stalk and manure insulation seems relatively inefficient at limiting the digester's cooling during the winter, while even counterproductive during the summer. The efficiency of a greenhouse is also in question.

法国发起发展组织 Initiative Développement (以下简称 ID)为 2500 余户农村家庭建设了户用沼气池，为了向受益者提供持续的项目后期维护，ID 进行了为期一年的“沼气池优化管理”研究。

ID 中国从 2008 年开始在云南北部地区实施户用沼气池项目。由于云南北部冬季气温较低，气候因素使得沼气池产气处于欠佳状态，其冬季平均产气量仅为夏季平均产气量的 1/3 至 1/10。

中国农村地区普遍使用固顶式沼气池，政府和非政府组织经常对农户进行有关沼气保温的培训，即在冬季将有机材料覆盖在沼气池上以保持池内温度。

为测试保温层的实际功效，ID 在其项目实施地选择了三户农户，从 2012 年 9 月至 2013 年 7 月对每个农户的两个沼气池进行了一系列的实验。在每个农户所提供的两个沼气池中，一个覆盖保温层，另一个不予任何覆盖。在覆盖保温层的沼气池中， A 户沼气池覆盖粪肥，B 户沼气池覆盖玉米秸秆，C 户沼气池覆盖用玉米秸秆和粪肥混合物。除了保温层用料的不同，每一组沼气池在其它方面的管理相同。ID 工作人员每三周对六口沼气池进行一次温度测量，并进行比较。结果显示，保温层起到的作用微乎甚微。覆盖了保温层的沼气池温度比不覆盖保温层沼气池的温度高出最多不超过 1 摄氏度。在 3 月 15 日后，沼气池甚至出现了降温情况。

另外一个增加沼气池温度的做法，是在池体上修建温室。ID 中国曾在 2010 年修建过带温室的试点沼气池。对这个沼气池的温度测试从 2013 年 1 月起 7 月止。同时，测试结果与附近一个没有覆盖任何材料并搭建温室的沼气池温度想对比。结果，带温室的沼气池，冬季温度比没有任何覆盖的沼气池的温度还低 3.2 摄氏度。在夏季，带温室的沼气池温度比没有任何覆盖的沼气池温度高出最高 2.7 摄氏度。温室的构造和农户对温室的管理会对温室所起到的保温作用产生重要影响。我们从这项研究中得知，农户更喜欢使用温室种植蔬菜、晾晒衣物和豆子，这就使得温室的门时常处于打开状态。而利用温室对沼气池进行保温，要求温室的门要时常是关闭的。所以在为沼气池修建配套温室时，应该考虑到这些因素。

在以上两个实验中，沼气池的产气量都由气体流量计来监测，夏季每天的产气量从 0.2-1.0 立方米不等，冬季产气量要低于夏季产气量，在 0.05-0.1 立方米不等。

研究结果表明，与普遍观念相反，玉米秸秆和粪肥保温层对限制沼气池在冬季的保温方面起到的作用效果不明显，在夏季的作用效果也微乎其微。而温室对于沼气池的保温功效也甚小。

2 GOALS AND RELEVANCE

The experiment was primarily motivated by the following facts:

- In the winter, the production of the biogas tanks drops sharply because of the lowered temperature of the liquid in the tank; the families can at best only cook one meal a day on the biogas, compared to two or three in the summer;
- Previous insulations experiments have shown that insulating the ground above the tank can have a positive although limited impact on the temperature;
- Other organisations, as well as the Chinese government, advocate the insulation of the tanks by covering the ground with a layer of insulation material such as straw;

Goals of the experiment:

- Measure and compare the temperature of an insulated tank with a non-insulated tank;
- Measure the gas consumption of the family, and if possible, relate the gas production to the potential temperature difference.

3 METHOD

3.1 Experiment planning and preparation

3.1.1 Selection of the beneficiaries

Three beneficiaries were recruited amongst the 2500 biogas households owing a digester built with the help of ID China since 2008 in Zhaotong 昭通, Yunnan province, China.

These beneficiaries were selected amongst the few families having two digesters. ID China generally helps building only one digester per family, but sometimes two related families can be found living close to another. It was crucial for the good running of the experiment that the related families would manage the digesters in common, but unfortunately it was difficult to ensure (according to prior conversations with the beneficiaries). Ideally, a single person should effectively be in charge of both digesters.

Most digesters built with the help of ID China have their manure input directly integrated with the animal pen, so that the manure flows from itself into the digester. However, the experiment design required to load both digesters with strictly the same amounts of manure. With the integrated animal pen system, it would not have been possible to ensure that strictly equal amounts of manure would flow into the digesters. Therefore, only households with no connection to the animal pen were considered candidates for the experiment, in addition to the requirement of managing two digesters in common, which narrowed considerably the pool of potential suitable households.

Finally, a genuine motivation, sense of responsibility and reliability were sought from the households participating in the experiment. The household were not remunerated, although a few small gifts were brought, such as biogas spare parts or fresh vegetables.

According to these criteria, three households were recruited between September and December 2012. Additionally, monitoring was resumed with one beneficiary who had benefited from the construction of a greenhouse above his biogas digester for experimentation purposes (table 1 page 7).

Two of the households were equipped with biogas metering devices (see section 3.1.3). These digesters were also homogenised in their content prior to the experiment (see section 3.1.4).

Name of responsible person (化名)	Township	Village	Type of experiment	Gas meter	Initial mixing
Ben 1	青冈岭	白沙	Manure insulation	YES	YES
Ben 2	青冈岭	白沙	Corn stalk insulation	YES	YES
Ben 3	靖安	洪家营	Corn compost insulation	NO	NO
Ben 4	青冈岭	沈家沟	Greenhouse insulation	NO	NO

Table 1: List of household participating in the experiments

3.1.2 Role of the beneficiaries – role of ID China

The beneficiaries were responsible for the daily management of the biogas digester, which includes loading with manure (inputs), retrieving bio-slurry from the water chamber (outputs), consuming the gas, writing down the gas meter index and pressure on a daily basis, and maintaining the proper layer of insulation on the selected digesters.

ID China visited the households every three weeks on average. During each visit, temperature, pH and electrical conductivity measurements were made, and the completed gas index sheets were picked up. Complementary advise or instructions were discussed with the beneficiary in case problems were noticed.

Regarding input-outputs, the beneficiaries were instructed to input the exact same quantities of manure in the two biogas tanks, to remove the exact same quantities of bio-slurry from the two water chambers, and even to use both toilets with equivalent frequency.

The insulation layer had to be kept as thick and homogeneous as possible. The corn straw placed on top of the digesters, in particular, was consumed throughout the season for animal bedding and feeding, but beneficiaries were asked to use the insulation straw last of all available straw.

3.1.3 Gas metering

Two of the experiments were equipped with gas metering devices. One device was placed for each digester (one for the insulated digester / one for the non-insulated digester). Thus, four meters were installed in total (illustration 1).

To log the gas consumption, the beneficiaries were given monthly sheets on which to write the gas meter index on a daily basis. Starting from the second month, the beneficiaries also wrote down the gas pressure once a day, in the morning before starting to use gas.

The first meters that were installed in Autumn 2012 were diaphragm models from a Chinese manufacturer. Two benchmark tests performed in January and March 2013 showed that one device was deficient (see the document "Performance test of two models of gas flow meters" for more details). Another model from another Chinese manufacturer, working on an impeller measurement principle, was tested alongside with more reliable results. Therefore, in March/April 2013, all gas meters were changed to the impeller model. Later benchmark tests however showed that some devices from this model suffered failures as well and that the precision was generally poor at low flows.

Illustration 1: Complete installation with filter, pressure gauge, diapragm meter and daily logging sheet

At the end of the campaign of measurements in November 2013, all gas meters were tested again. One device that performed with an error worse than ±20% above 0.1 m^3/h was excluded from this study, therefore some curves and records are not complete. The remaining measurements are generally of a precision of ±10%, but some errors can be as important as [+10%; -20%].

Furthermore, it has to be stressed that what was measured was the **consumption** of the households, and not the **production** of the biogas digesters. In the absence of leaks upstream from the gas meters, the two can evidently be equated. The circuits were therefore regularly checked for leaks. However, the gas meters (whether diaphragm- or impeller-based) were not able to detect very small flows, consequently any leaks downstream of the measurement devices would also lead to potentially important errors. Because of the risk of leaks, all results should be taken with great care. One should not rely on the data of a single experiment for making conclusions related to gas production.

In this report, all mentioned gas volumes have been corrected to match **standard conditions of 25°C and 1 atm of pressure**. Corrections in temperature were made according to estimated gas temperatures depending on the season. Pressure corrections were made since the experimental sites were located at approximately 2000 m altitude.

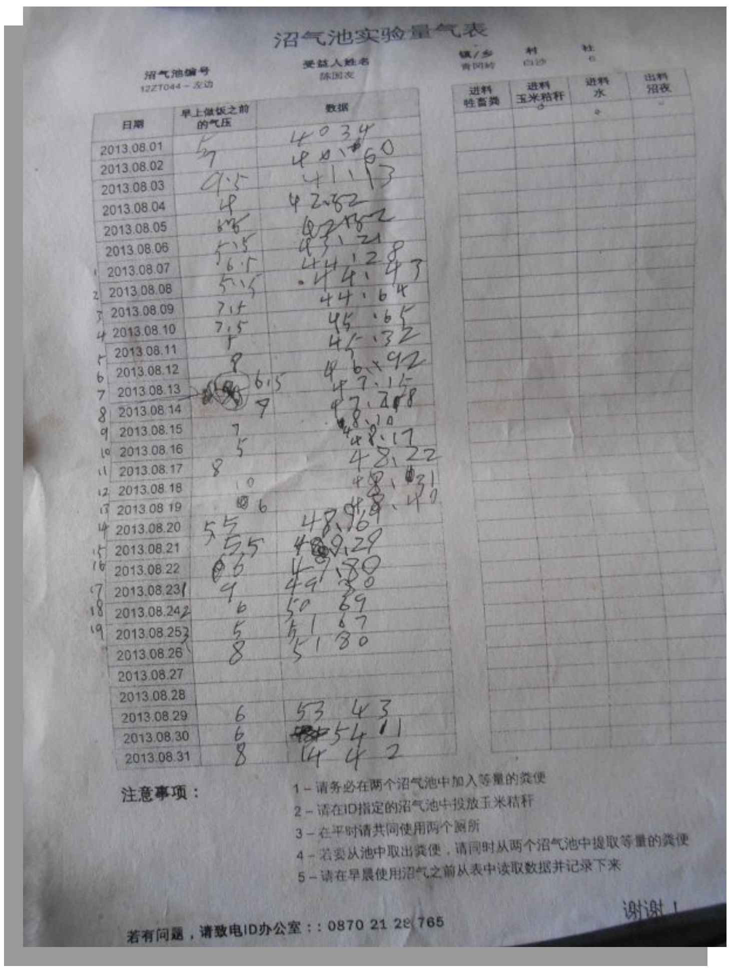


Illustration 2: Gas index sheet filled by the beneficiary to keep track of gas consumptions

3.1.4 Mixing of the content of the two biogas digesters

As explained above, in two of the experiments the gas consumption was monitored. Besides temperature monitoring, the secondary goal of the research was to observe how temperature differences between the two digesters (insulated/uninsulated), if any, would influence the gas production.

Therefore, all parameters (other than temperature) that could influence the gas production had to be made equal amongst the two digesters. One of these parameter was the initial content of the tanks, which were already loaded and producing at the beginning of the experiment.

To begin the experiment with similar initial conditions, the contents of the tanks were therefore mixed into another, using an electrical pump. This was done only on the two experiments which had been equipped with gas meters.

Illustration 3: Mixing the content of the two digesters

Illustration 4 shows the measurements, over three iterations, of mixing the content of two biogas digesters for the experiment in 白沙 Baisha 3. One iteration consisted of the following sequence:

- a sample of bio-slurry was taken in each water chamber, and analysed for pH, EC (electrical conductivity) and temperature with our hand-held pH/EC meter
- the liquid was pumped from the water chamber of BGT1 onto the input of BGT2, until BGT2 was full
- the liquid was pumped from the water chamber of BGT2 onto the input of BGT1, until BGT1 was full

This iterative process was repeated until it was considered that the pH, EC and temperature were sufficiently close amongst the two digesters, indicating a satisfying mixing. The levels of liquid were then equalised in the two digesters. In the above example, three iterations were necessary.

The efficiency and relevance of this mixing method is discussed in section 4.7 page 29.

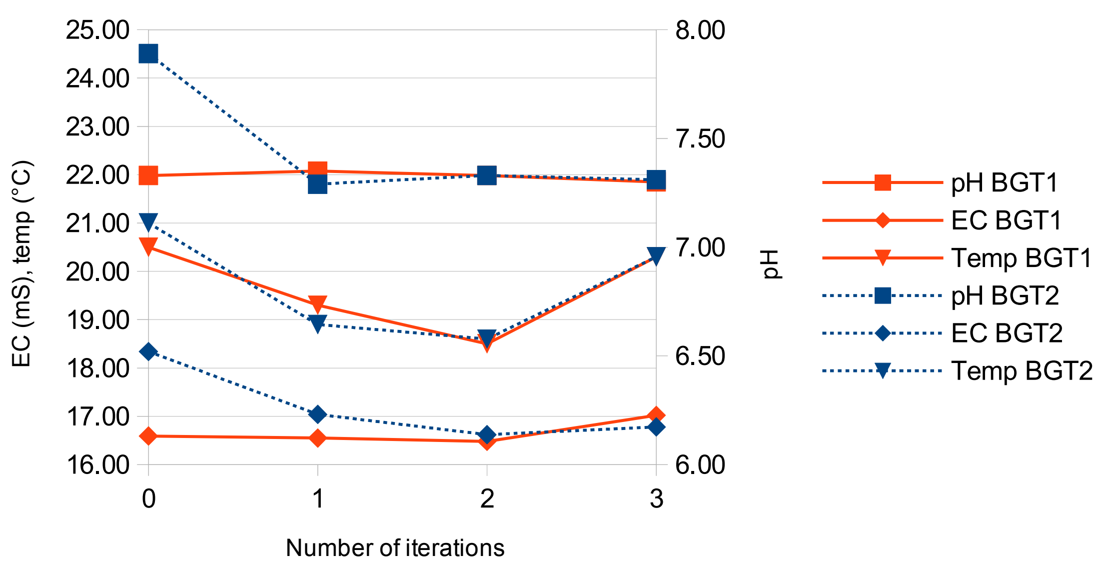


Illustration 4: Initial mixing of the liquid content of two biogas digesters

3.2 Measurements

3.2.1 Water chamber

At each visit of the household (on average every three weeks), the following measurements were taken on a sample of bio-slurry from the water chamber using a hand-held Hanna HI 98130. The sample was taken with a little agitation in the upper 20cm of the water chamber.

- **pH**, since it is know as a crucial parameter of the anaerobic process
- **EC** (electrical conductivity): this parameter indicates roughly the quantity of dissolved minerals in a sample. We have not heard of this parameter being widely used for evaluating the performance of biogas digesters or the quality of bio-slurry, and in the absence of information or literature on the subject the values cannot be interpreted in the biogas context. However, the parameter could be taken at no further expense since the measurement device was a dual pH/EC meter. Furthermore, and regardless of the meaning of the parameter, following the EC over time allowed to compare the set of two digesters for divergences. It was also useful for checking the homogeneity of the mixing when the content of two digesters were mixed together. It is actually possible that the EC might give an approximate reading of how concentrated the slurry is (i.e. solid content), but this has to be confirmed.
- **Temperature**

The pH/EC meter was calibrated once every two months and no significant deviations were observed.

3.2.2 Temperature

In the first experiment in 白沙Baisha group 3, the temperature was at first monitored by measuring the temperature of the liquid in the water chamber as described above. It was however quickly found out that the water chamber reacts more quickly to external temperature variations than the liquid in the centre of the digester. Since it is the central temperature that is determinant for the gas production, a K-type thermocouple with a 3 metre long wire was introduced in November 2012 in the water chamber and through the discharge tube to the bottom of the main chamber, and left in place.

Illustration 5: Passing the wires for two K-type thermocouples through the lid clay sealant

For the second experiment in 白沙Baisha group 6, two (for redundancy) K-type thermocouples were introduced from the start (November 2012) in each digester and passed directly through the lid down the clay sealant (illustration 5).

It was however later realised that these thermocouples were too imprecise for our requirements. Indeed, the K-type thermocouple technology provides a usual precision of ±2°C, while the expected differences of temperature to be measured and compared across the two tanks could be no more than 1°C. Furthermore, disposing of two probes in each digester allowed not only for redundancy, but also for comparison; discrepancies of up to 1°C were observed, which confirm the unreliability of the probes.

Finally, some leaks were discovered along the lid of one of the digesters, and it is likely that passing the cable through the mud sealant was the cause.

A Hanna Checktemp-Dip thermometer, a device specially designed for the measurement of the temperature in water tanks, was hence used for subsequent measurements. This device has a resolution of 0.1°C and a precision of ±0.2°C. The probe, which is held at the end of a 3 metre cable, was strapped to the end of a camping tent pole. For each measurement, the pole could be assembled and dipped in the water chamber, through the discharge tube down to the main chamber. It was found that the temperature evolves with depth in the discharge tube, with a total top-to-bottom variation of approximatively 1.5°C. The depth of sampling is therefore important. For all measurements, we agreed on the convention to hold the probe about 20cm above the bottom of the digester floor (see illustration 6).

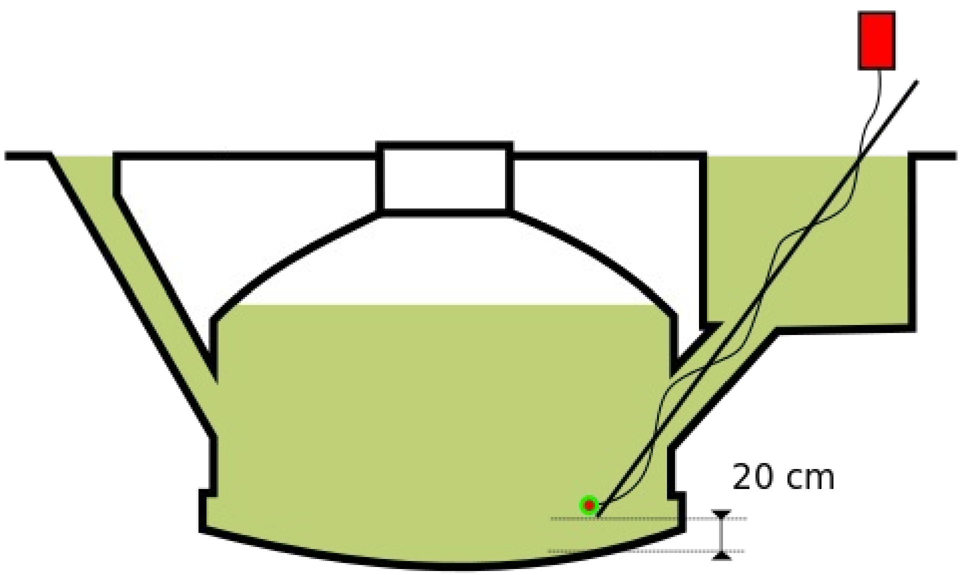


Illustration 6: Introduction of the temperature probe into the digester

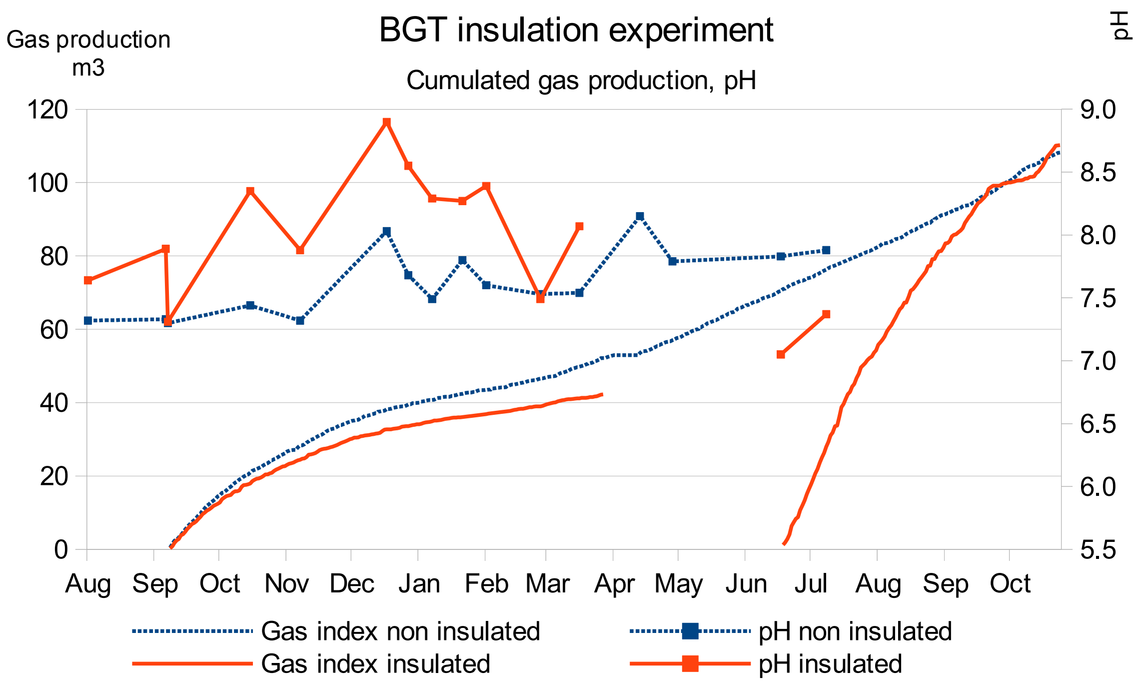
4 RESULTS AND DISCUSSION

4.1 EXPERIMENT 1: INSULATION WITH MANURE (BAISHA 白沙 - GROUP 3)

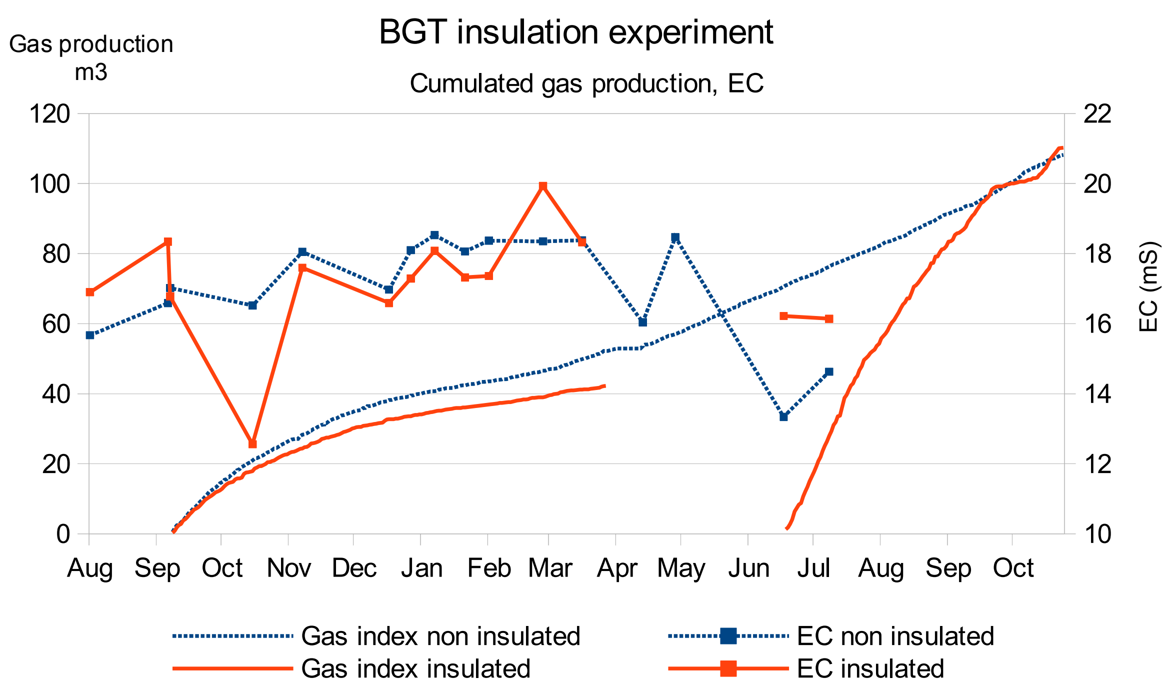
In this experiment, the beneficiary used an insulation made of a layer of cow manure, piled up progressively during the year. At the time the experiment was started (September 2012), the layer of manure was already approximately 1m in thickness and 3.5m in diameter, thus covering a surface 150% larger than the digester itself. The layer of manure was removed in June 2013 and the piling was started again. The other digester was not covered.

Illustration 7: The two digesters in Baisha 3

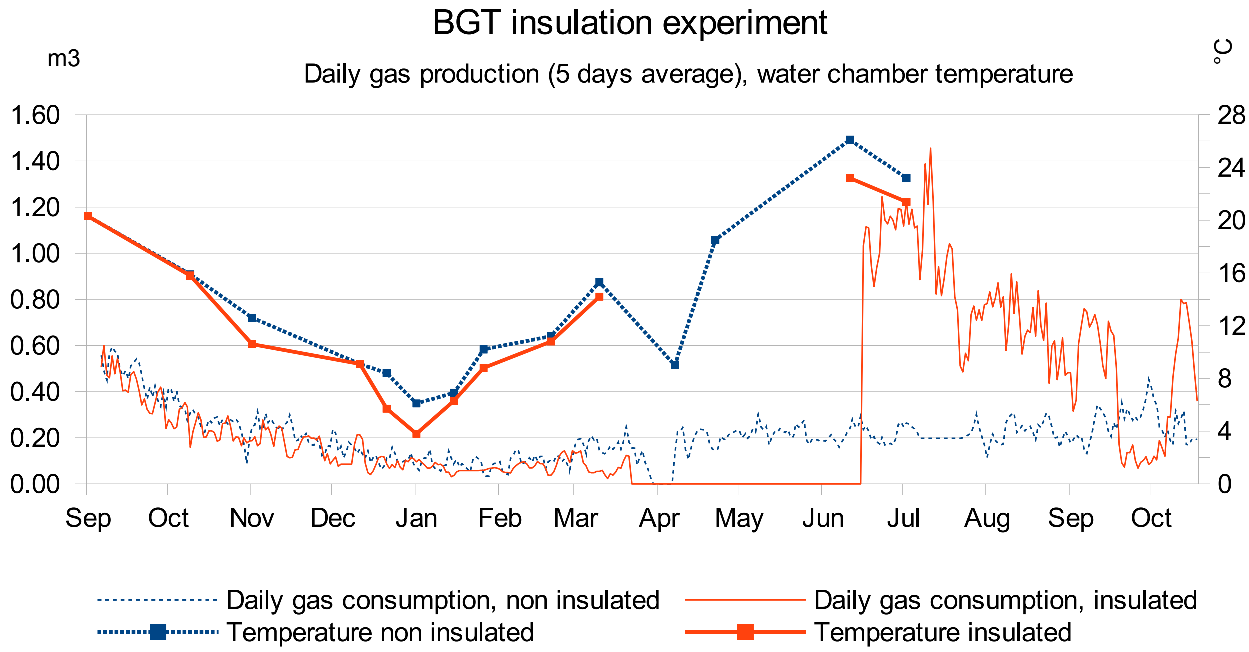
4.1.1 pH


BGT insulation experiment
Cumulated gas production, pH
Gas production m3
pH
120
100
80
60
40
20
0
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct
Gas index non insulated
Gas index insulated
pH non insulated
pH insulated

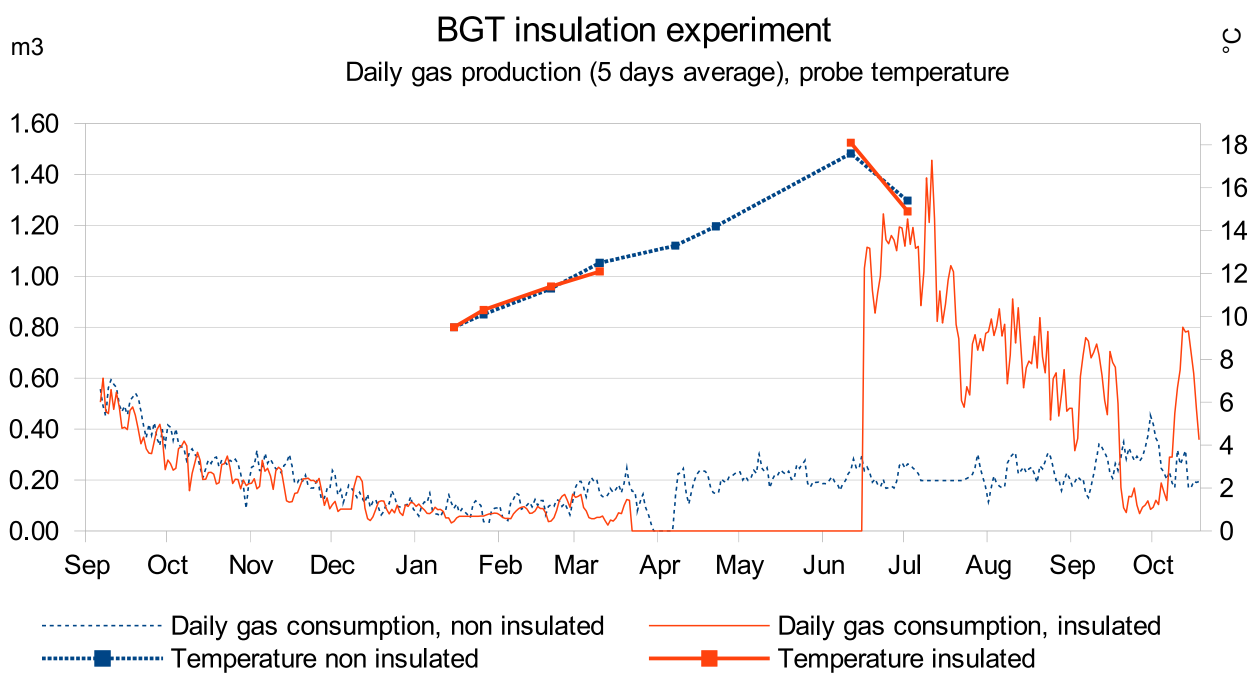
4.1.2 EC


BGT insulation experiment
Cumulated gas production, EC
Gas production m3
EC (mS)
120
100
80
60
40
20
0
22
20
18
16
14
12
10
Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct
Gas index non insulated
Gas index insulated
EC non insulated
EC insulated

4.1.3 Temperature (water chamber)



4.1.4 Temperature (central probe)

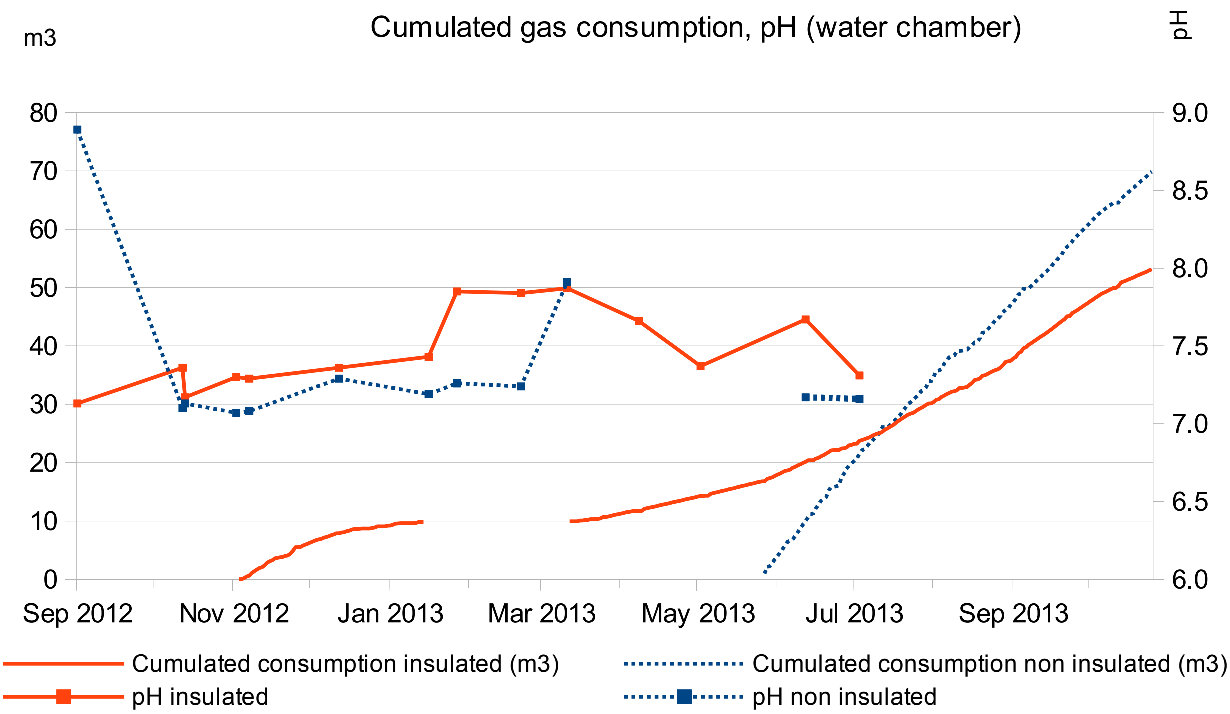


4.2 Experiment 2: insulation with corn straw (Baisha 白沙 - group 6)

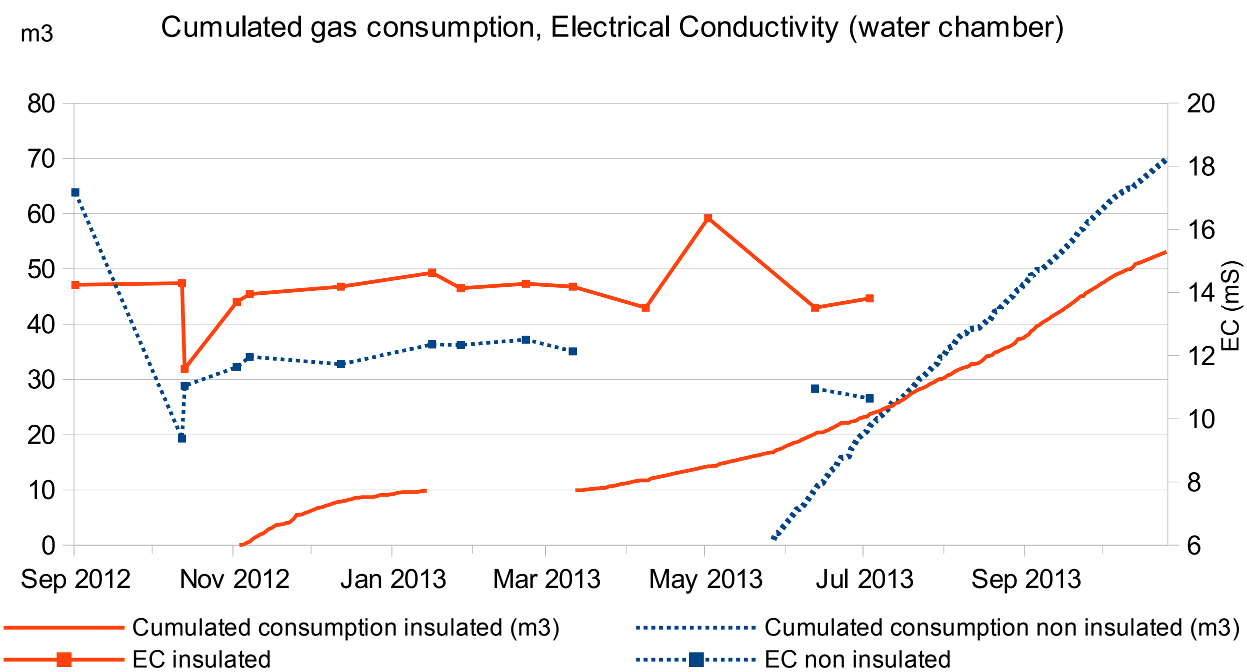
In this experiment, the beneficiary used an insulation made of a thick layer of corn stalks, piled in the month of November. The layer was then approximately 3m in thickness and 5m in diameter, thus covering a surface 200% larger than the digester itself. The other digester was not covered. The corn stalk was then consumed progressively for animal feeding and bedding until most of the insulation was gone by June 2013 (illustration 8).

Illustration 8: The two digesters in Baisha 6. Here the insulation has thinned down by the end of the season.

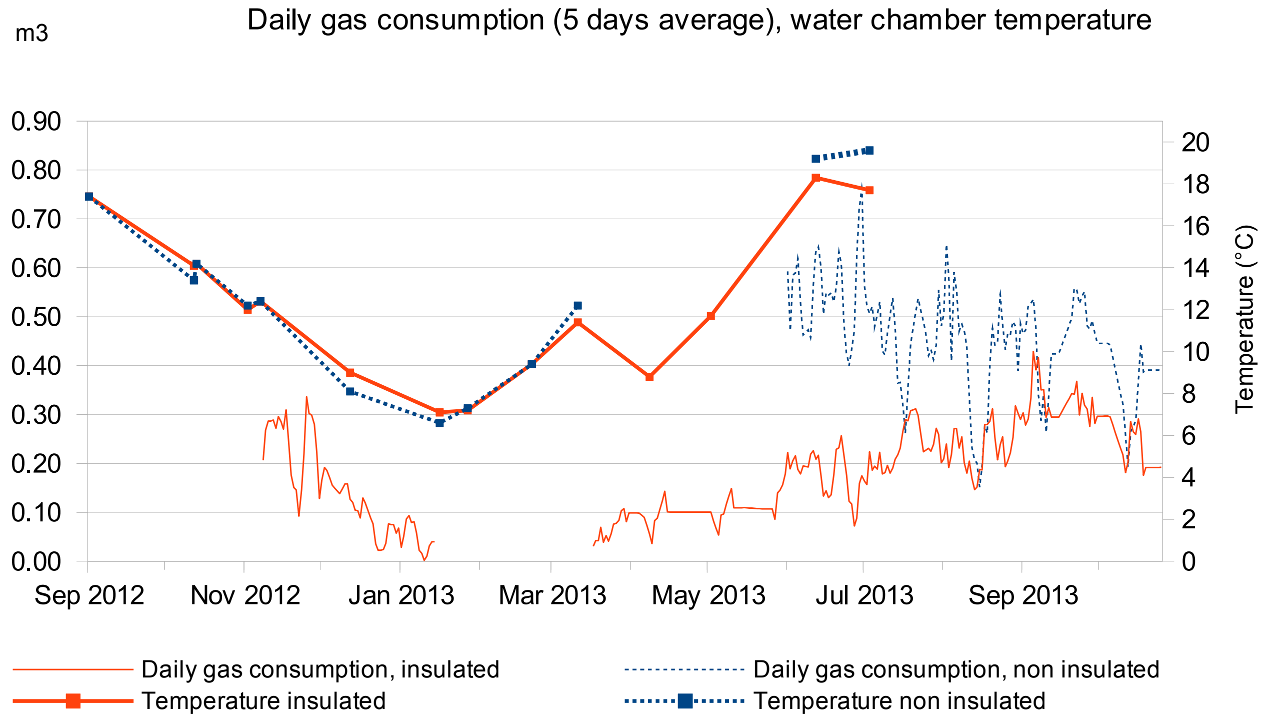
4.2.1 pH


Cumulated gas consumption, pH (water chamber)
m3
pH
80
70
60
50
40
30
20
10
0
9.0
8.5
8.0
7.5
7.0
6.5
6.0
Sep 2012
Nov 2012
Jan 2013
Mar 2013
May 2013
Jul 2013
Sep 2013
Cumulated consumption insulated (m3)
Cumulated consumption non insulated (m3)
pH insulated
pH non insulated

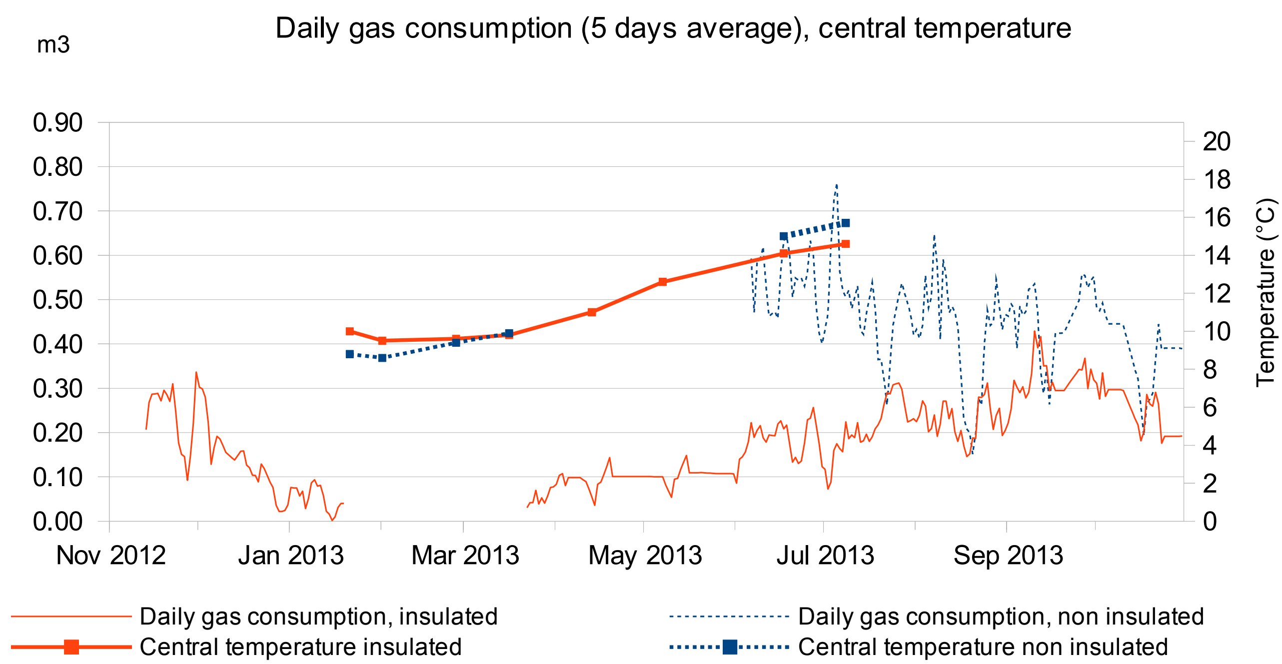
4.2.2 EC


Cumulated gas consumption, Electrical Conductivity (water chamber)
m3
EC (mS)
80
70
60
50
40
30
20
10
0
20
18
16
14
12
10
8
6
Sep 2012
Nov 2012
Jan 2013
Mar 2013
May 2013
Jul 2013
Sep 2013
Cumulated consumption insulated (m3)
Cumulated consumption non insulated (m3)
EC insulated
EC non insulated

4.2.3 Temperature (water chamber)



4.2.4 Temperature (central probe)



4.3 Experiment 3: insulation with corn straw (Hongjiaying 洪家营 - group 8)

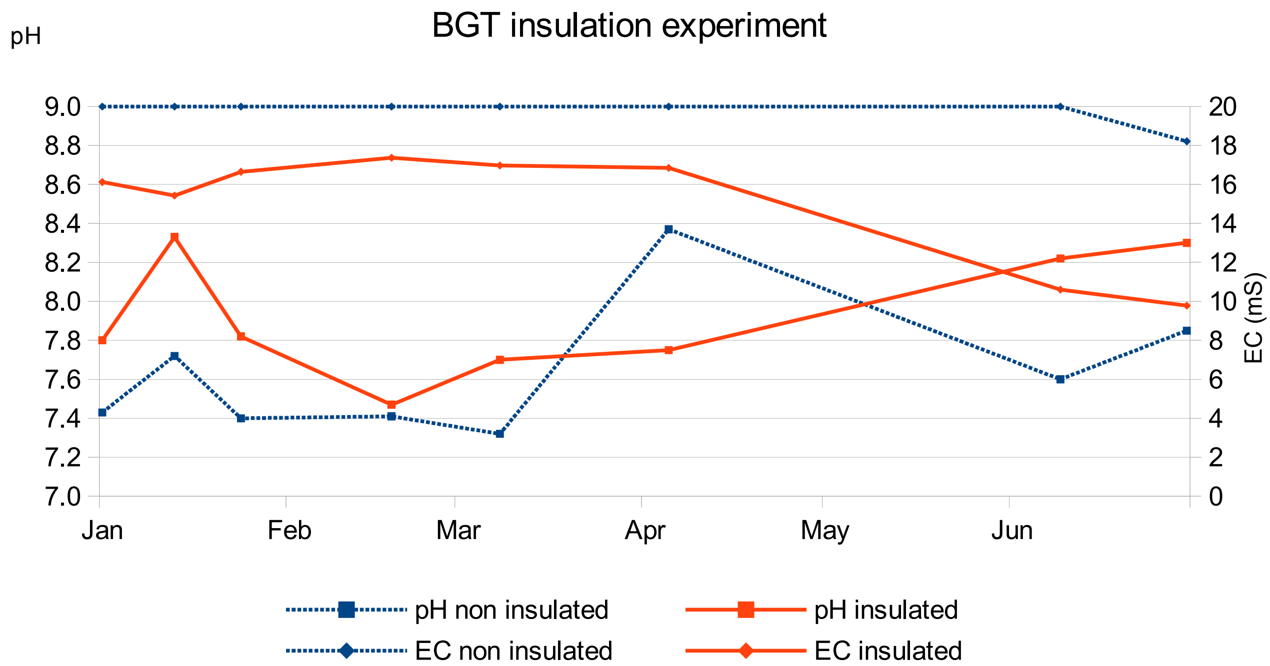
This insulation experiment was started late, after the onset of the winter. A layer of approximately 50cm of corn stalk was layered on top of the digester in January, covering a diameter of 4m. The stalks were then soaked with bio-slurry taken from the water chamber of the digesters, in the hope to start a heat-producing composting reaction. However, no temperature increase was recorded, neither did the stalks visually decompose until later in the spring. It is assumed that several factors prevented the pile from degrading and heating:

- the initial temperature of the compost (a few degrees above freezing) was too low for the bacteria to start the degradation process at a significant speed
- corn stalk is covered in a waxy coating. Since the stalk had not been chopped down to pieces, the soft inside was not exposed and the surface of contact was limited
- since the stalk was not chopped, the pile lacked the necessary density to self-insulate

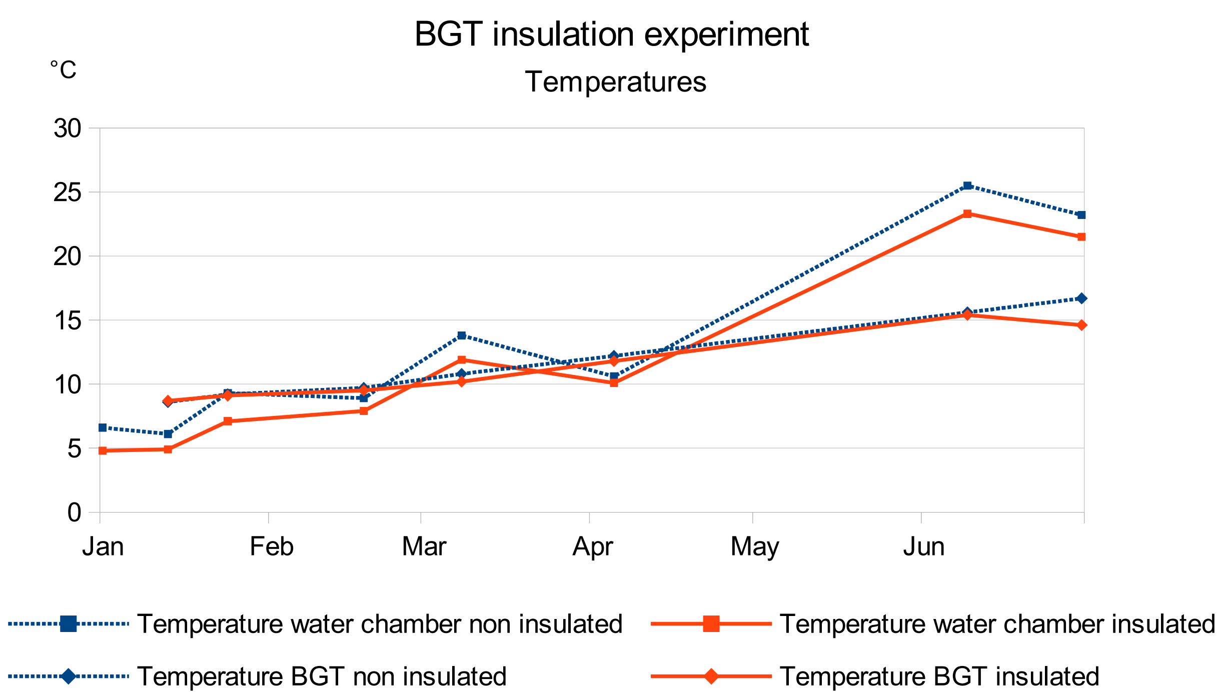
It is suggested that this type of compost shall rather be made with finely shredded stalks and started before the winter.

Illustration 9: Digesters in Hongjiaying, before and after insulation

4.3.1 pH and EC



4.3.2 Temperature



4.4 Discussion – insulation experiments

4.4.1 Temperature as compared between the digesters

The results of the three experiments show that the effect of the insulation in the winter is negligible or nil. Indeed, the highest recorded temperature gain was 0.1°C in the first experiment (manure insulation) and 1.2°C in the second experiment (corn stalk insulation). In the third experiment (corn stalk compost) the insulated digester was even colder by 0.2 °C.

In the spring and towards the summer, the insulation seems to be even counter-productive. In the first experiment, the insulated digester got **colder** by 0.4°C, in the second one by 1.1°C and in the third one by 2.1°C.

The tipping point between beneficial and detrimental effect of the insulation appears to be around the 15th of March.

The results hint furthermore at the fact that the corn stalk insulation was more efficient than manure or corn stalk compost, since temperatures in this experiment differ more significantly, in both positive and negative.

4.4.2 Biogas production

Concerning the measurements on the biogas production (measured indirectly through consumption), it was initially hoped that the expected differences in digester temperature would translate in measurable differences in production. However, no such thing could be observed for the following reasons:

- the temperature differences were probably too small to significantly influence the gas production
- the tests carried out on the gas meters have shown that most are of limited precision, ±20% in the worst case, ±10% for the best. Data from a defective gas meter had to be excluded from the study
- despite our instructions and their assurance, at least one of the beneficiaries (Ben 1) has not been loading his set of two digesters with exactly the same amounts. This was discovered during conversations with the beneficiary posterior to the experiment. It is assumed that Ben 2 respected the instructions, but no guarantee can be given.
- The initial mixing of the set of digesters was not efficient (see section 4.7 page 29), as testified by the quick divergence in pH and EC in the weeks following the initial mixing

Hence, the differences in gas production on a given set of digesters, as presented in the charts of the previous sections, cannot be linked to differences in temperature.

These differences would rather be traced to either initial differences in the load, or to different inputs made by the beneficiaries, or to perhaps other reasons linked to the obviously different biochemical conditions in the digesters, as attested by the diverging pH and EC measurements all along the season. The pH in particular is known to be a crucial variable in the anaerobic process, but is itself influenced by how the digester is loaded, so that rather than being an ultimate factor, as a parameter it might only reflect the difference in the management of the two digesters. In any case, no correlation seems to appears between gas production and the pH or EC.

However, a clear correlation appears between the gas production and the digester temperature through the season, as could be expected.

Although the data is not conclusive for making comparisons between digesters, at least some absolute values of typical gas productions have been obtained (table 2). Strong disparities can be observed from one digester to another. By looking at the charts on pages 16 and 19, it appears that the production of the digesters is highest just after reloading with fresh manure. Furthermore, the start-up time is very short: the gas production after reloading reaches its maximum very quickly, rather than progressively as usually assumed. Furthermore, the reduction of gas production in the winter is very evident, with daily gas productions divided by a factor 5 or 6 compared to the summer.

Daily gas production (m3)	Ben 1		Ben 2	
	Non insulated	Insulated	Non insulated	Insulated
Max	0.3	1.0	0.5	0.3
Min	0.1	0.1	0.4	0.05

Table 2: Typical daily gas productions of the four followed digesters (volumes are given at 25°C and 1 atm)

4.5 Greenhouse (Shenjiagou 沈家沟 - group 7)

Illustration 10: Experimental greenhouse, Shenjiagou

A greenhouse was built by ID China in 2010 above a digester, to experiment whether trapping heat would increase the digester's temperature and the gas production. Furthermore, the greenhouse could be used for growing vegetables.

To assess the impact on the temperature, the digester was compared with a neighbouring digester which was not covered by a greenhouse or any other kind of insulation. The temperatures were taken in both digesters at 3 weeks interval during a period of 6 months, from January until July.

The south-facing side of the greenhouse was built on a one meter high brick wall foundation, and the overlaying roof on that side was covered with a layer of soil and straw (see illustration 10). This mass was supposed to act as a heat accumulator, regulating the temperature by storing heat during daytime and releasing it at night.

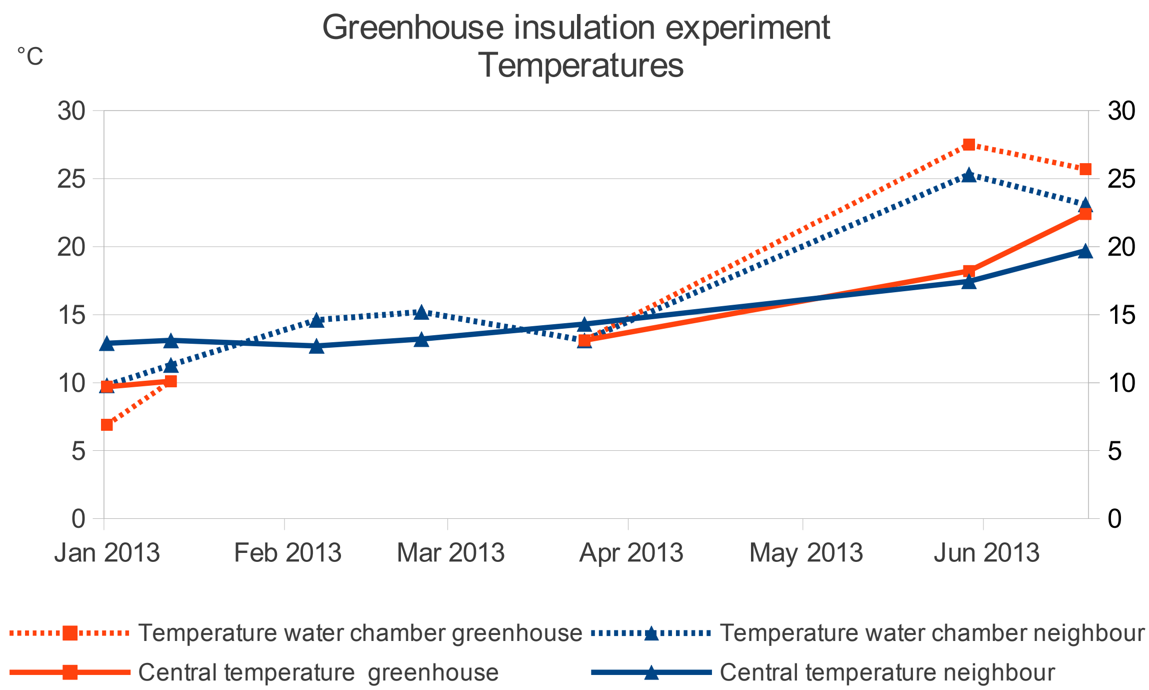
The management of the greenhouse by the beneficiary plays a crucial role. Indeed, whether the door and window on both extremities are left open or closed has a huge impact on the air temperature in the greenhouse. For the purpose of the experiment, the beneficiary was asked to keep the door and window closed at all times. However, at the occasion of our field visits they were generally found open, despite repeated reminders.

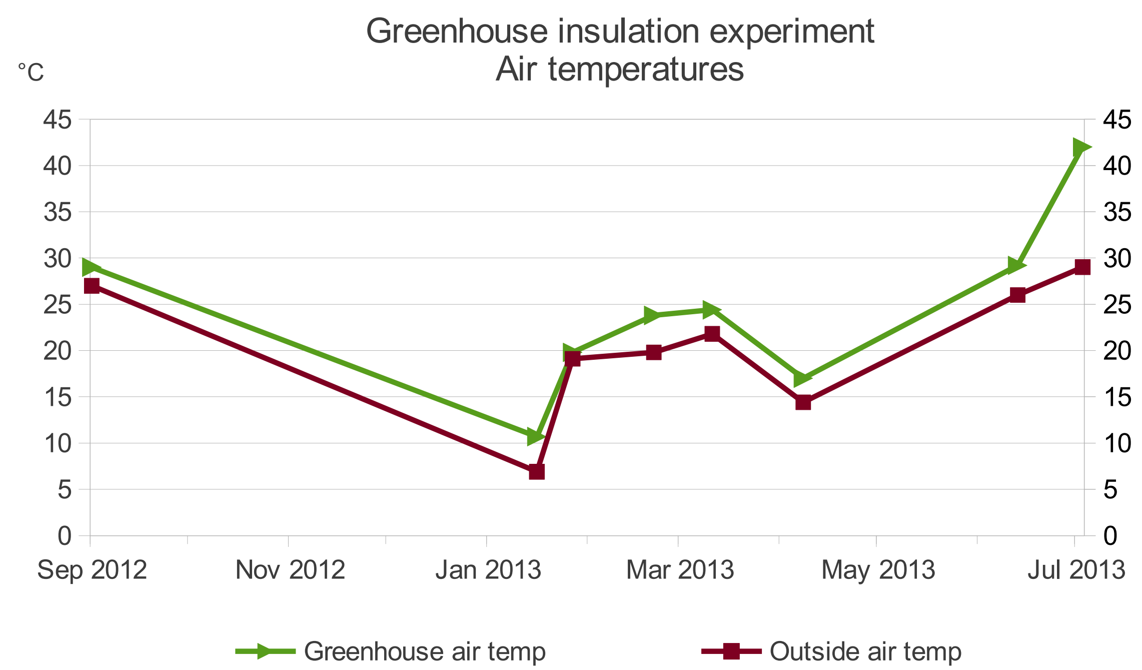
To explain this situation one should keep in mind that the greenhouse fulfils other roles than the sole heating of the digester. Besides growing vegetables, we observed that the greenhouse was put at various other uses that had not been foreseen, such as drying clothes or beans. All these uses requires some ventilation or partial opening. For example, the beneficiary observed that the Chinese cabbage was not growing well if the greenhouse was too hot.

Hence, the various other uses of the greenhouse do diverge from its intended function of increasing the digester temperature. According to discussions with the beneficiary, we established that gas production was not a priority for the family compared to growing vegetables or drying the laundry basket, which can explain why the heating potential of the greenhouse was not fully exploited by closing the door.

The results of the temperature measurements are presented in the following section.

4.5.1 Temperature





4.5.2 Discussion - Greenhouse

As it can be seen from the temperature measurements, and contrary to what was expected, the digester located under the greenhouse stayed **colder** (by up to 3.2 °C in January) for the measured winter season. In the summer however, our measurements indicate a higher temperature under the greenhouse (by up to 2.7°C in July). Temperatures mentioned here are the ones taken with the probe closer to the centre of the digester as described above in “3.2.2 Temperature“.

It should be noted that both digesters were opened, partly emptied and refilled with new manure load in February. According to the beneficiaries, around 1750kg, that is 25% of the digester's content, was replaced. The neighbour digester was only left opened for a short time, however the digester under the greenhouse was open for two whole months and the temperature measurements could not be made during this time. Obviously, the opening and change of material would have had an influence on the temperature of the digesters.

The differences of air temperature inside and outside the greenhouse were generally limited, certainly because the door and window were often left open as explained above. The air inside the greenhouse was warmer by an average of 4°C (max 13°C - July; min 0.7°C - February). These measurements of air temperatures were not taken in standard conditions and are therefore highly variable depending on the weather, time of the day, and on whether the greenhouse had been opened prior to our arrival.

An explanation for the lower temperatures in the winter under the greenhouse is that the slightly higher air temperatures inside the greenhouse were not compensated by the loss of solar radiation on the ground, hence lowering the soil temperature. Here the dark layer on the south-facing roof might have played a detrimental role by absorbing or reverberating the solar radiation. As the sun picked up later in the season, the greenhouse heating effect would have become predominant against the direct solar radiation on the soil.

The tipping point for the temperature difference is indeed around April for the water chamber and around May for the central temperature. Since the water chamber reacts to external temperature changes faster than the core of the digester, this result can be expected and tend to show that the efficiency of the greenhouse increases with the season.

Altogether however, since the main heating requirements are in the winter, when the gas production drops sharply because of the low temperatures, the greenhouse solution as described here appears counter-productive.

4.6 Temperature throughout the season

The global digester temperature seasonal profile is consistent within the three experiments, see table 3. The experiment sites in 白沙 are located higher in altitude on the plateau, and the two others in the valley.

It shall be noted that the digester chosen to compare against ("Greenhouse neighbour") recorded unusually high temperatures compared to the average in the region. Perhaps the micro-climate of the valley could play a role. Unfortunately, no other measurements from the same village are available. Additional temperature measurements could be made in the neighbourhood to ensure that the comparing digester is not biased.

Temperature °C (non insulated / insulated)	Manure	Corn stalk	Corn compost	Greenhouse	Greenhouse neighbour
Village	白沙		洪家营	沈家沟	
Altitude (m)	2065	2195	1875	1880	
21st of Jan	9.5 / 9.5	8.8 / 10.0	8.6 / 8.7	9.7	12.9
8th of July	15.4 / 14.9	15.7 / 14.6	16.7 / 14.6	22.4	19.7

Table 3: Temperature of 8 digesters in winter and summer

4.7 Efficiency of the initial mixing

The charts on pages 15 and 18 show that after initial mixing, the two monitored biochemical parameters, pH and EC, started differing quickly amongst the two sets of digester. This should be interpreted as a sign that the mixing had not been complete. A look at illustration 11 can help to explain why a complete mixing cannot be achieved by using the method described above in section 3.1.4 “Mixing of the content of the two biogas digesters“, page 10.

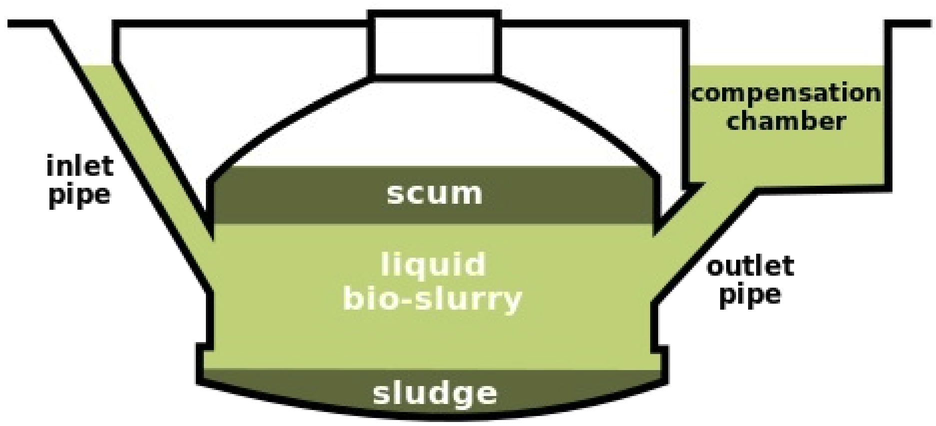


Illustration 11: Layering of the content in a fixed dome household digester

In the method used for mixing, only the liquid was pumped from the compensation chamber of one digester into the inlet pipe of the other and vice-versa, until similar pH, EC and temperature were measured in both compensation chambers. Hence, although the liquid layer in the digesters was homogenised, it can be assumed that the sludge and the scum stayed mainly immobile. The scum in particular contains a lot of anaerobically digestible matter, and is an important part of the digester's biochemistry.

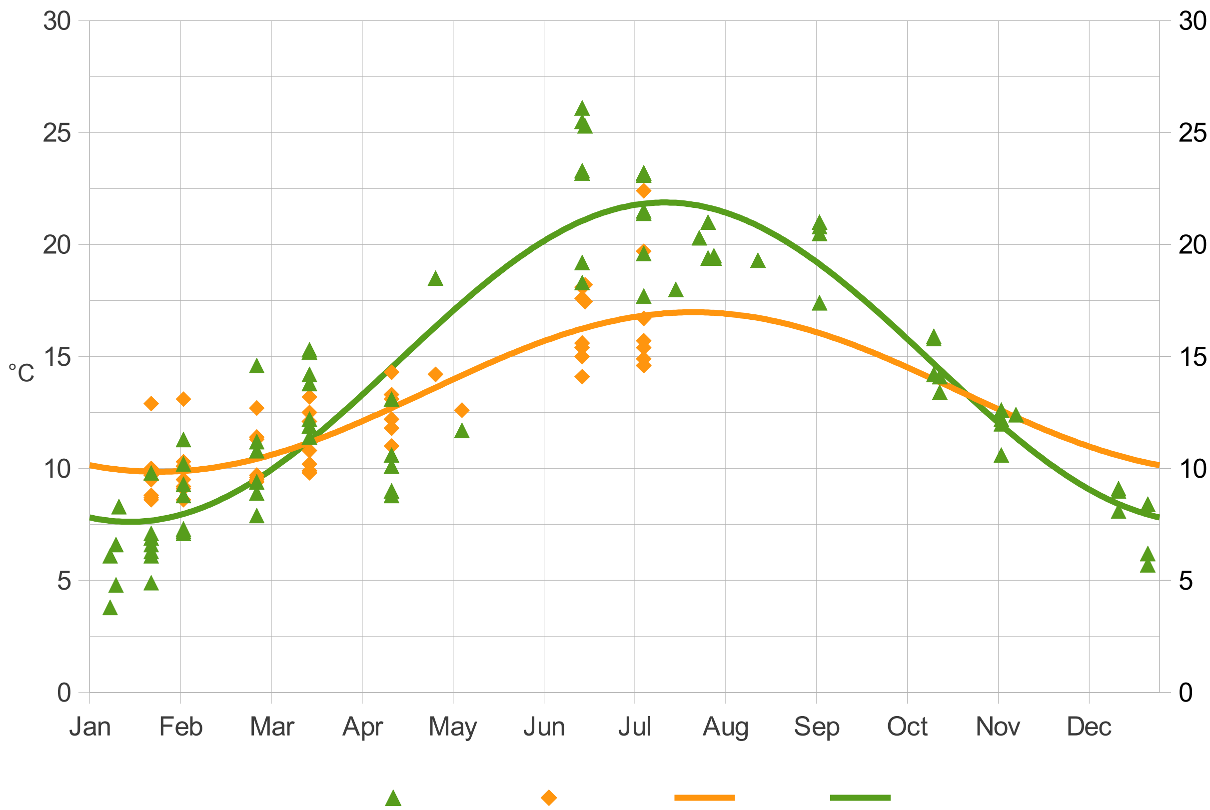
Hence, no proper mixing can be achieved unless the scum is either removed or mixed through. The mixing method described above is not working for trying to homogenise the content or the gas production of two digesters.

To start an experiment on two household digesters in conditions as equal as possible, we could rather recommend that the lids are opened, the scum scooped away, and that the liquid then be pumped using an incremental method as described above. The digesters can finally be reloaded with equal amounts of manure and water. In Zhaotong prefecture, since farmers usually open and reload the digesters between February and April to match the potato and corn planting time, we would recommend to start any such experiment at that time of the year.

4.8 Other measurements of temperature

During the year 2012-2013, many measurements of bio-slurry from the water chamber were done routinely when visiting beneficiaries, as well as for the experiments. Furthermore, many measurements of central digester temperature (using the probe though the outlet pipe as described above) were carried out. Since these measurements were spread through the year, curves of temperature can be approximated. For the central temperature, data was available on half a year only. The following chart presents all data together with sinusoidal regressions. Note the smaller amplitude of the central temperature curve as well as the slight phase shift.

Summary of 90 temperature measurements of bio-slurry from the water chamber and 54 measurements of central temperatures of the digesters 2012-2013



4.9 Using an aerobic compost pile for heating a biogas digester?

A pile of warm aerobic compost could be used as an insulation/heating for a biogas digester during the winter. The heap could be placed directly above the digester over a sufficient radius.

However, the strong heat production is generally limited to the first 3 or 4 weeks after the compost is initiated. Instead, the compost could be made layer per layer throughout the winter, which would further have the advantage of spreading the workload. If bio-slurry is used on the compost, this would also spread its consumption over the winter.

The other experiments presented above have shown that placing insulating material on top of the biogas digester during the winter has little or no efficiency. There is therefore some doubt on the insulating performance of a pile of aerobic compost. This solution could be experimented in practice with a compared trial of two insulated and uninsulated biogas digesters.

4.10 Working with the households

This study highlighted the difficulty of carrying out a rigorous experiment with beneficiaries of a rural biogas program. Altogether the work and cooperation with the households was carried out in excellent terms. However, a majority of the beneficiaries did take little personal interest in the project, but this lack of initiative did not prevent the agreed protocol to be applied.

Regrettably, and despite close support and attention by ID team, the beneficiaries did only partially respect the instructions that were agreed for the good running of the experiment. In particular, it was difficult to rely on the beneficiaries for equally loading the digesters. Despite repeated instructions and promises, in at least one household the two digesters were generally not loaded with equal amounts of manure, as was later discovered.

The gas indexes were generally kept up to date, however gaps and erroneous or inconsistent records frequently happened. Generally, only one member of the family had the necessary literacy confidence to write the indexes, and when that member was away the indexes were not written. The children, who are generally more confident in writing due to increased schooling, did occasionally help with keeping the records.

Despite these marginal problems, the team of ID China would like to thank all the involved beneficiaries for their warm welcome and their cooperation, as well as for the many friendly cups of tea and biogas-cooked meals shared around the (coal) fire.

5 RECOMMENDATIONS

- In Zhaotong, similar experiments should be started in March after the digester is opened and reloaded. If the aim is to compare a series of digesters, this will allow to start the experiments with a similar initial load.
- Mixing the liquids from the water chamber with a pump is not satisfactory because the scum is not displaced. It is rather suggested that the scum be entirely removed, before attempting to mix the liquids.
- pH, EC and temperature can be efficiently and precisely measured with a quality hand-held device.
- Thermocouples should not be used in immersion because of their imprecision and the risk of corrosion.
- For precise temperature measurements (±0.2°C), specific probes of resistive type, with a long cable, should be chosen. The probe can then be inserted with a stick in the outlet or inlet tubes.
- No cables for in-place probes should be passed directly through the digester mud sealant because of the risk of leaks.
- Every gas meter should be benchmark tested before and after the experiment. Each gas meter should be marked with a unique reference code for tracking purposes.
- The precision and reliability of the gas flow meters was still unsatisfactory, whether diaphragm- or impeller-based. Devices with a better precision are yet to be found.
- In biogas metering experiments, it is suggested to also monitor the inputs-outputs in the digester, by asking the beneficiary to fill in the added or retrieved quantities on a monthly monitoring sheet.

6 CONCLUSIONS

In the three experiments above three typical although different methods of insulation were tested. One experiment used a layer of wet manure, the second a layer of dry corn stalk, and the third a layer of corn stalk compost. These three insulation methods were retained for testing not because of their supposed efficiency, but because they represent three types of responses to keeping the digester warm, that are already seen on the terrain in Zhaotong. Households on the terrain are aware that the temperature plays an important role and many attempt to insulate their digester in the winter following advise spread by word of mouth as well as direct governmental and non-governmental training, including by ID China. However, the real efficiency of the various techniques is still largely unknown.

The experiments and measurements described above show that the different insulations do not prove their efficiency during the winter. After spring, partial results seem to indicate that the insulation has even a negative impact on the temperature.

In the third experiment, making a compost was attempted. However, because of the low temperatures of the winter and the unsuitability of the raw material, not heat was produced. Other methods could be tried, and the compost should be started before the winter. In any case, all other results indicate that the digester temperature is only marginally impacted by the ground cover, so it is still doubtful whether a heat-producing compost would be an effective solution for increasing the digester temperature in the winter.

The impact of a greenhouse built above the digester was also tested. The results show that the impact on the digester temperature is negative in the winter, and only beneficial in the summer. Since heating requirements are in the winter, the greenhouse should not be recommended for the purpose.

The biogas metering data also shows that after opening the digester in the spring, emptying the scum and reloading the digester, the gas production reached its maximum within a matter of days. After reloading, the biogas production was several times at its prior level of before opening the digester. According to this result, it appears that the common practise in Zhaotong of opening the digester in the early spring to remove the scum and reloading with manure is beneficial to the biogas production. Further biogas records should be make to assess this claim.

It is recommended that the following advises be given to the beneficiaries. The winter insulation of the digesters is optional and has generally little efficiency. However, if used, the insulation should be removed by the 15th of March to allow the ground to heat and avoid counter-productive effects. Compost can be made on top of the digesters during the winter if this leads to a good release of heat, but the effect on the digester temperature is not guaranteed. These advises shall be included in future biogas trainings given by ID China.